Contribution to the Study of the Impact of Building Materials on the Urban Heat Island and the Energy Demand of Buildings

Bisam Al-Hafiz

Thèse de Doctorat

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Contribution à l'étude de l'impact des Matériaux de Construction sur l'îlot de Chaleur Urbain et la Demande Energétique des Bâtiments

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UNIVERSITE BRETAGNE LOIRE

CENTRALE NANTES

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Résumé

Dans notre siècle, le monde a déjà connu la plus grande augmentation de sa population à travers l'histoire de l'humanité. Ce phénomène conduit à une utilisation accrue de la terre agricole pour l'urbanisation et à réduire les zones vertes en ville. Les villes connaissent des températures plus élevées la nuit que les zones rurales environnantes. Ce phénomène est connu sous le nom d'îlot de chaleur urbain (ICU). Il contribue à la dégradation du confort thermique en ville à l'extérieur et dans les bâtiments et à l'augmentation des consommations énergétiques pour le refraichissement. L'une des principales raisons de ICU est liée aux matériaux de construction pour la construction l'enveloppe des bâtiments et pour les surfaces urbaines. De nombreuses études portent sur le développement des revêtements pour réduire l'ICU. Cette thèse traite de la conception de l'enveloppe du bâtiment, et principalement ses types de matériaux de construction et sa forme pour lutter contre l'îlot de la chaleur urbain et réduire la consommation d'énergie des bâtiment. Elle est appliquée à l'un des principaux complexes résidentiels à Mossoul, qui sera construit dans de nombreuses villes en Irak. La ville de Mossoul se caractérise par un climat semi-aride et chaud. En été, il est sec et extrêmement chaud, tandis qu'en hiver il fait très froid et les températures sont au dessous de zéro. L'objectif principal de cette recherche est montrer qu'une conception d'enveloppe du bâtiment appropriée permet d'atteindre de bonnes performances thermiques à l'égard de la température extérieure et intérieure de la surface Cette recherche aborde les questions suivantes, quel est le lien entre la conception de l'enveloppe bâtie et : 1/ la température des surfaces extérieures des bâtiments et des surfaces urbaines qui entraîne l'augmentation de la température de l'air et donc la formation du phénomène d'ICU, 2/ la température des surfaces intérieures des bâtiments qui influence le confort thermique intérieur et la quantité d'énergie nécessaire pour maintenir ce niveau de confort? Pour répondre, des simulations ont été réalisées en utilisant solene-microclimate. D'après les résultats des simulations, il est démontré qu'il est possible d'établir des combinaisons de matériaux, formes de surfaces et al.bédo permettant d'améliorer à la fois les conditions de confort thermique intérieures et extérieures. Ces combinaisons peuvent différer en fonction de l'exposition solaire des surfaces et de leurs interactions. Nous proposons ainsi une méthodologie de conception adaptée aux phases de conception et qui a été appliquée au cas d'étude.

Mots clés
îlot de chaleur urbain; matériaux; revêtements; consommation d'énergie; confort; température de l'air; températures de surface; Façade des bâtiments; Mossoul.

Abstract

In this century, the world has already witnessed the biggest increase in its population in human history, which led to the increase of the use of the land and shrinking green areas. The main concern of the present thesis is the city which is characterized by higher nighttime temperature compared to rural areas. This phenomenon is known as an urban heat island (UHI). UHI leads to degraded comfort conditions both outdoor and indoor, and as a result, higher energy consumption for cooling.
One of the main reasons for the UHI is the materials used for building envelope and urban areas. Many attempts have been made to avoid UHI by using a new type of materials such as using materials with high solar reflectance. In addition, these types of materials help minimize energy consumption if used on an urban scale. In our research, we address the building envelope design with respect to its main types of construction materials as well as its layer design and its shape to mitigate the urban heat island and achieve energy consumption reduction. The work is applied on one of the important residential complexes in Mosul city – Iraq, which will be constructed in many cities in Iraq. The weather of the Mosul city is characterized by hot semi-arid climate. In summer, the climate is dry and extremely hot, whereas it is very cold and the temperatures are down to below zero in winter. The main objective of this research is to propose an appropriate building envelope design and design strategy which provides high thermal performance regarding the exterior and interior surface temperature, high-level of indoor thermal comfort with minimum energy needed, reduce the air temperature difference between the city and its surrounding rural area. It tackles some important questions that are related to the case study: What is the relation between the building envelope design and the following aspects: 1. The external surfaces temperature of buildings and urban surfaces which lead to raise the air temperature, and finally contribute to the UHI phenomenon, 2. The indoor surfaces temperature of buildings which influence the indoor thermal comfort and the energy needed to maintain this level of comfort?
To answer the research questions, simulations have been achieved by using Solene-microclimat. From simulation results, it is shown that it is possible to find different combinations of materials, forms and surface coatings to both to reduce the interior and exterior surfaces temperature and consequently, maintain indoor and outdoor thermal comfort. We also show that the strategy can be different depending on the surface exposure to the sun and the interaction between surfaces. We propose a methodology to find the best combination depending on the case study.

Key Words
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Doctoral Thesis

Contribution to the Study of the Impact of Building Materials on the Urban Heat Island and the Energy Demand of Buildings

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(Case Study: Al-Hadba Residential Complex, Mosul-Iraq)

A thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy

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To my country …………. Iraq

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To my father and my mother

To my wife and my children

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One of the main reasons for the UHI is the materials used for building envelope and urban areas. Many attempts have been made to avoid UHI by using a new type of materials such as using materials with high solar reflectance. In addition, these types of materials help minimize energy consumption if used on an urban scale. In our research, we address the building envelope design with respect to its main types of construction materials as well as its layer design and its shape to mitigate the urban heat island and achieve energy consumption reduction. The work is applied on one of the important residential complexes in Mosul city – Iraq, which will be constructed in many cities in Iraq. The weather of the Mosul city is characterized by hot semi-arid climate. In summer, the climate is dry and extremely hot, whereas it is very cold and the temperatures are down to below zero in winter. The main objective of this research is to propose an appropriate building envelope design and design strategy which provides high thermal performance regarding the exterior and interior surface temperature, high-level of indoor thermal comfort with minimum energy needed, reduce the air temperature difference between the city and its surrounding rural area. It tackles some important questions that are related to the case study: What is the relation between the building envelope design and the following aspects: 1. The external surfaces temperature of buildings and urban surfaces which lead to raise the air temperature, and finally contribute to the UHI phenomenon, 2. The indoor surfaces temperature of buildings which influence the indoor thermal comfort and the energy needed to maintain this level of comfort?

To answer the research questions, simulations have been achieved by using solene-microclimat. From simulation results, it is shown that it is possible to find different combinations of materials, forms and surface coatings to both to reduce the interior and exterior surfaces temperature and consequently, maintain indoor and outdoor thermal comfort. We also show that the strategy can be different depending on the surface exposure to the sun and the interaction between surfaces. We propose a methodology to find the best combination depending on the case study.

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Physical Constants Symbols

Latin Symbols

Symbol	Definition	Unit
a	Thermal diffusivity	[m^2/S]
A	Area	[m^2]
AH	Absolute humidity	[kg/m^3], [g/m^3]
AR	Absolut humidity	Kr/m^3
B_i	Radiosity of the element i	[W.m^2]
C_a	Thermal capacity	[J/K/kg]
Ce	Thermal capacity of the outdoor surface	[J / K]
Ci	Thermal capacity of the indoor surface	[J / K]
Cp	Specific heat of the substance	[J/kg.ºC], [J/(kg.K)]
D	Sky radiation	[W/m^{2}k]
e	Thickness	[m]
e_a	The actual vapor pressure at the reference height	[kpa]
e_f	Thermal effusivity	[J/m2.°C.S$^{1/2}$]
E_i	The energy density emitted from the element i	[W/m^2]
F_{conv}	Sum of convective fluxes	[W/m^2]
F_{ij}	Form factor	
h	Solar height	[º]
hc	The surface heat transfer coefficients by convection	[W/m^{2}k]
hi	CHTC (Convection Heat Tansfer Cefficient)	
hr	The surface heat transfer coefficient by radiation	[W/m^{2}k]
HS	Specific humidity	[g/kg], [kg/kg]
I	Direct solar radiation	[W/m^2]
I_d	Diffuse sky radiation	[W/m^2]
I_n	Intensity of radiation normal to the solar beam	[W/m^2]
I_s	Intensity of radiation falling on surface	[W/m^2]
K	Thermal conductivity of the material	[W/m.K]
k	Thermal conductivity in	[W(m.k)]
K^*	Net short-wavelength radiation	[W/m^2]
K, λ	Thermal conductivity	[W/(m. K]
$K_\uparrow$	Outgoing shortwave radiation (reflected)	[W/m^2]
$K_\downarrow$	Incoming short wavelength radiation	[W/m^2]
K_{inc}	The solar direct and diffuse radiations received by the facet from the Sun and the sky	[W/m^2]
K_{refl}	The reflected flux away from the surface	[W/m^2]
$K_{refl\text{-}sur\text{-}i}$	Reflected flux from urban surfaces in view	[W/m^2]
L^*	Net longwave radiation	[W/m^2]
$L_\uparrow$	Outgoing longwave radiation	[W/m^2]
$L_\downarrow$	Incoming longwave radiation	[W/m^2]
L_{net}	The net difference between the thermal radiation components: received from the sky and the reflections on the other facets,	[W/m^2]

	reflected towards the scene, and emitted by the facet	
m	Mass of substance	[kg]
m_a	Mass of dry air	[kg]
MRT	Mean radiant temperature	[°C]
m_v	Mass of water vapor	[kg]
n	The number of elementary surfaces of the environment	
$Psat$	The saturation pressure of the water vapor	[kpa]
P_v	The partial pressure of water vapor	[kpa]
q	Amount of heat transferred (heat flux)	[W/m^2]
$Q*$	The net all-wave radiation	[W/m^2]
QE	The turbulent sensible and turbulent latent heat flux densities	[W/m^2]
QF	The anthropogenic heat release, the turbulent sensible and turbulent latent heat flux densities	[W/m^2]
Q_g	The heat flux by conduction through the materials	[W/m^2]
Q_h	The sensible heat flux to the atmosphere by turbulent convection	[W/m^2]
Q_m	Air mass flow in the control zone	
QH	The turbulent latent heat flux densities	[W/m^2]
QS	The Heat transfer into the earth (conduction)	[W/m^2]
R	Thermal resistace	[m^{2}K/W]
r_a	The aerodynamic resistance	[M^2. ºC:W^{-1}]
Rc,e	The convective resistance between Tse and outsid air	[M^2. ºC:W^{-1}]
Rc,i	The convective resistance between Tsi and Tair,i	[M^2. ºC:W^{-1}]
RH	Relative humidity	[%]
R_j	The thermal resistance of the layer j [m^{2}k=W].	[m^{2}K/W]
r_j	Thickness of the layer	[m]
Rn	The net radiation	[W/m^2]
Rr,i	The radiation-resistant between Tsi and Tmr	[M^2. ºC:W^{-1}]
r_w	The resistance to water transfer	[s/m]
S_e	The envelope surface area of the building	[m^2]
$Tair$	Air temperature	[ºC, K]
T_c	The thermal adaptive comfortis (°C).	[ºC]
$T_{eq,t}$	Air temperature in the control zone at time step t	[ºC]
T_h , T_I	The maximum and initial temperature of the material. (Th - TI) is referred to the temperature swing.	[ºC]
$T_{i,mr}$	The mean indoor air temperature	[ºC]
T_{indoor}	The indoor air temperature	[ºC]
T_{mr}	The mean radiant temperature	[ºC]
T_{ot}	The operative temperature	[ºC]
$T_{ot,i}$	The Indoor comfort operative temperature	[ºC]
$T_{out,mr}$	The mean outdoors air temperature	[ºC]
T_{se}	The surface temperature	[ºC]
T_{sky}	Sky temperature	[K]
v	The wind speed, Air speed	[m/s]
V	Volume of substance ()	[m^3]
V_a	Air volume of the control zone	[m^3]
V_G	The mean wind speed at the gradient height Z_G	[m/s]
V_Z	The mean wind speed at the height Z under the gradient height	[m/s]
Z	The height under the gradient height	[m]
Z_G	The gradient height	[m]
Pi	The reflectivity (fraction of incident energy reflected into the environment)	[W/m^2]

Greek Symbols

Symbol	Definition	Unit
ΔQ	Sensible heat stored in the material (J)	[°C]
ΔT	Change in temperature	[ºC or K]
ε	Emissivity	[-]
Θ	The angle of incidence	[Degree]
$\Theta_{m,i}$	The running mean outdoor air temperature ().	[°C]
U-Value	Thermal transmittance	[W m^{-2} K^{-1}]
α	Solar azimuth angle	[Degree]
β	Solar altitude	[-]
β	Bowen Ratio (β)	[-]
γ	The psychometric constant	[-]
ΔQA	The net heat advection (the heat advection through the sides of the control volume) (the net horizontal heat advection)	[W/m^2]
ΔQS	The heat storage (the net storage flux)	[W/m^2]
ξ	The variable related to the vegetation cover fraction and the leaf area index.	
ρ	Density of substance	[kg/m^3]
ρ_a	Density of air	[kg/m^3]
ρ_j	Density of the layer	[kg/m^3]
ρ_{ws}	Density of water vapor (kg/m^3)	[kg/m^3]
σ	Stefan-Boltzmann constant (5.67x10^{-8})	[W/m^2.K^4]
$\varphi_{clo,e}$	The solar flux by the outside surface of the walls	[W/m^2]
$\varphi_{clo,f}$	Solar radiation flux absorbed by leaves	[W/m^2]
$\varphi_{clo,i}$	Part of the solar flux transmitted and absorbed by the indoor sirface of the walls	[W/m^2]
$\varphi_{clo,se}$	Solar radiation flux absorbed by the exterior surface of the substrate	[W/m^2]
$\varphi_{cond,se-n1}$	Flux transmitted through the wall by conduction	[W/m^2]
$\phi_{conduction}$	Heat flux	[W/m^2]
$\varphi_{conv,a,\infty}$	Convective flux exchanged between the air within the canopy and the external environment	[W/m^2]
$\varphi_{conv,a-fa}$	Convective flux exchanged between air within canopy and foliage	[W/m^2]
$\varphi_{conv,a-se}$	Convective flow exchanged between the air within the canopy and the exterior surface of the substrate	[W/m^2]
$\varphi_{glo,\infty}$	Long wave radiation flux between leaves and the environment	[W/m^2]
$\varphi_{glo,e}$	Net total IR flux exchanged with the environment	[W/m^2]
$\varphi_{GLO,emis,i}$	Infrared flux emitted by surface i	[W/m^2]
$\varphi_{GLO,net,i}$	Infrared net flux exchanged by surface i with environment	[W/m^2]
$\varphi_{glo,se}$	Long wave radiation flux between the foliage and the exterior surface of the substrate	[W/m^2]
$\varphi_{lat,f}$	Evapotranspiration flux of Leaves	[W/m^2]
$\varphi_{lat,se}$	Evaporation flux at the exterior surface of the substrate	[W/m^2]
ψ	Wall orientation (wall azimuth) angle, measured clockwise from north	[Degree]

Acronyms

ASHRAE	American Society for Heating, Refrigerating, Air-conditionning Engineers
BBC	The British broadcasting corporation
BLHI	Boundary layer heat island
CAD	Computer-aided design
CERMA	Le centre recherche méthodologique d'architecture
CFCs	Chlorofluorocarbons
CFD	Computational fluid dynamics
CHTC	Convective heat transfer coefficient
CLHI	Canopy layer heat island
CRENAU	Le Centre de Recherche Nantais Architectures Urbanités
CWSI	The crop water stress index
GHG	Green House Gas
IFSTTAR	Institut Français des Sciences et Technologies des Transports, de l'Aménagement et des Réseaux
IGU	Insulating glass units
IPCC	The Inter-governmental Panel on Climate Change
IRSTV	Institut de Recherche en Sciences et Techniques de la Ville
Met Office	The United Kingdom's national weather service
PMV	Predicted mean vote
PPD	Predicted Percentage of Dissatisfied
QGIS	Geographic information system
SRI	The Solar Reflectance Index
STEVE-tool	Screening Tool for Estate Environment Evaluation
SubUHI	The subsurface urban heat island
SUHI	Surface urban heat island
MUHI	micro urban heat islands
SUP	strategic urban planning
UBL	The urban boundary layer
UCL	The Urban Canopy Layer
UHI	Urban heat island
UHIs	Urban heat islands
UNDP	*United Nations Development Programme*
US EPA	United states environmental protection agency
SubUHI	The subsurface urban heat island
WMO	The World Meteorological Organization

General Introduction

General Introduction

Summary

General Introduction

1 Background to Study

Over the centuries, the world has already seen a growth in its cities, in spite of the fact that some cities have experienced slow growth or decline, such as New York and London. The current growth projections indicate that by 2050, the world population is expected to reach about 9.6 billion with about 66 per cent of people living in urban areas. Nearly 90 percent of the increase will concentrate in Asia and Africa, according to a new UN report launched today (United Nations 2014).

Accordingly, humanity faces a serious and immediate threat. Iraq as one of the Asian countries is witnessing a highly significant increase in the population; it is expected that her population will be about 71.3 million by 2050, according to UN report (Abd-El-Mooty et al., 2016; United Nations, Department of Economic and Social Affairs, Population Division, 2013**).**

As a matter of fact, several reasons have led to rapid urbanization, the most important ones are either increasing the birth rate or increasing migration from other countries, cities or at least rural areas. As Emmanuel and Krüger (2012) write, in developing countries, despite a decline in the population growth rate, cities are still being expanded more than other countries, whereas they will increase their built area by 2.5 times between 2000 and 2030. On the other hand, the transport sector will also see more improvement. Therefore, the increase of the use of intensive land use has led to more and more land per person (Emmanuel and Krüger, 2012).

In this case, regardless of the motives that lead to cities growth, this growth causes an increased demand of basic facilities, such as public transport services, hospitals, water supply, housing and employment opportunities (Hove et al., 2013). Moreover, a lot of modifications have taken place on cities' surfaces, through replacing the green areas with buildings, roads, and other infrastructures (Synnefa et al., 2009). These modifications have affected storage, radiative and turbulent transfers, especially when using low reflective materials. Consequently, these changes seriously affect all climate levels: locally, regionally and globally. A lot of geographers, scientists demonstrate that weather or current climate has changed, and will continue changing significantly during the next few decades. From their part, urban climatologists have paid great attention to the micro- and meso-climatology of urban areas (Lun et al., 2009).

Regarding the climate change, Abubakar et al. (2012) confirm that "Climate change refers to a statistically important variation in either mean state of the climate or in its variability, persisting for an extended period (typically decades or longer), it involves a shift of climatic conditions to a new equilibrium position with values of climatic elements changing significantly" (Abubakar et al., 2012).

Numerous factors cause climate change: from his part, Reddy (2014) has classified them into two categories: the first one contains the factors related to natural processes whereas the second one is related to human activity. The natural factors are external to a climate system, such as changes in volcanic activity, solar output, and the Earth's orbit around the Sun. The main contribution of human activities is that changing nature of ecosystems through logging, pollution of seas and oceans, pollution of atmospheric, cities with high-rise buildings, and other interventions the impact of which appears on the long-term change in the prevailing weather patterns now (Reddy, 2014). Many environmental problems and changes are unavoidable at global and regional levels. In this regard, urban thermal environment stands as one of the main urban environmental issues. Scientists refer to these changes of cities' local weather as the Urban Heat Island (UHI) effect (United Nations Environment Programme, 2007; Wong et al., 2008).

UHI effects are currently considered as a stand out amongst the most genuine urban environmental problems everywhere throughout the world. This effect arises because of the urbanization and may also be affected by changes in water runoff, pollution and aerosols. UHI are often localized and depend on local climate factors such as windiness and cloudiness (which in turn depend on season), and on proximity to the sea (Solomon et al., 2007).

In the 18th Century in London, British meteorologist Luke Howard was one of early researchers who noticed that temperature in the city of London was becoming higher than those in rural areas. In spite of the fact that he never took real-time measurements at different sites in London and its surroundings, he deduced that it was an urban phenomenon and he investigated and described the main cause of this phenomenon, writing that: "urban development was having a direct impact on the local weather" (Howard, 1818; Mills, 2008).

This phenomenon is described as a ‘pool’ of warmer air within the built-up area, and this "pool" increases toward the core of the settlement, where building density is the greatest one. While ‘natural’ features (e.g. parks and rivers) keep on as pools of cooler air within the general pattern (Howard, 1818). In 1958, this phenomenon is called ‘urban heat island’ by Manley. The major causes of the UHI phenomenon are: "alternations of the land surface covering, increased anthropogenic exhaustion heat, and low wind velocity due to the high density of urban structures" (Lun et al., 2009).

UHI occurs in both Winter and Summer, with a difference in temperature which is the strongest at night under calm and clear skies. Most researchers recognize that this is due to urban development, especially, when the area covered by the expanded city and open green areas are replaced with asphalt roads and tall blocks or concrete (Santamouris, 2012). These types of materials retain heat emanated by the Sun and release it through the night (Cullen et al., 2014). Buildings and urban spaces generally absorb more of the energy from the Sun, then the surface temperatures increases and contributes in both the formation of surface and atmospheric urban heat islands and increase energy consumption for buildings' cooling (Wong et al., 2008).

So what can we do about these changes, especially these changes are caused by urban sprawl where it is beginning to affect our quality of life?

In the world, many attempts have been made to reduce the negative impacts of urban sprawl and to achieve efficient and socially acceptable environmental behavior through: propose new urban policy for cities design and urban sprawl such as sustainable city, compact city, smart growth, urban intensification, etc. (Resnik, 2010; Williams, 2004), or some modification that may be achieved on the existing buildings and urban spaces such as using vegetation strategy as green roofs or green walls (Kleerekoper et al., 2012), or using types of construction materials that are fast to warm and cool and store a little of energy (Slomšek et al., 2012).

Construction materials in both buildings and urban spaces play a major role in affecting urban temperatures and heat storage. Near-surface air temperatures depend mainly on the behavior of the surface with solar radiation and how the energy is reflected, emitted, and absorbed (Wong et al., 2008). The behavior of the surface with solar radiation mainly depends upon a set of self-properties of the material, such as physical thermal properties (thermal conductivity, specific heat capacity, and density), radiative properties (albedo and emissivity). These properties mitigates the behavior of the material with regards to external phenomenon: solar radiation (direct and indirect) falling on their surface (National Aeronautics and Space Administration, 2000; Kannamma, 2012), long-wave radiations and wind exposure.

The right selection of building materials, the increased use of green spaces, the use of cool sinks for heat dissipation, etc. help to improve the urban microclimate and finally to resist to the UHI effect, and its impacts as the increasing need of cooling energy needs (Santamouris, 2002). Generally, the cities and urban areas with low air and climatic quality consume more energy for air conditioning, heating units and the largest electricity consumption for lighting.

Thereby, it is not surprising that the negative impacts related to urbanization are an increasing global concern and capturing the attention of people worldwide, especially the researchers. They studied carefully the UHI phenomenon to learn more about its causes, its impacts, especially on human comfort and health requirements. Wide ranges of reasons have been diagnosed, including the land surface energy balance (or imbalance) due to urbanized land surface and built structures, anthropogenic heat release and different atmospheric constituents over the city (Lee et al., 2012).

According to UNDP, (71%) of Iraqis live in urban areas and (13%) of these households will have more than ten occupants by 2030 (Slomšek et al., 2012). Hence, Iraqi cities experience a significant increase in population, therefore, the demand for housing grows. This is due to two major results, firstly new urban agglomerations emerge and population migration from rural to urban/suburban areas continues. Secondly, the shortage in appropriate strategic urban planning (SUP) including clarifying the cities model is needed in the future, and the type of construction materials to avoid the problems which has been mentioned above. This situation embodies the responsibility for those in charge of the country to work in order to find the appropriate solutions and strategies to avoid the problems that will accompany this growth. For more details, the following sentences can sum up the problem of this thesis:

1. The urgent needs to find the appropriate ways and means to develop the construction industry in general and construction materials in particular, to avoid or reduce the environmental problems and energy needed in Iraq, in light of Iraqi development plans in the construction of multi-residential projects.

2. In Iraq, the limited use of new construction materials, in addition to other complementary strategies, which help to simultaneously provide exterior and interior thermal comfort through reducing storage of sensible heat and finally reducing urban environmental problems, especially in summertime.

3. Knowledge is needed on the influence of construction materials selection on microclimate in Mosul city-Iraq, with respect to thermal properties of materials and the amount of the effect of their characteristics on:

- The surface temperature of urban areas
- The air temperature in the urban area
- The indoor/outdoor thermal comfort
- The energy needed in the buildings to sustain the thermal comfort

2 Purpose of the Study

The purpose of this study sheds light on:

1. The development of types of construction materials (used in France and suitable for the application in Iraq) that can absorb energy and later dissipate it, which are suitable for use in urban typology (building envelope, roofs, and urban spaces), therefore, these materials can help:

Firstly, to provide acceptable level of thermal indoor comfort and reduce the artificial power energy needed.

Secondly, not to contribute to raise the outdoor air temperature, so that to provide acceptable level of thermal outdoor comfort. They reduce the temperature difference between the city and its surrounding areas or in other words they resist to the phenomenon of urban heat islands.

2. The investigation of the direct and indirect impacts of these new materials on the thermal behavior of buildings and urban surfaces. The direct effect is related to the change in heat balance

of buildings and urban surfaces, while the indirect effects are due to the modification of indoor and outdoor air temperature. The modification of indoor air temperature induces a change in the use of cooling systems and then in anthropogenic loads, while the modification of outdoor air temperatures leads to higher solicitations for the building.

3 Research Objectives

Specifically, this study is intended to achieve the following objectives:

Chapter One: urban microclimate

1. Understanding the issues related to environmental, weather, climate, and microclimate.

Chapter Two: UHI

2. Identifying the environmental problems resulting from increasing the land use and shrinking green areas in the city, in other word resulting from urbanization and industrialization.

3. Identifying the urban heat island phenomenon and potential mitigation strategies.

4. Identifying the interactive relation between construction materials and the urban environmental problems in general, and urban heat island in particular.

Chapter Three: materials

5. Identifying the components of urban typology and materials that can be used for each component.

6. Investigating the construction materials types and properties which contribute to a successful urban typology (buildings external envelope and urban spaces) which contribute to overcome urban heat island effect and provide thermal comfort with minimum amount of the required energy.

Chapter Four: Iraqi context

7. Highlight the housing sector in Iraq and scope of new alternative building materials.

Chapter Five: Methods

8. Review the methods of analysis that can be used in a practical phase suitable to study the behavior of building materials.

Chapter Six: Results

9. Identifying the possibility of using the new construction materials that are invented in France and in Iraq, in light of the requirement to overcome the UHI effect, achieving thermal comfort, and energy savings.

10. Determining the proper radiative properties of construction materials such as albedo value to reduce the urban heat island and lead to energy efficiency.

11. Proposing and formulating a guideline about the possibility of using the new construction materials produced in France which can be used for the development of the construction industry in Iraq.

12. Examining the ability of numerical simulation to achieve the main objective of this study.

4 Research Questions

This study is conducted to address building envelope design with respect to construction materials available, as well as wall design and shape which are suitable for using in Iraq with environmental approach. It raises one main question, as the following:

What is the relation between the building envelope design and;

1. The external surfaces temperature of buildings and urban surfaces, which lead to heat the atmosphere, then raise the air temperature, and finally form the UHI phenomenon?

In this regard, this study offers the following sub-question:

What is the influence of materials types and self-shading technique for building envelope on its external surface temperature?

What is the influence of building envelope layer design and shape on its external surface temperature?

2. The indoor surfaces temperature of buildings, which influence on the indoor thermal comfort and the energy needed to maintain this level of comfort?

In this regard, this study offers the following sub-question:

What is the suitability and impact of an alternative among double wall, vegetated system, and variation of reflection coefficient on one hand, and the best self-shading scenario to reduce solar energy transfer into a building's interior on the other hand?

3. The indoor and outdoor thermal comfort as well as the air temperature of urban area (air temperature between the buildings)?

In this regard, this study offers the following sub-question:

Is it possible to select both appropriate urban construction materials with complementary solutions to maintain a high level of indoor and outdoor thermal comfort, as well as to reduce the difference in temperature between an inner city and its surrounding suburbs?

5 Scope of the Study

The construction materials, depending on their properties are considered as one of the most important factors that sequentially causes the storage of solar energy in the urban fabric, increased urban surfaces temperatures, increased air temperatures, decrease indoor/outdoor thermal comfort, finally increase overall energy consumption, and cause UHI phenomenon in urban areas.

At this moment, major cities in Iraq suffered from maintaining higher temperatures compared with their surrounding countryside, which affect the human comfort; therefore, the main scope of this study is:

Focusing on discovering the appropriate construction materials produced in France which are suitable for use in Iraqi construction projects, with respect to environmental performance and thermal behavior of urban surfaces (buildings and urban spaces) to avoid the UHI effect.

All analyses have been carried out in Al-Hadba residential complex, which is the first and the largest residential project built in Mosul city.

6 Significance of the Study

The significance of this study is divided into three main groups:

1. Significance related to construction materials:

This study will first guide the engineering and architects on the environmental problems arising from using the existing types of construction materials in Iraq and their effect on microclimate and the formation the UHI phenomenon.

Secondly, it will shed light on the new types of construction materials which can be used in Iraq and which would lead to minimize the environmental problems.

2. Significance related to housing development policies in Iraq:

This study will raise the policy makers awareness and Iraqi government need to benefit from the experiences of developed countries such as France to improve and implement new policies that support the production and the use of new types of construction materials that would reduce the environmental problems in Iraq and that would be used in future plans for further residential complexes all over the country.

3. Significance related to further research:

This study intends to be a source of help to other academics and researchers interested in achieving further research in the field of building materials engineering, if it is applied it will provide new details to this topic.

7 Research Methodology

This point discusses the methodology followed in this study that is how the research will be done. In order to conduct this research successfully, there are two main steps namely a qualitative description and quantitative simulation.

1. Qualitative descriptive Method

The present method provides a full description of:

A. Accurately characterizing the urban surfaces materials of the selected case study (Al-Hadba Residential Complex).

B. Alternative construction materials proposed by manufacturers in Iraq.

C. New construction materials proposed by manufacturers in France.

2. Quantitative simulation Method

The present method is designed to carry out the numerical simulation by using SOLENE-microclimat model, which provides representative indicators of thermal behavior of urban surfaces and thermal comfort conditions in the indoor/outdoor environment in function of construction materials types. Therefore, it is a useful means to achieve the main objectives of the present study.

To achieve all the above-mentioned points, the stages of solving the research problem were identified as follows:

- Propose a theoretical framework about the key concepts related to the topic of this study which focuses on the characteristics of construction materials and their effect on the temperature of cities and the required energy for building.

- Develop a search string to find appropriate materials for building external walls, which are manufactured in France and are suitable for use in Iraq. Groups of manufacturers of construction materials and specialized research centers who deal with developing properties of construction materials should be in contact for guidelines and technical assistance to select materials types that have an effect on indoor/outdoor microclimate and cooling energy use compatible with the climate condition in the Middle East in general and in Iraq in particular. Finally, the types of the vast range of materials are selected according to standards commensurate with a whole range of factors, summed up the price, and environmental performance, endurance and others.

- The application of the theoretical framework through analytical (simulation) study of the existing case study at urban level, which means achieving simulation to examine the relation between construction materials of urban typology and both

1. External/internal air temperature

2. Energy needed

- Analysis of the results of the application to get to the understanding of the climate behavior with each materials types selection, and this would certainly lead to select the best type of materials suitable for Mosul city at the present time through planning and design practices.

8 Overview of Research

The material for the study has been divided into three parts, it comprises of total six chapters which impulse you step by step to find the appropriate construction materials. The first part, the theoretical side of the present study, which includes the first three chapters dealing with the literature review about the effects of construction materials on thermal comfort, thermal performance of the buildings, and UHI. The second part, the practical side of the study, which includes the fourth (case study) and fifth chapters (methodology and simulation steps). Finally the last part, the research finding and conclusion.

Part One: The impact of construction materials on UHI

Chapter one: Fundamentals: Climate and Buildings

This chapter deals with the basic definitions of the environment, climate, and the factors which affect each other in addition to addressing many basic concepts related to climate e.g. scale, factors, types, etc. It studies the thermal behavior of buildings with aim to reach a comprehensive understanding of the most important factors affecting the thermal comfort concept and its indicators.

Chapter two: Current Problems of Cities, Energy and Climate

This chapter focuses on the interaction relation between climate factors and the consequences of urbanization to understand the influence of these factors on the formation of UHI. Moreover, it reviews a number of previous studies on this phenomenon, looking for the additional knowledge related to the UHI definition, identify the causes, the types, etc. Finally, it points out the formation of this phenomenon with respect to urban energy balance.

Chapter Three: Role of Construction Materials

This chapter has focused on the role of construction materials in order to diagnose a range of solutions to avoid or minimize the UHI effect, in addition to its contribution to providing an acceptable level of thermal comfort.

Part Two: Case study and research methodology

Chapter Four: Research case study

This chapter represents the starting point of the practical aspect of this thesis, where all the aspects related to the case study, its urban components, and nature of construction materials used will be described.

Chapter Five: Research methodology

This chapter will clarify the requirements of the practical phase. It will deal with the theoretical framework, research variables and then the presentation of the simulation tool that will be used.

Part Three: The results and conclusion

Chapter six: Results and discussions

This chapter has been assigned to demonstrate the simulation results, and to discuss, evaluate and compare the results of alternative envelopes design application to the reference case.

Chapter seven: Conclusions and recommendations

The finding of the research is summarized in this chapter, describing future actions and recommendations.

9 Research Flow Chart

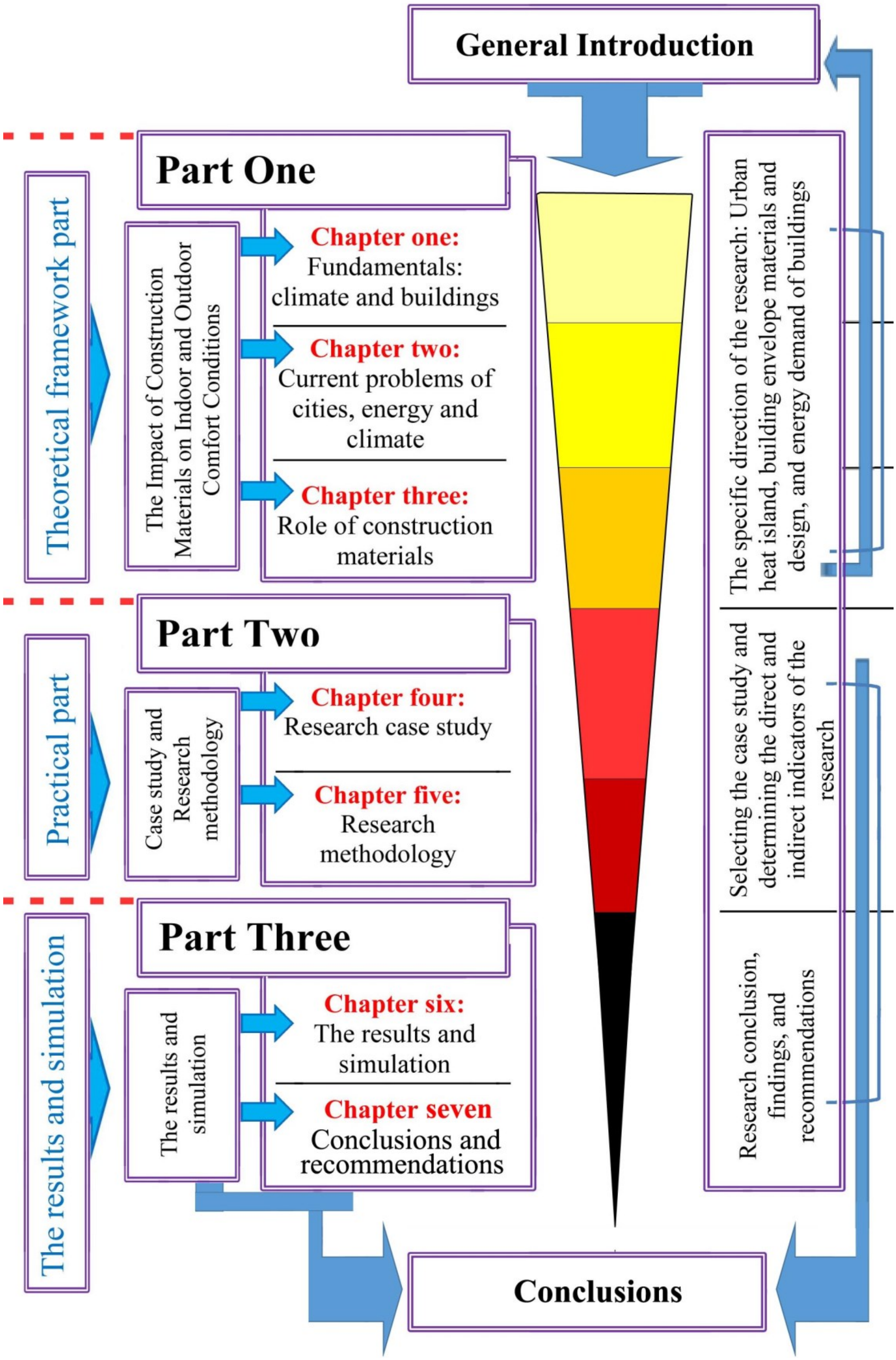


Figure 1: Research Flow Chart

Part 1

The Impact of Construction Materials on Indoor and Outdoor Comfort Conditions

Summary

Chapter 1

Fundamentals: Climate and Buildings

Summary

1. Impact of urban environment on the local microclimate.
2. Impact of urbanization on microclimate in urban areas.
3. Impact of spatial limitations on the study of the climate phenomenon.
4. Climate zones and its impact on the building and urban design.
5. Factors affecting urban microclimate.
6. Thermal Performance of building.
7. Summary and conclusion

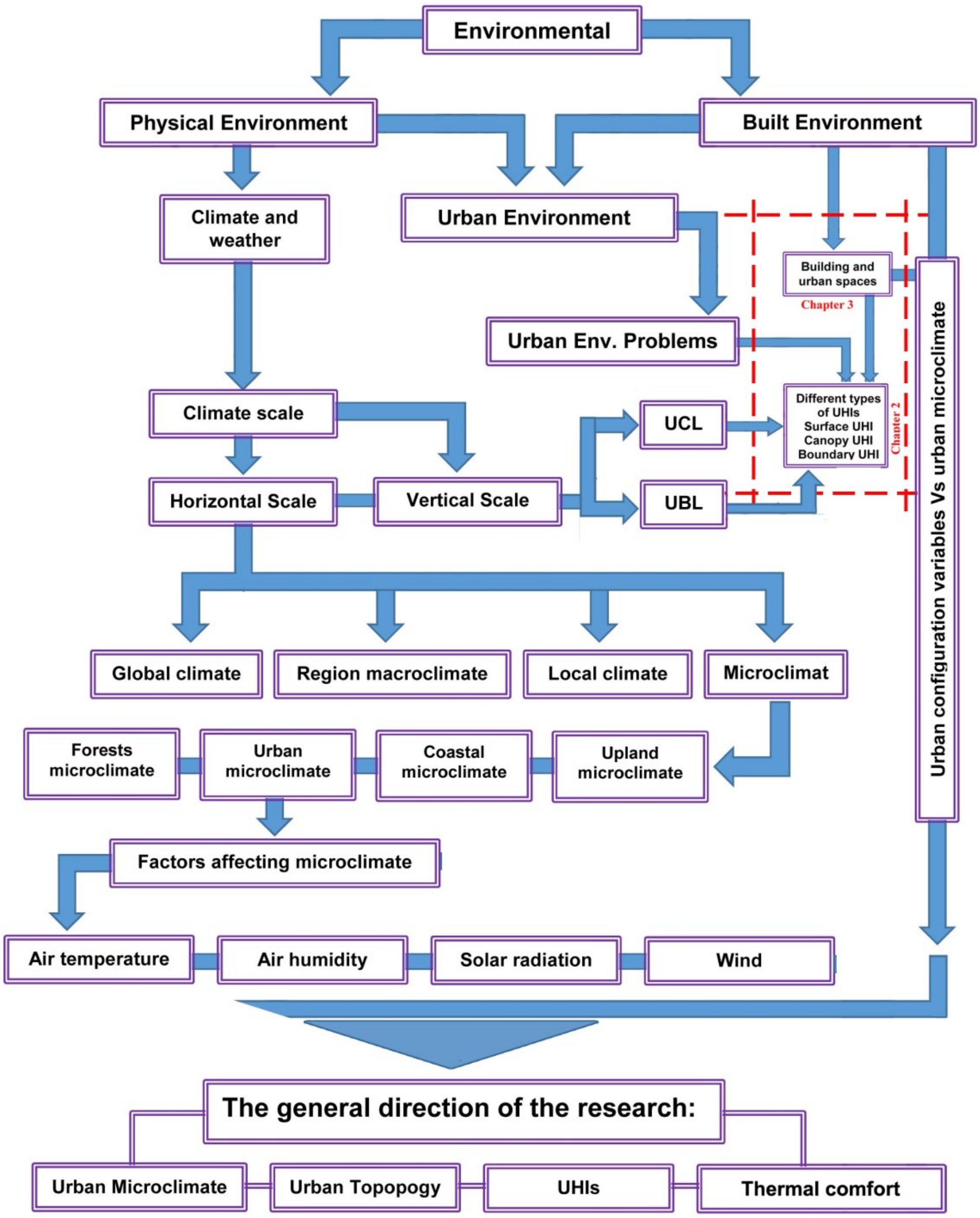


Figure 1. 1: Flow chart of chapter one

Chapter 1 Fundamentals: Climate and Buildings

1.1. Introduction:

To understand the impact of construction materials on UHI, it is paramount to grasp the urban microclimate system, where UHI is one of its issues.

The UHI describes an urban area that is significantly warmer than its surrounding rural areas. As it can lead to higher Green House Gas (GHG) emissions, it contributes to global warming and the most recent climate change pattern that includes the gradual warming of the Earth's temperature (National Geographic Society, 2011).

Nowadays, many issues are related to environment and climate facing us either the UHI effect, or the greenhouse effect and climate changes, etc. Global warming is "a gradual increase in the overall temperature of the earth's atmosphere generally attributed to the greenhouse effect caused by increased levels of carbon dioxide, CFCs, and other pollutants" (Bhakta, 2017). The greenhouse effect is "the process by which radiation from a planet's atmosphere warms the planet's surface to a temperature above what it would be without its atmosphere" (BBC Earth, 2017).

The Inter-governmental Panel on Climate Change (IPCC) defines climate change as "any change in climate over time", as a result of both natural and human factors. The natural factors consist of terrestrial causes (alternation in the orientation of the earth) and extraterrestrial causes (solar activities). While the human causes consist of emissions of greenhouse gases and aerosols, changes in land use and surface characteristics, shrinkage of vegetation open spaces covers, removing forests, depletion of the ozone layer and etc. (Abubakar et al., 2012).

According to United States Environmental Protection Agency (US EPA), climate change and the UHI effect interact together, through, "firstly, our warming climate will increase already higher temperatures in heat island areas. Secondly, cooling strategies to reduce heat islands can help communities adapt to the impacts of climate change as well as lower the greenhouse gas emissions that cause climate change" (US EPA, 2017). The characteristics of urban areas have strong relations with that changes (Romero-Lankao, 2008). According to the US green building council, the building sector can play a major role in reducing the threat of climate change (Shim, 2016).

Accordingly, the design of any construction project (large or small) at a certain region with respect to the environmental issues and climate change cannot be achieved without considering the climatic characteristics of that region, and how this project will interact and affect his surrounding urban environment. For example, in hot-dry regions, especially in Summer, the building design and materials selected should be considered as the environmental dimension to validate the ability of that buildings, firstly, to reduce the hazard of climate change, and secondly to provide comfortable and healthy conditions for its occupants, and in same time this does not contribute to increase the air temperature surrounding the building. One of the most important examples of harmonious cities with environmental features are the traditional cities in the world, for example the old part of Mosul city-Iraq, where it is characterized by compact urban fabric made of courtyard houses and narrow alleys and use adobe as a building material (see Figure 1.2).

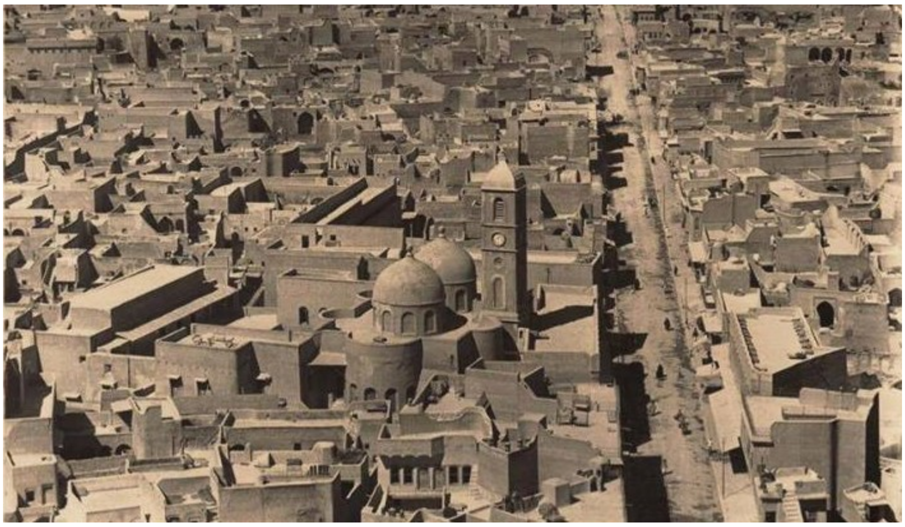


Figure 1. 2: The old city of Mosul, Compact urban fabric and adobe as a building material
Source: ("Old Photos of Mosul City," 2017)

In 1992, Changnon said that "the impact of urban built environments on human health has become a critical issue facing the global society as the number and percentage of humans living in urban areas continues to grow" (Changnon, 1992). Therefore, the study of microclimate increases the understanding of urban climatology, environmental change, and human-environment interactions that influence the human life in many dimensions (Ifatimehin et al., 2013).

This chapter deals with the basic definitions of the environment, climate, and the factors that affect each other, in addition to addressing many basic concepts related to climate e.g. scale, factors, types, etc. Then it studies the thermal performance of building aiming at reaching a comprehensive understanding of the most important factors affecting it and its indicators.

1.2. Impact of urban environment on the local microclimate

What is an urban environment?

Over the past decades, the notion of environment was used dramatically and with different definitions (Rakos and Antohe, 2014). Although Kiss and Shelton (1997) have defined the environment as "the house created on earth for living things" (Kiss and Shelton, 1997), the Merriam-

Webster Dictionary has defined it in its largest physical sense as "the circumstances, objects, or conditions by which one is surrounded" (Merriam-Webster Online Dictionary, 2016). Ullah and Wee (2013) defined environment literally as "surrounding and everything that affect an organism during its lifetime is collectively known as an environment" (Ullah and Wee, 2013).

Therefore, researchers differ in determining the environmental concept between a small space which does not exceed a house for living things, and larger limited to include everything that surrounds us. Accordingly, environmental data can provide an approach to the understanding of the nature of the environment in which we live as well as surrounds us.

The environment of our earth consists of natural or physical environment and built environment, which together constitute the urban environment (see Figure 1.3). ***Natural environment*** is everything that surrounds us, living organisms (plants, animals, and microorganisms) or non- living organisms (geological features, land, air, mountains etc.). (El-Khateeb, 2006). While, ***built environment*** is the human-made structures, ranging in scale from personal shelter and buildings to neighborhoods and cities including their supporting infrastructure and landscape (Anagnostopoulos et al., 2013). From his part, Roof (2008) defined the built environment as "the human-made space in which people live, work, and recreate on a day-to-day basis and it includes the buildings and spaces we create or modify" (Roof, 2008). ***Urban environment*** is complexly structured and is a combination of natural, built-form, with economics, social and cultural dimensions. The long-term urban environment can be constituted of natural environment, built environment and social components which include aesthetic and amenity, architectural styles, heritage, behavior, laws, and traditions of the resident community (Haughton and Hunter, 2003).

Therefore, and according to these three environmental concepts, the urban environmental behavior may depend mainly on the relation between the natural environment and the built environment, for example when built environment in any region is designed, it is based on respect for natural environment (green building, sustainable building, etc.), as a result, it improves its urban environmental quality.

Now, one question is asked,

What are the reasons that lead the built environment to develop some urban environmental problems?

Previous studies give an answer to this question where the growth of built up area is the main reason which makes the built environment to create urban environmental problems, as a result of either increasing urban population (Allen et al., 1999; McGranahan et al., 1993; Torrey, 2004). There is little or no institutional framework able to avoid these populations (Mohapi, 2009), or there are other reasons which are not related to population growth. Emmanuel and Krüger (2012) say that in developing countries, the cities have grown more rapidly than the rate of population growth (Emmanuel and Krüger, 2012). Therefore, escalating and growing of urban environmental problems threaten cities and societies, poor and affluent alike.

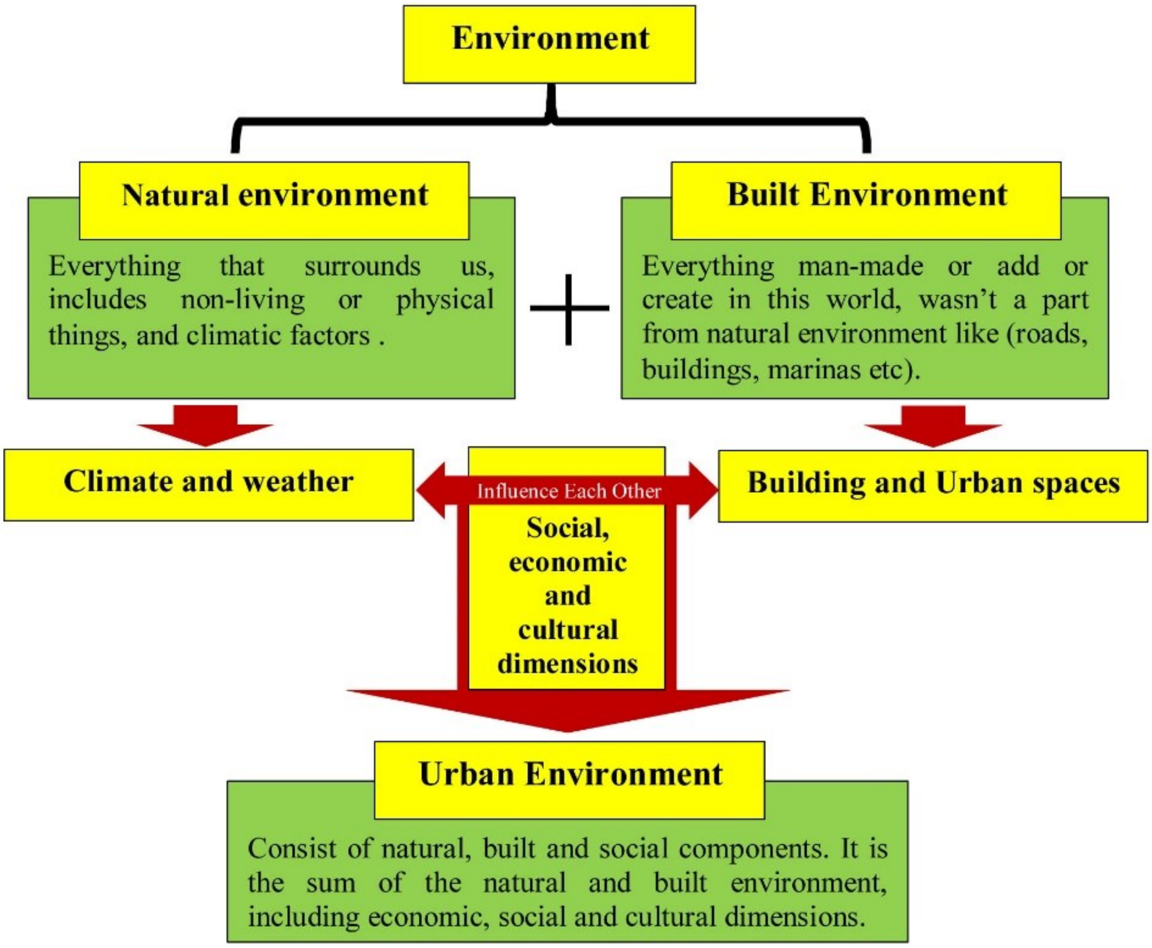


Figure 1. 3: Compounds of Urban Environment

Source: (El-Khateeb, 2006)

1.3. Impact of urbanization on microclimate in urban areas

Urbanization tendency is growing rapidly in the world and especially in the developing countries. It may cause microclimatic changes in these areas. In fact, urbanization is the process by which a large number of people permanently live in relatively small areas forming cities, as a result of both the natural increase (population growth) and net migration which are the major contributory factors to urban growth. High urbanized city term is used for cities experiencing rapid growth in population and high proportion of the population living in the city. According to Tahir et al. (2015) "rapid urbanization can be determined as rapid increase in the number of urban dwellers who need civic amenities at the cost of social, economic, and environmental degradations" (Tahir et al., 2015). According to Nelson et al. (2009), the climate change and urbanization may cause changes in thermal characteristics of various ecosystems which may consequently is induced undesirable effects (Nelson et al., 2009), in addition to other long-term effects such as increasing the frequency and intensity of droughts and floods in other areas (Alcamo et al., 2007).

According to many studies dealing with the side effect of urbanization, the direct results of urbanization phenomena can be summarized as follows:

- The degradation of urban water, air, land, noise and thermal stresses pose greatest threat to health and safety in the cities. (IIED, 2001; Kahn, 2007).
- Increase of uncollected and improperly handled solid waste (Tahir et al., 2015).
- Processes of transforming the natural land areas like forests and wetlands into urbanized areas (Faulkner, 2004).
- Increase regional or microclimatic changes in large cities from their surroundings.

But in spite of all these problems, the UHI effect is still the most serious problem facing the world (Santamouris, 2012). The policy framework to reduce this phenomenon which was proposed by Japanese ministry of the environment in 2004, stated the important fact that “urban heat island effect is an environmental problem unique to urban areas” (Japanese ministry of the environment, 2004).

Therefore, regardless of many problems that are described by the **scientists**, we should work hard in order to prevent the cities from UHI effect.

Hrebicek et al. (2011) have written "Urban heat island effects are often very localized and depend on local climate factors such as windiness and cloudiness (which in turn depend on season), and on proximity to the sea" (Hrebicek et al., 2011).

Therefore, it is necessary to discuss the concept of climate in more detail, especially it is one of the main factors of natural environment which is directly affected by urban environmental.

What is the climate and urban microclimate?

The original term of climate emanated from Ancient Greek klima, meaning inclination. In a narrow sense, climate is referred to as the average expected weather (Morshed, 2013). In other accurate words, it is the behavior of the atmosphere near the earth's surface in a specific area over a long period of time (months to thousands or millions of years) (Altena et al., 2010). The classical period is 30 years, as defined by the World Meteorological Organization (WMO). As for the weather, it differs from climate; the weather describes what happens over a short time (Lovejoy and Schertzer, 2013).

On a global scale, climate is influenced by many factors: latitude, earth's axial tilt, the movements of the Earth’s wind belts, temperatures with difference between land and sea, and topography. A region’s climate is defined as "the general or average weather conditions of that certain region at a certain time interval, including temperature, rainfall, and wind." (Altena et al., 2010).

1.4. Impact of spatial limitations on the study of the climate phenomenon

Climates can be studied at several scales generally on horizontal and vertical scale (Oke, 2004). Each one has its characteristics and what sets it apart, as follows:

1.4.1. Horizontal scale

The horizontal scale is a critical factor for the study of weather and climate phenomena. Most of the literature has classified the horizontal scale into several types, namely macroclimate, mesoclimate, localclimate and microclimate. These terms differ on the basis of spatial scale (Blocken et al., 2002; Nasrollahi, 2009). Figure (1.4) shows the approximate spatial distance of each, where there is some overlap between them.

1.4.1.1 Mesoscale climate:

The mesoscale scale climate focuses on the climate and weather measurements influenced by the city and at the scale of a total city. To measure this scale, a single station is not able to represent it, where mesoscale scale extends to tens kilometers (see Table 1.1 and Figure 1.4a).

1.4.1.2. Local scale climate:

The local scale climate focuses on the climate of neighborhoods without any difference in urban development (surface cover, size and spacing of buildings, activity). This type of climate is being monitored in standard climate stations. Typically, this scale ranges from one to several square kilometers (see Table 1.1 and Figure 1.4b).

1.4.1.3. Microscale climate:

The microscale climate concentrates on an area around the buildings in an urban environment. Surface and air temperatures may differ by many degrees in very short distances, and airflow can be greatly disturbed by small objects. Normal scales of urban microclimates are linked to the dimensions of individual buildings, trees, roads, streets, courtyards, gardens, etc. This scale ranges from one meter to hundreds meters (Altena et al., 2010) (see Table 1.1 and Figure 1.4 c).

1.4.2. Vertical scale

The term vertical scale refers to the layers formed above an urban area which are the urban canopy layer and urban boundary layer. Figure 1.4a shows the urban atmosphere and its division in the vertical axis. In a rural area or urban area with low level of urbanism, the energy and moisture exchanges take place in nearly planar surfaces. While in a large urban area these changes happen in a thick layer which is the Urban Canopy Layer (UCL) (Oke, 2004).

1.4.2.1. Urban Canopy Layer (UCL)

UCL is the layer located at the bottom of the urban boundary layer (UBL, see below) in which the urban climate phenomena happen. UCL's height is equal to the mean height of the roughness elements of the urban environment (buildings and trees).

1.4.2.2. Urban boundary layer (UBL)

UBL's height is not fixed, where it depends on the urban environments variation. According to GM2100 Synthesis project published by Geo-Information technology of Delft University of

Technology (2010), "in densely built sites the UBL can be found at 1.5 × (UCL height) whereas in low density areas can be found at heights up to 4 × (UCL height)" (Altena et al., 2010).

The measurements that are recorded of any urban area differ depending on its location with regard to the UBL layer, where the measurements that take below the height of the UBL can be indicative for the microclimate whereas above that level it can be indicative.

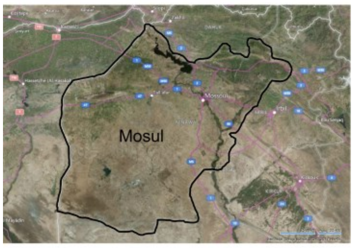
	Scale	Approximate limits	Characteristic climatic phenomena
	Macro-scale	>100km	Jet stream, hurricanes
	Mesa-scale	10km-200km	Local winds, thunderstorms, large cumulus clouds
	Local/urban scale	100m-50km	Tornados, small cumulus clouds
	Micro-scale	1cm-1km	Dust devils, small scale turbulence

Table 1. 1: Spatial distance of different climate scales
Source: (Erell et al., 2012)

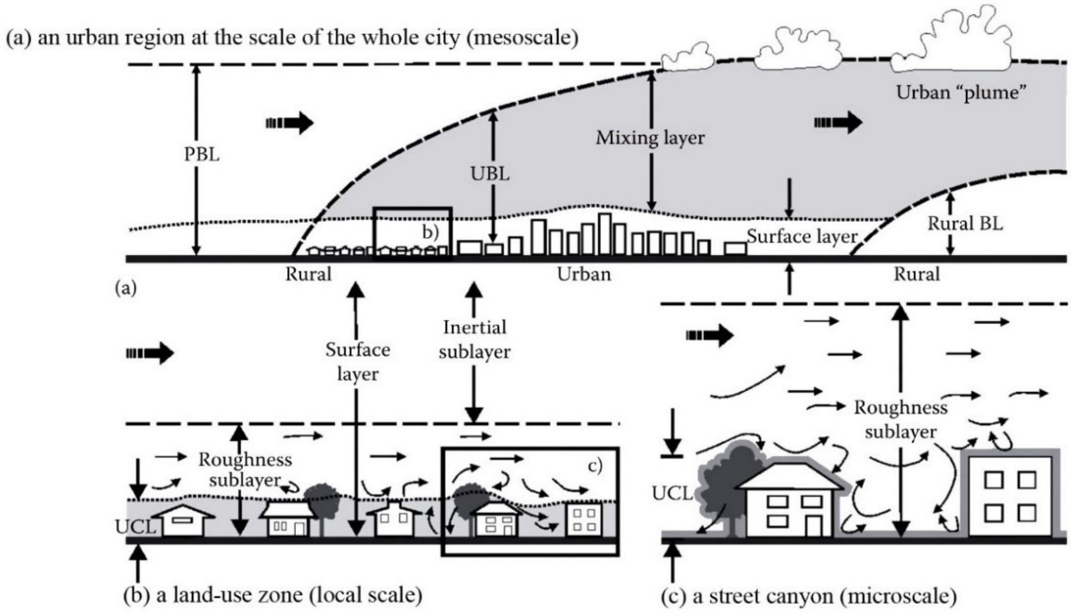


Figure 1. 4: Climatic scales and vertical layers found in urban areas. PBL(planetary boundary layer), UBL, UCL
Source: (Oke, 2004)

Hence, the study of any climate phenomena is considered as a complicated task. This fact imposed on researchers the necessity to identify spatial limitations related to climate scale, which depends on the orientation of the study either mesoscale, local scale or microscale, as well as the vertical height acompanying each scale a specific problem.

This study concentrates on the relation between construction materials and UHI effect. Their spatial limitations will be the level of microclimate (horizontal scale), and the urban canopy layer (vertical scale). We will discuss the terms of microclimate in more detail.

1.5. Climate zones and its impact on the building and urban design

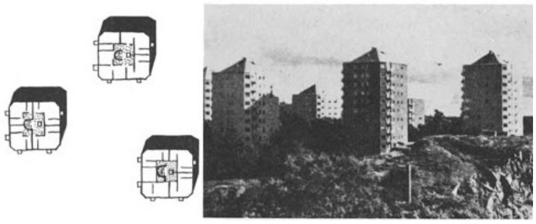
The characteristics of a climate of any region certainly influence the built form and urban configuration as well as the selection of construction materials types, these impacts will be discussed in more detail in the following:

1.5.1. The urban morphology design with respect to climate zones

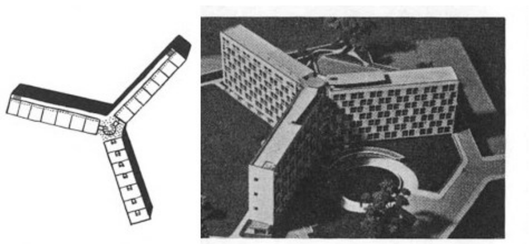
The climates prevailing in the world vary greatly. There are many climate zones, which are primarily influenced by the sun's energy heating the land, water masses (World Health Organization, 1987) geographical location, regions (Herrmann et al., 2010) and time scales (hour, day, week, etc.) (Morshed, 2013). Ayinla, and Odetoye (2015), have identified the main four climate zones (the cool zone, the temperate zone, the hot-arid zone, and the hot-humid zone) and the main problems related to each one (Table 1.2) (Ayinla and Odetoye, 2015). Golany (2015), has a particular point of view regarding the urban morphology. He said "there is a strong correlation between urban climate and the urban design physical configuration and form pattern" (Golany, 1995). Olgyay (2015) identified the appropriate city morphology for each type with respect to micro thermal performance (Olgyay et al., 1963).

climate types	**The main problems** *Ayinla & Odetoye (2015)*	**City Morphology** *Olgyay (2015)*	
In cold climate	"The lack of heat (under heating), or an excessive heat dissipation for all or most parts of the year".	In a cool zone: "the layout tries to provide shelter against the winds. Large building units are closely grouped, but spaced to utilize beneficial sun heat effects. The houses tend to join in order to have less surface exposed to heat loss. The town structure is an insulated dense layout".	Figure 1.5-a
In temperate climate	"A seasonal variation between under heating and overheating, but neither is very severe".	In the temperate zone: "plans ate open nature and the houses merge. The town structure utilizes the possibilities of free arrangement".	1.5-b
In hot-dry climate	"Overheating, but the air is dry, so the evaporative cooling mechanism of the body is not restricted. There is usually a large diurnal (day - night) temperature variation".	In the hot-arid zone: "the walls of the houses and the gardens provide shade to the living areas and to the street, like a horizontal egg crate device for shading. Unit dwellings are arranged around closed courtyard like cooling wells, and are grouped together to achieve dense in volume. Here the town layout reacts against the heat with shaded dense structure".	Figure 1.5-c
In warm-humid climates	"The overheating is not as great as in hot-dry areas, but it aggravates by very high humidity, restricting the evaporation potential. The diurnal temperature variation is small".	In the hot-humid zone: "the buildings are freely elongated, and this freedom is accentuated in the layouts. The houses are separated to utilize the air movements; shade trees become important elements. The character of the town fabric becomes scattered and loose".	Figure 1.5-d

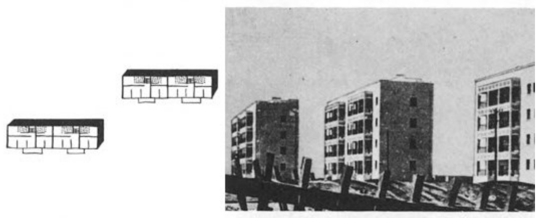
Table 1. 2: The main problems and the cities' morphologies for different climate types



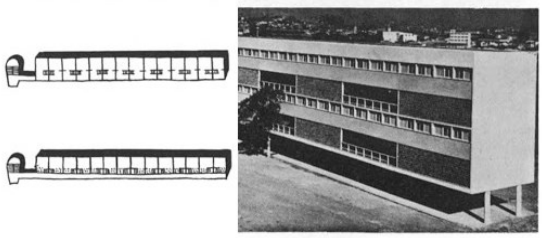
a – Cool zone



b - Temperate zone



c – Hot zone



d – Warm humid

Figure 1. 5: Buildings in different climate regions

Source: (Olgyay et al., 1963)

1.5.2. The urban materials with respect to climate zones

According to many of the physical properties of urban typology (with respect to materials for both buildings and urban open spaces), and its ability to absorb or to reflect the solar radiation and infrared radiation, the urban materials plays a main role in thermal performance of urban configurations and may cause many urban environmental problems specifically UHIs. Therefore, the utilization of correct building materials compatible with climate zone is important (Zarkesh et al., 2012).

The selection of urban construction materials in a manner which does not fit with the climate characteristics may lead to absorb and hold more of the sun's heat and gradually release it back into the environment. Targhi and Dessel (2015) identified the reasons of this behavior as "1- most urban construction materials are impervious and watertight, and 2- these materials are usually darker than natural ones and therefore, they collect more of the sun's energy " (Targhi and Dessel, 2015).

Accordingly, there are many factors that determine the behavior of materials with respect to climate zones such as the thermal physical characteristic of materials and the color of the surface. Therefore, engineers and architects should understand both these characteristics and those of the local climate (University of Colorado Boulder, 2016).

For example, in hot and dry climates; according to Hirbo’s study (2010); the types of construction materials that are suitable for achieving a better thermal performance should be "materials with high reflectivity to reflect away excessive heat, poor conductors of heat to avoid absorbing it and high thermal capacity to provide the required thermal mass for the maximum possible time lag" (Hirbo, 2010). Whereas in the humid and cold tropics and according to Nematchoua and Orosa’study (2016) "The effect of marble as an external coating helps to improve indoor ambience during the dry season. This is due to more indoor air and relative humidity being accumulated" (Nematchoua and Orosa, 2016).

Due to its importance and its link to the current study, this aspect will be discussed in detail at a later stage in a separate chapter.

1.6. Factors affecting urban microclimate

What is the difference between microclimate and urban microclimate?

Naiman et al. (2010) wrote: " microclimate is the set of climatic conditions (temperature, light, wind speed, and moisture) measured in localized areas near the earth's surface" (Naiman et al., 2010). Obi (2014) wrote: "microclimate includes large areas with fairly uniform conditions which are influenced by air masses moving over earth surface within parameters that characterize a localized area with a geographic scale between 1m2-100m^2" (Obi, 2014).

The United Kingdom's national weather service (Met Office) confirms that "there is a distinctive microclimate for every type of environment on the Earth’s surface". Met Office has classified microclimate into four types, which include upland microclimate (upland regions), coastal microclimate (coastal regions), forests microclimate (forests), and urban microclimate (urban regions) (see Figure 1.6). It also adds that the urban microclimate is the most complex of all microclimates as a result of the increase of the population that lives in cities (Met Office-UK, 2011).

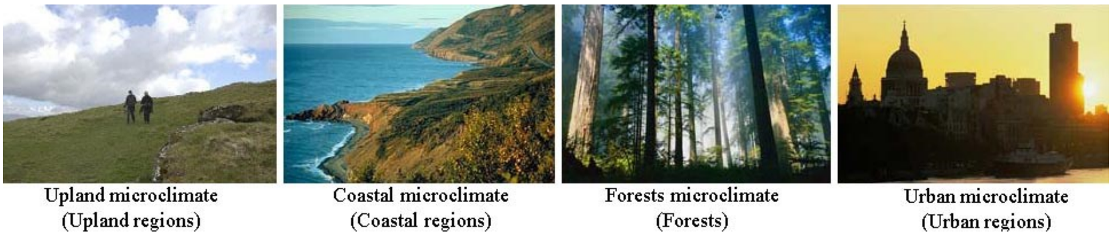


Figure 1. 6: Types of microclimates
Source: (Met Office-UK, 2011)

Therefore and according to Dorer et al. (2013), "the urban microclimate is determined by (i) local air velocity, temperature and humidity; (ii) solar irradiation and specular and diffuse reflections; (iii) surface temperatures of building and ground, and the respective long-wave radiation exchange, also with the sky" (see Figure 1.7) (Dorer et al., 2013).

Givoni (1998) wrote "the urban geometry and profile (shape, height, size of the buildings, orientation of streets and of buildings, and nature of the surfaces of the urban open areas) have an impact on the urban climate", therefore, each urban element (buildings, roads, parking area, factories, etc.) creates around and above it a modified climate with which it interacts" (Givoni, 1998).

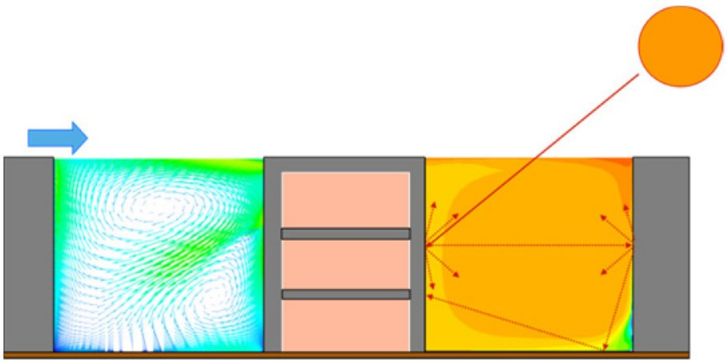


Figure 1. 7: Local phenomena of the urban microclimate affecting heat fluxes at building surfaces (on the right, temperatures in the street canyon is represented and on the left air flows
Source: (Dorer et al., 2013)

There are numerous studies identifying specific classification concerning factors affecting microclimate. Obi (2014) has summarized these factors as follows (Obi, 2014):

A.**The conventional factors**: air temperature, atmospheric humidity, solar insulation fluxes, wind speed and wind direction.

B.**The National environmental factors**: topography, sun angle exposure, latitude, soil type, vegetation cover.

C.**The meteorological factors**: cloud cover, regional precipitation, high altitude, wind characteristics.

In addition to these factors Hogan (2010) states that Man-made is an important factor, which includes built structures and roads; conversion of natural habitat to agriculture; replacing native forests with plantations; introduction of exotic species as landscaping elements; mass grading to alter topography; and installation of power generation schemes such as windfarms, solar arrays, hydroelectric dams or other power plants that generate thermal pollution or air pollution plumes (Hogan, 2010).

Since the present study is related to the environmental issues, the study of conventional factors is significantly important, which is preponderant to build a perception on the thermal performance of the building in one hand and the building with its surroundings on the other hand. Therefore, the air temperature, air humidity, solar radiation, wind will be discussed extensively.

Generally, these factors are measured in open spaces such as the airports or the meteorological stations to ensure accuracy of measurements, which must not be affected by external factors from surrounding. In many cases, these factors are different from the microclimate conditions at the building site, but these lasts are always affected by the climate conditions which is measured at the nearest meteorological station (Bin, 2011).

1.6.1. Air temperature or ambient temperature

To describe the outside temperature, the temperature of air (dry-bulb temperature) is measured below a shaded enclosure, well ventilated (Stevenson screen or instrument shelter), at (1.2 - 1.8 m) above ground level (Chandrasekar, 2013; Strangeways, 2003; Sutherland, 2006). Two types of devices are generally used to measure it: thermometer (read visually) and thermistor (record temperature variation). It is generally expressed in Fahrenheit degrees in the United States and the Celsius temperature scale as the international standard.

$$T(F) = 1.8\, T(°C) + 32 \quad [1.1]$$

Many factors influence the daily increase or the decrease of air temperature. At a given site it depends on the wind and the local factors such as altitude, latitude, distance from the sea, cloud cover and rainfall, length of the day, shading, presence of water body, etc. (Magu, 2006; Elaiab, 2014). When "the wind speed is low, local factors strongly influence on temperature of air close to the ground, while with higher wind speeds, the temperature of the incoming air is less affected by local factors" (Magu, 2006).

1.6.1.1. Daily and annual cycles of air temperature

There is one reasons behind daily cycles of temperature in our earth: the changes in incoming solar energy as a result of the Earth's rotation on its polar axis once every 24 hours (see Figure 1.8), therefore:

- Creates day and night.

- The Earth's net radiation (net flux[1]) varies significantly positively or negatively, where

• Net radiation is positive: During the day solar energy enters our atmosphere as shortwave radiation. Part of this solar radiation is absorbed by the Earth's land surface, oceans, etc. Therefore, the surface warms quickly and transfers heat by convection to the air in contact. "This heat is transferred to the upper layers mainly by convection and with the turbulence and eddies in the air. Currents and winds bring large masses of air into contact with the earth's surface, to be warmed in this way" (Givoni, 1969).

• Net radiation is negative: At night, the sun stops shining. This means incoming shortwave radiation stops, while the Earth continues to radiate longwave radiation, and the ground temperature decreases and cools the surface air layer to its lowest temperature.

As a result, "air temperature rises sharply in the morning hours and continues to rise long after the noon peak of net radiation". In other words the air next to the surface is warmed or cooled as well, thus the daily cycle of air temperatures happens (James, 2004; Magu, 2006; Strahler, 2010).

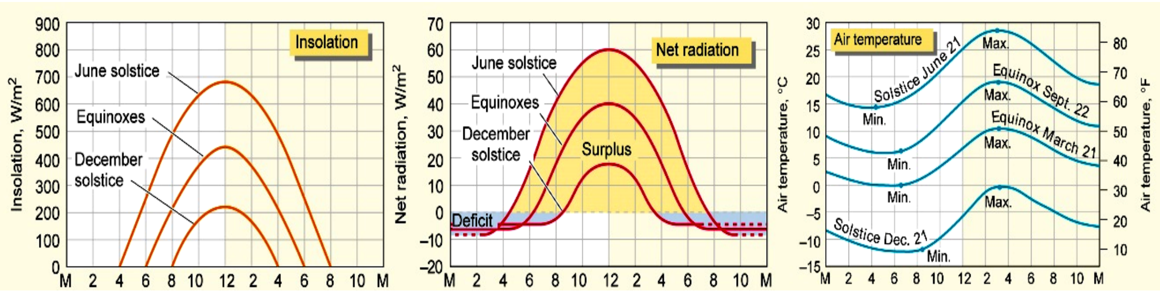


Figure 1. 8: Daily cycles of insolation, net radiation, and air temperature [2]

Source: (Strahler, 2010)

1.6.1.2. Calculation of air temperatures in an urban area

Many methods and mathematical models have been proposed by researchers to calculate air temperature in an urban area. They can be summarized as follows:

Based on the thermal equilibrium in the thin layer,

For example, Zhang and Meng (2009) have calculated the air temperature of the near surface layer in urban environment through the coupled calculation using the energy balance equations of underlying surfaces and building walls. This method "divided the surface layer air into several layers in the vertical direction, and some energy balance equations were developed for each air layer, in

[1] Net flux (W m-^{2}): "is the balance between incoming and outgoing energy at the top of the atmosphere. It is the total energy that is available to influence the climate. It can be expressed as the sum of sensible heat flux, latent heat flux, and heat flux into the soil" (Zhan, 2015).

[2] Air temperature rises sharply in the morning hours and continues to rise long after the noon peak of net radiation.

which the heat exchange due to vertical turbulence and horizontal air flow was taken into account", see Figure (1.9) (Zhang and Meng, 2009).

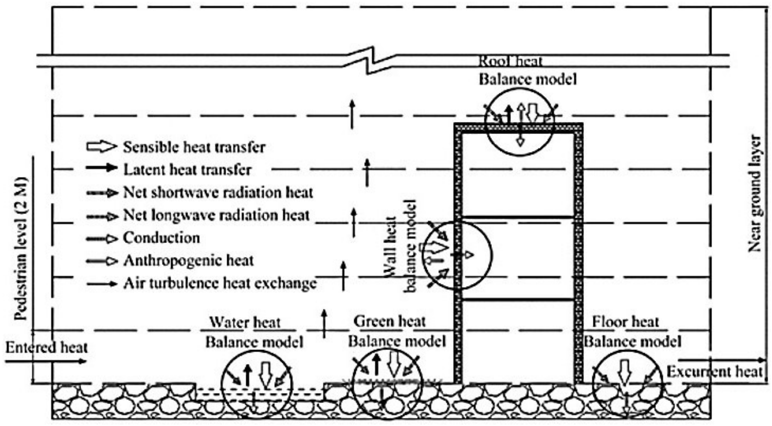


Figure 1. 9: Near ground air heat balance model
Source: (Zhang and Meng, 2012)

Base on coupling between the thermo-radiative model and the aeraulic model

Malys studied the coupling between the thermo-radiative model and the aeraulic model, which was developed to simulate thermal comfort conditions in urban spaces. Based on the thermal balance on the mass of air of this volume, he proposed a method to calculate the air temperature on a control zone. This method is considering a control volume in which the air has a homogeneous temperature. The air enters the volume at the meteorological air temperature and exits at the equivalent temperature of the control volume. The thermal balance on the air mass of the control volume is written as:

$$c_a \rho_a V_a \frac{T_{eq,t} - T_{eq,t-1}}{\Delta t} = F_{conv}(T_{eq,t}) + c_a Q_m (T_{meteo} - T_{eq,t}) \quad \textbf{[1. 2]}$$

c_a, ρ_a :Thermal capacity ($J/K/kg$)And density of air (kg/m^3)

V_a :Air volume of the control zone (m^3)

$T_{eq,t}$:Air temperature in the control zone at time step t (°C)

F_{conv} :Sum of convective fluxes (W), It is expressed as a function of the surface temperatures and the equivalent air temperature:

$$F_{conv} = \sum_i S_i h_i (T_{se,i} - T_{eq,t}) \quad \textbf{[1. 3]}$$

hi :CHTC (Convection Heat Tansfer Cefficient) Variable according to the wind speed according to BOUYER(2009),

$$h_c = 5.85 + 1.7 v_{meteo} \quad \textbf{[1. 4]}$$

Q_m :Air mass flow in the control zone, calculated from the wind profile $v(z)$, Of the height (H) and the width (L) of the zone

$$Q_m = \rho L \int_{z=0}^{z=H} v(z) dz \quad \textbf{[1. 5]}$$

Based on surface temperature data,

For example, Unger et al. (2009) developed a method for the estimation of the early night-time near-surface air UHI pattern in view of the surface temperature data. This study presents five different equations, depending on the radius of the study area (Unger et al., 2009).

	Regression equation	The radius of target urban area (m)	
1.	***Tair = 0.373 × Tse + 17.691***	100	**[1. 6]**
2.	***Tair = 0.406 × Tse + 16.898***	200	**[1. 7]**
3.	***Tair = 0.426 × Tse + 16.453***	300	**[1. 8]**
4.	***Tair = 0.436 × Tse + 16.228***	400	**[1. 9]**
5.	***Tair = 0.447 × Tse + 15.982***	500	**[1. 10]**

Based on some specialist tool such as STEVE Tool, ENVI-met and etc.

Ignatius et al. (2015), uses STEVE-tool (Screening Tool for Estate Environment Evaluation) to calculate the outdoor temperature. STEVE tool is an empirical model that calculates the maximum, minimum and average air temperature of a point of interest based on a (50m) radius in an urban area. This study reported that the air temperature of a point at a certain height level is the function of the local climate characteristics, which deviates according to the surrounding urban morphology characteristics (building, pavement and greenery) at a certain radius. Therefore, the air temperature can measured in different levels for example air temperature at base (ground), air temperature at altitude, air temperature influenced by tree, etc. (see Figure 1.10) (Ignatius et al., 2015).

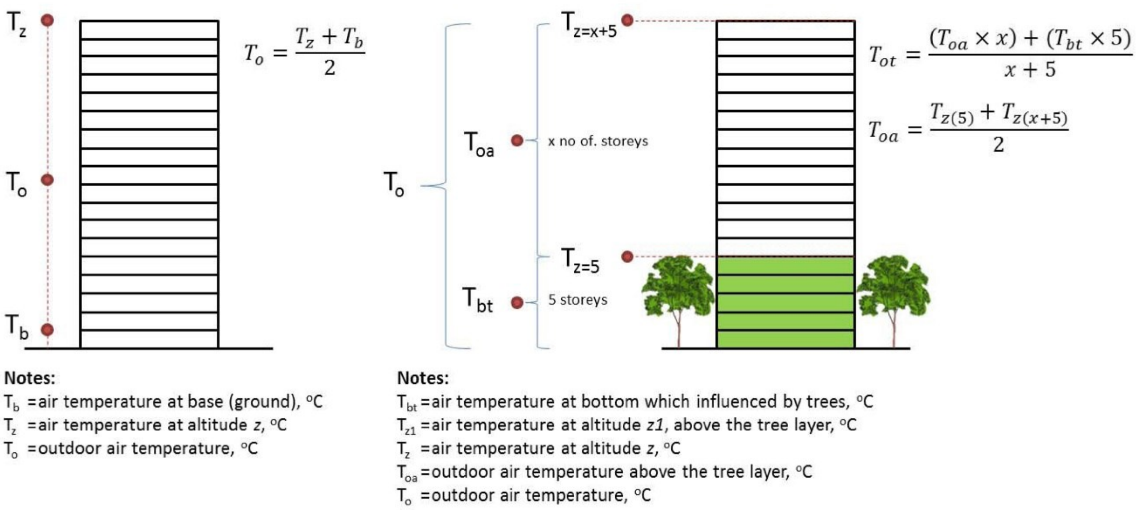


Figure 1. 10: Model proposed by IGNATIUS et al. to calculate the air temperature at different heights points

Source: (Ignatius et al. 2015)

Based on remote sensing data

Another attempt to estimate the air temperature by applicability of land surface temperature (LST) is derived from satellite images. For example, Sun et al. (2005) estimated the ambient air temperature from land surface temperature by using MODIS satellite data, for a location situated in the North China Plain. In this method, two important parameters were used to build a quantitative relation between the land surface temperature and the ambient air temperature: crop water stress index and aerodynamic resistance. This study proposed the equation [1.11] (Sun et al., 2005).

Therefore, to estimate the air temperature we should consider:

- The surface temperature of the scene, where the surface temperatures have direct effect on the air temperature in an urban area.

- Boundaries of the study area, either the radius of the study area or the diminution of control zone, depending on mathematical model that will be used.

$$Tair = Tse - [\,(1-\xi)\, Rn \times ra \times CWSI\,] / [\rho\, Cp] \qquad [1.\ 11]$$

Where:

ξ	*The variable related to the vegetation cover fraction and the leaf area index. It is estimated accordingly as:* $\xi = 0.35 * (1 - f) + 0.05 * f$ *f is vegetation cover fraction*		
Rn	*The net radiation*		
r_a	*The aerodynamic resistance*	*CWSI*	*The crop water stress index*
Tse	*The surface temperature*	*Cp*	*The air specific heat at constant pressure (1004 J/kg/K)*

1.6.2. Air humidity of atmosphere

Air humidity reflects the amount of water vapor present in the air. It is usually expressed in many ways as an absolute, specific or a relative value.

A. **Relative humidity (RH)** is defined as "the ratio of mass of water vapor present in a given volume of gas to the mass of water vapor necessary to saturate the same volume of gas at the same temperature".

It ranges between RH = 0% (dry air) and RH = 100% (Saturated air) (Nakra, 2009) and is expressed as a percentage and is calculated by using the equation [1.12]:

$$RH = (P_v / Psat) \times 100\ \% \qquad [1.\ 12]$$

Where:

RH	*The relative humidity*	*Psat*	*The saturated vapor pressure of water*
P_v	*The partial pressure of water vapor*		

B. **Absolute humidity (AH):** is defined as the ratio of the mass of water vapor to the mass of dry air in a given volume of the mixture (Cengel et al., 2009; Morvay and Gvozdenac, 2008). Thus it is expressed as equation [1.13]:

$$AH = m_v \times m_a$$ **[1. 13]**

Where:

AH	*Absolute humidity*	m_a	*Mass of dry air*
m_v	*Mass of water vapor*		

If ideal gas behavior is assumed, the absolute humidity can be calculated using equation [1.14] (Bothale and Katpatal, 2015):

$$AH = C \times Pv / Tair\ )$$ **[1. 34]**

Where:

AH	*Absolute humidity*	*Tair*	*Temperature in K*
Pv	*Vapour pressure in Pa*	*C*	*Constant 2.16679 gK/J*

When the value of relative humidity, air temperature, and barometric pressure are known, the absolute humidity can be calculated by using the following chart (see Figure 1.11) (Conservation Physics website, 2012).

C- Specific humidity (HS) is a ratio of the water vapor content of the mixture to the total air content on a mass basis. According to the formula proposed by Nadeau and Puiggali (1995), the specific humidity at saturation (HS) may be expressed as a function of relative humidity by the relation as equation (Nadeau and Puiggali, 1995) [1.15]:

$$HS = [0.622 \times Psat_{(Tair)} \times HR] / [1001325 - Psat_{(Tair)} \times HR]$$ **[1. 45]**

While, the maximum saturation pressure of the water vapor in moist air (P_{sat} (Tair)) varies with the temperature of the air, vapor mixture can be expressed as equation [1.16], (Chantoiseau et al., 2016):

$$Psat_{(Tair)} = exp\left[23.3265 - \frac{3802.7}{Tair - 273.18} - \left(\frac{472.68}{air - 273.18}\right)^2\right]$$ **[1. 56]**

Where:	*HR*	*Relative humidity (value between 0 and 1)*	*HR*	*Relative humidity*
	Tair	*The air temperature in ºC (value between 0 and 45 ºC*		

If we know the relative humidity of the moist air, the water vapor density and density of the air, the specific humidity can be expressed as equation [1.17], (Ibojo, 2013):

$$HS = 0.622\ RH\ \rho_{ws} / (\rho - \rho_{ws})\ 100\%$$ **[1. 17]**

Where:	*HS*	*Specific humidity of air vapor mixture (kg/kg)*	ρ	*Density of the moist or humid air (kg/m^3)*
	RH	*Relative humidity (%)*	ρ_{ws}	*Density of water vapor (kg/m^3)*

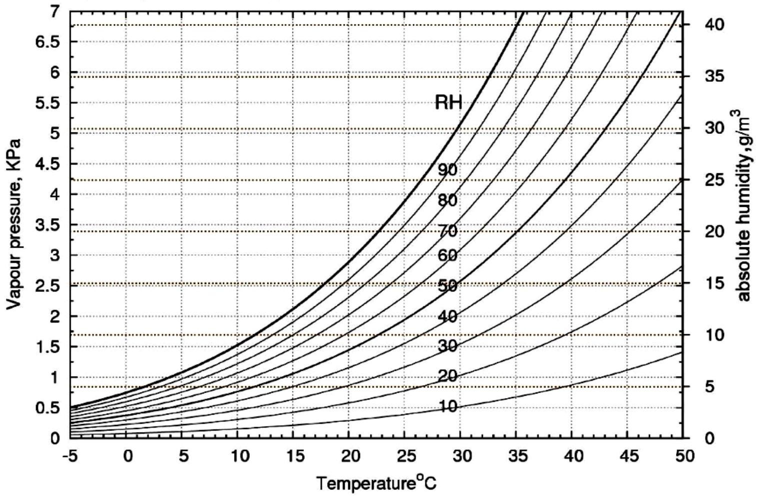


Figure 1. 11: Relation between vapor pressure, relative humidity, absolute humidity and air temperature

Source: (Conservation Physics website, 2012)

1.6.2.1. Air temperature vs relative humidity

There is an inverse relation between both relative humidity and air temperature for a given viewpoint, where relative humidity is going to be the highest when the air temperature is at its lowest values (night) and lowering as the air temperature rises (day), (see Figure 1.12) (Ackerman, 1987; Comet, 2016).

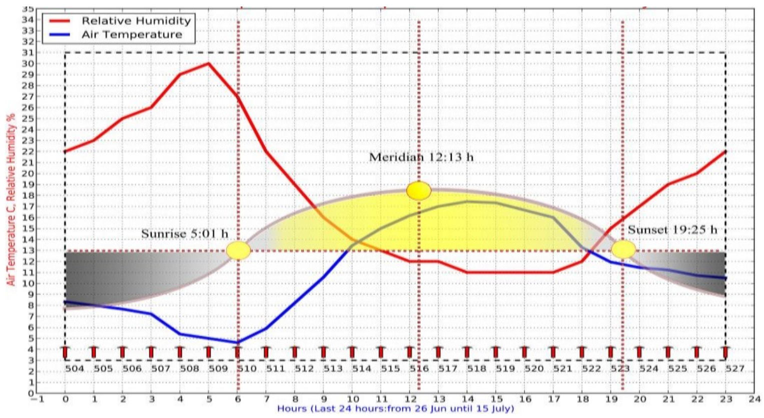


Figure 1. 12: Relation between air temperature and relative humidity (Mosul, Iraq-Sunrise, Sunset, 15 July 2013)

Source: http://www.timeanddate.com/sun/iraq/mosul?month=7&year=2013)

In an urban climate, the relation between air temperature and humidity is considered as the main factor that greatly affects both human comfort and health, and comfortable environment. Manibhai identified three cases of the relation as following (see Figure 1.13) (Manibhai, 2013):

Case one, high temperature and high humidity

High humidity and high temperature cause discomfort if sweat doesn't evaporate, but proper design to provide good air movement by natural ventilation can reduce discomfort.

Case two, low temperature and high humidity

On low temperature and high relative humidity, the urban outside surfaces will be cool as well as the human body feels cold, as a result of heat convection from the urban surfaces and the human body to the air surrounding, and condensation of water vapor occurring on cooler side of surfaces leading to the deterioration of building materials.

Case three, high temperature and low humidity (dry days)

On dry days, sweat evaporates quickly, the body cooling itself by releasing water and salts in the process called sweating. This process needs heat to change liquid water to vapor. Finally, this "body's heat" is transferred to the ambient air layer. Thus, Evaporation provides comfort and leads to reduce this heat. The same phenomenon is used by urban trees and green infrastructure or mist systems (water mist spraying system, misting fans).

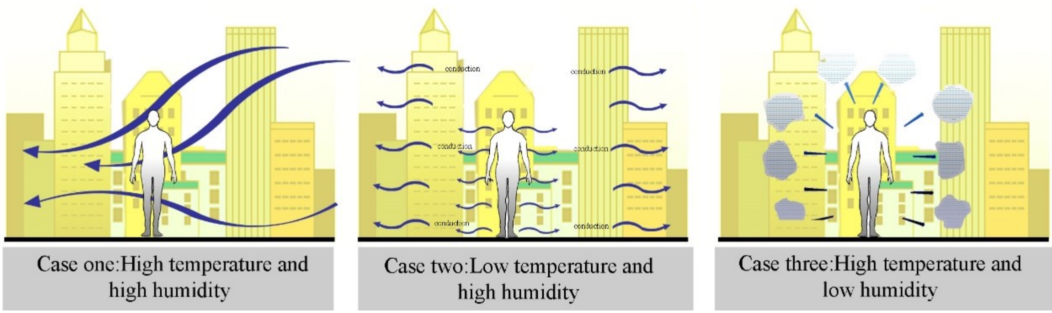


Figure 1. 13: The relation between air temperature and humidity
Source: (Manibhai, 2013)

1.6.3. Wind

Wind is a mass of air that moves above the surface of the Earth in a mostly horizontal direction from an area of high pressure to an area with low pressure (Hyndman, 2010). Generally, wind is named by the direction it comes from, for example a north wind blows from the north to the south. An anemometer tool measures wind speed. In the surroundings of cities, measurements were taken at a high of 10m above ground level, while in an urban area measurement are taken at a height of 10-20m, to avoid the influence of the urban fabric. Regarding the wind speed, when the wind speed is low, local factors strongly influence on air temperature especially near the ground, while at higher wind speeds, the air temperature is less affected by local factors (Manibhai, 2013).

The primary reason for the occurrence of wind is the variations in temperature of Earth's surface or in other word the variation of ability of surface materials to absorb the solar radiation. As a result differences in air pressure are created. The mechanism of wind generating starts from the rise of "the hot air and creates an area of low pressure underneath it, while cool air falls and creates high pressure above it. Air from high pressure areas flows into nearby low pressure areas, creating wind" (Deziel, 2017). Many tools and software have been developed to study the wind behavior such as wind-tunnel (experimental) or Computational Fluid Dynamics (CFD) techniques (simulation).

1.6.3.1. Wind conditions

Many factors affect the wind flow through the urban area thereby cause a gradual decrease in wind speed. Some are related to the earth's surface and others to the buildings shape and urban configuration (Houda et al., 2011), streets, trees, etc. The wind speed versus friction against the surface of the Earth depends on so-called the gradient height[3]. Three factors can determine the friction against the Earth: the roughness of the terrain, the influence of obstacles and the effect of the terrain contours. In this regard, there are two cases either above the gradient height where there is no effect, or below the gradient height where it has the highest rate of impact and determine the vertical profile of the wind speed (Tamura and Kondo, 2015) (see Figure 1.14). Bin (2001) wrote, "below the gradient height the mean wind increases with height and its turbulence level decreases with the height because the influence of the friction between the wind and earth surface decreased with height" (Bin, 2011).

According to the "power law", the mean wind speed V_Z at the height Z under the gradient height can be calculated by equation [1.18].

$$V_Z = V_G\,(Z / Z_G)^a \qquad \textbf{[1. 68]}$$

Where: V_Z *The mean wind speed at the height Z under the gradient height (m.s-1)*
V_G *The mean wind speed at the gradient height ZG (m.s-1)*
Z_G *The gradient height (m)*
Z *Some height under the gradient height*
a *Exponent dependent on the ground terrain*

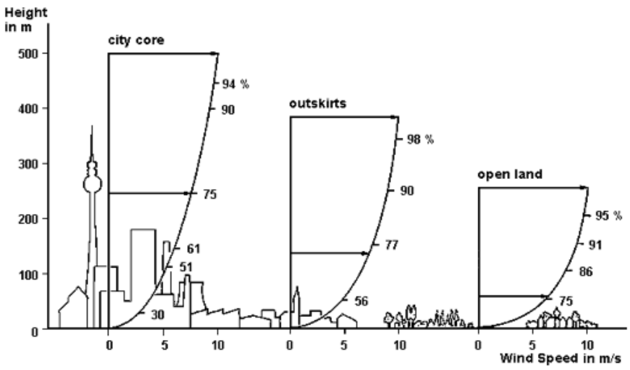


Figure 1. 14: Decrease in Wind Speed as Influenced by Varieties of Terrain Roughness
Source: (Berlin Environmental Atlas, 2017)

Oke (1988) has identified a classification of flow regimes in urban outdoor space depending on the canyon geometry (H/W ratios): isolated roughness flow regime, wake interference flow regime and skimming flow regime (Fenger et al., 2013). The basis of this classification depends on the ratio between the average height of the canyon walls (H) and canyon width (W) which is called as canyon aspect ratio (H/W), as follows (Karra et al., 2011; Shen et al., 2015).

[3] The gradient height: The height of turbulence boundary layer

Isolated roughness flow: This regime happens when the buildings are widely spaced, where the H/W < 0.3. In this type, the flow air is associated with the individual buildings without interaction between them.

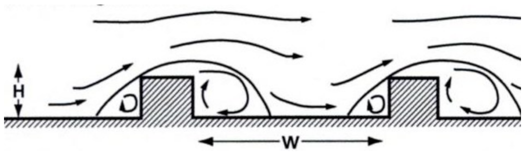


Figure 1. 15: Isolated roughness flow
Source: Based on Oke (1988)

The skimming flow: This regime happens when the buildings are not sufficiently far apart, where the H/W=1. In this regime, a main vortex can form inside a street canyon

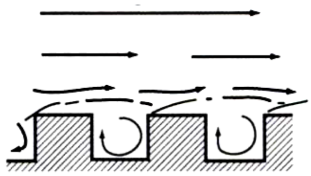


Figure 1. 16: The skimming flow
Source: Based on Oke (1988)

The wake interference flow: This regime exists between these other regimes where the separation vortex does not have enough space to be developed fully. Here the canyon aspect ration is 0.3<H/W≤ 0.5.

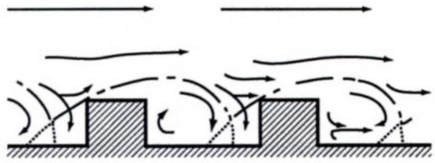


Figure 1. 17: The wake interference flow
Source: Based on Oke (1988)

1.6.3.2. Effect of urban geometry on roughness parameters

Estimating the roughness of a urban area may be expensive and complex in actual urban areas therefore, morphometric models have been settled which use algorithms to relate Roughness length (z0) and Zero-plane displacement (d) from generic measures of surface geometry (see Figure 1.18). The roughness of the urban area was covered by many researchers. Based on urban surfaces, Wierṅga (1993) has proposed estimates of the roughness of urban areas for general categories of urban form, range from (0.0002m) for concrete and flat desert to about (1.5m) for regularly built large town (Table 1.3) (Wierṅga, 1993). Based on urban zones, Grimmond and Oke (1999) have proposed estimates of the roughness, range from (0.3) for low height and density to about (2.0) for high rise buildings (Table 1.4) (Table 1.4) (Grimmond and Oke, 1999).

Surface type	Roughness length (m)
Concrete, flat desert	0.0002-0.0005
Fallow ground	0 001-0004
Short grass	0.008--0.03
Continuous bushland	0.35-0.45
Mature pine forest	0.8-1.6
Tropical forest	1.7-2.3
Dense low buildings (suburb)	0.4-0.7
Regularly built large town	0.7-1.5

Table 1. 3: Typical roughness length (z0) of homogeneous surfaces
Source:(Wierṅga, 1993)

Urban surface form	*Canopy height H(m)*	Two-thirds of H d(m)	z0 (m)
Low height and density	5-8	2-5	0.3-0.7
Medium height and density	7-11	4-7	0.-1.4
Tall and high density	11-18	7-13	1.0-2.2
High rise	>18	>10	>2.0

Table 1. 4: Typical roughness properties of homogeneous zones in urban areas
Source: (Grimmond and Oke, 1999)

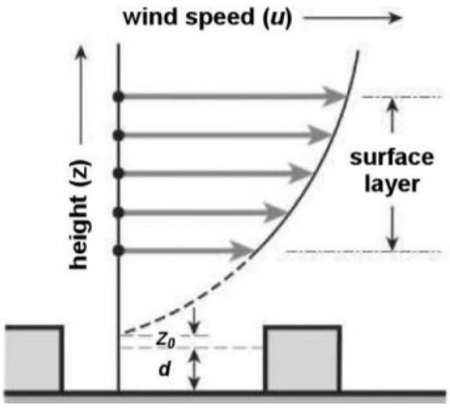


Figure 1. 18: The relation between the roughness length (z0) and zero-plane displacement (d) "Note: The logarithmic curve in the surface layer (i.e. inertial sub-layer) extrapolates to a zero wind speed at a height equal to the sum of the zero-plane displacement (d) and roughness length (z0)" Source: (Erell et al., 2012)

1.6.4. Solar radiation

Solar radiation striking the surface perpendicular to the sun's rays at the top of the earth's atmosphere, called the solar constant, is about 0.082 MJ m-2 min-1. The angle between the direction of the sun's rays and the normal to the surface of the atmosphere is the main factor in determining the local intensity of radiation. This angle is always changing during the day and also it varies depending on the seasons of the latitudes. Consequently, the extraterrestrial radiation is the radiation received at the top of the earth's atmosphere on a horizontal surface.

In 2006, Manivanan clarified some details about the extraterrestrial radiation: "if the sun is directly overhead, the angle of incidence is zero and the extraterrestrial radiation is 0.0820 MJ m^{-2} min^{-1}. As seasons change, the position of the sun, the length of the day and, hence, the solar radiation change as well".

Therefore, we can say that the extraterrestrial radiation is a function of three factors latitude, date and time of day.

Solar radiation is considered the most factor that could influence micrometeorological processes, sensible heat flux, surface and air temperatures, wind and turbulent transport, evapotranspiration and growth and activity of plants and animals, as well as they are affecting the other climate factors. According to Kumar et al. (1997) 99.8% of energy at the Earth’s surface comes from the Sun (Kumar et al., 1997).

The behavior of the earth's surface with the incident solar radiation (direct and indirect) depending on the characteristics of surface materials can be divided into absorbed solar radiation and reflected solar radiation.

- The absorbed solar radiation (short-wave radiation such as ultraviolet, visible, and short-wave infrared) is the radiation that is heating the land and later re-emited in the form of long-wave infrared (Prinsloo and Dobsonm, 2014).

- While the reflected solar radiation is the radiation received at the Earth's surface and then redirected back to space by reflection (Gurney et al., 1993).

Accordingly, the total global radiation at the terrestrial objects consists of both shortwave and longwave radiation.

Shortwave radiation

Solar radiation is the amount of radiation emitted by the Sun reaching a horizontal plane of the earth. Before it reaches the surface of the earth and just enters the atmosphere, portion of the radiation is scattered, reflected or absorbed by the atmospheric gases, clouds and dust. Because the sun emits energy as short wavelengths, solar radiation is also referred to as shortwave radiation (Manivanan, 2006). Solar radiation is also known as global radiation, meaning that "the total short-wave radiation from the sky falling onto a horizontal surface on the ground, it includes both the direct solar radiation and the diffuse radiation resulting from reflected or scattered sunlight." (Chabane et al., 2016).

-Direct radiation:
It reaches the surface of the Earth from the solar beam without any interactions with particles in the atmosphere (see Figure 1.19-1).

-Diffuse radiation:
It is scattered out of the solar beam by gases (Rayleigh scattering) and by aerosols (which include dust particles, as well as sulphate particles, soot, sea salt particles, pollen, etc.) (see Figure 1.19-2).

-Reflected radiation:
It is mainly reflected from terrain and is therefore more important in mountainous areas (see Figure 1.19-3).

According to Kondrat'Yev (2013) and the radiation balance equation, direct shortwave radiation is the most important component of global radiation because it contributes the most to the energy balance and also the other components depend on it, either directly or indirectly (Kondrat'Yev, 2013).

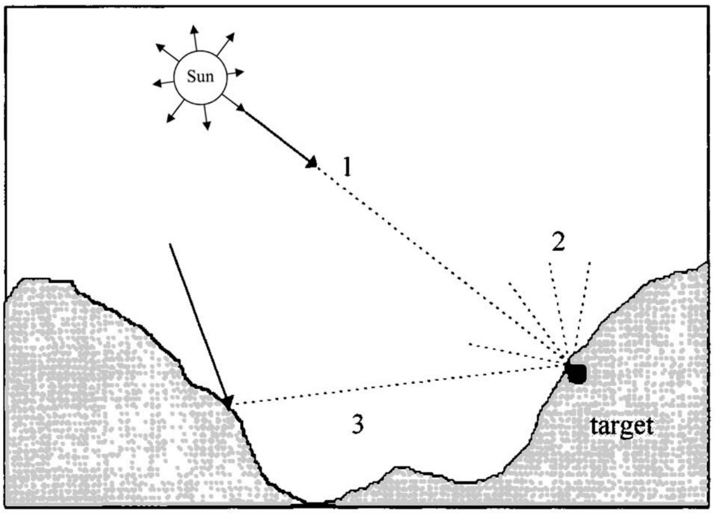


Figure 1. 19: Downward irradiance received in a mountainous region (1) direct irradiance,(2) diffuse irradiance from the sky, and (3) terrain reflected irradiance
Source: (Kondrat'Yev, 2013)

Albedo and net solar radiation

When the solar radiation hits the earth's surface, portion is reflected. This portion is known as the albedo which varies considerably, for example, for freshly fallen snow it may be as large as 0.95, on the contrast that the dark materials, like dirt and dust, have low albedo of (0.1 to 0.25).

While, the net solar radiation is the fraction of the solar radiation that is not reflected from the surface.

Longwave radiation

After the solar radiation hits the earth surface, a portion is absorbed by the earth and converted to heat energy. Later on, the earth emits radiative energy with wavelengths longer than those from the sun (around 10 μm and intensities of several hundred W/m^2). Therefore, the terrestrial radiation is referred to as longwave radiation. After this longwave radiation reaches the atmosphere, it may be absorbed or lost into space.

This type of radiation always suffers from continuous radiation exchange with their surroundings since the building components absorb long-wave radiation emitted from other objects and then they emit such radiation themselves. The most important characteristic of this long-wave radiation exchange is having mutually similar temperatures, their long-wave radiation exchange is quite balanced, and despite the considerable amounts of energy passed back and forth, the exchanged net radiation flows are comparatively low.

In 2006, Manivanan said that "the longwave radiation can effectively increases the temperature of the atmosphere and, as a consequence, the atmosphere radiates energy of its own. Part of the radiation finds it way back to the earth's surface. Consequently, the earth's surface both emits and receives longwave radiation" (Manivanan, 2006).

"The difference between outgoing and incoming longwave radiation is called the net longwave radiation. As the outgoing longwave radiation is almost always greater than incoming longwave radiation, represents an energy loss"(Manivanan, 2006).

Net longwave radiation

Net longwave radiation is a measure of the difference between outgoing longwave radiation from the earth surface and incident atmospheric longwave counter-radiation. Thus, net longwave radiation can be expressed by (Nasa, 2017):

Net longwave radiation (W/m2) = incident longwave counter-radiation (W/m2) - outgoing longwave radiation (W/m2)

Outgoing longwave radiation

It is the energy radiating from the Earth as infrared radiation at low energy to Space. It is electromagnetic radiation emitted from Earth and its atmosphere out to space in the form of thermal radiation (Kondrat'Yev, 2013). It depends on surface temperature and surface emissivity.

Net radiation

"The net radiation is the difference between incoming and outgoing radiation of both short and long wavelengths. It is the balance between the energy absorbed, reflected and emitted by the earth's surface or the difference between the incoming net shortwave and the net outgoing longwave radiation. It is normally positive during the daytime and negative during the nighttime. The total daily value for Net radiation is almost always positive over a period of 24 hours, except in extreme conditions at high latitudes"(Manivanan, 2006).

Further details will be provided later on in chapter 2

Accordingly, the radiative situation of any exterior wall where all radiation terms can be seen as Figure 1.20.

Direct solar radiation: the fraction of solar radiation which comes directly from the sun, as incident on the building surface.

Diffuse solar radiation: the fraction of solar radiation scattered by the atmosphere and by clouds, incident from all directions.

Reflected solar radiation: the short-wave radiation which reaches the building surface after having been reflected by the ground or other terrestrial objects.

Atmospheric counter-radiation: the long-wave radiation emitted by the sky (atmosphere + clouds).

Reflected atmospheric counter-radiation: the atmospheric counter-radiation which reaches the building surface after having been reflected by the ground or other terrestrial objects. -

Terrestrial counter-radiation: the long-wave radiation emitted by the terrestrial surroundings.

Long-wave emission: the long-wave radiation thermally emitted by the exterior surface of the building component. It only depends on the temperature and the long-wave emissivity of the surface.

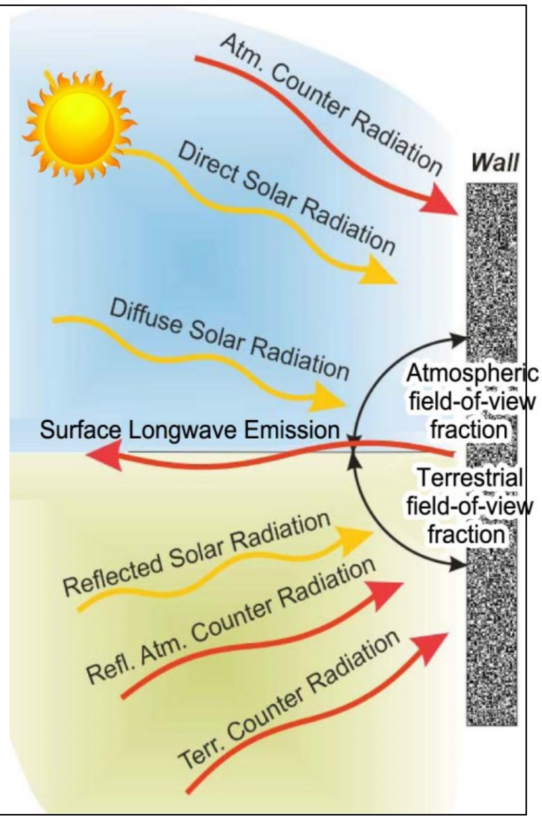


Figure 1. 20: The radiative situation of an exterior wall

Source: (Manfred and Schmidt, 2008)

1.6.4.1. The components of electromagnetic spectrum

According to the notes of Illinois Central College, total (global) solar radiations from the Sun are mixture of range of different wavelength electromagnetic waves (ultraviolet radiation, infrared radiation, visible radiation, and other X-rays, Gamma rays, and Radio) (Prinsloo and Dobson, 2015). **Ultraviolet radiation** (UV), accounts for about 7% of the solar spectrum, much of them is absorbed by the ozone layer.

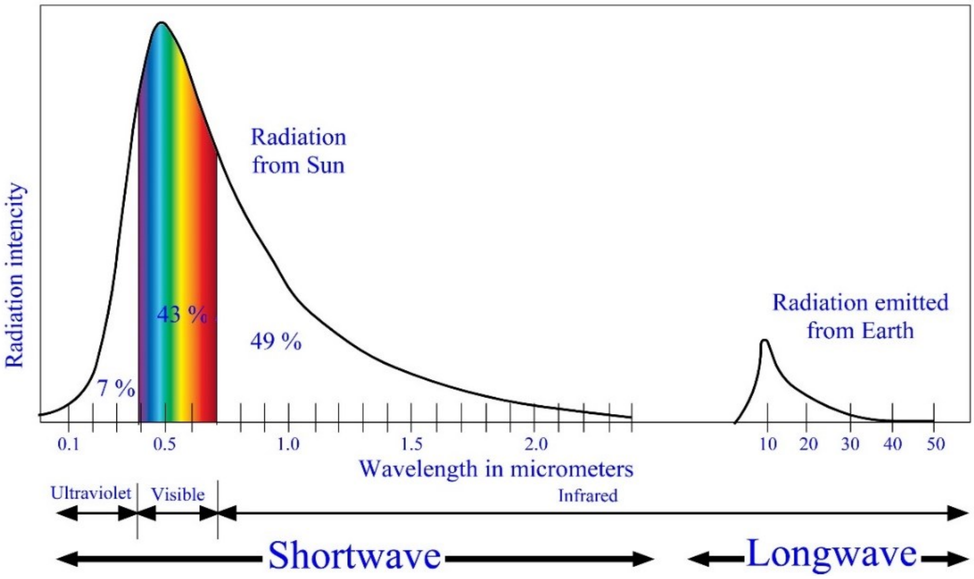


Figure 1. 21: The components of electromagnetic spectrum

Source: (Prinsloo and Dobson, 2015)

It is shortwave radiation with wavelength ranges are 0.001-0.4 micrometers (μm). **Infrared radiation** (IR), accounts for about 49% of the solar spectrum, with wavelength ranges are 0.7-100 micrometers (μm). It gets absorbed by the clouds and other atmospheric gases. **Visible radiation** (visible light), accounts for about 43% of the solar spectrum. It represents most of solar radiation part of the electromagnetic spectrum that reaches the Earth's surface, with wavelength ranges are 0.4-0.7 micrometers (μm). **X-rays, Gamma rays, and Radio waves**, accounts for about 1% of the solar spectrum (see Figure 1.21).

1.6.4.2. Factors influencing the amount of global radiation on surfaces:

According to Jemaa et al. (2013), the amount of global radiation is obtained by "summation of the direct, diffused and terrain- reflected" (Jemaa et al. 2013). Studies varied in the description of the factors that determine the amount of global radiation. In 2009, Nasrollahi has identified these factors with different orientations as the following (Nasrollahi, 2009):

With respect to geographical viewpoint, these factors are:

- The solar constant, "the amount of energy received at the top of the Earth's atmosphere on a surface oriented perpendicular to the Sun's rays".
- The latitude of the location, the solar elevation angle and thus determines the length of the solar path until strikes the surface on the Earth.
- Angle of incidence (The zenith angle), the angle between a ray incident on a surface and the line perpendicular to the surface at the point of incidence.
- The influence of the atmosphere, by scattering and absorbing incoming solar radiation (see Figure 1.22).
- The albedo of the earth's surface affecting multiple scattering of solar radiation.

- The elevation above sea level, where the higher the elevation, the shorter the path from the atmosphere (see Figure 1.23).
- The time-unit which effects the amount of solar energy per 'day', (see Figure 1.24).

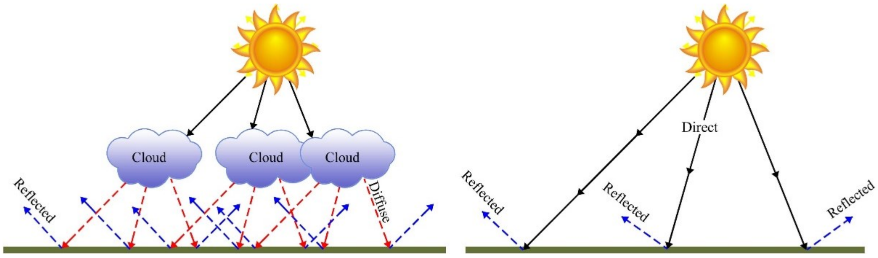


Figure 1. 22: The influence of the atmosphere
Source: Adapted by (Sen, 2008)

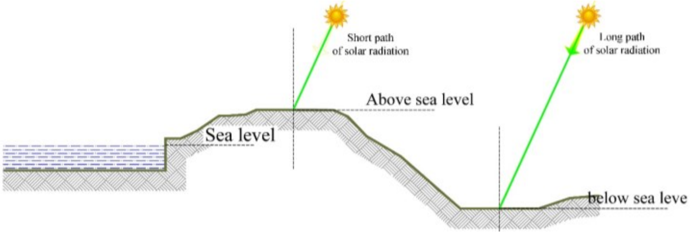


Figure 1. 23: The elevation above sea level
Source: Adapted from (Cockell and Blaustein, 2013)

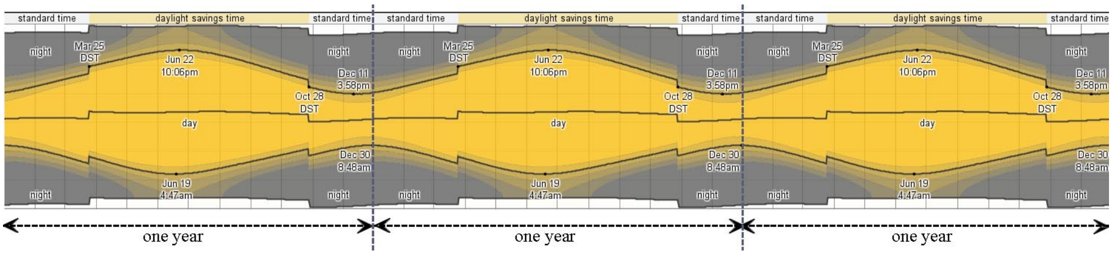


Figure 1. 24: The time-unit
Source: ("Sunrise and Sunset Times in Mosul", 2017)

With respect to solar energy indicators, these factors are:

"The distance between the earth and the sun, the distance of the sun's rays travel through the atmosphere, the angle at which these rays strike the surface, the time the sun is above the horizon, and atmospheric conditions of the site" (Nasrollahi, 2009).

At a particular site, these factors are going as:

Turbidity of the atmosphere, and geometric obstructions (topography, vegetation, and buildings).

1.6.4.3. Estimating the global radiation:

As mentioned previously and according to Jemaa et al. (2013), the hourly calculation of global radiation (total short-wave) is obtained by the sum of the direct components (R_{dir}) , diffused (R_{diff}) and reflected (R_{ref}) with, (Jemaa et al. 2013) :

$$R_{dir} = Sh \times R_{out} \times t^{M} \times \cos(i) \quad [1.19]$$

where R_{dir} Direct radiation; Sh A binary value of shadowing
R_{out} solar flux
t^M The transmissivity coefficient;
t= 0.6,
M is the length of the route with the solar azimuth, In mountain areas, it is necessary to use a correction factor related to atmospheric pressure (P/P_0) , which depends on the altitude. The formula used is:

$$M = M_0\left(\frac{P}{P_0}\right) \quad [1.\ 20]$$

$$M_0 = \left(\sqrt{1229 + (614 * \sin(\alpha))^2}\right) - 614 * \sin(\alpha) \quad [1.\ 21]$$

$R_{out} = Sc \times (1+ 0.034 \times \cos(360J)/ 365)$

Sc Supplied value used by the World Radiation Center 1367w/m²; *J* Julian day

$$R_{diff} = R_{out} * (0.271 - 0.294 * \tau^M) * \sin(\alpha) \quad [1.\ 22]$$

Where α value of angle solar

$$R_{ref} = r * S_c (0.271 + 0.294 * \tau^M) * \sin(\alpha)\sin^2(\chi / 2) \quad [1.\ 23]$$

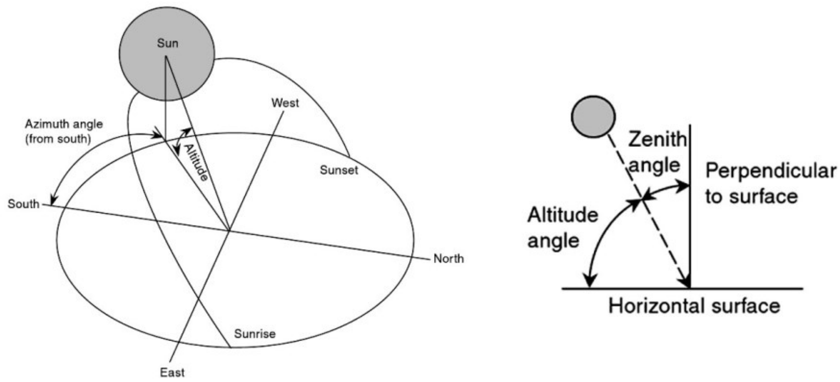


Figure 1. 25: Azimuth and altitude angle
Source: (Bonan, 2015)

1.6.4.4. Estimating the outgoing solar radiation:

To estimate the outgoing solar radiation:

$$\text{The outgoing radiation} = \varepsilon \times \sigma \times Tse^4 \quad [1.\ 24]$$

Where: σ *Stefan-Boltzmann constant* ($5.67\times10^{-8}\ w/m^2\ K^4$)
Tse *Surface temperature of the body (K)*; ε *Emissivity*

1.6.4.5. The building's solar gain via solar radiation

Solar gain (solar heat gain or passive solar gain) is the increase in temperature in a space, object or structure that results from solar radiation, especially when building envelope materials have high transparent surfaces rates. The solar radiation is either absorbed by the opaque elements of the building envelope, then conducted to the indoor spaces or directly reaches the inner wall through the windows and heats them. Therefore, minimizing heat gain requires setting clear design objectives and appropriate materials selection. Al-Sallal (2016) has summarized some strategies related to reduce heat gain, as explained below (Al-Sallal, 2016).

1. Improving the landscape around the building

The main concept related to form configuration is reducing surface exposure to high solar radiation. This concept can be achieved by developing urban forms types that help reduce surface exposure and then building's form that helps shade itself so that to prevent heat gains. A kind of solution is termed compact forms (Al-Sallal, 2016).

2. Form configuration of the building

The main concept related to form configuration is reducing surface exposure to high solar radiation. This concept can be achieved by developing a building form that helps shade itself and using urban forms types that help reduce surface exposure to harsh outdoor conditions and prevent heat gains, such type is termed compact forms (Al-Sallal, 2016).

3. Arrangement of the building's spaces

Arrangement of the building's spaces means that the spatial zoning of the building spaces should respond to the environmental influences, through taking advantage of desirable environment and blocking undesirable ones such as hot and dusty wind. One of the architectural elements that can be effective to serve climatic and thermal comfort needs is the courtyard (Al-Hawsh in Arabic). It is a nexample of a sustainable design configuration that holds a balance between climatic and sociocultural requirements (Al-Sallal, 2016).

4. Shading the building envelope and openings

Solar shading are architectural elements that can help provide shading to the opaque and glazing surfaces which can lead finally to controlling solar gain (Al-Sallal, 2016).

5. Color of the envelope

The color of the envelope surfaces has remarkable effect on the impact of solar radiation on heat gains and the resulted indoor temperatures. White roofs are highly recommended in hot climates. This point will be fully discussed later in chapter 3 (Al-Sallal, 2016).

6. Thermal insulation of the envelope

The selected envelope materials should minimize transmittance of heat to the interior by using some types of materials that have high resistance thermal insulation (minimize heat transfer by conduction)."Radiant heat transfer can also be minimized by using a low-emissivity material (radiant barrier) next to an air gap in a multi-layer roof assembly. It helps reflect the radiation causing reduction of the inner layer temperature and the radiant temperature of the internal spaces, while at night, it blocks radiant exchange, thus reducing the required cooling load" (Al-Sallal, 2016) (see Figure 1.26 and Figure 1.27).

Figure 1. 26: Non insulated wakk and wall insulated with the radiant barrier
Source: (Escudero et al., 2013)

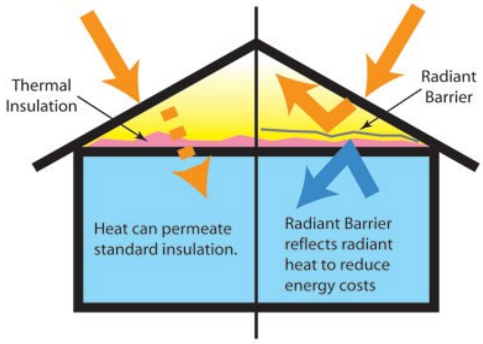


Figure 1. 27: Radiant barrier-roof
Source: http://www.gingerichco.com/radiant-barrier/

7. The opening

The openings is term used regarding windows, doors, skylights. It plays main role regarding gain and lose heat through:

- Direct conduction through the components of the opening (glass, frame, and/or door).
- The radiation of heat into a building (typically from the sun) and out of a building from spaces-temperature objects, such as people, furniture, and interior walls
- Air leakage or infiltration through and around opening that enters a building uncontrollably.

In addition, openings also represent a major source of visual and thermal discomfort, and condensation problems. Three factors can control the thermal performance of opening as following

- U-factor is the rate at which a window, door, or skylight conducts thermal flux. The lower the U-factor, the more energy-efficient the window, door, or skylight.
- Solar heat gain coefficient (SHGC) is the fraction of incident solar radiation admitted through a transparent element (e.g. windows), both directly transmitted and absorbed and respectively transmitted as heat inside a building. SHGC is expressed as a number between 0 and 1. The lower the SHGC, the less solar heat it transmits.
- Air leakage is the rate of air movement around a window, door, or skylight in the presence of a specific pressure difference across it. It's expressed in units of cubic feet per minute per square foot of frame area (cfm/ft2). A product with a low air leakage rating is tighter than one with a high air leakage rating.
- The window-wall ratio, according to Yang et al. (2015), the total energy consumption increased when the window-wall ratio is also increased (Yang et al., 2015).

One way of achieving better performance of opening is

1. Using advanced glazing systems. Using more than one pane for the window and high-performance low-emissivity coated glazing (which provides better thermal performance than clear glass) can dramatically improve the energy performance of the building.

2. The better orientation.

1.6.4.6. Control of internal gains

In public and large buildings (cold and hot regions) which have large numbers of people, the internal heat gains from the surrounding environment have more impact on the building cooling load, being added to the other sources of internal heat gains. The most practical ways to reduce internal heat gains can be summarized as follows, (Al-Sallal, 2016):

A. An increased reliance on natural light and use electrical lighting only when necessary, such as the use of automated sensors (help to integrate natural and electrical lighting).

B. Replacing the equipment and appliances with high performing energy-efficient types and install them in places that reduce their effect on the internal gains.

C. Allocate the necessary spaces in proportion to the occupation densities and types of activities.

1.7. Thermal Performance of building

According to Badea (2014), the assessment of thermal performance of a building refers to "the process of modeling the energy transfer between a building and its surroundings" (Badea, 2014). There are two types of building regarding the thermal performance:

- Conditioned building, the thermal performance means estimating the heating and cooling loads, so that sizing and selection of HVAC equipment can be properly made.

- Non-conditioned building, the thermal performance means calculating temperature variation inside the building over a specified time, and helps one estimate the comfort conditions.

To this point, a knowledge of the methods used to estimate buildings' performance is essential and enables the determination of the effectiveness of their design in order to achieve energy efficient buildings with comfortable indoor conditions (Nayak and Prajapati, 2006).

The heat exchange usually occurring either between a building and the external environment, or between a human body and the indoor environment are conduction, convection, radiation and ventilation (including infiltrations). These processes affect either directly or indirectly the level of thermal comfort of users (See Figure 1.28).

In addition to the heat gained by the internal space from surrounding walls, roof, ceiling, and floor, it is of great importance to know that part of heat is added to the indoor space, which certainly affects the level of thermal comfort due to two outstanding factors namely the human itself (metabolic activities[4]) and the use of lights and equipment. The ventilation not only affects the energy balance but also body comfort through the rate of convection and perspiration. The body either feel cool or hot. When the body loss heat, one feels cool, on the contrary when he gains heat from its surroundings, one feels hot and begins to perspire (Nayak and Prajapati, 2006).

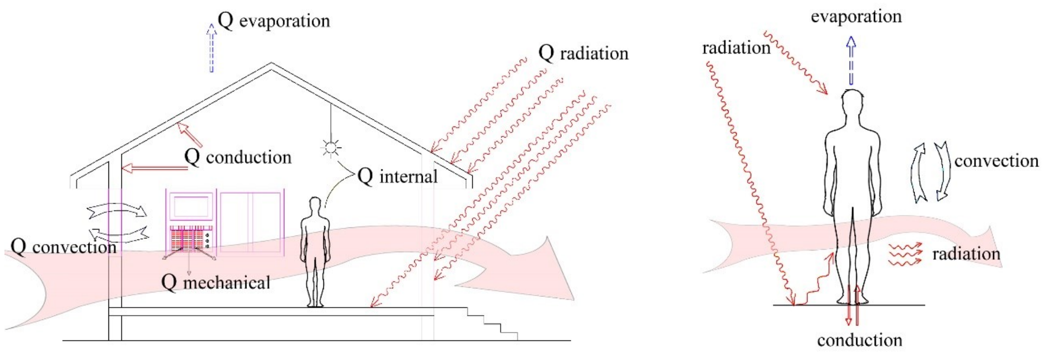


Figure 1. 28: Heat exchange processes between a building/ a human body and the external environment

Source: (Nayak and Prajapati, 2006)

The heat transmitted through transparent windows can also be added to the space, and then absorbed by the internal surfaces of the building. The amount of heat transmitted depends on a number of factors including window orientation, size, amount of external shading, and glass treatments (Sustainable Energy Authority, 2002).

1.7.1. The mechanism of heat transfer occurring in a building

To understanding the mechanism of heat transfer (conduction, convection and radiation occurring) in a building, we suppose the existence of a wall having two faces: one exposed external environment and the other faces a room (indoor space) (see Figure 1.29), in this case many processes occur:

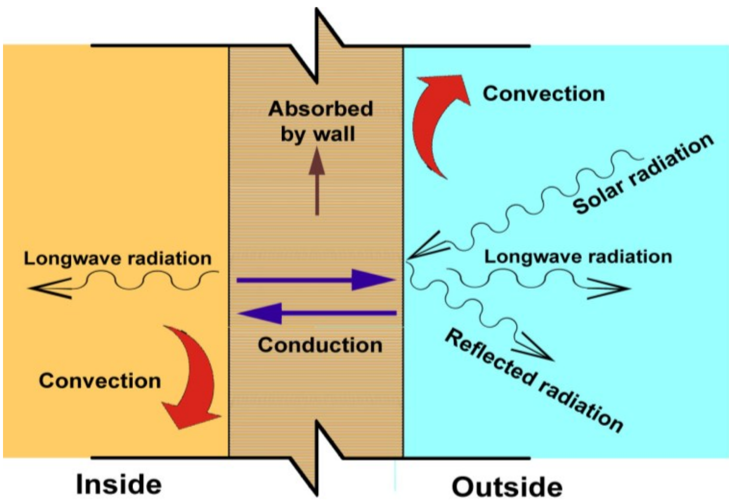


Figure 1. 29: Heat transfer processes occurring in a wall

Source: (Nayak and Prajapati, 2006)

[4] The body continuously produces heat, part of which is used as work, while the rest is dissipated into the environment for maintaining the body temperature.

Step one: process related to wall's outer surface; at daytime, the solar radiation hits the wall outer surface, a part is released to the outdoor environment, and the remaining part is absorbed by the wall and converted into heat energy. The surface albedo value affects the amount of reflected radiation, e.g. example high albedo materials mean high reflection.

Step two: it is a process related to wall's outer surface balance equation: after the wall's outer surface absorbed solar flux, the heat is divided into three parts:

The first part is lost to the environment through convection and longwave radiation from the wall's outer surface. Note that these fluxes can also be gains if the surface temperature is smaller than air temperature for convection and then surrounding surfaces temperature for longwave radiations.

The remaining part is conducted into the wall where it is partly stored, thereby raising the wall temperature. The rest reaches the room's interior surface.

Step three: transfer through the wall. The heat is transferred from the colder face of the wall to the warmer one. The exchanges flux depends on thermal characteristics of the layers composing the wall.

Step four: It is a process related to the inner surface: the inner surface exchanges heat by convection and radiation with the room air and other surfaces.

Sequentially, heat exchanges like these happen through building elements such as walls and roofs. Furthermore, mutual radiation exchanges between the inner surfaces of the building (between walls, floors and ceiling) occur. Such heat transfer processes affect the indoor temperature of a room and consequently the thermal comfort experienced by its occupants.

1.7.1.1. Type of heat and mass transfers between a building and its surroundings

Concerning the importance of the subject of heat exchange, it is necessary to understand in detail the basic concepts on conduction, convection, radiation and evaporation.

a. Heat conduction - The conductive exchanges

Conduction is the process of energy transfer between substances that are in direct contact with each other; it occurs only if there is a difference in temperature between these substances. The rate of thermal conduction depends on the properties of the substance being heated. The materials in which the heat is rapidly transferred are called high conductivity material (low resistance) e.g. metals (silver, copper and aluminum), but non-metals, plastic or some organic materials are poor conductors, and are called thermal insulators. Thermal inslolater materials (also known as non-conductors or bad conductors of heat) are those which do not allow heat to flow through them (Bhatnagar, 2005; McKeen, 2015; Rajput, 2004).

McKeen (2015) explained the process of conduction: "Conduction occurs when a substance is heated, particles will gain more energy, and vibrate more, these molecules then bump into nearby particles and transfer some of their energy to them. This continues and passes the energy from the hot end down to the colder end of the substance" (McKeen, 2015).

The temperature difference drives the flow of energy. Considering a homogeneous layer with a thickness (e) and cross-sectional area (A) and each face on both sides of the layer varies in temperature (Tse_{face1}) and (Tse_{face2}), where (Tse_{face1}) > (Tse_{face2}) (see Figure 1.30).

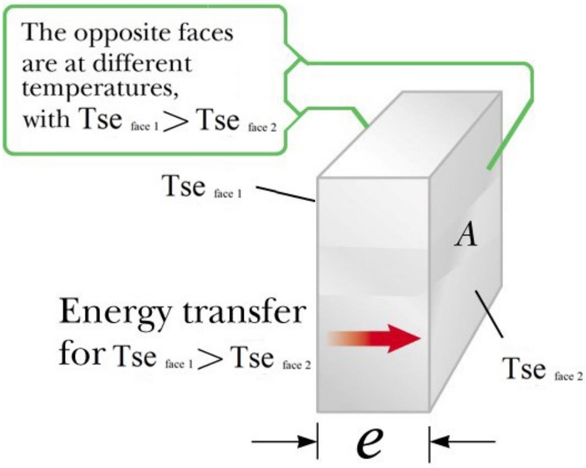


Figure 1. 30 : The conduction flux density

Source: Adapted from (Lavigne et al., 1994)

Therefore, energy is transferred from the zone of higher temperature to the zone of lower temperature by thermal conduction. The density of heat flux φ is:

- Proportional to the cross-sectional area of the layer and the temperature difference,
- Inversely proportional to the thickness of the layer.
- Proportional to the difference in temperature between both sides of the layer
- Proportional to the conductivity of materials

The rate of energy transferred by conduction is given as equation [1.25]

$$\phi_{conduction} = K \times A \times ((Tse_{face1} - Tse_{face2}) / e) \quad [1.25]$$

Where
	$\phi_{conduction}$	*heat flux (W)*
	K	*thermal conductivity of the material, (W/m.K)*
	A	*Is cross-sectional area, (m^2)*
	Tse_{face1}	*temperature of the hot surface (K)*
	Tse_{face2}	*temperature of the cold surface (K)*
	e	*thickness (m)*

b. Thermal convection - the convective exchange

Convection is the heat transfer which occurs either as a result of the movement of liquid or the gas over a surface such as wind blowing against a building; or inside empty cavities such as the movement of air in a double-pane window. When there is a difference in temperature between the air (or other fluid) and a wall (Figure 1.31), the air having a temperature Tair and the surface a temperature Tse, they exchange heat, so that a flux (ϕ_{conv}) is transmitted in the direction from the highest temperature to the lowest.

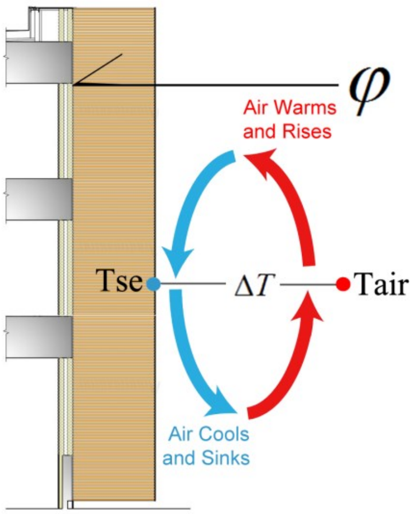


Figure 1. 31: The density flow by convection

Source: Adapted from (Lavigne et al., 1994)

The rate of energy transferred by convection is given as equation [1.26]

$$\phi_{conv} = hc \times A \times (T_a - T_{se}) \quad [1.76]$$

Where		
	ϕ_{conv}	*Convective flux (W)*
	hc	*heat transfer coefficient (W/m²K)*
	A	*area (m2)*
	T_{air}	*temperature of the gas (K)*
	T_{se}	*temperature of the surface (K)*

If the air is calm the convection is called natural convection. Then the air movement is generated by its change in density (buoyancy forces) due to its change in temperature. The convective heat transfer coefficient (hc) is generally low and depends on temperature difference. If the air flow is generated by an external source force (wind, action of a large renewal of air or a fan) it is called forced or assisted convection (see table 1.5), in this case, the convective heat transfer coefficient (hc) is important, depending on the speed of the air.

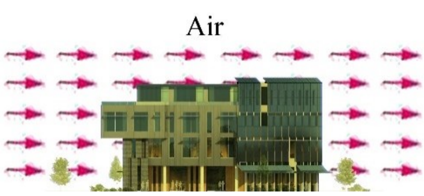
	NATURAL OR FREE CONVECTION	FORCED CONVECTION
Caused by	Density differences	Outside forces
Example	Loops of hot air and cool air, hot air has a lower density than the surrounding cool air therefore, hot air rise up and on the opposite cool air falls. 	Winds are blowing, the air movement across the outside of the wall will be higher, increasing the rate of heat transfer. 

Table 1. 5: The difference between forced convection and natural or free convection

The rate of heat energy transferred by convection depends upon:

- The temperature difference,
- The velocity of the liquid or gas, and
- Kind of liquid or gas.

On indoor surfaces, the convective heat transfer coefficients are generally considered as constant values, different for vertical and horizontal surfaces.

To estimate the convective heat transfer coefficient on the surfaces exposed to the wind, several correlations are available in the literature. The typical correlation for this type is given as following empirical correlation suggested (equation [1.27]) by McAdams (McAdams, 1959):

$$hc = 5.7 \times 3.8\, v \qquad v < 5 \qquad [1.27]$$

Where v The wind speed in m/s

For zero wind speed, this equation gives the heat-transfer coefficient for natural convection. It is one of the earliest experiments of forced convection heat transfer (Tiwari and Tiwari, 2016).

As generally done in building thermal calculations, the correlation given in previous equation includes the effect of both convection and longwave radiation. The correlation for the heat-transfer coefficient due to convection is only given as follows equation [1.28]:

$$hc = 2.8 \times 3.0\, v \qquad 0 <= v <= 7\ ms^{-1} \qquad [1.28]$$

Where v The wind speed in m/s

c. Radiative exchanges

Thermal solar radiation is electromagnetic, and the energy transferred depends on wavelength usually measured in micrometers (µm) (see Figure 1.32). It is the main source of energy for the earth-atmosphere system, it is a form of heat transfer present in vacuum, it does not require any material medium to pass through, it occurs when the emitted radiation strikes another body and then it is absorbed.

The electromagnetic spectrum classifies radiation according to wavelengths of the radiation. The main types of radiations are (from short to long wavelengths): gamma rays, x-rays, ultraviolet (UV), visible light, infrared (IR), microwaves, and radio waves. The radiative balance of the surfaces is usually classified into two parts, the first one is the solar band (short wavelengths radiation including the visible and the near infrared, band between 1.15 and 3.0 µm), and the second one is the infrared exchanges (long wavelengths radiation, band between 5 and 100 µm), see Figure 1.33 (Vinet, 2000).

Though the sun emits different kinds of electromagnetic radiation, 99% of its rays are in the form of visible light, ultraviolet rays, and infrared rays.

The walls of the buildings, our skin, our clothing at current temperatures, emits the IR (Infra-Red) radiation only, while they can be receivers of UV, visible, near IR from lighting and sun and the IR emitted by our surroundings.

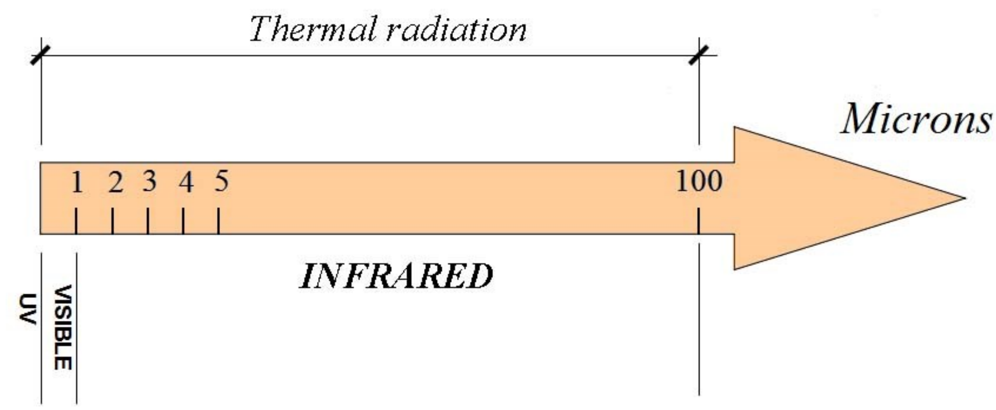


Figure 1. 32: A wavelength expressed in microns
Source: Modified by (Lavigne et al., 1994)

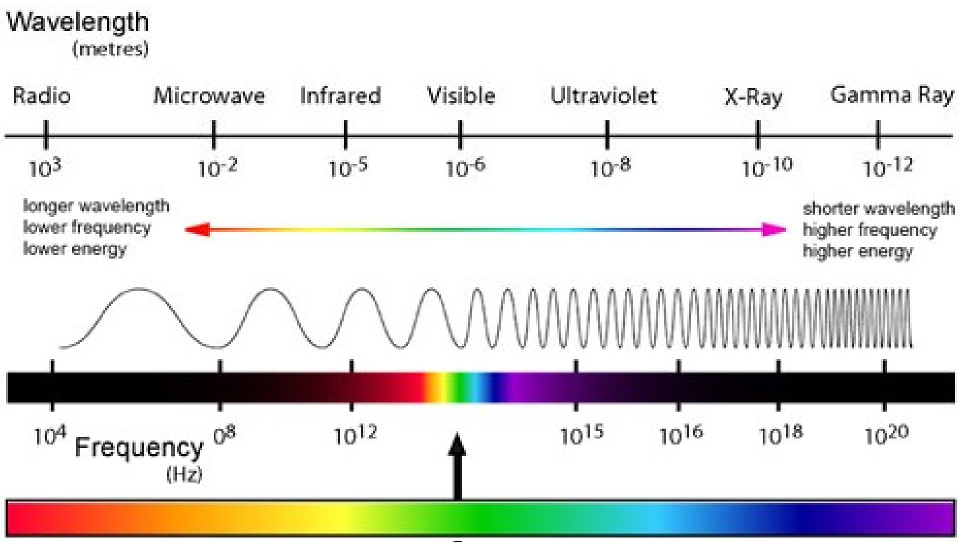


Figure 1. 33: The solar spectrum
Source: http://physics.tutorvista.com/waves/electromagnetic-waves.html

1.7.1.2. Behavior of a receiver of solar radiation

To understand solar radiation, we consider a receiving transparent plate with thickness (e) submitted to an incident flux radiation ϕ_i (see the Figure 1.34). In the most general case, we can see

- The reflection on the surface (S) leading to the reflected flux (ϕ_r).
- The transmission through the thickness (e) leading to the transmitted flux (ϕ_t).
- The absorption in the thickness (e) leading to the absorbed flux is (ϕ_a).

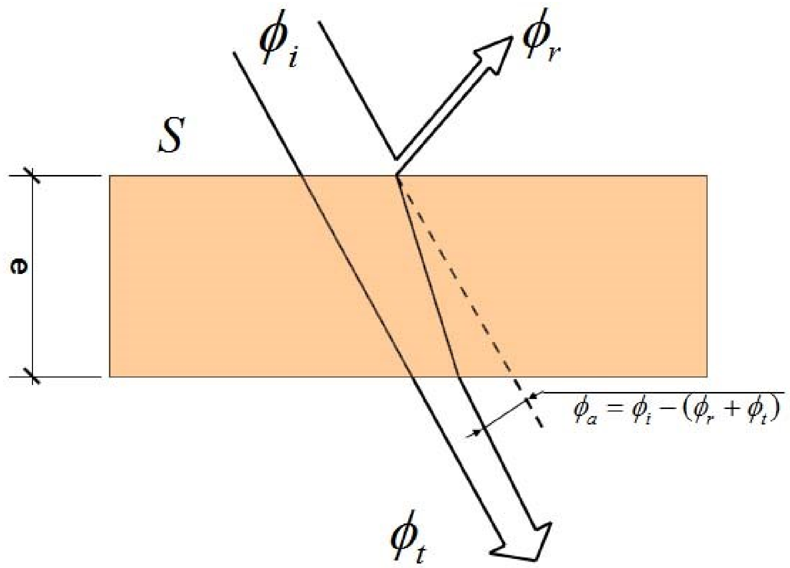


Figure 1. 34: Extinction of radiation (absorption, transmission, and reflection)
Source: Adapted from (Lavigne et al., 1994)

From Figure 1.34, three factors can be defined

Factor of absorption or absorptivity or absorbance	$\alpha = \phi_a / \phi_i$
Factor of reflection or reflectivity or reflectance	$\rho = \phi_r / \phi_i$
Factor of transmission or transmittivity or transmittance	$\tau = \phi_t / \phi_i$

According to the mathematical relations between reflection, transmission, and absorption, as equation [1.29]: incident solar radiation must equal reflected plus transmitted plus absorbed (A) radiation.

$$\phi_i = \phi_r + \phi_a + \phi_t \qquad [1.29]$$

Then, under these terms, the energy balance leads to the well-known relation given by

$$\alpha + \rho + \tau = 1$$

1.7.1.3. Longwage radiations exchanges between surfaces

a. Emission of longwave radiation

At any point P of a surface there is an emission of longwave radiation in a solid angle of half a space (see Figure 1.35). Without going into the detail of the emission as a function of direction, a body emits a flux density (W/m^2) called energy emittance represented by Q (Lavigne, Brejon, and Fernandez 1994).

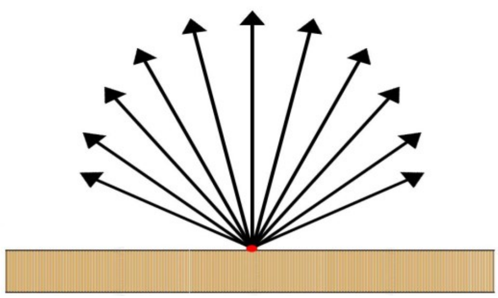


Figure 1. 35: The emitted radiation at any point

Source: Adapted from (Lavigne et al., 1994)

According to STEFAN-BOLTZANN law, the total emittance of a perfect emittor (black body), is given as equation [1.30]

$$Q_{black\ body} = \sigma \times Tse^4 \qquad [1.30]$$

This means that Q depends considerably upon the temperature (in K in this equation).

The total emittance of anybody with temperature above 0 Kelvin is given as equation [1.31]

$$Q = \varepsilon \times \sigma \times Tse^4 \qquad [1.31]$$

ε, the emissivity has a value between (0) and (1), and is a measure of how efficiently a surface emits longwave radiations. It is the ratio of the radiation emitted by a surface to the radiation emitted by a black body at the same temperature.

b. Longwave radiation exchanges between surfaces

Regarding the radiation exchange between two parallel plane surfaces (of equal area A) at uniform temperatures T1 and T2 respectively, is given as equation [1.32] (Nayak and Prajapati, 2006):

$$\phi_{radiation\ 1,2} = \varepsilon_{eff} \times A \times \sigma\ (T_1^4 - T_2^4) \qquad [1.32]$$

Where
- $\phi_{radiation\ 1,2}$ — *net radiative exchange between surfaces (W)*
- ε_{eff} — $[1/\varepsilon_1 + 1/\varepsilon_2 - 1]$
- $\varepsilon_1, \varepsilon_2$ — *emissivities of surfaces 1 and 2 respectively*; A — *area of surface (m2)*
- σ — *Stefan-Boltzmann constant (5.67×10^{-8} W/m^2.K^4)*
- Tse_1 — *temperature of surface 1 (K)*; Tse_2 — *temperature of surface 2 (K)*

In case of buildings, external surfaces such as walls and roofs are exposed to the atmosphere. Thus, the radiation exchange by radiation between the exposed parts of the building and the atmosphere is an important factor and is given as equation [1.33], (Nayak and Prajapati, 2006):

$$\phi_{radiation} = A \times \varepsilon \times \sigma\ (Tse^4 - T_{sky}^4) \qquad [1.33]$$

Where
- $\phi_{radiation}$ — net radiative exchange between surfaces (W)
- ε — *emissivity* of the building exposed surface
- σ — Stefan-Boltzmann constant (5.67×10^{-8} W/m^2.K^4)
- A — area of the building exposed surface (m^2)
- Tse — temperature of the building exposed surface (K)
- T_{sky} — sky temperature (K)

T_{sky} represents the temperature of an equivalent atmosphere. It is the fact that the atmosphere is not at a uniform temperature, and that the atmosphere radiates only in certain wavelengths.

To calculate the heat exchange by radiation between many surfaces in the environment, one must consider all the exchanges between them. If there are n surfaces, n*n fluxes will have to be calculated, each one including the surfaces' temperature, their emissivity and the view factor between them (solid angle). This calculation is intensive in the case of numerous and non-orthogonal surfaces.

1.7.2. Factors Affecting Thermal Performance of Buildings

The thermal performance of a building depends on a large number of factors. Many studies have summarized the ones affecting the most the thermal performance of a building, which can be summarized as, (see Figure 1.36):

Design variables	(Geometrical dimensions of building elements such as walls, roof and windows, orientation, shading devices, etc.);
Material properties	(Density, specific heat, thermal conductivity, transmissivity, etc.);
weather data	(Solar radiation, ambient temperature, wind speed, humidity, etc.)
Building's usage data	(Internal gains due to occupants, lighting and equipment, air exchanges, etc.).

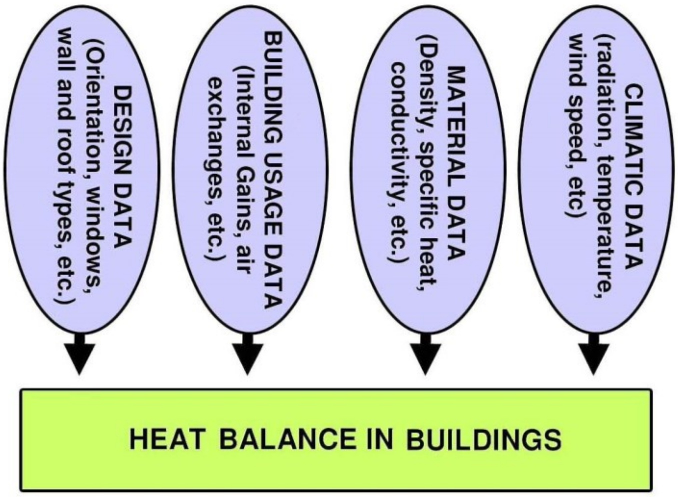


Figure 1. 36: Factors Affecting Thermal Performance of Buildings
Source: Adapted from (Nayak and Prajapati, 2006)

1.7.3. Thermal performance of building and energy

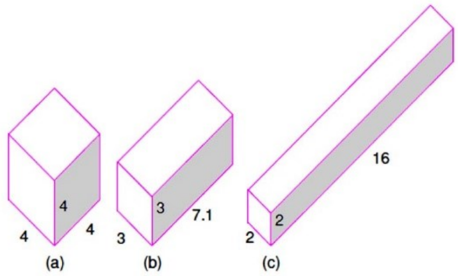
The thermal performance is considered as one of the most important aspects related to thermal comfort and energy needs in buildings. Nicolae (2014) said that the concept of thermal performance differs according to the state of the weather and whether it is a conditioned building or a non-conditioned building. Concerning the conditioned building, "it estimates the heating and cooling load and hence, the sizing and selection of HVAC equipment can be correctly made". For the non-conditioned building, "it calculates temperature variation inside the building over a specified time and helps one estimate the duration of uncomfortable periods" (Badea, 2014).

Thermal performance vs energy consumption

Ghisi and Massignani (2007) declared that the energy consumption of any building is related to their thermal performance (Ghisi and Massignani, 2007). The heat transfers through the building walls, windows and floors, are considered as the most important factors affecting the thermal performance. Accordingly, the control of heat transfer leads to determine the required heating and cooling energy to maintain acceptable level of thermal comfort (Abed, 2012). Yu et al. (2011) established that the most significant factor either for cooling or heating energy consumption is "the heat transfer coefficient of wall, followed by the building shape coefficient" (Yu et al., 2011). The heat transfer coefficient is the surface area to volume (S/V) ratio, which can be expressed as follows equation [1.34]:

$$C_f = \frac{S_e}{V} \qquad [1.34]$$

Where C_f *Building shape coefficient;* V *Inner volume of the building*
S_e *the envelope surface area of the building, i.e. the external skin surfaces*



SOLID SHAPE	SURFACE AREA 'S'	VOLUME 'V'	SURFACE AREA/ VOLUME RATIO 'S/V'
a	96	64	1.5
b	103.2	64	1.61
c	136	64	2.13

Figure 1. 37: Surface area to volume ratio (S/V ratio) for a few building shapes
Source: (Abed, 2012)

The heat transfer coefficient is the proportionality constant between the heat flux and the thermodynamic driving force for the flow of heat (temperature differences), it can be expressed as follows equation [1.35]:

$$hc = q / \Delta T \qquad [1.35]$$

Where ΔT *difference in temperature between the solid surface and surrounding fluid area, K.*
q *Amount of heat transferred (heat flux), W/m^2*
hc *heat transfer coefficient, $W/(m^2 K)$*

1.7.4. Impact of building's form and urban configuration on thermal performance

In order to achieve the optimal building design, different parameters which are essential for the building's performance requirements should be considered and combined: thermal and visual comfort, energy use, environmental performance and life cycle cost. Poirazis (2005) identified some of the most important parameters as follows (Poirazis, 2005):

- The location and orientation of the building,
- The area of the building's skin in relation to the volume of space enclosed,
- The type of façade (proportion of glazing, structure, etc)
- The building's use (type of occupants' tasks, schedule, etc)

On the other hand, the building's form, spacing between buildings and urban configuration mainly influences the amount of solar radiation that falls on the building's surface and the airflow around it (Nayak and Prajapati, 2006). As the building surface is the exposed component to the outdoor environment, the length, height, and depth of the building usually control the objective values that determined the building shape coefficient. A small value of this coefficient corresponds to good conditions for the energy saving of building and can enhance the thermal performance, as shown in Figure 1.38 (Elaiab, 2014; Abed, 2012).

Additionally, some buildings shapes and their arrangement can affect the airflow patterns, natural daylight and provide self-shading. The building self-shading strategy can be produced by using some specific shapes such as H-type or L-type (Nayak and Prajapati, 2006). According to Capeluto (2002) self-shading geometry can reduce the amount of direct solar radiation, consequently, it is the ideal alternative for enhancing energy performance in buildings in hot climates (Capeluto, 2003).

It is worth mentioning that building design does not only affect the indoor condition or energy consumption of building but also can affect microclimates conditions in the urban canopy layer, which play an important role in the city's overall temperature as shown in Figure (1.39) (Shashua-Bar et al., 2004). Krüger et al. (2010) concluded that "the relation between the building's height and the street's width (aspect ratios H/W) can affect shading at street level during daytime which has a side effect on nighttime cooling and natural ventilation as night winds are more restricted with higher aspect ratios" (Krüger et al., 2010).

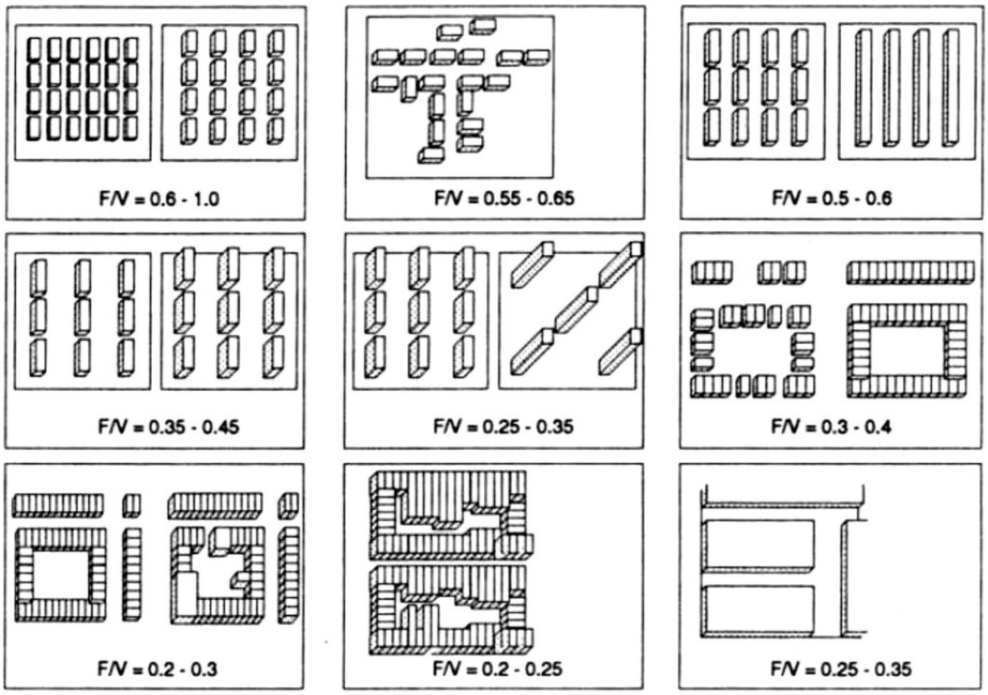
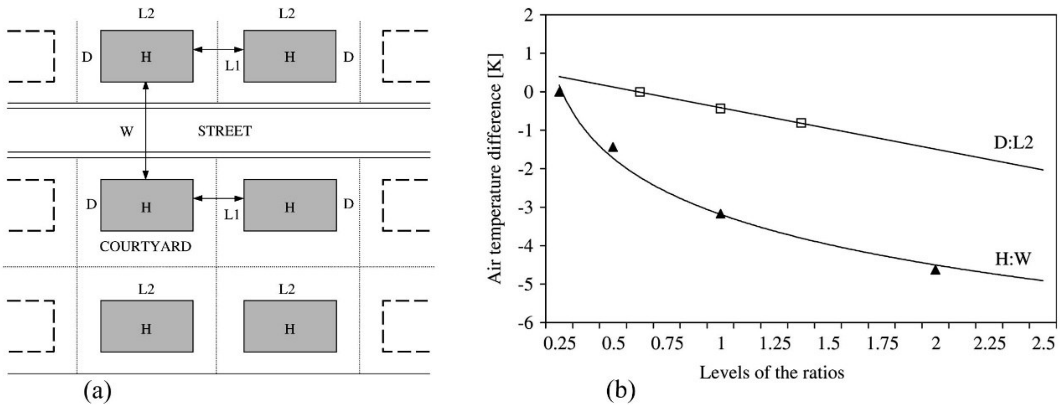


Figure 1. 38: Site layouts showing different surface area (F) to volume (V) ratios
Source: (Goulding et al., 1992)



a Plan representation of the generic building form and definition of length components. *H*, *D*, L2 refer to the height, depth, frontal length of each unit, L1 refers to the spacing between the units and *W* refers to the width of the street

b The effects of the building depth ratio (*D* : L2) and the aspect ratio (*H* :*W*) on the UCL air temperature at 1500h

Figure 1. 39: The relation between the building depth ratio and the aspect ratio

Source: (Shashua-Bar et al., 2004)

The appropriate urban design details can certainly change and modify the urban air temperature, wind conditions and solar radiation exposure of the building, urban spaces and the streets. In many cases, these changes are not always the right alternative of improving the internal climate, especially with the omission of other factors such as the selection of appropriate construction materials (Elnahas 2003).

Studies varied in terms of relations between the urban microclimate factors and energy and urban configuration variables. Elnahas (2012) has discussed the impact of urban configuration variables such as building density, spacing and orientation on urban air temperatures. He said that each single building interacts with their envelope of air, while small groups of buildings have an effect on the external climate. As well as "the thermal performance of a building is dependent on the micro-meteorological conditions outside the building, the thermal behavior of the building fabric, and the internal thermal loads" (Elnahas, 2003). This study reaches to some impressive conclusions points regarding building density, spacing and orientation, as follows:

Results regarding buildings spacing: This study showed that there are three interrelated effects of aspect ratio (the ratio between building height (H) and street width (W): (H/W) on the temperature pattern, as following.

"Deeper canyons increase both thermal inertia (heat storage) and shaded areas, but decrease the sky view factors of canyon walls" so that to induce:

- "A decreasing sky view factor results in a roughly steady temperature increase over the course of the day".
- "The increase of shaded areas causes a more noticeable temperature decline at the maxima than at any other time".

This study has given important scientific particulars related to aspect ratio and its effect on air temperature variations. Indeed, street aspect ratios affect short-wave and longwave radiative fluxes at the surfaces of urban canyons so that:

- "Hourly solar radiation input to the canyon is greatly influenced by shades of canyon surfaces during the day".
- "Long-wave radiation loss from the canyon is affected by the obstruction of the canyon surfaces from the sky temperature sink".

Results regarding buildings orientation: according to the climatic conditions of ELNAHAS's case-study the East-West street axis proved to lead to preferable temperatures in both solstice seasons.

The selection of preferable orientation is not an easy task especially when winter and summer have nearly equal strength leading to the need for both sun and shade, and cool breeze and wind shelter. This study shows two facts related to the orientation:

- The orientation with respect to the sun affects solar heat gains and ambient air temperatures.
- The orientation with respect to wind affects ventilation heat losses.
- With respect to urban design, this study classified two levels of the issue of orientation:
- The first level, "the most important in low-density urban areas, is the orientation of the buildings. In medium- and high density urban areas, orientation of urban street canyons, which represent the basic urban form unit, definitely affects the overall orientation of buildings flanking the street".
- The second is "the orientation of streets and open spaces, which could affect the siting of buildings along the street".

Results regarding building density: "Increased building density usually means increased population density as well as activities that increase the anthropogenic heat and consequently the external air temperature". Therefore, the result was the higher density experiences warmer temperatures during the afternoon until early morning.

Behavior of building envelope to external and internal changes

The building envelope "is the physical separator, including the roof, walls, windows, floor, between the interior and the exterior environments of a building". It is "a key aspect of energy-efficient high performance buildings". Solar gains, air leaks, moisture control and thermal (conduction) losses and gains are all influenced by the design and construction of the building envelope. It affects the design and forms of mechanical systems needed to maintain thermal comfort by providing heating and cooling. Ahmad (2015) said that even when the air temperature and humidity within the space are within acceptable bounds, comfort cannot be achieved if an occupant is surrounded by hot or cold surfaces (Ahmad et al., 2015).

Thus, the design and selection of construction materials of the building envelope have a significant effect on comfortable buildings and energy efficiency.

1.7.4.1. Heat Transfer through the Building Enclosure

Heat transfer through envelope components is complex and dynamic. Its direction and intensity are affected by solar gains from the sun, outdoor temperature, indoor temperature, and the exposed surface area. Building envelope components have three important characteristics that affect their thermal performance:

- Envelope U-factor or thermal resistance;
- Envelope thermal mass or ability to store heat, measured as heat capacity (HC); and
- Envelope exterior surface condition and finish for example, white or light colors can reflect the sun and minimize overheating, and in contrast with the dark colors which it can absorb solar heat.

1.8. Summary and conclusion

After all these explanations, it could be concluded that this chapter has focused on the fundamental knowledge related to the relation between the climate and the buildings, and the impacts that will be reflected on the characteristics of the urban climate. It starts discussing the concept of the environment with all its types: natural and built environment. It also expounds the relation between them to form a broader concept of environment known as the urban environment. Then, it points out the role that climate plays in this interaction as a component of the natural environment. Therefore, the climate types, scales and factors and the interactive relation between each other have been fully discussed. By this, it is meant that the urban environment and its association with increased urbanization have played a key role in changing the local climate dramatically. This creates many urban environmental problems, especially the urban heat island (UHI), phenomena which is an environmental unique problem to urban areas. Moreover, this chapter has dealt with the effect of climate in deciding the urban morphology design as well as the urban materials types. Then, it aimed at clarifying the mechanism of heat transfer occurring in a building.

From this chapter, we draw the following conclusions:

- Based on the relation between the natural environment and the built environment, the main urban environmental problems threatening any cities and societies which increase the regional or the microclimatic changes from their surroundings is the growth of built-up area, as a result of rapid increase in the number of urban dwellers through either increasing urban population or the growing of cities faster than population growth. Although there are many environmental problems, there remains the phenomenon of UHI which is the most serious environmental problem facing the world.
- In any environmental study dealing with local climate, the climate scale (e.g. macroclimate, mesoclimate, local climate and microclimate) must be determined when each one has its own characteristics: our will be microclimate

- The accurate knowledge of climatic factors, especially solar radiation behavior with urban typology on one hand, and interactive relation between one-factor to another on the other hand are the most important rules to put the appropriate design strategies, with respect to urban configuration variables.
- The appropriate urban design details and building material selection can certainly change and modify both the environmental conditions around the buildings such as air temperature conditions, wind conditions, surface temperature, radiation, and the internal conditions.
- The assessment of thermal performance of a building is essential to determine the effectiveness of its design so that to improve energy efficiency with comfortable indoor conditions. Therefore, it is necessary to understand the process of heat exchange occurring between a building and the external environment, within the building, and between a human body and its environment.

Chapter 2

Current Problems of Cities, Energy and Climate

Summary

1. Definition, theoretical background of the urban heat island (UHI).
2. The thermal comfort
3. Summary and conclusion

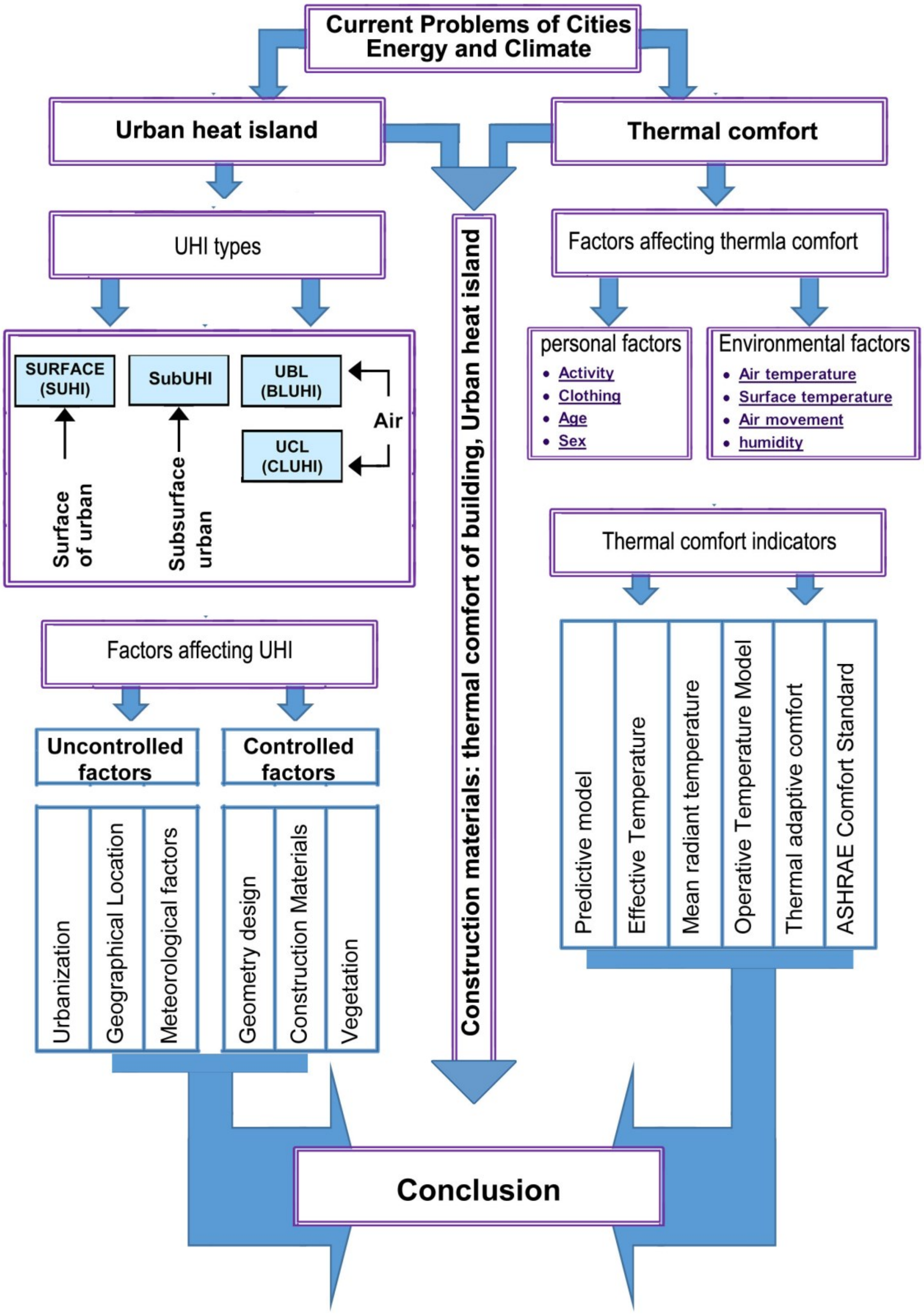


Figure 2. 1: Flow chart of chapter Two

Chapter 2 Current Problems of Cities, Energy and Climate

2.1. Introduction:

After what has been analyzed in the first chapter concerning climate and urban microclimate issues, this chapter concentrates on the interactions between climate factors and the consequences of urbanization to understand the influence of these factors on the formation of UHI. Moreover, it reviews a number of previous studies on this phenomenon, looking for the additional knowledge related to the UHI definition and identifying its causes and finally the formation of this phenomenon with respect to urban energy balance. This chapter will also focus on the concept of thermal comfort of pedestrians in cities, which, with impact on mortality during heat waves, is considered as one of the main issues that are directly affected by the UHI phenomenon.

2.2. Definition, theoretical background of the UHI

As previously mentioned, the world is facing a rapid urban growth, especially in Africa and Asia. Iraq as a one of the Asian countries is witnessing a highly significant increase in her population which is expected to be about 71.336 million in 2050 with the majority of population living in urban areas ("Iraq", 2016) (see Figure 2.2). As a result, the physical structure of the cities will be changed by the modifications of the earth's surface, the replacing of vegetation, open water surfaces and open land surfaces with urban infrastructure.

These changes will certainly create variation in the city surface temperatures, influencing the atmospheric air temperatures, leading to the so-called urban heat island (UHI) phenomenon, which is differences between rural areas, which have cooler surface temperatures (and then cooler air temperatures) and dense, built-up areas (downtown) which have warmer surface temperatures, (and consequently , warmer air temperatures), see Figure 2.3 (Wong et al., 2008). In most cases, the peak differences between urban and rural temperatures happen during clear nights with light winds, and temperature elevations are commonly about (1–4º Celsius).

This phenomenon has recently attracted the attention of many researchers. Its intensity varies on a diurnal and seasonal basis. It is named island because it is similar to the pattern of isotherms and height contours of an island.

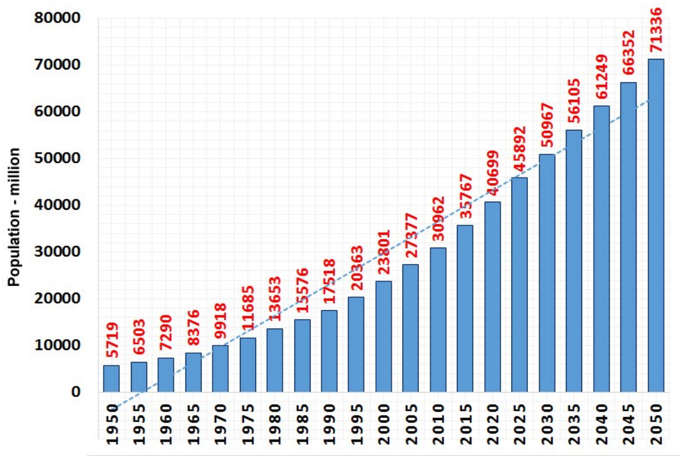


Figure 2. 2: The population of Iraq

Source: United Nation, Department of economic and social affairs. Population division (2015).The 2015 Revision.

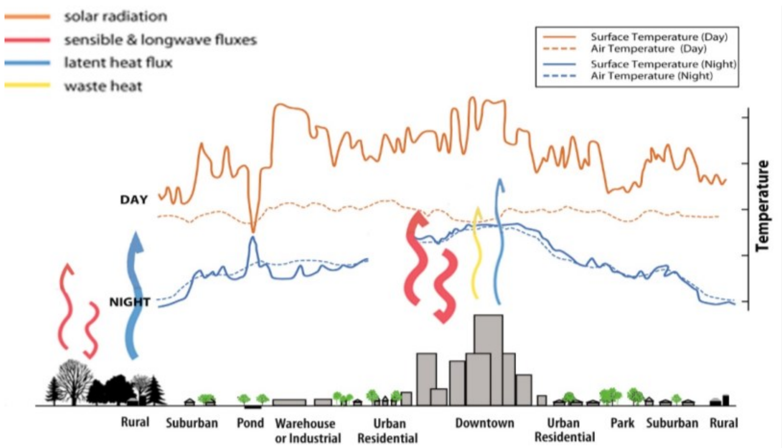


Figure 2. 3: Variation of surface and atmospheric temperatures

Source: Modified from (Wong et al., 2008)

Although, Ooststroom (2012) mentioned that the main cause of UHI is the urbanization, and provided a simple scheme of how urbanization influences the formation of UHI (see Figure 2.4), Shahmohamadi et al. (2009), say that urbanization is not the only reason to get changes toward climate, but also increasing of temperature and sunlight, decreasing wind speed, humidity and precipitation can be major factors on formation of urban heat island" (Shahmohamadi et al., 2009), (see Figure 2.5).

The UHI represents one of the most significant human-induced changes to Earth's surface climate. The UHI phenomenon plagues both the atmosphere and surfaces in urban areas (see Figure 2.6) it occurs in both day and night, winter and summer, with difference in temperatures which is usually stronger at night in summer and during the day in Winter (Watts, 2015) (see Figure 2.7), affecting regional, local climates and global temperatures. According to Winguth and Kelp (2013), the diurnal UHI cycle are influenced by "the daytime sensible heat storage of urban areas because of the thermal conductivity of building and construction materials. Man-made surfaces and constructions also cause turbulent heat transfer, further amplifying the heat island".

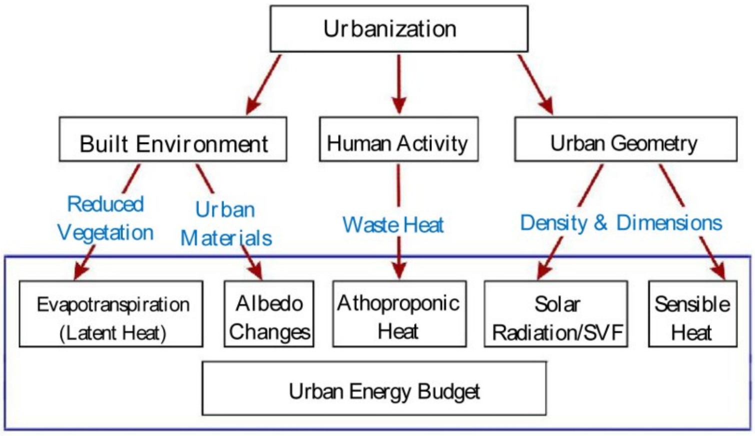


Figure 2. 4: Simple overview of formation of UHI
Source: (Oostroom, 2011)

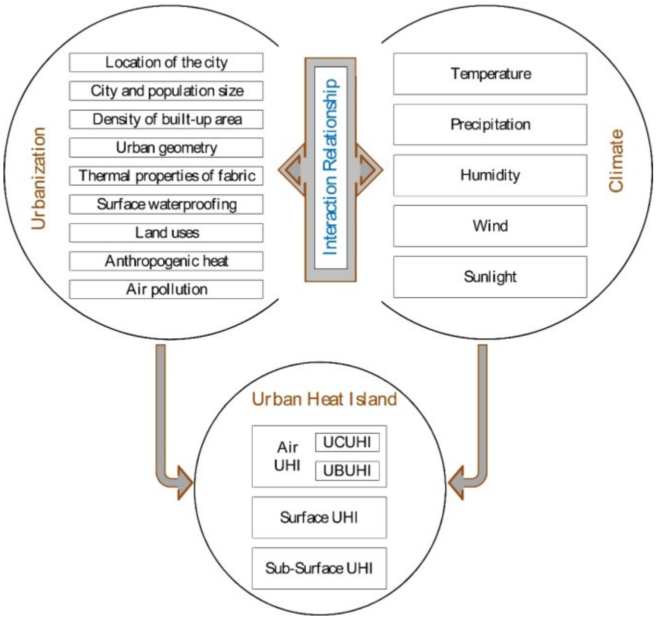


Figure 2. 5: Interaction between urbanization and climate factors
Source: Modified from (Shahmohamadi et al., 2009)

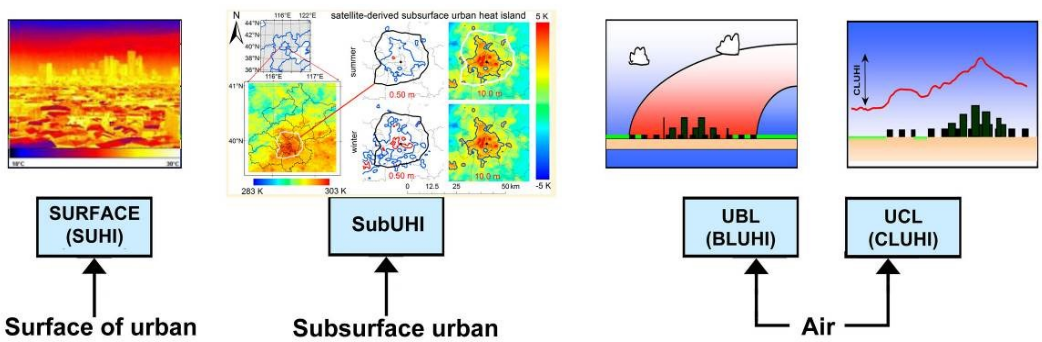


Figure 2. 6: Types of urban heat island
Source: Modified from (Voogt, 2000)

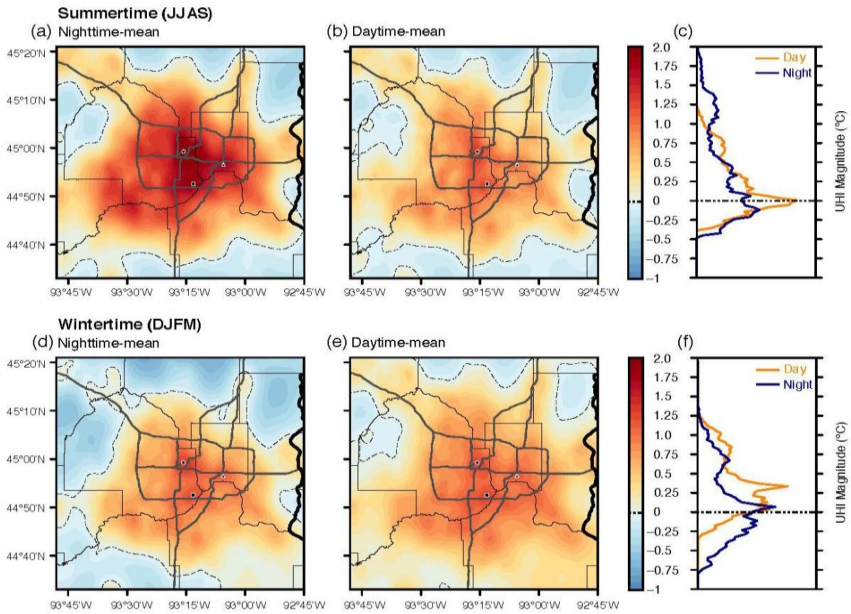


Figure 2. 7: The urban heat island averaged over nighttime and daytime, by season

Source: (Watts, 2015)

There are significant differences in defining UHI and their effects (Oostroom, 2011; Voogt, 2000). However, there is a shared understanding on the basic principles of UHI, which can be defined as:

"Difference between background rural and highest urban temperatures, (ΔT_{u-r})", (**Tim R. Oke 1973**)

The intensity of the UHI is not the same in all regions. It varies around the world and depends on local climate factors (Shahmohamadi et al., 2009), owing to the existing differences both in regional climate conditions and size of the city. Asimakopoulos (2001) wrote that the greater the size of the city, the greater amount of heat, which leads to increase the temperature in range between 1.1 K and 6.5 K (Asimakopoulos, 2001) (Table 2.1).

City	Temperature increase, (K)
30 US cities	1.1
New York	2.9
Moscow	3.0 - 3.5
Tokyo	3.0
Shanghai	6.5

Table 2. 1: The UHI effect in some cities

Source: (Asimakopoulos, 2001)

Roth (2012) said that "under ideal conditions for UHI development (calm and clear) and measured in city centers with deep canyons, maximum UHI intensities of up to 12°C have been recorded. On an annual mean basis, including the dampening effects of wind and clouds, a city of about one million inhabitants may have a UHI of about 1°C–2°C " (Roth, 2012).

The modern literature provides many terms related to UHI such as micro urban heat islands (MUHI) and urban heat sink. **MUHI** refers to "urban hot spots as poorly vegetated, parking lots, non-reflective buildings materials, material and color of pavement and asphalt roads. MUHI are strongly affected by micro climate factors, therefore, remotely sensed data (thermovision) are generally used". (Rosca and Rosca, 2015; Stathopoulou, et al. 2009; Synnefa, et al. 2009). **'Urban heat sink'**, also called negative heat island, refers to "a city colder than their country sides which have been observed in cities with temperate, tropical, semi-arid and arid climates, and mainly during the mornings" (Carnahan and Larson, 1990; Clinton and Gong, 2013).

Many of the side effects of UHI are studied. They consist in the worsening of living environment and increase in energy consumption (Konopacki and Akbari, 2002), water consumption (Niizawa, 1985), raise in ground-level ozone (Rosenfeld et al., 1998), increase in mortality rates (Changnon et al., 1996).

2.2.1. Urban heat island types:

Heat islands occur on the surface and in the atmosphere, therefore, three types of UHI are defined, the surface urban heat island (SUHI), the subsurface urban heat island (SubUHI) and the atmospheric urban heat island (UHI) which include boundary layer heat island, canopy layer heat island. All these types are typically present in day and night. However, during the day (when the sun is shining), SUHI is usually stronger than atmospheric UHI. While the atmospheric UHI is generally weak throughout the day, and becomes positiver after sunset, as a result of the slow release of heat from urban structures and surfaces (Wong et al., 2008).

Wong et al. (2011) identified the basic characteristics of UHI types in many faces as it is shown in the following table 2.2:

FEATURE	SURFACE UHI	ATMOSPHERIC UHI
Temporal development	• Present at all times of the day and night • Most intense during the day and in the summer	• May be small or non-existent during the day • Most intense at night or predawn and in the Winter
Peak intensity (most intense UHI conditions)	• More spatial and temporal variation: -Day: 18 to 27°F (10 to 15°C) -Night: 9 to 18°F (5 to 10°C)	• Less variation: -Day: -1.8 to 5.4°F (-1 to 3°C) -Night: 12.6 to 21.6°F (7 to 12°C)
Typical identification method	• Indirect measurement: -Remote sensing	• Direct measurement: -Fixed weather stations -Mobile traverses
Typical depiction	• Thermal image	• Isotherm map • Temperature graph

Table 2. 2: Basic Characteristics of Surface and Atmospheric Urban Heat Islands

Source: (Wong et al., 2008)

2.2.1.1. Surface urban heat island (SUHI)

SUHI represents the surface temperature differences between urban and rural areas. It is a surface energy balance phenomenon, it involves all the uncovered urban facets (street, vertical walls, roofs, road, lawns trees, etc.). The surface temperature varies depending on whether the surface is in the sun or the shade. In Summer day (hot and sunny), these surfaces can be heated up to reach about 27 to 50°C this means that they are hotter than the air, in contrast with the shaded or moist surfaces which remain close to air temperatures (rural area).

SUHI is present in day and night, and is at its strongest level during the day (when the sun is shiny), where the average difference surface-temperature between urban area and rural areas may reach 10- 15°C; while during the nighttime the difference is about 5 to 10°C. Its intensity differs according to the seasons as a result of variations in the sun's intensity, ground cover and weather during different seasons. Therefore, SUHIs are largest in the summer (Lun et al., 2009).

It is worth mentioning that the warmest surfaces of the city are located in industrial or commercial zones especially those with large, flat-topped buildings or extensive open areas of pavement (e.g., airport, shopping malls, and major highway intersections) rather than in the central business district where buildings are high and roofs are not the main surface (Roth, 2012).

Many factors may affect the urban surface temperatures which are typically the amount of solar radiation hitting the surfaces, the orientation of the surface components to the sun by day and the sky at night, the thermal (e.g., heat capacity, thermal admittance) and radiative properties of urban topology (e.g., reflectivity or albedo). To determine the SUHI, the researchers use remote sensing and an indirect measurement technique. They use the data collected to produce thermal images (Wang and Akbari, 2015; Wong et al., 2008), as shown in Figure (2.8).

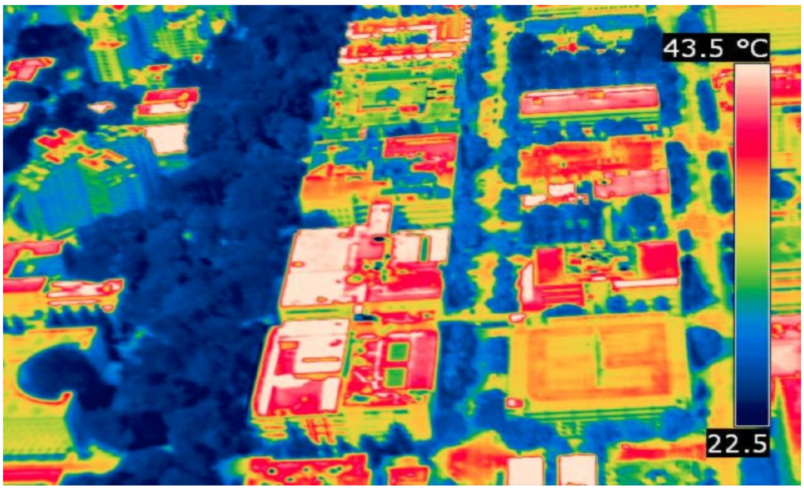


Figure 2. 8: Thermal photos - Portland's park blocks
Source: http://www.opb.org/news/article/mapping-portlands-hottest-places/

2.2.1.2. The subsurface urban heat island (SubUHI)

The subsurface urban heat island (SubUHI) is the warmth of urban ground temperatures against the rural background. To estimate the SubUHI, satellite-based moderate-resolution imaging spectroradiometer data are used. According to the study of Zhan et al. (2014), which carried out the reconstruction of the subsurface thermal field over the Beijing metropolis through a three-time-scale model, it found that "at depths between 0.5 and 10 m, the time for the SubUHI intensity getting to its extremes during an annual temperature cycle is lagged 26.2 days per meter. Within these depths, the SubUHI prevails without exception, with an average intensity of 4.3 K, varying from 3.2 to 5.3 K " (Zhan et al., 2014), see Figure (2.8).

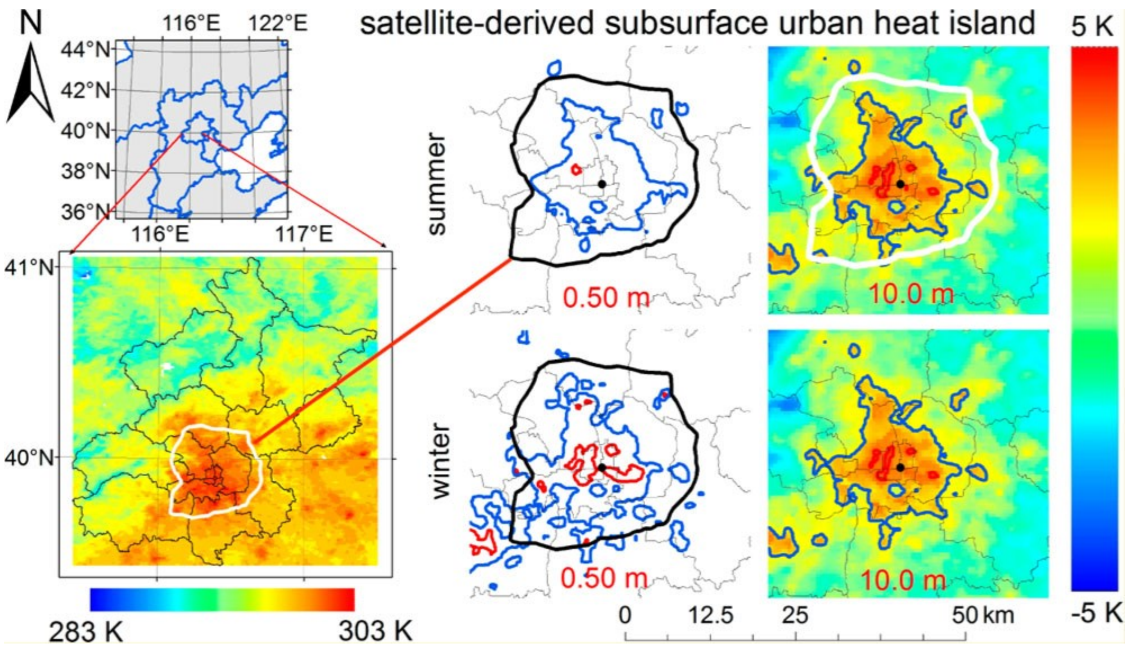


Figure 2. 9: The subsurface urban heat island (SubUHI)
Source: (Zhan et al., 2014)

2.2.1.3. Atmospheric urban heat island

Atmospheric urban heat islands is generally weak during the late morning and through-out the daytime, and becomes more effective after sunset as a result of slow outgoing heat from urban structures and surfaces. In comparison to surface temperatures, "the intensity of the atmospheric island varies much less". It directly increases air temperatures of the cities. Therefore, the temperature in cities tend to be 1.2 to 4.4°C warmer than in rural areas (Oostroom, 2011).

Experts often classify this type of UHI into two different types, canopy layer heat island (CLHI) and boundary layer heat island (BLHI). In 1987, Oke identified the commonly hypothesized causes of each type (Roth, 2012), the following table explains his final results: Table (2.3).

Altered energy balance terms leading to positive thermal anomaly	Features of Urbanization Underlying Energy Balance Changes
A. Canopy layer	
1. Increased absorption of shortwave radiation	Canopy geometry—increased surface area and multiple reflection
2. Increased longwave radiation from the sky	Air pollution—greater absorption and reemission
3. Decreased longwave radiation loss	Canyon geometry—reduction of sky view factor
4. Anthropogenic heat source	Building and traffic heat losses
5. Increased sensible heat storage	Construction materials—increased thermal admittance
6. Decreased evapotranspiration	Construction materials—increased "waterproofing"
7. Decreased total turbulent heat transport	Canyon geometry—reduction of wind speed
B. Boundary layer	
1. Increased absorption of shortwave radiation	Air pollution—increased aerosol absorption
2. Anthropogenic heat source	Chimney and stack heat losses
3.Increased sensible heat input—entrainment from below	Canopy heat island—increased heat flux from canopy layer and roofs
4. Increased sensible heat input—entrainment from above	Heat island, roughness—increased turbulent entrainment

Table 2. 3 : Commonly Hypothesized Causes of the Urban Canopy and Boundary-Layer Heat Islands

Source: (Oke, 1982)

a. Canopy layer heat island (CLHI)

CLHI is a local (neighborhood) scale phenomenon. It is relevant to human activities, therefore, it is most studied of all heat island types. It is existing within the atmosphere from the ground and below the tops of buildings and trees in the spaces between buildings where humans exist (i.e., in the urban canopy) (El-Khateeb, 2006). It is an indication of the surface energy balance that impacts the air volume inside the canopy, through sensible heat transfer from the surface into the canopy in order to change the temperature. Some exchange of air between the canopy and the air above also occurres during the day. At night, some cold air coming off the roofs may contribute to cooling. The heat island intensity growths with time from sunset to a maximum between a few hours after sunset to dawn hours. During daytime, the urban-rural difference is relatively small or even negative (i.e., Cool Island) in city centers or other developments with dense and tall buildings that promote shading at the surface. The factors that contribute to this type of UHI are primarily building materials, urban geometry, albedo modification and evapotranspiration (Wong et al., 2008). The heat island intensity increases after sunset and sometimes it reaches its maximum between a few hours after sunset and before sunrise.

b. Boundary layer heat island (BLHI)

BLHI is a local meso-scale phenomenon and its intensity is less compared to that measured in the canopy layer (~1.5°C–2°C). The layer that starts at the top of the canopy layer and extends up to the point where the influence of urban landscapes exists in the atmosphere stops. In most regions, this point is about (2) kilometers (1.25 mile) above the surface (Oostroom, 2011). The air temperature above the city is indirectly influenced by UHI affecting entire cities or even metropolitan and surrounding areas. BLHI is positive during day and night but much smaller in magnitude than CLHI or SHI. The factors that primarily contribute to this kind of UHI are city form and function, urban geometry, weather/wind patterns and urban energy budgets.

2.2.2. Factors affecting UHI

In published articles, many factors of UHI have been identified as weather, geographic location, time of day and season, city form, city functions (Voogt, 2000), sky view factor, surface albedo, altitude, vegetation cover, average height to floor area ratio, location, proximity to sea (Giridharan et al., 2007), distance from the center (Kolokotroni et al., 2012), roughness, surface resistance to evaporation (SRE), anthropogenic heat , size of the urban area, street canyon geometry (Kolokotroni and Giridharan, 2008), population, density of built-up spaces, heat from buildings (Devadas and Lilly Rose, 2009), thermophysical properties of materials (specific heat capacity, conductivity) (Sharifi and Lehmann, 2014).

Based on the energy balance equation, Oke (1982) lists a number of factors which are: incoming/outgoing long-wave radiation, storage heat, anthropogenic heat, and latent heat fluxes. He has also explained the mechanism of the effect of each of these factors as it is shown below:

Incoming Long-wave radiation ($R_L\downarrow$)

Increased because of air pollution: the incoming long-wave radiation is absorbed and later re-emitted by the polluted urban atmosphere (urban greenhouse effect).

Outgoing long-wave radiation loss ($R_L\uparrow$)

Decreased because of urban from: as long-wave radiation is emitted from the buildings and streets surfaces within the canyons, their sky view factor is reduced, and much warmer surfaces replace the cold sky hemisphere. These surfaces receive a high proportion of the infrared radiation emitted from the ground and radiate back an even greater amount (canyon radiative geometry).

Storage heat (ΔHs)

There is greater daytime storage of perceptible heat because of the thermal properties of urban materials and heat release at nighttime.

Anthropogenic heat (Ha)

Addition of anthropogenic heat in the urban area by the combustion of fuels from both mobile and stationary sources (transportation, heating/cooling, industrial operations).

Latent heat flux (HL)

Reduction of evaporating surfaces and the surface waterproofing of the city puts more energy into sensible and storage heat and less into latent heat.

Based on the urban configuration**,** Oke (2006) argues that the UHI effect has four contributing factors: Urban geometry design, urban cover and surface materials thermodynamic specification, urban landscape and waterscape, and urban metabolism and anthropogenic (see Figure 2.10) (Sharifi and Lehmann, 2015).

Urban geometry design

It affects the exposure of urban surfaces to sunlight and the consequent heat storage in thermal mass. As a result it affects heat exchange balance in the built environment.

Urban cover and surface materials thermodynamic specification

Colour, texture, density of materials, and area exposed to sunlight, all these factors can affect the heat absorption and reflection time-rate in the built environment.

Urban landscape and waterscape

It affects photosynthesis and evaporation processes in urban greenery and then consequently contributes to decrease the ambient temperature. It affects heat exchange balance in the built environment.

Urban metabolism and anthropogenic (human made) waste heat in cities

It is mainly related to energy consumption for indoor air-conditioning and motorized transportation.

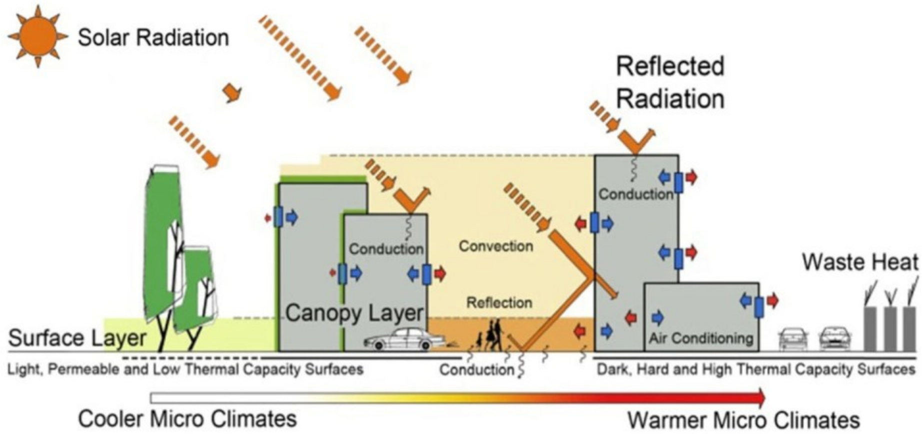


Figure 2. 10: Urban structure, landscape, land-cover and metabolism contribute to the UHI effect

Source: (Sharifi and Lehmann, 2015)

Therefore, all the factors that are previously mentioned can broadly be categorized as:

- Controlled factors (geometry design, vegetation, and selection construction materials, anthropogenic heat).
- Uncontrolled factors (urbanization, geographical location, and meteorological factors).

They can further be categorized as sub factors as shown in table (2.4). Controlling and reducing the UHI effect is accomplished through the modification of three main factors: geometry design, selection construction materials, and finally vegetation.

According to the objective of this study, we will focus on the construction materials factor and the sub-factors related to building materials which will be dealt with in a separate chapter.

From the above-mentioned explanation and according to the urban energy balance equation, it can be initially concluded that the UHI certainly results from changes in the components of this equation, because of:

- The anthropogenic heat flux changes as a result of changing the human activity;

- The land cover changes besides the widespread use of industrial building materials such as concrete, brick and tarmac instead of vegetation. Building materials present a wider range of surface emissivities than in typical rural area (undeveloped areas)

- Changing the surface morphology from a simple rural surface to a complex urban surface. Voogt (2002) has identified three impacts related to the complex urban surface which effect on the urban temperature (Voogt, 2002), as follows:

Firstly, "the trapping of solar radiation in build-up areas leads to greater absorption of solar radiation".

Secondly, "closely spaced buildings effect the Sky View Factor (SVK) and reduce radiative heat loss".

Thirdly, "urban density influences surface-air exchanges, reducing convective heat loss".

Accordingly, it becomes necessary to pay attention to the detail of the urban energy balance to identify exactly the differences between the microclimate of the built environment and its surrounding rural areas so that to understand the UHI formation process and thereby, to identify the possible methods to mitigate this phenomenon.

Sub- factors of UHI	**Main factors of UHI**	**Status**
Size of the urban area *Distance from the centre* *Population* *Anthropogenic heat* *City functions*	Urbanization	Uncontrolled factors
Altitude *Location* *Proximity to sea* *Weather* *Time of day* *Season*	Geographical Location	
Temperature *Humidity* *Precipitation* *Wind*	Meteorological factors	
Sub- factors of UHI	**Main factors of UHI**	**Status**
Sky view factor *Average height to floor area ratio* *Street canyon geometry*	Geometry design	Controlled factors Figure below
Surface albedo *thermophysical properties of materials* *Heat from buildings* *Surface resistance to evaporation* *Roughness*	Construction Materials	
Vegetation	Vegetation	

Table 2. 4: Factors effecting UHI

2.3. The surface urban energy balance

In the complex environment of a metropolitan urban area or neighborhood, energy and mass transfers are the basis of climate and microclimatic processes. The atmosphere is a thermal system the energy state of which depends on the balance between incoming and outgoing flows (Vinet, 2000). The heat balance of the earth's surface (see Figure 2.11), is written as follows equation [2.1]:

$$QS = RN + QC + QE \qquad \textbf{[2. 1]}$$

Where *QS : The Heat transfer into the earth (conduction)*
QC, QE, RN Respectively the Sensible heat flux (convection), Latent heat flux (evaporation or condensation), and Net radiative flux (radiation)

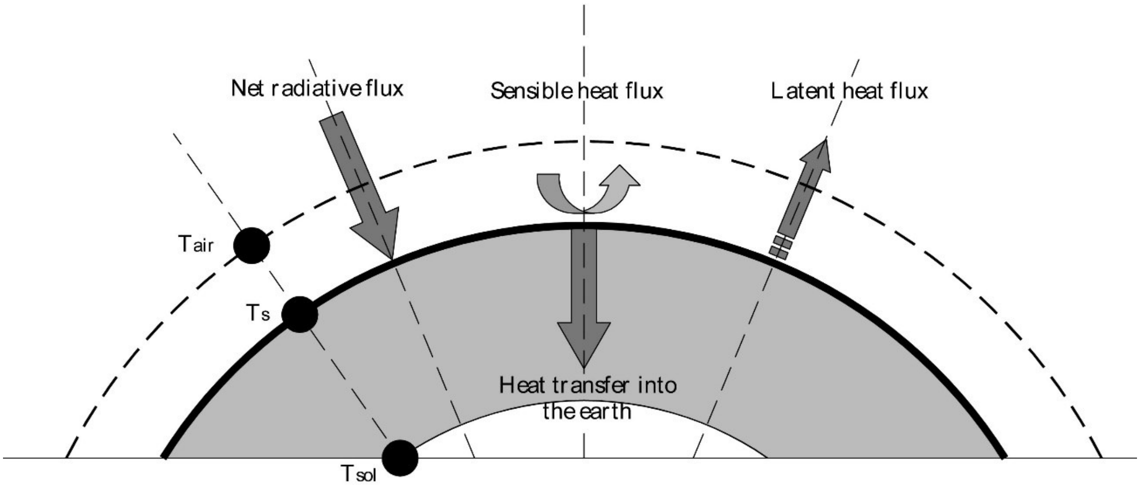


Figure 2. 11: The heat balance of the earth's surface
Source: Modified from (Lavigne et al., 1994)

At the surface of cities, as a result of the interface between the urban surface layer and the atmosphere, other fluxes will be involved in the energy equation (see Figure 2.12). Previous studies have expressed the urban surface energy balance (SEB) theoretically as the balance of a surface including an air layer, as follows (equation [2.2]):

$$Q^* + QF = QH + QE + \Delta QS + \Delta QA \qquad \textbf{[2. 2]}$$

Where:
Q The net al.l-wave radiation ΔQS The heat storage (the net storage flux)*
ΔQA The net heat advection (the heat advection through the sides of the control volume) (the net horizontal heat advection)
QF, QE, QH Respectively the anthropogenic heat release, the turbulent sensible and turbulent latent heat flux densities

Regarding the most effective variable in the equation of urban SEB, Roberts (2003) said that "ΔQS (heat storage by the elements) is of particular relevance to the urban environment ", in which it represents over half of the daytime net radiation at highly urbanized sites (Roberts et al., 2003). This factor (ΔQS), in terms of its contribution to the formation of UHI phenomenon, depends mainly on: the type of construction materials and the structure of the urban surface and its night-time release. ΔQS also affects other applications e.g. building climates.

Therefore, the measuring of ΔQS can directly affect the understanding of urban SEB.

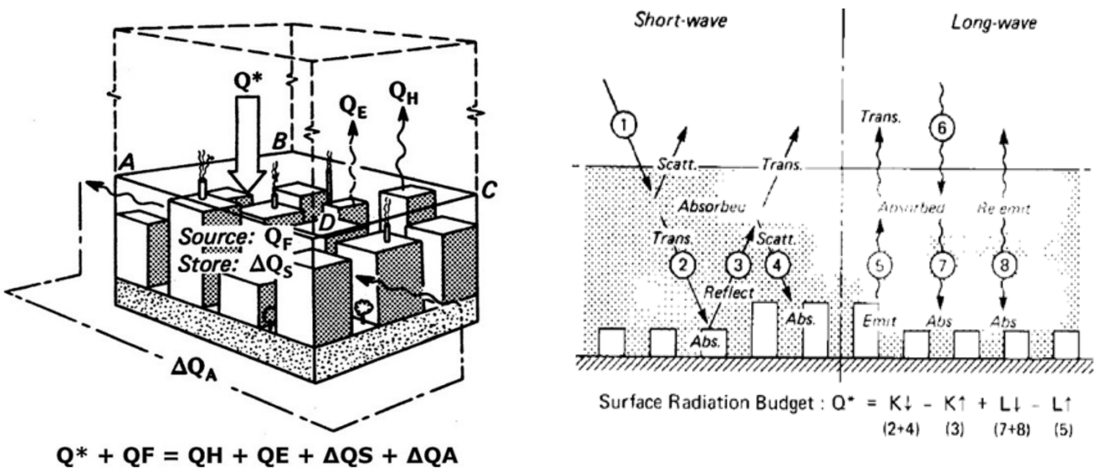


Figure 2. 12: a.The energy balance of an urban area, b. The surface radation budget
Source: (Oke, 1988)

As a result of the development of new techniques and technologies related to the measurement of urban climate such as radiometric and eddy covariance techniques, net wave radiation at the top (Q∗), sensible heat flux (QH), and latent heat flux (QE) are measured directly. Regarding (QF), approaches have been developed for constructing diurnal and seasonal anthropogenic heating flux (QF) for cities, (Sailor et al., 2003).

A. Net al.l wave radiation (Q*):

This part of energy balance represents the short wave radiation and longwave radiation captured by an area. It represents the balance between incoming and outgoing energy. Both of these types of radiation could be measured by using suitable sensors, then the net al.l-wave radiation represents the difference between the incoming and outgoing parts (Christen and Vogt, 2004). It generally affects the climate through warming the earth's surface, heating the air, leading the water to evaporate (Hillel, 1998). It can be expressed as equation [2.3]:

$$Q^* = K^* + L^* = K_{\downarrow} - K_{\uparrow} + L_{\downarrow} - L_{\uparrow} \quad \textbf{[2. 3]}$$

Where: *Q** *: Net al.l-wave radiation ("net radiation")*

- Summary effect of all radiation processes
- Net radiative energy that is absorbed and then transformed into a different form (non-radiative) Available to be partitioned in the Energy Balance to Heat the air, Heat the ground or Evaporate water

Shortwave Radiation (K*) can be expressed as equation [2.4]:

$$K^* = K_{\downarrow} - K_{\uparrow} \quad \textbf{[2. 4]}$$

Where:

K^* Net short-wavelength radiation

- *Summary effect of all short-wavelengh radiation processes*

$K_\downarrow$ Incoming short wavelength radiation

- *Emitted by the sun, transmitted through the atmosphere, accounts for the majority of energy in the solar spectrum*
- *Dependent on solar altitude, transmissivity of the atmosphere above.*
- *Solar constant: maximum $K_\downarrow$, occurs at the top of the earth's atmosphere at right angles = 1376 $W\,m^{-2}$.*

$K_\uparrow$ Outgoing shortwave radiation (reflected)

- *Depends on $K\downarrow$ and albedo value (α). : $K\uparrow = \alpha\, K\downarrow$*
- *Albedo : ratio of reflected to incoming shortwave radiation ($\alpha = K\uparrow / K\downarrow$)*

Longwave Radiation (L*) can be expressed as equation [2.5]:

$$L^* = L_\downarrow - L_\uparrow \qquad [2.5]$$

Where:

L^* Net longwave radiation

- *Summary effect of all longwave radiation processes*

$L_\downarrow$ Incoming longwave radiation

- *Depends on sky temperature (T_s) and sky emissivity (ε_s)*
- *Represented by the following equation: $L_\downarrow = \varepsilon_s\, \sigma\, T_s^4$*
- *(ε_s) and (T_s) summary effect of all layers of the atmosphere; depend on cloud cover, humidity, temperature structure*

$L_\uparrow$ Outgoing longwave radiation

- *Depends on surface temperature (T_{se}) and surface emissivity (ε_0).*
- *Represented by the following equation: $L_\uparrow = \varepsilon_0\, \sigma\, T_{se}^4$*

B. The anthropogenic heat flux (QF)

The anthropogenic heat flux (QF) is the heat flux from human activities which include transportation, heating and cooling of buildings, industrial processes and the metabolic heat release by people (Chrysoulakis et al., 2014; Rizwan et al., 2008). This type of heat is a significant factor in the energy balance of the city which is largely considered as a function of latitude and season of the year. Thus, it is different from one city to another (see Table 2.5). Taha (1997) said that in spite of the fact that the anthropogenic heat flux is one of UHI factors it can be ignored in some cases, depending on the location of the case study: "The effects of anthropogenic heating seems to be relatively small and the impact of anthropogenic heating may be important in urban centers but negligible in residential and commercial areas (Taha 1997).

Residual of other terms method	Reported anthro- pogenic heat (W/m2)
Basel, Switzerland	5–20
Lodz, Poland	32
Reykjavik, Iceland	35
USA	60–75
Tokyo, Japan	200–1590

Table 2. 5: Reported anthropogenic heats in various parts of the world
Source: (Rizwan et al., 2008)

C. Turbulent heat fluxes (sensible and latent heat flux)

Turbulent heat fluxes comprise of the sensible heat flux (QH) and the latent heat flux (QE), which could be directly derived from eddy correlation (technique for measuring in situ fluxes), (Rizwan et al., 2008).

Sensible heat flux

Husher (2008) has defined sensible heat flux as the process where heat is transferred from the surface to the atmosphere directly by conduction and convection, when there is a difference in temperature between them (Husher, 2008). For example, at the boundary layer, heat is conducted from a warm surface to the atmosphere and then convection moves the heat higher up into the atmosphere (scienceofdoom, 2010). The transfer of sensible heat can be noticed through the rise or fall in the temperature of the air.

The sensible heat transfer takes place in two directions, either, from the warm surface to cool air, when the surface is warmer than the air above (positive sensible heat transfer), or from the warm air to cool surface when the air is warmer (negative sensible heat transfer). The positive sensible heat transfer leads to raise the air temperature but cools the surface, whereas negative sensible heat transfer leads to cool the air and warm the surface (Michael, 2017).

Latent heat flux

Tang and Li (2013) have defined latent heat flux as "The flux of heat from the earth's surface to the atmosphere that is associated with evaporation or transpiration of water at the surface and subsequent condensation of water vapor in the troposphere". It is an important component of Earth's surface energy budget (Tang and Li, 2013).

Latent heat flux is commonly measured by eddy covariance. Latent heat flux can be expressed as equation [2.6] (Tang and Li, 2013).

$$\mathbf{HQ} = \frac{\rho c_p}{\gamma} \frac{e_s - e_a}{r_w} \qquad \textbf{[2. 6]}$$

Where:

QH	*: the latent heat flux [W /m²]*	*ρ*	*: the air density [kg/m³]*
c_p	*:the specific heat of air at constant pressure [J/(g · K)]*	*γ*	*: the psychometric constant [kPa/°C]*
Psat	*the saturated vapor pressure near the surface [kPa]*	e_a	*the actual vapor pressure at the reference height [kPa]*
r_w	*the resistance to water transfer [s/m]*		

Bowen Ratio (β)

Tang and Li (2013) have defined Bowen Ratio as " the ratio of energy fluxes from one state to another by sensible and latent heating, respectively" (Tang and Li, 2013), it is expressed as equation [2.7]

$$\beta = QH / LE \quad \textbf{[2. 7]}$$

Where:

β : the Bowen ratio [-]
QH : the sensible heat flux [W/m²]
LE : the katent heat flux [W/m²]

According to Oke et al. (1999), in dense urban areas, the sealing of urban surface and the absence of vegetation are responsible for increasing the sensible heat compared to latent heat flux because these surfaces are warmer than the surfaces that contain water and lower flows latent heat (Oke et al., 1999).

The heat storage (ΔQS) and the net heat advection (ΔQA)

The heat storage (ΔQS)

The thermal energy is stored by materials during daytime and return to the air during nighttime, it leads to variation of the temperature of materials. The amount of heat stored depends on the specific heat of the materials (C_p), the temperature changes (ΔT) and the mass of heat storage medium (m) (Sharma et al., 2009). The sensible heat storage can be calculated as equation [2.8]:

$$\Delta Qs = m.c_p.\Delta T \quad \textbf{[2.8]}$$

Since $\Delta T = T_h - T_I$, therefore, it can be expressed in another form as equation [2.9]:

$$\Delta Qs = m.Cp.(T_h - T_I) \quad \textbf{[2.9]}$$

Where:

ΔQ	*sensible heat stored in the material (J)*
M	*mass of substance (kg); m= V ρ, V volume of substance (m3), ρ density of substance (kg/m3), m mass of substance (kg)*
Cp	*specific heat of the substance (J/kg°C)*
T_h , T_I	*The maximum and initial temperature of the material. (Th -TI) is referred to the temperature swing.*

The net heat advection (ΔQA)

Net heat advection refers heat transfer due to air movement in the considered air layer. Roberts (1999) said that net local advection can be considered negligible if energy budget measurements are conducted at sites with extensive horizontal homogeneous fetch. Thus, it is often overlooked in urban studies. Based on the above discussions and according to Roberts (2003) finding, the urban SEB can be expressed as follows [2.10]:

$$Q^* = QH + QE + \Delta QS \quad [2.10]$$

2.3. The thermal comfort

According to ISO 7730 (1994) and ASHRAE standards 55-66 (American Society of Heating, Engineers, and Institute, 2010; Esther and Sagada, 2014), thermal comfort is "the condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation". Maintaining this level of thermal comfort is one of the outstanding objectives of architects and design engineers which make them face many challenges to utilize all the possibilities available to achieve it. Achieving a perfect state of comfort by one set of conditions for all occupants is impossible. This is due to the large number and diversity of factors that control thermal comfort such as age, sex, clothing and level of activity of each person (Driver et al., 2012).

Thermal comfort is considered as one of the three thermal environment components: thermal comfort, thermal stress, and thermal discomfort (see Table 2.6). However, as it has been defined by Sala et al. (1999), the comfort zone is "the range of climatic conditions within which the majority of people would not feel thermal discomfort, either of heat or cold" (Sala et al., 1999).

Thermal comfort	Thermal stress	Thermal discomfort
Occupants feel neither too hot nor too cold, and without being bothered by the temperature	The thermal environment causes unhealthy conditions, and can prove fatal	The area between the first two. Occupants can feel too hot or too cold, but do not display medical symptoms

Table 2. 6: Type of thermal environment components

Source : (Sala et al., 1999)

2.3.1. Thermal comfort factors

Thermal comfort is affected by independent environmental variables and independent personal variables (ASHRAE Handbook, 2001). The literature has identified the environmental factors that affect both person's thermal balance and thermal comfort:

- The dry bulb temperature, the humidity and the relative velocity of the surrounding air,
- The temperature of any surfaces that can directly view any part of the body and thus exchange radiation (Levin, 1995).

While the personal factors are expressed by activity level, clothing, metabolic heat, state of health, acclimatization, expectations, and even access to food and drink (Ubbelohde et al., 2003; Chen et al., 2003).

According to Esther and Sagada (2014), the commonly used indicator of thermal comfort is air temperature because it is the easiest to use and people can rate it without any difficulty. Although it has vital importance but it is not the only factor that can be used to define thermal comfort accurately (Esther and Sagada, 2014). In this regard, Shakir (2009) has written: " to define thermal comfort, the air temperature must be considered in relation to other environmental and design factors " (Shakir, 2006).

In 2016, Maureen has written "temperature and relative humidity are the two local climatic factors that affect indoor comfort while building envelop, orientation, shading, glazing type and size, vegetation, thermal mass are the design dependent parameters that contribute to the thermal comfort condition" (Maureen, 2016).

Regarding the factors influencing thermal comfort of building, Latha et al. (2015) have written "the thermal comfort of a building and the energy saving is influenced by various factors including the thermo physical properties of the building materials, building orientation, ventilation, building space usage and integration of modern and passive energy saving technologies" (Latha et al., 2015).

2.3.2. Envelope materials and thermal comfort of building

The envelope of a building in addition to its primary role in separating the building from the external environment, plays a key role in protecting the building from the climatic elements that directly affect the building. In this regards, the internal thermal comfort is dependent on the building orientation, natural ventilation, and the properties of the envelope building materials used and that are influenced by the external temperature and humidity. In many workplaces, "the orientation of the building and consequent natural ventilation may not be an option owing to industrial zoning, spacing issues or other regulatory reasons, where building materials might be easy to adopt option" (Latha et al., 2015).

In this regard, the indoor air conditions are affected by the thermophysical properties of materials where materials having lower thermal conductivity, have less inside surface temperature compared to the materials with high thermal conductivity (Ozel, 2011). Although and according to study of Latha et al. (2015), some types of building materials that have low thermal conductivity not always provide the optimal thermal comfort which depend mainly on the type of material and where it will be used, such as nylon, polystyrene foam, polyurethane foam (Latha et al., 2015).

According to Kumar and Singh (2013), the use of advance and innovative materials types (such as Phase change materials (PCMs), thermochromic materials, radiant and thermal barrier materials) as an alternative of conventional materials is very effective in achieving the best indoor thermal comfort and energy saving. This does not mean not benefiting from conventional materials where many studies have proposed different strategies to enhance the thermal properties of conventional types of materials by "modifying and adopting a better composition, design and/or integration of the technology have been suggested for addressing future energy needs with added co-benefits of thermal comfort" (Kumar and Singh, 2013).

2.3.3. Building bioclimatic charts and thermal comfort

A bioclimatic chart is an analysis tool that can be used during the early stages of any architecture project to build a perception about the thermal comfort. According to Sala et al. (1999), bioclimatic charts can be used for different purposes (Sala et al., 1999):

- To assist the analysis of the climate characteristics of a given location from the viewpoint of human comfort,
- To specify building design guidelines to maximize indoor comfort conditions when the building's interior is not mechanically conditioned.
- To present the concurrent combination of temperature and humidity at any given time on a psychrometric chart.

There are three types of this chart: Olgyays bioclimatic chart, Giovoni's bioclimatic chart, and Szokolay's bioclimatic chart. All such charts are organized around the "comfort zone". It is defined as "the range of climatic conditions within which the majority of persons would feel thermally comfortable" (Givoni, 1992). The following table (2.7) shows a comparison among these three charts.

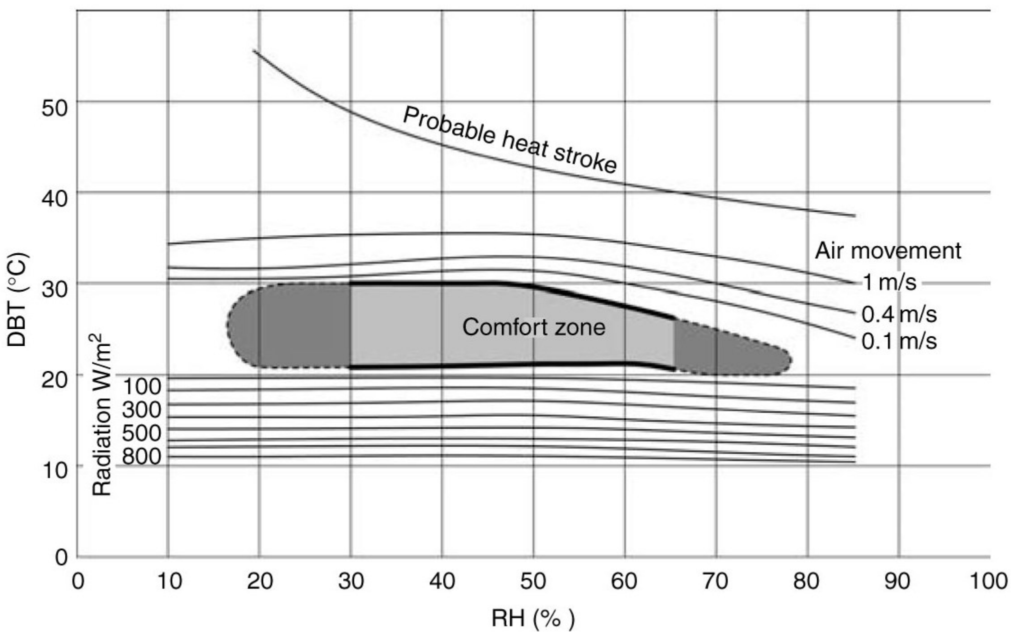


Figure 2. 13: Olgyay's bioclimatic chart, converted to metric, modified for warm Climates

Source: (Szokolay, 2014)

Olgyays bioclimatic chart	Givon's bioclimatic chart	Szokolay's bioclimatic chart
Developed in the 1950s to integrate the outdoor climate into building design.	Aims at calculating the indoor conditions of the building according to the outdoor prevailing conditions	Developed in 1986 with the concept that; depending on the location and the people; there are two comfort zones rather than one.
Based on the outdoor climatic conditions	Based on the linear relation between the temperature amplitude and vapor pressure of the outdoor air in various regions.	
It indicates the comfort zone in relation to ambient temperature and humidity, mean radiant temperature (MRT), wind speed, solar radiation and evaporative cooling	It defines the proper passive cooling strategies (evaporative cooling, thermal mass, natural ventilation cooling, passive heating), according to the climatic conditions prevailing outside the building envelope.	It indicates the comfort zone, based on thermal neutrality correlated to the outdoor mean temperature
It is applicable to a hot humid climate since there is no high range of fluctuation between indoor and outdoor conditions.	The chart can be applied mainly to residential scale structures which are free of any internal heat gains.	
Figure 2.14	Figure 2.15	Figure 2.16

Table 2. 7: A comparison among Olgyays bioclimatic chart, Givon's bioclimatic chart and Szokolay's bioclimatic chart

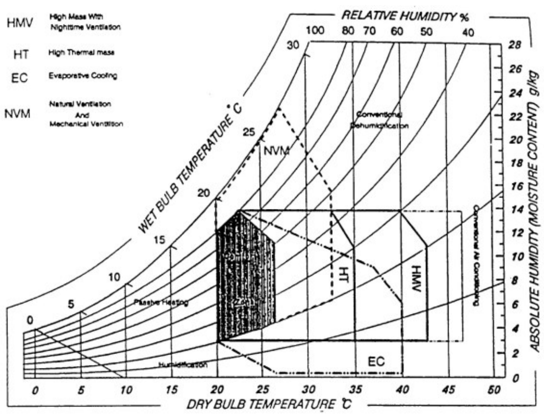


Figure 2. 14: Givoni's building bioclimatic chart
Source: (Sayigh and Marafia, 1998)

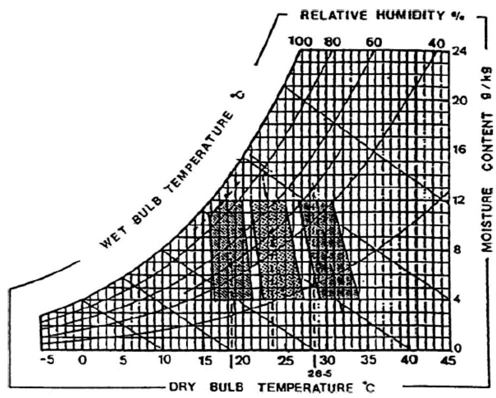


Figure 2. 15: Szokolay's bioclimatic chart
Source: (Sayigh and Marafia, 1998)

2.3.4. Thermal comfort indicators

Thermal comfort standards and models are required to help building designers to estimate thermal comfort according to the climate factors. A number of thermal comfort models is proposed in the literature. They are based on different assessments from calculation of equivalent temperatures (operative temperature, effective temperature, mean radiant temperature) to predicted mean value of comfort assessment by occupants. According to Krarti (2016) "most of these models are based on heat balance applied to the human body to indicate that heat generated by metabolic activities (Qmet,heat) must be dissipated by convection (Qconv), radiation (Qrad), evaporative heat transfer (Qevap), and respiration (Qresp,sen and Q resp,lat)" (Krarti, 2016)

1. Predictive model

This model has two types: Fanger's single-node model, and Pierce's two-node model. Both of them have been developed primarily to examine indoor comfort but their use has later been extended to outdoor conditions (Ullah and Wee, 2013).

Fanger's single-node model

It is based on the heat balance of the human body. Fanger (1970) proposed "that thermal comfort is achieved if the heat flowing to and from the human body is balanced". In this model, "the human body exchanges energy with the environment through evaporation of sweat and/or water vapor diffusion through the skin, respiration, skin exchanges energy by convection and radiation" (Gauthier, 2013). As a measure of thermal comfort, the indices of this single-node model predict the mean comfort vote of a group of people, defined as the Predicted Mean Vote (PMV), and Predicted Percentage of Dissatisfied (PPD), where:

$$PMV = (0.028 + 0.03\, e^{-0.036M}) \times (Hi - Le) \quad \textbf{[2. 11]}$$

$$PPD = 100 - 95\; e^{(-0.03353 PMV^4 - 0.2179 PMV^2)} \quad \textbf{[2.12]}$$

Hi *The internal heat production rate per unit area (W/m2).*
Le *All modes of energy loss from body (W/m2).*

As a rule, these models are used to assess occupants level of thermal comfort when a building is mechanically heated or cooled. Although this model is a good indicator it holds formulation and evaluation errors (Humphreys et al., 2010).

Pierce two-node model

In 1986, the latest version of the Pierce two-node model was proposed (Gagge et al., 1986). In this model, the human body is shown as the core, the skin, and the environment. It has two types of skin surface heat loss: sensible part (conduction through clothing, radiation, and convection from the body surface), and insensible part (evaporation of perspiration on the skin surface). This model has six indices: the effective temperature (ET), the predicted mean value modified by effective temperature (PMVET), Standard Effective Temperature (SET), PMVSET, the Thermal Sensation Index (TSENS), the Discomfort Index (DISC).

2. Effective Temperature (SET)

It is a model of human response to the thermal environment. Developed by A.P. Gagge and accepted by ASHRAE in 1986, it is also referred to as the Pierce Two-Node model. It has the advantage of allowing thermal comparisons between environments at any combination of the physical input variables, but the disadvantage of also requiring "standard" people (Megri et al., 2016).

According to ASHRAE 55-2010 SET is "the temperature of an imaginary environment at 50% relative humidity, <0.1 m/s [0.33 ft/s] average air speed, and mean radiant temperature equal to average air temperature, in which total heat loss from the skin of an imaginary occupant with an activity level of 1.0 met and a clothing level of 0.6 clo is the same as that from a person in the actual environment, with actual clothing and activity level" (American Society of Heating, Engineers, and Institute, 2010).

3. Mean radiant temperature

MRT is defined as the "uniform temperature of an imaginary enclosure in which the radiant heat transfer from the human body equals the radiant heat transfer in the actual non-uniform enclosure" (ASHRAE 2001). It is used to indicate the thermal comfort, especially outdoor (Szűcs, Gál, and Andrade 2014) by considering the air temperature and radiation. Poirazis (2005) has said that "the mean radiant temperature, however, is a more appropriate thermal comfort indicator since it is a measure of the average radiation exchange between the occupant and the surrounding surfaces" (Poirazis, 2005).

It is a calculated variable which cannot be directly measured (Grondzik et al., 2014), therefore, over the years, several models and methods have been proposed in the literature its calculation. The most prominent of these methods for estimating indoor and outdoor MRT are given in the following.

Indoor mean radiant temperature can be estimated by (Gauthier 2015):

(1) Applying equations derived from empirical relation with dry-bulb temperature and mean air velocity (Prentice et al., 2012).

(2) Measuring surface temperatures and view factor, and then calculating it analytically. This method currently described in the ASHRAE Handbook (1997) (Palmer and Chapman, 2000).

(3) Applying computer simulation technology, e.g. RayMan software, ENVI-met software, and vector-based TownScope model (Goulding et al., 1992).

Outdoor mean radiant temperature can be estimated through the following methods:

(1) Globe thermometer method (Chen et al., 2014).

(2) The six-direction short- and long-wave radiation method, which is regarded as the most accurate way to measure MRT (Chen et al., 2014; Lin and Matzarakis, 2011)

(3) The estimating method based on integral radiation measurements and angular factors (Thorsson et al., 2007)

(4) The modeling of the five components of radiation fluxes: direct solar radiation, diffuse solar radiation, reflected solar radiation, long-wave radiation from the atmosphere, and long-wave radiation from urban surfaces - each weighted by view factors (Huang et al., 2014).

(5) The application of computer simulation technology, for example RayMan model, ENVI-met model and SOLWEIG model (Chen et al., 2014).

4. Operative Temperature Model:

To estimate the level of comfort it is not logical to ignore the air temperature (dry bulb, Tair). Therefore, the MRT and Tair must be combined into what is known as the operative temperature. It is a weighted average of the heat transfer by convection (hc) and by radiation (hr) at the occupant's cloth surface, thus, it can be expressed in the following, equation [2.13] (Ferrari and Zanotto, 2015).

$$T_{op} = (hr \times Tmr + hc \times Tair) / (hr + hc) \quad [2.13]$$

Where

hc	*convective heat transfer coefficient*	h_r	*The surface heat transfer coefficient by radiation*
T_{op}	*Operative temperature*	*Tmr*	*Mean radiant temperature*

Researchers have varied in the estimation of the heat transfer coefficients.

In (Pichatwatana, 2016) method, the ratio hc/hr=√10v is adopted, where v is the air speed (m.s-1), and therefore, operative temperature can expressed as equation [2.14] (Pichatwatana, 2016):

$$T_{ot} = (T_{mr} + (T_{air} \times \sqrt{10\, v})) / (1 + \sqrt{10v}) \quad [2.14]$$

Where:

T_{ot}	*The operative temperature (ºC)*
T_{air}	*The air temperature (ºC)*
T_{mr}	*The mean radiant temperature (ºC)*
hc	*The surface heat transfer coefficients by convection (W/m²k)*
hr	*The surface heat transfer coefficient by radiation (W/m²k)*
v	*air speed (m/s)*

In case the air speed is less than 0.1m/s, (as is typical in buildings) radiative and convective heat transfers may be similar, and operative temperature can expressed as: (American Society of Heating, Engineers, and Institute, 2010)

$$To = (T_{indoor} + T_{mr}) / 2 \quad [2.15]$$

According to Designing Buildings Ltd (2016), "In many spaces, with low air velocity and where air temperature and mean radiant temperature may be similar, air temperature alone can be a reasonable indicator of thermal comfort. However, in spaces where surfaces may be heated or cooled, where there is significant thermal mass, or where solar radiation is present, air and radiant temperatures may be different and as a result, it is necessary to take account of radiant temperatures in assessing thermal comfort" (Designing Buildings Ltd, 2016).

5. Thermal adaptive comfort models

The theory of adaptive comfort is based on the adaptive principle, which stated that when changing climatic conditions in a manner incompatible with comfort conditions, the people always tends to restore their comfort. Adaptive model takes into consideration the ways people sense their environment change, seasonal expectations of air temperature, relative humidity, and the capacity to control the spatial conditions (Malys et al., 2016). A number of equations of estimating adaptive comfort temperature has been developed by some specialized organizations (e.g. ASHER) and researchers as follows:

Adaptive model according to research works

Humphrey's model: Using the available data of more than 30 comfort surveys from around the world, Humphreys proposed a series of simple correlations of adaptive comfort prediction. For free-running buildings, the comfort temperature (T_{co}) can be estimated from the mean monthly outdoor temperature ($T_{out,mr}$) in ˚C (Feriadi and Wong, 2004), through the equation [2.16]:

$$T_{co} = 0.53\ T_{out,mr} + 11.9 \qquad [2.16]$$

Where:

T_c *The thermal adaptive comfortis (°C).*

$T_{out,mr}$ *The mean outdoors air temperature (°C).*

Auliciems' model: Auliciems has proposed a new equation based on Humphrey ones, taking out some incompatible information and including combined data for both buildings with active and passive climate control (e.g. the data of natural ventilation in building and air-conditioned buildings). The absence of thermal discomfort is predicted by a simple equation in terms of mean indoor (Ti,mr) and outdoor monthly temperature (Tout) (Feriadi and Wong, 2004):

$$T_{co} = 0.48\ Ti,mr + 0.14 T_{out,mr} + 9.22 \qquad [2.17]$$

Where:

$T_{i,mr}$ *The mean indoor air temperature (°C).*

$T_{out,mr}$ *The mean outdoors air temperature (°C).*

Nicol's model: Nicol has proposed two equations according to several surveys under different climatic conditions in Pakistan. He has proposed a relation between comfort temperature and outdoor temperature as in equation [2.18] (Bouden and Ghrab, 2005).

$$T_{comfort} = 0.38\ T_{air} + 17.0 \qquad [2.18]$$

From a second survey, he has proposed a second regression given by equation [2.19]:

$$T_{comfort} = 0.36\ T_{air} + 18.5 \qquad [2.19]$$

Adaptive model according to ASHRAE and EN15251 standards

Toe and Kubotaa (2014), have explained the adaptive comfort equations of ASHRAE and EN15251, which is given by equation [2.20]:

$$T_{ot,i} = 0.31\times (T_{i,mr} + 17.8) \quad [2.20]$$

Where:

$T_{ot,i}$ *Indoor comfort operative temperature(°C)*

$T_{i,mr}$ *The monthly mean outdoor air temperature (°C).*

Or as equation [2.21]

$$T_{ot} = 0.33\times (\Theta_{m,i} + 17.8) \quad [2.21]$$

Where:

T_{ot} *Indoor comfort operative temperature(°C)*

$\Theta_{m,i}$ *The running mean outdoor air temperature (°C).*

The outdoor running mean temperature $\Theta_{m,i}$ is formulated on the basis of its value on the previous day ($\Theta_{m,i-1}$), the mean daily value of outdoor temperature on the previous day ($\Theta_{e,i-1}$) and a coefficient, α (recommended value equals 0.8), as equation [2.22], (Gauthier, 2015 2013):

$$\Theta_{m,i} = (1-\alpha)\,\Theta_{e,i-1} + \alpha\ \Theta_{m,i-1} \quad [2.22]$$

Where:

$\Theta_{m,i}$ *The outdoor running mean temperature,*

$\Theta_{m,i-1}$ *The outdoor running mean temperature on the previous day,*

$\Theta_{e,i-1}$ *The mean daily value of outdoor temperature on the previous day,*

α *Coefficient and its recommended value is 0.8.*

The Limits of the comfort zones for a residential building are given by the following three categories:

$T_{ot} = 0.33\times\Theta_{m,i} + 18.8 \pm 2$	Cat. 1	Acceptable limits of the comfort zones is 90% acceptability	[2.23]
$T_{ot} = 0.33\times\Theta_{m,i} + 18.8 \pm 3$	Cat. 2	Acceptable limits of the comfort zones is 80% acceptability	[2.24]
$T_{ot} = 0.33\times\Theta_{m,i} + 18.8 \pm 4$	Cat. 3	Acceptable limits of the comfort zones is 65% acceptability	[2.25]

T_{ot} *: operative temperature(°C)*

7. ASHRAE Comfort Standard

ASHRAE has developed a standard to describe comfort requirements in buildings. The standard is identified as ASHRAE Standard 55, Thermal Environmental Conditions for Human Occupancy. The main aim of this standard is to specify the combinations of four primary environmental factors (temperature, thermal radiation, humidity, and air speed) and two personal factors (activity and clothing) that produce thermal environmental conditions acceptable to the occupants within the space. The important feature of Standard 55 is the ASHRAE Comfort Zone are described on a modified psychometric chart as Figure 2.17. The Standard allows the comfort charts "to be applied to spaces where the occupants have activity levels that result in metabolic rates between 1.0 met and 1.3 met and where clothing is worn that provides between 0.5 clo and 1.0 clo of thermal insulation". The comfort zone is based on the PMV (Predicted Mean Vote) values between -0.5 and +0.5, on a scale from -3 (cold) to +3 (hot) (see Figure 2.18). This standard is similar to other comfort standards like EN 15251 and the ISO 7730 standard (Krarti, 2016).

Value	Sensation
+ 3	Hot
+2	Warm
+1	Slightly warm
0	Neutral
-1	Slightly coll
-2	Cool
03	Cold

Figure 2. 16: ASHRAE Thermal sensation scale
Source: (Krarti 2016).

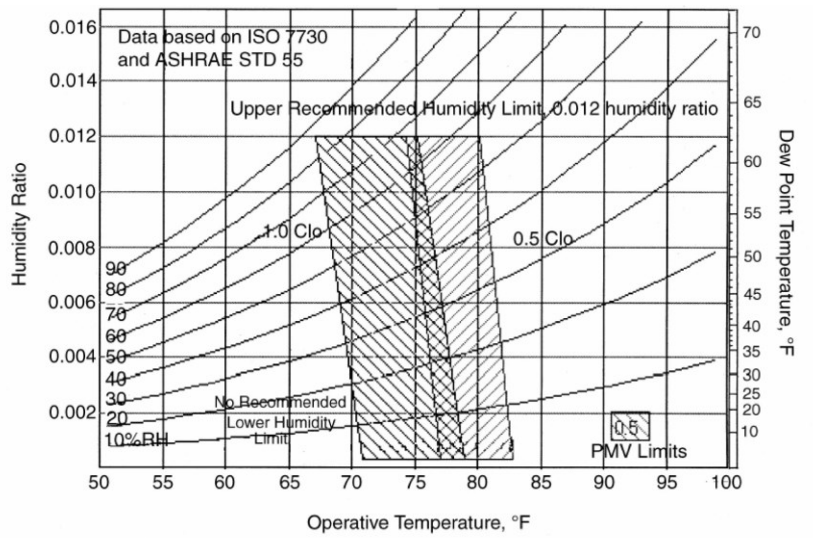


Figure 2. 17: ASHRAE Comfort Zone
Source: (Krarti, 2016)

2.4. Summary and conclusion

After all the above mentioned discussions, it could be said that this chapter has built a theoretical basis related to two concepts that have a direct relation with the energy balance of an urban area. These two concepts are: the UHI phenomenon and the thermal comfort.

This chapter has provided an overview of the types of UHIs, the factors contributing to their formation and the key concepts that help mitigating them. From what is previously discussed, we could conclude the following:

- UHI is an environmental problem affecting large cities, plaguing the atmosphere, sub-surface and surfaces, causing the raised temperatures in the city center.
- Based on the energy balance equation, many factors may affect the formation of UHIs. The ΔQS among the other factors is the most influential. It depends mainly of the type of construction materials and the structure of the urban surface.
- Based on the urban configuration, the factors effecting UHI are urban geometry design, urban cover and surface materials thermodynamic specification, urban landscape and waterscape, and urban metabolism and anthropogenic.

Regarding thermal comfort, this chapter goes on to clarify the most important information related to thermal comfort such as the factors, the most commonly used indicators, etc. From that, we conclude the following:

- Specifically, the thermal comfort can be classified into three levels: thermal comfort, thermal discomfort and thermal stress. The thermal comfort is affected by the independent environmental variables and the independent personal variables. Indoor, the building materials are the main factor effecting the level of comfort. Consequently, the use of either advance and innovative materials types (such as Phase change materials (PCMs), thermochromic materials, radiant and thermal barrier materials) or conventional materials after modifying and adopting a better composition, design and/or integration of the technology can contribute effectively to achieve the gain related to the thermal comfort.
- The low thermal conductivity materials have high ability to sustain an acceptable level of comfort inside the building in which it is equivalent to high insulating capability. In this case, these types of materials, even if they do not prevent the heat flowing completely inside or outside of building spaces, they can slow the heat flow. It helps provide thermal comfort to people rather than causing discomfort.
- Studies have presented several methods and indicators to assess the thermal comfort. These methods differ in their criteria adopted in determining the thermal comfort zone. For example, there are those who say that the air temperature is the most important factor because it is the easiest to use and people can rate it without any difficulty. Whereas other studies state that air temperature is not quite enough to determine the level of thermal comfort where it must be considered in relation to other environmental and design factors such as humidity. Other studies go further by describing other indicators away from the primary factors of climate, such as the mean radiant temperature, operative temperature, etc.

Chapter 3

Role of Construction Materials

Summary

1. Factors Affecting Selection of Construction Materials
2. Classification of Construction Materials Properties
3. Urban typology components and materials types
4. Related studies
5. Summary and conclusion

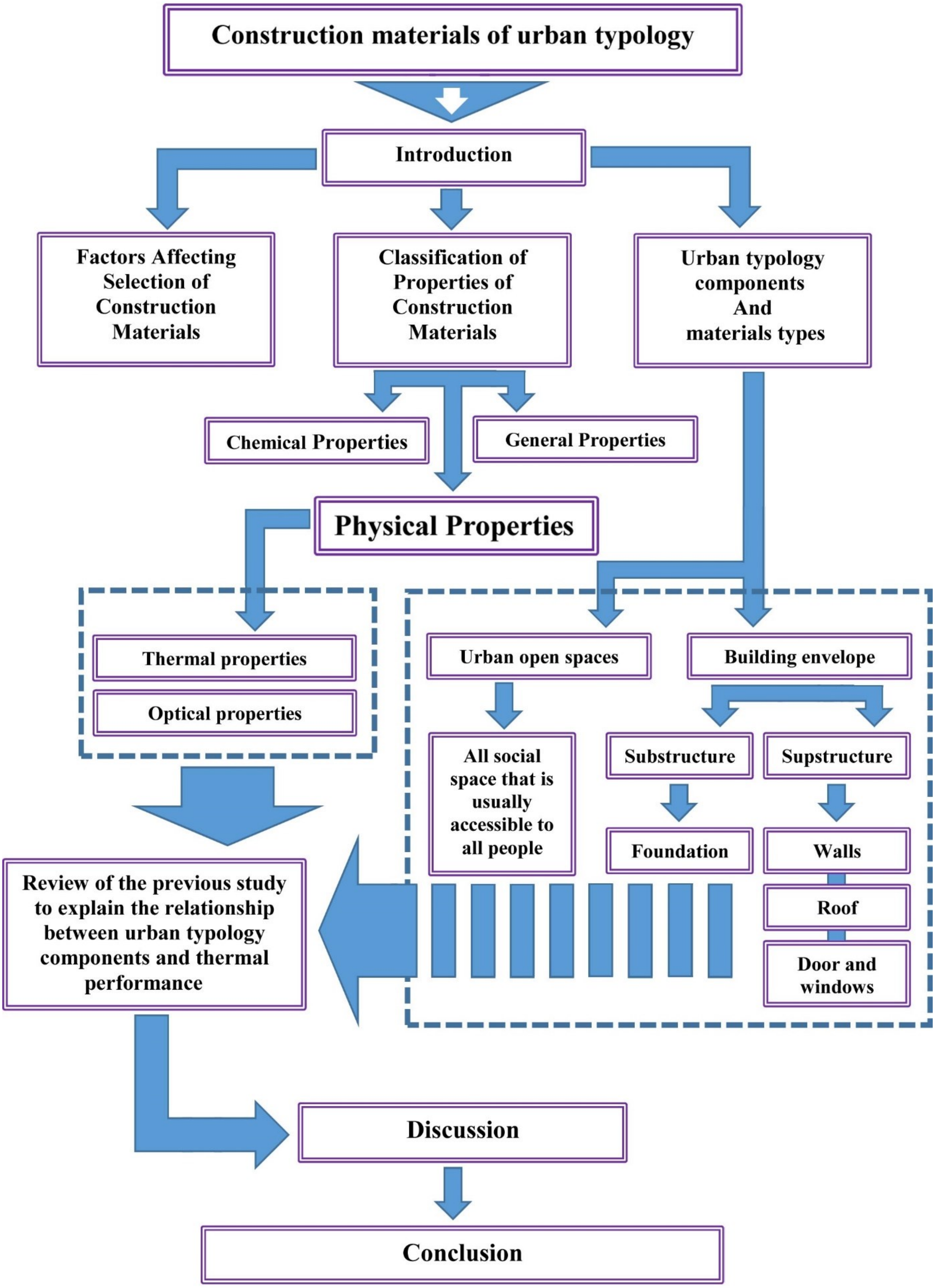


Figure 3. 1: Flow chart of chapter Three

Chapter 3 Role of Construction Materials

3.1. Introduction

There are three basic needs of human beings which are food, clothing and shelter. Consequently, the fundamental function of any simple or complex building is to protect occupants against harsh climatic conditions (sun and rain, heat and cold), external aggressions (animals and attacks from humans), privacy and storage of possession. Any architectural project cannot be constructed without a basic comprehension of the building materials and the related factors such as thermal performance, strength, cost etc. These variables always affect the selection of one material over another (Fasogbon et al., 2015).

Construction material is any material used in construction field whether it occurs naturally or it is man-made. The human beings have used various types of materials during different eras to construct their buildings, road, urban space, pavements, etc. Since the early beginning of civilization Man has discovered the materials science through the use of natural materials in the construction of his first house. Rock, hides and minor wood elements were considered as the first types of materials used for construction in the nomadic lifestyle. As a result of the development of civilization, new types of material have been discovered which were represented by stone, brick, cement paste and plaster.

Early in the 18^{th} Century, and as a result of the industrial revolution both iron and steel became essential materials used for the construction with the invention of tools and machines, to ships, buildings and infrastructure.

In the 1920s and 1930s, glass and steel, in combination with usually less visible reinforced concrete were used as construction materials. This style represents the first start of buildings types that could be located in any climate and in any context combined with the developments in environmental systems. The development of materials continued until the advent of smart materials. This is the best attempt to integrate the various variables of an environmental design which led to find great solutions in terms of providing comfort to occupants and also compatible with the energy efficiency requirements, (see Figure 3.2) (Yahya and Abdul Samad, 2014) .

The construction materials properties, either exterior building walls or outdoor urban spaces materials affect the thermal performance and energy needed in relation to indoor and outdoor thermal comfort with regards to their various thermal performance. For example, the study of Doulos et al. (2004) involved the thermal performance of total (93) commonly used pavement materials which were measured in detail using mainly infrared thermography procedures (see Figure 3.3). This study presented detailed results concerning the mean daily surface temperature for a wide range of materials with different surfaces texture and color. (Doulos et al., 2004).

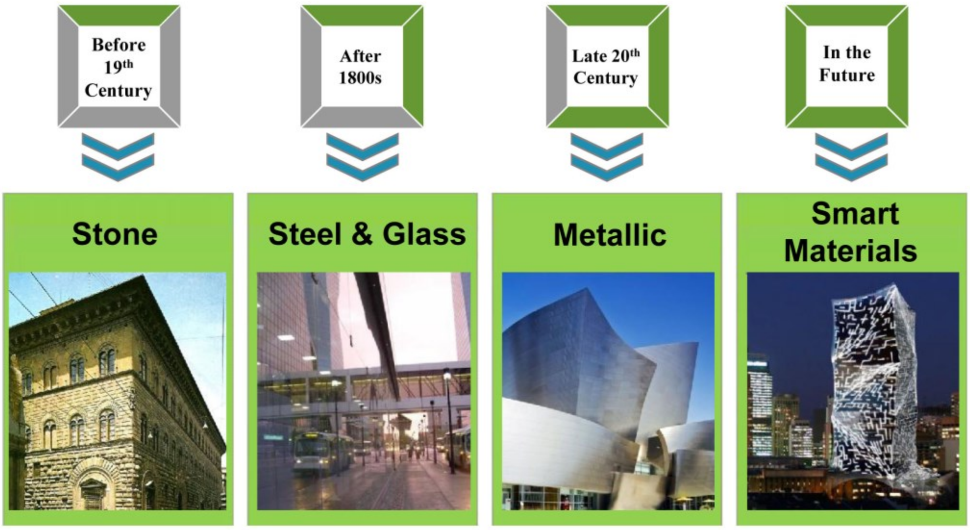


Figure 3. 2: Historical development of materials
Source: (Yahya and Abdul Samad, 2014)

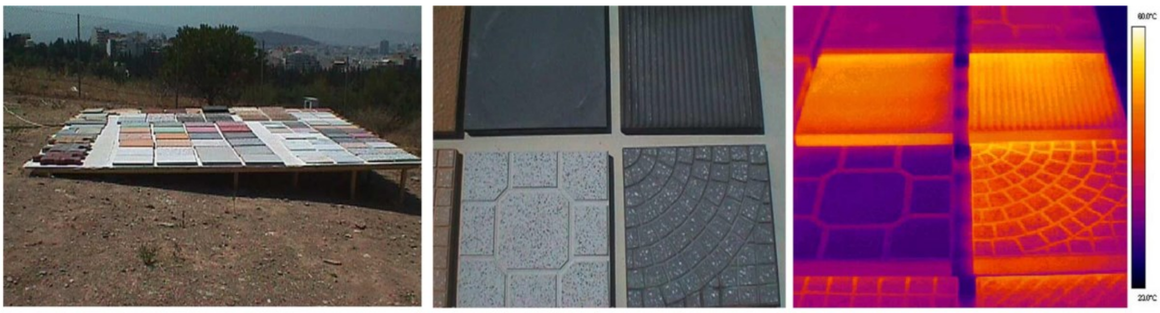


Figure 3. 3: The site of the experimental campaign with the modulated platform | Visible and infrared image of selected building materials
Source: (Doulos et al., 2004)

According to the Australian Institute of Refrigeration, Air Conditioning and Heating (AIRAH), the conductivity of 250 mm-thick mud bricks with a density of 1540Kg/m^3 and specific heat capacity of 1260J/Kg.K is 1.25W/m.K, about the same that given by ASHRAE for the concrete with a density of 2240Kg/m^3 (1.3W/m.K). However the specific heat would be between respectively 800 and 1000J/Kg.K (Soebarto, 2009).

Previous studies ranging from assessing the performance and cost, development of traditional types of materials, propose new types of building materials (Bhatia, 2014; McGee, 2013; Dietrich, 2004; Thomas, 2006; Rakos and Antohe, 2014; Reddy and Jagadish, 2003; Treloar et al., 2001; Jain and Jain, 2012). Some of these studies, relevant to the objectives of this research will be discussed later in the chapter.

Determining the thermal performance of any construction materials is of prime importance to determine the heating and cooling load within a building but also outdoor local climate conditions. The thermal performance of any materials is a function of several factors such as thermal conductivity, thermal resistance, emissivity, absorptivity, reflectivity, specific heat capacity, density… which can vary over time due to weather and aging conditions.

In the current era, the construction industry becomes one of the most complex and multipurpose economic sectors which has evolved dramatically (Marrengula et al., 2012). These developments have occurred in three directions:

- The production of new materials types e.g. textile-reinforced concrete and other fiber-based materials;
- The development of conventional materials types e.g. adding some chemical materials or other materials (strew, rubber, etc.) to concrete to enhance its properties;
- The re-introduction of biosourced materials (wood, straw, clay…) so that to lower greenhouse gas emission due to construction materials.

The main motivation which encourages having new types of building materials is to achieve better specifications and meet the needs of the occupants. This means lower costs to run, reduced carbon emissions and better quality, durability, etc. (Probst et al., 2014).

Many directions and methodologies that may be considered when selecting proper materials already appeared (Braganca, 2007). The selection of building materials is a stage which precedes the beginning of the construction phase, it follows the design stage, where the selection process is conducted according to many factors and considerations e.g. thermal performance, cost, function, etc.

This chapter will point out several issues related to construction materials. It will begin with a brief survey of the construction materials, their characteristics. More attention will be put on the thermal properties and optical properties of materials. Then, it will deal with the most important factors for the selection of the appropriate construction material, urban typology components and materials types, and finally it will throw light on some of the previous studies related to this topic.

What is the construction materials?

The construction material is the center of building engineering. It decides some of the most outstanding features of the building; make the building strong, durable, applicable, economic and beautiful (Wu, 2015). Based on a large number of studies and scientific works the building materials is:

"Any material which is used for a construction purpose. Many naturally occurring substances, such as clay, sand, wood and rocks, even twigs and leaves have been used to

construct buildings. Apart from naturally occurring" (Board, 2012; CTI Reviews, 2016; Satyanarayana et al., 2012; Zhang, 2013).

The studies varied in classification of building materials, which mainly relied on the orientation of the study. Some studies use the nature type, artificial type and hand-mad type, while others use ceramic, metallic, polymeric, composite, and so on. As a general rule, the classification of building materials included structural materials, decoration materials and some special materials.

- **Structural materials:** contain wood, bamboo, stone, cement, concrete, brick, ceramic tile, metal, glass, plastics, and composite materials;
- **Decorative materials**: contain a variety of coatings, paints, coatings, veneers, colored tiles, glass with special effects, etc.;
- **Special materials:** contain materials for waterproof, moisture, corrosion, fire prevention, sound insulation, flame retardant, heat insulation, thermal insulation, sealing, etc.

Table 3.2, below lists some of classification of building materials mentioned in the literatures.

Source	The classification
Wu (2015)	Load-bearing structure uses material (brick, stone, concrete, mortar, steel and wood, etc.) and special materials (sound absorption board, refractory brick, antirust paint, foam glass, color cement etc.).
Ogwuda (2007)	Ceramic, metallic, polymeric, composite (Ogwuda 2007).
R. Pendleton (212)	Fibrous, laminar and particulate (Pendleton and Tuttle 2012).
Mutua J	Metals, ceramic, polymer, and composite ("Introduction: Classification and Properties of Materials" 2016; Mutua 2016).
Johri N. and Prakash A. (2012),	Materials naturally occurring types and artificially occurring type (Satyanarayana et al. 2012).
According to Combustibility	Non-combustible material, Combustible material, Fire Retardant Treated Wood, Intumescent Coatings
Alchapar et al. (2014)	building materials used in the urban envelopes (Alchapar et al. 2014).

Table 3. 1: Classification of building materials

3.2. Factors Affecting Selection of Construction Materials

The selection of construction material is not an easy process. It depends upon several factors and criteria. It must often be made to the requirements of performance and/or cost (Palomba et al.2014). Several methods of quantitative and qualitative analysis have been applied to achieve this task such as the use of one the methods of measurement scales (ratio, interval, ordinal, and nominal) (Javaherdashti et al., 2013).

Thomas (2006) confirms that before starting the selection of materials two significant points must be taken into consideration. The first one is to determine the criteria which will be used (e.g. fitness for the purpose, cost, mechanical resistance, stability, safety and many other factors). The second one is to determine its impacts on the natural environment and on health before examining any specific ones (Thomas, 2006). **Kutz (2005)** defines three stages of materials selection: initial screening, comparing and ranking alternatives, and selecting the optimum solution (Kutz, 2005).

Al-Bassam and Al-Atraqgy (2007) listed the most common and analytical methods which are used in materials selection: cost vs. performance indices, decision matrices (weighted property indices, digital logic method, rating chart, pugh method), incremental return method, geometrical approach, algebraic approach, benefit-cost analysis, limits on properties, value analysis, other (Al-Bassam and Al-Atraqgy, 2009).

Regarding the material performance requirements, many studies had identified five main aspects, which consist of: functional requirements, processability requirements, cost, reliability, and resistance to service conditions, as tale 3.3 (Farag, 2013; Kutz, 2002; Surendranathan, 2014).

		Definition	Example
Performance Requirements	**Functional requirements**	Related to the needed characteristics of the part or the product.	Thermal shock resistance can be related to the thermal expansion coefficient, thermal conductivity, modulus of elasticity, ductility.
	Processability requirements	Is a measure of its ability to be worked and shaped into a finished element.	Ductility and hardenability can be relevant to processability if the material is to be deformed or hardened by heat treatment, respectively.
	Cost	Important factor because in many applications there is a cost limit for a given component.	When the cost limit is exceeded, the design may be changed for the use of a less expensive material or process.
	Reliability	The probability that it will perform the intended function for the expected life without failure.	Defects in materials and processing, faulty design, unexpected service conditions, or misuse of the product.
	Resistance to service conditions	The environment in which the product will operate plays an important role in determining the material performance requirements.	The coefficients of thermal expansion of all the materials involved is similar to avoid thermal stresses.

Table 3. 2: Material performance requirements

3.3. Classification of Construction Materials Properties

Each type of materials has some properties reflecting its given distinctive qualities and characteristics, which can be defined and tested. **Mukherjee (2011)** has classified the properties of engineering materials into two main groups, physical and chemical, as well as some general properties such as density, cost, and anisotropy (see Figure 3.4) (Mukherjee, 2011).

According to the orientation of this study, the major properties that will be discussed are the thermal and optical properties, whereas many specific factors related to these properties will be studied and discussed later.

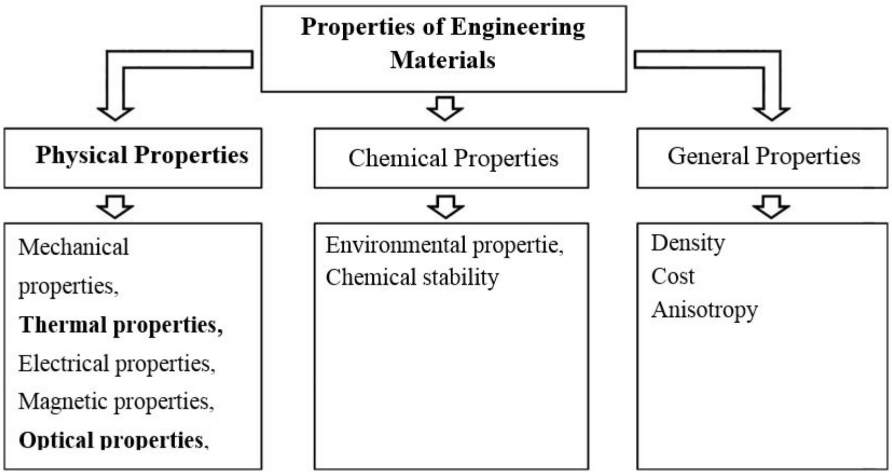


Figure 3. 4: Classification of properties of construction materials
Source: (Aran, 2007)

3.3.1. Thermal properties of materials

One of the most important objectives of the study of the thermal properties of materials is its impact on energy performance. Every material used in urban typology especially the building envelope has fundamental physical properties that determine their energy performance (Mohammad and Shea, 2013). **Rashwan et al. (2013)** wrote that "the researches have shown that building envelopes contribute more than 50% of the embodied energy distribution in major building elements in residential buildings; it also contributes approximately 50–60% of the total heat gain in buildings" (Rashwan et al., 2013). Therefore, the understanding of these properties will help to select the appropriate construction materials to control heat flows. The thermal properties of materials include thermal conductivity and thermal mass, each one includes a set of factors (Autodesk Education Community, 2015) (see Figure 3.5).

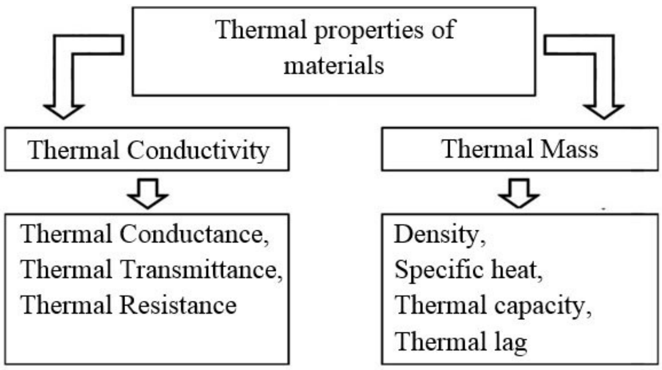


Figure 3. 5: Thermal properties of materials
Source: (Autodesk Education Community, 2015)

3.3.1.1. Thermal Conductivity

In physics, thermal conductivity (K, λ), or K value, or coefficient of thermal conductivity, or K value is a thermophysical measure of how much heat is transferred through a material by the conductive flow, it is measured in watts per meter kelvin (W/(m.K)) (Söderholm, 2000). Materials that have a high thermal conductivity are called conductors. They have greater ability to transmit thermal energy, whereas materials of low thermal conductivity are called insulators (Anusavice, 2003).

a. Thermal Conductance

The conductance (C) is the conductivity per unit area for a specified thickness and it is measured by units of W/m^2K for metric and Btu/h ft2 ºF for Imperial. It depends on the material type and its thickness. It allows to compare directly the performance of different single layer walls.

b. Thermal transmittance

Thermal transmittance, also known as U-value or U-factor, is the rate of transfer of heat (in watts) through one square metre of a structure, divided by the difference in temperature across the structure. It is expressed in watts per square meter kelvin, or W/m^2K. Well-insulated parts of a building have a low thermal transmittance whereas poorly insulated parts of a building have a high thermal transmittance (Dubai municipality, 2017). U-value is used for assemblies. It is described by the equation [3.1]:

$$Q = A \times U \times (T_1 - T_2) \qquad [3.1]$$

Where		
	Q	*The heat transfer in watts*
	U	*The thermal transmittance*
	T1	*The temperature on one side of the structure*
	T2	*The temperature on the other side of the structure*
	A	*The area in square metres.*

c. Thermal Resistance

Thermal resistance or R-value or **(R-value = 1/U)** is **a material's ability to resist heat flow.** It determines how effective any material is as an insulator. A greater thickness means less heat flow and so does a lower conductivity. The materials that have high thermal resistance (e.g. rock wool) indicate a better insulating performance. R-value differs from the U-value when it is not typically specified for assemblies of materials. It measured in m^2K/W for metric, while in the Imperial system, the units are ft^2°Fhr/BTU.

$$R = 1 / U \qquad [3.2]$$

3.3.1.2. Thermal Mass

Thermal mass is a material capacity to absorb, store and release heat over time. For example, the concrete or any other heavy material has a high capacity to store heat and is known as high thermal mass materials. Insulation materials like timber has very little heat storage capacity and low thermal mass. It is a key cause in dynamic heat transfer exchanges within a building (thermal lag). Density, specific heat, thermal capacity are the main factors of thermal mass.

a. Density

Density is the mass of a material per unit volume, expressed in kg/m^3. When there is a change in the volume of material, greater density will lead to store more heat. What is more, dense materials store more heat (Grondzik et al., 2014).

b. Specific Heat

Specific heat is a measure of the amount of heat necessary to increase the temperature of a 1 kg of material by 1°. A low-specific-heat material needs less energy input to raise its temperature, when compared that of a high-specific-heat material. It is expressed as J/kg K (Grondzik et al., 2014).

c. Thermal Capacity

It is an indicator of the capability of a material to store heat per unit volume. The greater the thermal capacity of the material, the more heat it can store in a given volume per degree of temperature increase. Higher thermal capacity can reduce heat flow from the outside to the inside of building envelope by storing the heat within the material. For example, the appropriate weather conditions and acceptable thermal capacity, heat entering a wall construction during the daytime, and it be stored for several hours, until the heat flows back out to the cool night air (Grondzik et al., 2014). Thermal capacity for a material is obtained by multiplying the density by specific heat, it is expressed in J/K.

d. Thermal Lag (Time Lag)

Time lag (Φ) also termed thermal lag is the time difference between the temperature maximum on the outside surface of a building element and the temperature maximum on the inside surface when subjected to periodic conditions of heat flow.

$$\Phi = t_{[Tin\,(\max)]} - t_{[Tout\,(\max)]} \qquad [3.3]$$

Where, $t_{[Tin\,(max)]}$ *and* $t_{[Tout\,(max)]}$ *are the time of day when the inside and outside surface temperatures reach maximum*

It is a result of the heat storage capabilities of the materials. Balaji N.C et al. (2012) have proposed diagram in order to clarify the time lag (Balaji et al., 2013), as it is shown in (Figure 3.6).

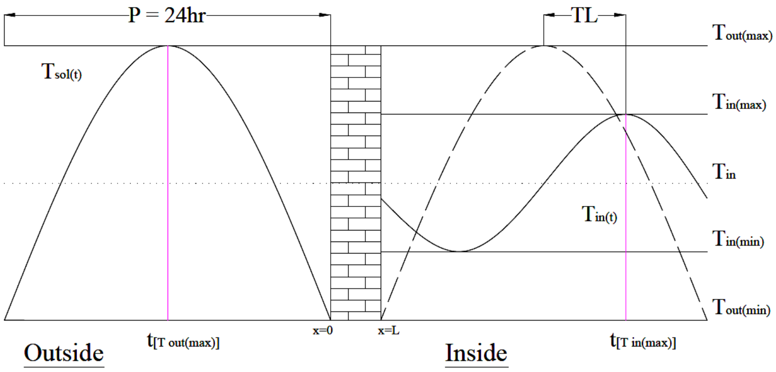


Figure 3. 6: The schematic representation of time lag and decrement factor
Source: (Balaji et al., 2013)

The time lag varies depending on the thermal mass of the materials, it increases in parallel with the increase in thermal mass. For example, in a brick veneer wall, the time lag is 5 hours, whereas, in the un-insulated cavity brick (high thermal insulation or high thermal mass) it is (7 hours), see Figure (3.7).

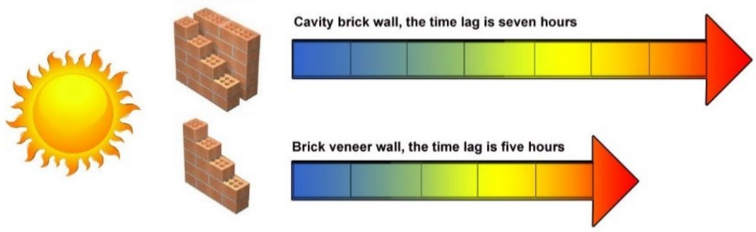


Figure 3. 7: The time lag difference between brick veneer and cavity brick
Source: Adapted from http://myclaybrick.com/html/whybrick-thermalmass.html

As a general rule, the higher time lag represents the solution that are the preferred thermal performance, and it certainly leads to minimize energy consumption.

3.3.1.3. Thermal effusivity and diffusivity

Thermal effusivity and diffusivity are two factors expressing the relation between each of the thermal conductivity, density and heat capacity. These two properties are considered as specific parameters related to the thermodynamic regimes.

Thermal effusivity is a measure of a materials ability to store heat and give it back later (exchange thermal energy with its surroundings). While the thermal diffusivity of a material "is a measure of how fast the material temperature adapts to the surrounding temperature, it does not require much energy from their surroundings to reach thermal equilibrium" (Eindhoven University of Technology, 2017). The thermal diffusivity and effusivity can be expressed as the following equations:

Thermal effusivity (e_f) = $\sqrt{k \cdot \rho \cdot C_p}$ [J/m^{2}Ks$^{0.5}$] **[3. 4]**

Thermal diffusivity (a) = $\dfrac{\lambda}{\rho c}$ [m^2/s] **[3. 5]**

Where k *Thermal conductivity in W(m.k)*

ρ *Density in kg/m^3*

Cp *Specific heat capacity in J/(kg.K)*

To understand these two dynamic thermal phenomena, we present the experiment test carried out by Lavigne (1994). He used two spherical balls (A) and (B) with same diameter, and two different materials, at the same place initially, for a long time. Their temperature T1 is homogeneous in mass and the same for both. At time t = 0, he puts the two balls A and B in a container of boiling water, maintained at temperature T2, by means of a sensor, observes in the center of each ball the evolution of the temperature as a function of time (Lavigne et al., 1994), (see Figure 3.8).

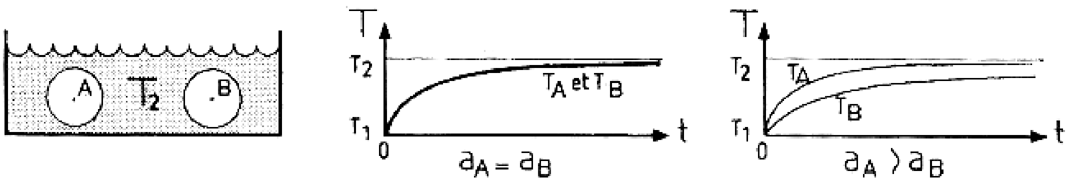


Figure 3. 8: The evolution of temperature as a function of time

Source : (Lavigne et al., 1994)

From this test, Lavigne has found that if the temperatures TA and TB evolve in the same way, it can be said that the diffusion of the temperature is the same in the materials of each ball (thermal diffusivity, the diffusion of a temperature in a material in which it varies as a function of time, it expresses the capacity of a material to transmit a temperature variation.). While, if the temperature TA grows more rapidly than the temperature TB, it can be said that the diffusion of the temperature is better in the material A (thermal effusivity, the effusion of a thermal power in a material, it expresses the capacity of a material to absorb or restore thermal power) (Lavigne, et al. 1994).

The application of thermal effusivity

When the concepts of diffusivity and effusivity are known, the thermal inertia of a material can be easily identified. The thermal inertia of a body is the ability of a material to store heat (or cold) and then restores it gradually. The heavier and more compact the material, the greater the thermal inertia. Since thermal effusivity reflects materials ability to store heat and give it back later and it also represents the materials ability to exchange heat energy with its environment.

Therefore, it characterizes the sensation of hot or cold that the material gives. If the effusivity value is high, the material quickly absorbs a lot of energy without significant heating on the surface (metal, stone, earthenware, etc.). Conversely, a low effusivity value indicates that the material rapidly heats up on the surface by absorbing little heat (insulation, wood, etc.) (Lavigne, et al. 1994).

3.3.2. The radiative properties of materials

3.3.2.1. The albedo

'Albedo' is of Latin origin, meaning whiteness. Albedo or reflection coefficient "indicates the fraction of short-wave radiation that is reflected from land surfaces into the atmosphere". It is the index representing the surface reflectance (Filho et al., 2016). It is the characteristics of the surfaces that decide their ability to reflect or absorb solar radiation falling on them. The rest of radiation which is not reflected is absorbed (or transmitted) by the surface, therefore, contributes to raise the surface temperature. Surfaces differ in their albedo value, for example, oceans, lakes, and forests reflect small portions of the incident solar radiation and have low albedos, snow, sea ice, and deserts reflect have high albedos. The albedo value depends on the spectral and angular distributions of the incident light which are controlled by atmospheric composition and the direction of the beam of light from the sun.

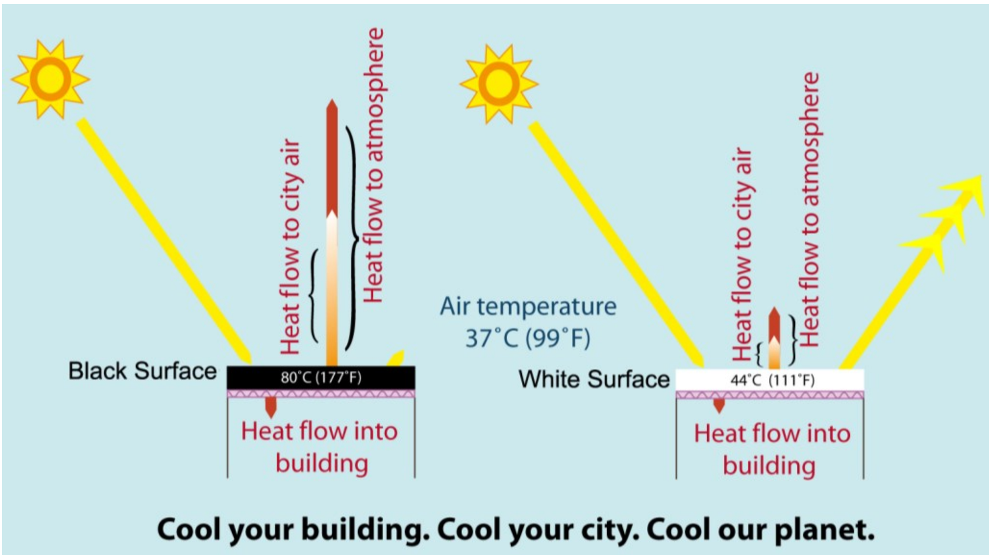


Figure 3. 9: The difference between high albedo surface and low albedo surface
Source: (Chao, 2010)

When a surface albedo is equal to 0 it doesn't reflect any amount of radiation, while when it is 1 all the incoming radiation is reflected to the atmosphere (Coakley, 2003; Filho et al., 2016). High albedo material is one of the available solutions to reduce heat absorption by the urban fabric, reduce the surface temperature and the phenomenon of UHI. The materials with low albedo increase the ability to store the heat from direct sunlight along daytime (see Figure 3.10).

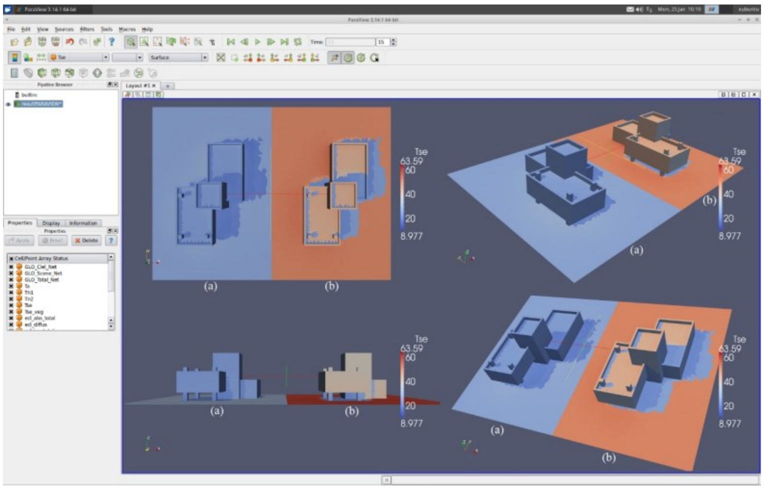


Figure 3. 10: Compartion between high and low albedo building envelope and outdoor space (a-high albedo coating-0.8, b-low albedo coating-0.25)

Source: The researcher | simulation by using SOLENE-Microclimate

Difference between albedo and Solar Reflectance Index

The Solar Reflectance Index (SRI) is a measure of the surface ability to reject solar heat, using surface temperature measurement. It rely on a scale on which standard black (reflectance 0.05, emittance 0.90) is 0 and a standard white (reflectance 0.80, emittance 0.90) is 100. For example, the black standard has a temperature rise of (50 deg. ºC) in full sun, and the white standard has a temperature rise of (8.1 deg. ºC). Once the maximum temperature rises of a given material has been computed, the SRI can be computed by interpolating the values for white and black standards (Designing Buildings Ltd, 2017).

3.3.2.2. The emissivity

Emissivity is the surface characteristic used to measure the surface ability to emit infrared energy (longwave radiation). It is considered as an important factor which helps to indicate the temperature of the surface. Emissivity can have a value from 0 (shiny mirror) to 1.0 (perfect black body). It is the ratio between the energy radiated by a material and the energy radiated by a blackbody at the same temperature. For a given wavelength, the absorption coefficient of a material is equal to its emissivity (Salvaggio et al., 2009).

The relation between emissivity and reflectance

According to what has been discussed, for hot climates, the perfect exterior surface coating has a solar reflectance near 1.0 and infrared emissivity near 1.0, therefore, little proportion of solar radiation is absorbed and the heat is radiated out to the sky. For example, the white plaster is considered as the best types that help to achieve this combination. On the contrary, the dark asphalt is the worst type that absorbs most proportion of solar radiation, as shown in Figure (3.11), (USAID, 2007).

3.3.2.3. The roughness

The roughness is a characteristic that determines the surface convective heat exchange with the air. The roughness is a component of surface texture of the material. It also greatly reduces the reflection because of solar trapping effect. Therefore, the surface temperature is seen to increase monotonically with roughness (Guha and Chowdhuri, 1996).

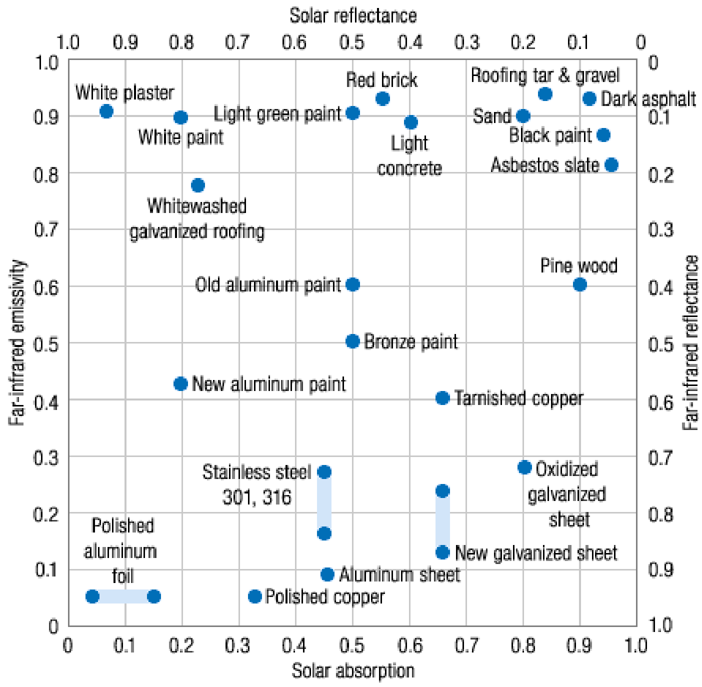


Figure 3. 11: The relation between emissivity and reflectance

Source: (USAID, 2007)

3.4. Urban typology components and materials types

The urban typology components which will be discussed in detail contains two main components: the building envelope materials and the urban public space materials.

Mitleton-Kelly (2013) identified the typology term in urban planning and architecture field as:

> The systematic classification of physical characteristics commonly found in buildings and urban places, such as construction materials, finishing, intensity of development, degrees of formality, school of thought (modernist or traditional), and etc. (Mitleton-Kelly, 2013).

Construction materials are considered as the basic physical characteristics of urban typology which have a significant impact on people's life and various activities, through its direct effects on ambient air quality. These effects mainly depend on the thermal properties of materials as well as their characteristics regarding radiation energy absorbed, reflected, and transmitted, both buildings and urban spaces.

3.4.1. Urban typology: building envelope

The building envelope (building enclosure) is the outer shell between the interior and the exterior environments of any building. It separates the varying outdoor conditions from the indoor conditions by controlling the flow of heat, air, moisture. The building envelope equally plays a significant role to minimize the effect of solar radiation through the control of the amount of solar radiation that is absorbed and its effect on air temperature in outdoor spaces. It consists of a sub-structure or foundation as a lower portion of the building) and external envelope which has roof, walls, doors and windows (Central Public Works Department, 2013; Department of Energy-Republic of South Africa, 2013; Olaniyan et al., 2013).

3.4.1.1. Foundation - Substructure of construction

a. Definition

Sub-structure or foundation is the lower component part of the building. "Foundations are that part of the structure designed and constructed to be in direct contact with and transmitting loads to the ground" (British Standards Institution, 1998). Normally, it is found below the ground level, but in some projects it may be part of the foundation located above the ground floor (see Figure 3.12).

b. Materials types

The foundation consists of many types of materials. **Dunlop C. (2003),** identified the most widely used materials which are: concrete, concrete block, cinder block, hollow clay tile (terra cotta), brick, stone and wood (very old buildings) (Dunlop, 2003), see Figure 3.1.

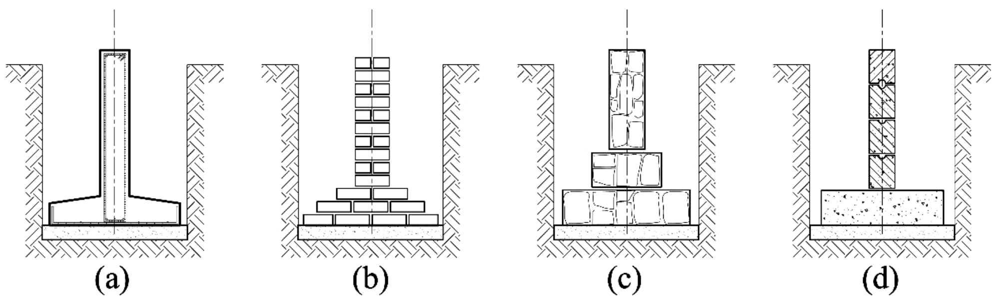


Figure 3. 12: Most popular material types of foundation, a. concrete, b. brick, c. stone, d. concrete block

Source: The researcher

c. Thermal behavior of Sub-structure (foundation)

According to the nature of this component, which is located under the ground level, there is no significant effect of the foundations which is not exposed directly to sunlight on the outdoor air temperature. According to the **White (2013)**, the impact of the foundation especially those types that are produced in factories is limited by the energy use and pollutant emissions associated with the manufacture, installation, maintenance and disposal of it such as pile foundation (White, 2016).

But there are effects if there is a part of the foundations above the ground level. In this case, it is a part of building form (envelope). **Hwaish (2015)** said that the building envelope has a significant impact on the external variations of external climatic conditions (Hwaish, 2015). According to **Guan (2011)** the increase of the external surface area generally leads to the increase of the "the rate of solar radiation absorption, surface temperatures increases until ambient air temperatures also increase through convection from the materials" (see Figure 3.13 and 3.14) (see Figure 3.13 and 3.14) (see Figure 3.13 and 3.14) (Guan, 2011).

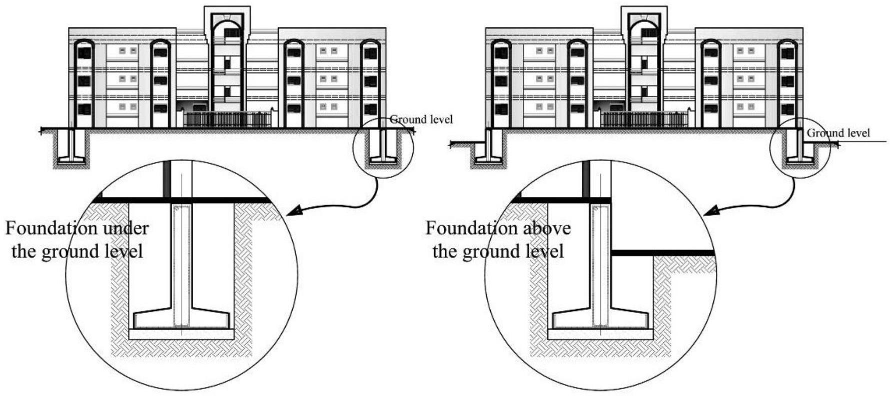


Figure 3. 13: The relation between the foundation of building and the ground level
Source: The researcher

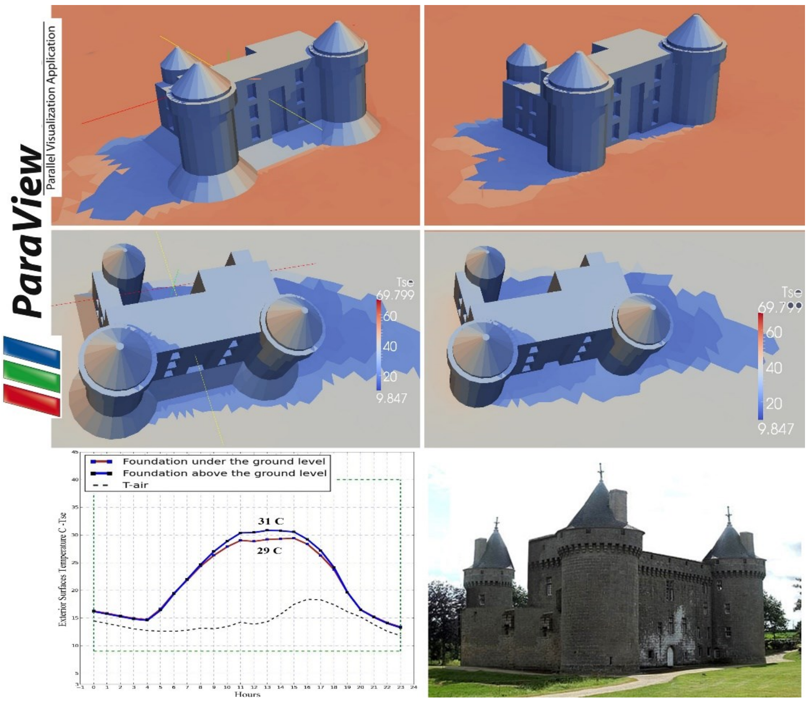


Figure 3. 14: Compersion between building with foundation under the ground level and building with foundation above ground level
Source: The researcher

3.4.1.2. External building envelope - Superstructure

Building envelope is considered as the physical separator between the inside and outside part of the building. It usually consists of: column and external walls, roof and fenestrations and doors.

a. Column and external walls

Definition

Ramamurthy (2011) defined the **column** as a vertical element of a structure whose purpose is to transmit the weight of the structure through compression (Ramamurthy, Narasimhan, and Divya 2011). The column is the part that can be both decorative elements and structural components. Decorative columns are common of clocks and cabinetry and other ornate pieces (see Figure 3.15) (Conover, 1996).

Structural element

www.archiexpo.com/prod/planas/product-105237-1026645.html

Structural and decorative element

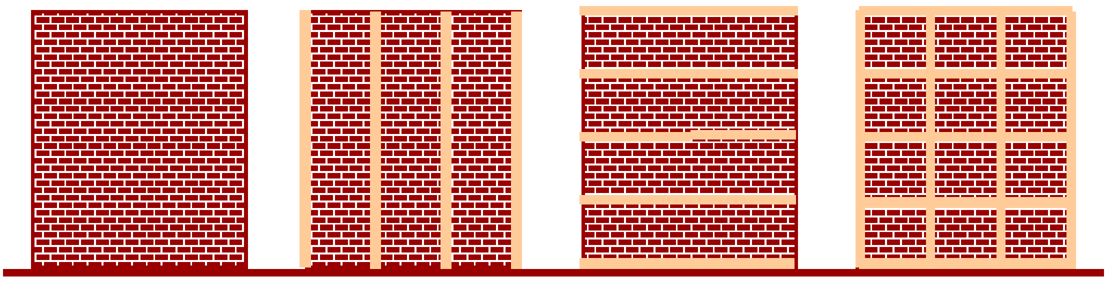
www.minervarelais.com/en/gallery

Decorative element

interldecor.blogspot.fr/2014/07/decorative-columns-modern-interior.html

Figure 3. 15: Types of column Structural element, Structural and decorative element, decorative element

The relation between the external walls and the columns is different whereas in some cases the columns are totally enclosed by the walls, but in other cases the columns or all the building frame (columns and floor) expressed through the external walls, see Figure 3.16 (Usyd Faculties, 2017).



Wall encloses frame completely | Columns expressed through wall | Floor expresses through wall | Frame exposed through wall

Figure 3. 16: The relation between columns, floor, and frame and external wall

Source: (Usyd Faculties, 2017)

Definitely, these elements (columns and floor expressed through the external walls) can help achieve environmental gains through creating a shadow on the walls. How much heat gains, this is what will be conclude in the case study analysis phase.

The walls are considered as the most important components of the building envelope, they provide privacy, protection from hazards and weather condition. Therefore, their construction ought to control the way of heat, infiltrating air, sound, moisture, and water vapor. In addition, they must be able to resist horizontal wind loading. Emmitt S. and Gorse C. (2014), defined the wall as "a continuous, vertical structure, which is thin relative to its length and height" (Emmitt and Gorse, 2014). But it may be tilted.

The types of walls with respect to building envelope (super structural - above ground) can be opaque wall, curtain walls and window-walls, see Figure 3.17 (Schwartz, 1991). They can be of different forms: square wall, square irregular wall, zigzag wall and serpentine wall (Emmitt and Gorse, 2014). The impact of each wall of these types on the surrounding air varies depending on the wall type, this also is what will be concluded in the case study analysis phase.

Exterior walls can be finished with a wide array of materials and techniques. Sometimes an exterior wall structure provides the decorative finishing, but it must also protect the building from the harsh climatic conditions. Moreover, one of the new techniques is using imprinted or stamped concrete walls. There are many patterns of stamped concrete which depends on the mold that is used ("RECKLI – Design Your Concrete", 2017), (see Figure 3.18).

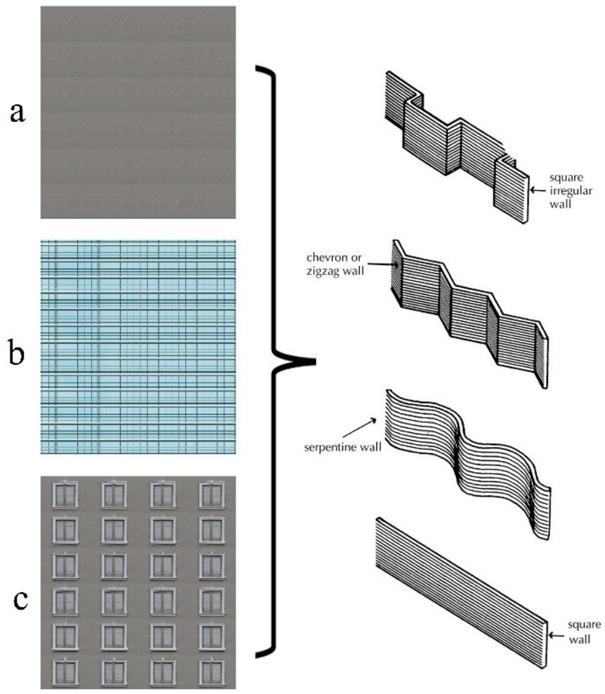


Figure 3. 17: Type of wall design (opaque wall, curtain walls and window-walls)
Source: modification from (Emmitt and Gorse, 2014)

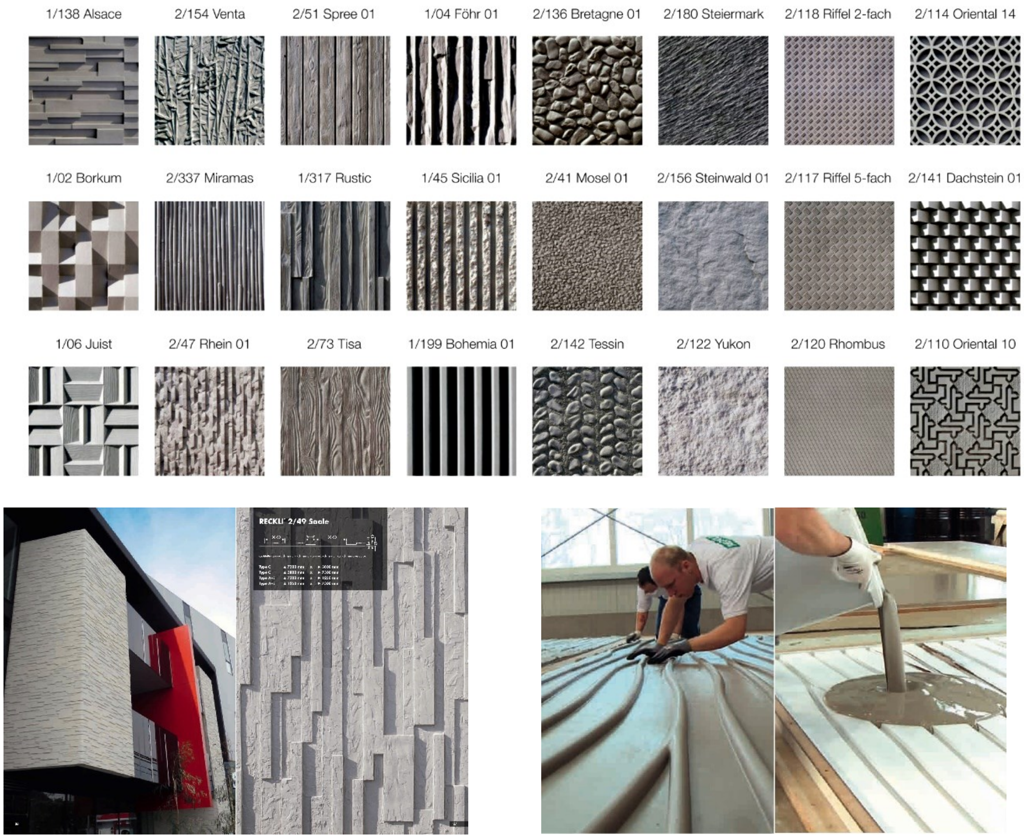


Figure 3. 18: Patterns of stamped concrete walls

Source: ("RECKLI – Design Your Concrete", 2017)

b. Materials types

Many researchers and companies are working to improve or manufacture new types of construction materials with new properties of external wall materials in line with the global climate changes (see Figure 3.19).

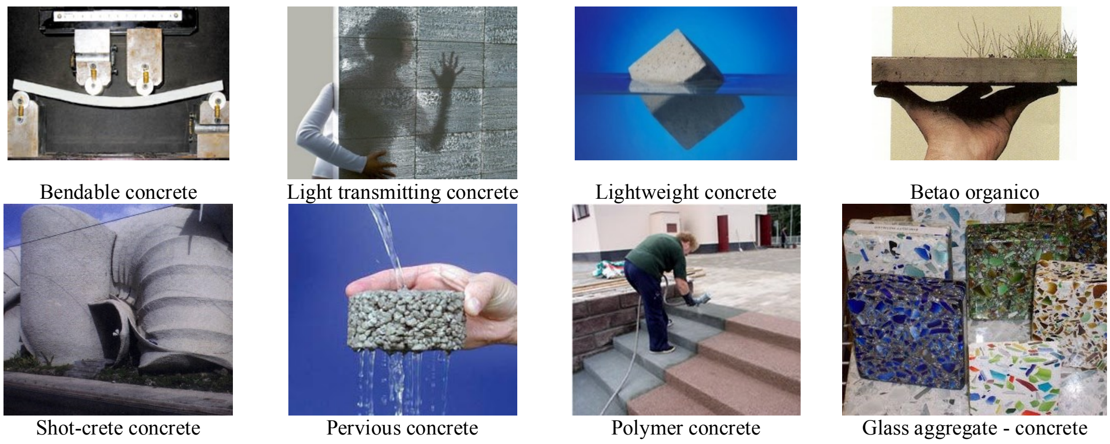


Figure 3. 19: New materials in construction (Concrete)

Source: ("New Materials in Construction (Concrete)", 2012)

Accordingly, the process of selecting the right type of material is an important process. It especially plays a major role in affecting the environmental performance and its strength where the strength of the wall is determined by the strength of a material in carrying the loads from roofs, upper floors and their own weight (Emmitt and Gorse, 2014).

In 1992, U.S. Department of Commerce, Economics and Statistics Administration, Bureau of the Census identified the type of materials used for exterior walls (Census, 1992), which are as follows:

1. Poured concrete (see Figure 3.20);
2. Concrete blocks/bricks (the wall may be covered with plaster cement), (see Figure 3.21);
3. Metal, including Zinc, Tin, Aluminium - Copper - Steel - Terne, etc. (see Figure 3.22);
4. Wood, including woodboards, plywood, etc. (see Figure 3.23);
5. Other (see Figure 3.24)

These types of materials are used for all other types of construction materials that cannot be described by any of the specific categories, for example stone, both natural and artificial (reconstituted) stone, blocks/bricks of clay, glass, or any other materials.

Cast in-situ / cast-in-place   Precast walls

Figure 3. 20: Poured concrete
Source: (Kuće Beodom company, 2016; "Structure | Urban Eden | UNC Charlotte", 2016)

Concrete blocks

Figure 3. 21 : Al hadba residential building
Source: The Iraqi Ministry of Construction & Housing - Nineveh

Metal wall , Tin wall

Figure 3. 22: Metal external wall (Tin wall)
Source: ("Insulated Metal Wall Panels for Exterior Wall Systems", 2017)

Figure 3. 23: Wood wall construction

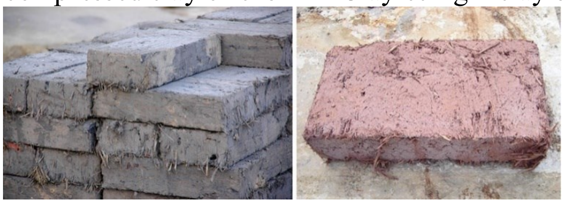
Source: (“Bunk Bed Plans With Dresser, Wood For Exterior Use In India”, 2016)

Adobe blocks

Claytec compressed clay bricks

Claytec light clay bricks

Fired clay block (Poroton Block)



Cob block

Clay plasterboard block

Glass block

Hemp block

Straw block

Figure 3. 24: Other types of construction materials

Source: (“Clay Block”, 2017)

c. Strategies to improve thermal performance of external walls

To improve thermal performance of building walls, several strategies have been proposed by designers and engineers, as follows:

1. Insulation materials:

One of the strategies is to use insulation materials. There are two main types of wall insulation: cavity wall insulation and solid wall insulation. The cavity insulation wall has two layers or more of materials, with an air gap in between. The thickness of the gap can be from 20 to 100mm. This type of wall tend to be much wider than a solid wall. In many cases, some types of insulation materials can fill this gap such as rock wool, foam, etc. In the solid insulation wall, there is no gap between the materials, the wall materials themselves have insulation properties such as lightweight wall materials (see Figure 3.25)

- a - - b -

Figure 3. 25: a.Cavity wall insulation, b.Solid wall insulation
Source : http://sophieandalex.free.fr/histoire_chantier.htm and http://cc-champsaurpaille.blogspot.fr/2011/08/le-mur-de-soubassement.html

Several factors influence the selection of the type of exterior wall, which depends on the availability of materials, environmental factors, economic factors and the design approach (Emmitt and Gorse 2014).

2. Double skin façade system

There is another application of the external walls known as double skin façade system (also called component wall). It is made of an external façade, an intermediate space (soft material or air) and an inner façade. This type of wall responds to changing ambient conditions, including a range of integrated sun-shading, natural ventilation, and thermal insulation devices or strategies (Ventura, 2009), see (Figure 3:26).

Palazzo Italia in Milan, Italy
Source: ("Italy Pavilion at Expo Milan" ,2017)

Hongzhu Housing Sales Centre
Source: (Parafianowicz, 2012)

Figure 3. 26: Double skin façade system

3. Vertical greenery systems (living wall, green façade or vertical gardens)

A vertical greenery system (VGS) is an external wall partially or completely covered with greenery that includes a growing medium, such as soil. Most green walls also integrate a water delivery system see (Figure 3.27). Additionally, after reviewing several studies in this area, Pérez et al. (2014) conclude that "some aspects must be studied in depth, such as which species are the most suitable for each climate, influence one energy savings of the façade orientation, foliage thickness, presence of air layers, and finally, substrate layer composition and thickness in the case of green walls. (Pérez et al., 2014).

Figure 3. 27: Vertical greenery systems
Source: (Pérez et al., 2014)

4. By using high-reflection coatings

The reflective surfaces can provide high solar reflectance and high thermal emittance. One of the main strategies to increase the surface reflectivity is using cool colored coatings such as complex inorganic color pigments rather than conventional pigments (as Figure 3.28). These types of coating are dark in color but have the capacity to reflect intensely the near infrared part of the solar spectrum which has been created by manufacturers in recent years (Ferro, 2017; The Shepherd Color Company, 2017).

They can be used on buildings (roofs and walls) and other surfaces in the urban environment. They can maintain lower surface temperatures than conventionally coatings and finally improve building comfort and reduce cooling energy use (Synnefa et al., 2007).

Figure 3. 28: Complex inorganic color pigments
Source: (The Shepherd Color Company, 2017)

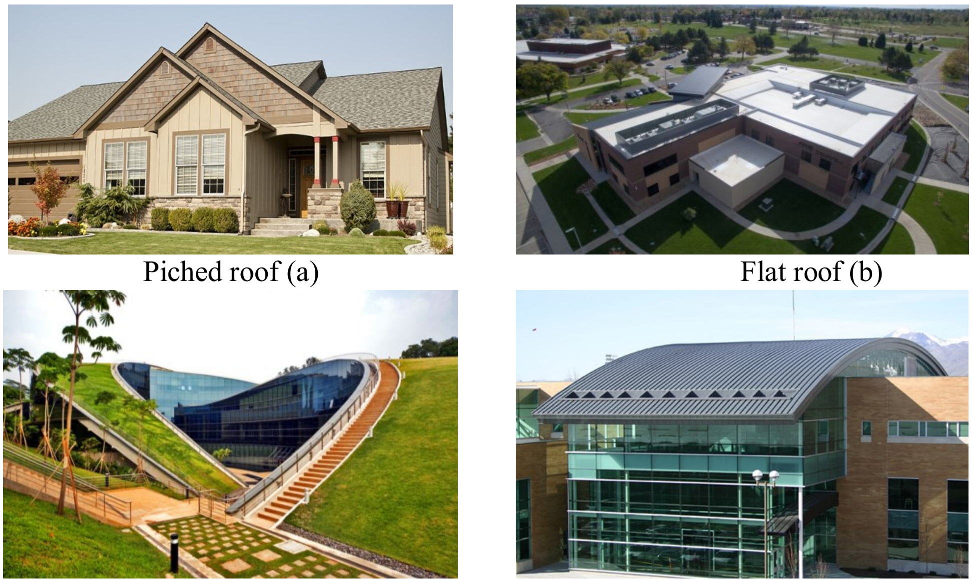
In 2007, Synnefa et al. have compared 10 prototypes near-infrared reflective color pigments (developed at the National and Kapodistrian University of Athens) and conventionally pigmented coatings to measure the solar spectral properties and the thermal performance. This study found that "the coatings containing infrared reflective pigments have solar reflectance values higher than those of standard coatings. Furthermore, it was demonstrated that cool colored coatings maintain lower surface temperatures than color-matched conventionally pigmented coatings", see Figure (3.29) (Synnefa et al., 2007).

Figure 3. 29: The tested samples placed on the modulated horizontal platform
Source : (Synnefa et al., 2007)

3.4.1.3. Roof structure

a. Definition

Roof is the external upper covering part of the interior spaces of a building. The roof can be an essential component which protects the **building** from bad weather conditions such as **rain, snow, sun and wind.** Additionally it controls the moisture vapor, the infiltration of air, and the flow of heat, solar radiation and resist the spread of fire (Ching, 2014; Schwinge, 2009).



Piched roof (a) Flat roof (b)
Green roof (c) curved panel roof (d)

Figure 3. 30: Pich roof (a), flat roof (b), green roof (c), curved panel (d)
Source: ("Roof Contractors | Residential and Commercial", 2017, "Pitched Roofs Types", 2007, "Curved Panel Metal Roof Systems", 2017; Santoso, 2017)

Roofs structures are categorized as being either pitched (see Figure 3.30-a), or flat (see Figure 3.30-b), or curved panel (see Figure 3.30-d). All these types may be covered by vegetation layers, and in this case it is called green roof (see Figure 3.30-c). In any roof, there are two components: roof decking and roof covering. Roof decking is a structural part, which supports the roof covering. It is characterized by diverse forms, flat, dome, truss, portal or shell. The roof covering is the part furnished on the roof deck to protect the building against environmental hazards. Roof covering may be in the form of tiles, thatch, slates, flagstone, and asbestos cement and so on (Emmitt and Gorse, 2014; Punmia et al., 2005).

b. Materials types

Many types of materials can be used as roofing material, as the following: (Department of arts, Heritage and the gaeltacht-Dublin, 2011; Harrison et al., 2000).

- Thatch is roofing made of plant stalks in overlapping layers.
- Shingle is the generic term for a roofing material that is in many overlapping sections, regardless of the nature of the material,
- Ceramic tile.
- Membrane roofing. Membrane roofing is in large sheets, generally fused in some way at the joints to form a continuous surface.
- Metal roofing.
- Concrete or fiber cement, usually reinforced with fibers of some sort.

Roof thatch material (a)

Roof shingle material (b)

Roof metal material (c)

Roof concrete or fibre cement (d)

Roof ceramic tile (e)

Roof membrane material (f)

Figure 3. 31: Different types of roofing materials

Source: ("Home Design", 2013, "Roof Membranes and PVC Roofing Membranes", 2017, "Sheet Metal Roofing – KSS Thailand", 2017, "Shingle Roofing in Phoenix", 2017, "Thatched Roof | Commonwealth Roofing", 2017, "Tile Roofing", 2017)

c. Thermal behavior

This will be discussed later on in this chapter (previous study part)

3.4.1.4. Door and windows

a. Definition

Doorway is the door which provides access from the outside into the interior of a building. It should be large enough to facility movement and have enough resistance under the anticipated frequency of use, as well as security provisions and fire resistance, emergency egress, and safety. The window is an opening made in the walls; made of framework of wood, steel, aluminum, composites etc.; with goal of providing daylight, ventilation, view potential, architecture purpose (Ching, 2014) (see Figure 3.32). The exterior doors, windows ought to give a weathertight seal when closed. Window and door glazing ought to impede the transmission of heat and control sunlight and glare (Ching and Mulville, 2014).

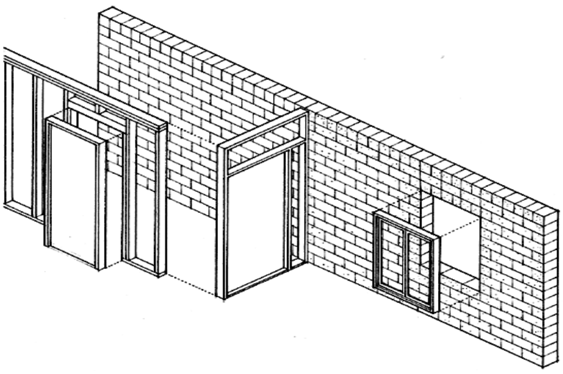


Figure 3. 32: Door and windows
Source: (Ching, 2014)

b. Materials

Different materials have been used in the manufacture of doors or windows. They range from steel, aluminum, wood, fiber glass, and PVC, in addition, it may be a combination of more than one material at one time. For example, “the inside frame can be made of wood, polyurethane foam used for the core, and the outside layer can be made of steel, aluminum or PVC” (“Exterior Doors: Types and Materials”, 2016), see Figure (3.33). For the windows glass or in some types of doors that contain glass, the recommended type is double or triple-glazed insulating glass units (IGU), which typically consists of two/three sheets of glass spaced apart with a hollow aluminum frame that is sealed to both panes then be filled the space between the panes with dry air or with argon gas, see Figure 3.34 (BRANZ Ltd, 2016)

Steel Entry Door | Aluminum Entry Door | Wood Entry Door

PVC Entry Door | Fiberglass Entry Door | Combination type

Figure 3. 33: Different types of door materials

Source: ("Build Solid Wood Exterior Door", 2015; "Door Surround L by APM", 2017; "Entry Door - Sepalumic", 2017; "Exterior Doors Installation in Caledon | Forhomes Ltd.", 2017; "How to Build a Custom Home, Exterior Doors", 2010; "Luxe Interiors Design Magazine", 2017)

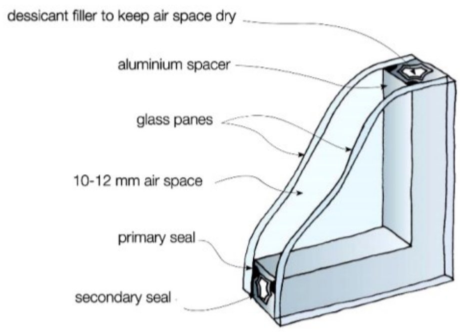


Figure 3. 34: Insulating glass units (IGU)

Source: (BRANZ Ltd, 2016)

c. Door Windows thermal performance

The thermal behavior of door or windows depends on many factors, such as the influence of boundary conditions, empty or filled frame cavities, the components of inner layers, adjustable versus wrap-around frame, the type of the materials, the presence of an insulating material, the color, and the type of glass, and other factors which may vary from one type to another (Wakili, et al. 2008).

With respect to the materials and coating type, these components of building envelope along the lines of the exterior walls and to enhance the thermal performance, highly reflective coating materials (low emissivity) or mirrored appearance is desired to use.

Regarding the glass type, generally the heat (solar energy) absorbed by glass is either moved away by air or re-radiated by the glass surface depending on the emissivity value. Reducing the emissivity of glass surfaces is one of the ways of improving the insulating properties. According to Kaklauskas et al. (2006), in any attempt to enhance the thermal behavior of any existing building is usually done in the following order: first, windows replaced and, then, walls are insulated. They have studied the effect of low-e windows[5] on heat losses of a building compared to the old type of windows. This study has found that most heat lost of buildings is caused by poorly insulated low-quality windows and their replacement by low-e windows can cut heating expenses up to 30% (Kaklauskas et al., 2006), see Figure (3.35).

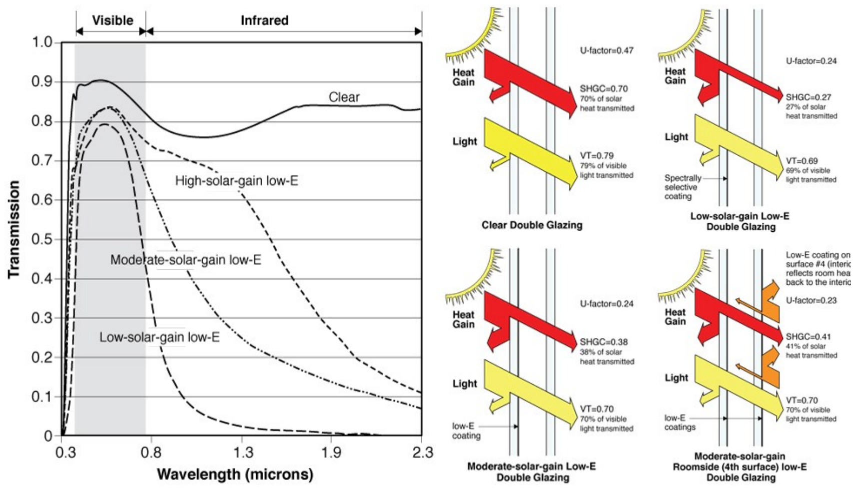


Figure 3. 35: Window with and without low-e glass coatings

Source: http://www.efficientwindows.org/lowe.php

It is worth mentioning that to achieve the good performance of doors and windows, they must be a hermetically sealed frame. Otherwise the heat flow from the outside pass inside the building (and inversely), and it needs more energy to sustain good level of thermal comfort (Kaklauskas et al., 2006).

3.4.2. Urban typology: urban open spaces

The dictionary of planning defines the public places as "a social space that is generally open and accessible to people. Roads (including the pavement), public squares, parks and beaches are typically considered public space".

Regarding the urban open space, the researchers did not lose sight of the development of materials that are used in urban open spaces (roads, pavements, green areas, etc.), where they give a great attention to develop many types of cool materials to be used in the city e.g. cool asphalt and cool.

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[5] Low-e windows or low emissivity windows refers to a glass condition that reflect much more sunlight than simple glass windows Source: https://en.wikipedia.org/wiki/Low_emissivity

3.4.2.1. Roads

In their study, Du Yinfei et al. proposes a specific design for roads to reduce asphalt pavement temperature and decrease air temperature at night in summer. This design consists of low thermal conductivity layer and three-layered gradient heat conduction structure. The structure of each layer was made by adding different dosages of low thermal conductivity powders. The results show that "the average temperatures of middle and bottom layers is reduced by 1.6◦C (at 2:30 pm) and 1.5◦C (at 6:00 pm) respectively, and finally the structure has a continuous cooling capacity, and is expected to reduce high temperature rutting of asphalt pavement and help to reduce high air temperature at night" (Yinfei et al., 2015).

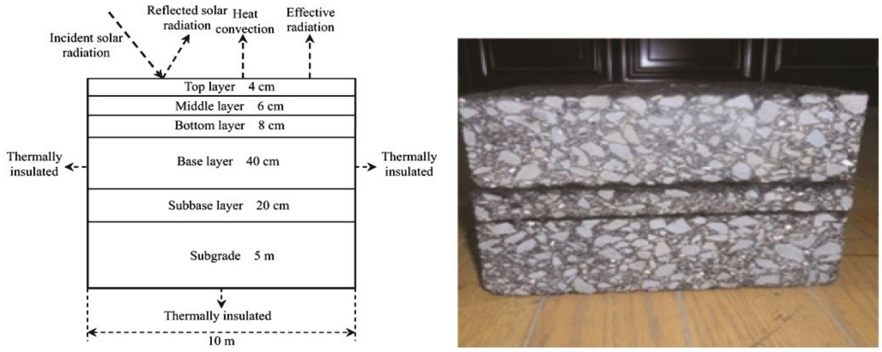


Figure 3. 36: Asphalt pavement design proposed by Du Yinfei et al.
Source: (Yinfei et al., 2015)

In 2014, A. Dimoudi et al. started from the idea that "paved surfaces contribute to sunlight's heating of the air near the surface depending on their ability to absorb, store and emit radiant energy which has effect on urban microclimate". They conducted a comparative study between the thermal behavior of typical construction materials and cool material in an urban center at Serres (North Greece). CFD simulations results showed that cool materials accompanied by other mitigation techniques in the area leads to reduce of the mean surface temperature of streets and pavement by 6.5◦C. This temperature reduction will have a great influence on the microclimate of the area, the outdoors spaces thermal comfort as well as affect indoor conditions and buildings' cooling loads (Dimoudi et al., 2014).

Figure 3. 37: Typical and cool paved surfaces
Source: (Dimoudi et al., 2014)

Synnefa et al. (2011), in their study "Experimental testing of cool colored thin layer asphalt and estimation of its potential to improve the urban microclimate" analyzed the thermal performance of 5 color thin layer asphalt samples in comparison to the conventional black asphalt. They showed that the colored thin layer asphalt is described by higher values of solar reflectance, therefore, their surface temperatures are lower compared to conventional asphalt. The maximum temperature difference recorded was for the off-white sample and was equal to 12°C. Finally, this study has proved that the use of this strategy can lead to decrease the external surface and air temperatures (Synnefa et al., 2011).

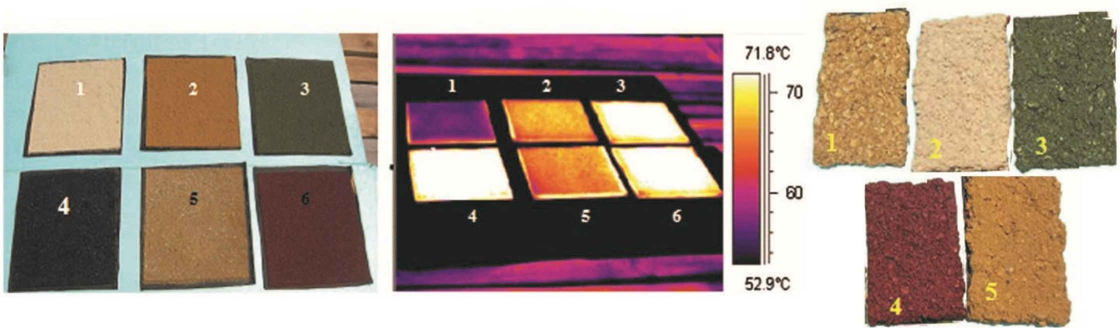


Figure 3. 38: Cool colored thin layer asphalt
Source: (Synnefa et al., 2011)

Zoras et al. (2014), in their study "Evaluation of the application of cool materials in urban spaces: A case study in the center of Florina" have focused on the replacement of conventional materials with cool materials in routes linking traditional monuments in the Greek city of Florina, with aim to improve external human thermal comfort conditions during summer time. The study found that the use of cold material gives ability to reduce the mean surface temperature by 3.52°C while the mean maximum air temperature would be reduced by 1.39°C during noon of the warmest day (Zoras et al., 2014).

Kinouchi et al. (2003), in their study dealing with asphalt pavement also confirmed that cool pavement is one of the solutions to overcome UHI. In the region of the study (Japan), several kinds of cool pavements have been developed but have never been widely used in practice because the brighter surface is not acceptable for reasons of driving safety and visibility of white line. In this study, a new type of high albedo and low brightness pavement is developed by using the paint coating technology (Kinouchi et al., 2003).

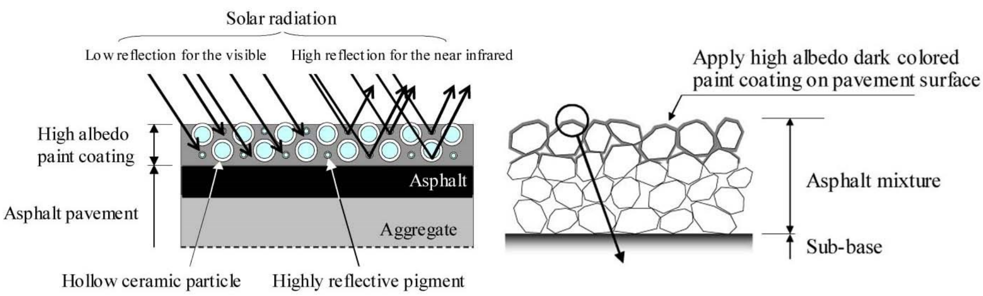


Figure 3. 39: Paint-coated asphalt pavement
Source: (Kinouchi et al., 2003)

3.4.2.2. Pavement and open spaces:

Santamouris et al. conducted largest application of cool pavements (4500 m2) in urban areas in the world, located in an urban park in the greater Athens area. With the aim to improve external human thermal comfort, it reduces the effect of UHI and increases the global environmental quality in the study area. To assess the thermal performance of this cool paving materials some precise and accurate measurements of the climatic conditions have been collected before and after their implementation. In order to study the climatic quality in the park, CFD simulations have been conducted for two different cases. The results show that the use of cool paving materials helps the decrease of the peak ambient temperature during a summer day, by up to (1.9 K). The pavements surface temperature was decreased by (12 K), additionally comfort conditions have been improved considerably. This study concludes that "the use of reflective paving materials is a very efficient mitigation technique to improve thermal conditions in urban areas" (Santamouris et al., 2012).

Starting from the idea put forward by him that “Pavements present a very high fraction of the urban areas and contribute highly to the development of heat island in cities”, Santamouris conducted a state of the art which concentrated on the reflective and permeable/water retention pavements. In general, the results of this study confirm that one of the contributions to decrease the interurban environment temperature is the use of cool pavements which reduce the surface temperature and the sensible heat flux to the atmosphere (Santamouris, 2013).

3.5. Related studies

3.5.1. Studies related to select appropriate construction materials

Thomas (2011) mentions that the development of the construction and building materials industry has been accompanied by an increase in awareness of the importance of developed strategies to help to select appropriate construction materials, especially after getting more awareness of the environmental impacts of materials where it affects the structure, form, aesthetics, cost, method of construction and internal and external environments. Therefore, before selecting any specific materials, some necessary and important considerations are required such as meeting the purpose, cost, mechanical resistance, stability and safety, as well as their impact on the natural environment and impact on health (Thomas, 2006).

3.5.2. Studies related to modifications in the traditional materials

3.5.2.1. Improving the thermal properties of concrete external walls

Wadsö et al. (2012) studied the ability to increase the thermal properties of concrete by using aggregates with high heat capacity and/or materials with high thermal conductivity. This study concludes that both volumetric heat capacity and thermal conductivity can be increased by at least 50% compared to standards concrete (Wadsö et al., 2012).

Jedidi et al. (2014) tried to find the effect of mixing rubber particles with concrete (rubcrete mix) to study the effect of rubber aggregates on the thermo-physical properties of self-consolidating concrete (SCC). The rubber aggregates are obtained by grinding used of-life tires with two particle sizes 0/4 and 4/8 mixed together with different proportions. This study tested four rubber mixed concretes prepared by varying the proportion of the rubber aggregates with percentages of 0 %, 10 %, 20 % and 30 % of the volume of gravel. The results showed that the thermal conductivity and thermal diffusivity were decreased according to the increase of the percentage of rubber aggregates. This decrease significantly improved thermal performance of the (SCCR) (Jedidi et al., 2014).

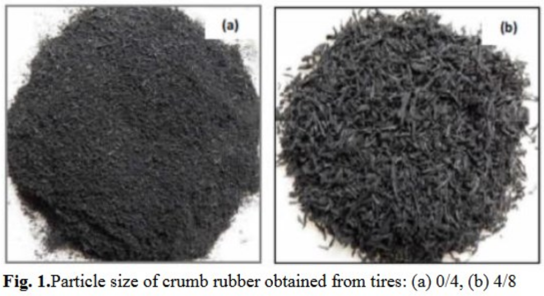


Figure 3. 40: Mixing rubber particles with concrete (a-0/4, b-4/8)
Source: (Jedidi et al., 2014)

Xu and Chung (2000) developed the thermal properties of cement material by adding silane and silica fume for mixture which leads to increase the specific heat up to 50% and the thermal conductivity up to 38% (Xu and Chung, 2000).

Belhadja et al. (2015) have studied the effect of mixing barley straws with concrete on the thermo-physical properties of concrete external wall in arid regions. This study was completed by comparing two mixes: one without barley straws (SC-W-BS) and another with barley straws (SC-BS). The results indicate that adding barley straws significantly improves the thermo physical properties of sand concrete (thermal conductivity, specific heat and density) (Belhadj et al., 2015).

Figure 3. 41: Barley straws with concrete
Source: (Belhadj et al. 2015)

On the other hand, the study conducted by **Nooraini et al. (2010)**, focuses on the thermal insulation properties of foam concrete, which plays an important role in providing great thermal insulation performance. This new type of materials is one of the materials in lightweight concrete category which have lower density between 300 kg/m3 to 1600kg/m3 and thermal conductivity properties between 0.10W/mK to 0.66 W/mK. The study concludes that foam concrete can be used as a great option as building insulation (Nooraini et al., 2010).

Figure 3. 42: Lightweight foam concrete
Source:(Nooraini et al., 2010)

3.5.3. Studies related to vertical greenery systems

Safikhani et al. (2014), tried to examine the thermal performance of living wall and green façade as a main type of vertical greenery systems in hot and humid climates. They found that the living wall and the green facade reduced indoor temperature up to (4.0 °C) and (3.0 °C), respectively (Safikhani et al., 2014).

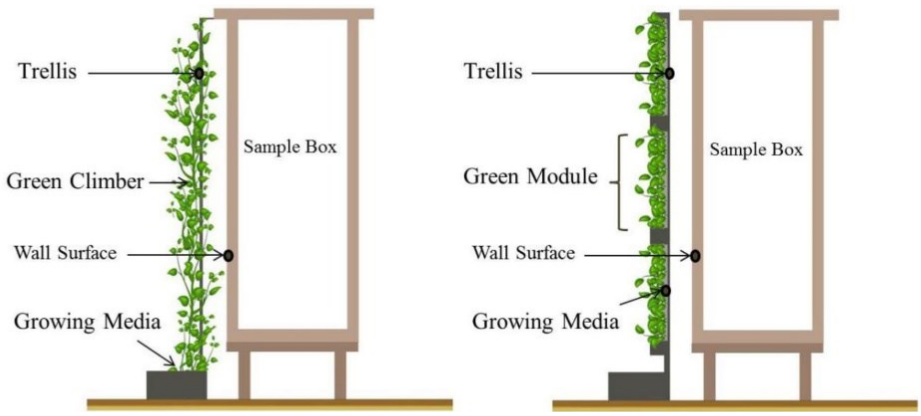


Figure 3. 43: Green façade (left) and living wall (right)
Source: (Safikhani et al., 2014)

Wong et al. (2009), tried to study the effects of vertical greenery systems on the temperature and energy consumption of buildings. They found a linear correlation between shading coefficient and leaf area index (LAI[6]) where a lower shading coefficient leads to a greater thermal insulation in addition to the vertical greenery systems in mitigating the UHI effect. The

[6] Leaf area index is a dimensionless quantity that characterizes plant canopies. It is defined as the one-sided green leaf area per unit of covered surface area.

increase of greenery coverage from vertical greenery systems is significantly felt with a drop in the minimum estate air temperature throughout a large region (Wong et al., 2009).

3.5.4. Studies related to high reflective surfaces

Numerous studies have been carried out regarding high reflective surfaces and how energy is reflected, emitted, and absorbed.

3.5.4.1. Effect of reflective materials on rooftop

Akridge (1998) have stated that the conventional dark and impervious roofs can store much heat compared to high albedo materials and contribute directly to global urban environmental problems such as UHI effect and higher summertime energy consumption rates for cooling (Akridge, 1998). Simpson and McPherson (1997) have mentioned that the increase of the albedo of a building surface may not be always effective in reducing its temperature. For example, the silver roof is more reflective than the grey roof, but their temperatures are similar due to the difference in emissivity (Simpson and McPherson, 1997). Rosenzweig et al. (2006) give an appropriate rooftop albedo value at least equal to 0.8 for all types of building (Rosenzweig et al., 2006). Therefore, thermal emittance or thermal emissivity is another important factor which works together with the surface albedo affecting rooftop temperature and the best-performing construction materials for surface temperature, cooling load, air temperature reduction has both high albedo and high emittance. Generally, almost all the previous studies related to the high-reflectance roof have shown that high-albedo materials can greatly influence the surface temperature through shed heat by re-radiation, regardless of percentage of temperature reduction that is provided by high albedo rooftop (Yang et al., 2015).

3.5.4.2. Effect of reflective materials on Interior air temperature

Bansal et al. (1992) have studied the effect of external surface colour on the thermal behaviour of a building. Investigations were done under different conditions; completely light building, effect of doors' openings and of an overhang on the window for complete shading throughout the day. This study found "the black painted enclosure was a maximum of 7 °C higher temperature than the similar white painted enclosure during hours of maximum solar radiation (daytime), while during the night the two enclosures showed nearly the same temperatures (being the light weight constructions)". This study has shown that there was a significant effect of external building envelope colour on the indoor building room temperature (Bansal et al., 1992). Cheng and Givoni (2005) have added another factor working together with the reflectivity that can affect indoor temperature: the 'thermal mass' of the building envelope. This study was applied on test cells with different specifications, black and white. It reports that there was a difference in the internal temperature of the cells: the air temperature inside the black test cell was about 12°C higher than that of the white cell, as well as the air temperature inside the white cell was 2–3 °C higher than the outdoor one. Finally, it concludes that the use of lighter surface colour and thermal mass can reduce maximum indoor temperatures (Cheng et al., 2005).

3.5.4.3. Effect of reflective materials on outdoor air temperature

The air temperature within the city rises as a result of using artificial surfaces, which can absorb and store great amounts of heat throughout the day. Starting from the idea that "paved surfaces contribute to sunlight's heating of the air near the surface, depending on their ability to absorb, store and emit radiant energy, which has effect on urban microclimate", Dimoudi et al. (2014) conducted a comparison between the thermal behavior of typical construction materials and cool material in an urban center at Greece. CFD simulations results showed that cool materials, accompanied by other mitigation techniques in the area lead to reduce of the mean surface temperature of streets and pavement by 6.5◦C. This temperature reduction will have a big influence on the microclimate of the area, the outdoors thermal comfort as well as affect indoor conditions and buildings' cooling loads (Dimoudi et al., 2014).

In 2011, Guan has examined the surface temperatures of impervious, pervious, and natural ground materials and their association to ambient air temperatures in the urban microclimate. As a case study, it focused to investigate an area on the University of California, Berkeley campus exhibiting open areas of asphalt, concrete, brick pavers, and grass lawns. This study conclude that during warmer summer months, ground materials are exposed to more intense radiation from the sun and absorb more heat (low albedo materials). As solar radiation is absorbed, surface temperatures increases until ambient air temperatures also increase through convection from the materials. However, temperatures remain relatively cooler over natural cover due to evapotranspiration. Generally, air temperature variations above different materials are not as readily apparent during cooler winter months since net differences between the ground and air temperatures are not as large as during the summer (Guan, 2011).

3.5.4.4. Effect of reflective materials on energy consumption

According to the change of buildings' external walls albedo, Yu B. et al. (2008), have analyzed energy savings for two building models under certain meteorological conditions in different seasons by using Laplace integral transform method. The internal and external microclimate parameters were measured. The results show that, when the albedo changed from 0.21 to 0.86, the indoor air temperature reduction was up to 4.7ºC with the average daytime temperature decrease up to 3.5ºC in summer, and the increase was up to 2.8ºC in winter. The results indicate that the wall-facing materials with high albedo have the function of heat-protection and heat-insulation and could help to reduce by 150.3 W per day the buildings' cooling load in summer and 69.5 W per day the heating load in winter (Yu et al., 2008). Yang J et al. (2015) stated that reflective materials that have advantages in energy summer consumption can increase heating loads during winter (Yang et al., 2015).

3.5.4.5. Effect of reflective materials on Building envelope

Song and Park (2015), have conducted a study on a single residential area and commercial complex with high densities of artificial cover materials, before and after the changes related to the development of green areas and increase in reflectivity of coating materials. It is found that the cooling effect has a positive correlation with the peak solar radiation intensity in which the surface temperature decreases as reflectivity increases. However, the results show that the reflectivity increase does not always lead to decrease the temperature of the surface. It mainly depends on the distance between the buildings, where the reflected radiation energy is absorbed by the surrounding buildings and is consequently re-radiated to the surface from the building, increasing its surface temperature, while in the park (without buildings) low surface temperature are observed. Finally, it is concluded that in order to improve the thermal environment of complex urban areas, it is necessary to improve green-area development and to use high-reflectivity ground and building cover materials taking into account the spatial characteristics of land-use types and their surrounding areas (Song and Park, 2015).

3.5.4.6. Effect of reflective materials on pavements and roads

Kinouchi et al. (2003) have put forward a range of views concerning albedo value, "It is not difficult to raise the albedo of the building roof as it can be attained by bright colored painting but for pavements, the brighter surface is not allowable for reasons of driving safety and visibility of white line". Therefore, a new type of pavement satisfying both high albedo and low brightness was developed by introducing the paint coating technology. It is found that the paint-coated asphalt pavement experiences around 15°C lower surface temperature than that of the conventional one at the maximum. Even in the nighttime, the surface of the paint-coated asphalt is cooler for more than 2°C. in Winter. Therefore, this new technology has contributed to reduce pavement temperature and sensible heat flux and thus have contributed to reduce the air temperature near the ground and the longwave radiation emitted from the pavement surface (Kinouchi et al., 2003).

3.6. Summary and conclusion

In the first chapter, we have already discussed a set of issues related to the climate, environments, and urbanization. In the second chapter, we have clarified some of the results of the interaction between these three concepts in one hand and the natural environment and the built environment in other hand. The urban heat island has been highlighted among other environmental problems. This third chapter has focused on the role of construction materials in order to diagnose a range of solutions to avoid or minimize the UHI effect, in addition to its contribution to providing an acceptable level of thermal comfort. From this chapter, we conclude the following:

Any urban project consists of two main components: the building envelope and the urban public space (Roads, public squares, parks, etc.). Each component has specific types of materials. The construction material is the center of building engineering. It decides some of the most outstanding features of the urban area and buildings: make it strong, durable, applicable, economic, beautiful…

In the current era, many construction materials companies compete to create and produce new materials types, develop conventional ones; re-introduce biosourced materials (wood, straw, clay…) with the main motivation to achieve better specifications and meet the needs of the occupants.

The construction materials properties such as thermal conductivity, thermal resistance, emissivity, absorptivity, reflectivity, specific heat capacity, density, etc. either exterior building walls or outdoor urban spaces materials affect the thermal performance and energy needed in relation to indoor and outdoor thermal comfort.

In residential buildings, the envelope is the major element contributing to the embodied energy with 50–60% of the total heat gain in buildings. Therefore, the understanding of the materials properties will help selecting the appropriate construction materials to control heat flows and reduce the exterior surface temperature.

The literature has proposed the low capacity materials to sustain the acceptable level of indoor thermal comfort and also they have proposed three strategies to reduce the exterior surface temperature: double wall, green wall/roof, and high albedo wall/roof.

In this regard and according to the orientation of this work, a series of studies have been made concluding the following:

Regarding Building envelope

Employing high albedo coatings on the building exterior wall is an active and effective approach to improve the urban buildings' micro-heat environment.

Regarding rooftop

High-albedo and high emissivity roof materials (white color material, or another material with another color after change their chemical composition) can play an important role in enhancing the thermal behavior of a roof, indoor/outdoor air temperature, and energy consumption. The appropriate rooftop albedo value is (0.8) for all types of building.

Regarding pavement and road

Most of the studies have explained the advantages of using high-albedo pavement and road, but still there are some visual problems. Therefore, many other studies have proposed some alternative ideas to reduce the brightness of high reflective pavement with sustain high level of reflectance. They have also shown that the pavements can help improving the urban thermal environment through their effect of the air temperature near ground surfaces. But at the same time, the studies have not proposed optimum albedo values for pavements and roads, they have only suggested some strategies to reduce the surface brightness with sustain high level of reflectance.

Part 2

Case study and Research methodology

Summary

Chapter 4

RESEARCH CASE STUDY

Summary

1. Case study - Selection and location.
2. Construction materials of AL HADBA residential complex.
3. Alternative construction materials that can be used in the project.
4. Geographic and climatic condition of studied area.
5. Selecting the most appropriate building for data collection.
6. Internal thermal loads of the case study.
7. Summary and conclusion

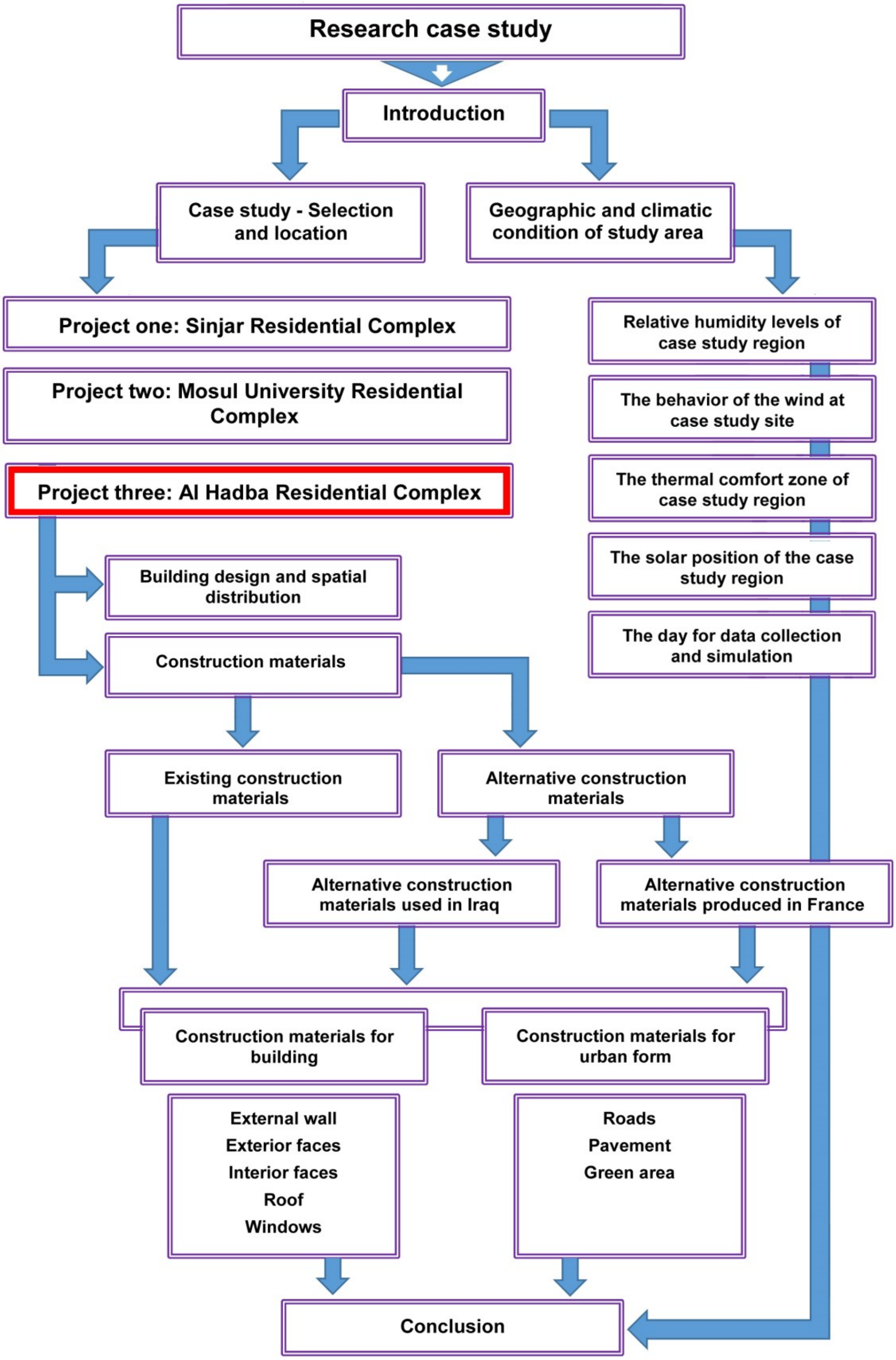


Figure 4. 1: Flow chart of chapter Four

Chapter 4: Research case study

4.1. Introduction

This chapter explains the background of the investigated area which is closely related to the analysis and the simulation, such as the case study selection, the geographical location, the prevailing climate, the building materials which are used etc.

The main residential complexes in Mosul city-Iraq will be the case study of the present research. As a matter of fact, this type of residential real estate is considered as a large version of the residence. It includes a detached house, semi-detached house, rowhouse unit, multi-unit residential condominium or apartment complex, together with any common areas and land that are reasonably necessary for the use and enjoyment of the residential unit. It is one of the basic building blocks for cities (Beam et al., 2007). In many cases, this complex is a cluster characterized by a series of functions (residences, bank services, retail shops, cinema, school, swimming pool, health center, sports court, etc.), but the main significant parts of the residential complex are the residential buildings which consist of many apartments.

An apartment (U.S. and Canadian English) or a flat (British English) is a self-contained housing unit that occupies only part of a building on a single level without stairs. Such a building may be differently called an apartment building, apartment complex, flat complex, block of flats, tower block, high-rise or, occasionally mansion block (British English), especially if it consists of many apartments for rent.

4.2. Case study - Selection and location

The present study comes in light of the rapidly growing need for housing and the need to develop construction techniques in Iraq as a logical result of urbanization (discussed in previous part). Moreover, this study mainly deals with the housing sector, which constitutes the largest proportion of city's buildings. In order to apply this study, the Ministry of Housing in Iraq – Ninevah branch proposed three residential complex projects suitable for the present study which are:

1. Sinjar Residential Complex	**-**	**Proposal**	**(Figure 4.2)**
2. Mosul University Residential Complex	**-**	**Project under construction**	**(Figure 4.3)**
3. Al Hadba Residential Complex	**-**	**Completed project**	**(Figure 4.4)**

Depending on the orientation of this study, Al-Hadba Residential Complex has been adopted as the case study of this research, due to the following reasons:

1. This project has been completed and inhabited by occupants. Thus, all components have been completed: construction materials, distance between the buildings, hard spaces and green spaces, finishing, etc.

2. This project represents a typical residential buildings related to the design characteristics in the country, while Mosul University Residential Complex has been designed with high-quality characteristics, taking into account some issues related to the insulation and energy consumption because it will be inhabited by the professors and lecturers of the University of Mosul.

3. Al-Hadba Residential Complex is located in the investigated area, while Sinjar Residential Complex is located in Sinjar city not in Mosul city itself.

4. Al-Hadba Residential Complex represents one of the future models that will be adopted and contracted in many cities in Iraq.

Figure 4. 2: Sinjar Residential Complex

Source: The Ministry of Housing in Iraq - Ninevah branch

Figure 4. 3: Mosul University Residential Complex

Source: University of Mosul

Figure 4. 4: Al-Hadba Residential Complex
Source: The Ministry of Housing in Iraq - Ninevah branch

4.2.1. AL-HADBA Residential Complex project

Al-HADBA complex is the largest residential complex in Mosul city. It has cost more than 57 billion dinars (43.5 million euros). The complex includes 56 residential buildings (each building consists of 3 floors, and each floor has 3 apartments (see Figure 4.6) and a group of services buildings e.g. primary school and two secondary schools for boys and girls, shopping center, religious center, and a health center. In addition, this project has been provided with a set of internal roads, squares, gardens and (11) parking spaces.

4.2.2. Building design and spatial distribution

This project consists mainly of multiple repeated units; each unit consists of three buildings linked to each other by a staircase core and corridors. What is more, these multiple repeated units are linked together according to certain spatial relations, depending on the point of view of the architects, with a total of 56 groups of residential buildings (see Figure 4.5). The percentages of the total area covered by building's area, landscape, hardscape, and roads, are 17.65 % (25176 m2), 27.81 % (39671 m2), 50.94 % (72661 m2), 3.6 % (5134 m2), respectively (table 4.1).

Figure 4. 5: Spatial distribution of the buildings groups
Source: The Ministry of Housing in Iraq - Ninevah branch

Figure 4. 6: Housing unit details (top view, elevation, and section) of Al-HADBA complex
Source: The Ministry of Housing in Iraq - Ninevah branch

Urban components	Area	The percentage of total area
Coverage area	25176 m^2	17.65 %
Green area	39671 m^2	27.81 %
Hard scape	72661 m^2	50.94 %
Roads	5134 m^2	3.6 %
Total area	142642 m2	

Table 4. 1: Area of the urban components- AL-HADBA project

The total number of apartments is 504. The two types of buildings consist of 3 floors with a single apartment per floor, containing either two (building type one) or three bedrooms (building type two) as well as living room, kitchen, toilet, bathroom, store and two balconies, with a total floor area of 122 m2, 136 m2 respectively (see Figure 4.7). The building's windows occupy about 27.5% (110 m2) of the total building's facade (400 m2). These residential units are designed for a family size ranging from (4) to (6) members.

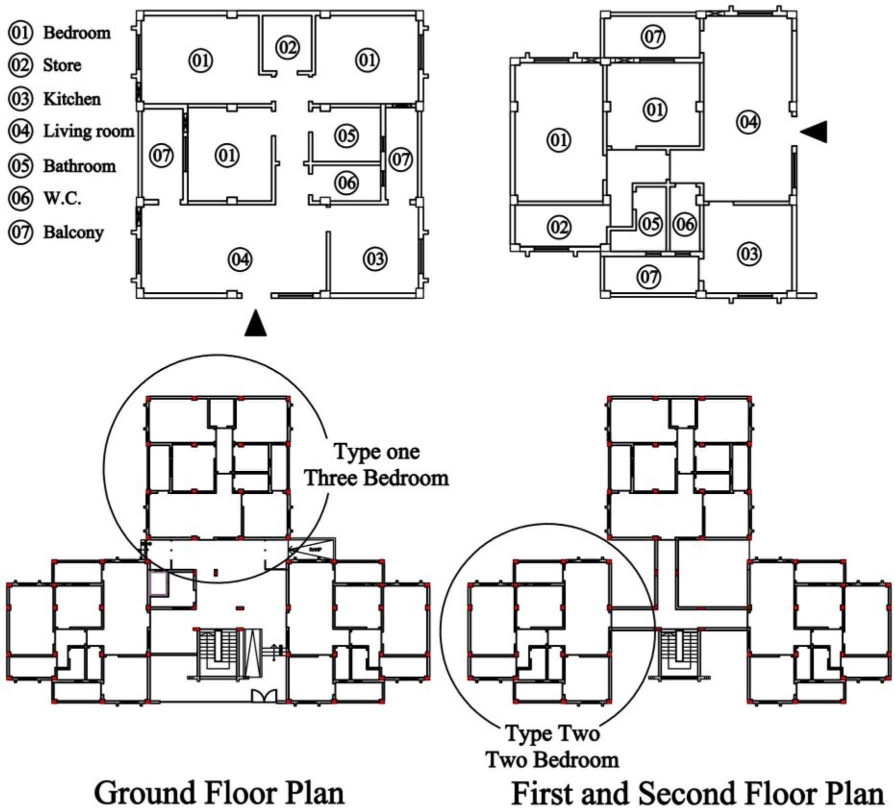


Figure 4. 7: Types of ALHADBA project apartments
Source: The Ministry of Housing in Iraq - Ninevah branch

4.3. Construction materials of AL HADBA residential complex

4.3.1. Construction materials for building

The types of structural materials for each building are basic components as it is shown in table (4.2).

Building components	Materials description	Figures
External wall	Ordinary concrete block - one layer without use of insulators, thickness 20 cm	4.09 4.10
Exterior faces	Concrete plaster and coating with normal types of painting, different colors to identify group of buildings.	4.08
Interior faces	White gypsum material "Gypsum plaster, perlite aggregate" ($CaSo4.H2O$)	
Roof	Paving Tiles on the reinforced concrete slab	4.11
Windows	Plastic windows with single-layer glass	4.12

Table 4. 2: Building materials of AL-HADBA residential complex

Figure 4. 8: AL-HADBA residential complex zones

Source: The Ministry of Housing in Iraq - Ninevah branch

Figure 4. 9: Building materials

Source: The Ministry of Housing in Iraq - Ninevah branch

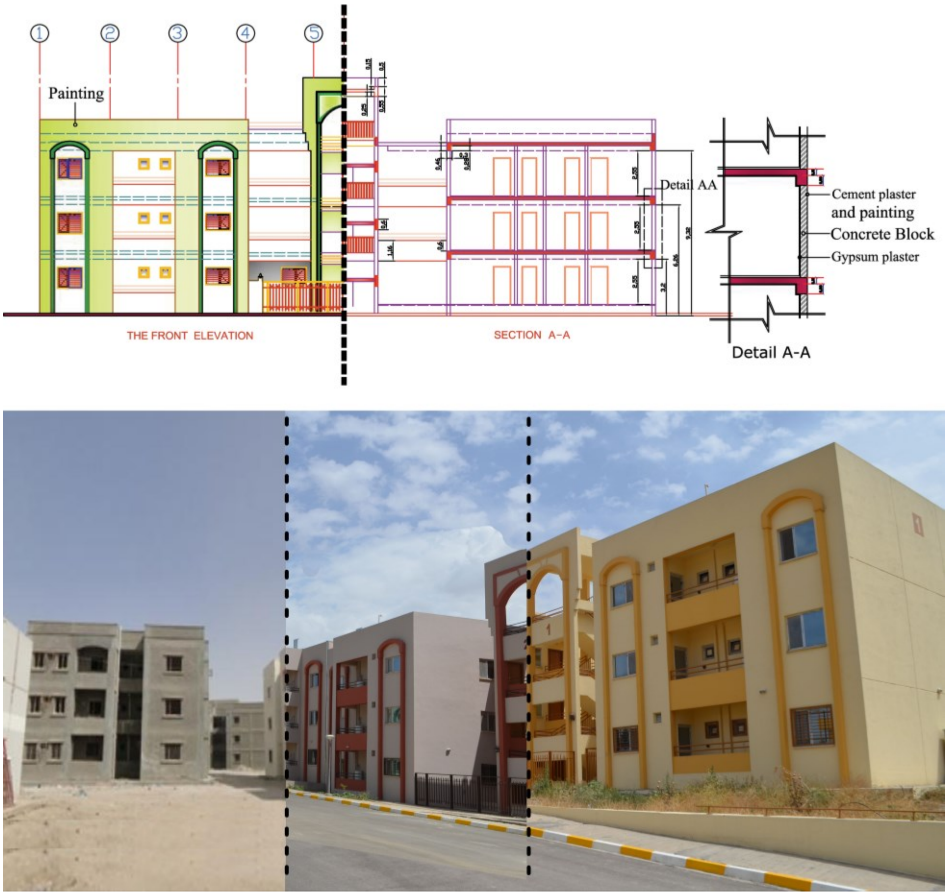


Figure 4. 10: Urban spaces materials
Source: The Ministry of Housing in Iraq - Ninevah branch

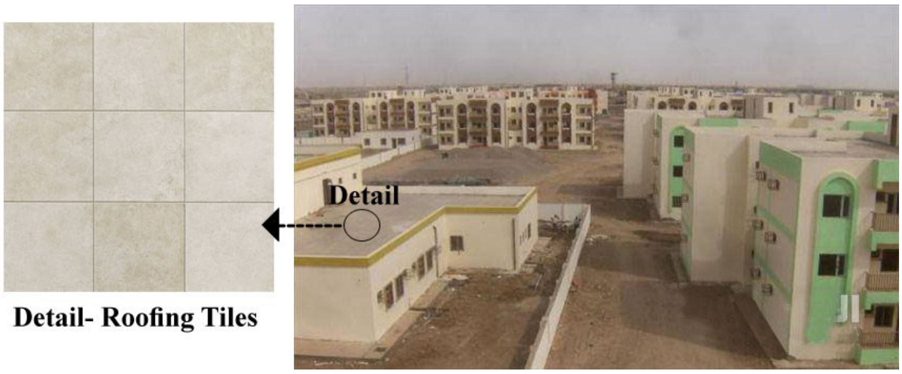


Figure 4. 11: Roof materials
Source: The Ministry of Housing in Iraq - Ninevah branch

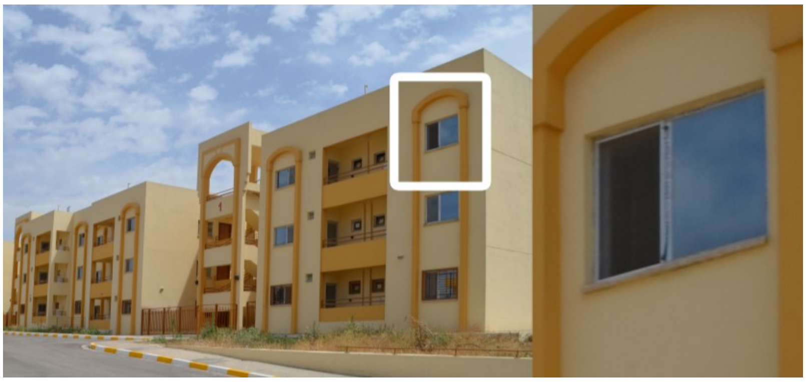


Figure 4. 12: Plastic windows with single-layer glass
Source: The Ministry of Housing in Iraq - Ninevah branch

4.3.2. Construction Materials for urban form

Three main components of urban form are available in AL-HADBA complex which are roads, pavements, and green areas. The materials that are used for each component are shown in Table (4.3).

Urban components	Materials description	Figures
Roads	Conventional asphalt	**Figure 4.13**
Pavement	Concrete pavement	
Green Area	Two layers soil and natural grass	

Table 4. 3: Urban spaces materials of AL-HADBA residential complex

Figure 4. 13: Urban spaces materials of AL-HADBA residential complex
Source: The Ministry of Housing in Iraq - Ninevah branch

4.4. Alternative construction materials that can be used in the project.

The world has witnessed a great development in the construction industry, in both building materials and construction methods, especially the concrete material. It is the only material which is widely used all over the world and one of the richest fields of research study because of the development of its properties. Our research will select modern types of construction materials that are produced and used in Europe in general and in France in particular with respect to the following criteria:

- Possibility of using them in Iraq as far as weather conditions are concerned (green roofs and walls, as well as wood can't be used because of extreme temperatures).
- Strength: for security reasons,
- Cost: the material mustn't be too expensive and difficult to implement.
- Insulation characteristics: The materials should have a low conductivity and enough mass to retain heat.

- Possibility of producing these materials in Iraq: compatibility with the nature of the available raw materials in the country.

According to these criteria and in line with the case study, a search string was developed to find appropriate materials for building external walls, roofs, and roads and urban open spaces, which are manufactured in Europe in general and in France in particular and are suitable for use in Iraq. Groups of manufacturers of construction materials and specialized research centers were contacted for guidelines and technical assistance to choose the types of materials having an effect on indoor/outdoor microclimate and cooling energy use, compatible with the climate condition in the Middle East in general and in Iraq in particular. Finally, eleven types of the vast range of materials have been selected according to standards commensurate with the whole range of criteria as previously mentioned (Table 4.4 and Table 4.5). These materials are described are:

4.4.1. Alternative construction materials for the external walls

According to the criteria already discussed, the alternative construction materials suitable for the use of the external walls can be classified into three categories as follows:

Existing construction materials which consist of solid concrete blocks, (Table (4.4)).

Alternative construction materials used in Iraq: reinforcement concrete, hollow clay bricks, sandstone wall, and adobe blocks, as Table (4.6).

Alternative modern construction materials produced in France: light weight concrete block / filled, light weight concrete block / hollow, aerated concrete blocks, concrete/mixed with straw, concrete rubber aggregates, pumice block (aerated concrete), (Table 4.5).

Existing construction materials				
Materials	**Solid dense concrete block**			
Thermal conductivity (λ) W/mK	**Density (ρ) kg/m^3**	**Specific heat capacity (C_P) J/(kg.k)**	**Material Effusivity J/m^{2}Ks$^{0.5}$**	**Reference**
2.24 (1630)	**2300**	**1000**	**2269.8 (1936.24)**	(Hens, 2016)

Table 4. 4: Existing construction materials in AL-HADBA complex

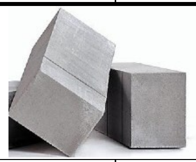
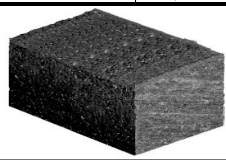
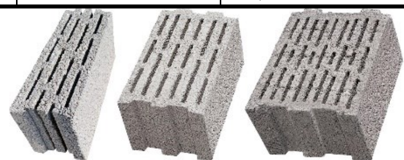
Selected new types of materials produced in France				
Materials 1	**Lightweight concrete block - Filled**			
Thermal conductivity (λ) W/mK	**Density (ρ) kg/m^3**	**Specific heat capacity (C_P) J/(kg.k)**	**Material Effusivity $J/m^2Ks^{0.5}$**	**Reference**
0.639	**1666**	**837**	**943.954**	(“IES Virtual Environment”, 2014)
Materials 2	**Lightweight concrete block - Hollow**			
Thermal conductivity (λ) W/mK	**Density (ρ) kg/m^3**	**Specific heat capacity (C_P) J/(kg.k)**	**Material Effusivity $J/m^2Ks^{0.5}$**	**Reference**
0.384	**1041**	**837**	**578.4334**	(“IES Virtual Environment”, 2014)
Materials 3	**Aerated concrete blocks**			
Thermal conductivity (λ) W/mK	**Density (ρ) kg/m^3**	**Specific heat capacity (C_P) J/(kg.k)**	**Material Effusivity $J/m^2Ks^{0.5}$**	**Reference**
0.43	**1350**	**840**	**698.298**	(Clarke et al.,1990)
Materials 4	**Concrete/mixed with straw**			
Thermal conductivity (λ) W/mK	**Density (ρ) kg/m^3**	**Specific heat capacity (C_P) J/(kg.k)**	**Material Effusivity $J/m^2Ks^{0.5}$**	**Reference**
1.32	**1895**	**1560**	**1975.395**	(Belhadj et al. 2015)
Materials 5	**Concrete rubber aggregates**			
Thermal conductivity (λ) W/mK	**Density (ρ) kg/m^3**	**Specific heat capacity (C_P) J/(kg.k)**	**Material Effusivity $J/m^2Ks^{0.5}$**	**Reference**
0.76	**1702**	**1380**	**1336.060478**	(Jedidia et al., 2014)
Materials 6	**Pumice block Clement Calica products**			
Thermal conductivity (λ) W/mK	**Density (ρ) kg/m^3**	**Specific heat capacity (C_P) J/(kg.k)**	**Material Effusivity $J/m^2Ks^{0.5}$**	**Reference**
0.15	**500**	**840**	**250.99**	(Pfundstein et al. 2008; Clarke, Yaneske, and Pinney 1990)

Table 4. 5 : Materials selected types, and their thermal-physical properties

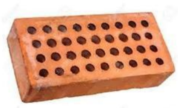
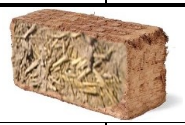
Typical type of materials used in Iraq				
Materials 1	**Reinforcement concrete**			
Thermal conductivity (λ) W/mK	**Density (ρ) kg/m^3**	**Specific heat capacity (C_P) J/(kg.k)**	**Material Effusivity $J/m^2Ks^{0.5}$**	**Reference**
2.5	**2400**	**1000**	**2449.5**	(EN12524, 2000)
Materials 2	**Hollow clay bricks**			
Thermal conductivity (λ) W/mK	**Density (ρ) kg/m^3**	**Specific heat capacity (C_P) J/(kg.k)**	**Material Effusivity $J/m^2Ks^{0.5}$**	**Reference**
0.82	**1826**	**800**	**1094.5**	(Harris, 2016)
Materials 3	**Sandstone wall**			
Thermal conductivity (λ) W/mK	**Density (ρ) kg/m^3**	**Specific heat capacity (C_P) J/(kg.k)**	**Material Effusivity $J/m^2Ks^{0.5}$**	**Reference**
1.830	**2200**	**712**	**1693.077**	(“IES Virtual Environment”, 2014)
Materials 4	**Adobe bricks**			
Thermal conductivity (λ) W/mK	**Density (ρ) kg/m^3**	**Specific heat capacity (C_P) J/(kg.k)**	**Material Effusivity $J/m^2Ks^{0.5}$**	**Reference**
1.1	**1800**	**880**	**1320**	(Style and Grove, 2014)

Table 4. 6: Type of material s in Iraq

4.4.2. Alternative construction materials and design for the roof

Most studies and scientific works have stated that the best thermal performance of the roofs are achieved through the use of high-reflectivity materials; with an albedo value higher than 0.8. Additionally, the previous studies have indicated these levels of reflectivity are not necessarily obtained by white color but modern techniques have proposed the use of cool colored coatings (e.g. complex inorganic color pigments). These types of coating are dark in color, but have the capacity to reflect intensely the near-infrared part of the solar spectrum and thus maintain lower surface temperatures.

The most popular roof type in Iraq is the flat one. In most buildings, this component of building envelope is cast in-situ concrete slabs with concrete tiles on the top. In Iraq, two design are available for roof either it contains an insulating material between its layers or not. Many types of roof insulation materials are used such clay block, thermo stone, expanded polystyrene, etc. (see Figure 4.14).

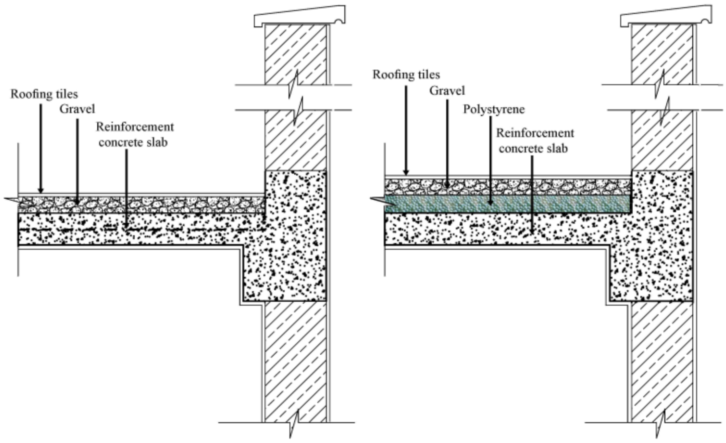


Figure 4. 14: Typical roof design in Iraq
(a- Non insulation roof type, b-Insulation roof type)

4.4.3. Alternative construction materials for open urban spaces

As explained in the first part, previous studies have discussed the advantages of replacing the conventional materials by using new materials types so that to enhance the thermal performance of this part of the urban form

This study will adopt what has been put forward by Synnefa et al. (2011) in their study tagged "Experimental testing of cool colored thin layer asphalt and estimation of its potential to improve the urban microclimate" (Afroditi Synnefa et al. 2011). The main idea proposed by this study is the use of a thin layer of colored asphalt (see Figure 4.15) over new or existing asphalt pavements in good condition in order to increase solar reflectance but maintaining a dark color. This study concluded that the use of colored thin layer asphalt in roads and pavements can have significant impact on lowering surface and air temperatures, mitigating thus the UHI effect and its consequences.

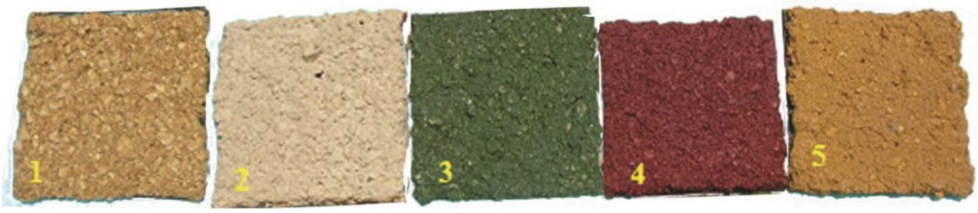


Figure 4. 15: Color thin layer asphalt samples (beige, off-white, green, red, yellow)
Source: (Synnefa et al., 2011)

4.5. Geographic and climatic condition of studied area

With a geographic area of (435,052) square km, Iraq is bordered by six countries: Jordan to the west, Syria to the northwest, Turkey to the north, Iran to the east, and Kuwait and Saudi Arabia and the Arabian Gulf to the south. These borders were almost entirely demarcated in 1920 by the League of Nations when the Ottoman Empire was divided by the Treaty of Sèvres. This geographical situation makes the climate of Iraq characterized by several types of dry and semi-dry climates. The climate types change from a warm desert climate into a warm steppe climate, a cold steppe climate and a moderate continental climate in the mountainous areas in the north. The largest part of Iraq consists of deserts with mild to fairly cool winters and hot and dry summers. During the summer, there are hardly any clouds and the total amount of hours of sunshine per day equals the hours of daylight.

Most of the months of the year is hot (summer season, April till October) while the cool months are not two months. The main source of energy during these hot months to create acceptable level of indoor is electrical energy while in cool months the main source of energy used to heat is oil.

Mosul is the second-largest city in Iraq and was a commercial hub in northern Iraq, with oilfields nearby to the north and east. Geographic coordinates of Mosul is Latitude: (36.335) North and Longitude: (43.11889) East. It is a center of cement, textile and sugar industries, and a marketplace for agricultural products. Ninevah governorate is historically 'the breadbasket of Iraq', producing grain (wheat and barley) and also hosts it contains the second-largest university in Iraq (REACH Resource Centre, 2015).

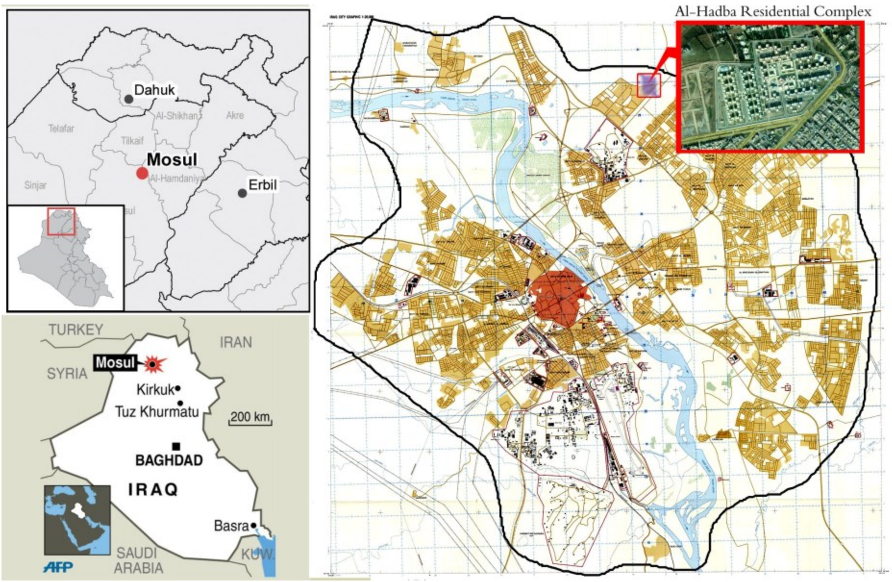


Figure 4. 16: Mosul city geographical location

Source: http://www.globalsecurity.org/military/world/iraq/mosul-maps.htm

Mosul city as any city in Iraq, has a weather characterized by hot semi-arid climate where July is the hottest month when the temperature reaches (35.5°C) (see Figure 4.17 and Figure 4.18). In summer (June, July and August), the climate is dry and extremely hot whereas it is very cold in winter when the temperatures down to below zero.

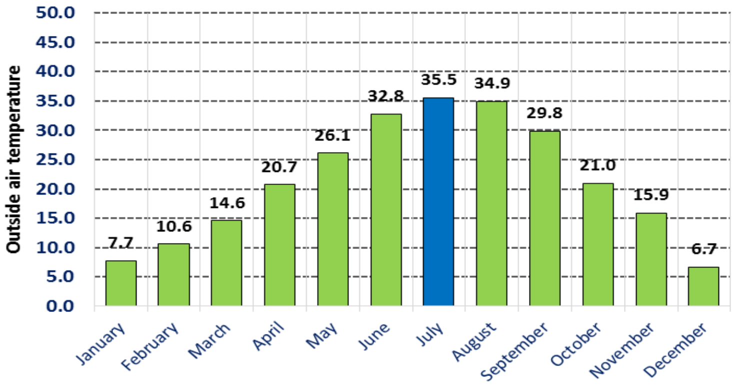


Figure 4. 17: Higher Air temperature for each months – Mosul city

Source: Adapted from Weather Analytics center (http://www.weatheranalytics.com)

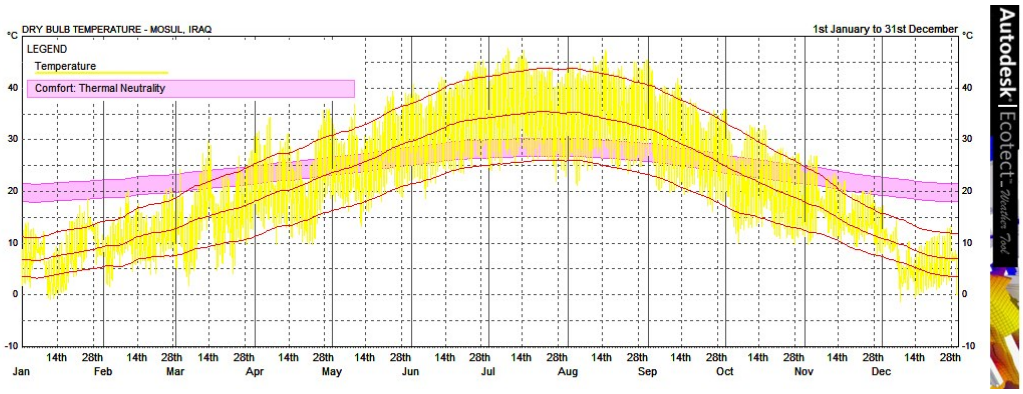


Figure 4. 18: The outside air temperature of Mosul city-Iraq- one year (2013)

Source: Adapted from Weather Analytics center (http://www.weatheranalytics.com)

Relative humidity levels for Mosul

The relative humidity in outdoor environment for Mosul city varies between summer and winter. The weather data gives the lowest average relative humidity value in the summer, which amounted to about 15%, while the highest average value in winter may reach 70%, see Figure (4.19) and Figure (4.20).

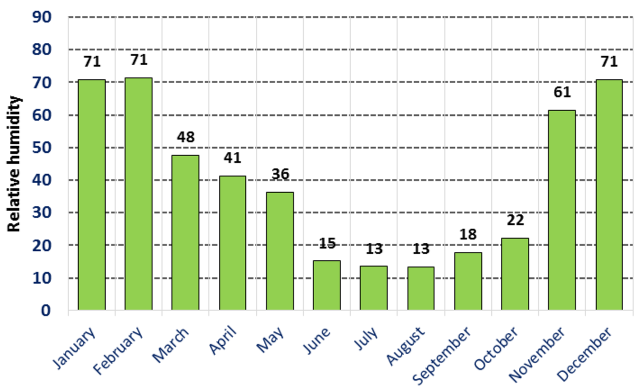


Figure 4. 19: The relative humidity

Source: Adapted from Weather Analytics center (http://www.weatheranalytics.com)

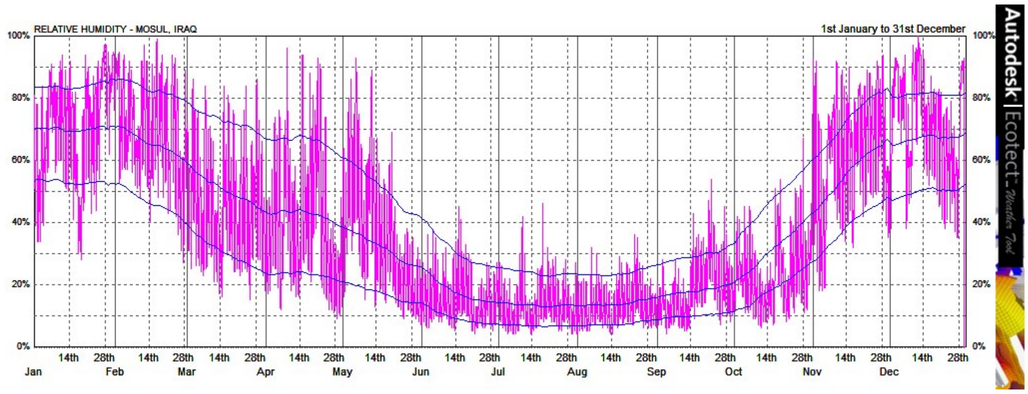


Figure 4. 20: The relative humidity of Mosul city-Iraq- one year (2013)

Source: Adapted from Weather Analytics center (http://www.weatheranalytics.com)

The behavior of the wind

According to the study of Al-Kassab and Al-Ta'ee (2011); "Optimal Location of Solid Waste in the City of Mosul" and Weather Analytics center in Washington, the prevailing winds of Mosul city on the North West in most months of the year, while the average wind speed of the year is 3 m/s (see Table 4.6) (Al-Ta'ee and Al-Kassab, 2011).

Month	Wind Speed	Wind Direction	Month	Wind Speed	Wind Direction
January	3 m/s	155	*July*	3 m/s	271
February	2 m/s	130	*August*	3 m/s	249
March	3 m/s	156	*September*	2 m/s	250
April	2 m/s	148	*October*	2 m/s	185
May	2 m/s	187	*November*	2 m/s	135
June	3 m/s	254	*December*	2 m/s	153

Table 4. 7: The wind speed and direction in Mosul city-Iraq

Source: Adapted from Weather Analytics center (http://www.weatheranalytics.com)

Accordingly, the behavior of the wind among the buildings of the case study (Al-HADBA Complex) is represented in Figure (4.21).

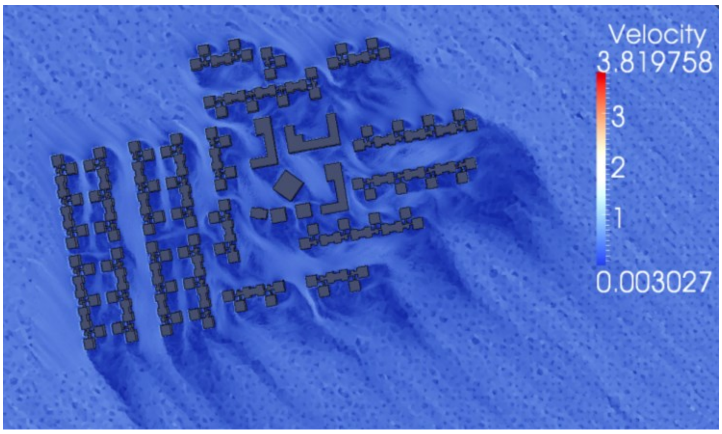


Figure 4. 21: The wind behavior in AL-HADBA residential complex

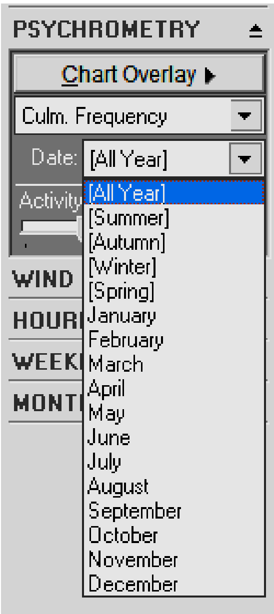
Source: The researcher

The thermal comfort zone of case study region | Mosul city

The weather data of Weather Analytics Center-Washington of Mosul city have been represented on the psychometric chart using Ecotect tool. This chart provides a graphic representation of the state or condition of the air at any particular time. The chart relates temperature along the horizontal scale to moisture content (absolute humidity) along the vertical scale. The color areas indicate "cumulative frequency", where the hourly weather data is overlaid on the chart. The cumulative frequency "displays the frequency of occurrence of different hourly conditions as a coloured block within the chart. The more solid the colour, themore frequently the conditions represented by a block occured over the selected period".

Different situations and comfort zones are available in this chart which depends on the date e.g. yearly psychometric chart, seasonally psychometric chart, and monthly psychometric chart (see Figure 4.22).

Date:



The period in which the results are displayed represents the period over which hourly data values are overlayed on the chart. The seasonal settings depend upon the currently set latitude to determine which hemisphere the location is in.

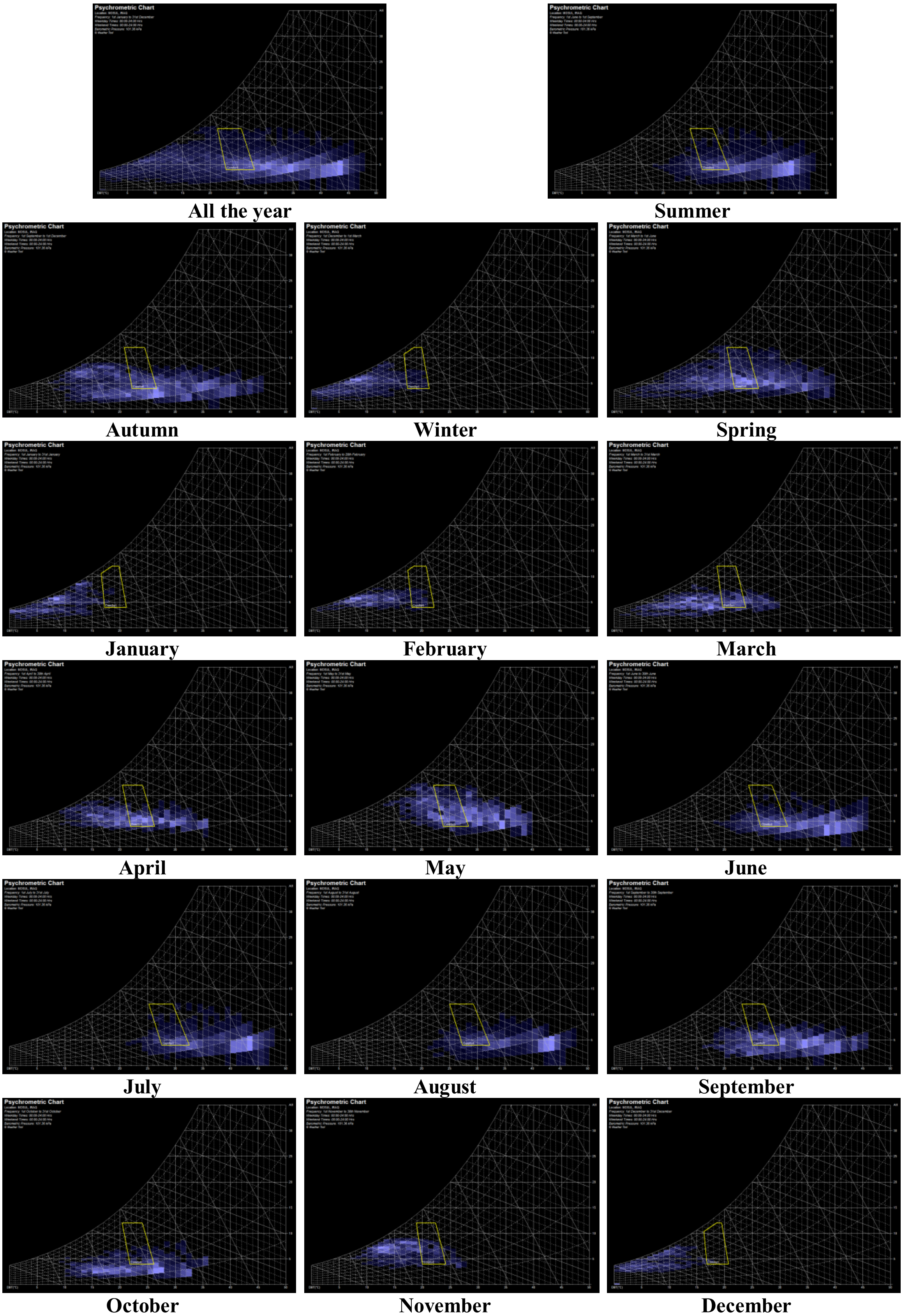


Figure 4. 22: The thermal zone in Mosul city-Iraq | Round the year

Source: Adapted from Weather Analytics center (http://www.weatheranalytics.com) - By using weather tool software- Ecotect analysis

Activity Slider

In this chart, it is also possible to set the activity rate of the people for whom the comfort band is displayed. This will affect both the base comfort zone. As you drag, you should see the comfort overlay interactively update. In terms of activity rates, the following is a guide:

Low activity	:	Anyone seated and relaxed or simply reclining.
Sedentary activity	:	Office workers, houses, schools and laboratories, people undertake only minor physical tasks and only occasionally move around.
Light activity	:	People moving around, washing, dressing, shopping or working in light industry.
Medium activity	:	Tasks such as ironing, brick-laying and other aerobic workouts.
Heavy activity	:	Running, ice skating, shovelling or working with a sledge hammer.

The operative comfort of the case study region | Mosul city

The operative temperature is an index of the thermal comfort. This index vary depending on the region data weather related to air temperature. Regarding our case study region, the adaptive chart during one year is described as Figure (4.23). From this Figure we found that the maximum thermal comfort acceptable is in summer season.

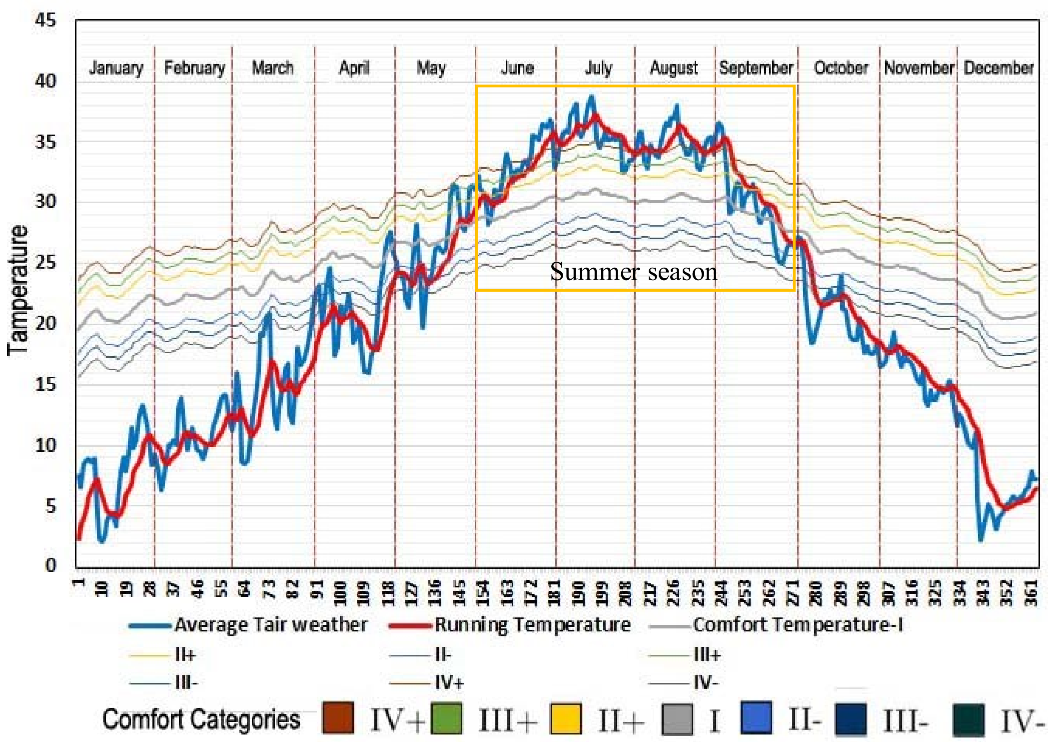


Figure 4. 23: Operative temperature of the case study region | one year

Regarding the target day of the simulation the operative temperature during 13 of July is described as Figure 4.26, in which the comfort categories as a following:

Comfort Temperature-I	II+	II-	III+	III-	IV+	IV-
30.7 ºC	32.7 ºC	28.7 ºC	33.7 ºC	27.7 ºC	34.7 ºC	26.7 ºC

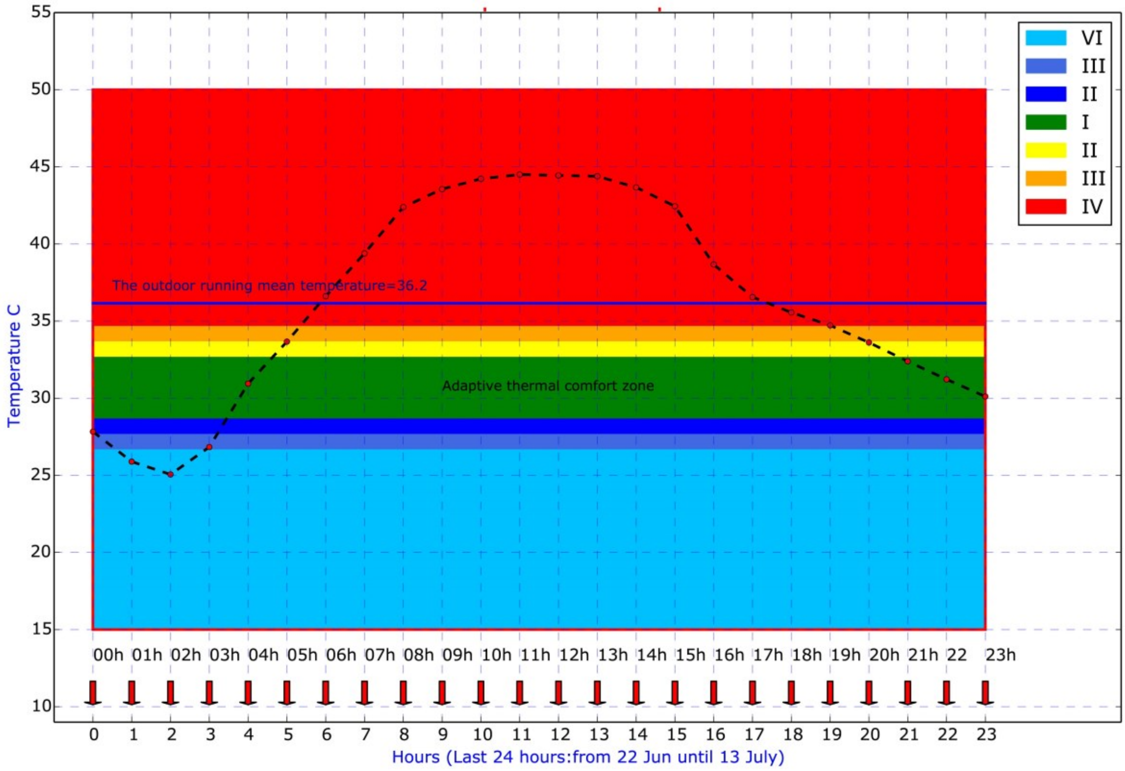


Figure 4. 24: Operative temperature of the case study region | one year

The solar position

The relation between geographic location and solar position throughout the year influences mainly on the Sun-path diagram and shadow projections change. Different ways can be used to identify this relation such as a day length chart, the sun path chart, etc.

Regarding Mosul city and according to the day length chart that is proposed by Andrew J. Marsh (2014), the longest days are in the summer, see Figure (4.25).

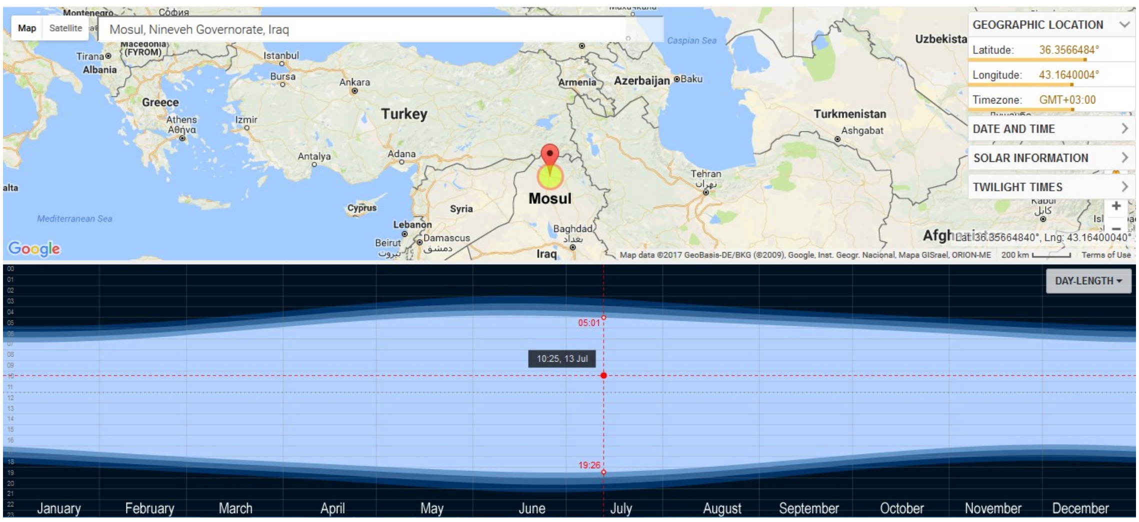


Figure 4. 25: Day length chart of Mosul city-Iraq | Round the year

Source: http://andrewmarsh.com/apps/releases/sunpath3d.html

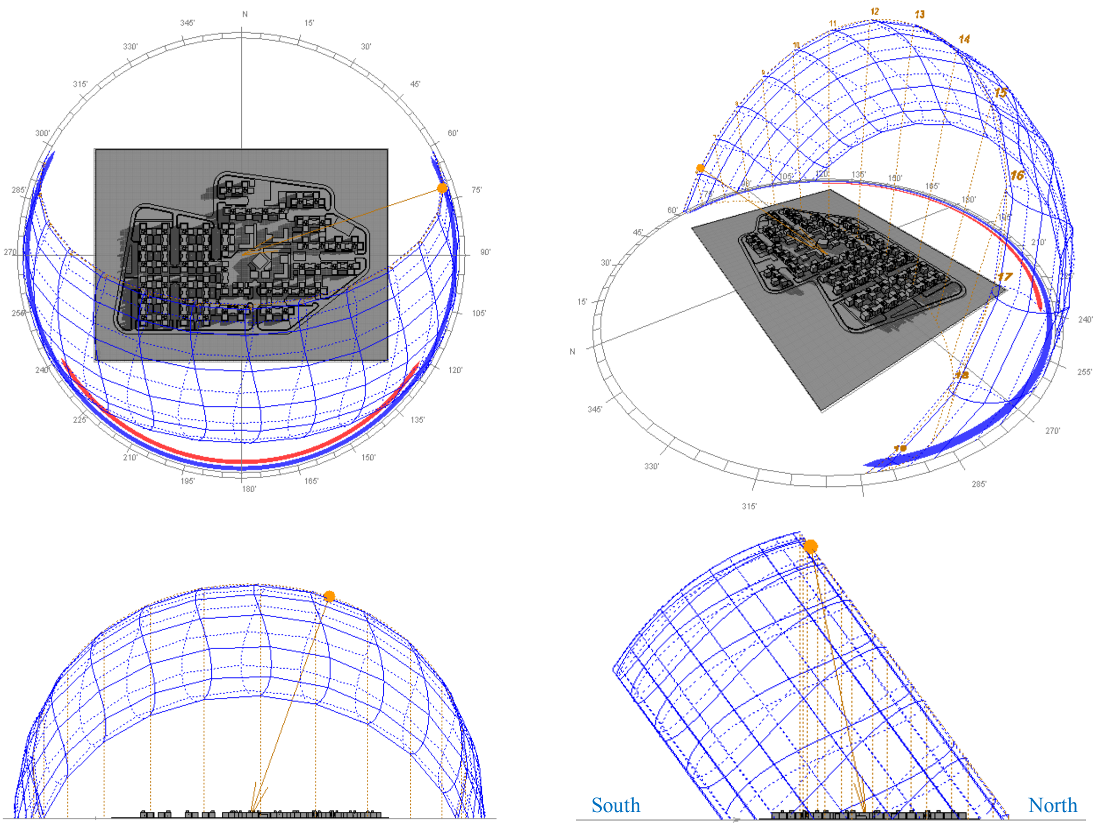


Figure 4. 26: The sun path of Mosul city

Source: Adapted from Weather Analytics center (http://www.weatheranalytics.com)-By using weather tool software- Ecotect analysis

Regarding the sun path of Mosul city, according to the Weather Analytics Center-Washington, the north elevation of the AL-HADBA complex buildings receives minimum amount of direct solar flux, while the other three elevations receive the solar flux through the day. This will certainly be reflected on the external surface temperature of the elevations, see Figure (4.25). The amount of flux received by each elevation of the case study project will be calculated later in result and simulation part of this study.

4.5.1. Selecting the day for data collection and simulation

In this study, the data collection and simulation will be conducted in the hottest months of the year. From the table (4.8) and Figure (4.27), it is obvious that July is the hottest month in Mosul city where the temperature reaches 35.5 C° or sometimes more than that.

Month	Temperature °C	Month	Temperature °C
January	7.7	***July***	**35.5**
February	10.6	*August*	34.8
March	14.6	*September*	29.8
April	20.7	*October*	21
May	26.1	*November*	15.9
June	32.8	*December*	6.7

Table 4. 8: Higher Air temperature for each months-Mosul city

Source: Adapted from Weather Analytics center (http://www.weatheranalytics.com)

Now, what is the day in July which will be dealt with in our simulation?

To guarantee the correct results of simulations, it is important to take at least two weeks before the analysed day. Therefore, our simulation started from 22nd June until 13th July, according to what will be clarified as follows:

We started to search the most frequent highest temperatures over July. Thus, we classified days by maximum temperature intervals as in table 4.9. Finally the most frequent interval is 25°C-30°C.

Which day is under this range?

According to air temperature data as table 4.8, there are 13 days under this range, these are: 1st, 2d, 6th, 7th, 10th, 13th, 14th, 15th, 17th, 20th, 21th, 25th and 26th.

What is the most frequent day suitable for simulation?

In order to achieve this objective, we show the data for all July's days as figure (4.27). Then we make a comparison between a diagram for all July's days and each day that has temperature in range of (28-29 C°) of 2d, 7th, 13th, 14th, 15th, and 17th and 20th, Figure (4.28).

20 C°-24 C°		25 C°-29 C°		30 C°-34 C°		35 C°-40 C°	
Days	**Temp.**	**Days**	**Temp**	**Days**	**Temp**	**Days**	**Temp**
11-July	21	1- July	26.3	3- July	30.7	30- July	35.67
12- July	23.9	2- July	28	4- July	31.3	31- July	35.78
18- July	24.8	6- July	25.8	5- July	31.67		
19- July	23.89	7- July	28.9	8- July	32.78		
22- July	22	10- July	26.4	9- July	34.4		
23- July	22	**13- July**	**29.6**	16- July	31.2		
24- July	21.89	14- July	27.7	28- July	31.9		
		15- July	29.4	29- July	32.78		
		17- July	28.6	27- July	30		
		20- July	28.2				
		21- July	25.78				
		26- July	25.78				
		25- July	25				

Table 4. 9: Classification of highest temperature over July- Mosul city

Source: Adapted from Weather Analytics center (http://www.weatheranalytics.com)

Finally, we notice that the days of 13th and 15th July are the days which represent the better days for simulation but 13th of July has air temperature higher than 15th of July. Therefore, for our Simulation, we took the period from 22th of June until 13th of July and concentrate on 13 of July.

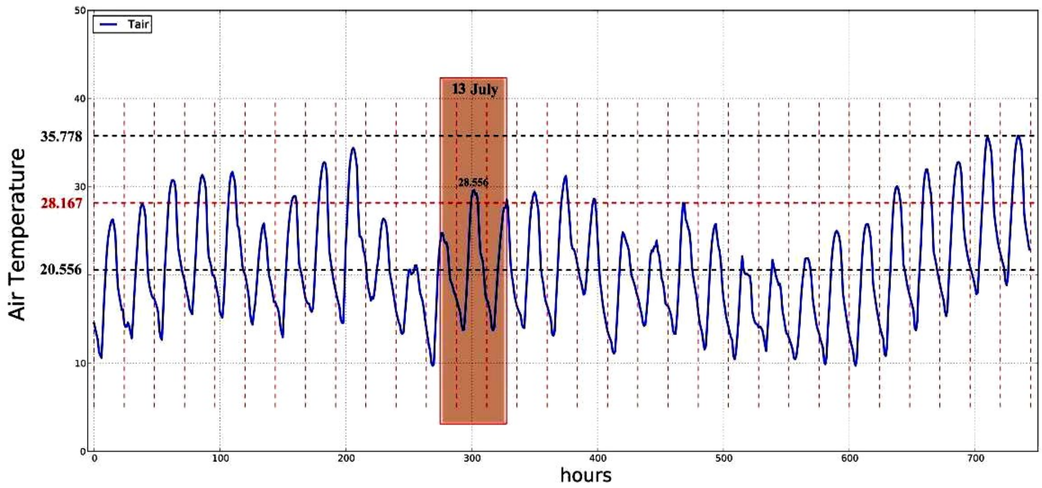


Figure 4. 27: Air temperature plot – 13th of July, -Mosul city
Source: Adapted from Weather Analytics center

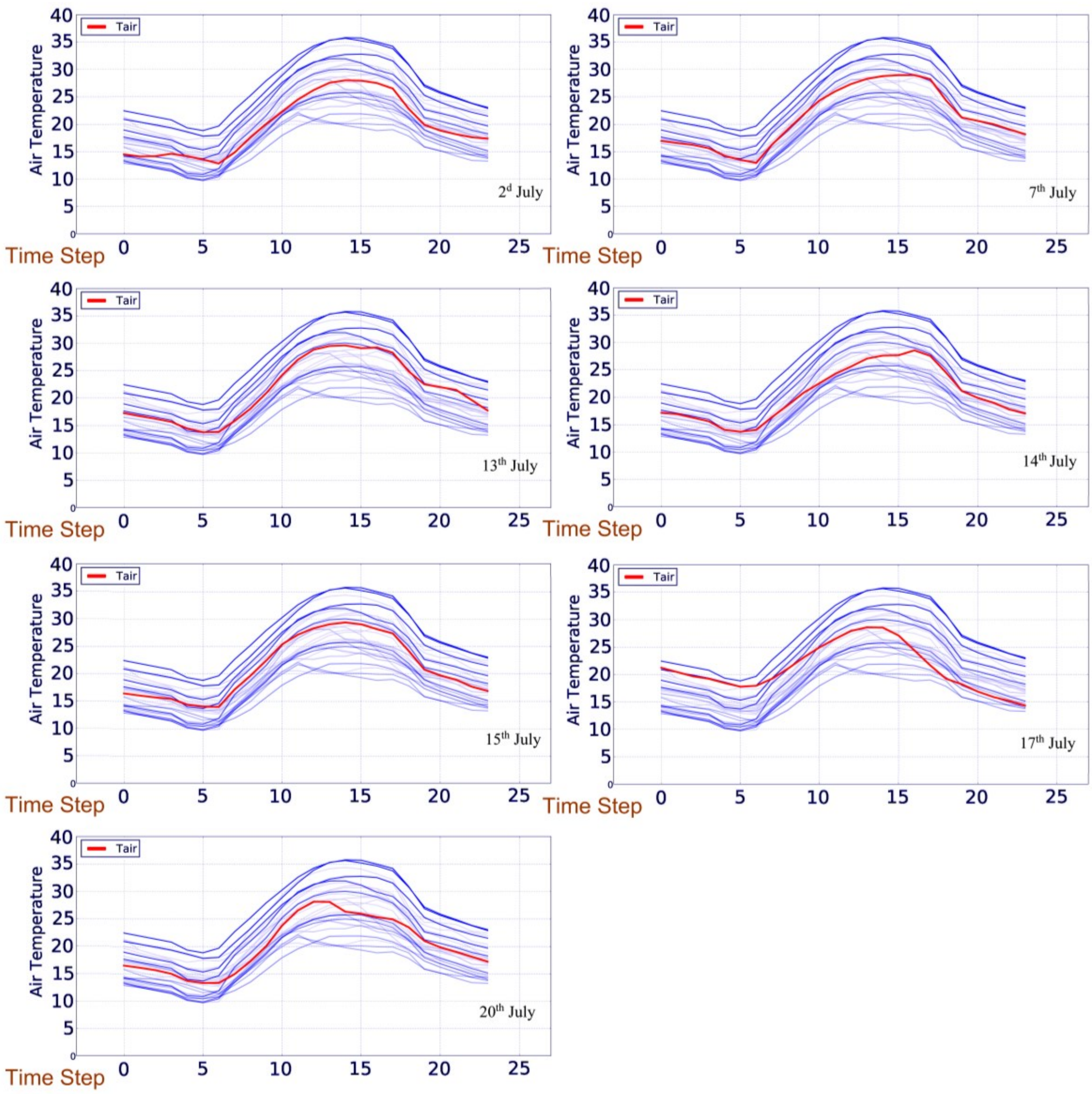


Figure 4. 28: Air temperature plot – 2d, 7th, 13th, 14th, 15th, 17th, 20th, and 27th of July-Mosul city
Source: Adapted from Weather Analytics center

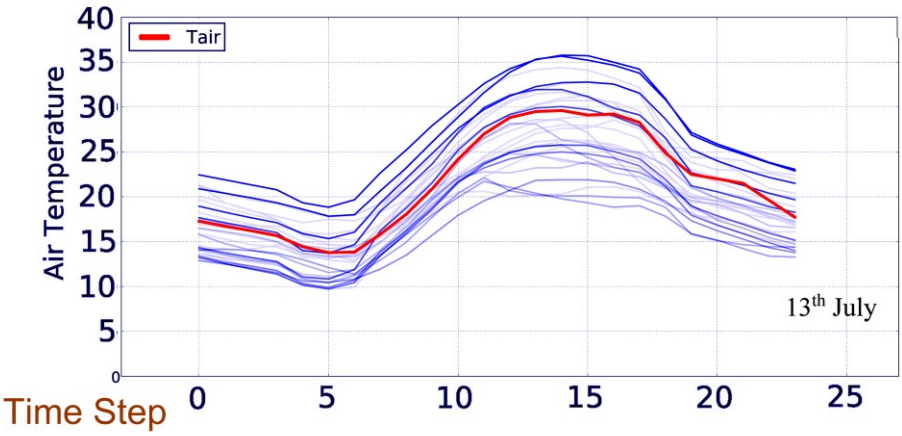


Figure 4. 29: Air temperature plot – 13th of July

Source: Adapted from Weather Analytics center

4.6. Selecting the most appropriate building

For an accurate assessment of the thermal performance of the building envelope materials by using SOLENE-Microclimat simulation, the simulation time can be minimized by focusing on one building within a group of buildings.

Now which group of building is suitable for our study?

When we have a look on the case study, the buildings can basically be categorized as five main groups (see Figure 4.31), with total five buildings types (see Figure 4.30).

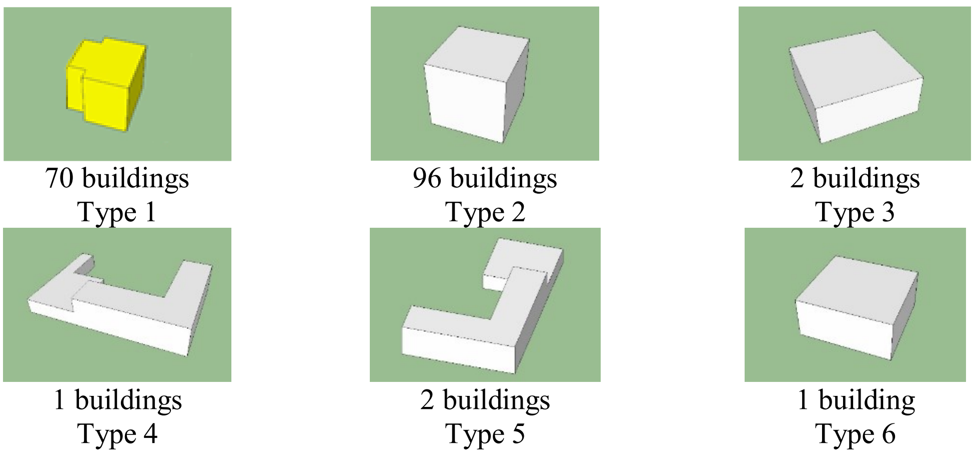
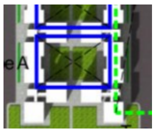
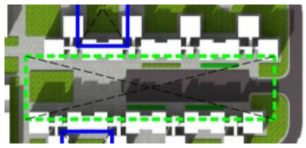


Figure 4. 30: The building types of AL-HADBA complex

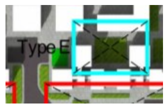
Source: The researcher



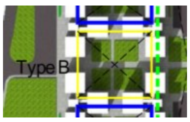
Type A, 10 groups



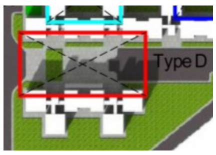
Type C, 5 groups



Type E, two groups



Type B, two groups



Type D, 4 group

Figure 4. 31: The building groups of AL-HADBA complex
Source: The researcher

According to the above mentioned explanation, we can conclude that the most frequent group is "group A", and the most frequent building type suitable for collecting the data results is "type 2".

4.7. Internal thermal loads of the case study

Internal thermal loads are the loads that come from heat generated by people, lighting, and equipment. It is therefore important to identify these loads to clarify appropriate simulation conditions. Table (4.10) clarify the types of lighting and equipment that were used in each apartment of AL-HADBA complex which is occupied by (4-6) persons.

Time steps	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
light bulb	2	2	2	2	2	2	2	2														1	2	2
Watt	120	120	120	120	120	120	120	120														60	120	120
Fridge	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Watt	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400
Frozen	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Watt	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400
Fluorescent lamp																		5	5	5	3	2	1	1
Watt																		160	160	160	96	64	32	32
TV																1	1	1	1	1	1	1	1	
Watt																100	100	100	100	100	100	100	100	
Satellite																1	1	1	1	1	1	1	1	
Watt																25	25	25	25	25	25	25	25	
Internet Router	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Watt	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Kettle+ Microwave								1						1						1				
Watt								1000						1000						1000				
Exhaust Fan								1	1					1	1					1	1			
Watt								55	55					55	55					55	55			
Laptops											1	1						1	1	1	1	1		
Watt											75	75						75	75	75	75	75		
others																		1	1					
Watt	50	50	50	50	50	50	50	50	50	50	1000	50	50	50	50	50	1000	50	50	50	50	50	50	50
Total Watt	980	980	980	980	980	980	980	2035	915	860	1885	935	860	1915	915	985	1935	1220	1220	2275	1211	1184	1137	1012
Total Watt/m²	7.1	7.1	7.1	7.1	7.1	7.1	7.1	14.7	6.6	6.2	13.7	6.8	6.2	13.9	6.6	7.1	14.0	8.8	8.8	16.5	8.8	8.6	8.2	7.3

Table 4. 10: Watts consumption on 24 hours

Source: The researcher

From this table, it was assessed that the lowest energy loads through the period is located between 11 pm to 6 am (the minimum used of lighting and equipment), while the highest loads occur during periods during the day corresponding to the use of the kitchen space, in which the maximum use of energy reaches about 2275 Watt (or. 16.5 W/m2), see Figure (4.32).

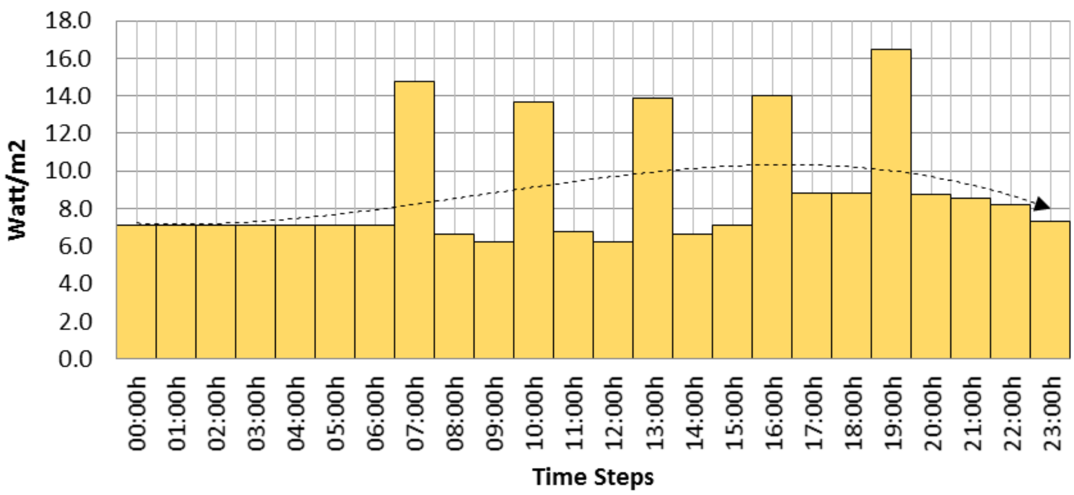


Figure 4. 32: The electricity consumption by one day

Source: The researcher

4.8. Summary and conclusion

This chapter represents the starting point of the practical aspect of this thesis, where all the aspects related to the case study, its urban components, and nature of construction materials used have been described. The alternatives construction materials available in the Iraqi local market in addition to the global market represented by France have also been addressed. The climatic characteristics of the study area, comfort zone, internal thermal loads have been tackled.

From this chapter, we can conclude the followings:

- In spite of the difference between the climates region of France and Iraq still there are a lot of materials types that are produced in France which can be used in the Iraqi construction where they meet the need of the Iraqi market in respect of many aspects, including the price, the similarity of the actual materials used, besides providing the best environmental performance, etc.

- According to the previous study, since the hottest seasons are in summer and the main source of energy needs to maintain an acceptable level of indoor thermal comfort is electrical energy, the innovative design alternatives to achieve energy efficiency must be found during this period.

- According to the floor area ratio of the apartments for the project under study, the lowest energy loads through the period is located between (11 pm to 6 am) (the minimum is used of lighting and equipment), while the highest loads occur during some periods during the day, which correspond to the use of the kitchen space, in which the maximum use of energy reaches about (2275 Watt) (or. 16.5 W/m2).

- From the data weather of case study region, the hottest months are in summer (April till October), especially in July (35.5 ºC). We determine that most frequent hot day in the weather data is 13 July, therefore, it will be considered in the simulation stage.

Chapter 5

RESEARCH METHODOLOGY

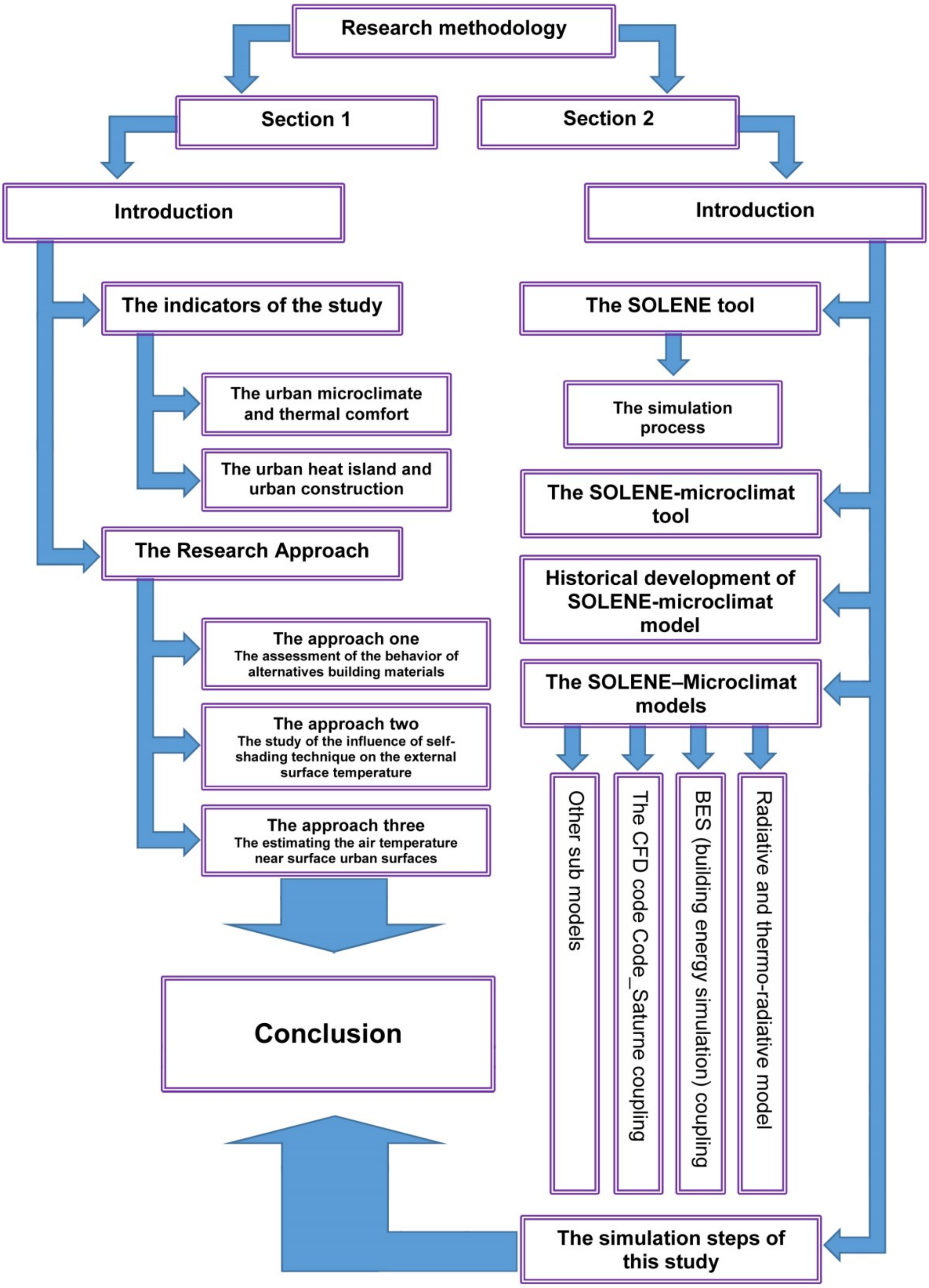


Figure 5. 1: Flow chart of chapter five

Chapter 5: Research methodology

Section 1 Theoretical framework and research variables

5.1. Introduction

After discussing all the questions related to the theoretical framework and identifying the research problem, this chapter deals with the practical aspects of our study. It begins with the process of identifying the indicators to express the resultst of the study and the methodology of the research. The investigation procedure, tools and software were used for data collection and to conduct a series of simulations with different orientations and in several stages to attain the aims of the study.

Generally, three main indicators have been identified and in their turn they will be in three axis:

- The first axis is linked with chapter one has focused on the identification of the indicators related to the urban microclimate and thermal comfort.
- The second axis is linked with chapter two has focused on the identification of the indicators related to urban heat island, energy balance, and thermal performance of building.
- The third one is linked with chapter three has focused on the identification of the indicators related to the construction materials.

5.2. Indicator identification

5.2.1. Indicators related to the urban microclimate and thermal comfort.

As it has been mentioned in the first chapter, the factors affecting microclimate include:

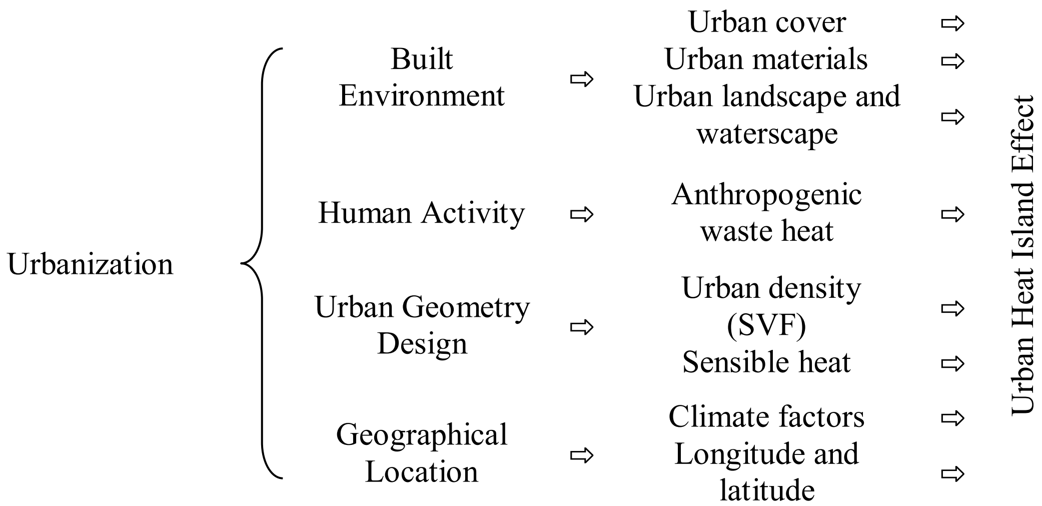
The conventional factors	**Air temperature**, atmospheric **humidity**, solar insulation fluxes, wind speed and wind direction.
The geographical factors	Topography, sun angle exposure, latitude, soil type, vegetation cover.
The meteorological factors	Cloud cover, regional precipitation, high altitude, wind characteristics.

Despite the diversity of these factors, and after passing through many of the previous studies related to the relation between climate and the strategies to achieve indoor thermal comfort, it can be stated that most of these studies confirm that air temperature is the most commonly used indicator of thermal comfort. According to this hypothesis, the researcher has identified outdoor air temperature as the independent factor and identified three dependent factors related to the outdoor air temperature, and at the same time affecting the thermal comfort especially in hot dry or semi-dry climate region as the case study location.

Independent Factors	Dependent Factors
Outdoor air temperature	Operative temperature
	Monthly mean outdoor air temperature
	The running mean outdoor air temperature

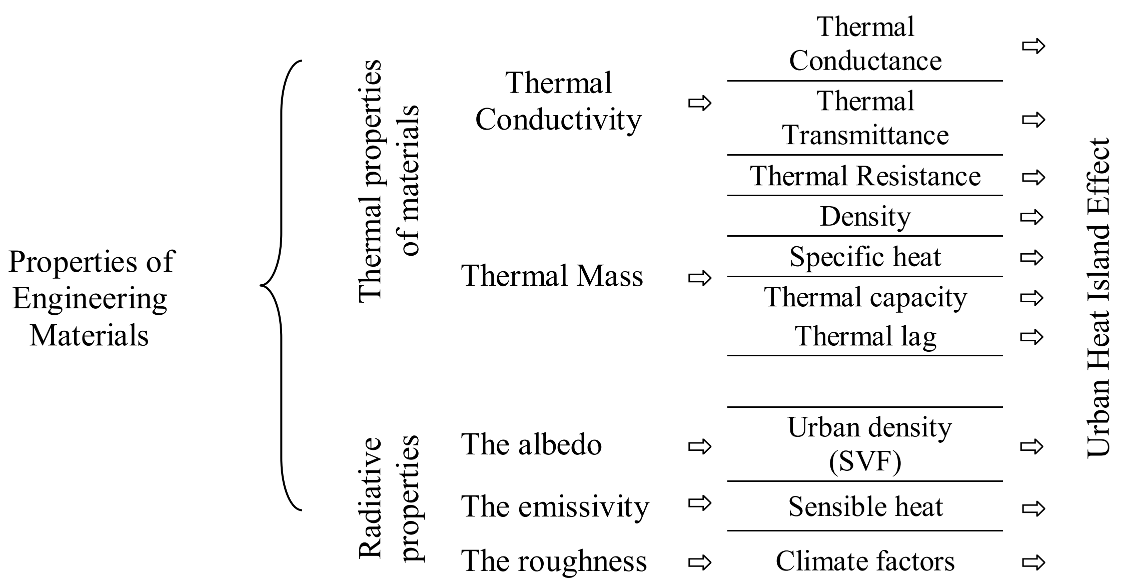
5.2.2. Indicators related to UHI and urban construction materials

As it has been stated in the second and third chapters, the studies varied in the description of the factors influencing the UHIs phenomenon. Most of them confirmed that the most important of these factors is the construction material, therefore, we can summarize these factors affecting UHI as follows:



Regarding the urban and building construction materials

As it has been stated in the third chapter, the thermal behavior of a building envelope or an urban open spaces mainly depends on the type of construction materials used which finally determine the air temperature between the building and indoor/outdoor thermal comfort. This behavior of materials depends upon their properties. These factors can be summarized as follows:



In this regard, we have identified the dependent and the independent factors which affect the UHI and outdoor thermal comfort depending on the orientation of the study and as follows:

Independent Factors	**Dependent Factors**
Urban materials types (Built Environment)	Thermophysical properties of materials which consist of : Thermal conductivity, Thermal capacity, Density
	Radiative properties of materials, especially albedo
Solar radiation	Direct solar radiation
	Diffuse solar radiation
	Interreflection radiation
Air temperature	Air temperature between the building
	Convective exchanges between surfaces and air
Wind	Air temperature between the building
	Convective exchanges between surfaces and air

5.3. Research Approach

The research approach will be carried out through three main components, corresponding ti the questions that are proposed by this study. All these steps will be achieved through the use of Solene-microclimate simulation model.

Approach one: impact of materials on external surface temperature

The first approach is the assessment of the behavior of alternatives building materials either alternatives construction materials available in Iraq or alternative modern types of construction materials that are produced in France, with respect to external surface temperature.

Approach two: impact of wall self-shading

The second approach is the study of the influence of self-shading technique on the external surface temperature.it consists of **three steps:**

- **The first step** is conducting a comparative study to select the suitable alternative materials among double wall, vegetated system, and variation of a reflection coefficient, with respect to exterior and interior surface temperature.

- **The second step** is estimating the exterior surface temperature of the selected alternative materials which are chosen in first step with different self-shading scenarios.

- **The third step** is estimating the indoor air temperature and the amount of energy needed to maintain high level of thermal comfort of the alternative that is selected in first step and the self-shading scenario that is selected in second step.

Approach three

This approach concentrates on estimating the air temperature near surface urban surfaces.

In order to achieve all these three approaches, SOLENE-Microclimat, a tool for numerical simulation of the urban microclimate developed in the laboratory CRENAU at the National School of Architecture in Nantes, will be used. It is more details will be added later on in section two of this chapter.

5.4. Simulation process in SOLENE-microclimat

SOLENE-microclimat is organized around a limited number of objects linked together to achieve the simulation. Generally, six types of files are needed to simulate any project: weather data file, geometry file, materials file, family file, param file, and the script related with model of simulation, see (Figure 5.2).

Figure 5. 2: the necessary type of files for simulation
Source: The researcher

The details of these files will be determined later during the simulation phase.

Chapter 5: Research methodology

Section 2 Presentation of SOLENE-microclimat

5.5. Introduction

The history of computer software covers many types of programming languages, some of them are specific to solve a certain scientific problem e.g. engineering issues whereas other ones are used in daily scientific life e.g. software to facilitate writing.

Mechanical engineering software as a range field of science has already witnessed a large development of its software products. It is a "collection of programs, processes and information that allow engineers to calculate, model and depict multifaceted engineering problems and to save calculations for future use" (Bayt, 2017).

Now, one question is proposed, why choose simulation?

According to many studies and scientific works related to the environment, specifically when analyzing the urban microclimate and the thermal comfort in outdoor space, the methods of impact analysis require an appropriate instrumentation, either through measurement campaigns or by site models placed in a special devices e.g. wind tunnel or by the use of simulation techniques. In this regard, the simulation is still the best method of the impact analysis as the point of view of (Vinet, 2000):

The interactions between surfaces, vegetation and atmosphere in an urban environment are complex, therefore it is not possible to hypothesize all the effects of changes in a system in total interaction, as in the case of a neighborhood where the effects on the local climate induce heating, cooling, recirculation of air, advection phenomena, etc. In this sense, only numerical simulations allow an estimation of these different effects. Additionally, the numerical simulations has other many advantages as following:

1. It is a help to construct digital models similar exactly to the actual situation with little or no modification

2. It is possible to simulate a wide range of phenomena and problems.

3. It is possible to change many parameters and observe their effects, while the in situ experiments do not allow easy change of many parameters.

4. It provides variety of scenarios to present the results and provide a well understanding of physical problems which cannot be obtained from experiments.

5. It is cheaper than conducting experiments on physical systems or building prototypes of physical systems.

Therefore, the scientific field has witnessed an increase in the need of accurate simulation and analysis tools for many analytical purposes and especially for the environmental problems that our world is facing today, such as visual comfort, thermal comfort, energy savings, as well as to analyze the environmental impact of new buildings or new types of materials on the neighborhood.

According to Miguet and Groleau (2002), most of the existing tools to analyse urban physics suffer from some disadvantages (Miguet and Groleau, 2001):

- -Lack of analysis of complex environments (morphology, materials and sky exposure),
- - Restrictive methods about the input geometry (rectangular shapes),
- - Limited sky conditions (CIE Standard Skies),
- - Separate approach for indoor and outdoor spaces.

Therefore and during the process of simulation, all the reasons mentioned may reduce the convergence between the virtual situation and the realistic situation. In this regard, SOLENE-microclimat is considered as an engineering software, answering the best to the present requirement for urban climate simulation. It is high-performance simulation tools, allowing no particular restriction about the geometry, shape, size and type of glazing and materials. It works for different scaled urban morphologies and also for indoor condition.

SOLENE-microclimat is a new generation of tools developed from SOLENE. This later tool has been created and developed in the Laboratory CRENAU (Le Centre de Recherche Nantais Architectures Urbanités) (the previous name: CERMA), Ecole d'Architecture de Nantes-France since 1990 to study the environmental aspects of the urban and architectural projects e.g. simulating sunshine (calculation of the mount of sunshine by using the radiosity method), natural lighting and thermal radiation over buildings or urban (Taleghani, 2015). Based on a (3D) model of finite elements, "SOLENE integrates several calculation modules that take into account solar, luminous or thermal effects of urban forms on outdoor conditions and pedestrian comfort. Its main interest is to enable the analysis of interactions between the urban form and its environmental and climatic dimensions, correlating geometrical data of the form with physical properties of the built space" (Idczak et al., 2010).

SOLENE-microclimat simulation tool performs the coupling of SOLENE with other models so that to model the urban microclimate and to study the building thermal behaviour (energy consumption of the building and thermal comfort) (Malys, 2012; Musy et al., 2015). This model provides:

- - Vast possibilities of data visualization and tests which outline the different behaviors observed in space and time.

- - Application to any type of geometry, simple or complex 'real' and not just the forms included in a grid (see Figure 5.9), where it has the ability to create (3D) geometry modelling via SALOME-platform, CAD, Sketch Up, and QGIS software, therefore, it provides different methods to create the geometric shape.

- Vast possibilities to change any parameters related to location, climatic conditions, wall and roof design (e.g. thickness, number of layers, finishing), construction materials of the urban area or natural surfaces (water or vegetation),

- Possibility to make a comparative case,

- Vast variety to show the results as visual results by using Preview software, table, list of value, etc.

- Possibility to couple with a computational Fluid Dynamics (CFD) code.

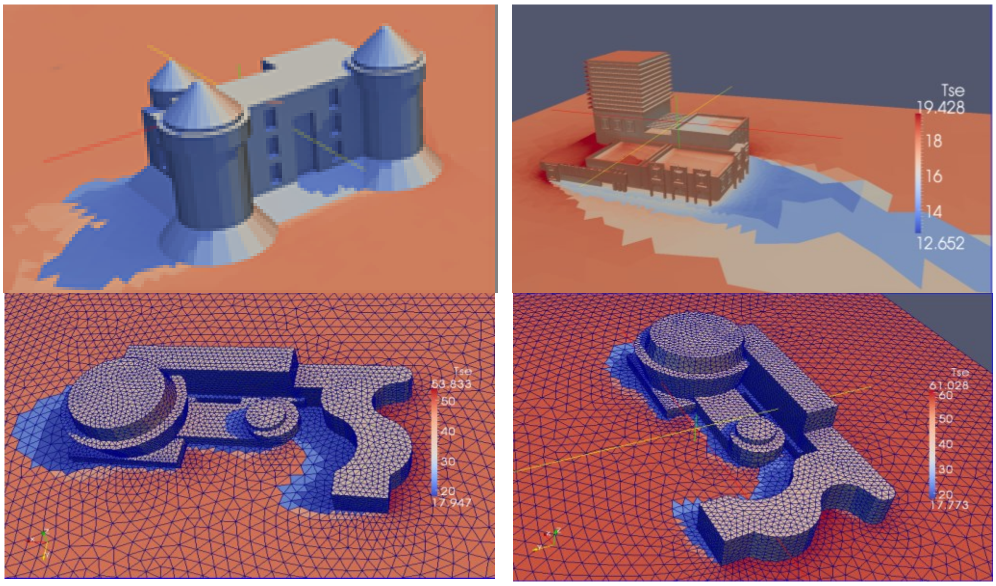


Figure 5. 3: Geometry Samples - Solene-microclimat

Source: The researcher

5.6. SOLENE

- Regarding the original version of SOLENE, there are nowadays several results of this simulation and the principals of SOLENE tool are:

- Shadow area presentation (see Figure. 5.9-a)

- Duration of insolation (see Figure. 5.10-b)

- Calculation and evaluation of direct solar radiation (see Figure. 5.910-c)
- Modeling of sky vault and its energy, i-e diffuse radiation (see Figure. 5.10-d)
- Evaluation of form factor (see Figure. 5.10-e)
- Prediction of artificial lighting (see Figure. 5.10-f)

5.6.1. The simulation process

The simulation by Solene consists of two main steps, which are:

- First step : gathering radiative energy from both the sun and the sky vault;
- Second step: analyzing the physical behavior of light when hitting a plane surface (obviously dependent on its material), in order to start a multi- reflection process.
- Regarding the way to assess direct solar energy received by the scene, results can be performed using, two different procedures which will lead to different presentations:
- The method of “Héliodon” which is a geometrical method consisting in projections from the sun position at each time step to explain sun lighting on building and its surrounding.
- The technique of mask which starts from each patch of the meshed scene and determines if it sees the sun (see Figure 5.11).

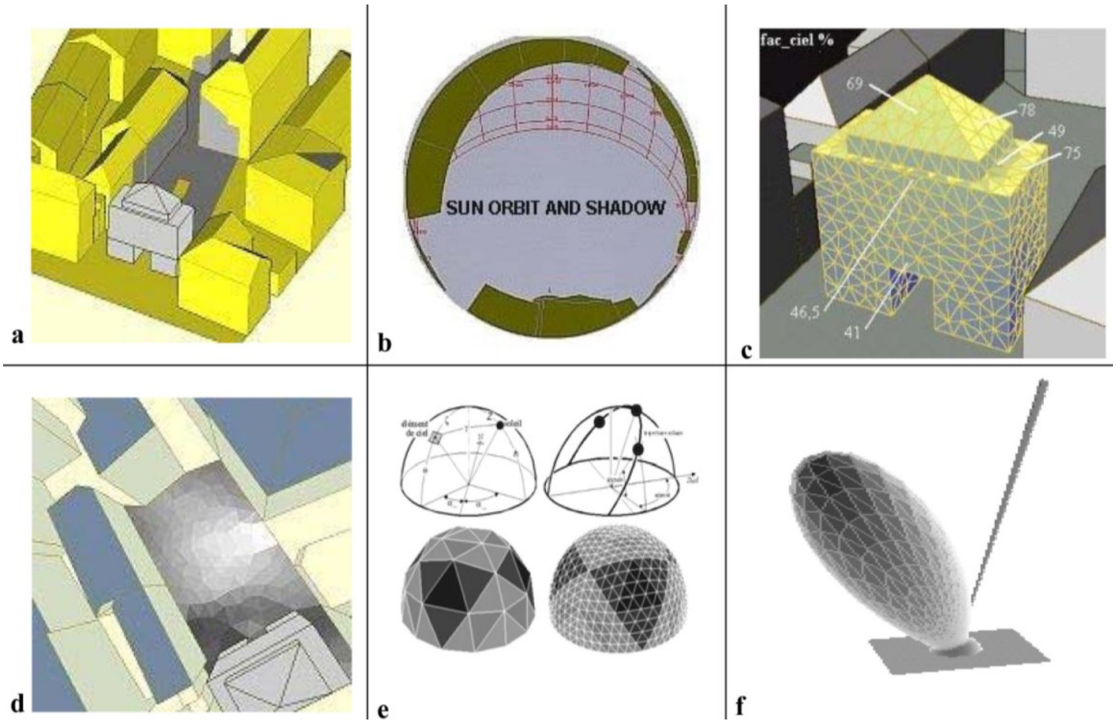


Figure 5. 4: Several observation analyses with SOLENE
Source: (Morille et al., 2015)

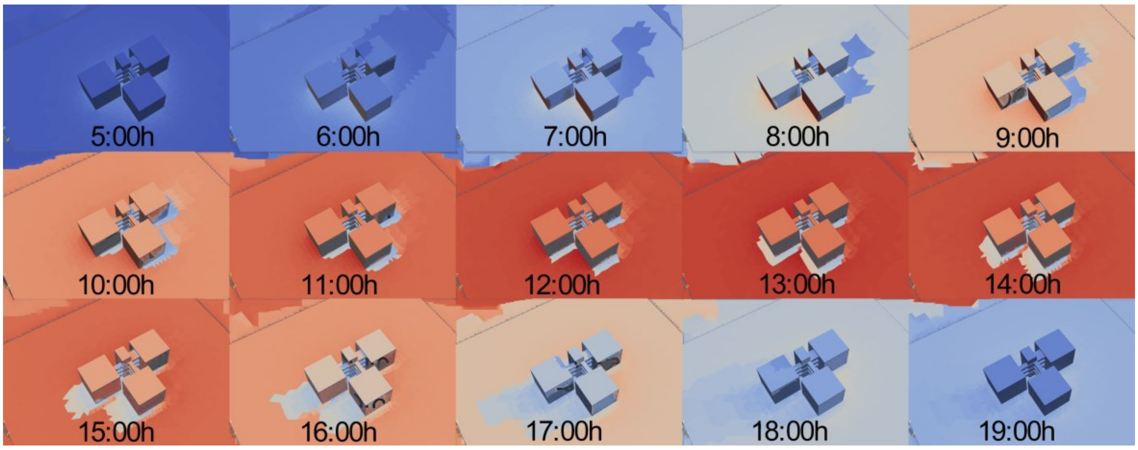


Figure 5. 5: A mask method-SOLENE-microclimate
Source: The researcher

5.7. SOLENE-microclimat

SOLENE-microclimat consists of a new module that has been developed, using the old version of SOLENE for radiation and keeping all its features and possibilities. From its capability to calculate the solar and luminous effects due to urban forms and materials used in urban architectural projects (Miguet and Groleau, 2001), it provides many additional possibilities, as Figure (5.12). The airflow simulation is performed through the coupling with code-saturne.

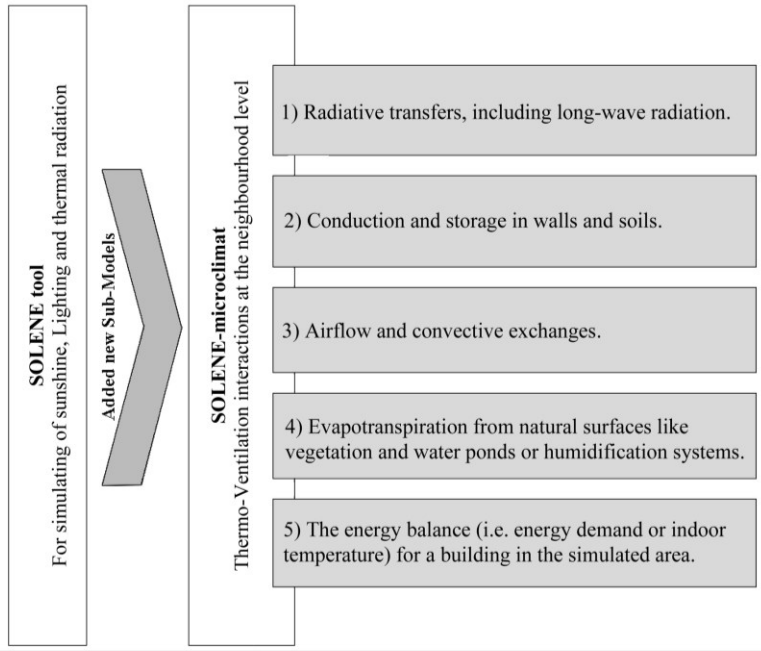


Figure 5. 6: New functionalities offered by SOLENE-microclimat tool
Source: (Musy et al., 2015)

The main advantage of SOLENE-microclimat model is the representation of the whole urban environment through the simulation of the following phenomena (see Table 5.2):

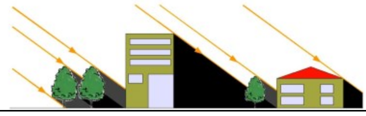
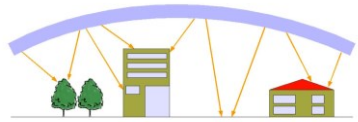
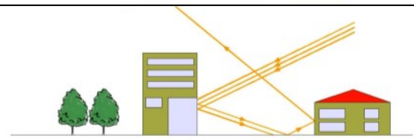
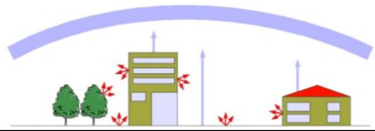
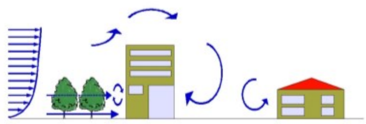
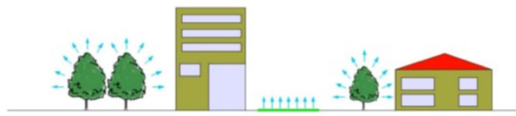
The phenomena	Figures
- Direct sunlight, solar masks.	
- Diffuse sunlight.	
- Solar inter-reflections, radiative trapping.	
- Infrared exchanges.	
- Aerodynamic phenomena.	
- Evaporative Phenomena.	

Table 5. 1: The phenomena that are simulated by SOLENE-microclimat
Source: Adapted from Solene workshop 2014, CRENAU Lab, ENSA Nantes

5.8. Historical development of SOLENE-microclimat model:

Many of previous scientific works and thesis contributed to development of this model (Figure 5.7). We summarise the key contributions in terms of functionality development or use illustration:

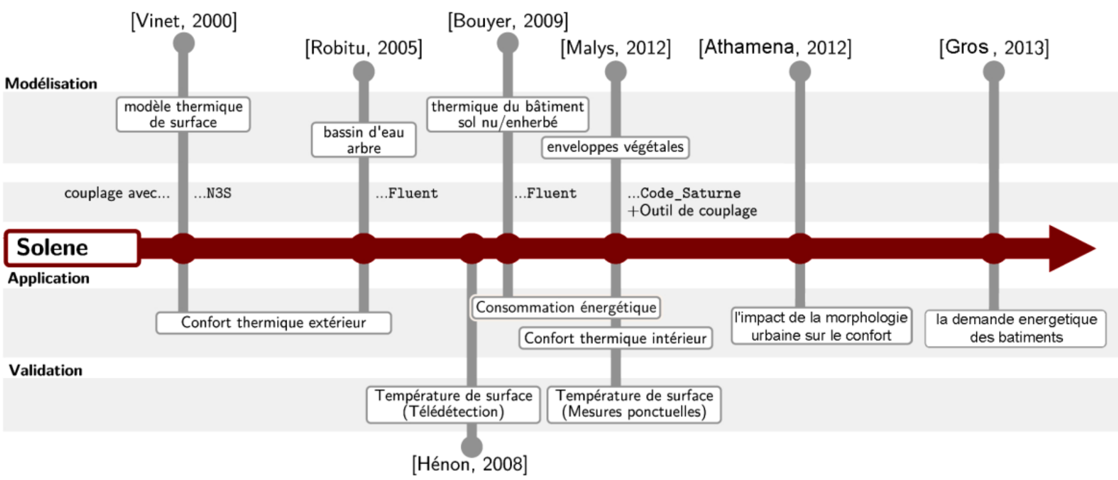


Figure 5. 7: Summary of previous study
Source: Adapted from Solene workshop 2014, CRENAU Lab, ENSA Nantes

DEVELOPMENT and USE: Jérôme VINET in 2000 – Ph.D. thesis "Contribution à la modélisation thermo-aéraulique du microclimat urbain: Caractérisation de l'impact de l'eau et de la végétation sur les conditions de confort en espaces extérieurs "[7].

In this PhD, the first thermo-radiative coupling have been performed so that to be able to calculate wall surface temperature. CFD coupling was developed with N3S which was a CFD model based on finite elements. Trees were also modeled in a simplified way, as semi-transparent bodies having the temperature of which is equal to air temperature.

This study has been applied to an open space called the "Place du Millenaire" in Montpellier (France). It focused on the direct impact of vegetation on microclimate and on outdoor thermal comfort, under hot summer conditions. According to various types of cases study (one without vegetation, the other with vegetation and the last with vegetation in 30 years), this study concluded that there are important evolutions over the years of urban form, microclimate conditions and a significant improvement in outdoor comfort (Vinet, 2000).

DEVELOPMENT and USE: Robitu in 2005 – Ph.D. thesis « Study of the interaction between the building and its urban environment: influence on the comfort conditions in outdoor spaces"[8].

This thesis deals with the numerical modeling of the physical phenomena of the urban microclimate and in particular to take into account of the presence of water and trees in urban areas. These new submodels have been developed in a new coupling of SOLENE with the CFD code FLUENT so that to take into account energy (convection, conduction, radiant and latent) and mass transfers (air, moisture).

The application of this model for the simulation of an open space, the Fleuriot square in Nantes, allowed to estimate the effect of a water pond and trees on the urban microclimate and thermal comfort conditions (**Robitu, 2005**).

VALIDATION and USE: Hénon, in 2008 – Ph.D. thesis « Temperature measured, modelled, and observed by infrared remote sensing, in the urban canopy: aero-thermo-radiative modeling of the urban heat fluxes »[9]

The main objective of this study was to "establish parametric relations between the sensible heat and infrared fluxes, which are both related to the surface temperature". Aero-thermo-radiative simulations of the urban canopy were accomplished using the SOLENE model, in two

[7] « Contribution of the thermo-ventilation modeling urban microclimate: Characterization of the impact of the water and vegetation on comfort conditions in outdoor spaces »,

[8] "Etude de l'interaction entre le bâtiment et son environnement urbain: influence sur les conditions de confort en espaces extérieurs"

[9] Températures mesurées, modélisées, et observées par télédétection infrarouge dans la canopée urbaine: modélisation aéro-thermo-radiative des flux de chaleur urbains".

French cities: Marseilles and Toulouse. It leads to an improvement of SOLENE wall model and the validation of the temperatures obtained against measurement in the CAPITOUL campaing (Henon et al. 2012).

DEVELOPMENT and USE: Julien BOUYER in 2009 – Ph.D. thesis, « Modelling and simulation of urban microclimates: study the impact of urban development on energy consumption in buildings”[10]

In this thesis, J. Bouyer developed a soil model and a building thermal model to compute the energy consumption of a building interacting with its urban environment.

The application was the first one addressing the impact of urban planning on indoor thermal conditions. I was applied to a real urban site, the Lyon Confluence project (France) and focused on the direct or indirect impact of the urban planning and energy demand by analysing the impact of three planning fixtures: the building energy consumption being calculated without taking into account interrelation with the environment (just mask effect being taken into account roughly), a mineralized environment (with surrounding buildings) and a vegetated one (with buildings and vegetation).

This application firstly underlined the significant difference between energy consumption simulated takings into the real built context, even without considering vegetation. Thus it showed that these considerations must be a priority.

Secondly, it has been show the potential of summer energy saving due to the climate mitigation by vegetation (Bouyer, 2009).

USE : Khaled ATHAMENA in 2012-Ph.D. thesis, « Modelling and simulation of urban microclimates: Study of the impact of urban morphology on comfort in outside spaces. Cases of Eco-districts »[11]

This study achieved by using solene software and coupled with Code_Saturne focused on “the relation between urban forms of Eco-districts, microclimate and outdoor thermal comfort in public outdoor spaces through modeling and numerical simulations. Applied on three eco-district configurations to analyze their impact on outdoor comfort, it proposed guideline for the eco-districts conception for architects and urban planners (Athamena, 2012).

DEVELOPMENT, VALIDATION and USE: Laurent MALYS in 2012 – Ph.D. thesis, « Evaluation of direct and indirect impacts of facades and green roofs on the thermal behavior of buildings »[12]

[10] "Modélisation et simulation des microclimats urbains Étude de l’impact de l’aménagement urbain sur les consommations énergétiques des bâtiments".

[11] "Modelisation et simulation des microclimats urbains: Etude de l'impact de la morphologie urbaine sur le confort dans les espaces exterieurs. Cas des_eco-quartiers"

In this Ph.D work, the development of green envelops of building has been realized (Malys et al., 2014). The new coupling with code-saturne which replaces FLUENT was also developed and a sensitivity analysis on the different ways to take into account infrared fluxes and aerodynamic coupling (Malys et al., 2015) made.

Malys has also conducted comparisons with measurements performed in Pin-Sec district during the fluxSAP campaign in VegDUD (Musy et al., 2014) project. This constitute a part of SOLENE-microclimat validation (Musy et al., 2015).

Concerning application, the study has been done in a district called "Pin Sec" located at neighborhood of the city of Nantes (France). It focused on the advantages of coating the building envelope and roofs with vegetation as one of methods to provide good thermal behavior of the building directly and indirectly. It also assessed the impact of lawns. This study concluded that the use of vegetation for façades, roofs and the external walls of neighboring buildings can help direct and indirect to improve the indoor thermal behavior and avoid discomfort of building especially in summer (Malys et al., 2016).

5.9. SOLENE–Microclimat sub-models

To identify the SOLENE-Microclimat models, see Figure 5.14

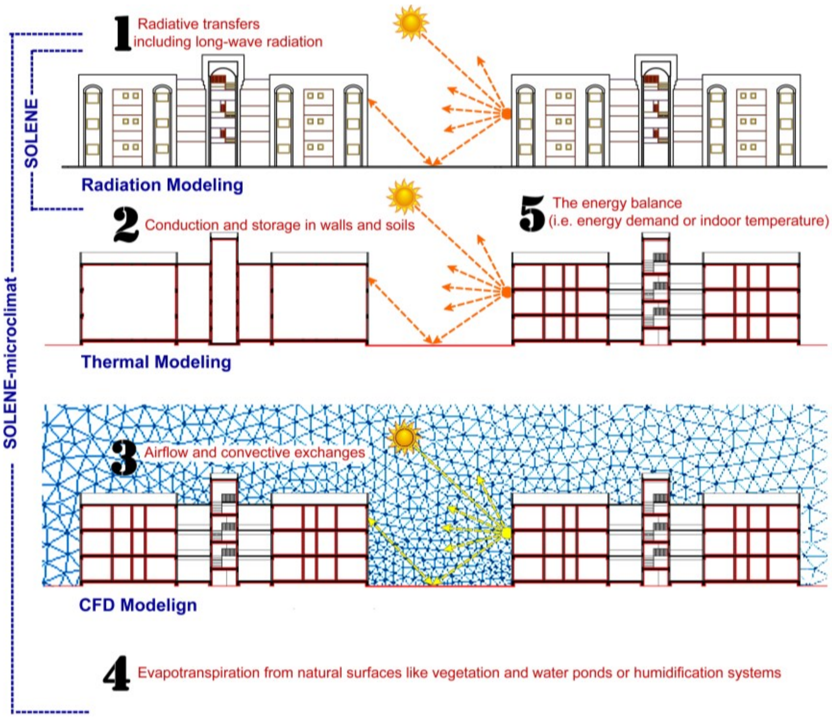


Figure 5. 8: SOLENE–microclimat model
Source: Adapted from (Musy et al., 2015)

[12] "Evaluation des impacts directs et indirects des façades et des toitures vegetales sur le comportement thermique des batiments ".

According to this figure, five models types can be identified as a following:

SOLENE	Situation (1) corresponds to the historical SOLENE radiative model,

SOLENE–microclimat	Situation (1+2) corresponds to the thermo-radiative model based on SOLENE and Situation (5) corresponds to the thermal building simulation Model, and the energy building simulation model (BES coupling) Situation (4) (is not represented), evapotranspiration is taken into account in the energy balance equation use to link all flux; the links in the scheme Situation (3) CFD coupling

5.9.1. Radiative and thermo-radiative model SOLENE

This model involves the radiative exchanges between the surfaces of the urban scene. The heat transfers are determined by a sequence of numerical treatments allowing successively the calculation of incident solar fluxes (direct and diffuse), solar inter-reflections and radiative exchanges in the long wavelengths between the surfaces and with the celestial vault. The calculation steps related to radiative exchange that are existing in the SOLENE software are going to be presented.

The radiative model (old version of Solene tool)

This model has been mainly developed to assess the radiation process in urban scene from 3D surface mesh (facets), as well as the anisotropy of diffuse solar radiation that is considered from a hemispherical geometry which represents the sky vault (see Figure. 5.15). This tool calculates direct and diffuse fluxes (sky irradiance, see Figure 5.16) which can be evaluated from the measurements data or from a sky mesh model. In this tool, the whole solar flux reaching each urban surface can be estimated by using radiosity algorithm (see Figure 5.17) and based on the radiative proprieties of materials, solar beams inter-reflections and infrared radiation balance. Radiation spectrum has been divided into two bands corresponding to solar radiation (0.3–2.5 mm) and infrared thermal radiation (2.5–18 mm). Sky thermal radiation is assumed to be isotropic.

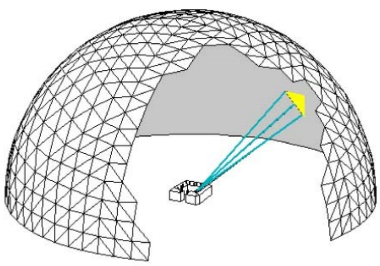


Figure 5. 9: Hemispherical geometry representing the sky

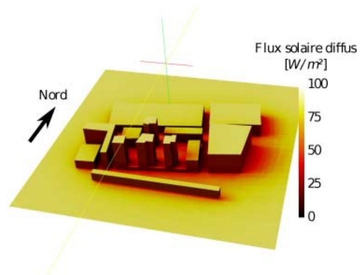


Figure 5. 10: Diffuse solar flux computed by SOLENE

Source: (Morille et al., 2015)

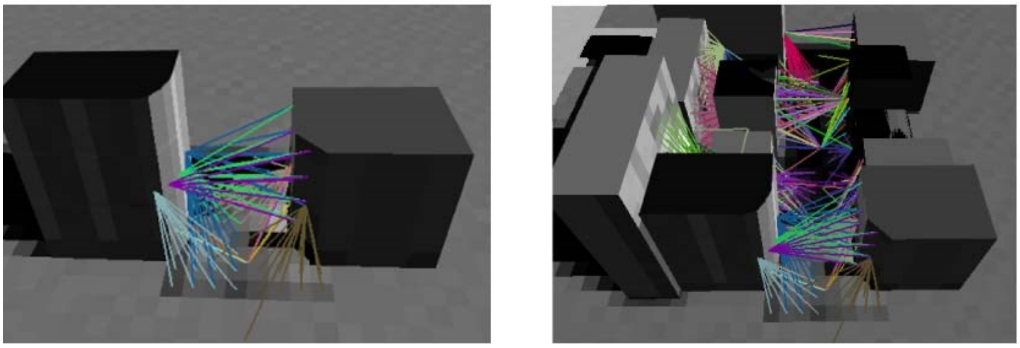


Figure 5. 11: Hierarchical Radiosity for Procedural Urban Environments
Source: (Roure et al., 2014)

The thermo-radiative model

This model allows simulating the thermo-radiative behavior of a three dimensional t urban part. It is considered as a new version of Solene radiative model termed thermo-radiative model representing the combination of old Solene model (radiative model) and thermal balances on each elementary facet. This combination provides this model addition ability to assess time evolution of surface temperatures, where thermal balances on each elementary facet (surface element of walls and soil) permits to realize dynamic simulations. During the thermo-radiative simulation, geometrical effects such as solar position, shadowing, radiation multiple reflections, as well as the wall characteristics, such as the materials and thickness of the layers are taken into account. The data that is related to the thermal parameters of wall and soil material gives access to the conduction fluxes to take into consideration the material inertia. Convective fluxes are taken into account with a meteorological air temperature and a convective heat transfer coefficient.

In this model, it can be noticed that at each time step and at every facet of the mesh grid,

1. The absorbed solar radiation of each mesh facet (i) as the result of direct and diffuse solar radiation received directly from both sun and sky, following reflection from all other urban surfaces in view, minus the reflected flux away from the surface which can be expressed in the equation [5.1] (Idczak et al., 2010):

$$K_{abs\text{-}i} = K_{inc\text{-}i} + K_{refl\text{-}sur\text{-}i} - K_{refl\text{-}i} \quad \textbf{[5. 1]}$$

Where

K_{inc} includes the solar direct and diffuse radiations directly received by the facet from the Sun and the sky and those received from the reflections on all other facets in view, and,

$K_{refl\text{-}sur\text{-}i}$ reflected flux from all other urban surfaces in view

K_{refl} is the reflected flux away from the surface (by convention $Kinc > 0$, $Krefl < 0$).

The reflected-to-incident ratio K_{refl}=K_{inc} is equal to the albedo of the facet.

2. The energy flux balance through a wall or ground facet is computed between the net radiative flux, the sensible heat flux due to convective transfers between walls and atmosphere

and to conduction inside the walls. This last flux may be computed with a multi-layer wall and introduces heat storage in order to reconstruct the inertial role of walls (Hénon et al., 2007). Accordingly, the energy flux balance can be expressed as the equation [5.2]:

$$K_{abs-i} = L_{net-i} + Q_{h-i} + Q_{g-i} \quad \textbf{[5. 2]}$$

Where

L_{net} is the net difference between the thermal radiation components: received from the sky and the reflections on the other facets, reflected towards the scene, and emitted by the facet

Q_h is the sensible heat flux to the atmosphere by turbulent convection

Q_g is the heat flux by conduction through the materials behind the facet. It is computed with a multiple-layers model including heat storage in the layers and conduction through the layers and to/from the building inside air or ground deep layer, as a function of the materials thermal properties

Through this model:

- The multiple-reflections are computed in function of the reflection and transmission properties of the surfaces by a radiosity method which implies the previous computation of geometrical form factors (or view factors) between all facets.
- The radiative transmission inside the buildings is computed by accounting for the glazing properties and the direction of the sun ray through the glazing. The radiations coming into the building through the glazing from the outside are thus estimated accounting for transparencies and masking.
- The convective heat flux between the surface and the atmosphere is computed by using the surface-to-air temperature difference and a convective heat transfer coefficient (CHTC) which can then be assigned to a constant value or a value dependent on wind velocity at a reference point.
- The long-wave radiation fluxes are evaluated from each thermal radiation emitted by each surface (depending on surface temperature) and the view factors between all surfaces.

The system of equations of this model is solved by iterative algorithm at each time step where the external surface temperature of each elementary mesh cell is tied to that of all the other elementary cells via the long-wave radiation calculation.

5.9.1.1. Calculation of incident radiation

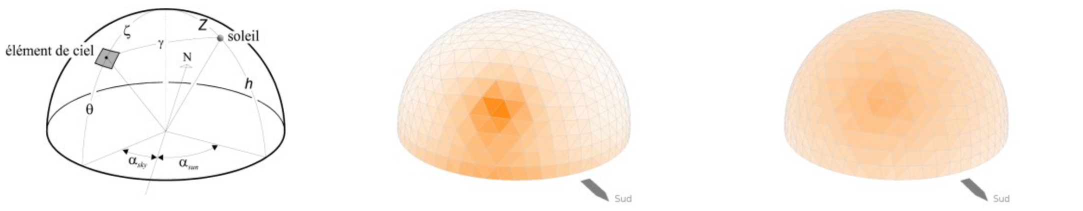
The direct solar radiation follows the Perrin de Brinchambault formula, which calculates the direct solar flux for a surface perpendicular to the sun rays. It is expressed as the following equation [5.3]:

$$I = 1230 \exp \frac{-1}{3.8 \sin(h + 1.6)} \quad \textbf{[5. 3]}$$

Where h *Solar height, If the sun directly hit the facets, the direct solar flux equivalent to the value of (I) weighted by the angle of incidence of solar radiation on the facet.*

If the sun is visible from any facet in urban scene, the direct solar flux it receives (direct sol) corresponds to the value of the radiation stated above (I) weighted by the cosine of the incidence angle of the solar rays on the facet.

The diffuse solar radiation corresponds to the radiation scattered by the sky. Its calculation requires sky models for different configurations (covered or clear sky). SOLENE comprises a sky geometric model in the form of an infinite radius geodesic dome that can be more or less meshed. Sky types available in Solene and the flow distribution according to the cloudiness are explained in Figure (5.18):



Bookmark and spherical angles | luminance distribution for Latitude 40 ° at 14h TSV for clear skies CIE | luminance distribution for Latitude 40 ° at 14h TSV for for a clear sky covered ε = 1; Δ = 0.35

Figure 5. 12: Sky types | SOLENE-microclimate

Source: (Bouyer, 2009)

In spite of the fact that Solene provides different types of standardized sky there is ability to calculate the luminance, based on model of Perez et al. in unstandardized case (Perez et al., 1993). This formula uses two coefficients to define the cloud from the sky: the purity of the sky and its brightness. An example of simulation resulting from the diffuse solar flux for a clear sky is given in Figure (5.19).

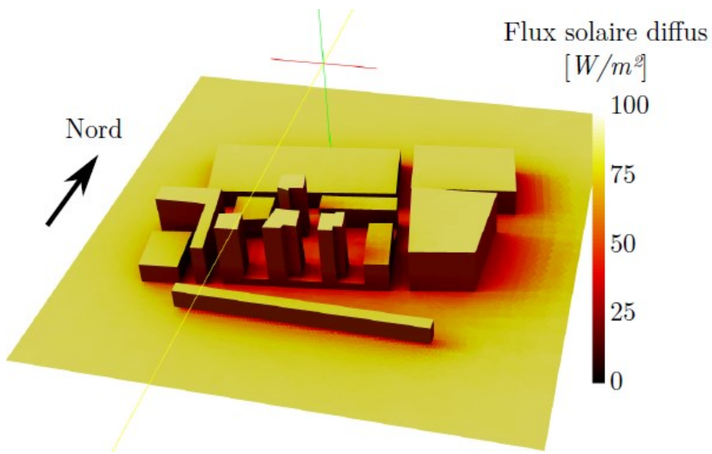


Figure 5. 13: Simulation results with Solene: diffuse solar flux with a clear sky

Source: (Malys, 2012)

In Solene simulations, the direct and diffuse fluxes are often recalculated from horizontally measured flows at experimental sites. There are also dedicated external functions that make it possible to find the distribution of the diffuse radiation of the sky model that is measured on a horizontal plane over the whole facets (Malys, 2012).

5.9.1.2. Calculation of inter-reflections

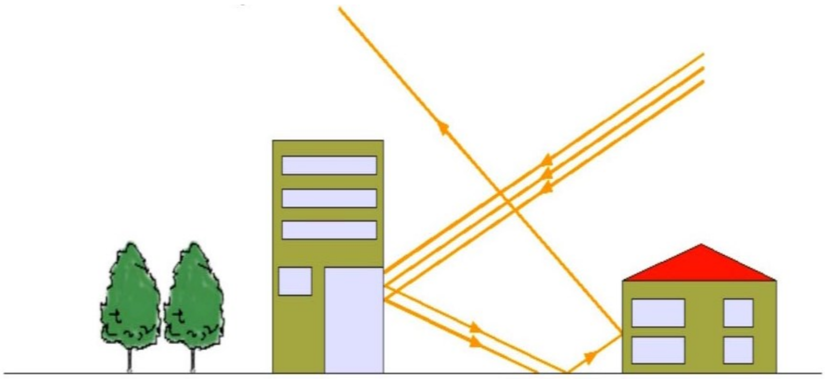


Figure 5. 14: Solar inter-reflections, radiative trapping
Source: Adapted from Solene workshop 2014, CRENAU Lab, ENSA Nantes

There are several numerical methods for modeling inter-reflections. Regarding Solene, their calculation is based on the principle of radiosity, which is a mathematical concept to describe the scattering of light applies to perfectly diffuse surfaces (Lambertian), according to the following expression [5.4]:

$$B_i = E_i + \rho_i \sum_{j=1}^{n} B_j \cdot F_{ij} \qquad [5.4]$$

Where

B_i *Radiosity of the element i (W/m²),*

E_i *The energy density emitted from the element i (W/m²),*

Pi *its reflectivity (fraction of incident energy reflected into the environment)*

F_{ij} *Form factor (fraction of energy leaving the element i and reaches j), and*

n *The number of elementary surfaces of the environment.*

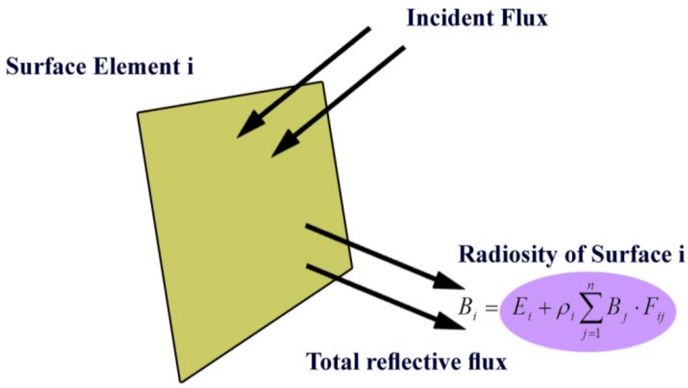


Figure 5. 15: Diagram of the radiative balance for a patch i
"Radiosity is the radiant flux leaving (emitted, reflected and transmitted by) a surface per unit area"
Source: (Bouyer, 2009)

Miguet summarizes the main hypotheses of the Solene model (Miguet and Groleau, 2001):

- "There is no re-emission of light towards the sky (theoretically wrong in case of low cloud ceiling, but according to authors, the error should not overcome a few percents only)".

- "Emitted or received energy and reflectance are constant over a whole patch (almost true if patches are small enough)".
- "Every non transparent surface (see below for Transparencies) are considered as opaque and Lambertian (ideal diffuse)".

5.9.1.3. Calculation of flux exchanged between surfaces

The density of heat flux exchanged by the wavelength radiation (See Figure 5.22) is calculated from the shape factors and surfaces temperatures between each element of surface according to Stefan-Boltzmann law.

$$\varphi_{GLO,net} = \sum_{j=1}^{n} \sigma F_{ij} (\varepsilon_i T_{si}^{\ 4} - \varepsilon_j T_{sj}^{\ 4}) \quad [5.\ 5]$$

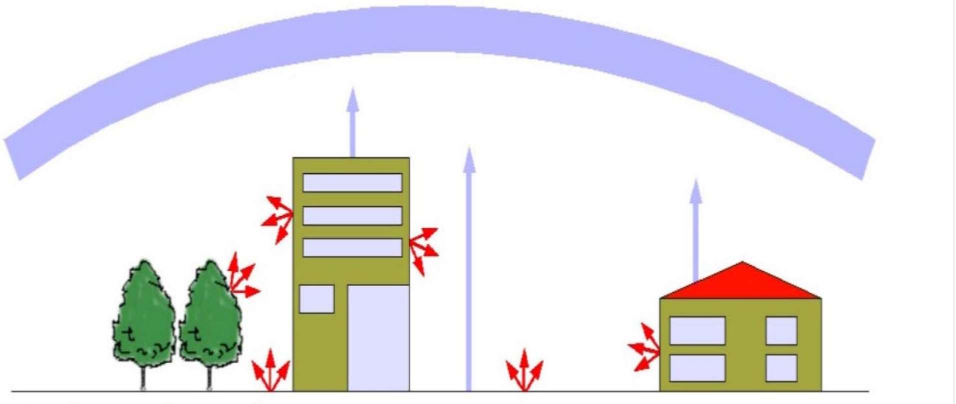


Figure 5. 16: Infrared exchanges

Source: Adapted from Solene workshop 2014, CRENAU Lab, ENSA Nantes

Shape factor is the proportion of the radiation which leaves one surface (A1) and strikes the other surface (A2). It is also sometimes known as form factor or view factor (see Figure 5.23). Therefore, the view factor from a general surface A1 to another general surface A 2 is given by:

$$F_{1\to 2} = \frac{1}{A_1} \int_{A_1} \int_{A_2} \frac{\cos\theta_1 \cos\theta_2}{\pi s^2} \, \mathrm{d}A_2 \, \mathrm{d}A_1 \quad [5.\ 6]$$

Where:

θ_1 and θ_2 are the angle between the surface normals and a ray between the two differential areas.

dA_1 and dA_2 are area of surfaces A_1 and A_2

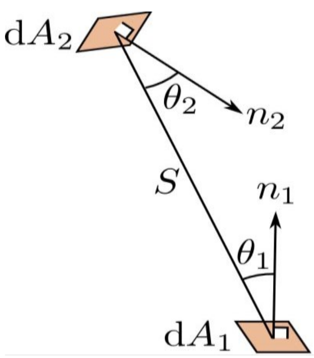


Figure 5. 17: View factor
Source: https://en.wikipedia.org/wiki/View_factor

5.9.1.4. Calculation of flux exchanged with the sky

The shape factors between each surface and the sky are calculated using the same discretized sky that is constructed for diffuse solar flux simulation. For each element of the scene, a spherical projection makes it possible to identify the obstructions of the sky and to evaluate the visible parts that correspond to the solid angles, their summing divided by π allows the calculation of the corresponding shape factor with the sky. The exchanged flow is then written as the following equation:

$$\varphi_{ciel} = F_{ext,ciel}\left(\sigma\varepsilon_{ext}Ts_{ext}^{4} - L\downarrow\right) \quad [5.7]$$

Where

L↓ : is calculated according to : 5.5 T_{air} + 213

Calculation process

The surfaces temperatures are all linked, tand also linked to the surface thermal balance of each element. This balance is dynamic since it takes into account the thermal storage in the wall. Thus, compared to solar calculations that could be carried out independently, the infrared balance is performed at each time step.

In this calculation, it is not possible to take into account all the infrared inter-reflections as in the case for short-wave radiation. Therefore it is limited to a single reflection, which is already satisfactory because the emissivities of the urban surfaces considered are generally greater than 90%.

The assessment of the infrared radiation mainly takes place in two stages:

- First, the radiation coming from the sky is distributed among all the facets taking into account the reflections.
- Second, iterations are carried out between the thermal balances of surface (and of the building when this is considered) and the radiation balance, until the surface temperatures converge.

5.9.2. BES (building energy simulation) coupling

The BES coupling consists of a sub-model for SOLENE-microclimat developed to evaluate the thermal variables inside the building in order to evaluate the indoor air temperature or estimate the amount of the energy needed to sustain acceptable level of comfort. This model is based on a multi-zone thermal model, whose nodes correspond to a building floor. All external facets allocated to a floor are linked, thus conductive fluxes and transmission through the windows contribute to the floor energy balance equation (Morille et al., 2015; Musy et al., 2015). Its hypotheses are the following:

1. Temperatures are considered as homogeneous for each floor,

2. For each floor, one wall temperature and one internal glass nodes are considered,

3. The boundary conditions on the external surfaces are heterogeneous, corresponding to facets,

4. To estimate the energy consumption fixed indoor temperatures and relative humidity are applied, or the simulation can be performed with a free running indoor temperature and humidity,

5. Latent and sensitive loads can be calculated, taking into account the internal gains and air change,

6. The thermal bridges are neglected.

5.9.2.1. Models for building's components in SOLENE-microclimat

The simulation of any building in Solene consists of the following components.

a. Vertical elements or walls-model by Solene

The outside walls or windows are represented by a nodal model with both thermal resistance and thermal capacity (R2C wall model) calculated by using similar hypothesis that are used in CoDyBa software (Dynamical Behavior for Buildings). It lies on the assumption that the temperature profiles are linear in each layer of the walls, which is acceptable for the hourly time used.

As a general rule, the basic nodal model consists of many parameters such as the thermal resistance, the thermal capacity of the inner surface and the thermal capacity of the external surface. They are calculated according to the thermal parameters and the thickness of each of the wall component layers, where:

(R)	The thermal resistance of elements	$R = \sum_j R_j$	R_j	The thermal resistance of the layer j [m^{2}K/W].	[5. 8]
(Ci)	The thermal capacity of the indoor surface	$C_i = \sum_{j=1}^{n} \rho_j c_j e_j \beta_j$	ρ_j C_j r_j	density of the layer specific heat of the layé thickness of the layer	[5. 9]
(Ce)	The thermal capacity of the external surface	$C_e = \sum_{j=1}^{n} \rho_j c_j e_j (1 - \beta_j)$	β_j	expressed for each layer by: $\beta_j = \frac{\frac{R_j}{2} + \frac{R_{j-1}}{2}}{R}$	[5. 10]

1. Exterior walls

Thermal model of external walls or glassing is shown in Figure (5.24)

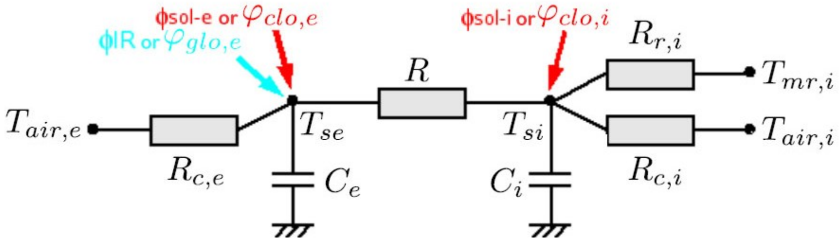


Figure 5. 18: Thermal model of external walls
Source: (**Bouyer, 2009**)

This scheme represents the thermal model of external walls, windows and roof. These components are located under the direct impact of outside air temperature and radiant temperature.

2. Interior walls

Thermal model of interior walls is shown in Figure (5.25)

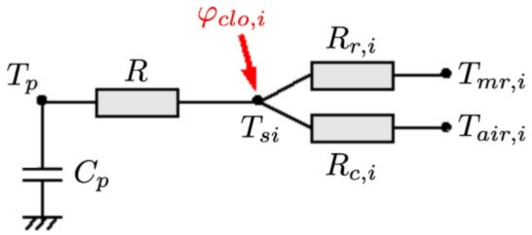


Figure 5. 19: Thermal model of interior walls
Source: (Bouyer, 2009)

This scheme represents the thermal model of the internal walls that affects the building thermal inertia which depends on the absorptivity, specific heat, thermal conductivity, dimensions, and other factors of the wall. In the thermal system, it is in contact only with the indoor environment.

b. Horizontal elements or floors -model by Solene

The horizontal wall in Solene-microclimat is shown in Figure (5.26)

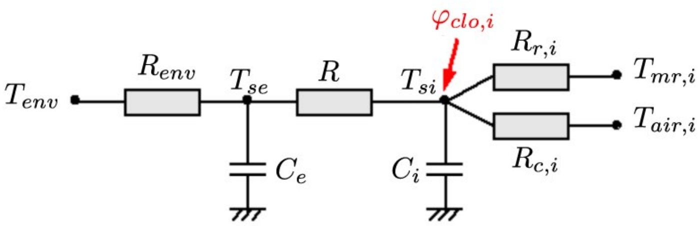


Figure 5. 20: Thermal model of floors
Source: (Bouyer, 2009)

This scheme represents the thermal model of floor. It is different from the other components of building because it is located under the effect of the two separated thermal zones contrary to the ceiling and the ground floor.

c. Thermal model of indoor air

The indoor air is represented as shown in Figure (5.27).

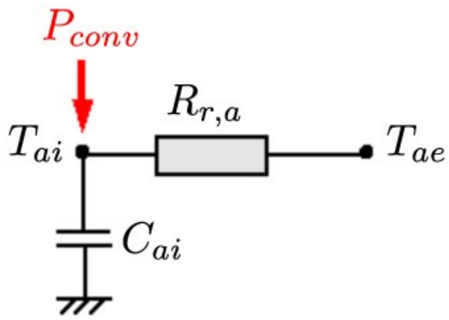


Figure 5. 21: Thermal model of indoor air
Source: (Bouyer, 2009)

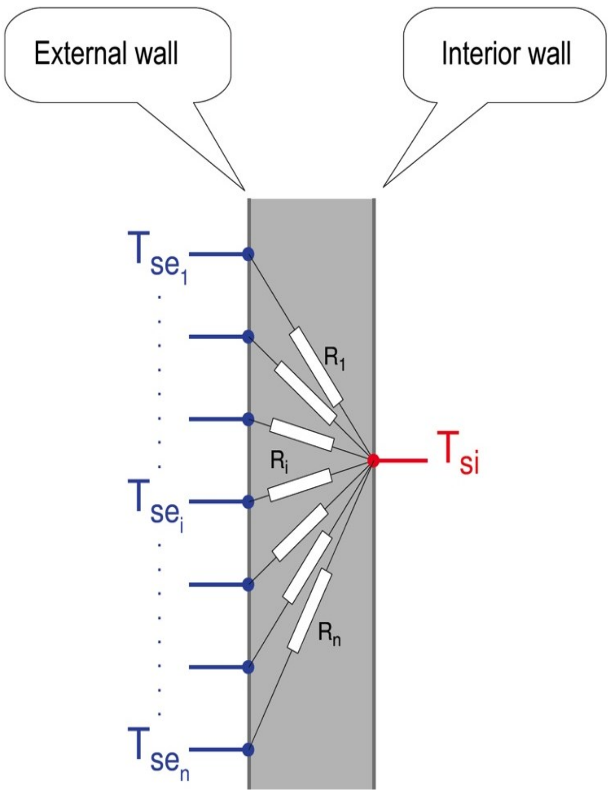


Figure 5. 22: Quantification of external building envelope
Source: (Bouyer, 2009)

The assembly of the components is shown is Figure (5.23).

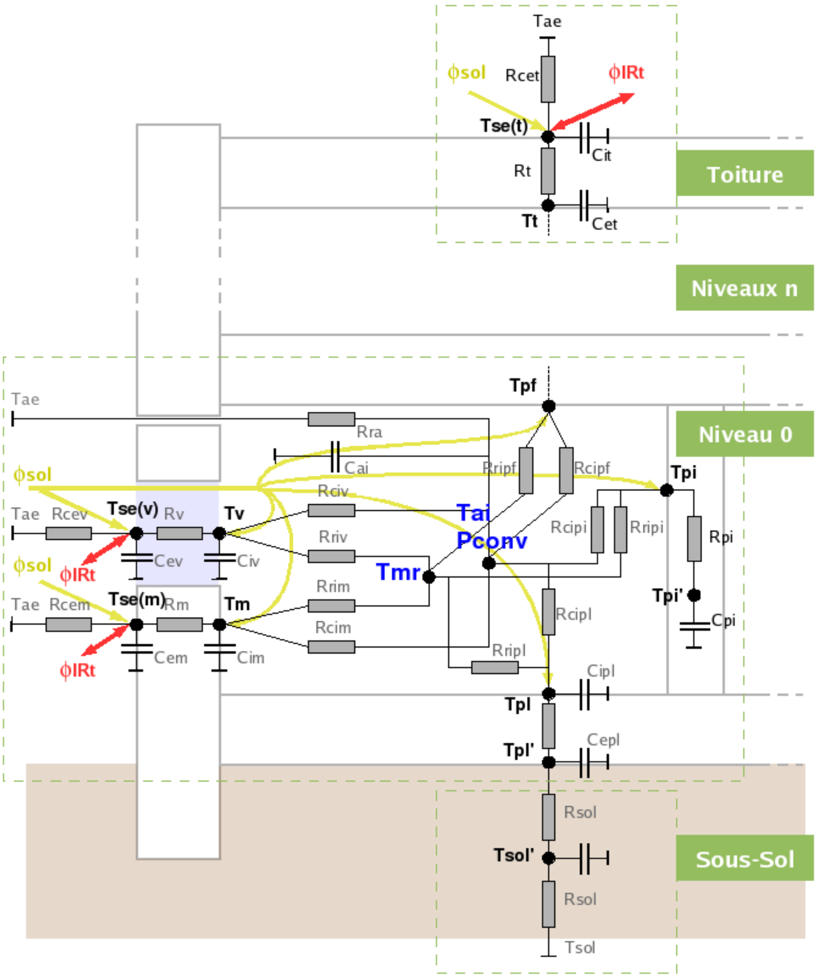


Figure 5. 23: Schematic representation of the complete thermal modeling of a building in the simulation tool

Source: (Bouyer, 2009)

a. Soil Model

The soil model is similar, with three capacities and 3 resistances as described on fig; 5.30.

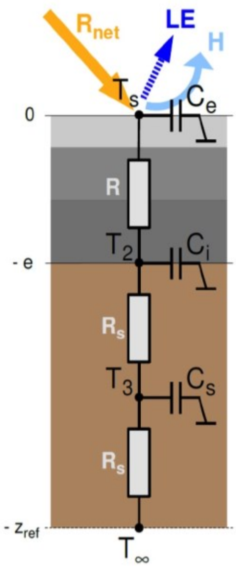


Figure 5. 24: Soil thermal model
Source: (Bouyer, 2009)

5.9.3. The coupling with the CFD code, Code_Saturne

The coupling is performed between either the thermo-radiative Solene model, the BES model and Code_Saturne[13]. This later deals with the distribution of wind on all the urban scene. It helps evaluating the convective heat transfer coefficient (CHTC) depending of local air velocity (see Figure 5.31). This model also provides the possibility of calculating the air temperature and humidity distribution on the urban scene by considering convective exchanges between each urban surface and air, and resolving equations of conservation (momentum, mass continuity, energy, species transport and using k-e turbulence model[14]) (Malys, 2012).

Bouyer (2011) analyzed the different principles of coupling. He “proposed an intermediate coupling whereby velocity and turbulence fields are pre-processed for each wind direction and velocity. Then, for each time step during iterative process, only transport equations for energy and moisture are solved. Computational cost is considerably reduced; this intermediate approach is tantamount to assuming that airflow is not disturbed by heat transfer at wall surface" (Musy et al., 2015).

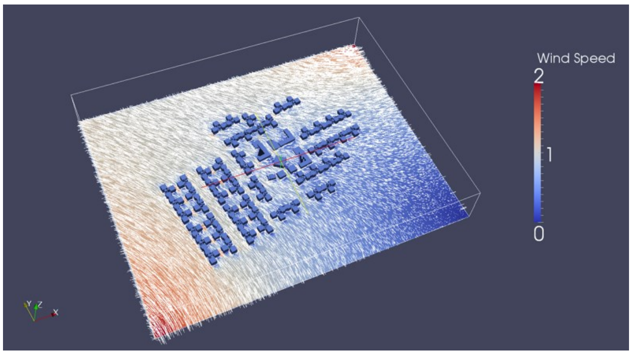


Figure 5. 25: Wind velocity distribution in AL-HADBA complex with an incoming wind from North-West

Source: The researcher

5.9.4. Other sub models and simulation aspects of SOLENE-microclimat

SOLENE-microclimat provides different possibilities to study different situations in the urban scene for various kinds of surfaces and volumes in order to evaluate their impact on building energy demand or indoor/outdoor thermal comfort, such as the presence of trees, lawns, green roofs, green walls.

a. Thermal comfort modeling, through estimating the MRT

As discussed in part one, among methods of estimating indoor/outdoor, Mean Radiant Temperature was proposed by researchers. MRT can be calculated in SOLENE-Microclimate.

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[13] Code_Saturne is a general purpose computational fluid dynamics. Developed since 1997 at Électricité de France R&D, Code_Saturne is distributed under the GNU GPL licence.

[14] k-e turbulence model is turbulence model is the most common model used in Computational Fluid Dynamics (CFD) to simulate mean flow characteristics for turbulent flow conditions.

Vinet's study (2000) is the first one which applied this method through defining the so-called "bonhomme confort" (see Figure 5.32). It is a human representative geometry on which MRT is calculated. It is worth mentioning that estimating MRT led to evaluating several comfort indices which are:

- Operative temperature,
- Predictive Mean vote, PMV* (Robitu, 2005),
- Physiological Equivalent Temperature, PET (Athamena, 2012), and
- Universal Thermal Climate Index, UTCI (Weihs et al., 2012).

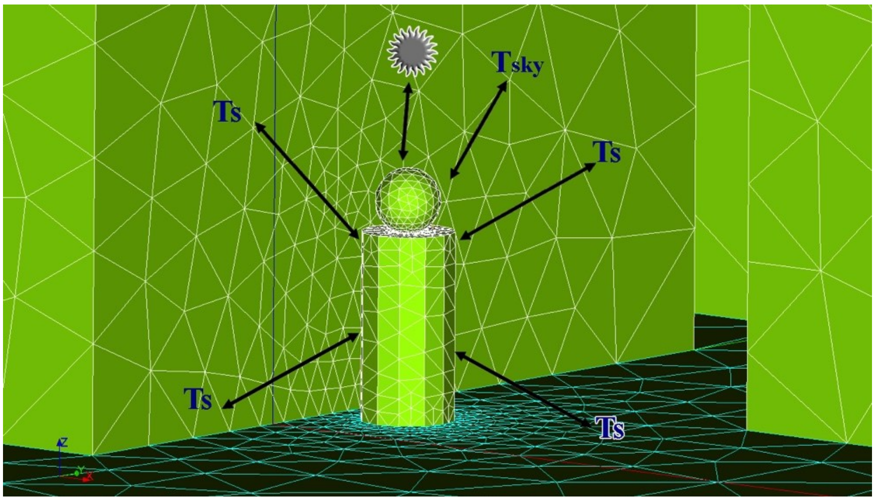


Figure 5. 26: "Bonhomme confort" in a meshed scene
(Ts: surface temperature, Tciel: sky temperature)
Source: Adapted from (Vinet, 2000)

b. Study the effect of Vegetation on the urban environmental

The influence of urban vegetation such as green roof, green wall and trees in the urban scene can be modeled and simulated by this tool, in order to evaluate the envelopes influencing this strategy on both inside and outside environment.

Trees modeling

Radiative impact of trees is considered taking into account their shading (transparent surface) and sun radiation absorption, as well as their long-wave radiation and aerodynamic resistance. Foliage temperature is calculated as well as latent mass and energy exchanges, see Figure (5.33). They are considered as a porous media inducing pressure losses. Air temperature and humidity within the tree is calculated from convection flux and transpiration calculation.

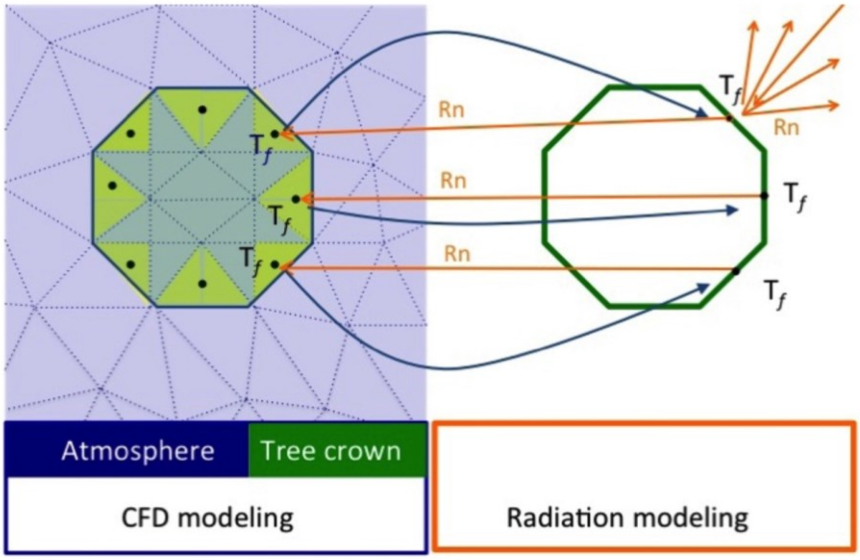


Figure 5. 27: Trees modeling by Solene-microclimat
Source: (Musy et al., 2015)

Green wall and green roof modeling

In 2012 Malys has introduced green roofs and walls (Figure 5.34).

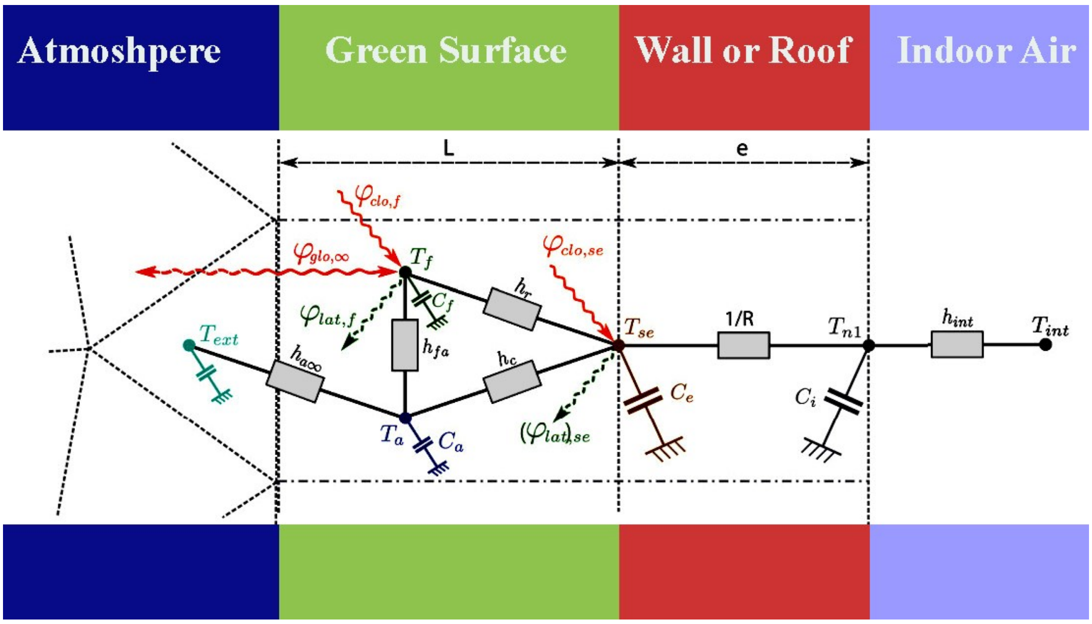


Figure 5. 28: Green wall and roof modeling by Solene-Microclimat
Source: Adapted from (Musy et al., 2015)

The presence of green walls or green roofs affects the exchanges within the urban form through several physical phenomena: latent, radiation and convective exchanges. They are modeled as a supplementary layer in the wall model, in which air temperature and humidity are calculated. The leaves layer partially shades the wall surfaces and exchange radiations with the other surfaces of the scene, instead of the wall.

5.10. The simulation steps of this study

The simulation process to complete the goal of this study by using different models of SOLENE-microclimate will be as follows:

1. Simulation by using thermo-radiative model

Step one	**This step consists of three sub-steps** **One-** The objective is **to identify the effect of the urban density** on the results. Four cases study will be simulated: 153 buildings, 128 buildings, 102 buildings, 42 buildings, **Two-** The objective is **to identify the effect of dimension of virtual air volume** on the results, **Three-** The objective is **to build initial perception regarding the thermal behavior of the construction materials** selected. In this step three categories of materials will be dealt with: • Existing materials in the case study project (*Al-hadbaa residential complex)* • Types of materials used in case study region (*Mosul-Iraq*) • Types of materials developed in France
Step two	**The objective of this step,** is to recognize the thermal behavior of materials selected when applied on buildings, through the calculation of the interior and exterior surface temperatures, as well as the selection of the wall design. In this step, the same categories of materials will be applied for four walls types : wall with thickness 12 cm, wall with thickness 20 cm, cavity air wall, and cavity rock-wool wall **This step consists of two sub-steps** ***Sub-Step one:*** the final selection of the appropriate type of materials and wall type. ***Sub-Step two:*** the final selection of the appropriate type of wall shape among 12 types.

Final conclusion regarding the type of construction materials, which will influence the orientation of the next steps of the research methodology (simulation).

<table>
<tr><td>Step three</td><td>This step consists of two sub-steps
Sub-Step one: The objective of this sub-step is to select the suitable alternative complementary solution that help to:
<table><tr><th>Either</th><th>Or</th></tr><tr><td>Increase the level of indoor thermal comfort e.g. natural ventilation</td><td>Increase the level of outdoor thermal comfort e.g. green wall</td></tr></table>
'As a proactive step, in order to demonstrate the next steps of the methodology, and also based on what the results of step two has shown, the alternative complementary solutions that help to increase the level of outdoor thermal comfort will be selected'.
In this regards, three alternatives solutions are proposed: double wall, vegetated system (green wall), and variation of reflection coefficient (high albedo value).

Sub-Step two: The objective of this step is to recognize the best wall shape among the same types of wall shape that is used in type three, which is 12 types.
In this step the final decision related to selection of the walls shape will be made.</td></tr>
</table>

2. Simulation by using thermal model

Step Four	**This step consists of two sub-steps** **The objective of this step** is: ***Sub-Step one:*** to calculate the indoor air temperature inside the building spaces. The simulation will be conducted for different scenarios of the complementary solution that is selected. ***Sub-Step two:*** to estimate the energy needed to maintain acceptable thermal comfort for occupants. The simulation will be conducted for the complementary solution that is selected.

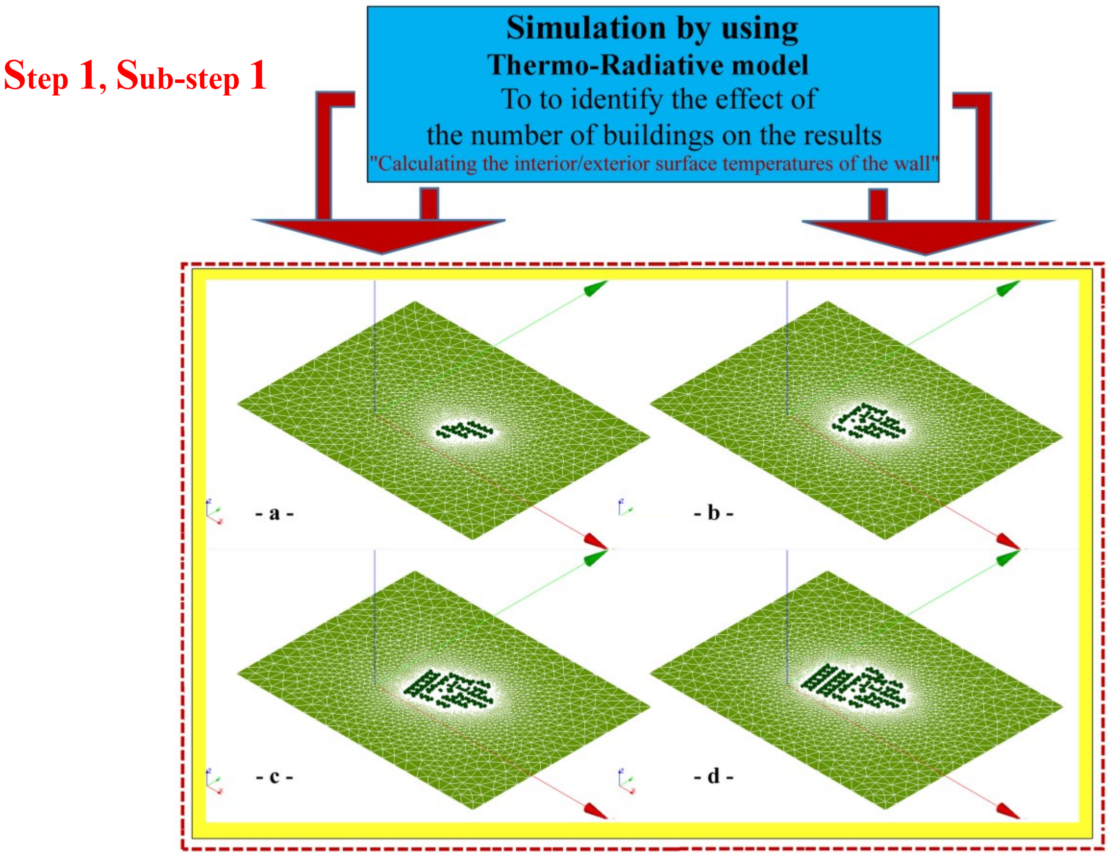
3. Simulation Simulation base on coupling between the thermo-radiative model and MRT Model

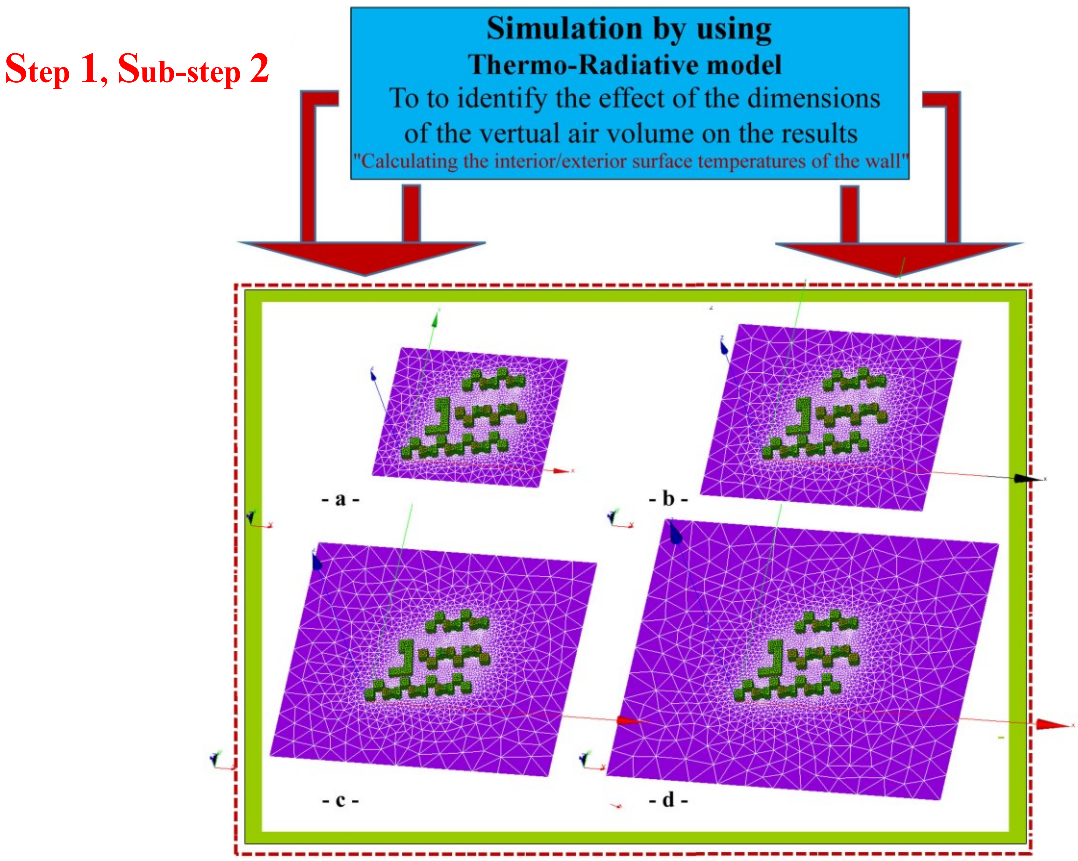
Step Five	**The objective of this step** is to find the outdoor mean radiant temperature. Simulation is carried out using the thermal model coupled with the mean radiant temperature model.

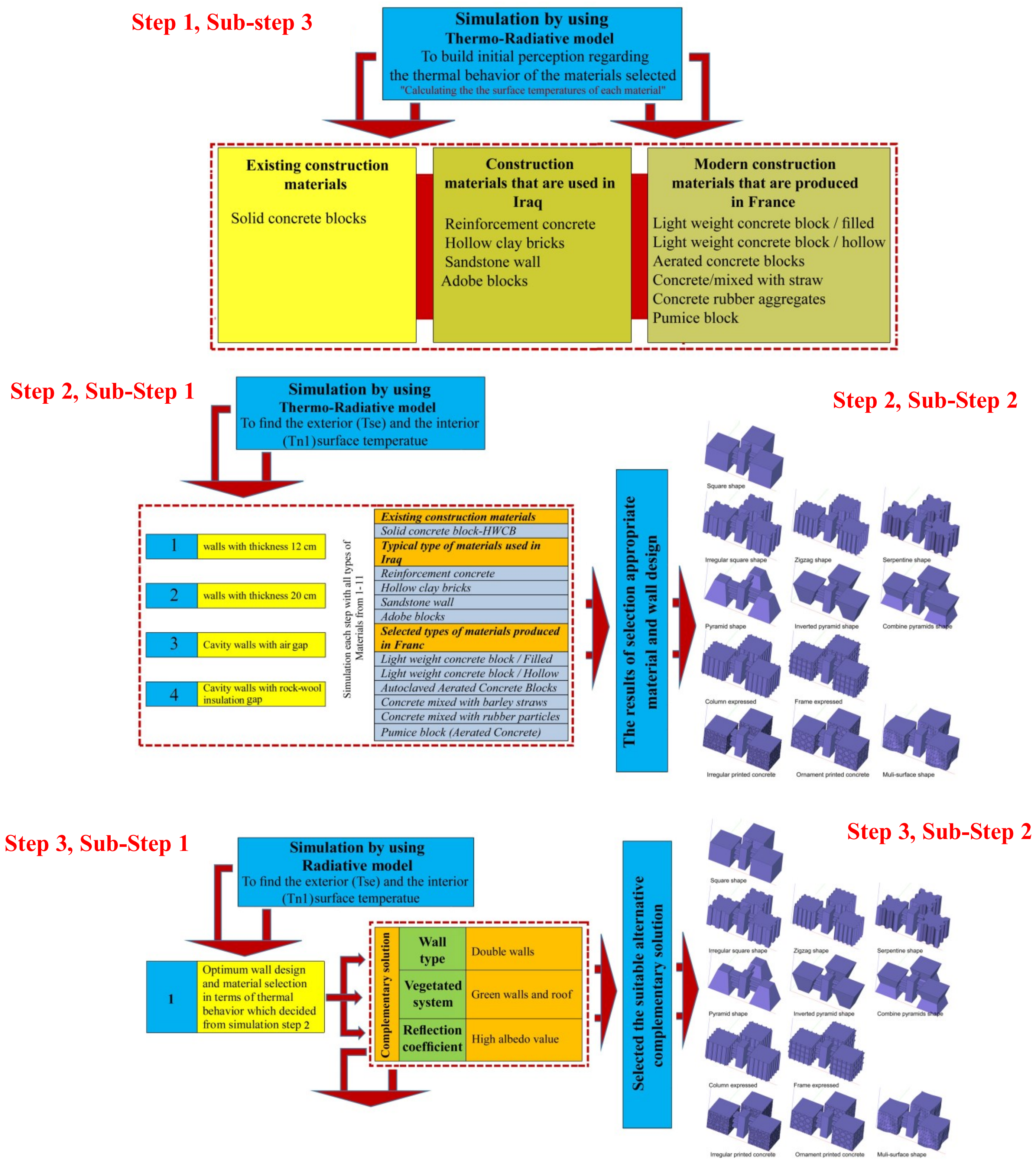
4. Simulation base on coupling between the thermo-radiative model and the aeraulic model

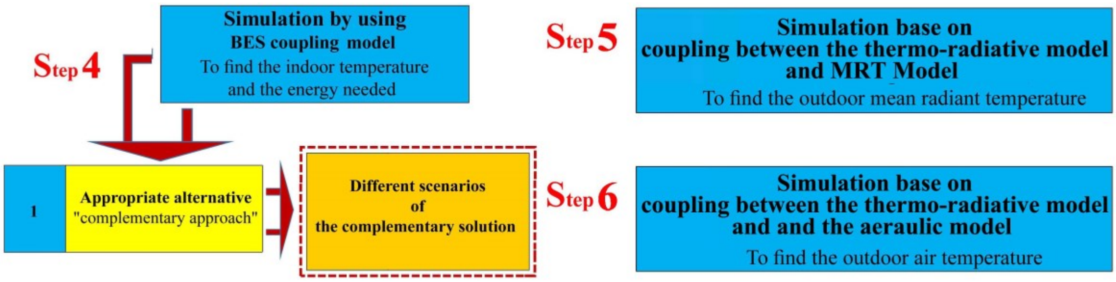
Step Six	**The objective of this step** is to find the outdoor air temperature. Simulation is carried out using thermal model coupled with energy balance equation to find the outdoor mean radiant temperature.

For further understanding and details regarding the methodology steps, graphical manner will be used as a follows:


Step 1, Sub-step 1
Simulation by using
Thermo-Radiative model
To to identify the effect of
the number of buildings on the results
"Calculating the interior/exterior surface temperatures of the wall"
- a -
- b -
- c -
- d -


Step 1, Sub-step 2
Simulation by using
Thermo-Radiative model
To to identify the effect of the dimensions
of the vertual air volume on the results
"Calculating the interior/exterior surface temperatures of the wall"
- a -
- b -
- c -
- d -


Step 1, Sub-step 3
Simulation by using
Thermo-Radiative model
To build initial perception regarding
the thermal behavior of the materials selected
"Calculating the the surface temperatures of each material"
Existing construction materials
Solid concrete blocks
Construction materials that are used in Iraq
Reinforcement concrete
Hollow clay bricks
Sandstone wall
Adobe blocks
Modern construction materials that are produced in France
Light weight concrete block / filled
Light weight concrete block / hollow
Aerated concrete blocks
Concrete/mixed with straw
Concrete rubber aggregates
Pumice block
Step 2, Sub-Step 1
Simulation by using
Thermo-Radiative model
To find the exterior (Tse) and the interior (Tn1)surface temperatue
1
walls with thickness 12 cm
2
walls with thickness 20 cm
3
Cavity walls with air gap
4
Cavity walls with rock-wool insulation gap
Simulation each step with all types of Materials from 1-11
Existing construction materials
Solid concrete block-HWCB
Typical type of materials used in Iraq
Reinforcement concrete
Hollow clay bricks
Sandstone wall
Adobe blocks
Selected types of materials produced in Franc
Light weight concrete block / Filled
Light weight concrete block / Hollow
Autoclaved Aerated Concrete Blocks
Concrete mixed with barley straws
Concrete mixed with rubber particles
Pumice block (Aerated Concrete)
The results of selection appropriate material and wall design
Step 2, Sub-Step 2
Square shape
Irregular square shape
Zigzag shape
Serpentine shape
Pyramid shape
Inverted pyramid shape
Combine pyramids shape
Column expressed
Frame expressed
Irregular printed concrete
Ornament printed concrete
Muli-surface shape
Step 3, Sub-Step 1
Simulation by using
Radiative model
To find the exterior (Tse) and the interior (Tn1)surface temperatue
1
Optimum wall design and material selection in terms of thermal behavior which decided from simulation step 2
Complementary solution
Wall type
Double walls
Vegetated system
Green walls and roof
Reflection coefficient
High albedo value
Selected the suitable alternative complementary solution
Step 3, Sub-Step 2
Square shape
Irregular square shape
Zigzag shape
Serpentine shape
Pyramid shape
Inverted pyramid shape
Combine pyramids shape
Column expressed
Frame expressed
Irregular printed concrete
Ornament printed concrete
Muli-surface shape



5.10.1. The numerical air volume

Concerning the size of numerical air volume, four cases will be tested varying the dimensions towards the X and Y axes, while the dimension towards Z will be ten times the height of the highest building or structure for all cases (Bouyer 2009b). The dimensional details are shown in the table (5.3) and Figure (5.35).

	Study zone	X_1 axis	Y_1 axis	Z_1 axis	Air volume size	Fig.
Case 1	X × Y× Y 150 × 130 × 11 m	$X_1 = 0.25$ X $X_1 = 37.5$ m	$Y_1 = 0.25$ Y $Y_1 = 32.5$ m	$Z_1 = 10$ Z $Z_1 = 110$ m	$(X+2X_1) \times (Y+2Y_1) \times Z_1$ 225 × 195 × 110	5.34-a
Case 2	X × Y× Y 150 × 130 × 11 m	$X_1 = 0.5$ X $X_1 = 75$ m	$Y_1 = 0.5$ Y $Y_1 = 65$	$Z_1 = 10$ Z $Z_1 = 110$ m	$(X+2X_1) \times (Y+2Y_1) \times Z_1$ 300 × 260 × 110	5.34-b
Case 3	X × Y× Y 150 × 130 × 11 m	$X_1 = 0.75$ X $X_1 = 112.5$ m	$Y_1 = 0.75$Y $Y_1 = 97.5$	$Z_1 = 10$ Z $Z_1 = 110$ m	$(X+2X_1) \times (Y+2Y_1) \times Z_1$ 375 × 325 × 110	5.34-c
Case 4	X × Y× Y 150 × 130 × 11 m	$X_1 =$ X $X_1 = 150$ m	$Y_1 =$ Y $Y_1 = 130$ m	$Z_1 = 10$ Z $Z_1 = 110$ m	$(X+2X_1) \times (Y+2Y_1) \times Z_1$ 450 × 390 × 110	5.34-d

Table 5. 2: The size of numerical air volume of different scenarios

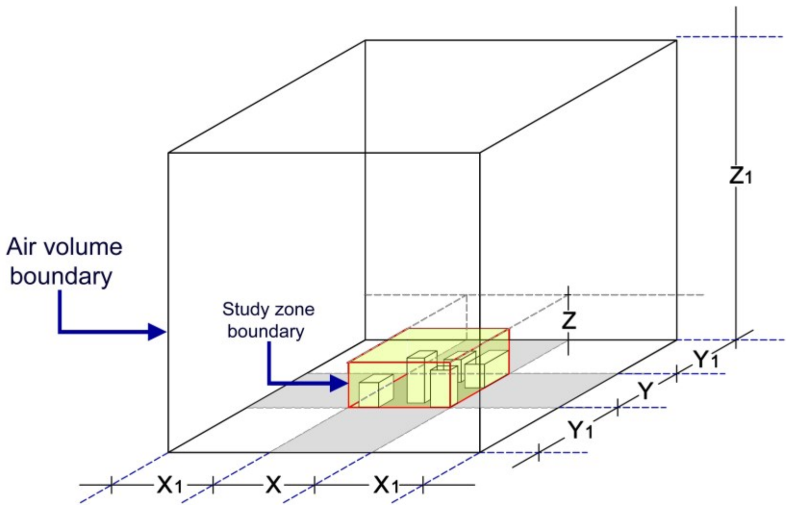


Figure 5. 29: The numerical air volume

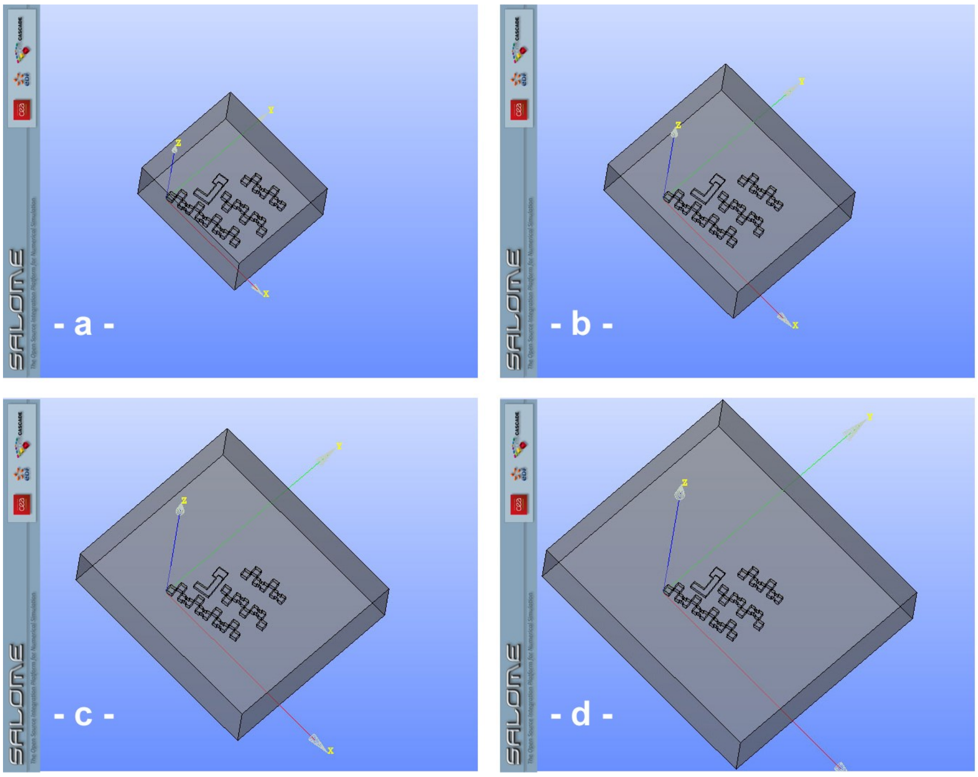


Figure 5. 30: The size of numerical air volume of different scenarios

5.10.2. Materials reflection coefficient scenarios for building, roofs, and urban surfaces

According the literature review, there is an agreement that using high albedo for roofs with range 0.7–0.85 leads to reduce the effect of UHI as well as to reduce the energy needs for cooling.

For pavement, the situation is different, some studies conclude that the reflective passages reduce the air temperature and finally reduce the UHI, while others conclude it increases building energy needs through reflection of solar radiation onto buildings' walls and into buildings through windows.

The conclusions are mainly depending on the nature of the spatial relation between the buildings as well as the building's design (shape the exterior wall, thermal properties materials, shading elements). For example, when there are vast distance between the buildings, the cool pavements help to reduce the ambient air temperature where the shortwave radiation will be reflected, while in case the narrow space between buildings, the shortwave radiation reflected onto building leads to increase the external surfaces temperature and increase the urban air temperature.

Accordingly, different scenarios of reflective coatings were proposed, differing in the reflection coefficient of rooftop, external walls, roads, urban spaces, and pavements with the purpose:

1-To determine the difference in the effect of using a high reflectivity material as compared to low reflectivity material.

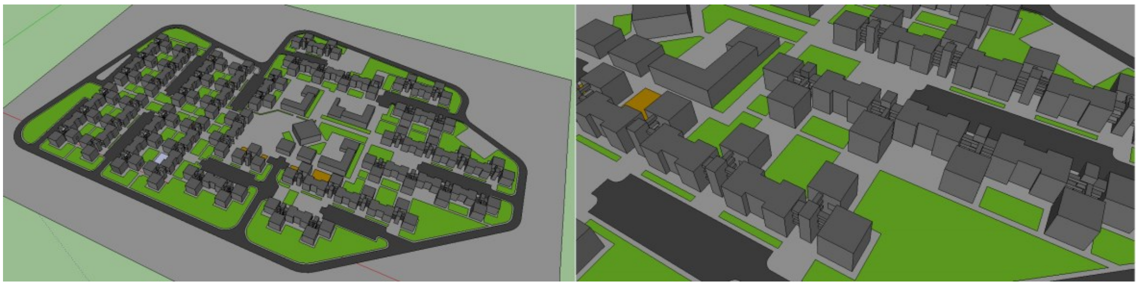
2- To select the right albedo value for each component.

The first comparison:

This comparison will be carried out between two scenarios, the use of low or high albedo for roofs.

Scenario one: *The use of low albedo roof materials*

Components	**Albedo value**	**Components**	**Albedo value**
North elevation	0.25	*Roads*	0.25
South elevation	0.25	*Pavements and urban spaces*	0.25
Est elevation	0.25	*Roofs*	0.25
West elevation	0.25	*Green area*	0.28



Scenario two: The use of high albedo roof materials

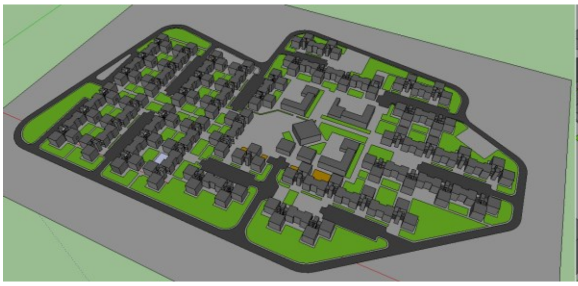
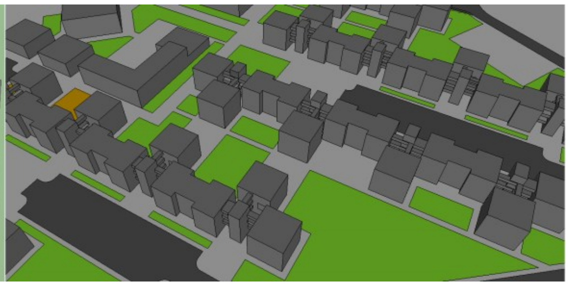
Components	**Albedo value**	**Components**	**Albedo value**
North elevation	0.25	*Roads*	0.25
South elevation	0.25	*Pavements and urban spaces*	0.25
Est elevation	0.25	*Roofs*	0.8
West elevation	0.25	*Green area*	0.28

The second comparison:

This comparison will be carried out also between two scenarios, the use of the old asphalt classic series (low albedo-black color) and the new types (high albedo-not black color).

Scenario one: The use of the old asphalt classic series

Components	Albedo value	Components	Albedo value
North elevation	0.25	*Roads*	0.25
South elevation	0.25	*Pavements and urban spaces*	0.25
Est elevation	0.25	*Roofs*	0.25
West elevation	0.25	*Green area*	0.28

Scenario two: The use of the new type asphalt

Components	Albedo value	Components	Albedo value
North elevation	0.25	*Roads*	0.6
South elevation	0.25	*Pavements and urban spaces*	0.7
Est elevation	0.25	*Roofs*	0.25
West elevation	0.25	*Green area*	0.28


The third comparison:

This step consists of 4 sub-comparisons to find the appropriate albedo value for each elevation of the buildings.

Sub-comparisons one:

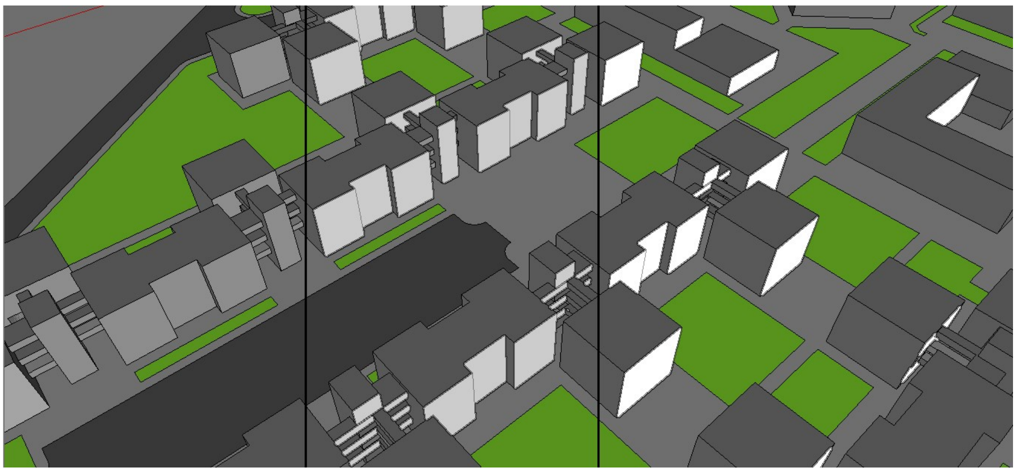
This comparison includes four scenarios that differ in the albedo value of the northern facade of the building, as follows

North Elevation – albedo value – 0.5			
Components	**Albedo value**	**Components**	**Albedo value**
North elevation	0.5	*Roads*	0.6
South elevation	0.8	*Pavements and urban spaces*	0.7
Est elevation	0.8	*Roofs*	0.8
West elevation	0.8	*Green area*	0.28

North Elevation – albedo value – 0.6			
Components	**Albedo value**	**Components**	**Albedo value**
North elevation	0.6	*Roads*	0.6
South elevation	0.8	*Pavements and urban spaces*	0.7
Est elevation	0.8	*Roofs*	0.8
West elevation	0.8	*Green area*	0.28

North Elevation – albedo value – 0.7			
Components	**Albedo value**	**Components**	**Albedo value**
North elevation	0.7	*Roads*	0.6
South elevation	0.8	*Pavements and urban spaces*	0.7
Est elevation	0.8	*Roofs*	0.8
West elevation	0.8	*Green area*	0.28

North Elevation – albedo value – 0.8			
Components	**Albedo value**	**Components**	**Albedo value**
North elevation	0.8	*Roads*	0.6
South elevation	0.8	*Pavements and urban spaces*	0.7
Est elevation	0.8	*Roofs*	0.8
West elevation	0.8	*Green area*	0.28



North ELE. | Albedo = 0.5 North ELE. | Albedo = 0.6 North ELE. | Albedo = 0.7

Sub-comparisons two:

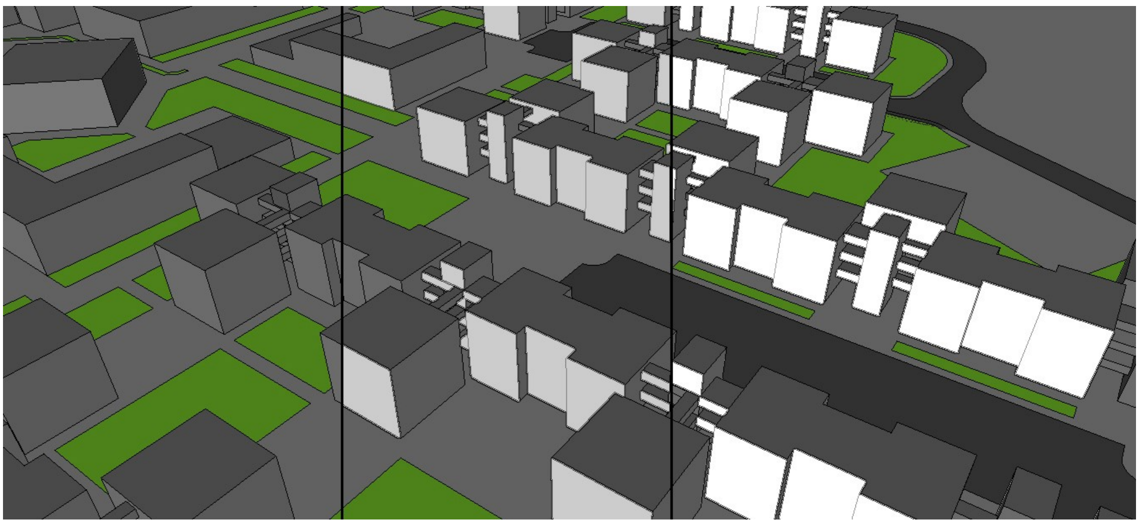
This comparison includes four scenarios that differ in the albedo value of the southern facade of the buildings, as follows

South Elevation – albedo value – 0.5			
Components	**Albedo value**	**Components**	**Albedo value**
North elevation	0.8	*Roads*	0.6
South elevation	0.5	*Pavements and urban spaces*	0.7
Est elevation	0.8	*Roofs*	0.8
West elevation	0.8	*Green area*	0.28

South Elevation – albedo value – 0.6			
Components	**Albedo value**	**Components**	**Albedo value**
North elevation	0.8	*Roads*	0.6
South elevation	0.6	*Pavements and urban spaces*	0.7
Est elevation	0.8	*Roofs*	0.8
West elevation	0.8	*Green area*	0.28

South Elevation – albedo value – 0.7			
Components	**Albedo value**	**Components**	**Albedo value**
North elevation	0.8	*Roads*	0.6
South elevation	0.7	*Pavements and urban spaces*	0.7
Est elevation	0.8	*Roofs*	0.8
West elevation	0.8	*Green area*	0.28

South Elevation – albedo value – 0.8			
Components	**Albedo value**	**Components**	**Albedo value**
North elevation	0.8	*Roads*	0.6
South elevation	0.8	*Pavements and urban spaces*	0.7
Est elevation	0.8	*Roofs*	0.8
West elevation	0.8	*Green area*	0.28



South ELE. | Albedo = 0.5 South ELE. | Albedo = 0.6 South ELE. | Albedo = 0.7

Sub-comparisons three:

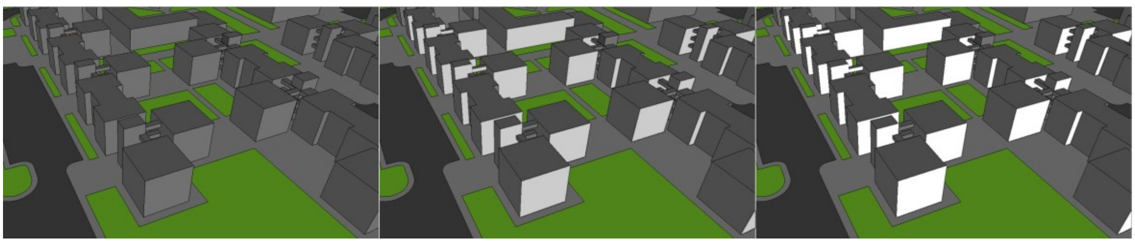
This comparison includes four scenarios that differ in the albedo value of the eastern facade of the buildings, as follows

East Elevation – albedo value – 0.5			
Components	**Albedo value**	**Components**	**Albedo value**
North elevation	0.8	*Roads*	0.6
South elevation	0.8	*Pavements and urban spaces*	0.7
Est elevation	0.5	*Roofs*	0.25
West elevation	0.8	*Green area*	0.28

East Elevation – albedo value – 0.6			
Components	**Albedo value**	**Components**	**Albedo value**
North elevation	0.8	*Roads*	0.6
South elevation	0.8	*Pavements and urban spaces*	0.7
Est elevation	0.6	*Roofs*	0.25
West elevation	0.8	*Green area*	0.28

East Elevation – albedo value – 0.7			
Components	**Albedo value**	**Components**	**Albedo value**
North elevation	0.8	*Roads*	0.6
South elevation	0.8	*Pavements and urban spaces*	0.7
Est elevation	0.7	*Roofs*	0.25
West elevation	0.8	*Green area*	0.28

East Elevation – albedo value – 0.7			
Components	**Albedo value**	**Components**	**Albedo value**
North elevation	0.8	*Roads*	0.6
South elevation	0.8	*Pavements and urban spaces*	0.7
Est elevation	0.8	*Roofs*	0.25
West elevation	0.8	*Green area*	0.28



East ELE. | Albedo = 0.5 East ELE. | Albedo = 0.6 East ELE. | Albedo = 0.7

Sub-comparisons three:

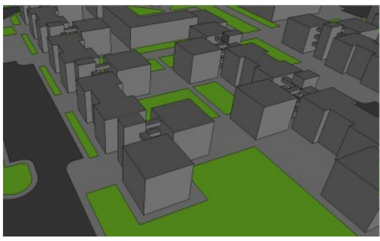
This comparison includes comparing among four scenarios that differ in the albedo value of the westtern facade of the buildings, as follows

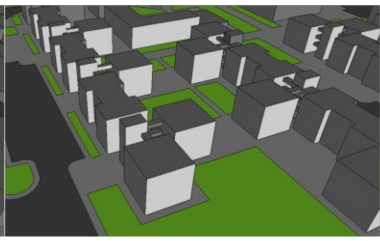
West Elevation – albedo value – 0.5			
Components	**Albedo value**	**Components**	**Albedo value**
North elevation	0.8	*Roads*	0.6
South elevation	0.8	*Pavements and urban spaces*	0.7
Est elevation	0.8	*Roofs*	0.8
West elevation	0.5	*Green area*	0.28

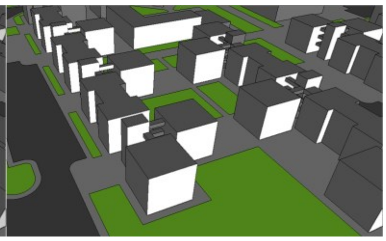
West Elevation – albedo value – 0.6			
Components	**Albedo value**	**Components**	**Albedo value**
North elevation	0.8	*Roads*	0.6
South elevation	0.8	*Pavements and urban spaces*	0.7
Est elevation	0.8	*Roofs*	0.8
West elevation	0.6	*Green area*	0.28

West Elevation – albedo value – 0.7			
Components	**Albedo value**	**Components**	**Albedo value**
North elevation	0.8	*Roads*	0.6
South elevation	0.8	*Pavements and urban spaces*	0.7
Est elevation	0.8	*Roofs*	0.8
West elevation	0.7	*Green area*	0.28

West Elevation – albedo value – 0.8			
Components	**Albedo value**	**Components**	**Albedo value**
North elevation	0.8	*Roads*	0.6
South elevation	0.8	*Pavements and urban spaces*	0.7
Est elevation	0.8	*Roofs*	0.8
West elevation	0.8	*Green area*	0.28


West ELE. | Albedo = 0.5


West ELE. | Albedo = 0.6


West ELE. | Albedo = 0.7

5.10.3. The different walls design

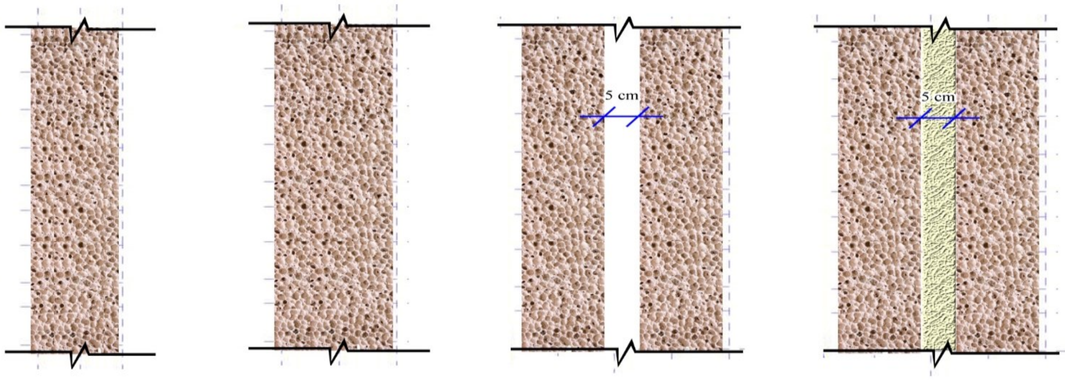
Regarding the wall design, the most common types that are used in the case study region will adopt, which are

Single layer wall with thickness 12 cm, see Figure (5.31a)

Single layer wall with thickness 24 cm, see Figure (5.31b)

Cavity air wall, see Figure (5.31c)

Cavity Rockwool, see Figure (5.31d)



-a- -b- -c- -d-

Figure 5. 31: Wall layer design

5.10.4. The different walls shape

This step consists of a large number of simulations with various forms of walls but the same material, decided in step one of the simulation (pumice block). The reference case is the normal type of the wall (Square wall), with the objective to implement whether there is any effect of the outside wall shape on the outside surface temperature (Tse) when the wall have high albedo value and low albedo value, see Figure (5.32).

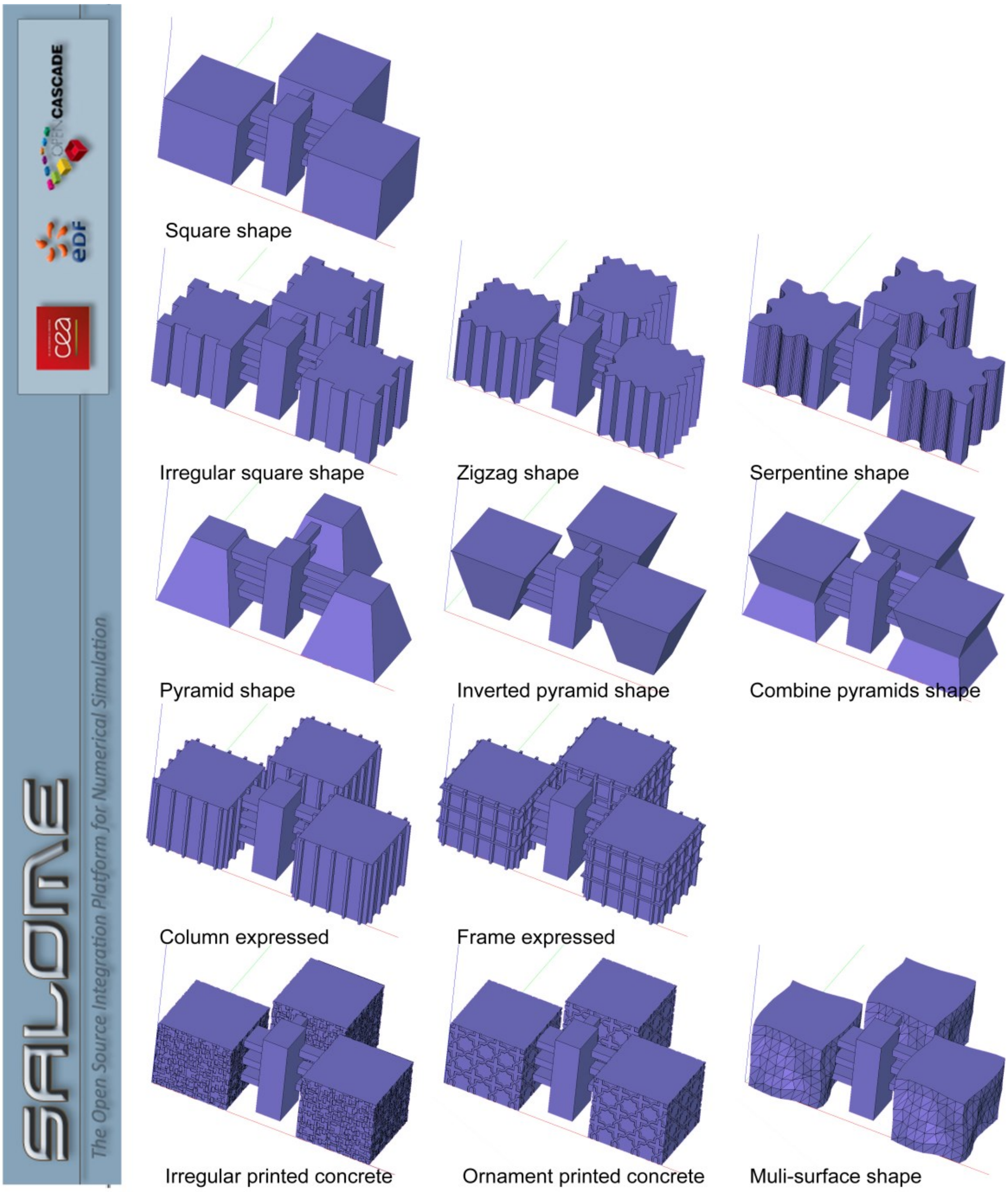


Figure 5. 32: The wall shape types

The types of the walls Adapted in the simulation were classified as follows:

1	Group one	Square wall
2	Group two	Irregular wall, Zig zag wall, and Arc wall
3	Group three	Pyramid wall, Inverted pyramid wall, and Combine pyramid wall
4	Group four	Wall-column outside, and Wall-column and floor outside
5	Group five	Printed concrete type one, and Printed concrete type two
6	Group six	Multi-surface building

5.10.5. The temperature balance in a neighborhood and calculation of the air temperature

In this part, we try to compare the differences between the meteorological temperature and the temperature of the air around the buildings. It is therefore necessary to calculate this temperature of the air, which depends on the exchanges with the surfaces of the scene.

This study will use the method proposed by Laurent MALYS, already explained in the chapter one.

$$c_a \rho_a V_a \frac{T_{eq,t} - T_{eq,t-1}}{\Delta t} = F_{conv}(T_{eq,t}) + c_a Q_m (T_{meteo} - T_{eq,t})$$

5.11. Summary and conclusion

After discussing many details concerning the case study which are closely related to the analysis and the simulation in chapter four, this chapter has moved on to clarify the requirements of the practical phase. It has consisted of two sections: the theoretical framework and research variables and then the presentation of the simulation tool that has been used. The first section has begun with the process of identifying the indicators of the study and the methodology of the research. The second section has dealt with the tools and software which have been used for data collection and down to conduct a series of computer simulations with different orientations which will be in several stages to attain the required objectives of the study.

Part 3

The results and simulation

Summary

Chapter 6

THE RESULTS of STUDY

Summary

Section 1: Simulation Steps
1. The simulation steps

Section 2: The main points of the results
1. Mechanism of presenting results
2. Collection of indoor or outdoor surface temperature
3. The main points of the results and discussion

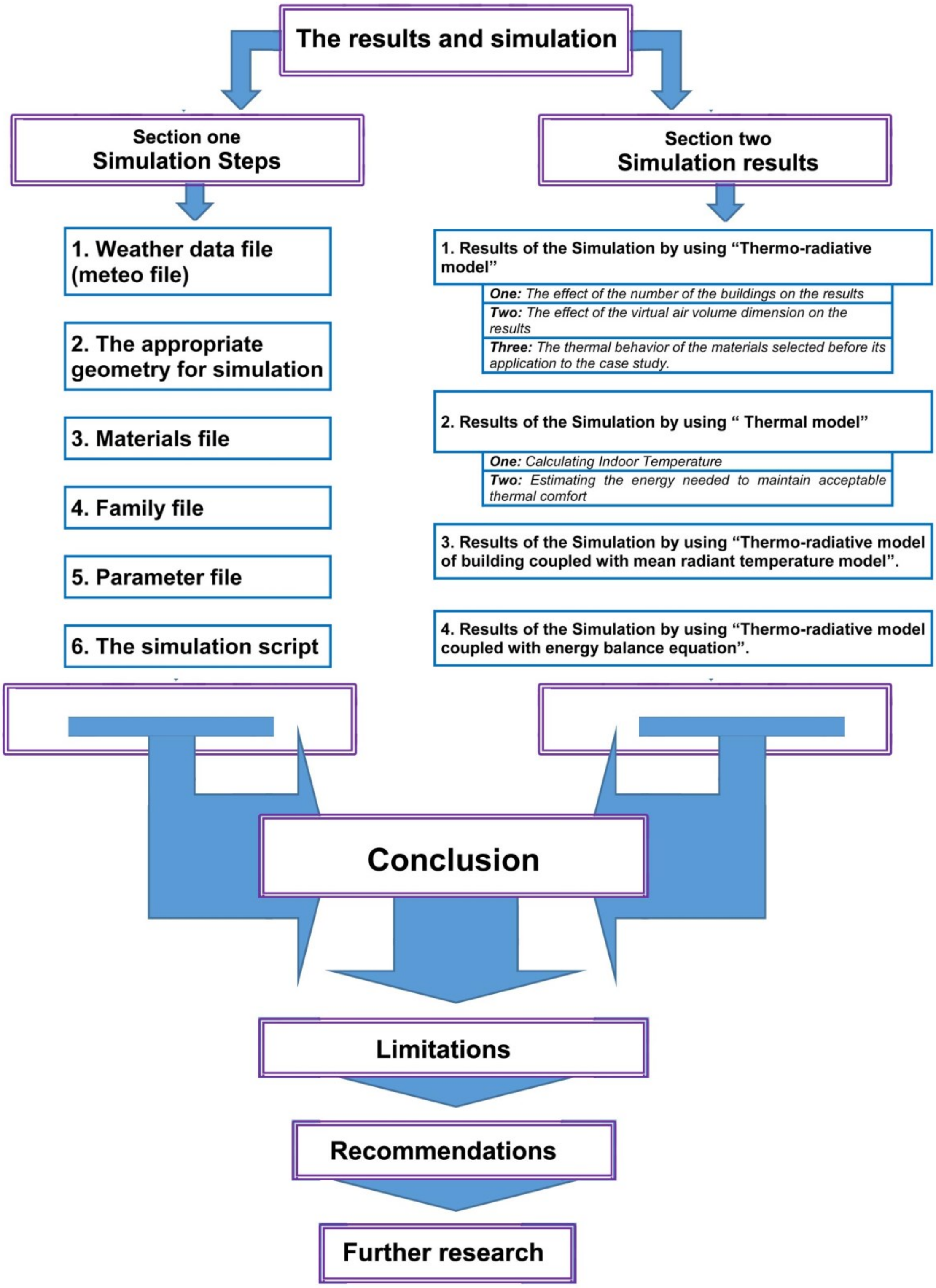


Figure 6. 1: Flow chart of chapter six

Chapter 6: The results and simulation

Section 1 Simulation Steps

6.1. Introduction

The present section of chapter six is designed to describe the preparatory steps before initiating the simulation. It is a prelude to the second part of this chapter which will focus on the results of the study. As it has already been mentioned in chapter III, there are six types of files must be initialized in order to conduct any simulation by using SOLENE-microclimat: geometry file, weather data file, materials file, family file, param file, and the script related to the suitable model of simulation. The following paragraphs contain the complementary steps for each one.

6.2. The Simulation Steps

The basic simulation steps of this study consists of two parts: 1/ the preparation steps which include preparation all the six files that necessary for simulation and 2/ the simulation steps.

6.2.1. Preparation Steps

6.2.1.1. ALHADBA complex geometry file:

SOLENE-microclimat deals with three-dimensional geometry file (with extension .med). This geometry comprises a set of triangles connected by their common edges or corners. Each triangle has a specific ID and a number of descriptors that define it. It is worth mentioning that any geometry should be created inside a virtual box which represents the urban air volume (see Figure 6.3). This numerical volume is represented as a box the dimensions of which are determined depending on the size of the area that will be studied.

To create appropriate geometry of the study four steps were followed, see Figure 6.2:

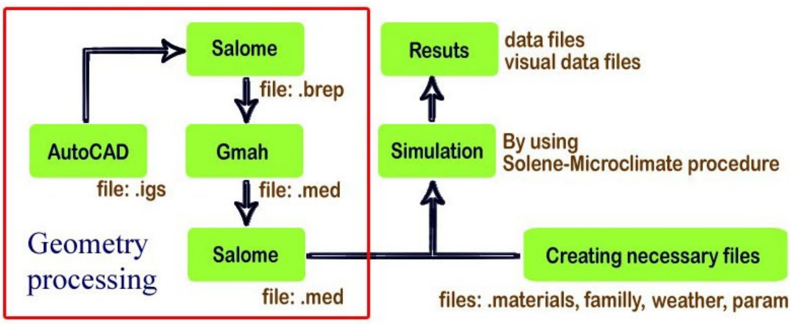


Figure 6. 2: The steps of creating geometry
Source: The researcher

1. The first step: By Auto CAD software, the target geometry is created. Then, it is split it into four components, each one representing a component of the urban form: buildings, streets, green areas, and urban open spaces. Finally, the four components are exported as (.igs) files to use it in SALOME platform. (See Figure 6.3).

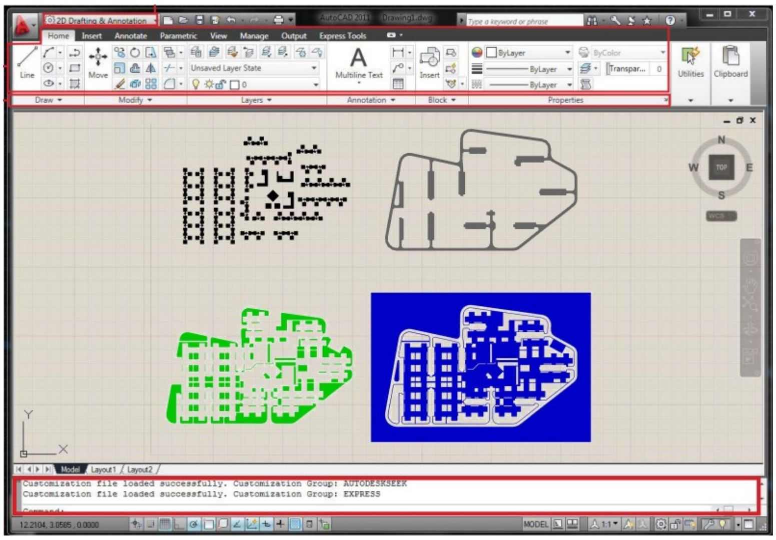


Figure 6. 3: Process of creating the geometry by Auto CAD software
Source: The researcher

2. The Second Step: The four components of the target geometry that have been created previously in Auto CAD software are imported in SALOME software. At this stage, the geometry is placed inside a box representing a virtual air volume. After completed the final geometry, it is exported as (.bred) file to use it in GMSH software in order to convert the geometry to mish form (see Figure 6.4).

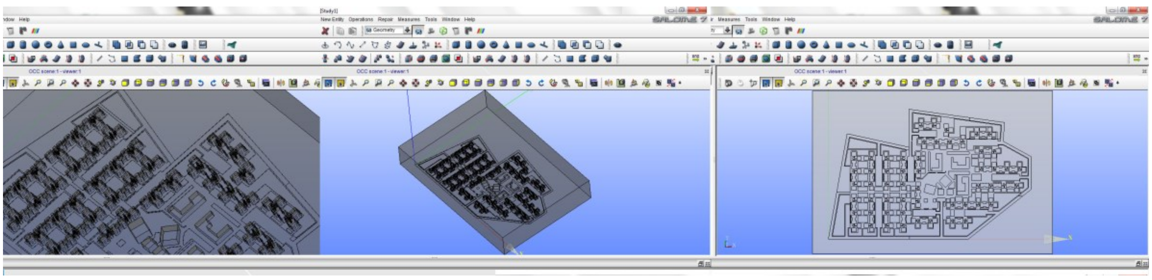


Figure 6. 4: The stage of SALOME software to create the geometry
Source: The researcher

3. The Third Step: GMSH software is started, the final geometry (.bred file) is opened in GMSH software, then saved it as (.geo) file. This geometry includes all urban components which are placed inside virtual air volume. In this step, physical groups and the characteristic lengths of points for control the mesh are defined. As a final step, the final geometry is saved as (.med) file.

4. The Fourth Step by using Salome, the geometry is re-exported and finally saves it as (med.) file to be ready for the simulation.

6.2.2 Weather data file and selecting the day of simulation

6.2.2.1 Weather data of Mosul city

In order to achieve the simulation, I got access to the Mosul weather file from *'Weather Analytics center-Washington'* which is the source for scientifically-precise data. (http://www.weatheranalytics.com/wa/). This file contains many data that are related to what is necessary for the simulation (see Figure 6.5), but there were still some data which are not included and therefore they have to be calculated, such as the infrared value (L) and Specific humidity.

```
Number  Name                     Description
1       SiteId
2       WsWaIdx         Internal Weather Analytics Index
3       DateHrGmt       Date and hour string in GMT [YYYY-MM-DD-HH]
4       DateHrLwt       Date and hour string in LWT [YYYY-MM-DD-HH]
5       Tsfc_F          Air temperature [Fahrenheit]
6       Tdew_F          Dew point temperature [Fahrenheit]
7       Twet_F          Wet bulb temperature [Fahrenheit]
8       Rh_PCT          Relative humidity [Percent]
9       Psfc_MB         Surface air pressure [Millibars]
10      CldCov_PCT      Cloud cover [Percent]
11      Twc_F           Wind chill index [Fahrenheit]
12      Tapp_F          Apparent (aka feels-like) temperature [Fahrenheit]
13      Spd_KTS         Wind speed [Knots]
14      Dir_DEG         Direction whence wind is blowing [Degrees]
15      PcpPrevHr_IN    Precip previous hour [Inches liquid-equivalent]
16      DnSol_WsqM      Downward solar radiation (Global Horizontal
Irradiation) [WattHours per square meter]
17      DiffHorz_WsqM   Diffuse horizontal radiation at sruface [WattHours
per square meter]
18      DirNormIr_WsqM  Direct normal irradiation at surface [WattHours per
square meter]
19      Spd_MPH         Wind speed [Miles per hour]
```

Figure 6. 5: Header keys of weather data file from Weather Analytics™ LLC

6.2.3 Materials file

According to the criteria for selecting the types of materials, eleven types of materials with three categories which have been considered in this study. These materials are the followings:

Existing construction materials	*Solid concrete block-OCB*
Typical type of materials used in Iraq	*Reinforcement concrete* *Hollow clay bricks* *Sandstone wall* *Adobe blocks*
Selected types of materials produced in Franc	*Light weight concrete block / Filled* *Light weight concrete block / Hollow* *Autoclaved Aerated Concrete Blocks* *Concrete mixed with barley straws* *Concrete mixed with rubber particles* *Pumice block (Aerated Concrete)*

6.2.4 Family file

This file contains the description configuration of each group of faces and sides of the project (wall, roof, windows, etc.) e.g. thickness of the walls, the number of layers, materials for each components, etc. Each group of faces within the family file is defined as follows:

1. Name: It represents the name of one face or group of faces which have the same characteristics.

2. Classe: In this file, each component of the urban scene is defined, which physical model must be used to calculate, for example, the surface temperatures and the fluxes. Indeed, they are different depending on whether it is considered as a wall, a ground, a vegetated soil, etc. All the types of classes used in SOLENE-microclimat are shown in Figure (6.6).

3. Albedo: it corresponds to reflection coefficient of each surfaces of the geometry, between (0-1)

4. Transmittance: it corresponds to the ability of surfaces on the light transmittance through it. It lvaries between 0 for a solid wall has and around 0.7 for glass, depending on the type of glass.

5. Emissivity: it corresponds to the material effectiveness in emitting energy as thermal radiation, between (0 – 1).

6. Layer: it corresponds to the number of layers for each surface of geometry components.

As a result, all these components are arranged with a certain sequence which responds to stimulation processes of SOLENE-microclimat Model.

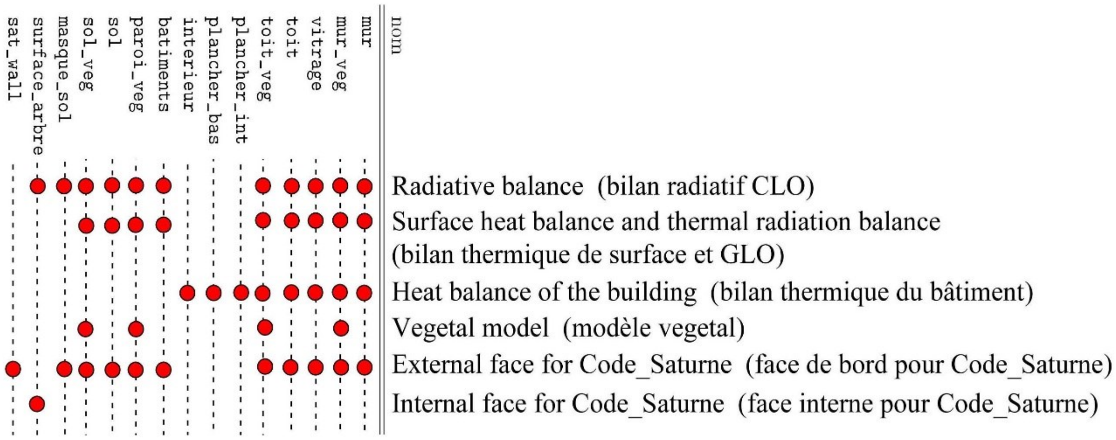


Figure 6. 6: SOLENE-Microclimat class types
Source: Adapted from SOLENE-Microclimat workshop 2014, CRENAU at ENSA Nantes

6.2.5. Parameter file

As it has already been mentioned, this file contains many parameters related to the solene model (the period of simulation, the paths of other solene initialization, solar flux, form factors, initialization wind, and etc). Concerning the period and the day of simulation, it is from 22th until 13th of July with concentrate to 13th of July as it has been discussed earlier in chapter four.

6.2.6 The simulation script

After preparing all the necessary files, the simulation is conducted as the following sequence:

1. Simulation by using thermo-radiative model.
2. Simulation by using thermal model (free thermal regime and force thermal regime).
3. Simulation base on coupling between the thermo-radiative model and MRT Model.
4. Simulation base on coupling between the thermo-radiative model and the aeraulic model.

Chapter 6 Results and simulation

Section 2 The main points of the results

6.3. Introduction

After specifying the limitations and simulation inputs in the previous chapter, the present chapter is confined to introduce, compare and evaluate simulation results. After the completion of all the steps of the simulation for case study in different scenarios, the result of this study will be shown in the following sequence:

1. Results of the Simulation by using "Thermo-radiative model"

Results of Simulation ***Step one*** *[initial steps of simulation]*	***Sub-Step one:*** The effect of the number of the buildings on the results. ***Sub-Step two:*** The effect of the virtual air volume dimension on the results. ***Sub-Step three*:** Initial choice regarding the thermal behavior of the materials selected before its application to the case study.
Results of Simulation ***Step two***	***Sub-Step one:*** Selection of an appropriate building materials and wall type. ***Sub-Step two:*** Selection of an appropriate wall shape.
Results of Simulation ***Step three***	***Sub-Step one:*** Comparison of three complementary solutions which will be collected, and finally selection of the appropriate alternative / complementary solution among three alternatives double wall, vegetated system (green wall), and variation of reflection coefficient (high albedo value). ***Sub-Step two:*** Complementary solutions selected vs wall shapes

2. Results of the Simulation that base on coupling between the thermo-radiative model and MRT Model"

Step four	***Sub-Step one:*** Indoor temperature of different scenarios of the complementary solution that is selected *"Free thermal regime"*. ***Sub-Step two:*** Comparison of the actual case study and the proposed case from previous sub-step regarding the energy needed to maintain acceptable thermal comfort *"Force thermal regime"*.

3. Results of the Simulation that base on coupling between the thermo-radiative model and the aeraulic model".

Step five	Comparison of the actual case study and the proposed case regarding the outdoor mean radiant temperature.

4. Results of the Simulation by using "Thermo-radiative model coupled with energy balance equation".

Step six	Comparison of the actual case study and the proposed case regarding the outdoor air temperature.

6.4. Mechanism of presenting results

The results of this study will be displayed through the use of many graphical ways showing the difference between tables, diagrams, and plot box, as well as the visual results (by using ParaView). Detailed results will be placed in the appendix at the end of the chapter. The main way to display the result in the context of this chapter is done through the use of the box plot diagram. The box plot "is a standardized way of displaying the distribution of data based on the five number summary: minimum, first quartile, median, third quartile, and maximum" (see Figure 6.7).

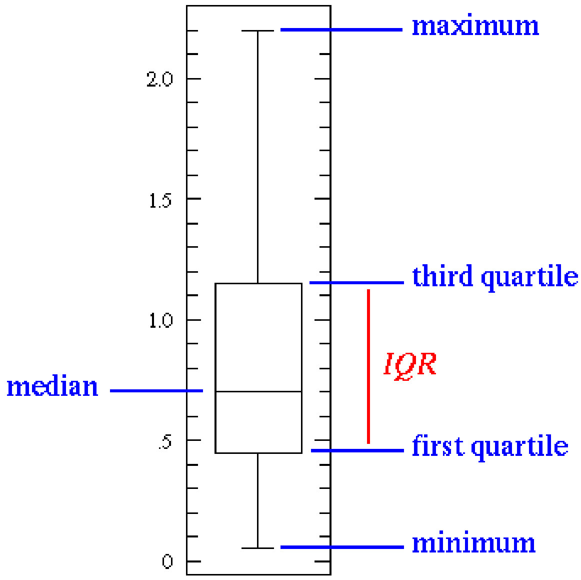


Figure 6. 7: Box Plot: the distribution of a dataset
Source: http://www.physics.csbsju.edu/stats/box2.html

Regarding the design of the box plot diagram for this study, it will be as it is shown in Figure (6.8). The distribution of the represented value (indoor temperature, surface temperature, and air temperature are measured) are given on the vertical axis. The comparison of these types is presented on the horizontal axis. The average of the measured values is presented as a small circle with a black color. In addition, this diagram has the distribution of temperature which is measured and based on the five number summary: minimum temperature, first quartile, median temperature, third quartile, and maximum temperature.

The diagrams showing temporal variations will take the shape shown in Figure (6.9). The indoor temperature, and/or the surface temperature, and/or the air temperature, the amount of Flux and in some diagram the energy are measured on the vertical axis. While the period of the simulation is measured on the horizontal axis and this shows the result of simulation for the last (24) hours of the total duration of the simulation, which starts from 22nd June until 13th July. Each diagram has a legend located at the upper left side which serves as a key for diagram contents.

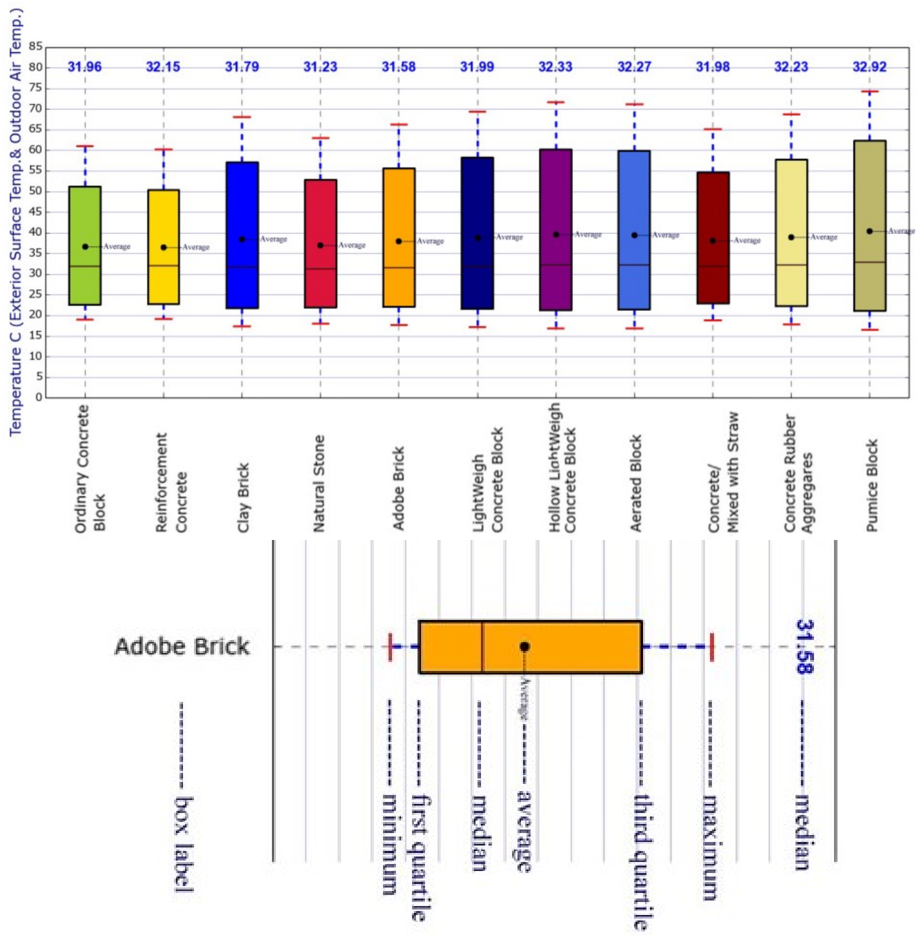


Figure 6. 8: Sample of the box plot results

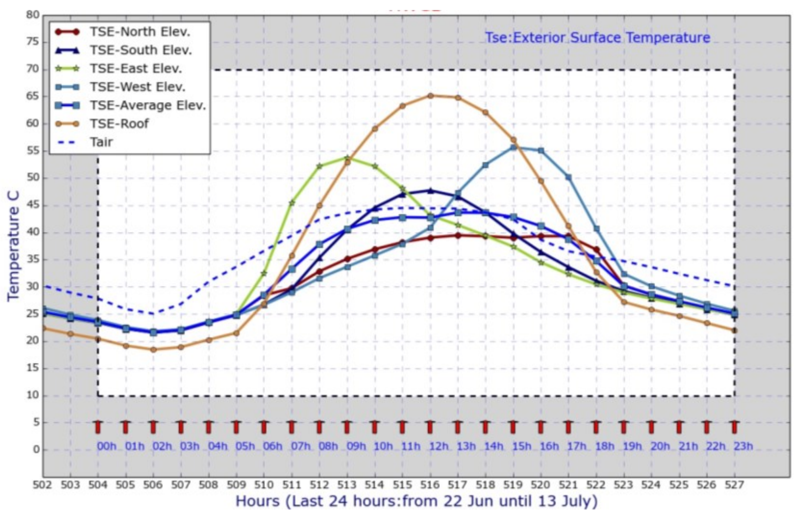


Figure 6. 9: Sample of the diagram plot results by Ipython

In addition, the results will be presented by using other types of charts provided by Excel.

6.5. Collection of indoor or outdoor surface temperature

The geometries consist of many faces, depending on the complexity of its geometry and size (see Figure 6.10). Each face consists of many mesh triangles, the number and size of which depend on the characteristic length of the geometry (see Figure 6.10). Each triangle has a specific name (ID), geometrical properties such as its area, material properties such as albedo for example, and after calculation, physical ones as its surface temperature, etc.

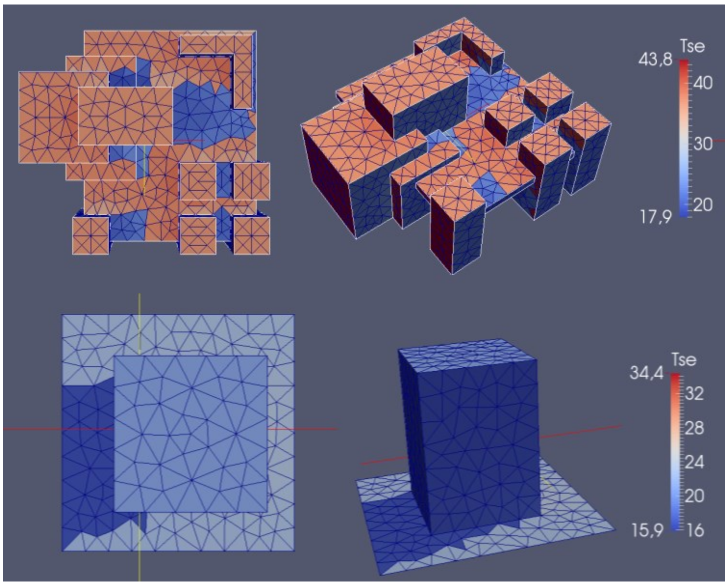


Figure 6. 10: Geometric shape represented by faces

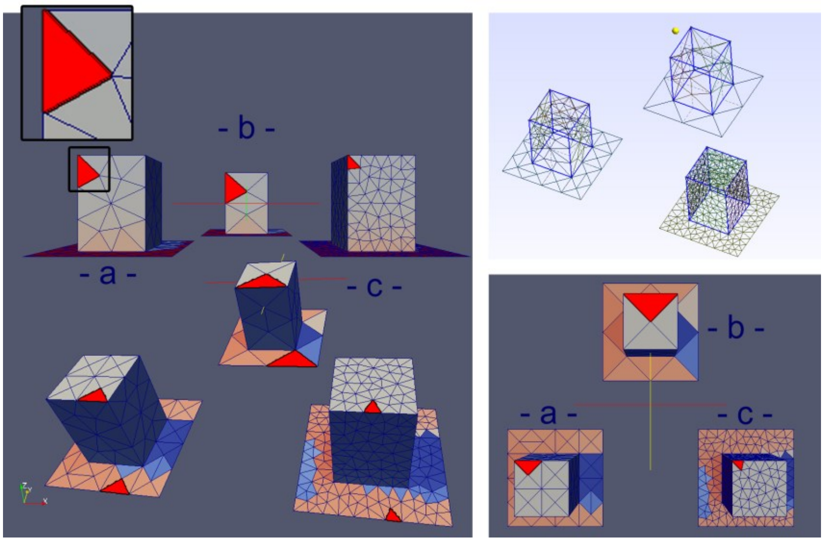


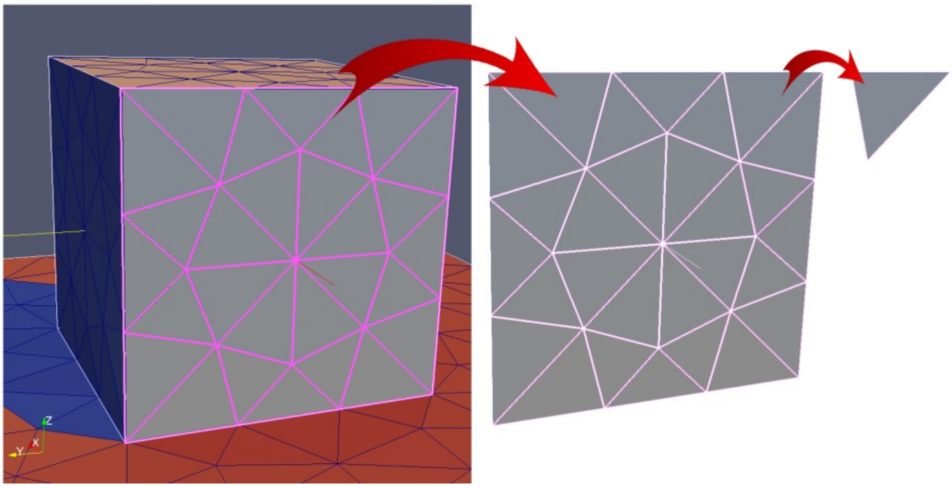
Figure 6. 11: Different characteristic length for same geometric faces

(Box size 5×5×7, the characteristic length of the geometry, respectively a=3, b=5, c=1)

In this study, the measured surface temperatures either exterior or interior, total flux, etc. correspond to the area-weighted average measurement values of the total surface. For example, to collect the data such as surface temperature, the average temperature of each surface will be taken, through applying the following equation:

$$Tse_{\text{one-face}} = \Sigma\, (Tse_{\text{triangle-1}} \times Area_{\text{triangle -1}}) + \ldots + (Tse_n \times Area_n) \,/\, Area_{\text{one-surface}}$$

Where	$Tse_{\text{one-face}}$	The surface temperature of one face
	$Area_{\text{one-face}}$	The area of one face
	$Tse_{\text{triangle -1}}$	The surface temperature of one triangle
	$Area_{\text{triangle -1}}$	The area of one triangle



Geometry consist of many faces   Face consist of many triangles   One triangle

Figure 6. 12: Basic geometric shape components

6.6. The main points of the results and discussion

The conclusions of this study reflect the simulations results of a target building of Al Hadba Residential Complex. This building represents the most frequent type (59%) of the total residential buildings (as description in chapter 4). Therefore, what we get from the results can be circulated to most buildings within this residential complex.

6.6.1. Results of the Simulation by using "Thermo-radiative model"

The simulation results by using "Thermo-radiative model" consists of three main steps and other sub-steps. In this part, the following conclusions are targeted:

- a. Identifying the difference in environmental performance of the building materials that have been selected before and after their application to the building.
- b. Determination of the wall design or type that fits the local reality in the region of study.
- c. Determination of the most appropriate wall form for the buildings of the case study.
- d. Determination of the appropriate complementary solution, that either "increase the level of indoor thermal comfort e.g. natural ventilation" or "increase the level of outdoor thermal comfort e.g. green wall" depending on what the results will show.

6.6.1.1. Step one | Sub-step one: Effect of the number of the buildings (scene size)

In this regard, the following question will be raised:

- ***Has the number of the buildings (urban density) any effect on the results of my case study?***

The following question will be raised: Has the number of the buildings (scene size) any effect on the results of the case study?

To answer this question, four different simulation scenarios are conducted. They differ in the number of buildings (153 buildings, 128 buildings, 102 buildings and 42 buildings). These four scenarios are created in the same virtual air volume dimensions (1530m x 600 m x 110 m).

After comparing simulation results of the four scenarios of buildings number (see Figures 13,14 and table 6.1), no difference is diagnosed among all the scenarios where the average exterior mean surface temperature of scenario 1, 2, 3, and 4, respectively is, 36.72 ºC, 36.63 ºC, 36.68 ºC, 36.61 ºC, while the average interior mean surface temperature of scenario 1, 2, 3, and 4, respectively is, 28.85 ºC, 28.81 ºC, 28.83 ºC, 28.80 ºC.

Therefore we can say: regarding our case study and according to the simulation model used (thermo-radiative model), the number of buildings did not have a significant impact on the results obtained for the studied building.

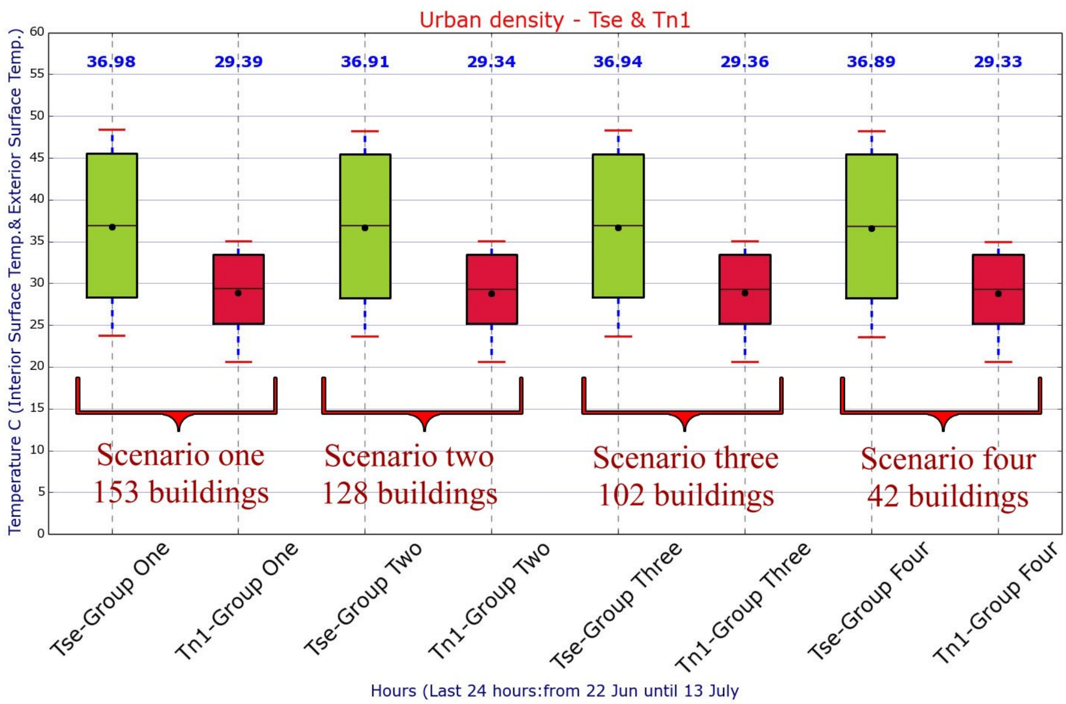


Figure 6. 13: Comparison results between different scene

		Scenario 1 153 Buildings	Scenario 2 128 Buildings	Scenario 3 102 Buildings	Scenario 4 42 Buildings
Exterior surface temperature (Tse) - ºC	Average	36.72 ºC	36.63 ºC	36.68 ºC	36.61 ºC
	Maximum	48.36 ºC	48.25 ºC	48.32 ºC	48.25 ºC
	Minimum	23.73 ºC	23.66 ºC	23.66 ºC	23.60 ºC
	Median	36.98 ºC	36.91 ºC	36.94 ºC	36.89 ºC
Interior surface temperature (Tn1) - ºC	Average	28.85 ºC	28.81 ºC	28.83 ºC	28.80 ºC
	Maximum	35.06 ºC	35.01 ºC	35.04 ºC	35.00 ºC
	Minimum	20.64 ºC	20.62 ºC	20.62 ºC	20.61 ºC
	Median	29.39 ºC	29.34 ºC	29.36 ºC	29.33 ºC

Table 6. 1: Exterior and Interior mean surface temperature for different scene

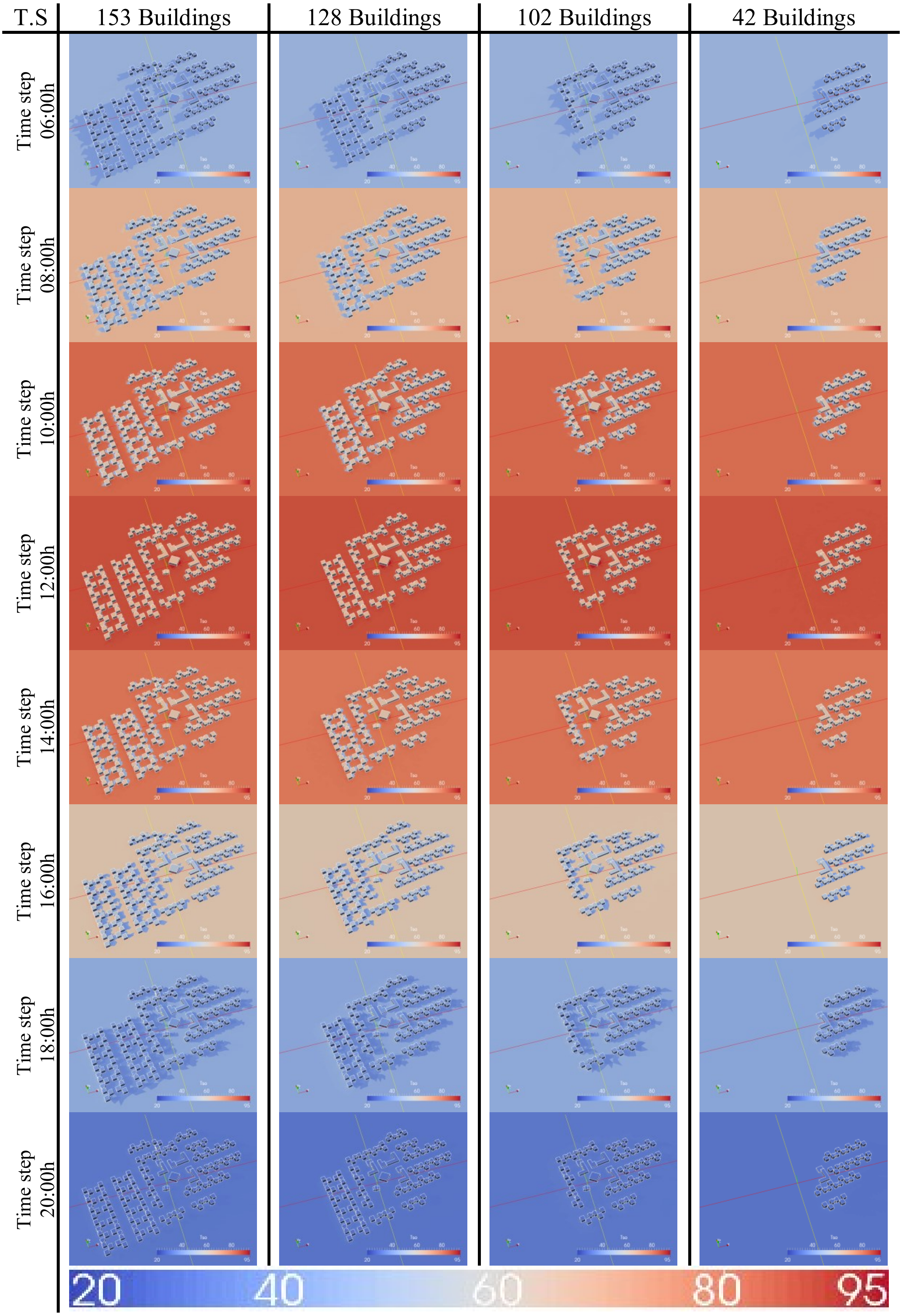


Figure 6. 14: Visual results regarding the exterior surface temperature for different scene size

6.6.1.2. Step one | Sub-step two: Effect of the virtual air volume

In this regard, the following question will be raised:

- ***Has the virtual air volume dimension any effect on the results of the case study?***

To answer this question, four different simulation scenarios were conducted. They were different in virtual air volume dimensions but they have the same urban size (buildings number) and the same height, which are:

The X and Y dimensions are close to the geometry boundary which is (150m), (130m) sequentially. The details dimensions of the four scenarios as follows:

Scenario 1				
Air volume one	:	(X1 × Y1 × L)	Fig. 6.6	First virtual air volume (225 × 195 × 110)
X1=X+(0.5×X) X1=150+(0.5×150) = 225 m		Y1=Y+(0.5×Y) Y1=130+(0.5×130) = 195 m		
Scenario 2				
Air volume two	:	(X2 × Y2 × L)	Fig. 6.6	Second virtual air volume (300 × 260 × 110)
X2=X+(1.0×X) X2=150+(1.0×150) = 300 m		Y2=Y+(1.0×Y) Y2=130+(1.0×130) = 260 m		
Scenario 3				
Air volume three	:	(X3 × Y3 × L)	Fig. 6.6	Third virtual air volume (375 × 325 × 110)
X3=X+(1.5×X) X3=150+(1.5×150) = 375 m		Y3=Y+(1.5×Y) Y3=130+(1.5×130) = 325 m		
Scenario 4				
Air volume four	:	(X4 × Y4 × L)	Fig. 6.6	Fourth virtual air volume (450 × 390 × 110)
X3=X+(2.0×X) X3=150+(2.0×150) = 450 m		Y4=Y+(2.0×Y) Y4=130+(2.0×130) = 390 m		

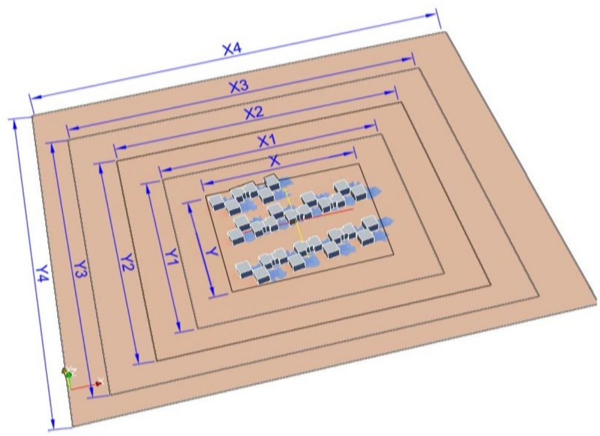
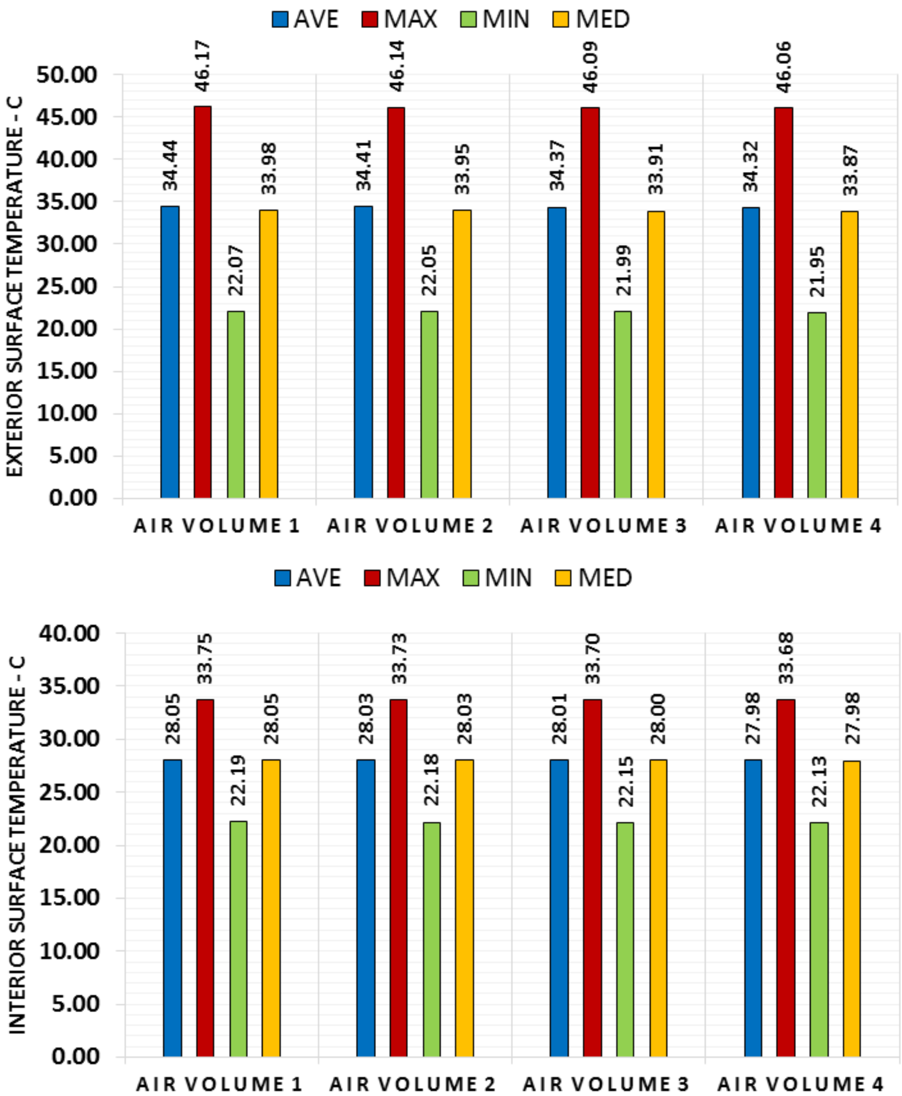


Figure 6. 15: The x- axis and y-axis of the virtual air volumes

The simulation results shown that the mean exterior surface temperature of scenario 1, 2, 3, and 4, respectively is, 34.44ºC, 34.41ºC, 34.37ºC, 34.32ºC (see Figures 6.16) while the mean interior surface temperature respectively is, 28.05ºC, 28.03ºC, 28.01ºC, 27.98ºC, no difference was diagnosed among all scenarios. Consequently and according to the simulation model that we use (thermo-radiative model), the dimension of the virtual air volume box has no significant effect on the results. However, concerning the position of a shading and visualizing the simulation results, the situation is different when the boundary of the numerical air volume is near to the boundary of the study zone, indeed some of the effects will be blocked (see Figure 6.17).



-A-

-B-

Figure 6. 16: A, the exterior mean surface temperature; B, the mean interior surface temperature for different scenarios of air volume dimension

		Air volume 1	Air volume 2	Air volume 3	Air volume 4
Exterior surface temperature (Tse) - ºC	Average	34.44 ºC	34.41 ºC	34.37 ºC	34.32 ºC
	Maximum	46.17 ºC	46.14 ºC	46.09 ºC	46.06 ºC
	Minimum	22.07 ºC	22.05 ºC	21.99 ºC	21.95 ºC
	Median	33.98 ºC	33.95 ºC	33.91 ºC	33.87 ºC
Interior surface temperature (Tn1) - ºC	Average	28.05 ºC	28.03 ºC	28.01 ºC	27.98 ºC
	Maximum	33.75 ºC	33.73 ºC	33.70 ºC	33.68 ºC
	Minimum	22.19 ºC	22.18 ºC	22.15 ºC	22.13 ºC
	Median	28.05 ºC	28.03 ºC	28.00 ºC	27.98 ºC

Table 6. 2: Exterior and Interior mean surface temperature for different virtual air volume dimensions

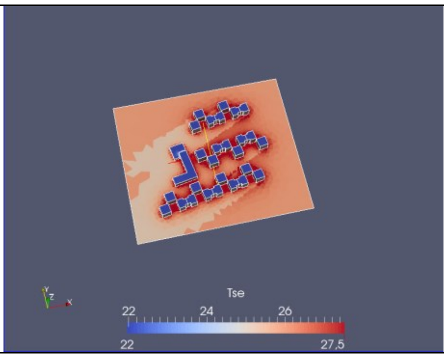
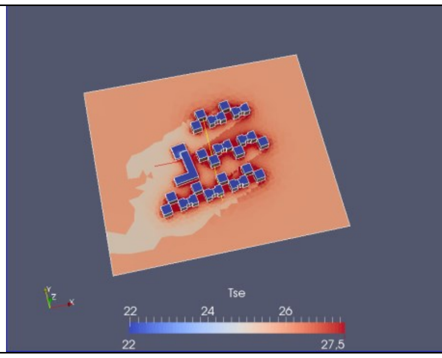
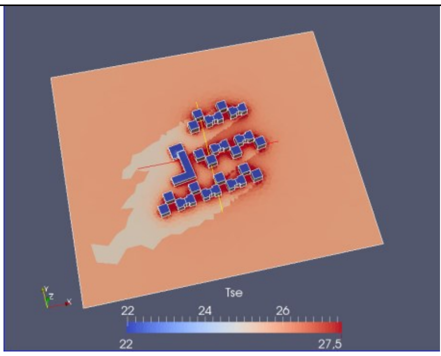
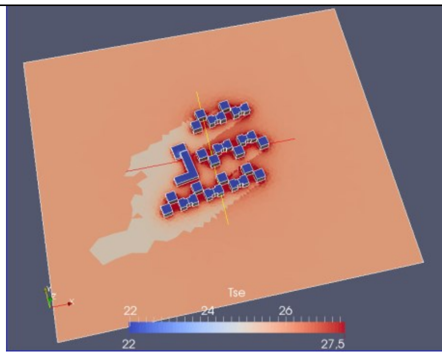
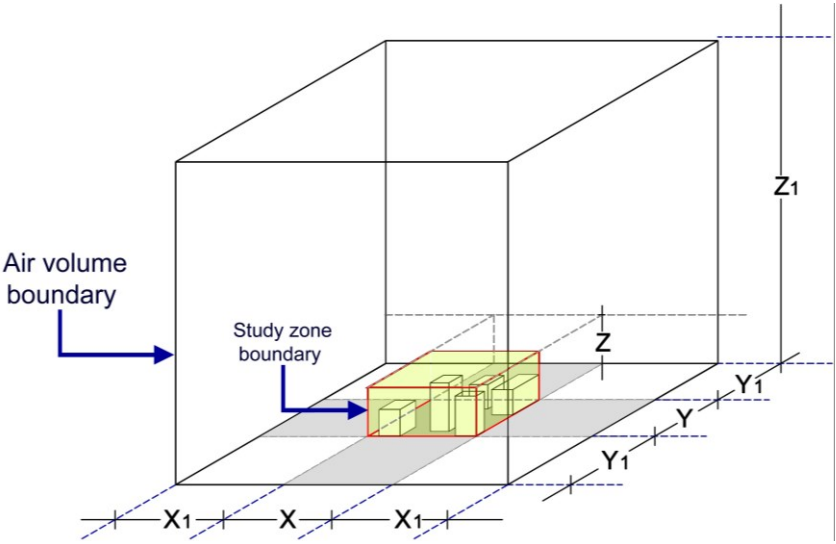
Numerical air volume one	Numerical air volume Two
	
Numerical air volume Three	Numerical air volume Four
	

Figure 6. 17: The numerical air volume vs the boundary of urban area

Therefore, we should determine the dimensions of the air volume which contribute to preserve the boundaries of numerical air volume effects as far away as possible from the volume of the study area. This is done in order to avoid blocking the effects keeping reasonable dimensions to limit the number of volume meshes which finally effect the simulation period. Therefore, this study concludes that the suitable numerical air volume for thermo-radiative Solene Model is as follows, see Figure 6.18:



X1 = X ; Y1 = Y ; Z1 = 10 Z

Figure 6. 18: The numerical air volume

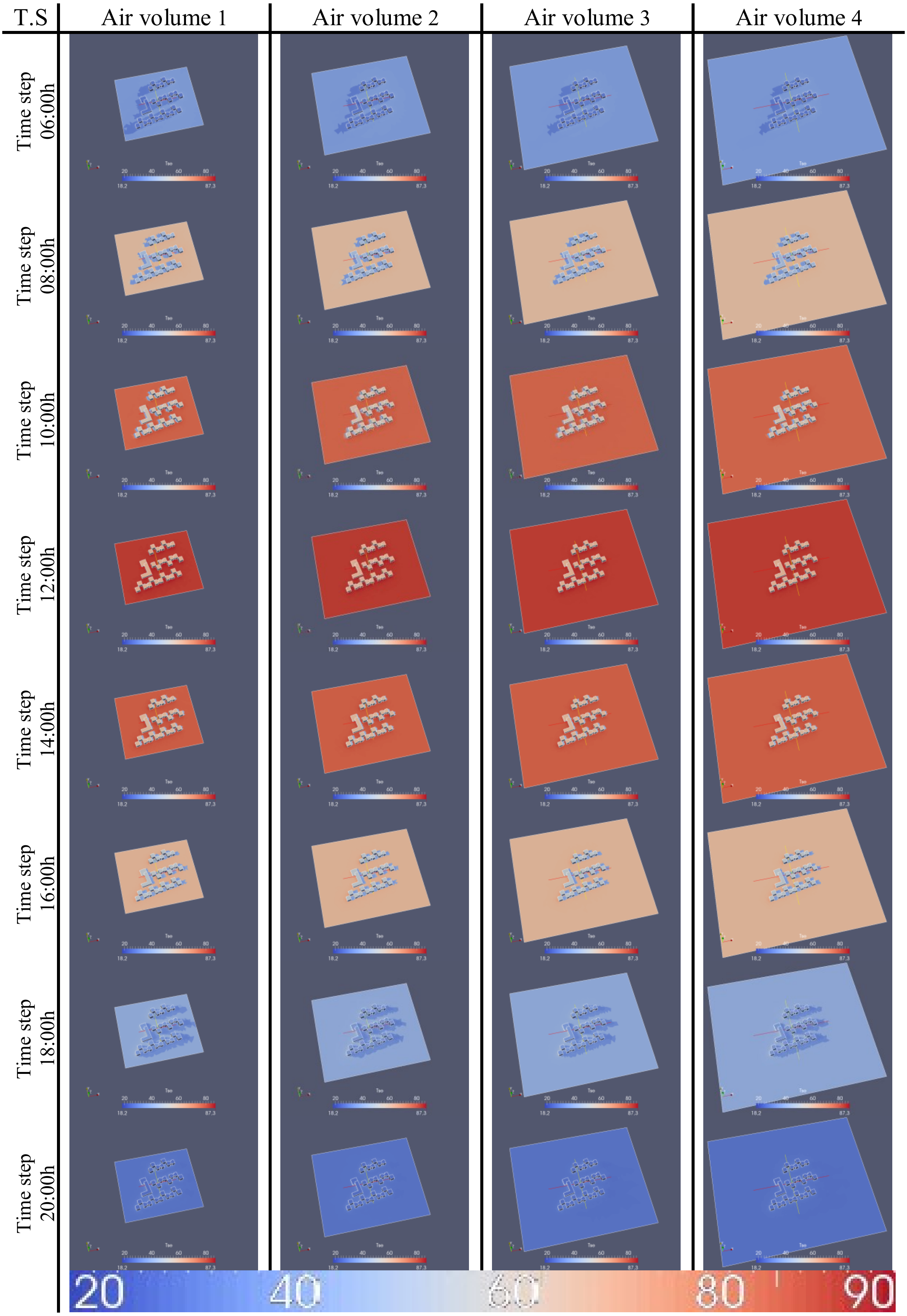


Figure 6. 19: Visual results regarding the exterior surface temperature for different air volume dimensions

6.6.1.3. Step one | Sub-step three: Initial perception regarding the thermal behavior of the construction materials

This step presents the results of a comparative study aiming at investigating the initial perception of the thermal performance of the building materials selected (table 6.3) which can be selected to be used for external building walls before being applied to the case study.

	Materials types	
Present construction materials	Ordinary concrete block	**OCB**
Typical type of materials used in Iraq	Reinforcement concrete	**REFC**
	Hollow clay bricks	**HClayB**
	Sandstone wall	**SStone**
	Adobe blocks	**Adobe**
Selected types of materials produced in France	Light weight concrete block / Filled	**LWCBF**
	Light weight concrete block / Hollow	**LWCBH**
	Autoclaved Aerated Concrete Blocks	**AeratedB**
	Concrete mixed with barley straws	**Cstraw**
	Concrete mixed with rubber particles	**CrubberB**
	Pumice block (Aerated Concrete)	**Pumice**

Table 6. 3: The building materials selected

To compare materials without taking into account a complex context, simulations are performed for horizontal samples, which are squares with a side of 100 cm and a thickness of 10 cm. In this step, eleven types of building materials are compared in three main groups as it is shown in (table 6.3).

As shown in Figure 6.20, 6.21 and Table 6.4, the simulation results of this step prove that the pumice block has recorded the highest upper surface temperature (Tse) among the materials tested. The average, the maximum, and the median surface temperature of pumice block are respectively (40.48 ºC, 74.26 ºC, 32.917 ºC). On the contrary, the reinforcement concrete material has recorded the lowest upper surface temperature (Tse) among the materials tested, in which it has the lowest upper surface temperature; the average, maximum, and median surface temperature are (36.55 ºC, 60.18 ºC, 32.15 ºC) respectively; compared to the rest (see Figure 6.20 and table 6.4). According to the average upper surface temperature of materials that are tested, these materials can be arranged from the highest mean surface temperature (Tse) to the lowest one, as shown:

Materials types	**Pumice**	**LWCBH**	**AeratedB**	**CrubberB**	**LWCBF**	**HClayB**	**Cstraw**	**Adobe**	**SStone**	**OCB**	**REFC**
Tse (°C)	40.48	39.55	39.42	38.95	38.85	38.43	38.08	37.92	36.97	36.73	36.55

Certainly, the main reason for this difference is due to the thermal properties of materials. For example, the pumice block material which has effusivity value equal to 250.99 $J/m^2Ks^{0.5}$, has maximum ΔT between upper surface and lower surface 50.32ºC, whereas the reinforcement concrete materials which has effusivity value equal to 2449.5 $J/m^2Ks^{0.5}$, has maximum ΔT between upper surface and lower surface 20.87ºC (see table 6.5).

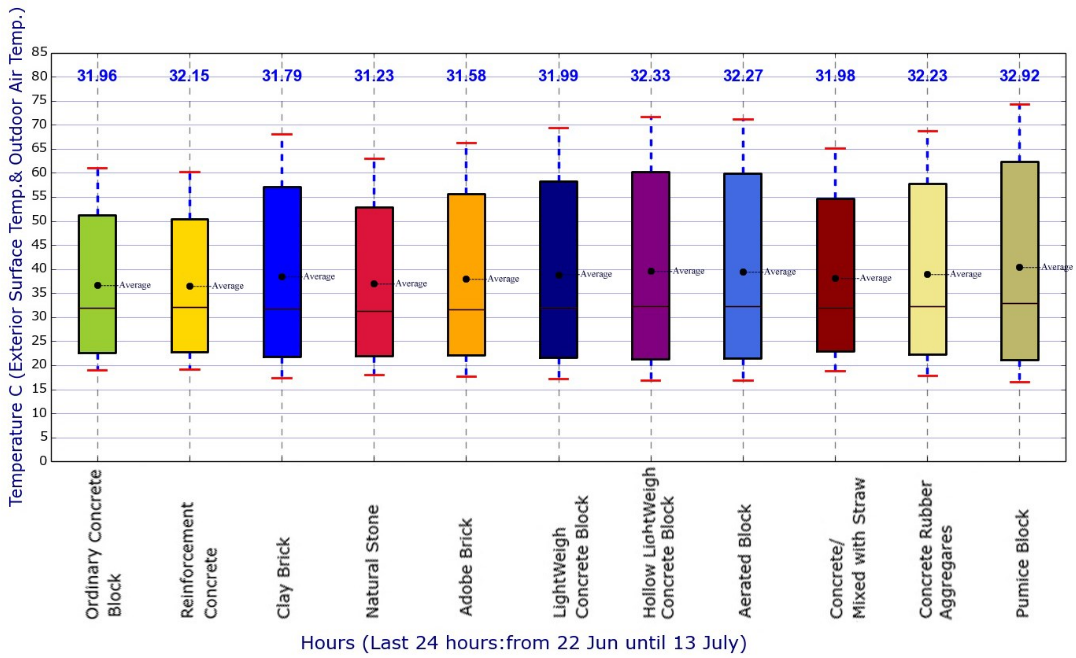


Figure 6. 20: Exterior surface temperature of different materials selected | Preliminary perception of the materials performance

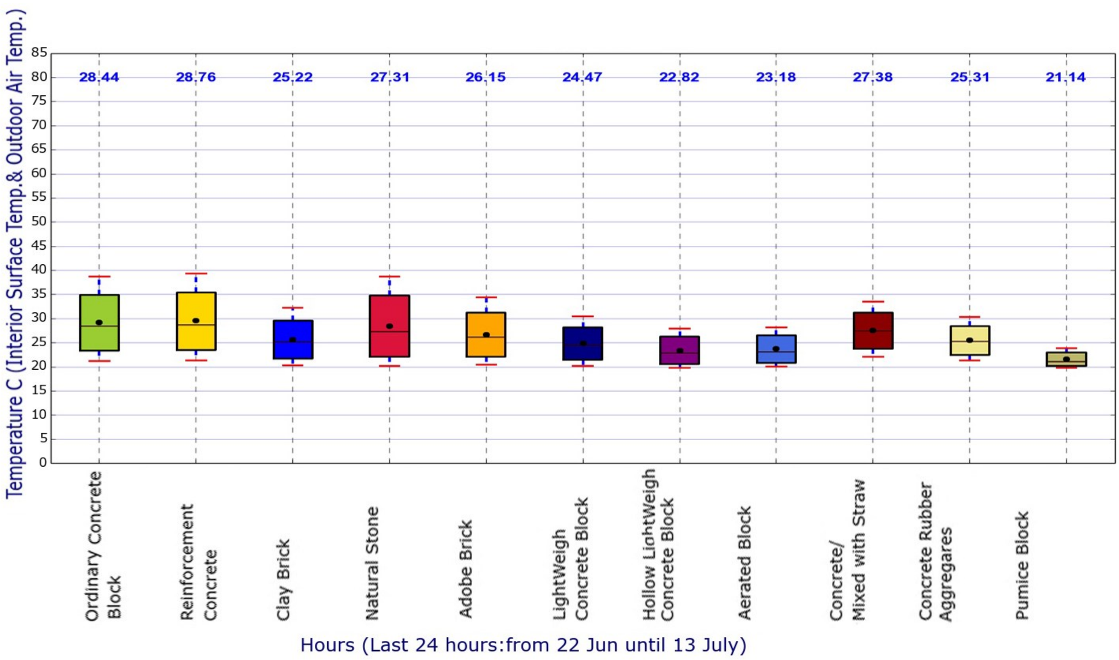


Figure 6. 21: Interior surface temperature of different materials selected | Preliminary perception of the materials performance

	OCB	REFC	HClayB	SStone	Adobe	LWCBF	LWCBH	AeratedB	Cstraw	CrubberB	Pumice
Tse : Surface temperature of the upper face of tested materials (ºC)											
A	36.733	36.55	38.43	36.97	37.92	38.85	39.55	39.422	38.081	38.95	40.48
MX	60.98	60.18	68.04	63.07	66.26	69.38	71.69	71.21	65.07	68.70	74.26
MN	18.92	19.14	17.41	18.06	17.69	17.23	16.81	16.93	18.83	17.93	16.54
MD	31.96	32.15	31.78	31.23	31.57	31.98	32.32	32.27	31.98	32.22	32.917
Tn1: Surface temperature of the lower face of tested materials (ºC)											
A	29.19	29.55	25.72	28.51	26.74	24.89	23.42	23.72	27.54	25.55	21.57
MX	38.69	39.31	32.24	38.79	34.37	30.46	27.97	28.23	33.56	30.33	23.94
MN	21.19	21.3	20.31	20.19	20.40	20.27	19.87	20.05	22.13	21.325	19.82
MD	28.44	28.76	25.22	27.31	26.15	24.47	22.83	23.18	27.38	25.32	21.14
Average absorption rate	20.5%	19.18%	33.07%	22.9%	29.47%	35.92%	40.78%	39.83%	27.68%	34.41%	46.73%

A: Average MX: Maximum MN: Minimum MD: Median

Table 6. 4: Average, maximum, minimum, and median exterior and interior surface temperature | Preliminary perception of the materials performance

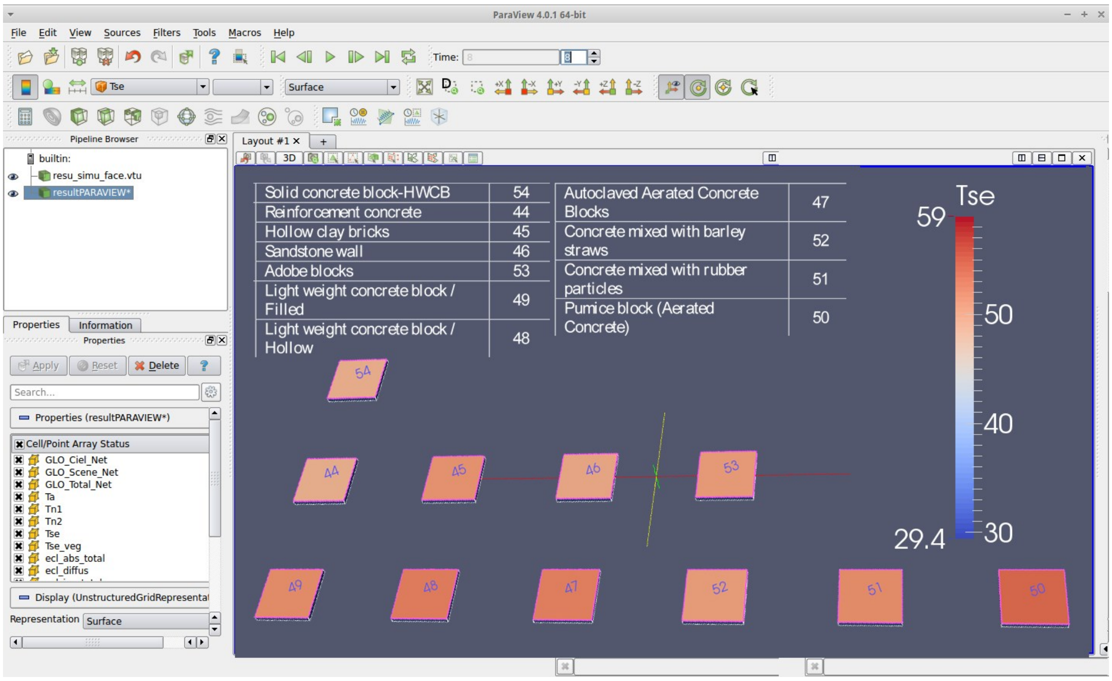


Figure 6. 22: Visual results regarding the exterior surface temperature for different materials types | Preliminary perception of the materials performance

As a matter of fact, there is no other reason since these materials are tested without the presence of any other factors that may affect the outcome of the analysis, such as, the presence of shade, interreflections between the faces of the urban scene, trees, etc. The result related to the flux is exchanged between the sky and the urban scene (GLO_Ciel_Net) on one hand, and between the faces of the urban scene (GLO_Scene_Net) on the other hand and this confirms this conclusion. For example, the total exchanged rates (GLO_Total_Net) for reinforcement concrete materials are equal to the exchange between the sky and the urban scene (GLO_Ciel_Net), where the exchange between the faces of the urban scene (GLO_Scene_Net) is equal to zero (there is no other surfaces) (see table below 6.4 and Figure 6.23)

00:00h-23:00h	GLO_Ciel_Net (W/m^2)	GLO_Scene_Net (W/m^2)	GLO_Total_Net (W/m^2)
Average	179.54	0	179.54

Table 6. 5: Flux exchanged of reinforcement concrete materials

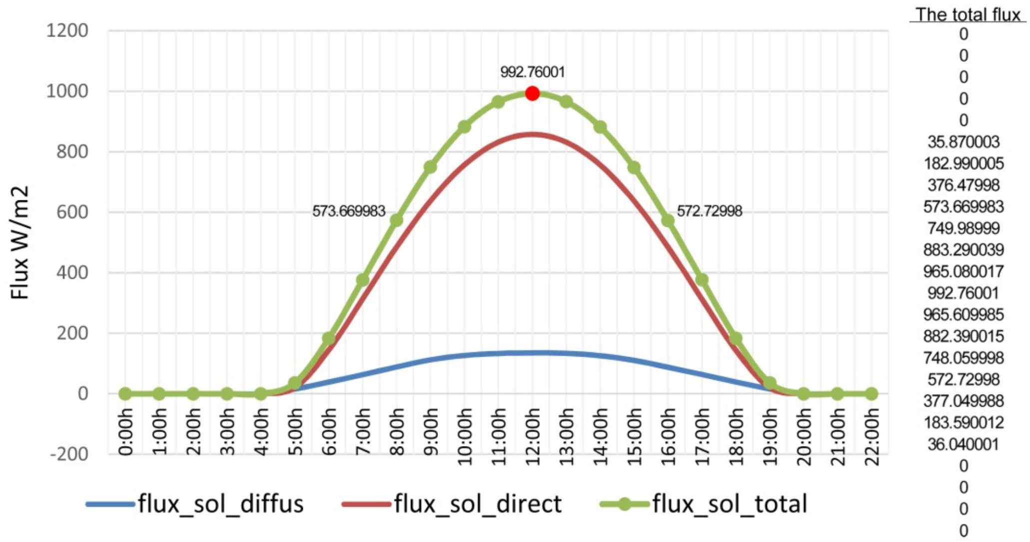


Figure 6. 23 : The amount of total flux radiation received by the samples

This step is considered as a preliminary estimation of surface temperature of each material.

The question now:

❖ ***Will the behavior of these materials change when applied to buildings?***

This is what we will study in the following steps

6.6.1.4. Step two, Sub-step one: thermal performance of materials selected when applied on buildings

This step presents the results of a comparative study with a view to investigate the thermal performance of building materials that were addressed in step one sub-step three but applied to the exterior buildings walls of the case study. Four types of exterior walls are considered: single layer wall with thickness 12 cm, single layer wall with thickness 20 cm, cavity "air-gap" wall, and cavity "rockwool-gap" wall. Therefore, this step consists of (44) simulation scenarios (see the Table 6.6).

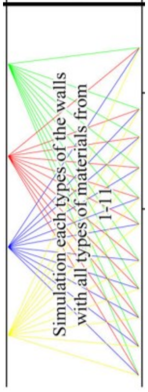
Types of the wall	Simulation steps	Types of materials	
Walls with thickness 12 cm		Solid concrete block-HWCB	Present construction materials
Walls with thickness 20 cm		Reinforcement concrete Hollow clay bricks Sandstone wall Adobe blocks	Typical type of materials used in Iraq
Cavity walls with air gap		Light weight concrete block / Filled Light weight concrete block / Hollow Autoclaved Aerated Concrete Blocks Concrete mixed with barley straws Concrete mixed with rubber particles Pumice block (Aerated Concrete)	Selected types of materials produced in France
Cavity walls with rock-wall gap			

Table 6. 6: The orientations of simulation scenarios of building materials assessment

The main objective of this step is to show the appropriate material type and wall design to use for the external walls of buildings in order to contribute to the reduction of ambient temperatures and improve the thermal indoor comfort, in line with the principles of energy efficiency and to fight UHI. The measured surface temperatures of exterior and interior faces correspond to the average values calculated for the total vertical surface (wall components). The measurements are taken on an hourly basis from 00:00 to 23:00 (local time) of 13th July 2013.

In order to understand and interpret the results that will be discussed in the subsequent steps, all the conditions regarding the target building are clarified, in the follows:

a. The solar flux for each elevation of the studied building

There is a difference in amount of direct flux of each elevation (vertical surfaces) and consequently, there is also a difference in amount of total flux received (see Figure 6.26), in which the north, the south, the east, and the west elevations receive respectively, (11.7 %), (18.8 %), (33.8 %), and (35.8 %) of total flux for all elevations. As well as they receive, respectively (2.6 %), (4.2 %), (7.6 %), and (8.0 %) of total flux of the urban scene.

Of course, this difference depends on many factors such as the region, the orientation, the height of the buildings, the distance between them, etc. The reviewing of the sun path of the region studied has also given an explanation for this difference (see Figure 6.24).

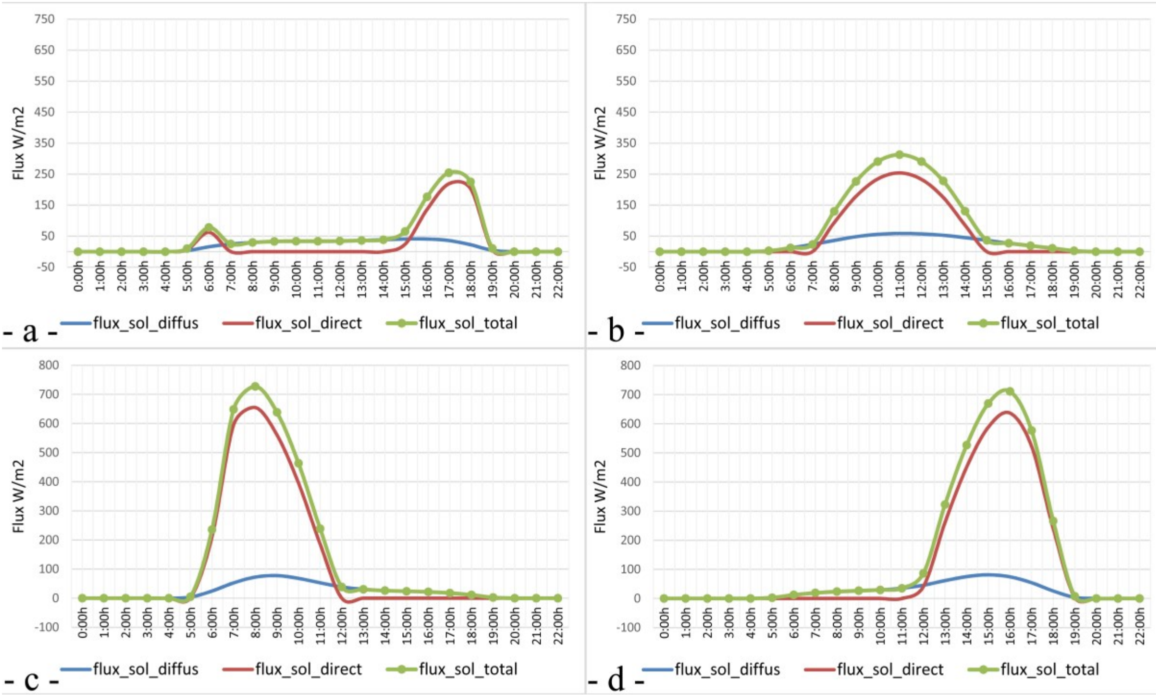


Figure 6. 24: Total Flux of building elevations
(a-North ELE., b-South ELE., c-East ELE., d-West ELE.)

Whereas the total flux scenario with regard to the horizontal faces (the roof, urban open spaces, road, and green area) are in the highest level especially the roofs of the buildings which reached (353.79) W/m^2 total flux, (see Figure 6.25 and table 6.7).

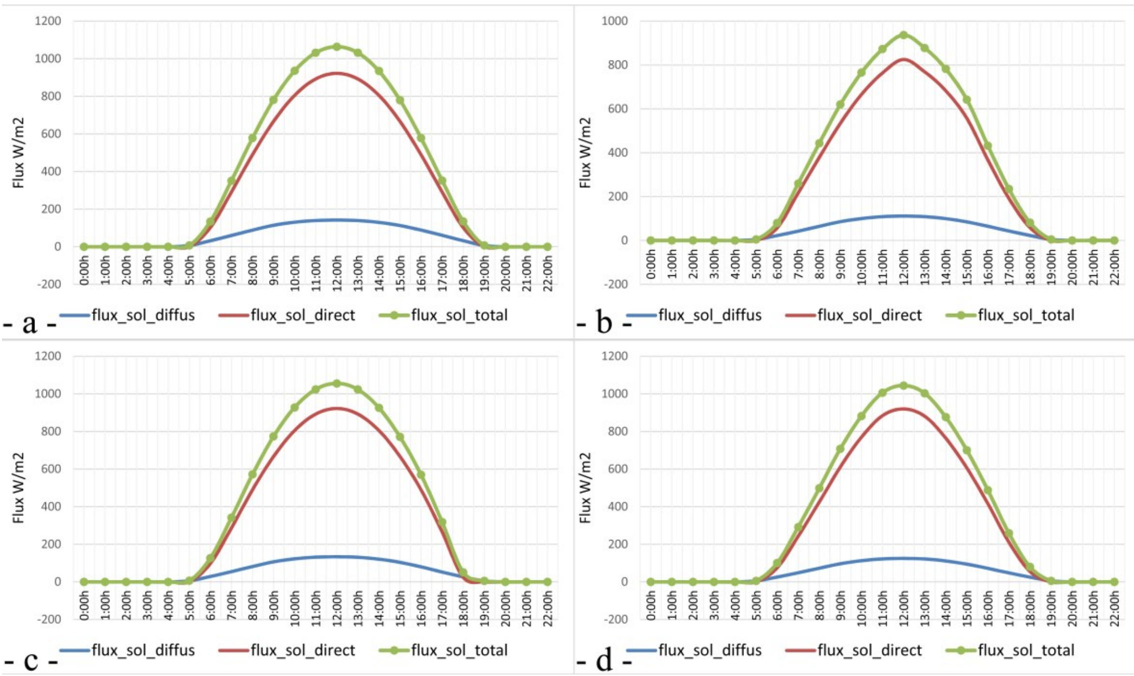


Figure 6. 25: Total Flux of a-Roof, b-Urban Spaces, c-Roads, d-Green areas

	Diffuse Flux W/m²	Direct Flux W/m²	Total Flux W/m²	% of total flux of all elevations.	% of total flux of Urban Scene
North	17.79	27.37	45.16	11.7	2.6
South	20.42	52.29	72.71	18.8	4.2
East	21.90	108.59	130.49	33.8	7.6
West	23.85	114.46	138.32	35.8	8.0
Total all elevations	***83.96***	***302.71***	***386.68***		
Roof	53.41	309.131	362.55		21.0
Urban Spaces	40.34	252.86	293.20		17.0
Green Areas	45.21	285.92	331.13		19.2
Roads	49.37	304.43	353.79		20.5
Total all urban scene	***272.29***	***1455.051***	***1727.35***		

Table 6. 7: The amount of flux for each urban component of the case study

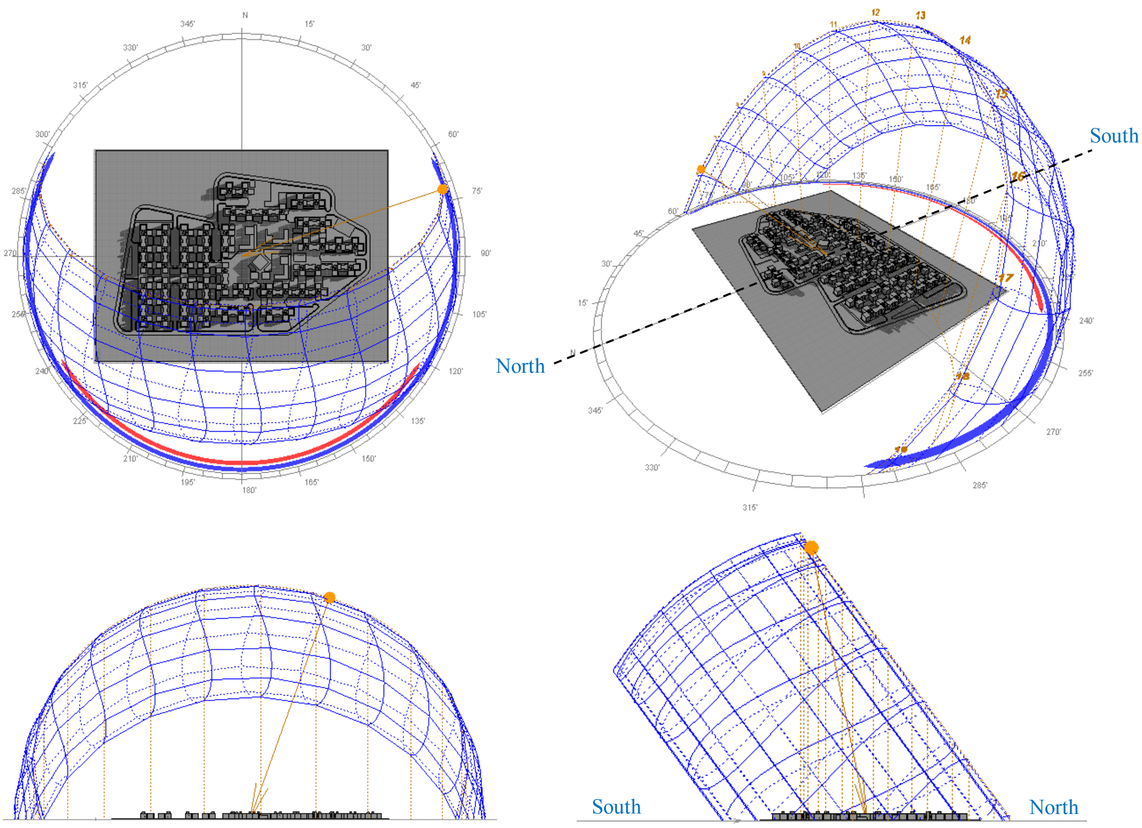


Figure 6. 26: The sun path around the AL-HADBA complex
Source: Adapted from Weather Analytics center (http://www.weatheranalytics.com)-By using weather tool software- Ecotect analysis

b. The result related the materials types and walls design

At this point, we will discuss the simulation results according to four directions depending on the wall design:

- Single layer with thickness (12cm),
- Single layer with thickness (20cm),
- Double layer "air-gap", and
- Double layer "rockwool-gab".

Later on, we will have a comparison with the simulation results of these four types to determine the difference in thermal performance among them and to determine the appropriate type of material for the exterior wall as well as the appropriate design of the wall.

The results have shown that there is an obvious difference between the external and internal surfaces temperature among each elevation (North, South, East, West elevation) which mainly depends on the amount of radiation falling on each elevation. In order not to complicate the presentation of the results, this part deals only with the results those related to the surfaces temperature for all elevations. The details of the simulation results for each material and each elevation are included in the appendix.

The simulation results of the selected materials - wall thickness (12 cm)

The maximum, minimum, average, and median of the exterior surface temperature (Tse) and interior surface temperature (Tn1) of building elevations are described in table (6.8), Figure (6.27), and Figure (6.28).

From table (6.8), and according to the average exterior surface temperature (Tse) for the wall with thickness (12 cm), the selected materials that have been simulated can be arranged from the highest (Tse) to the lowest, as below:

	Pumice	**LWCBH**	**AeratedB**	**LWCBF**	**CrubberB**	**HClayB**	**Adobe**	**Cstraw**	**SStone**	**OCB**	**REFC**
Tse (°C)	36.93	35.68	35.49	34.82	34.53	34.38	33.89	33.61	33.11	32.85	32.71

According to the simulation results, it is observed that there is a large surface temperature (external and internal) variation among all the selected materials that have been simulated. The pumice block material has a higher average exterior surface temperature (36.93 ºC) and a lower average interior surface temperature (22.06 ºC) compared to the rest. On the contrary, the reinforcement concrete has a lower average exterior surface temperature (32.71 ºC) and a higher average interior surface temperature (28.85 ºC).

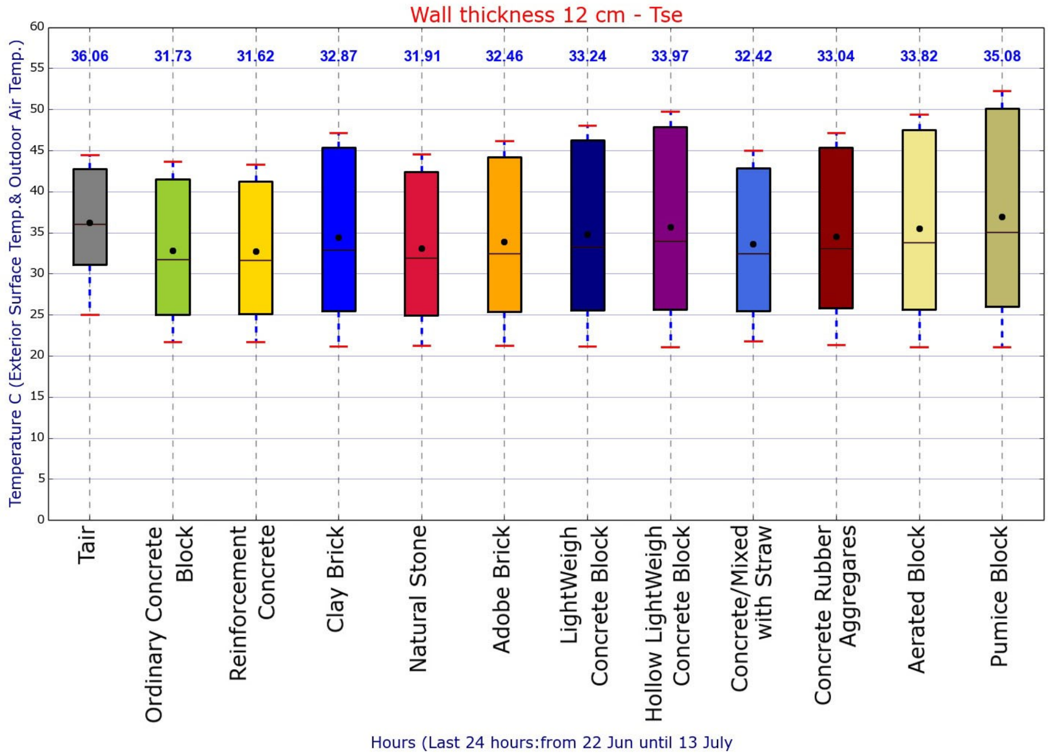


Figure 6. 27: Exterior surface temperature of different materials selected|wall thickness (12 cm)

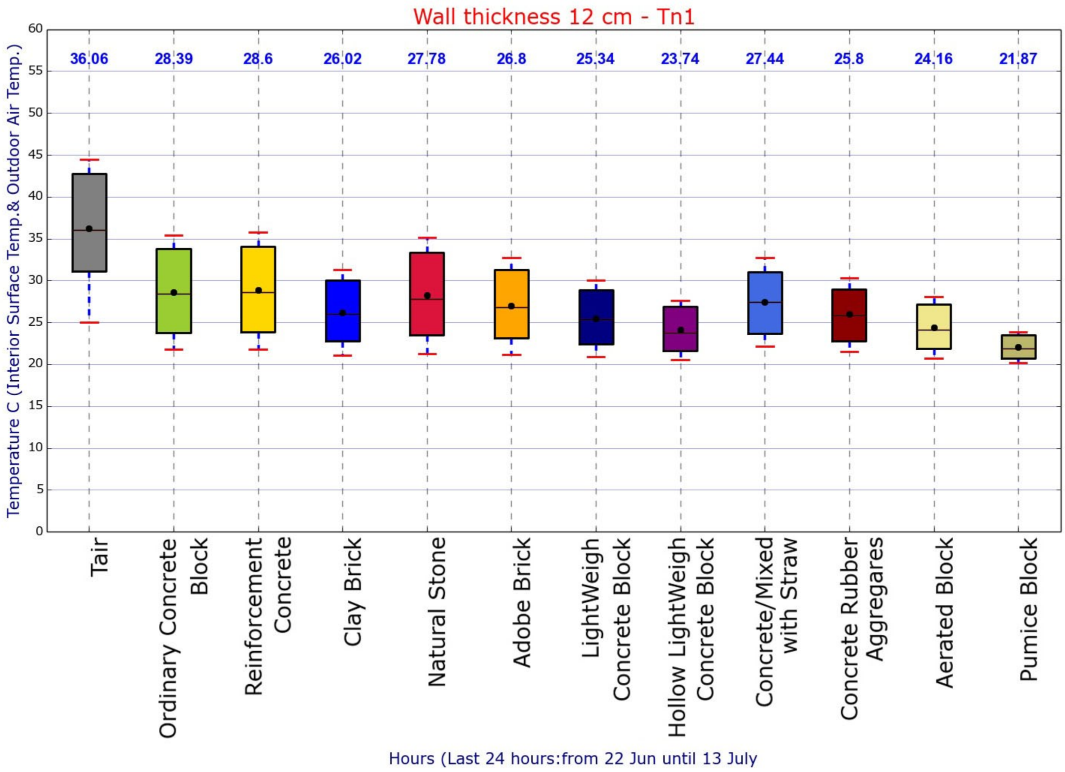


Figure 6. 28: Interior surface temperature of different materials selected | wall thickness (12 cm)

Wall thickness 12 cm

Tse : Surface temperature of the upper face of materials tested (ºC)

Types Of Materials	OCB	REFC	HclayB	Sstone	Adobe	LWCBF	LWCBH	Cstraw	CrubberB	AeratedB	Pumice
MAX	43.66	43.33	47.17	44.59	46.14	48.04	49.79	44.97	44.97	49.41	52.24
MAN	21.66	21.74	21.16	21.29	21.23	21.13	21.05	21.78	21.38	21.08	21.07
AVERAGE	32.85	32.71	34.38	33.11	33.89	34.82	35.68	33.61	34.53	35.49	36.93
MEDIAN	31.73	31.62	32.87	31.91	32.46	33.24	33.97	32.42	33.04	33.82	35.08

Tn1: Surface temperature of the lower face of materials tested (ºC)

Types Of Materials	OCB	REFC	HclayB	Sstone	Adobe	LWCBF	LWCBH	Cstraw	CrubberB	AeratedB	Pumice
MAX	35.43	35.77	31.30	35.14	32.74	30.02	27.63	32.71	30.34	28.09	23.88
MAN	21.76	21.83	21.05	21.29	21.19	20.94	20.57	22.16	21.56	20.69	20.21
AVERAGE	28.64	28.85	26.18	28.22	26.98	25.49	24.10	27.44	25.96	24.40	22.06
MEDIAN	28.39	28.60	26.02	27.78	26.80	25.34	23.74	27.44	25.80	24.16	21.87

Table 6. 8: The exterior and interior surface temperature | wall thickness (12 cm)

According to Fourier's Law (q = k A ΔT /s) and the average exterior and interior surface temperature, the conductive heat transfer of the wall with thickness 12 cm for each type of materials type will be as stated in the Table 6.9:

-The wall thickness (s) = 12 cm **-The surface area of all elevation (A) =510 m²** **Materials Types**	**Material Effusivity** ***J/m²Ks^0.5***	**Thermal conductivity** ***W/mK***	**dT = (Tse-Tn1)** **Tse** *K*	 **Tn1** *K*	**Conductive heat transfer** *kW*
Ordinary concrete block -OCB	1936.3	1.63	43.66	35.43	29.2
Reinforcement concrete	2449.5	2.5	43.33	35.77	41.1
Hollow clay bricks	1094.5	0.82	47.17	31.3	28.6
Sandstone wall	1693.1	1.83	44.59	35.14	38.1
Adobe blocks	1320	1.1	46.14	32.74	32.3
Light weight concrete block / Filled	943.9	0.639	48.04	30.02	25.4
Light weight concrete block / Hollow	578.4	0.384	49.79	27.63	18.9
Autoclaved Aerated Concrete Blocks	698.3	0.43	49.41	28.09	20.3
Concrete mixed with barley straws	1975.4	1.32	44.97	32.71	34.7
Concrete mixed with rubber particles	1336.1	0.76	44.97	30.34	27.7
Pumice block (Aerated Concrete)	250.9	0.15	52.24	23.88	19.3

Table 6. 9: Conductive heat transfer | wall thickness (12 cm)

Accordingly, the pumice block material (the effusivity of which is 250.99 $J/m^2Ks^{0.5}$) has a higher exterior surface temperature, a lower interior surface temperature, and a lower rate of conductive heat transfer (18.1 kW) which means that it does not distribute heat well and does not conduct heat. In other words it has a high level of insulation. On the contrary, the reinforcement concrete (the effusivity of which is (2449.5) $J/m2Ks^{0.5}$) has a lower exterior surface temperature, a higher interior surface temperature, and a higher rate of conductive heat transfer (80.4 kW) which means that it conducts heat rapidly and stores it relatively evenly throughout the inner layers of the wall.

The simulation results of the selected materials - wall thickness (20 cm)

The maximum, minimum, average, and median exterior surface temperature (Tse) and interior surface temperature (Tn1) of building elevations are described in table (6.10), Figure (6.29), and Figure (6.30).

From table (6.10), and according to the average exterior surface temperature (Tse) for the wall with thickness (20 cm), the selected materials that have been simulated have been arranged from the highest (Tse) to the lowest, as it is shown below:

	Pumice	**LWCBH**	**AeratedB**	**LWCBF**	**CrubberB**	**HClayB**	**Adobe**	**Cstraw**	**SStone**	**OCB**	**REFC**
Tse (°C)	37.38	36.44	36.30	35.71	35.51	35.30	34.79	34.56	33.91	33.60	33.43

According to the simulation results, it is observed that there is a similarity in simulation results with the previous ones (thickness 12 cm). It is also observed that there is a significant surface temperature (external and internal) variation among all the selected materials that have been simulated. For example, the pumice block material has a higher average exterior surface temperature (37.38 ºC) and a lower average interior surface temperature (21.33 ºC) compared to the rest. On the contrary, the reinforcement concrete materials have a lower average exterior surface temperature (33.43 ºC) and a higher average interior surface temperature (27.74 ºC).

Wall thickness 20 cm

Tse : Surface temperature of the upper face of materials tested (ºC)

Types Of Materials	OCB	REFC	HclayB	Sstone	Adobe	LWCBF	LWCBH	Cstraw	CrubberB	AeratedB	Pumice
MAX	44.57	44.09	48.77	45.76	47.65	49.64	51.22	46.52	48.89	50.89	53.09
MAN	22.12	22.25	21.31	21.58	21.43	21.25	21.10	22.02	21.54	21.15	21.11
AVERAGE	33.60	33.43	35.30	33.91	34.79	35.71	36.44	34.56	35.51	36.30	37.38
MEDIAN	32.44	32.30	33.70	32.53	33.28	34.06	34.66	33.16	33.95	34.56	35.49

Tn1: Surface temperature of the lower face of materials tested (ºC)

Types Of Materials	OCB	REFC	HclayB	Sstone	Adobe	LWCBF	LWCBH	Cstraw	CrubberB	AeratedB	Pumice
MAX	32.18	32.57	28.07	32.05	29.43	26.93	25.13	29.16	27.01	25.41	22.48
MAN	22.69	22.82	21.42	21.86	21.69	21.22	20.59	22.91	22.02	20.81	20.18
AVERAGE	27.47	27.74	24.75	26.97	25.57	24.08	22.87	26.07	24.54	23.12	21.33
MEDIAN	27.54	27.80	24.80	26.79	25.63	24.12	22.79	26.23	24.60	23.03	21.22

Table 6. 10: The exterior and interior surface temperature | wall thickness (20 cm)

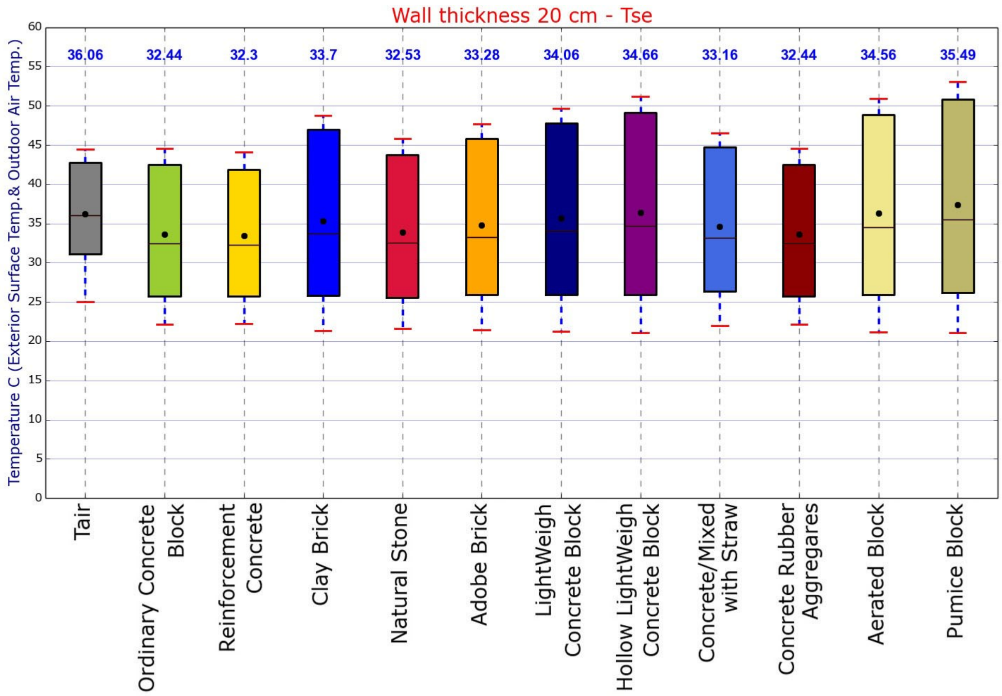


Figure 6. 29: Exterior surface temperature of different materials selected | wall thickness (20 cm)

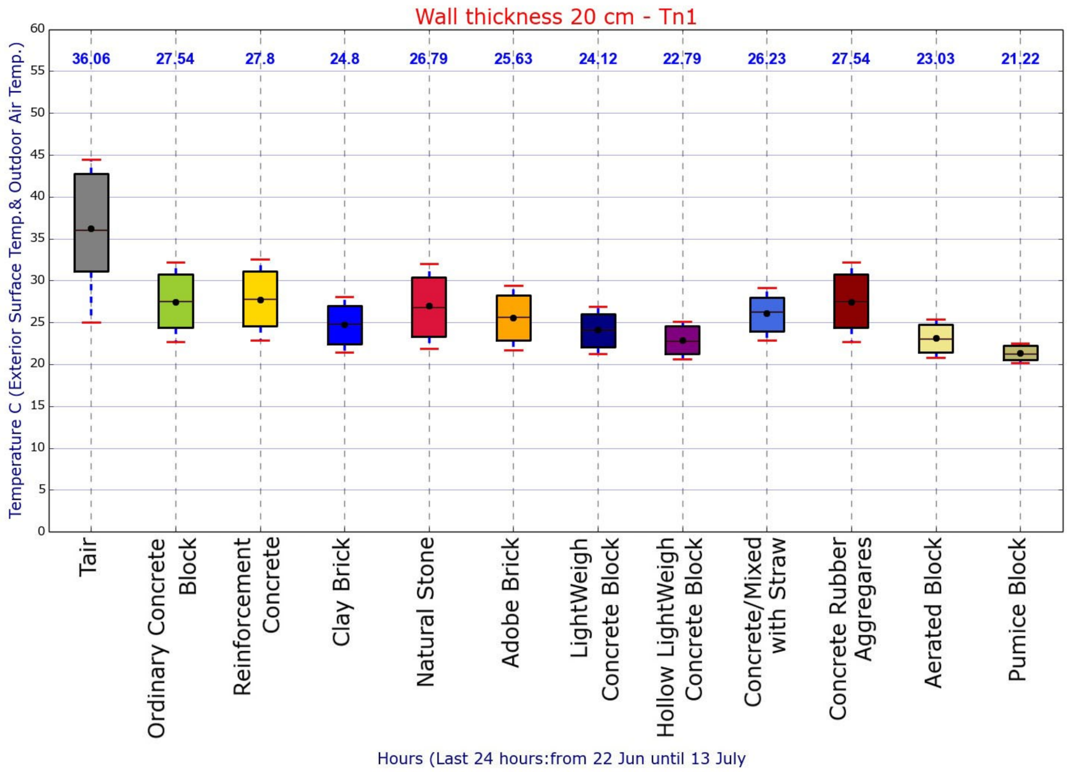


Figure 6. 30: Interior surface temperature of different materials selected|wall thickness (20 cm)

The conductive heat transfer of the wall with thickness (s =20 cm) for each type of materials are shown in the table (6.11):

-The wall thickness (s) = 20 cm -The surface area of all elevation (A) =510 m² **Materials Types**	**Material Effusivity** *J/m²Ks^0.5*	**Thermal conductivity** *W/mK*	**dT = (Tse-Tn1)** **Tse** *K*	 **Tn1** *K*	**Conductive heat transfer** *Kw*
Ordinary concrete block -OCB	1936.3	1.63	44.57	32.18	51.6
Reinforcement concrete	2449.5	2.5	44.09	32.57	73.5
Hollow clay bricks	1094.5	0.82	48.77	28.07	43.3
Sandstone wall	1693.1	1.83	45.76	32.05	64.1
Adobe blocks	1320	1.1	47.65	29.43	51.2
Light weight concrete block / Filled	943.9	0.639	49.64	26.93	37.1
Light weight concrete block / Hollow	578.4	0.384	51.22	25.13	25.6
Autoclaved Aerated Concrete Blocks	698.3	0.43	50.89	25.41	28.0
Concrete mixed with barley straws	1975.4	1.32	46.52	29.16	58.5
Concrete mixed with rubber particles	1336.1	0.76	48.89	27.01	42.5
Pumice block (Aerated Concrete)	250.9	0.15	53.09	22.48	11.7

Table 6. 11: Conductive heat transfer | wall thickness (20 cm)

The simulation results of the selected materials – cavity "air-gap" wall

The maximum, minimum, average, and median exterior surface temperature (Tse) and interior surface temperature (Tn1) are described in table (6.12), Figure (6.31), and Figure (6.32).

From table (6.12), and according to the average exterior surface temperature (Tse) for the wall with air gap, the selected materials that have been simulated can be arranged from the highest (Tse) to the lowest one , although the difference is very slight, as it is shown below:

	Pumice	**CrubberB**	**LWCBH**	**AeratedB**	**Cstraw**	**LWCBF**	**HClayB**	**Adobe**	**OCB**	**REFC**	**SStone**
Tse (°C)	37.79	37.66	37.62	37.62	37.61	37.57	37.54	37.51	37.48	37.47	37.45

According to the simulation results, it is observed that there is no significant surface temperature (external and internal) variation among all the types of materials for this type of the wall design (cavity "air-gap" wall). The exterior and interior mean surface temperature for all materials types has reached about, (38 °C) and (21°C) respectively (see Table 6.12). In other words, they have the same level of insulation. The main reason for this situation comes mainly from the air gap within the inner layer of the wall, although these materials vary in the effusivity value.

Cavity wall "air –gap"

Tse : Surface temperature of the upper face of materials tested (ºC)

Types Of Materials	HWCB	REFC	HclayB	Sstone	Adobe	LWCBF	LWCBH	Cstraw	CrubberB	AeratedB	Pumice
MAX	53.14	53.14	53.27	53.13	53.22	53.34	53.49	53.26	53.34	53.46	53.87
MAN	21.33	21.35	21.23	21.22	21.22	21.22	21.15	21.52	21.43	21.18	21.13
AVERAGE	37.48	37.47	37.54	37.45	37.51	37.57	37.62	37.61	37.66	37.62	37.79
MEDIAN	35.43	35.41	35.60	35.49	35.55	35.64	35.69	35.55	35.68	35.70	35.86

Tn1: Surface temperature of the lower face of materials tested (ºC)

Types Of Materials	HWCB	REFC	HclayB	Sstone	Adobe	LWCBF	LWCBH	Cstraw	CrubberB	AeratedB	Pumice
MAX	21.84	21.84	21.82	21.98	21.87	21.75	21.68	21.66	21.62	21.66	21.23
MAN	20.72	20.74	20.49	20.56	20.54	20.45	20.27	20.78	20.65	20.35	20.10
AVERAGE	21.29	21.30	21.16	21.28	21.21	21.11	20.98	21.24	21.14	21.01	20.67
MEDIAN	21.32	21.33	21.17	21.30	21.23	21.12	20.96	21.27	21.17	21.02	20.62

Table 6. 12: The exterior and interior surface temperature | cavity "air-gap" wall

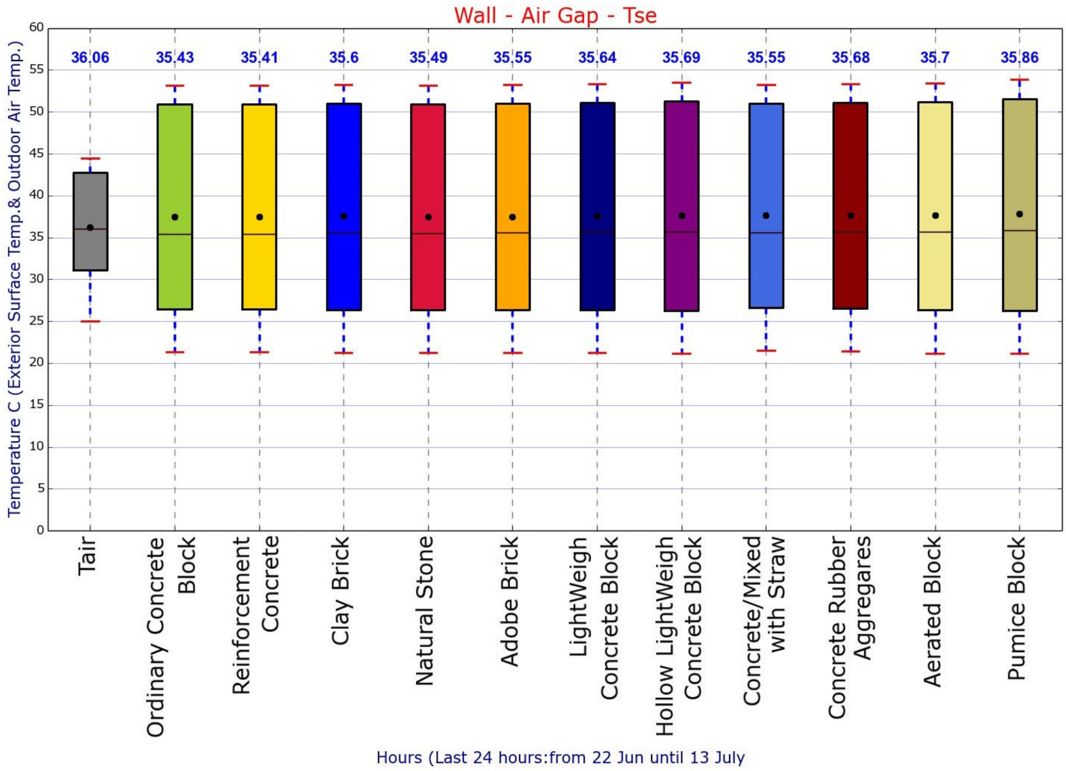


Figure 6. 31: Exterior surface temperature of different materials selected | cavity "air-gap" wall

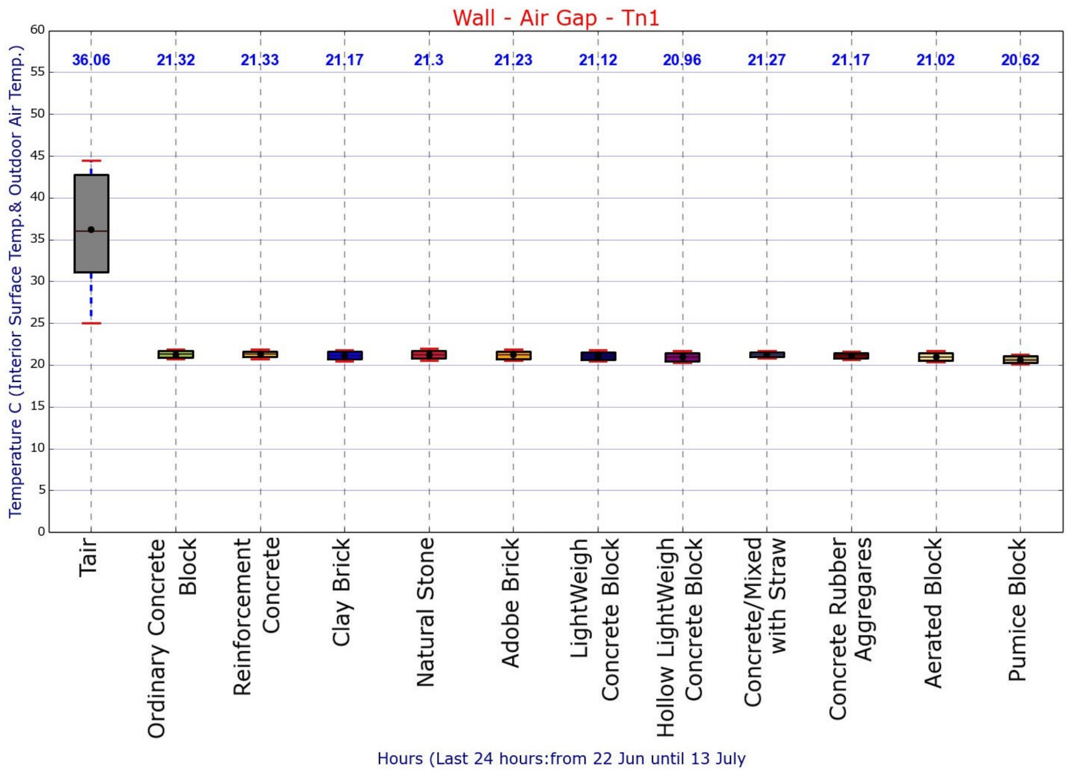


Figure 6. 32: Interior surface temperature of different materials selected | cavity "air-gap" wall

The simulation results of the selected materials – cavity "rockwool-gap" wall

The maximum, minimum, average, and median exterior surface temperature (Tse) and interior surface temperature (Tn1) are described in table (6.13), Figure (6.33), and Figure (6.34).

From table (6.13), and according to the average exterior surface temperature (Tse) for the wall with rock-wool gap, the selected materials that have been simulated are arranged from the highest (Tse) to the lowest one, although the difference is very slight, as it is shown below:

	Pumice	**CrubberB**	**LWCBH**	**AeratedB**	**Cstraw**	**LWCBF**	**HClayB**	**Adobe**	**OCB**	**REFC**	**SStone**
Tse (ºC)	37.79	37.66	37.62	37.62	37.61	37.57	37.54	37.51	37.48	37.47	37.45

It is observed that the simulation results of cavity "rockwool-gap" wall are similar to the cavity "air- gap" wall. There is also no significant surface temperature (external and internal) variation among all the types of materials. The exterior and interior surface temperature for all materials types has reached about, sequentially, (38 ºC) and (21ºC) (see Table 6.13) respectively. The main reason for this situation mainly comes from the rock-wool gap within the inner layer of the wall, although these materials vary in the effusivity value.

Cavity wall "rockwool –gap"

Tse : Surface temperature of the upper face of materials tested (ºC)

Types Of Materials	HWCB	REFC	HclayB	Sstone	Adobe	LWCBF	LWCBH	Cstraw	CrubberB	AeratedB	Pumice
MAX	53.14	53.14	53.27	53.13	53.22	53.34	53.49	53.26	53.34	53.46	53.87
MAN	21.34	21.35	21.23	21.22	21.22	21.22	21.15	21.52	21.44	21.18	21.14
AVERAGE	37.48	37.47	37.54	37.45	37.51	37.57	37.62	37.61	37.66	37.62	37.79
MEDIAN	35.43	35.41	35.60	35.49	35.55	35.64	35.69	35.55	35.68	35.70	35.86

Tn1: Surface temperature of the lower face of materials tested (ºC)

Types Of Materials	HWCB	REFC	HclayB	Sstone	Adobe	LWCBF	LWCBH	Cstraw	CrubberB	AeratedB	Pumice
MAX	21.84	21.84	21.82	21.98	21.87	21.75	21.68	21.66	21.61	21.66	21.23
MAN	20.72	20.74	20.49	20.56	20.54	20.45	20.27	20.79	20.65	20.35	20.10
AVERAGE	21.29	21.30	21.16	21.28	21.21	21.11	20.98	21.24	21.14	21.01	20.67
MEDIAN	21.32	21.33	21.17	21.30	21.24	21.12	20.96	21.27	21.17	21.02	20.62

Table 6. 13: The exterior and interior surface temperature | cavity "rock-wool gap" wall

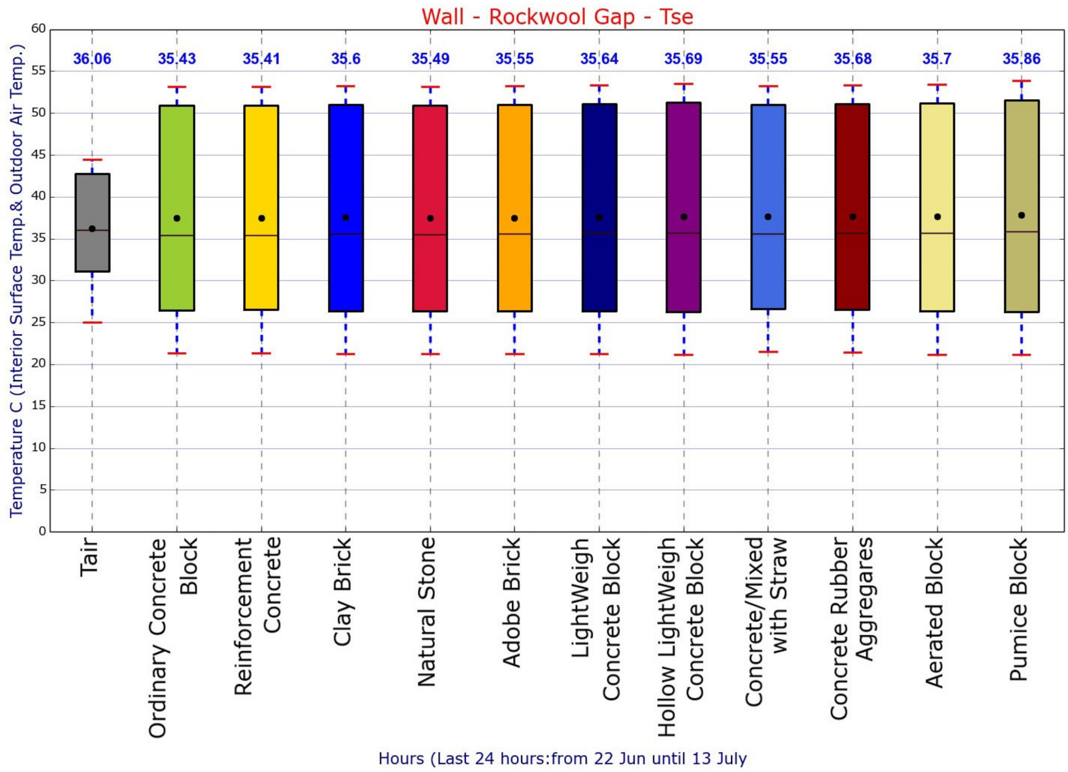


Figure 6. 33: Exterior surface temperature of different materials selected | cavity "rock-wool gap" wall

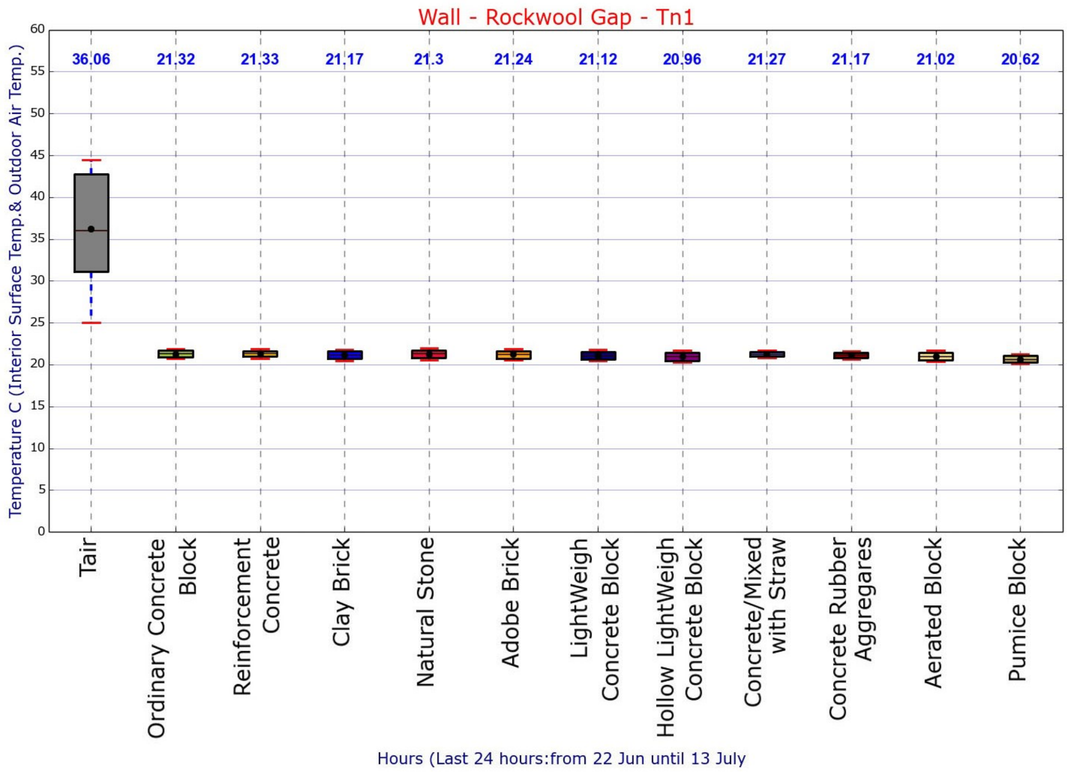


Figure 6. 34: Interior surface temperature of different materials selected | cavity "rock-wool gap" wall

c. Overview of step two, sub-step one results

As discussed above, the simulation results for the four types of walls have proved that the thickness of the wall or the component of inner layer do not always affect the exterior and interior surfaces temperature, for more details we will clarify this point:

The effect of the wall thickness

When we use the reinforcement concrete materials, we have found that the thickness of the wall has significant effect on the ability of the wall to transfer the heat from outside to inside of the wall, whereas the thick wall reduces the ability of heat to pass through it. As a result, the surface temperature of interior thick wall will be less than for lowest thickness. Consequently, the interior surface temperature peak of the reinforcement concrete wall with thickness (12 cm) and (20 cm) will be, (35.8 ºC), (32.6 ºC) respectively, see Figure 6.35.

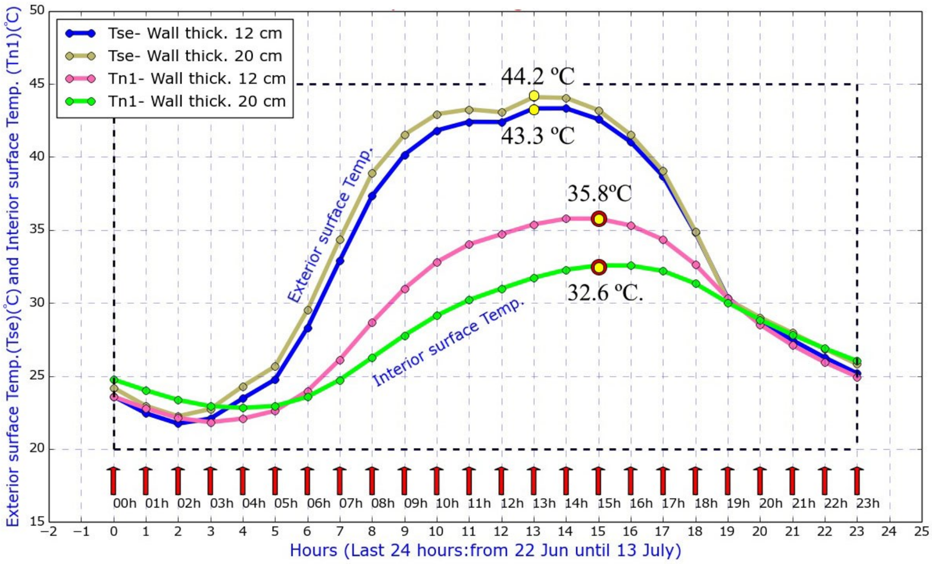


Figure 6. 35: Comparative external and internal surface temperature of reinforcement concrete wall with thickness (12cm) and (20 cm)

While regarding the pumice block, the situation is different. The thickness of the wall do not have a significant effect on the temperature of the external and internal wall surfaces where the peak interior surface temperature of the pumice block wall with thickness (12 cm) and (20 cm) will be, alternately, (23.8 ºC), (22.5 ºC), see (Figure 6.36.).

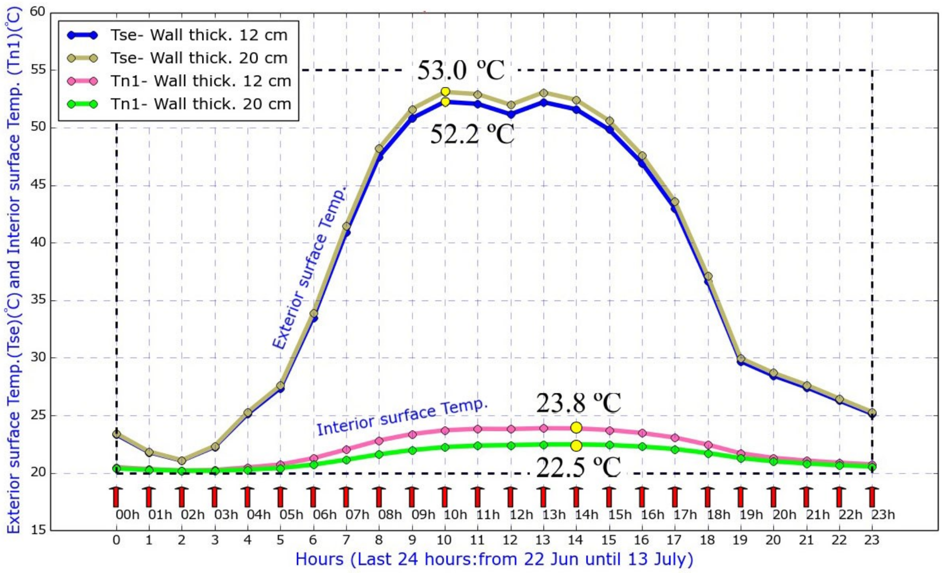


Figure 6. 36: Comparative external and internal surface temperature of heavy weight concrete block wall with thickness 20 cm and pumice block wall with thickness 12

The effect of the wall layers

In order to understand the effect of the existing gap inside the inner layer of the wall, the comparison is conducted between single layer wall with thickness (20cm) and cavity "air-gap" wall firstly and cavity "rockwool-gap" wall secondly.

- Wall with thickness 20cm versus cavity wall – Reinforcement materials

When we use the reinforcement concrete materials, the "air-gap" or the "rockwool-gap" wall will enhance the thermal performance of the wall by contributing to reduce the interior surface temperature from (32.6 ºC) forwall with thickness (12 cm) to (21.8 ºC) for cavity "air-gap"/"rockwool-gap" wall, see, see (Figure 6.37 and 6.38).

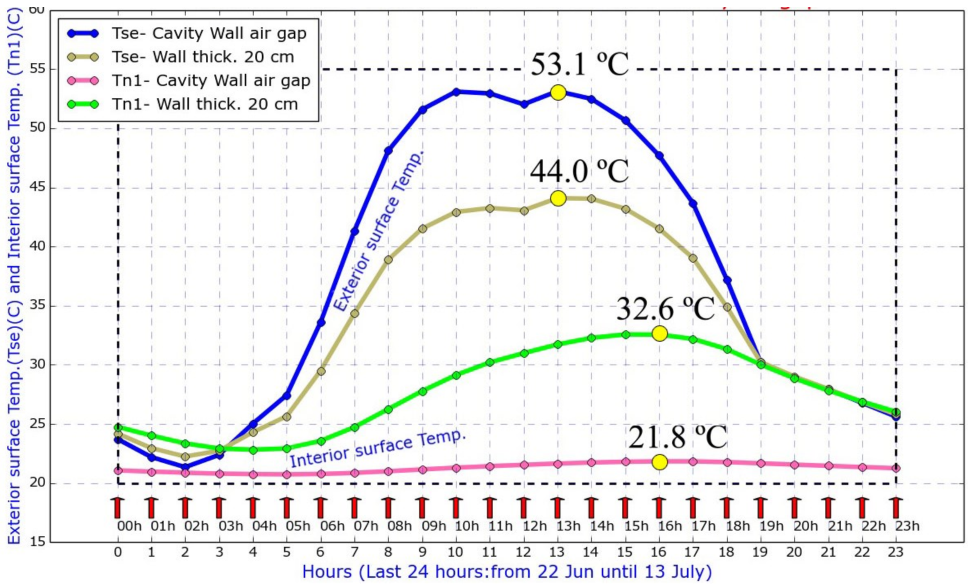


Figure 6. 37: Comparative external and internal surface temperature of reinforcement concrete wall with thickness 12cm and cavity air gap

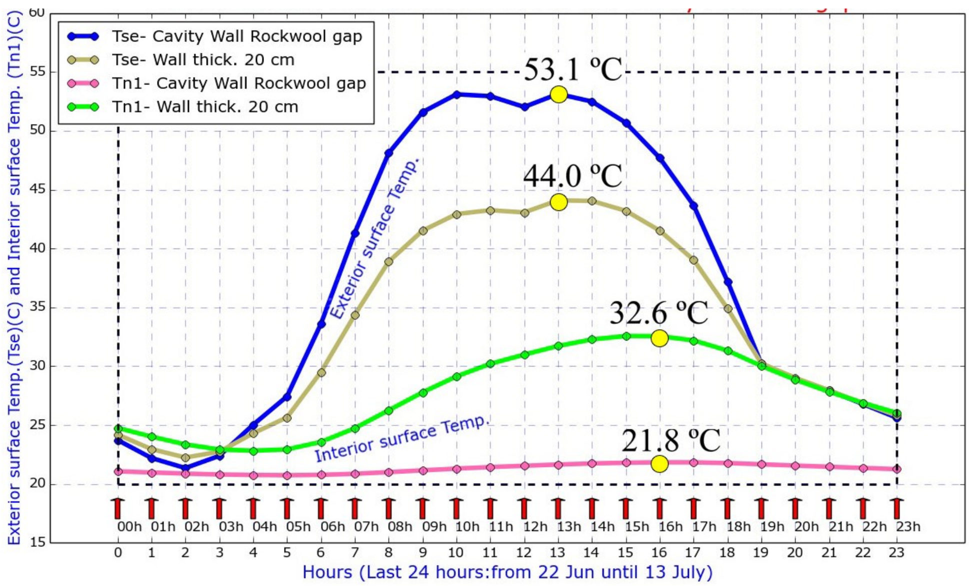


Figure 6. 38: Comparative external and internal surface temperature of reinforcement concrete wall with thickness 12cm and cavity rock-wool gap

- Wall with thickness (20cm) versus cavity wall – pumice block

On the other hand, for pumice block, the situation is different where the gap inside the inner layer of the wall does not have great effect on the interior surface temperature of the wall where the peak interior surface temperature of the pumice block wall with thickness (20 cm) and for cavity air gap is, (23.8 ºC), (22.5 ºC) respectively, see (Figure 6.39 and 6.40).

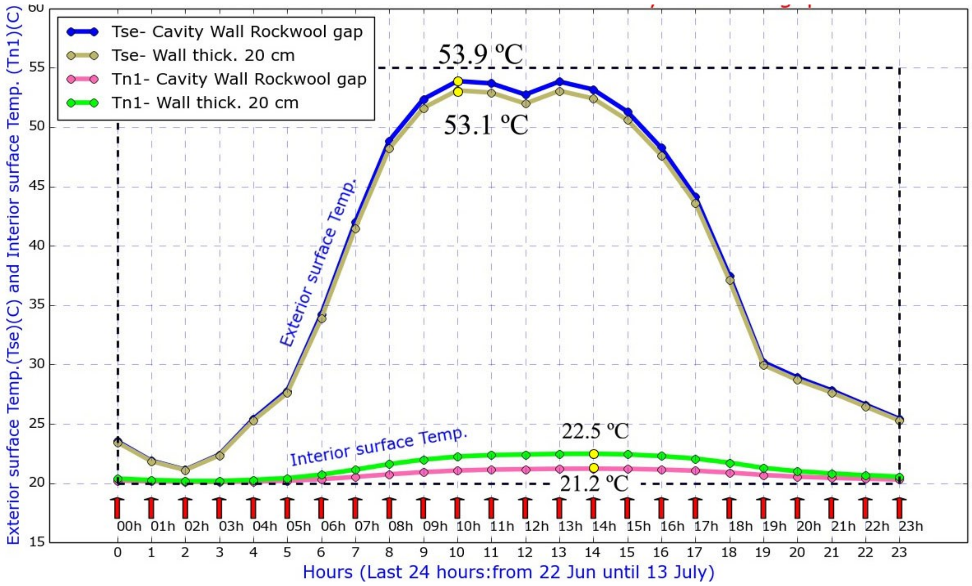


Figure 6. 39: Comparative external and internal surface temperature of pumice wall with thickness 20cm and cavity rock-wool gap

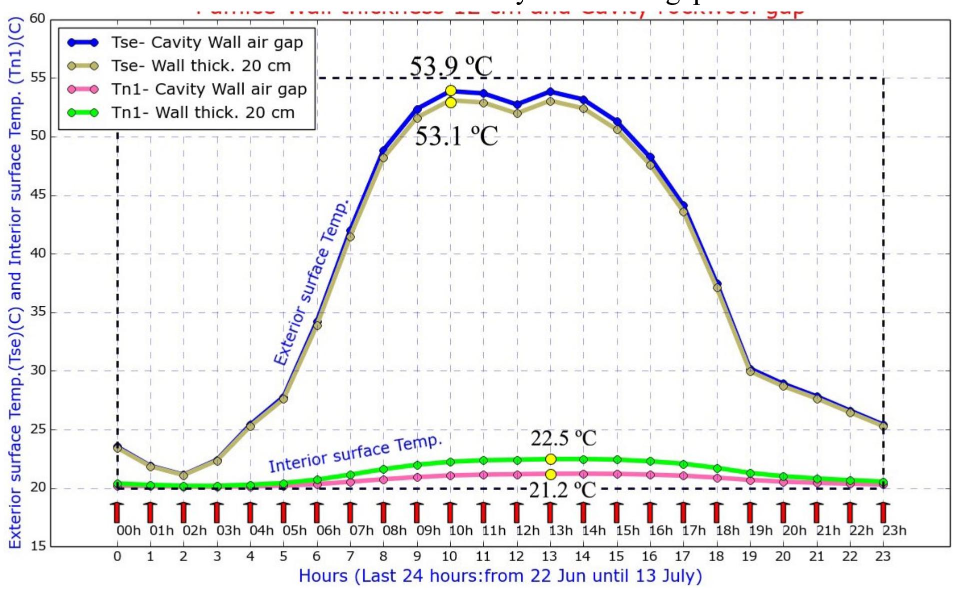


Figure 6. 40: Comparative external and internal surface temperature of pumice wall with thickness 20cm and cavity air gap

d. The conclusion of the step two, sub-step one

The results show that the main factor which dominates the thermal performance of the wall is the type of material. For example, when we use the pumice block as main wall material, we have found that this materias keep the same level of surface temperature even when there is a change in the wall thickness (wall type 1 and wall type 2) or the component of inner layer (wall type 3 and wall type 4), see Figure 6.41.

Concerning the cavity wall, the gap inside the inner layer of wall which is not related to the type of materials is responsible for the formation of the thermal performance. Whereas, in the single layer wall, we have found that the materials types are responsible for the formation of the thermal performance, see (Figure 6.41).

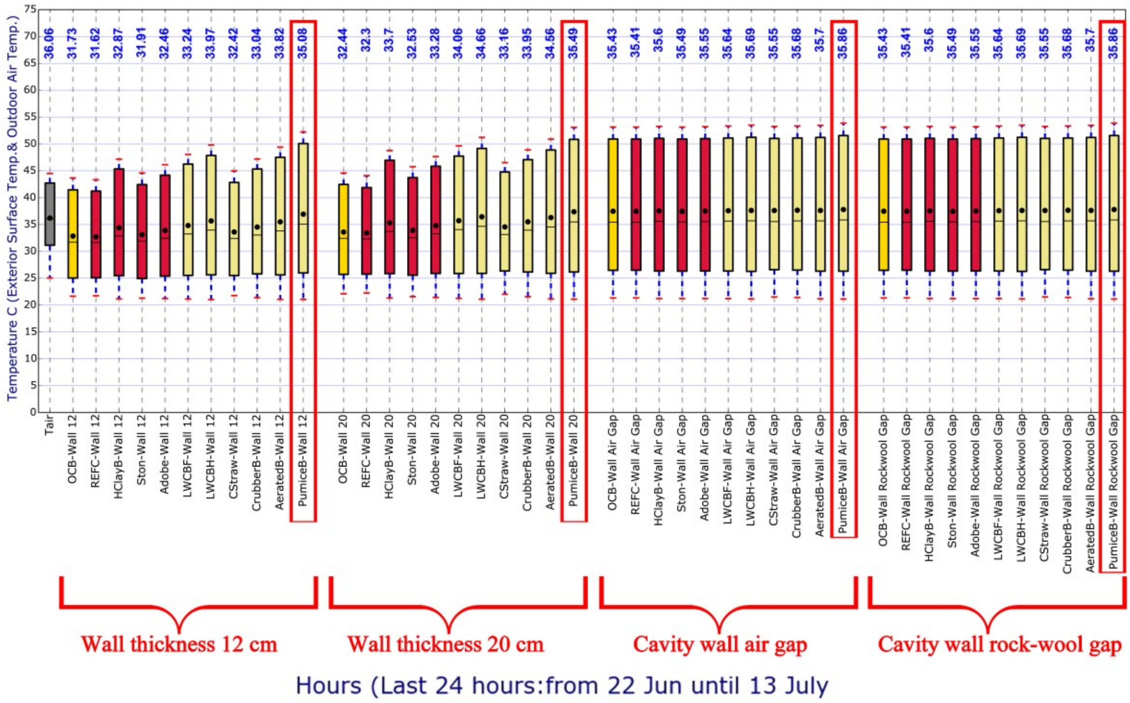


Figure 6. 41: Comparison of four scenarios of wall design

For the time being, we can come across the final conclusion to what has already been discussed earlier. In fact, we can state that for any materials there are two possibilities:

- The first possibility indicates that the materials lead to reduce the external surfaces temperature but adversely affected the indoor surfaces temperature and thermal indoor comfort such as heavy weight concrete block materials or reinforcement concrete. Therefore, we are in need of finding some way to reduce the interior surface temperature and finally maintain the high thermal comfort inside the building spaces e.g. insulated wall, natural ventilation, air conditioning.

- The second possibility indicates that the materials lead to reduce the internal surfaces temperature and finally maintain indoor thermal comfort such as pumice block. Thus, we need to find some methods to reduce the external surfaces temperature such as using double wall, green wall and roof, shade and shadow and high value of albedo. It is worth mentioning that when using self-insulating materials such as pumice block, it is not necessary to use a gap between the layers of the wall.

Finally and after having compared the results (appendix), we will select **pumice block materials and single layer wall with thickness (20cm)**, where this material has lower thermal effusivity. This material helps us to make the surface temperature of the internal wall at a lower level, and finally leads to reduce the energy needed to maintain the air temperature inside the spaces at comfort level as well as to reduce the cost of using the insulated walls types which may also require sophisticated construction methods, in addition to their high cost.

6.6.1.5. Step two, Sub-step two: Wall shape – low albedo (existing conditions)

This step represents the second sub-step of the simulation process of the second step. It investigates what can be obtained concerning the thermal performance of the building when changing the shape of the wall. This step consists of (12) simulation scenarios of wall shape for the target building in which its exterior wall is made of a single layer pumice block material with thickness (20cm), as it is shown in (Table 6.14).

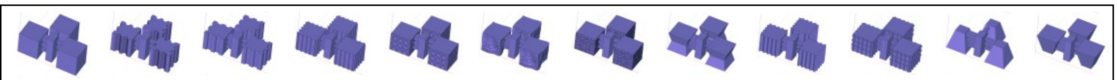
Types of the wall	Simulation steps	Wall Shapes types
Result of Simulation of first sub-step: - ***Single layer wall with thickness (20cm)*** - ***Pumice block a material type***	Simulate with 12 wall shapes	Square shape
		irregular square shape
		Zigzag shape
		Serpentine shape
		Pyramid shape
		inverted pyramid shape
		Combine pyramids shape
		Column expressed
		Frame expressed
		Irregular printed concrete
		Ornament printed concrete
		Muli-surface shape

Table 6. 14: Wall shape types

In this step, the results will be discussed for each elevation of the building separately to distinguish the thermal behavior for each one individually and as follows:

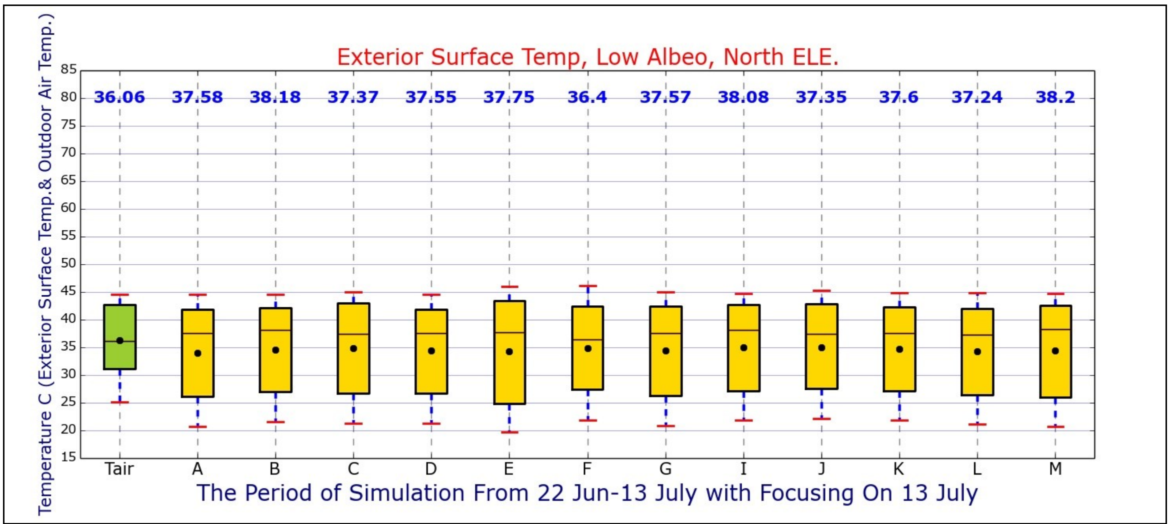
a. North Elevation

Table (6.15) describes the maximum, minimum, average, and median surface temperature of north elevation for each type of exterior wall shape. According to the maximum exterior surface temperature (Tse), the wall shape that has been simulated can be arranged from the highest (Tse) to the lowest, as it is shown below:



Max Exterior Surface Temp.	Square shape	Serpentine shape	Irregular square shape	Column expressed	Ornament printed	Muli-surface shape	Irregular printed concrete	Combine pyramids shape	Zigzag shape	Frame expressed	Pyramid shape	Inverted pyramid shape
	44.52 ºC	44.57 ºC	44.58 ºC	44.74 ºC	44.81 ºC	44.82 ºC	44.83 ºC	45.01 ºC	45.02 ºC	45.21 ºC	45.98 ºC	46.14 ºC

Accordingly, we conclude that the appropriate wall shape for north elevation is square wall where the maximum, minimum, average surface temperature is (44.52 ºC, 20.75 ºC, 34.02 ºC) respectively.



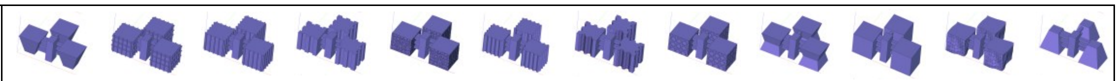
	A	B	C	D	E	F	G	I	J	K	L	M
	Square shape	**Irregular square shape**	**Zigzag shape**	**Serpentine shape**	**Pyramid shape**	**Inverted pyramid shape**	**Combine pyramids shape**	**Column expressed**	**Frame expressed**	**Irregular printed concrete**	**Ornament printed**	**Muli-surface shape**
AVE.	34.02	34.58	34.79	34.39	34.23	34.90	34.37	34.91	34.97	34.72	34.23	33.65
MAX.	44.52	44.58	45.02	44.57	45.98	46.14	45.01	44.74	45.21	44.83	44.81	44.82
MIN.	20.75	21.58	21.32	21.34	19.65	21.89	20.85	21.80	22.10	21.81	21.08	20.98
MED.	37.58	38.18	37.37	37.55	37.75	36.40	37.57	38.08	37.35	37.60	37.24	32.28

Table 6. 15: The exterior surface temperature of different wall shapes | North elevation

b. South Elevation

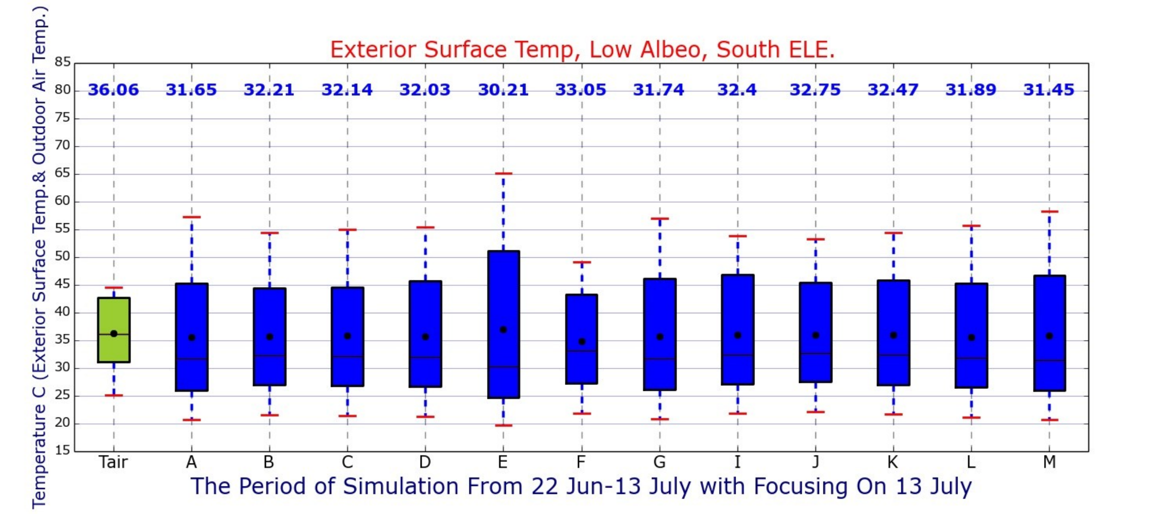
Table (6.16), describes the maximum, minimum, average, and median surface temperature of north elevation for each type of the building exterior wall shape.

From table (6.16), and according to the maximum exterior surface temperature (Tse), the wall shape that has been simulated are arranged from the highest (Tse) to the lowest, as it is shown below:



Max Exterior Surface Temp.	**Inverted pyramid shape**	**Frame expressed**	**Column expressed**	**Irregular square shape**	**Irregular printed concrete**	**Zigzag shape**	**Serpentine shape**	**Ornament printed**	**Combine pyramids shape**	**Square shape**	**Muli-surface shape**	**Pyramid shape**
	49.10 ºC	**53.27 ºC**	**53.89 ºC**	**54.44 ºC**	**54.44 ºC**	**54.99 ºC**	**55.39 ºC**	**55.63 ºC**	**56.90 ºC**	**57.28 ºC**	**58.22 ºC**	**65.15 ºC**

Accordingly, we conclude that the appropriate wall shape for south elevation is inverted pyramid wall where the maximum, minimum, average surface temperature, is (49.10ºC, 21.91ºC, 34.80ºC) respectively.



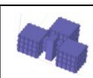
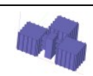
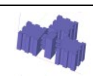
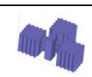
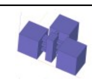
	A	B	C	D	E	F	G	I	J	K	L	M
	Square shape	**Irregular square shape**	**Zigzag shape**	**Serpentine shape**	**Pyramid shape**	**Inverted pyramid shape**	**Combine pyramids shape**	**Column expressed**	**Frame expressed**	**Irregular printed concrete**	**Ornament printed**	**Muli-surface shape**
AVE.	35.49	35.63	35.76	35.70	36.96	34.80	35.72	36.02	36.01	35.91	35.62	35.78
MAX.	57.28	54.44	54.99	55.39	65.15	49.10	56.90	53.89	53.27	54.44	55.63	58.22
MIN.	20.75	21.59	21.48	21.34	19.64	21.91	20.85	21.82	22.17	21.65	21.15	20.64
MED.	31.65	32.21	32.14	32.03	30.21	33.05	31.74	32.40	32.75	32.47	31.89	31.45

Table 6. 16: The exterior surface temperature of different wall shapes | South elevation

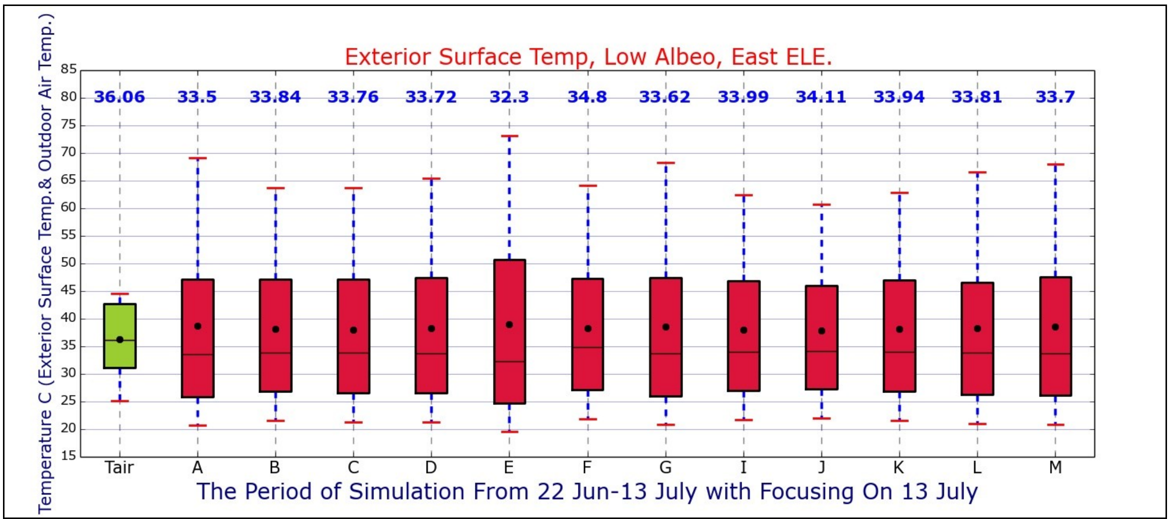
c. East Elevation

Table (6.17), describes the maximum, minimum, average, and median surface temperature of the east elevation for each type of the building exterior wall shape.

From table (6.17), and according to the maximum exterior surface temperature (Tse), the wall shape that has been simulated are arranged from the highest (Tse) to the lowest, as below:

Max Exterior Surface Temp.												
	Frame expressed	**Column expressed**	**Irregular printed concrete**	**Irregular square shape**	**Zigzag shape**	**Inverted pyramid shape**	**Serpentine shape**	**Muli-surface shape**	**Combine pyramids shape**	**Square shape**	**Ornament printed**	**Pyramid shape**
	60.62 ºC	**62.45 ºC**	**62.79 ºC**	**63.65 ºC**	**63.68 ºC**	**64.15 ºC**	**65.35 ºC**	**67.94 ºC**	**68.29 ºC**	**69.15 ºC**	**69.33 ºC**	**73.16 ºC**

Accordingly, we conclude that the appropriate wall shape for the east elevation is the frame expressed wall where the maximum, minimum, average surface temperature, is (60.62ºC, 22.03ºC, 37.82ºC) respectively.



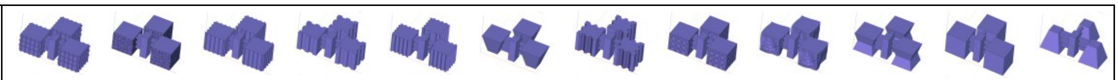
	A	B	C	D	E	F	G	I	J	K	L	M
	Square shape	**Irregular square shape**	**Zigzag shape**	**Serpentine shape**	**Pyramid shape**	**Inverted pyramid shape**	**Combine pyramids shape**	**Column expressed**	**Frame expressed**	**Irregular printed concrete**	**Ornament printed**	**Muli-surface shape**
AVE.	38.65	38.15	37.97	38.27	39.03	38.31	38.60	38.01	37.82	38.05	41.14	38.54
MAX.	69.15	63.65	63.68	65.35	73.16	64.15	68.29	62.45	60.62	62.79	69.33	67.94
MIN.	20.67	21.53	21.26	21.27	19.58	21.80	20.77	21.73	22.03	21.60	20.55	20.90
MED.	33.50	33.84	33.76	33.72	32.30	34.80	33.62	33.99	34.11	33.94	35.48	33.70

Table 6. 17: The exterior surface temperature of different wall shapes | East elevation

d. West Elevation

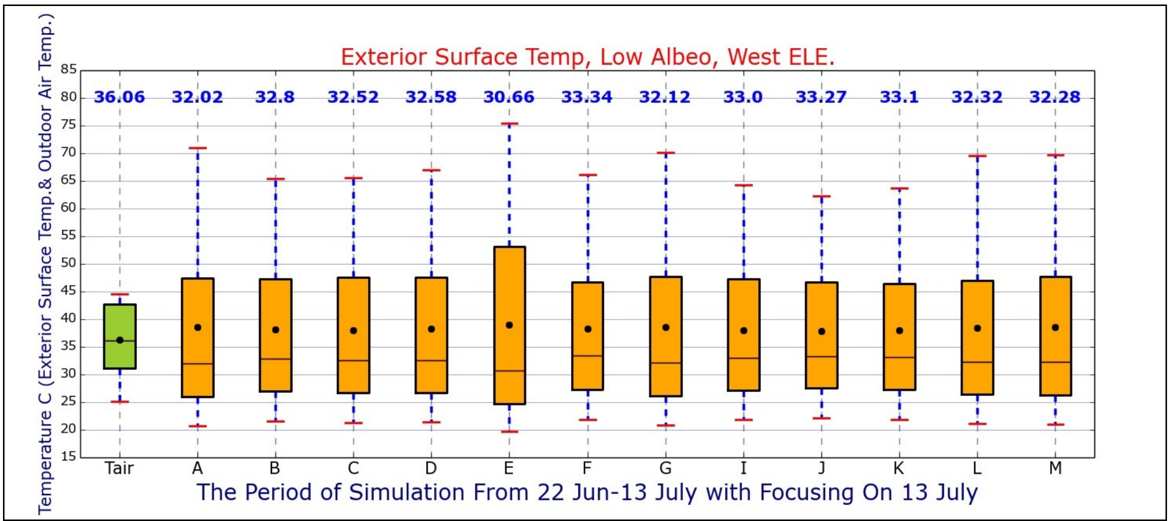
Table (6.18), describes the maximum, minimum, average, and median surface temperature of the west elevation for each type of the building exterior wall shape.

From table (6.18), and according to the maximum exterior surface temperature (Tse), the wall shape that has been simulated are arranged from the highest (Tse) to the lowest, as below:



Max Exterior Surface Temp.	**Frame expressed**	**Irregular printed concrete**	**Column expressed**	**Irregular square shape**	**Zigzag shape**	**Inverted pyramid shape**	**Serpentine shape**	**Ornament printed**	**Muli-surface shape**	**Combine pyramids shape**	**Square shape**	**Pyramid shape**
	62.24 ºC	**63.71 ºC**	**64.23 ºC**	**65.46 ºC**	**65.56 ºC**	**66.13 ºC**	**66.95 ºC**	**69.49 ºC**	**69.9 ºC**	**70.11 ºC**	**70.98 ºC**	**75.36 ºC**

Accordingly, we conclude that the appropriate wall shape for west elevation is the frame expressed wall where the maximum, minimum, average surface temperature, is (62.24ºC, 22.09ºC, 37.82ºC) respectively.



	A	B	C	D	E	F	G	I	J	K	L	M
	Square shape	Irregular square shape	Zigzag shape	Serpentine shape	Pyramid shape	Inverted pyramid shape	Combine pyramids shape	Column expressed	Frame expressed	Irregular printed concrete	Ornament printed	Muli-surface shape
AVE.	38.61	38.13	37.95	38.23	38.99	38.28	38.56	38.01	37.82	37.94	38.40	34.43
MAX.	70.98	65.46	65.56	66.95	75.36	66.13	70.11	64.23	62.24	63.71	69.49	44.62
MIN.	20.75	21.60	21.32	21.35	19.63	21.90	20.84	21.79	22.09	21.88	21.07	20.67
MED.	32.02	32.80	32.52	32.58	30.66	33.34	32.12	33.00	33.27	33.10	32.32	38.20

Table 6. 18: The exterior surface temperature of different wall shapes | West elevation

e. Conclusion of Step two, Sub-step two

According to the previous simulation results and as it has been shown in (Figure 6.42),), it can be concluded adopting a specific wall shape compatible with each building elevation , with respect to the thermal performance in general and external surface temperature reduction in particular wouldn't lead to an homogeneous form. The most appropriate shape of the envelope form varies according to the orientation of the building elevations towards the sun. The reason is that each building elevation does not receive the same amount of solar radiation (sun exposure) with the same incidence angle as long as the building orientation determines them.

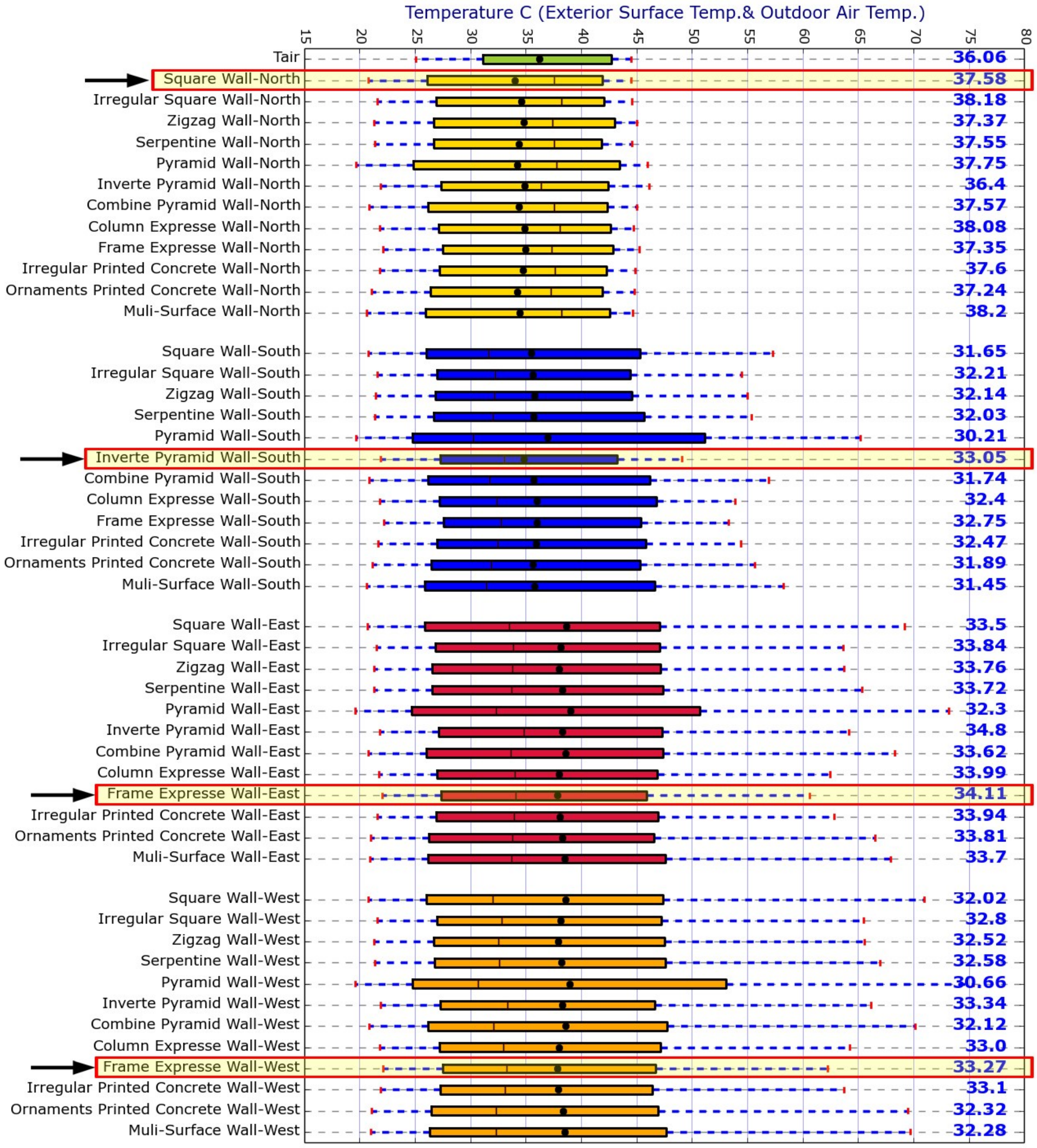


Figure 6. 42: The comparison results regarding the exterior surface temperature of different wall shapes

Therefore, according to the hourly and seasonal motion of the Sun across the sky of the region in which is our case study, the appropriate wall shape that contributes effectively to reducing the exterior surface temperature of north, south, east, and west elevation is square wall (the original wall shape of the case study), inverted pyramid shape reduced about (14.3%) of the original shape respectively see (Figure 6.43), frame exposed shape (reduced about 12.4% of the original shape, see Figure 6.44), frame exposed shape (reduced about 12.3% of the original shape, see Figure 6.45). Accordingly, the proposed final form of the building will be shown in the Figure (6.46) and Figure (6.47).

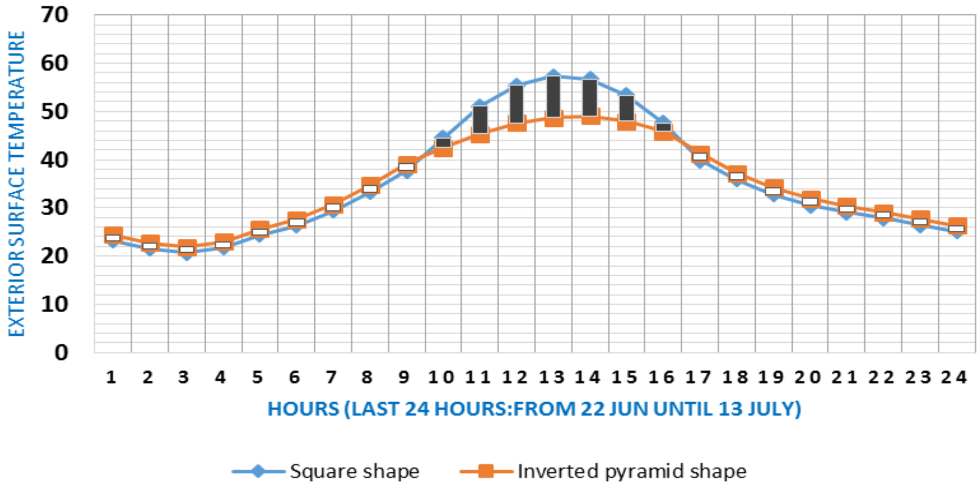


Figure 6. 43: The appropriate wall design (proposed wall-inverted pyramid) vs the square wall (existing wall) of South Elevation

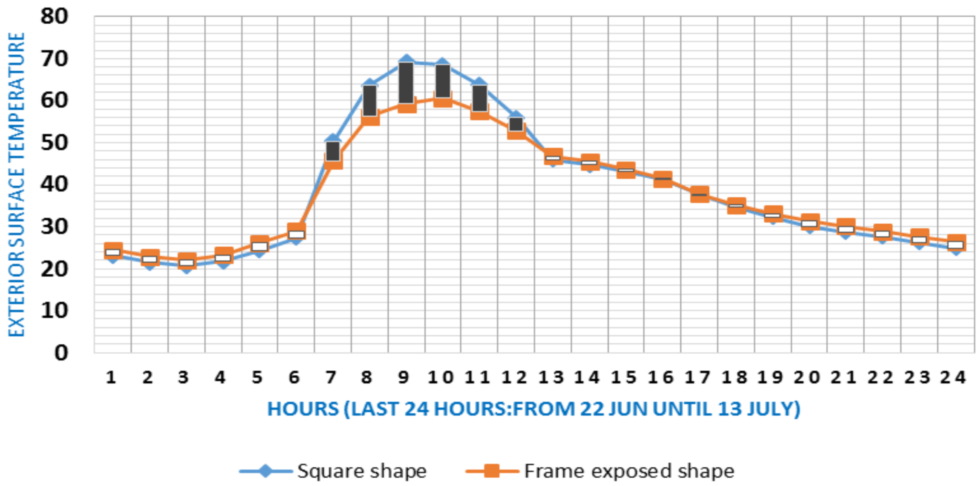


Figure 6. 44: The appropriate wall design (proposed wall-frame exposed) vs the square wall (existing wall) of East Elevation

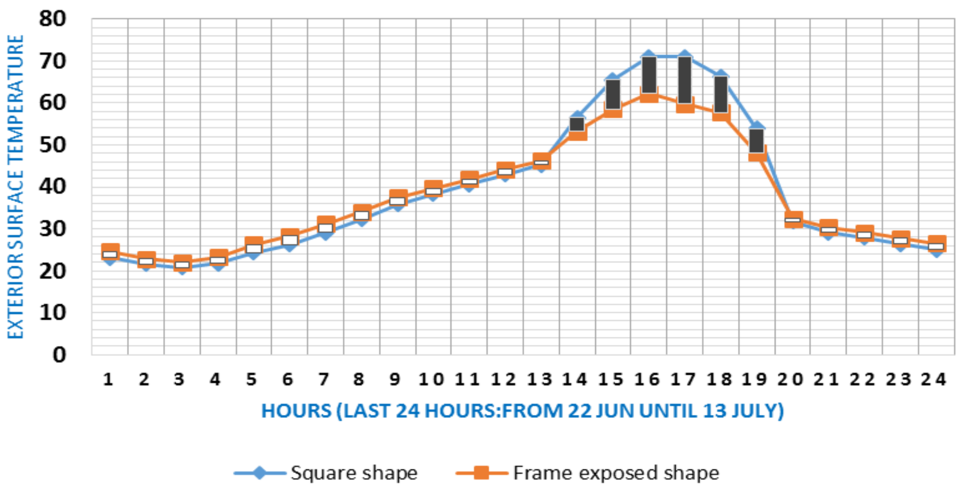


Figure 6. 45: The appropriate wall design (proposed wall-frame exposed) vs the square wall (frame exposed) of West Elevation

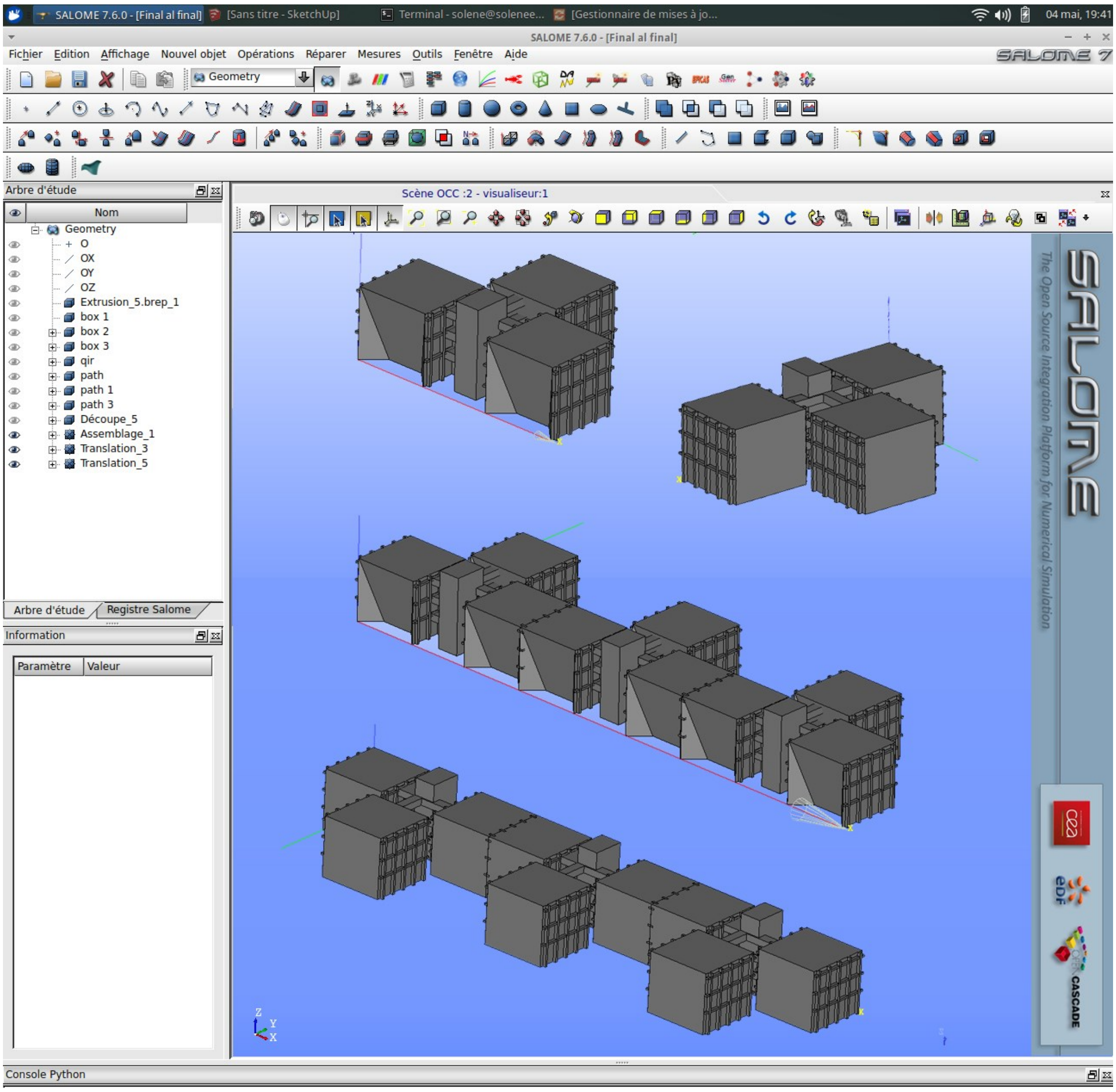


Figure 6. 46: The proposed building design

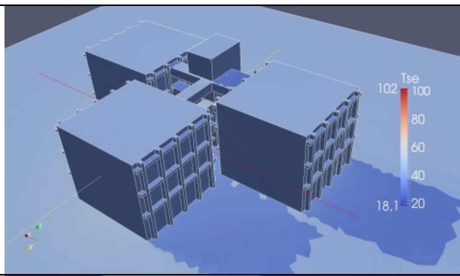
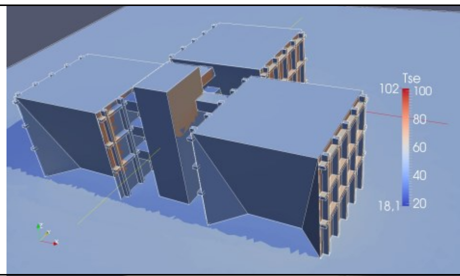
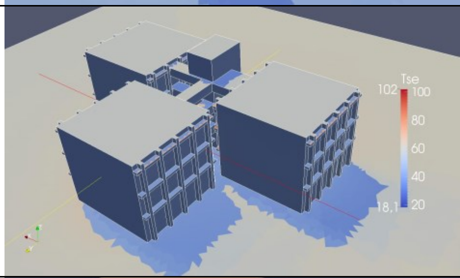
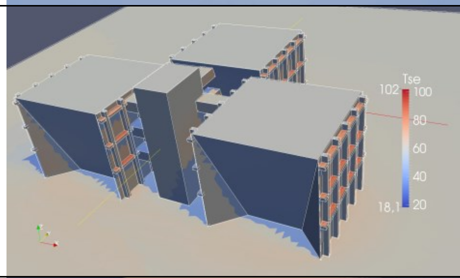
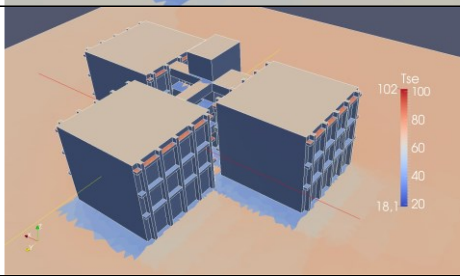
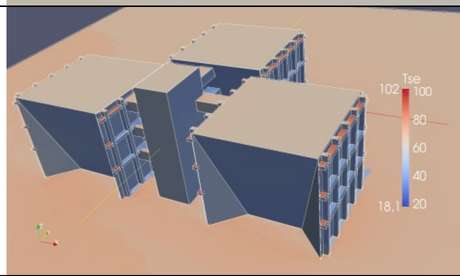
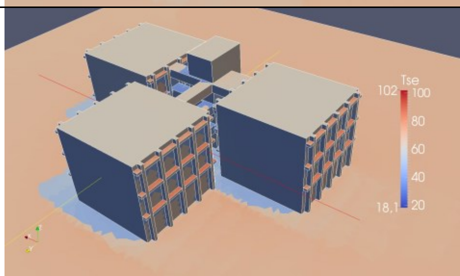
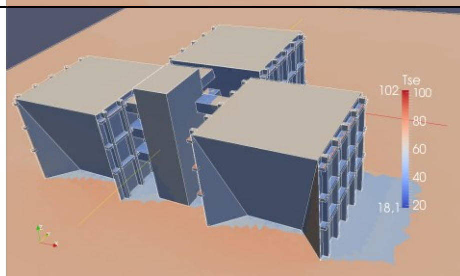
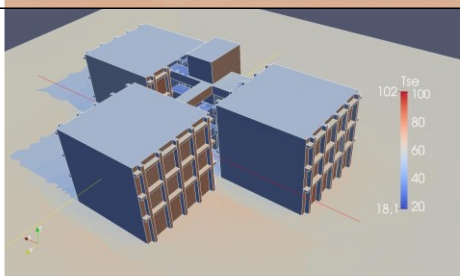
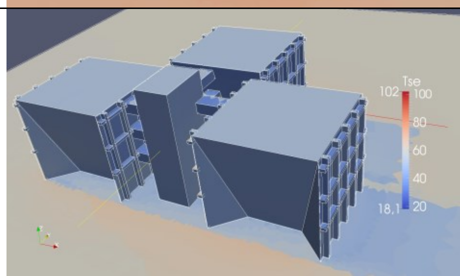
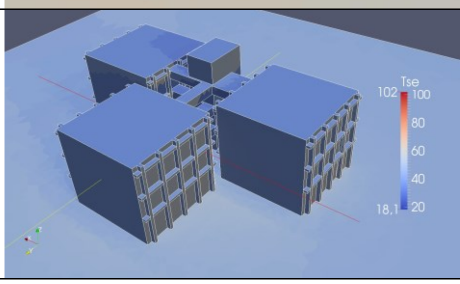
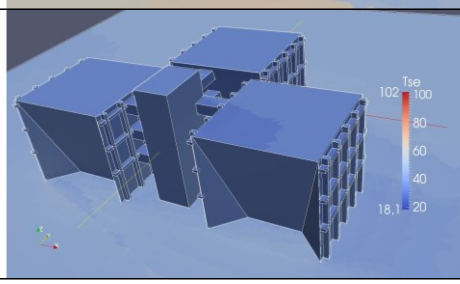
T.S	North and East ELE.	South and West ELE.
Time step 8:00h		
Time step 10:00h		
Time step 12:00h		
Time step 14:00h		
Time step 16:00h		
Time step 18:00h		

Figure 6. 47: Visual simulation result regarding the thermal performance of proposed building design

6.6.1.6. Step three, Sub-step one: Results related to the comparison of three complementary solutions

The result of this step is basically a comparison between the scenario that is selected in step 2 (pumice block as a main building materials and exterior wall with thickness 20cm) and the three complementary solutions: double wall, green wall, and high-albedo materials.

Regarding the interior surface temperature of the exterior building walls (Tn1)

The results show that (Tn1) stays in the same variation range when changing the complementary solutions. The maximum temperature is approximately (22 ºC), while the minimum temperature is approximately (20 ºC), see Figure (6.48).

Accordingly, we conclude that the interior surfaces temperature of the exterior building walls is affected mainly by the characteristics of building material and not by the solutions that may be applied to the external surfaces of the exterior building walls.

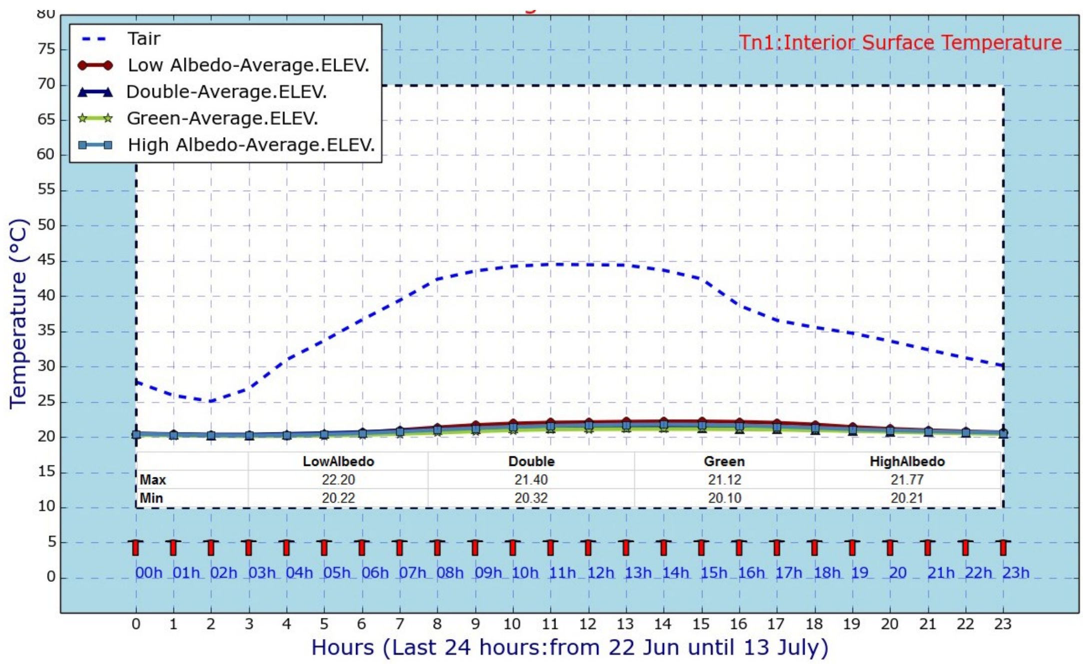


Figure 6. 48: The average interior surface temperature of building elevations

Regarding the exterior surface temperature of the exterior building walls (Tse),

When applying one of the proposed complementary solutions, the results show that each of these solutions has differed in the reduction of external surface temperature for each elevation. The rate of reduction of maximum values for each elevation is given in (table 6.19).

Elevation		Max Tse Before applying the complementary solution	Max Tse of Double wall alternative	Max Tse of Green wall alternative	Max Tse of High albedo alternative	Figure
North		45.38 ºC	37.96 ºC	41.30 ºC	43.48 ºC	(6.49)
	Rate of reduction		**16%**	**9%**	**4%**	
South		57.09 ºC	42.59 ºC	42.36 ºC	47.43 ºC	(6.50)
	Rate of reduction		**25%**	**26%**	**17%**	
East		67.65 ºC	50.29 ºC	42.66 ºC	46.06 ºC	(6.51)
	Rate of reduction		**26%**	**37**	**32%**	
West		67.91 ºC	51.43 ºC	41.89 ºC	47.33 ºC	(6.52)
	Rate of reduction		**24%**	**38%**	**30%**	
Average		59.51 ºC	45.57 ºC	42.05 ºC	46.08 ºC	
	Rate of reduction		**23%**	**29%**	**23%**	
Fig.			(6.53)	(6.54)	(6.55)	

Table 6. 19: The surface temperature reduction of the different building elevations

Consequently, it comes that all these alternatives can help to reduce the external surface temperature of the building's walls, but the best behavior emerges when using the vertical greenery systems (green wall) comp. From that one important question can be raised:

What is the complementary solution applicable to our case study?

Although the best complementary solution is the vertical greenery systems which achieves the lowest average surface temperature (about 42 ºC), it is not applicable in Iraq. This is due to a combination of reasons, the most important ones being: the absence of specialized staff responsible for the management of the maintenance work required for such type of walls, which requires a regular maintenance, the probability of the failure of the irrigation system as a result of insufficient or fluctuating water pressure.

Regarding the second complementary solution the "double wall", it can be said that this solution is not applied in Iraq in a large extent but it is limited to some small projects such as (small private home) especially when one of the objectives of the project is to take into consideration the lowest cost.

Finally, concerning the third complementary solution "high albedo materials" can be applied perfectly in Iraq for all types of projects whether big or small. It is the process of using coating materials with specific properties that increase the reflectivity of the surface. It can be in many colors. It reduces the exterior surface temperature of the northern, southern, eastern, and western façade by (4%, 17%, 32%, and 32%,) respectively with an average reduction of (23%).

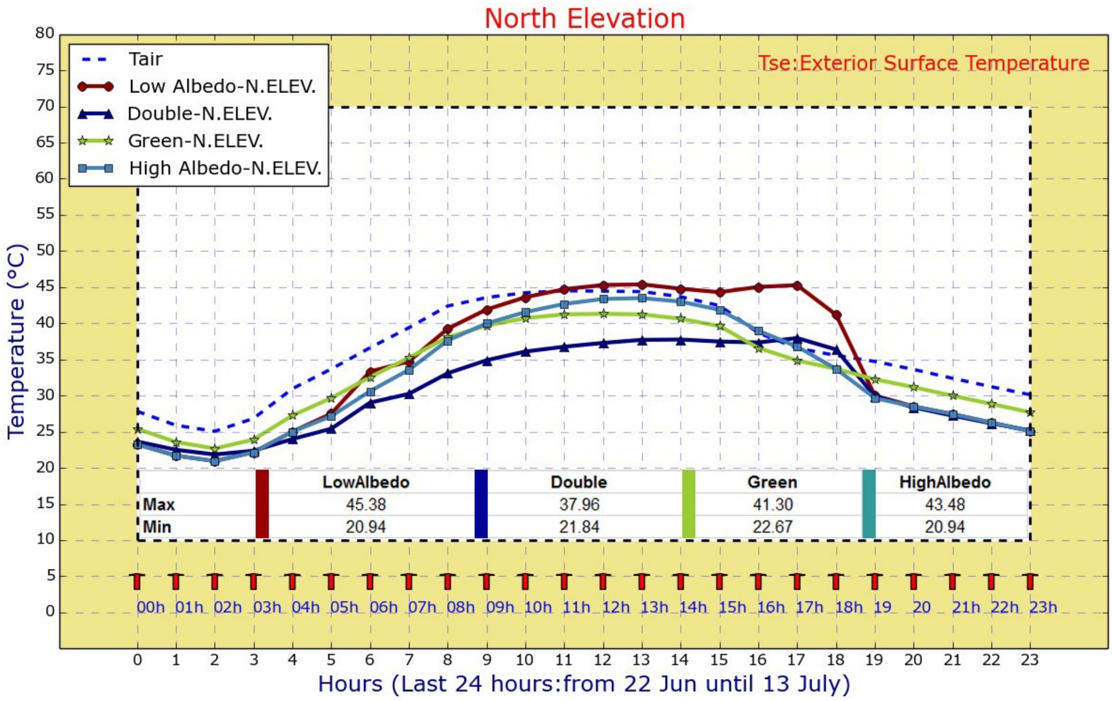


Figure 6. 49: The exterior surface mean temperature of North elevation

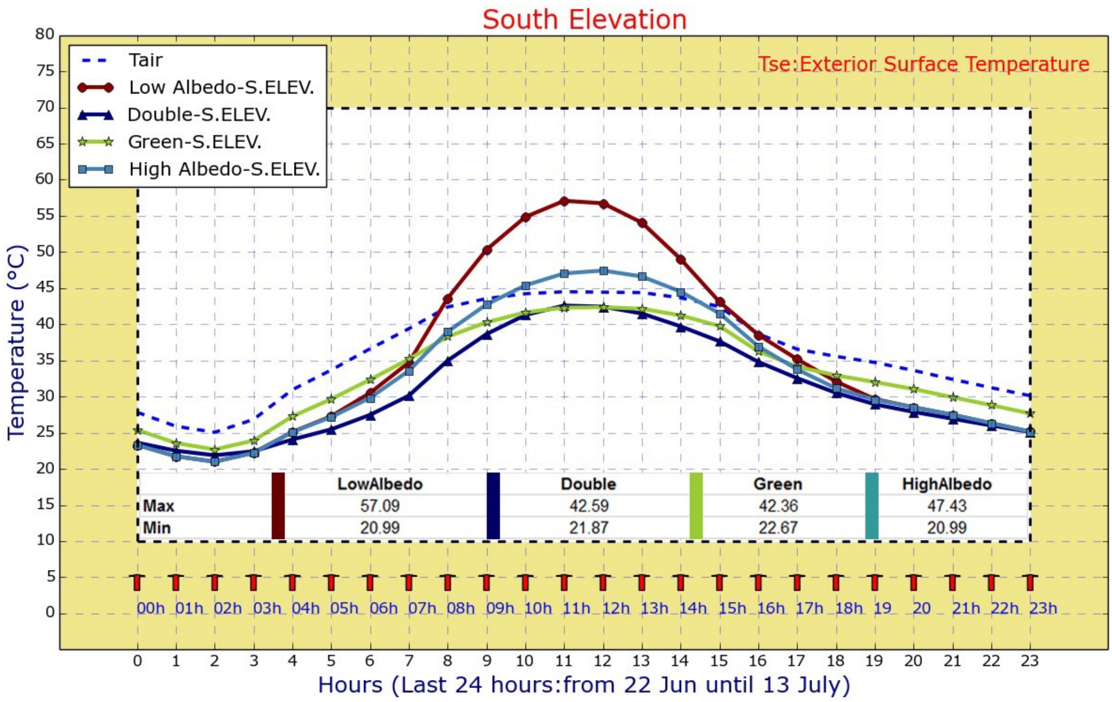


Figure 6. 50: The exterior surface mean temperature of South elevation

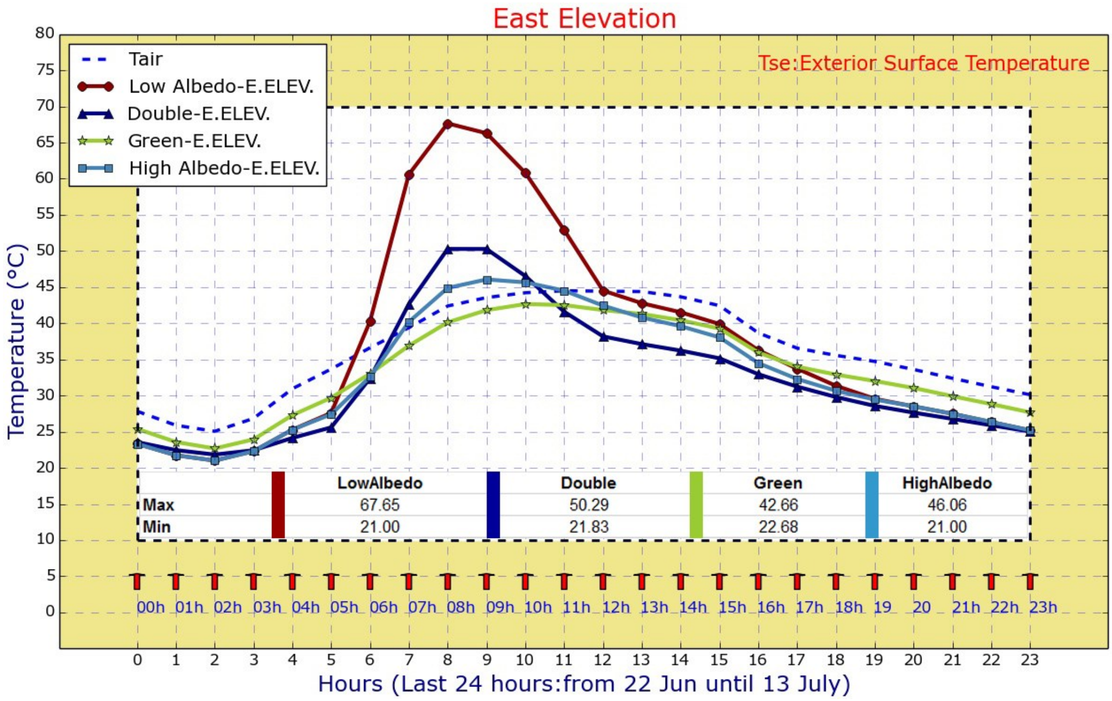


Figure 6. 51: The exterior surface mean temperature of East elevation

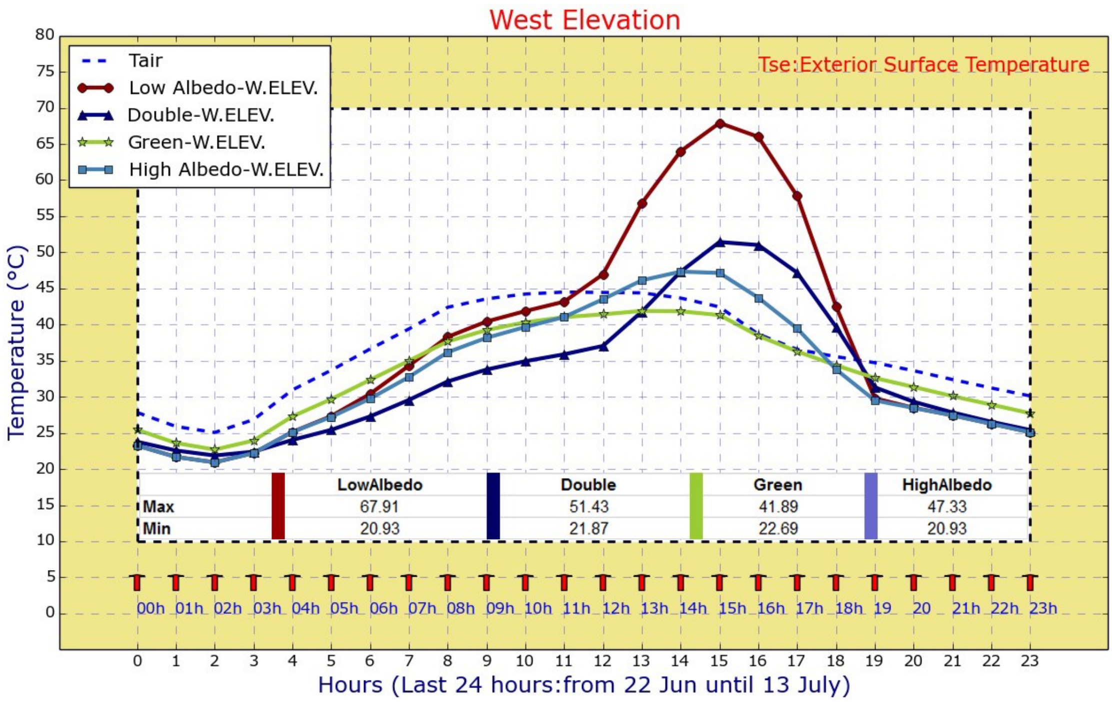


Figure 6. 52: The exterior surface mean temperature of West elevation

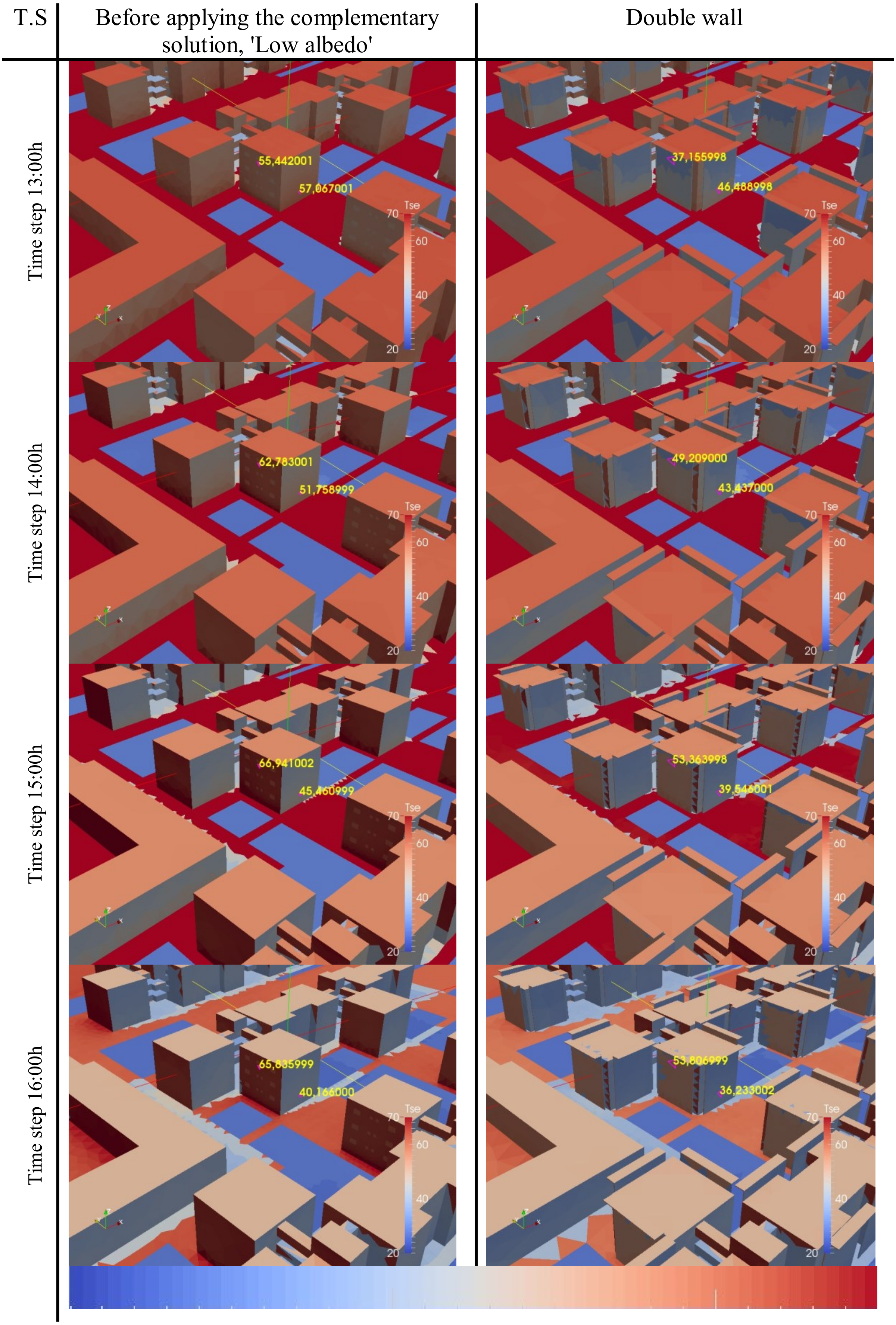


Figure 6. 53: Visual result of exterior double wall surface temperature

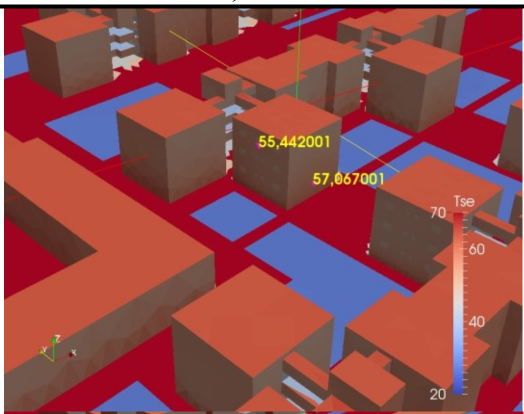
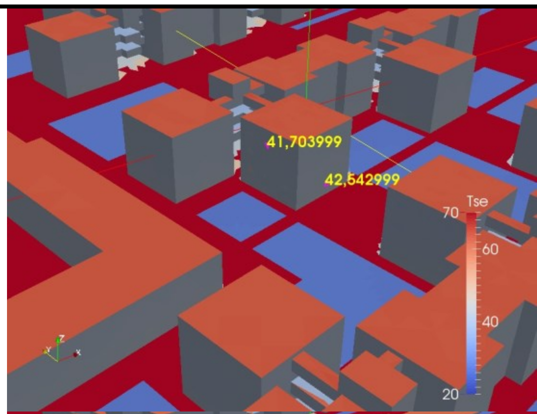
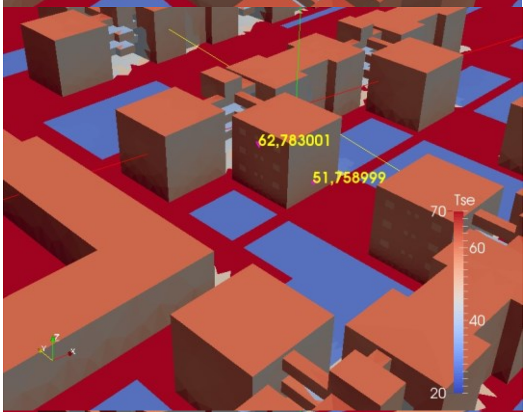
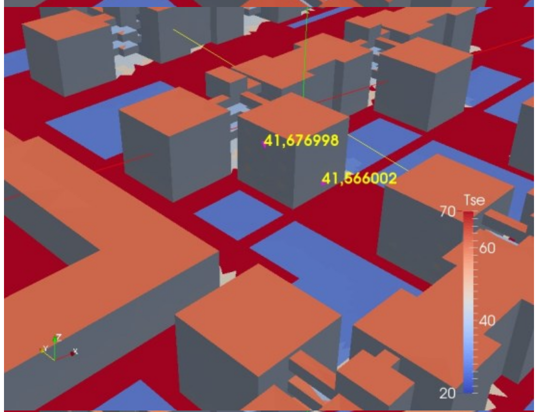
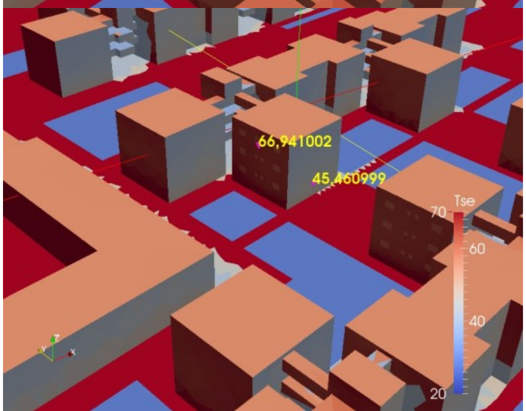
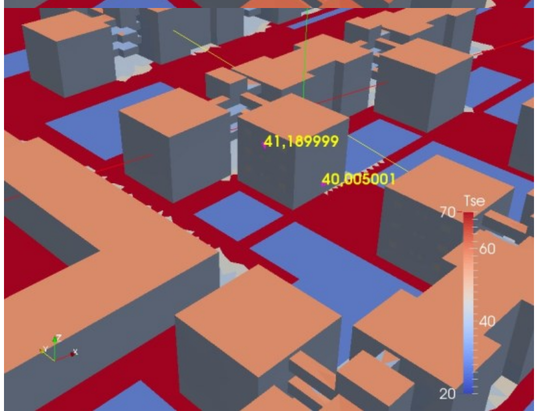
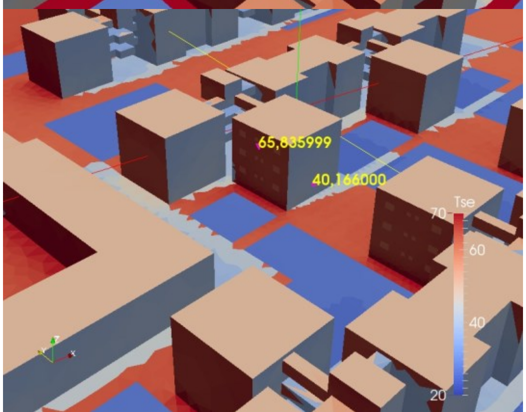
T.S	Before applying the complementary solution, 'Low albedo'	Green Wall
Time step 13:00h		
Time step 14:00h		
Time step 15:00h		
Time step 16:00h		

Figure 6. 54: Visual result of exterior green wall surface temperature

T.S	Before applying the complementary solution, 'Low albedo'	High albedo wall
Time step 13:00h		
Time step 14:00h		
Time step 15:00h		
Time step 16:00h		

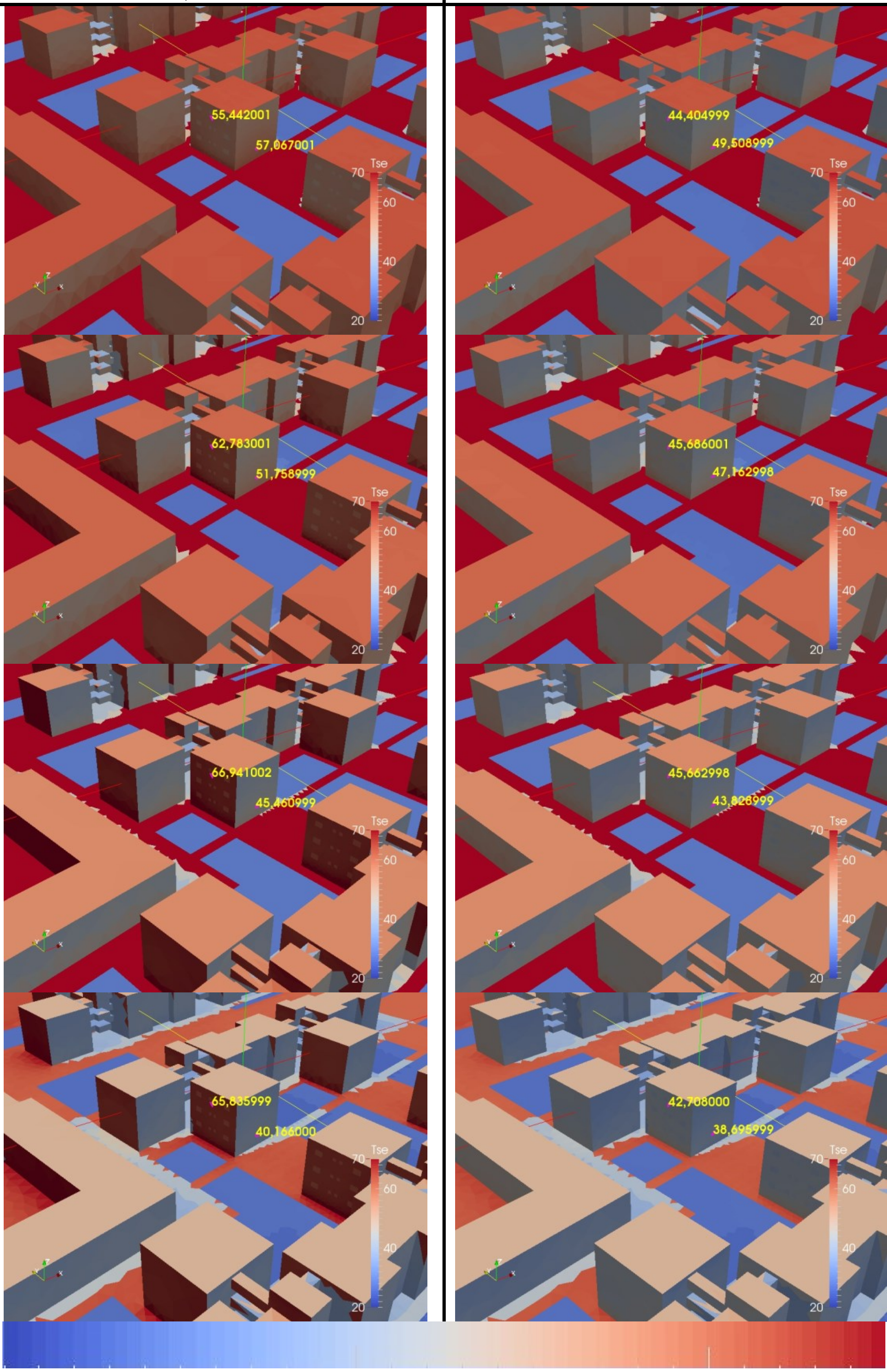


Figure 6. 55: Visual result of exterior high albedo wall surface temperature

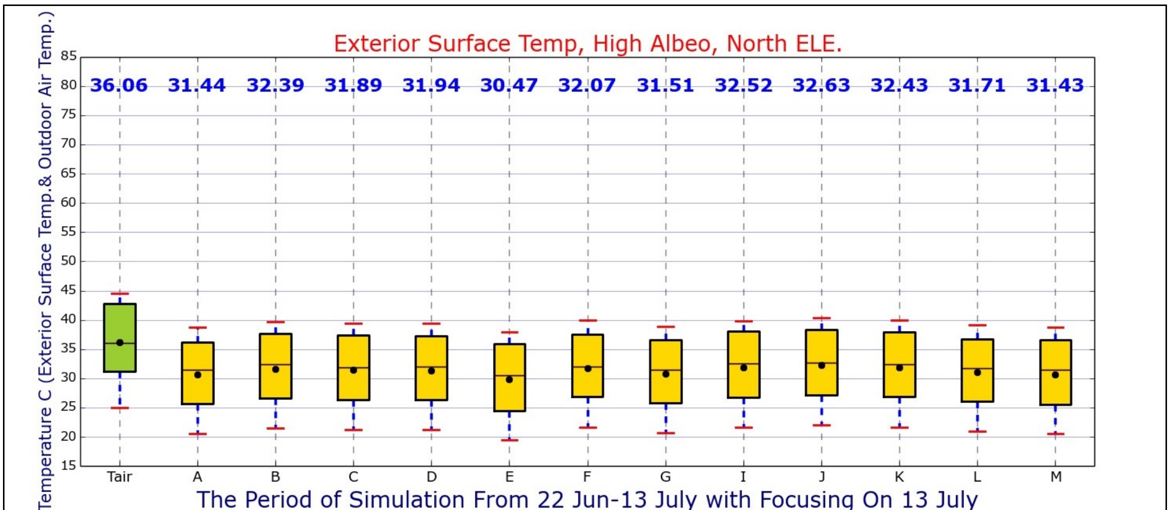
6.6.1.7. Step three, Sub-step two: Complementary solutions and wall shape

The result of this step is related to the wall shape design after applying the selected complementary solution. The results will be discussed for each elevation of the building separately to distinguish the thermal behavior for each one individually

a. The North Elevation

Table (6.20) describes the maximum, minimum, average, and median surfaces temperatures of north elevation for each type of the exterior wall shapes.

According to this table, there is no significant variance of the maximum exterior surface temperature among all the exterior wall shapes. This variance does not exceed (2 ºC). The maximum exterior surface temperature of all the types is located between (38-40 ºC), while the median, average, and minimum are between, (30-33 ºC), (30-32 ºC), (19-22 ºC) respectively.



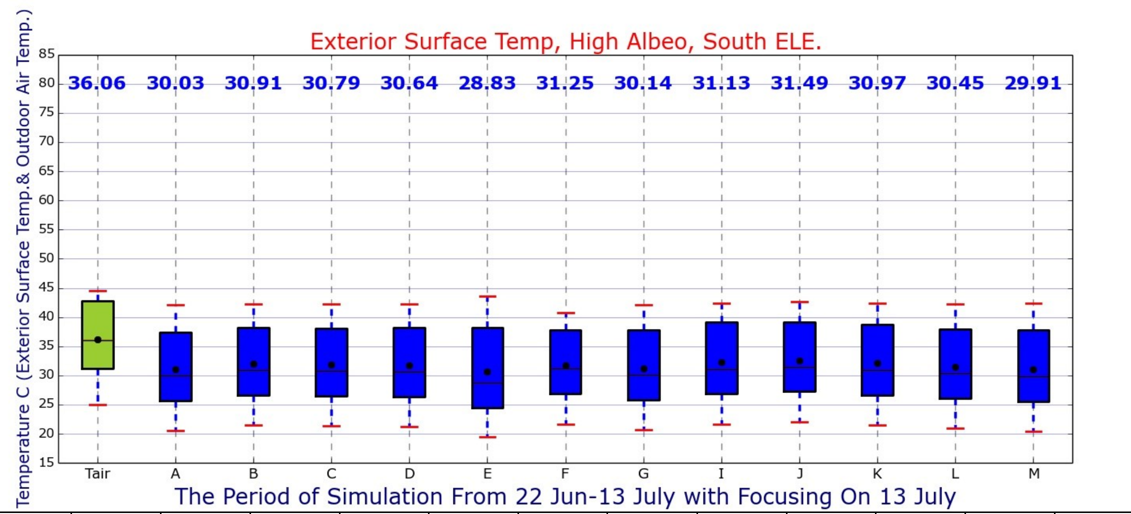
	A	B	C	D	E	F	G	I	J	K	L	M
	Square shape	**Irregular square shape**	**Zigzag shape**	**Serpentine shape**	**Pyramid shape**	**Inverted pyramid shape**	**Combine pyramids shape**	**Column expressed**	**Frame expressed**	**Irregular printed concrete**	**Ornament printed**	**Muli-surface shape**
AVE.	31 ºC	32 ºC	31 ºC	31 ºC	30 ºC	32 ºC	31 ºC	32 ºC	32 ºC	32 ºC	31 ºC	31 ºC
MAX.	39 ºC	40 ºC	39 ºC	39 ºC	38 ºC	40 ºC	39 ºC	40 ºC	40 ºC	40 ºC	39 ºC	39 ºC
MIN.	21 ºC	21 ºC	21 ºC	21 ºC	19 ºC	22 ºC	21 ºC	22 ºC	22 ºC	22 ºC	21 ºC	20 ºC
MED.	31 ºC	32 ºC	32 ºC	32 ºC	30 ºC	32 ºC	32 ºC	33 ºC	33 ºC	32 ºC	32 ºC	31 ºC

Table 6. 20: The exterior surface temperature of different wall shapes-high albedo coating | North elevation

b. The South Elevation

Table (6.21) describes the maximum, minimum, average, and median surfaces temperatures of south elevation for each type of the exterior wall shapes.

We can conclude that there is no significant variance of the maximum exterior surface temperature among all the exterior wall shapes. This variance does not exceed (3 ºC). The maximum exterior surface temperature of all the types is located between (41-44 ºC), while the median, average, and minimum are between, (29-31 ºC), (31-33 ºC), (20-21 ºC) respectively.



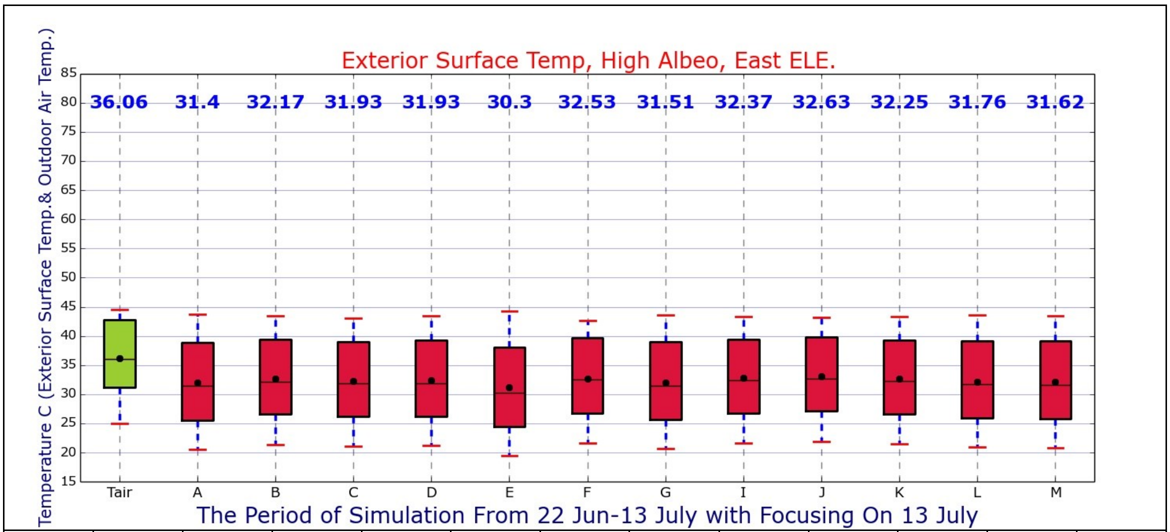
	A	B	C	D	E	F	G	I	J	K	L	M
	Square shape	**Irregular square shape**	**Zigzag shape**	**Serpentine shape**	**Pyramid shape**	**Inverted pyramid shape**	**Combine pyramids shape**	**Column expressed**	**Frame expressed**	**Irregular printed concrete**	**Ornament printed**	**Muli-surface shape**
AVE.	31 ºC	32 ºC	32 ºC	32 ºC	31 ºC	32 ºC	31 ºC	32 ºC	33 ºC	32 ºC	32 ºC	31 ºC
MAX.	42 ºC	42 ºC	42 ºC	42 ºC	44 ºC	41 ºC	42 ºC	42 ºC	43 ºC	42 ºC	42 ºC	42 ºC
MIN.	21 ºC	21 ºC	21 ºC	21 ºC	20 ºC	22 ºC	21 ºC	22 ºC	22 ºC	22 ºC	21 ºC	20 ºC
MED.	30 ºC	31 ºC	31 ºC	31 ºC	29 ºC	31 ºC	30 ºC	31 ºC	31 ºC	31 ºC	30 ºC	30 ºC

Table 6. 21: The exterior surface temperature of different wall shapes-high albedo coating | South elevation

c. The East Elevation

Table (6.22), describe the maximum, minimum, average, and median surfaces temperatures of the east elevation for each type of the exterior wall shapes.

According to this table, there is no significant variance of the maximum exterior surface temperature among all the exterior wall shapes. This variance does not exceed (1 ºC). The maximum exterior surface temperature of all the types is located between (43-44 ºC), while the median, average, and minimum are between, (30-33 ºC), (31-33 ºC), (19-22 ºC) respectively.



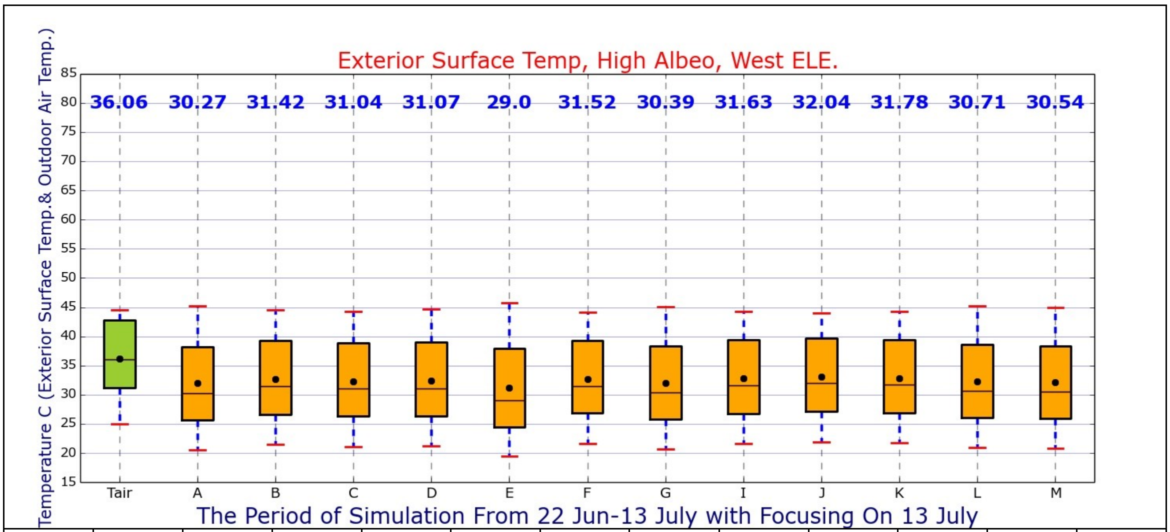
	A	B	C	D	E	F	G	I	J	K	L	M
	Square shape	**Irregular square shape**	**Zigzag shape**	**Serpentine shape**	**Pyramid shape**	**Inverted pyramid shape**	**Combine pyramids shape**	**Column expressed**	**Frame expressed**	**Irregular printed concrete**	**Ornament printed**	**Muli-surface shape**
AVE.	32 ºC	33 ºC	32 ºC	32 ºC	31 ºC	33 ºC	32 ºC	33 ºC	33 ºC	33 ºC	32 ºC	32 ºC
MAX.	44 ºC	43 ºC	43 ºC	43 ºC	44 ºC	43 ºC	44 ºC	43 ºC	43 ºC	43 ºC	44 ºC	44 ºC
MIN.	21 ºC	21 ºC	21 ºC	21 ºC	19 ºC	22 ºC	21 ºC	22 ºC	22 ºC	21 ºC	21 ºC	21 ºC
MED.	31 ºC	32 ºC	32 ºC	32 ºC	30 ºC	33 ºC	32 ºC	32 ºC	33 ºC	32 ºC	32 ºC	32 ºC

Table 6. 22: The exterior surface temperature of different wall shapes-high albedo coating | East elevation

d. The West Elevation

Table (6.23), describes the maximum, minimum, average, and median surfaces temperatures of the east elevation for each type of the exterior wall shapes.

According to this table, there is no significant variance of the exterior surface temperature among all the exterior wall shapes. This variance does not exceed (2 ºC). The median exterior surface temperature of all the types is located between (30-33 ºC), while the average, maximum, and minimum are between, (31-33 ºC), (43-44 ºC), (19-22 ºC) respectively.



	A	B	C	D	E	F	G	I	J	K	L	M
	Square shape	Irregular square shape	Zigzag shape	Serpentine shape	Pyramid shape	Inverted pyramid shape	Combine pyramids shape	Column expressed	Frame expressed	Irregular printed concrete	Ornament printed	Muli-surface shape
AVE.	31 ºC	33 ºC	32 ºC	32 ºC	31 ºC	33 ºC	32 ºC	33 ºC	33 ºC	33 ºC	32 ºC	32 ºC
MAX.	44 ºC	44 ºC	44 ºC	45 ºC	46 ºC	44 ºC	45 ºC	44 ºC	44 ºC	44 ºC	45 ºC	45 ºC
MIN.	21 ºC	21 ºC	21 ºC	21 ºC	19 ºC	22 ºC	21 ºC	22 ºC	22 ºC	22 ºC	21 ºC	21 ºC
MED.	31 ºC	31 ºC	31 ºC	31 ºC	29 ºC	32 ºC	30 ºC	32 ºC	32 ºC	32 ºC	31 ºC	31 ºC

Table 6. 23: The exterior surface temperature of different wall shapes-high albedo coating | West elevation

e. Conclusion of Step three, Sub-step two

According to the previous simulation results, it can be concluded that there is no significant variation of exterior surface temperature among all the tested walls shapes (see Figure 6.56). This is certainly due to the increase of the reflectivity of the exterior surfaces of building which consequently affected the surface temperature of building.

Therefore we can say that the increase the reflectivity value of the exterior surfaces of the buildings will give the architects and designers wide possibilities to select any ideas of the design that meet their orientations with respect to the environmental design issues.

Accordingly, this study will consider the square wall as a type of the wall shape. This is due to the following reasons:

The square wall is similar to the original wall shape of our case study. Therefore, the construction of a new similar project does not need to achieve substantial changes in the project plans.

The process of improving environmental performance doesn't need extra financial support. In fact, what we need is using types of materials that have high reflectivity commensurate with the amount of radiation falling on the target facade.

The type of building material chosen in the previous step (pumice block) is suitable for this type of wall.

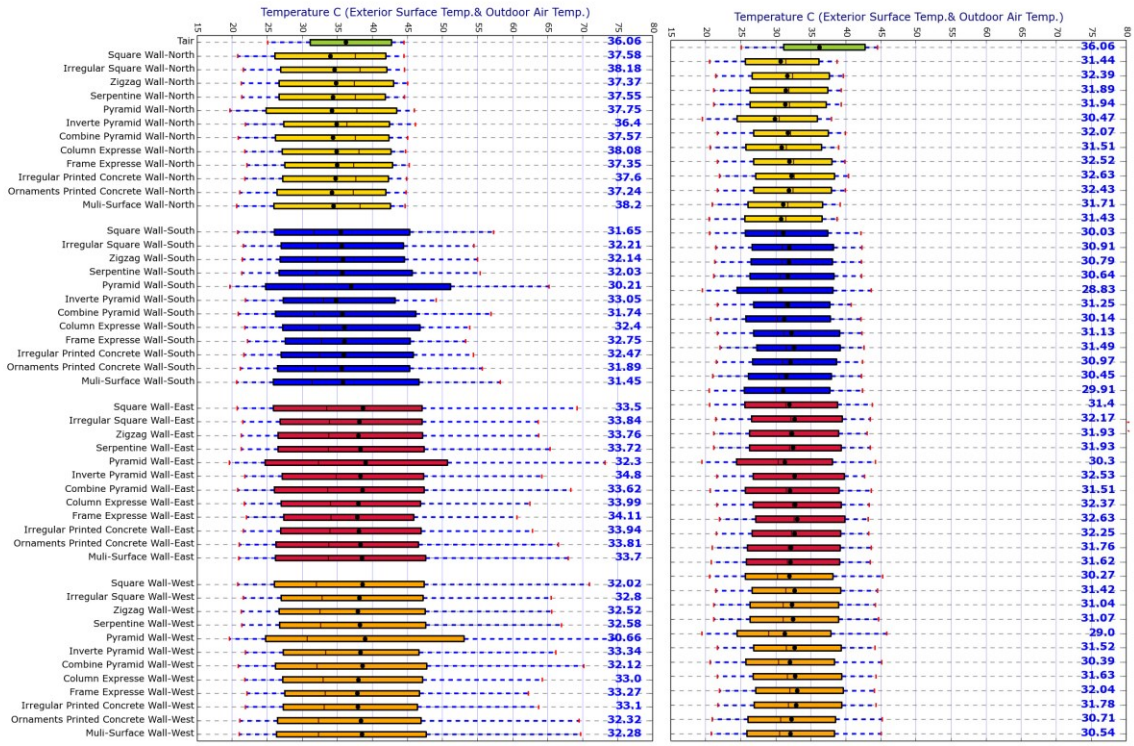


Figure 6. 56: The comparison results regarding the exterior surface temperature of different wall shapes (Left: low albedo, Right: High albedo)

At this point, a question can be raised when there is an increase of the albedo values:

What can we obtain out of the exterior surface temperature compared to the original state of the case study and what is the suitable albedo value for each elevation?

This question and many others will be answered in the next steps of simulation.

6.6.2. Results of the Simulation by using "Thermal model"

This stage of simulation is the fourth step of the simulation which consists of:

Sub-Step one "Free thermal regime"	Calculation of the indoor temperature for different scenarios of the high albedo complementary solution.
Sub-Step two "Force thermal regime"	Investigation of the amount of the energy needed to maintain the acceptable thermal comfort of final high albedo scenario that has been selected in the previous step. We compare the results of three cases: the actual situation of the case study, the case study when using pumice block for exterior walls building, and when using pumice block for exterior walls building and high albedo complementary solution.

6.6.2.1. Simulation results of step four | sub-step one

After selecting high albedo strategy as a complementary solution, this part of study deals with the effect of this strategy on the indoor air temperature and also the external surface temperature of all the urban components. Accordingly, three comparisons with difference scenarios of reflective coatings are done as follows:

First comparison: effect of roofs' albedo

The objective of this comparison is to highlight the effect of the increase of the albedo value of roofs on the indoor thermal comfort. This comparison is carried out between low albedo roof materials and high albedo roof materials as it has been shown in the previous studies

The second comparison: effect of pavements' albedo

The objective of this comparison is to highlight the effect of the increase of the albedo value of roads and pavement on the indoor thermal comfort. This comparison is carried out between the old asphalt classic series (low albedo-black color) and the new types (high albedo-not black color).

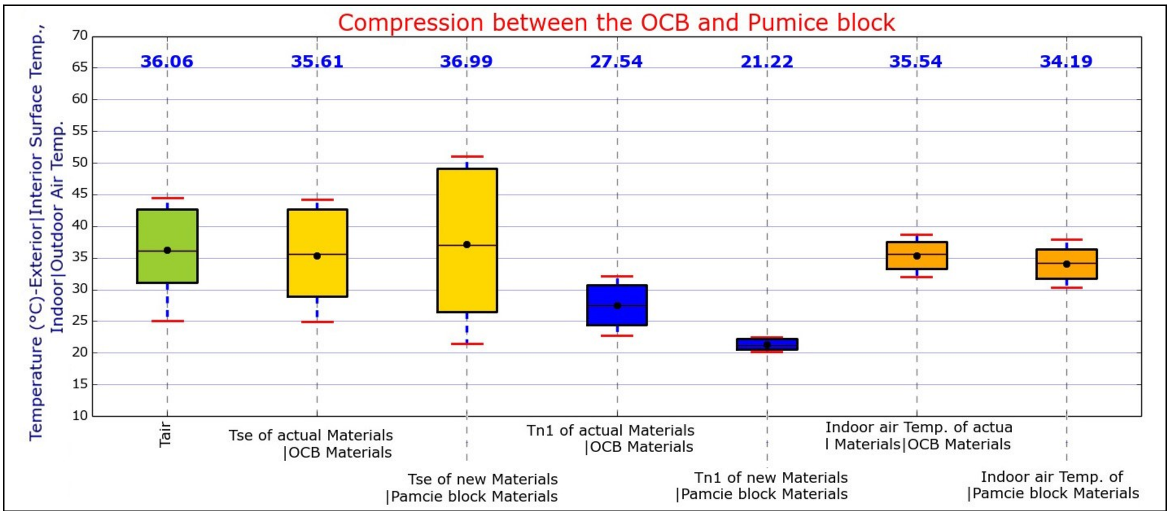
The third comparison: effect of walls' albedo

This step consists of 4 sub-comparisons with the main objective to determine the appropriate albedo value for each elevation of the buildings.

Sub-comparisons 1	***Sub-comparisons 2***	***Sub-comparisons 3***	***Sub-comparisons 4***
Comparison of the simulations with four different albedo values for the fade of the building facing			
North	South	East	West

In order to identify what happens with the increase of the albedo value of urban typology (building envelope and urban spaces) of Al-Hadba Residential Complex, firstly a comparison will be achieved between the actual case study (ordinary concrete block) and the new situation after using pumice block as the main building material for buildings.

The result of this comparison shows that the use of pumice block has effectively contributed to reduce the interior surface temperature as well as to reduce the indoor air temperate, but it also has contributed to increase the exterior surface temperate, see Table 6.24 and Figure 56.



	Tair	Tse OCB	Tse Pumice	Tn1 OCB	Tn1 Pumice	Indoor OCB	Indoor pumice
Max	44.50 ºC	44.26 ºC	51.02 ºC	32.18 ºC	22.48 ºC	38.71 ºC	37.85 ºC
Min	25.06 ºC	24.89 ºC	21.44 ºC	22.69 ºC	20.18 ºC	32.04 ºC	30.37 ºC
Average	36.19 ºC	35.34 ºC	37.09 ºC	27.47 ºC	21.33 ºC	35.37 ºC	34.11 ºC
Median	36.06 ºC	35.61 ºC	36.99 ºC	27.54 ºC	21.22 ºC	35.54 ºC	34.19 ºC

Table 6. 24: The exterior and interior surface temperature of OCB and pumice block

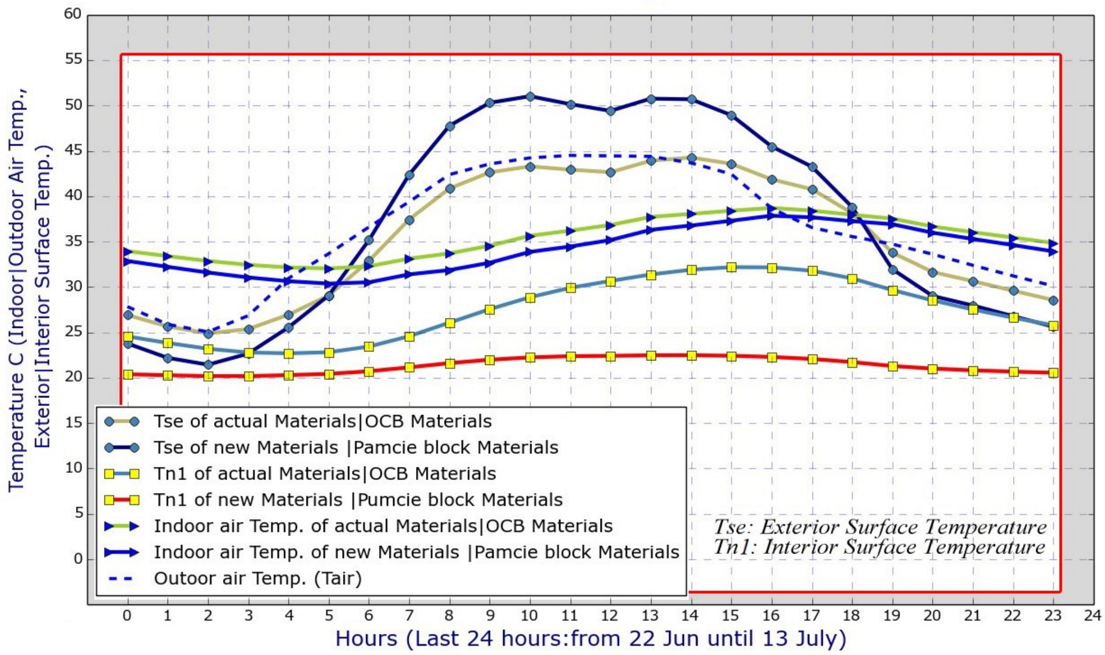


Figure 6. 57: The exterior and interior surface temperature of OCB and pumice block

In spite of the fact that this material (pumice block) has contributed to reduce the internal surface temperature and indoor air temperature, indoor air temperature has not reached totally the recommended thermal comfort zone yet, see (Figure 6.58 and Figure 6.59)

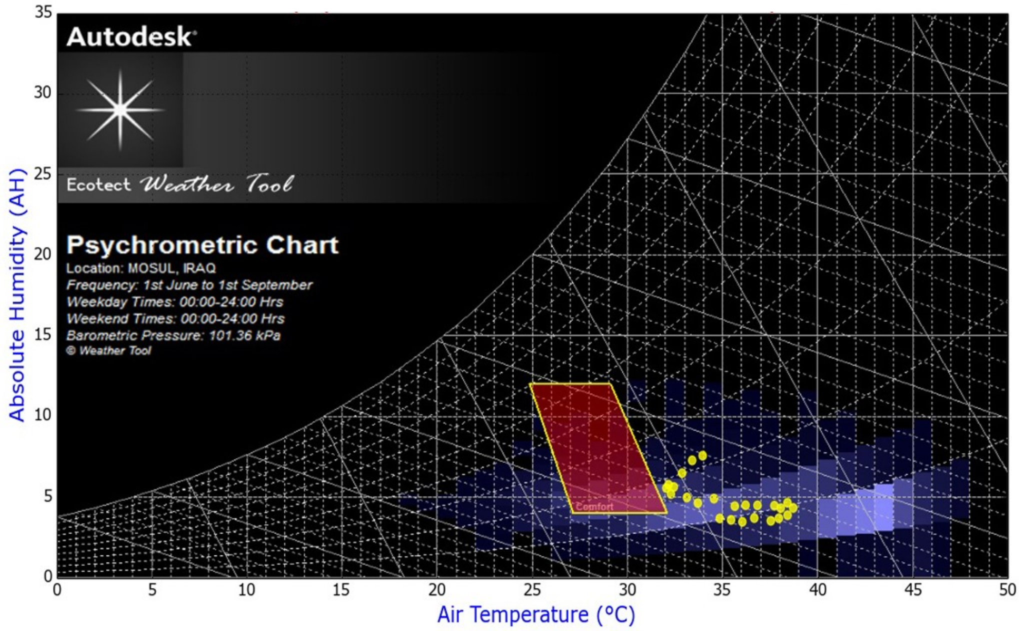


Figure 6. 58: Comfort zone – Actual case study

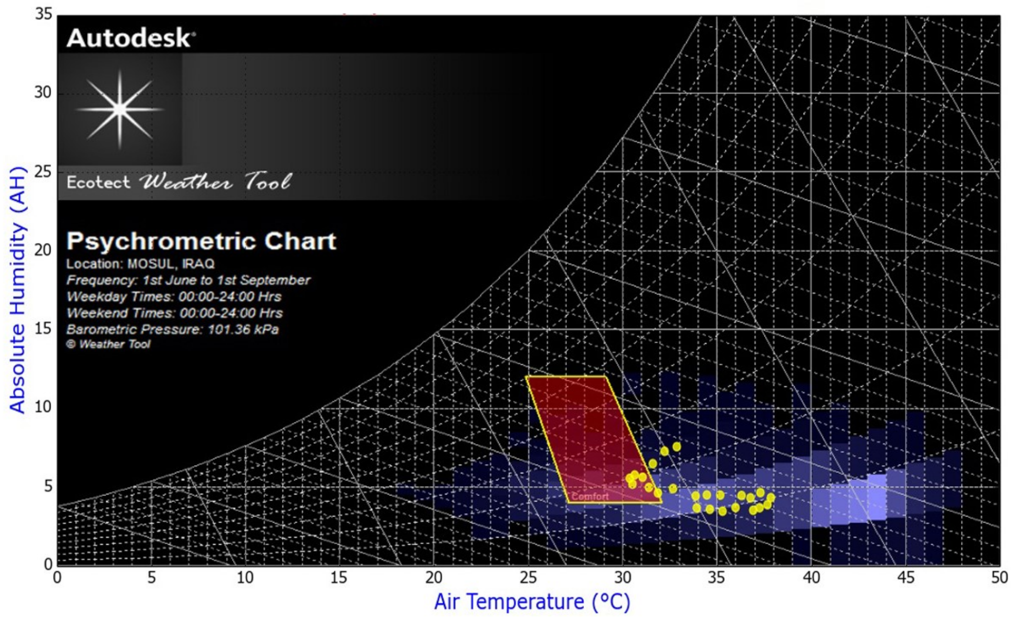


Figure 6. 59: Comfort zone – New building materials – pumice block

Consequently, in the following steps, a series of scenarios of albedo value will be adapted in order to reduce the exterior surface temperature. In addition and as a final step, it will deliver the indoor air temperature to the recommended comfort zone.

a. The first comparison roofs' albedo

According to Table 6.25, Figure 6.60 and Figure 6.61 we notice that the increase of the albedo value of roofs, a set of gains has been obtained as follows:

1. Reduce the average exterior surface temperature of roof from 40.85 ºC to 29.98 ºC.

2. Reduce the average indoor air temperature from 34.11 ºC to 30.55 ºC. It is worth noting that the highest impact with respect to indoor air temperature occurs on the floor directly connected to the roof (second floor), then followed by the first floor and then followed by the ground floor.

Even if this scenario has led to reduce the roof exterior surface temperature and deliver the indoor air temperature most of the time in the day to the recommended comfort zone (see Figure 6.62), there are no changes both in the surface temperature of all four building elevations and external urban spaces.

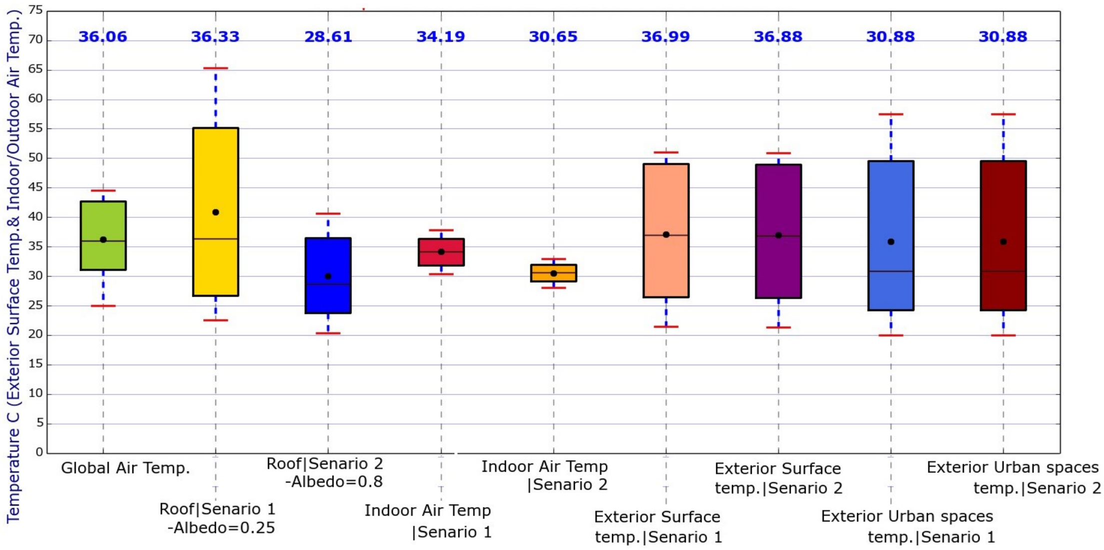


Figure 6. 60: The roof surface temperature – Low albedo and high albedo

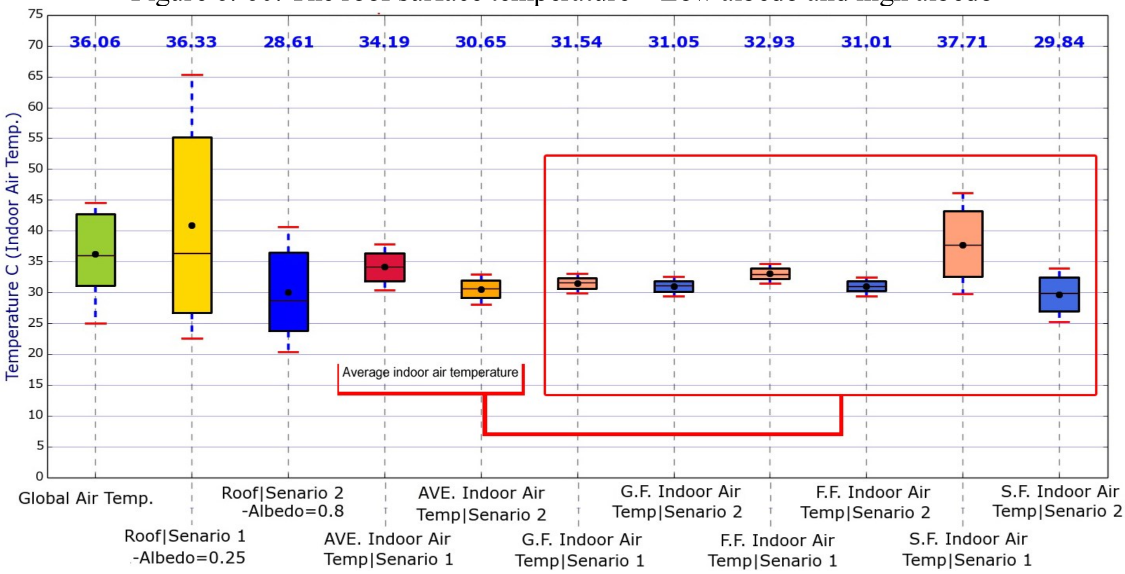


Figure 6. 61: The indoor air temperature | roof low albedo and high albedo

	Air temperature.	Roof surface temperature.	Average indoor air temperature.	Average exterior surface temperature.	Urban spaces surface temperature.
Scenario 1	*Low albedo*				
Average	36.19 ºC	40.85 ºC	34.11 ºC	37.09 ºC	35.88 ºC
Max	44.50 ºC	65.31 ºC	37.85 ºC	51.02 ºC	57.47 ºC
Min	25.06 ºC	22.58 ºC	30.37 ºC	21.44 ºC	19.95 ºC
Median	36.06 ºC	36.33 ºC	34.19 ºC	36.99 ºC	30.88 ºC
Scenario 2	*High albedo*				
Average	36.19 ºC	29.98 ºC	30.55 ºC	36.98 ºC	35.88 ºC
Max	44.50 ºC	40.64 ºC	32.98 ºC	50.93 ºC	57.47 ºC
Min	25.06 ºC	20.36 ºC	28.00 ºC	21.34 ºC	19.95 ºC
Median	36.06 ºC	28.61 ºC	30.65 ºC	36.88 ºC	30.88 ºC

Table 6. 25: The effect of roof albedo on its surface temperature and indoor air temperature

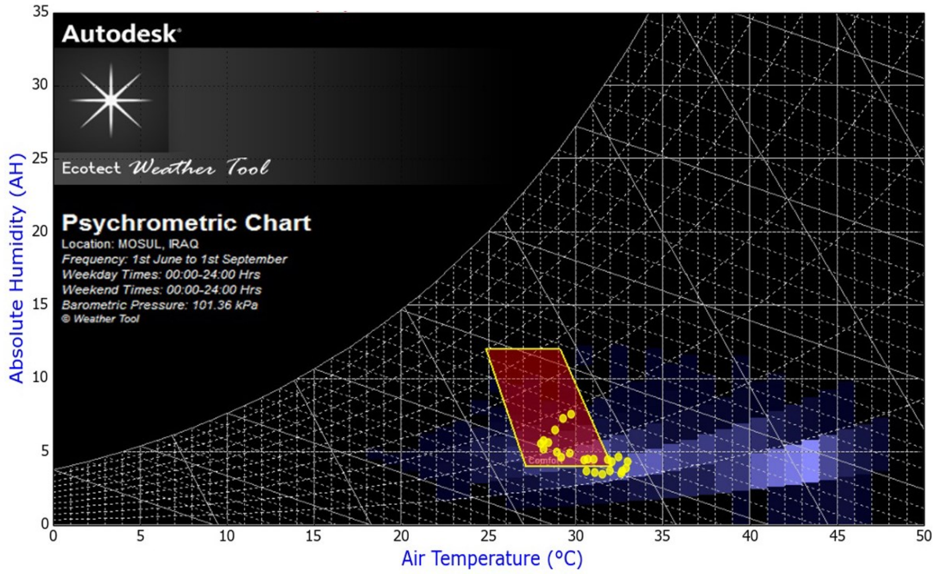


Figure 6. 62: Comfort zone – Roof high albedo materials

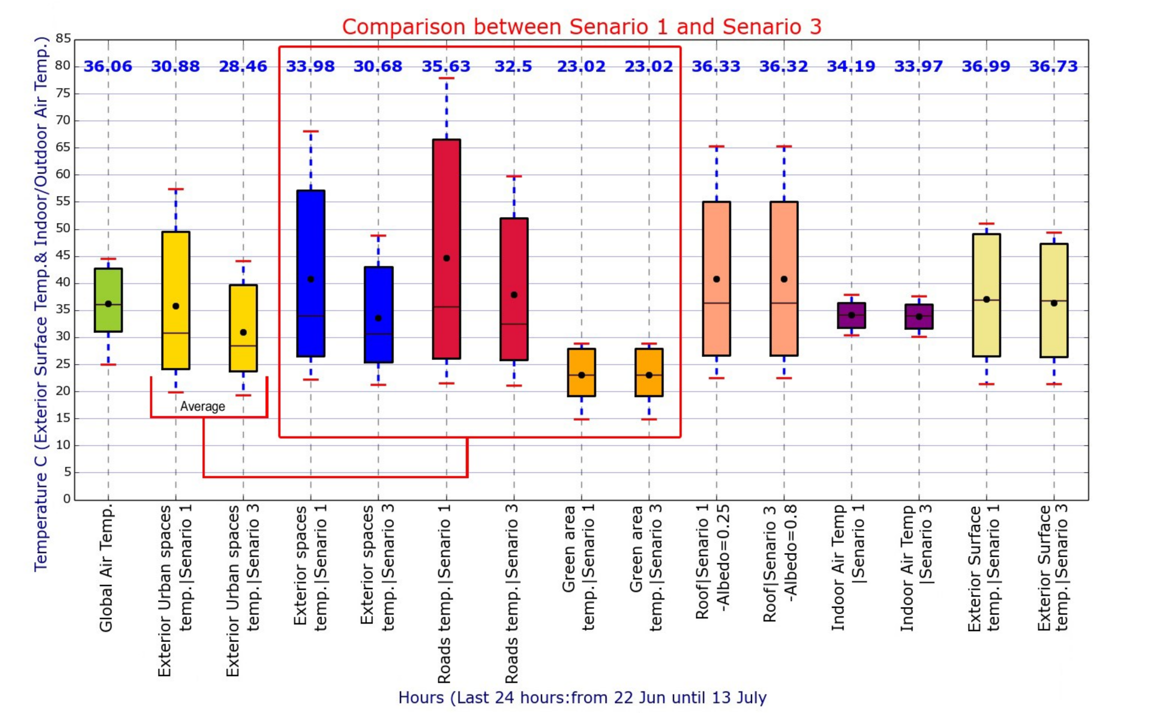
b. The second comparison: pavements' albedo

We come across that the increase of the albedo value of spaces and roads, a set of gains has been obtained as follows:

1. Reduce the average exterior surface temperature of spaces between the buildings from 40.74 ºC to 33.59 ºC.

2. Reduce the average exterior surface temperature of roads from 44.65 ºC to 37.91 ºC.

Despite these gains, no significant change is recorded, in the exterior surfaces temperature of the building exterior walls (approximatively 0.6°C for mean and maximum values) and indoor air temperature (less than 0.3°C for mean and max values). Indeed, these effect are due to secondary impacts: in our model cooling roads leads to lower the heat loads imposed to the building by longwave radiations. Because we are using thermo-radiativre model, the effect on outdoor air temperature is not taken into account (see Table 6.26).



	Air Temp	Urban spaces surface Temp	Spaces surface Temp	Roads surface Temp	Green area surface Temp	Roof surface Temp	Average indoor air Temp	Average exterior surface Temp
Scenario 1 *Low albedo*								
Average	36.19 °C	35.88 °C	40.74 °C	44.65 °C	23.02 °C	40.85 °C	34.11 °C	37.09 °C
Max	44.50 °C	57.47 °C	68.06 °C	77.94 °C	28.91 °C	65.31 °C	37.85 °C	51.02 °C
Min	25.06 °C	19.95 °C	22.23 °C	21.55 °C	14.92	22.58	30.37 °C	21.44 °C
Median	36.06 °C	30.88 °C	33.98 °C	35.63 °C	23.02	36.33	34.19 °C	36.99 °C
Scenario 3 *High albedo*								
Average	36.19 °C	30.93 °C	33.59 °C	37.91 °C	23.02 °C	40.83 °C	33.88 °C	36.37 °C
Max	44.50 °C	44.16 °C	48.83 °C	59.78 °C	28.91 °C	65.29 °C	37.58 °C	49.33 °C
Min	25.06 °C	19.35 °C	21.29 °C	21.12 °C	14.91 °C	22.56 °C	30.19 °C	21.35 °C
Median	36.06 °C	28.46 °C	30.68 °C	32.50 °C	23.02 °C	36.32 °C	33.97 °C	36.73 °C

Table 6. 26: The effect of increasing the albedo value of urban spaces

c. The third comparison: walls' albedo

This step consists of four substeps related to North, South, East, and West elevations

Sub-comparisons one – North elevation

i. The effect of increasing albedo value of North elevation on other elevations, roof and urban spaces.

According to Table 6.27 and Figure 6.63, we find that changing the albedo value of North elevation from (0.5) to either (0.6, 0.7), or (0.8) has no significant effect on the exterior surface temperature of other elevations (South, East, and West), roof and urban spaces exterior surface temperature which nearly stay at the same level for all scenarios. The maximum exterior surface temperature for South, East, West elevations, roof, and urban spaces are, (45 ºC), (45 ºC), (46 ºC), (40 ºC), (45 ºC) respectively.

ii. The effect of increasing albedo value of North elevation on the indoor air temperature and exterior surface temperature of itself.

According to Table 6.27 and Figure 6.63, we have found that the changing of the albedo value of North elevation from (0.5) to either (0.6, 0.7), or (0.8) has also no significant effect on the indoor air temperature and exterior surface temperature of itself. The maximum indoor air temperature is (31 ºC) and exterior surface temperature is (40 ºC).

	Global air temperature	**Average Exterior Surfaces Temperature**	**North ELE. Exterior Surfaces Temperature**	South ELE. Exterior Surfaces Temperature	East ELE. Exterior Surfaces Temperature	West ELE. Exterior Surfaces Temperature	**Roof Exterior Surfaces Temperature**	**Urban Spaces Surfaces Temperature**	Spaces Surfaces Temperature	Roads Surfaces Temperature	Grass Surfaces Temperature	**Average Indoor Air Temperature**	Ground Floor Indoor Air Temperature	First Floor Indoor Air Temperature	Second Floor Indoor Air Temperature
North Elevation with albedo = 0.5															
Average	**36.19**	32.65	**32.20**	32.75	32.77	32.92	**29.76**	**31.43**	34.48	37.76	23.01	**28.90**	28.81	29.05	28.83
Max	**44.50**	41.98	**40.20**	45.01	44.50	45.70	**40.41**	**45.10**	50.52	59.48	28.90	**31.01**	29.95	30.29	32.95
Min	**25.06**	21.24	**20.98**	21.32	21.37	21.29	**20.15**	**19.62**	21.75	21.11	14.92	**26.68**	27.58	27.78	24.68
Median	**36.06**	32.83	**32.64**	31.00	31.97	31.69	**28.40**	**29.08**	31.99	32.45	23.01	**29.00**	28.85	28.96	29.07
North Elevation with albedo = 0.6															
Average	**36.19**	32.58	**31.94**	32.73	32.77	32.91	**29.75**	**31.42**	34.48	37.76	23.01	**28.89**	28.80	29.04	28.83
Max	**44.50**	41.92	**40.01**	44.99	44.50	45.70	**40.40**	**45.09**	50.51	59.48	28.90	**31.00**	29.95	30.28	32.95
Min	**25.06**	21.24	**20.98**	21.32	21.37	21.29	**20.15**	**19.62**	21.75	21.11	14.92	**26.68**	27.57	27.77	24.68
Median	**36.06**	32.56	**32.30**	30.93	31.95	31.69	**28.39**	**29.07**	31.98	32.44	23.01	**28.99**	28.84	28.96	29.06
North Elevation with albedo = 0.7															
Average	**36.19**	32.50	**31.67**	32.71	32.77	32.91	**29.75**	**31.42**	34.47	37.76	23.01	**28.88**	28.80	29.03	28.82
Max	**44.50**	41.86	**39.82**	44.98	44.50	45.70	**40.40**	**45.09**	50.51	59.48	28.90	**31.00**	29.94	30.27	32.94
Min	**25.06**	21.23	**20.98**	21.32	21.37	21.29	**20.15**	**19.62**	21.75	21.11	14.92	**26.67**	27.56	27.77	24.67
Median	**36.06**	32.29	**31.96**	30.86	31.93	31.68	**28.39**	**29.06**	31.97	32.44	23.01	**28.98**	28.83	28.95	29.06
North Elevation with albedo = 0.8															
Average	**36.19**	32.43	**31.41**	32.69	32.76	32.91	**29.75**	**31.42**	34.47	37.76	23.01	**28.88**	28.79	29.02	28.81
Max	**44.50**	41.81	**39.63**	44.97	44.50	45.69	**40.40**	**45.09**	50.50	59.47	28.90	**30.99**	29.93	30.26	32.94
Min	**25.06**	21.23	**20.98**	21.32	21.37	21.29	**20.15**	**19.62**	21.75	21.11	14.92	**26.66**	27.56	27.76	24.67
Median	**36.06**	32.02	**31.61**	30.80	31.92	31.68	**28.39**	**29.05**	31.96	32.43	23.00	**28.98**	28.83	28.94	29.22

Table 6. 27: The simulation results of North elevation with different albedo values

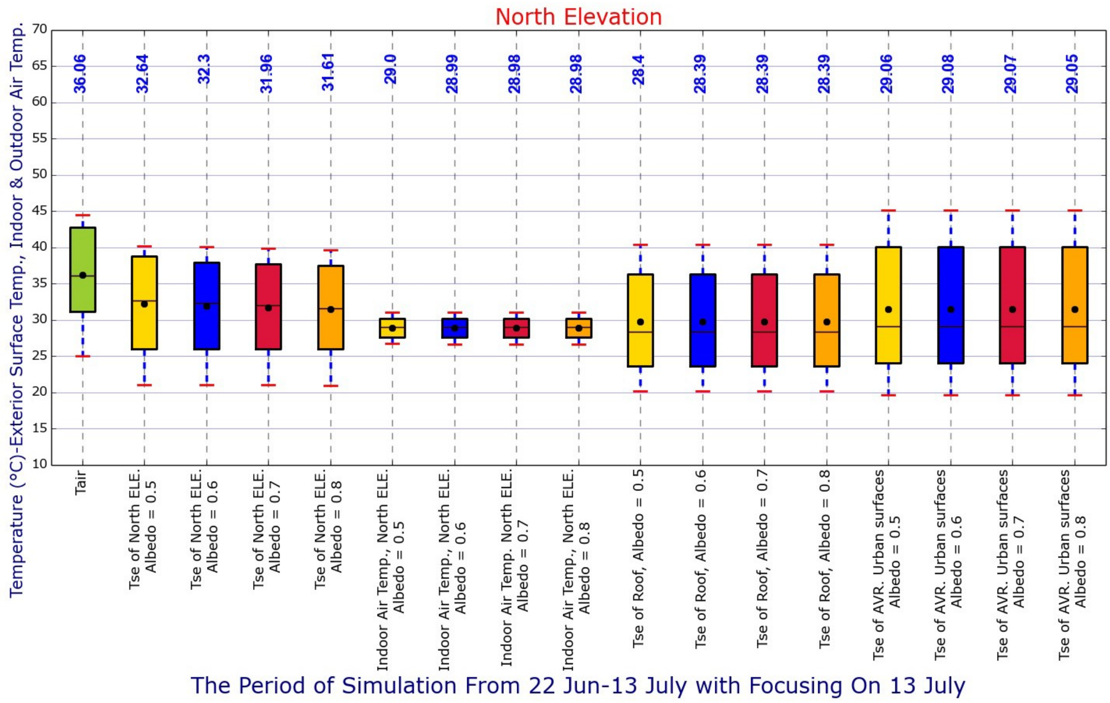


Figure 6. 63: The simulation results of North elevation with different albedo values

Sub-comparisons two – South elevation

i. The effect of increasing albedo value of South elevation on other elevations, roof and urban spaces.

According to Table 6.28 and Figure 6.64, we have found that changing the albedo value of South elevation from (0.5) to either (0.6, 0.7), or (0.8) has no significant effect on the exterior surface temperature of other elevations (North, East, and West), roof and urban spaces exterior surface temperature where they nearly maintain the same level for all scenarios. The maximum exterior surface temperature for North, East, West elevations, roof, and urban spaces are, (40 ºC), (45 ºC), (46 ºC), (40 ºC), (45 ºC) respectively.

ii. The effect of increasing albedo value of South elevation on the indoor air temperature and exterior surface temperature of itself.

According to Table 6.28 and Figure 6.64, we have found that changing the albedo value of South elevation from (0.5) to either (0.6, 0.7), or (0.8) has no significant effect on the indoor air temperature where the maximum indoor air temperature was about (31 ºC) for all scenarios. Whereas the exterior surface temperature of itself there is a significant effect. The maximum exterior surface temperature when albedo value is (0.5, 0.6, 0.7, 0.8), is (52.83 ºC). (50.19 ºC), (47.56 ºC), (44.97 ºC) respectively.

	Global air temperature	Average Exterior Surfaces Temperature	North ELE. Exterior Surfaces Temperature	**South ELE. Exterior Surfaces Temperature**	East ELE. Exterior Surfaces Temperature	West ELE. Exterior Surfaces Temperature	**Roof Exterior Surfaces Temperature**	**Urban Spaces Surfaces Temperature**	Spaces Surfaces Temperature	Roads Surfaces Temperature	Grass Surfaces Temperature	**Average Indoor Air Temperature**	Ground Floor Indoor Air Temperature	First Floor Indoor Air Temperature	Second Floor Indoor Air Temperature
South Elevation with albedo = 0.5															
Average	**36.19**	33.07	31.57	**34.76**	32.91	33.02	**29.78**	**31.44**	34.51	37.79	23.01	**29.10**	29.09	29.29	28.92
Max	**44.50**	43.88	40.20	**52.83**	44.85	45.84	**40.44**	**45.21**	50.68	59.61	28.91	**31.27**	30.29	30.56	33.08
Min	**25.06**	21.24	20.98	**21.33**	21.38	21.30	**20.17**	**19.62**	21.75	21.12	14.92	**26.84**	27.79	27.98	24.73
Median	**36.06**	32.10	31.66	**31.03**	31.96	31.71	**28.42**	**29.06**	31.97	32.44	23.00	**29.21**	29.15	29.23	29.16
South Elevation with albedo = 0.6															
Average	**36.19**	32.86	31.52	**34.08**	32.86	32.98	**29.77**	**31.43**	34.49	37.77	23.01	**29.03**	28.99	29.20	28.89
Max	**44.50**	43.19	39.99	**50.19**	44.73	45.79	**40.43**	**45.16**	50.62	59.57	28.90	**31.17**	30.17	30.46	33.03
Min	**25.06**	21.24	20.98	**21.32**	21.38	21.29	**20.16**	**19.61**	21.75	21.11	14.91	**26.78**	27.71	27.91	24.71
Median	**36.06**	32.07	31.64	**30.94**	31.94	31.70	**28.41**	**29.05**	31.97	32.44	23.00	**29.13**	29.04	29.13	29.12
South Elevation with albedo = 0.7															
Average	**36.19**	32.64	31.46	**33.39**	32.81	32.95	**29.76**	**31.43**	34.48	37.77	23.01	**28.95**	28.89	29.11	28.85
Max	**44.50**	42.50	39.81	**47.56**	44.61	45.74	**40.41**	**45.13**	50.56	59.52	28.91	**31.08**	30.05	30.36	32.98
Min	**25.06**	21.24	20.98	**21.32**	21.37	21.29	**20.15**	**19.62**	21.75	21.11	14.92	**26.72**	27.64	27.83	24.69
Median	**36.06**	32.05	31.63	**30.86**	31.93	31.69	**28.40**	**29.06**	31.97	32.44	23.00	**29.05**	28.93	29.04	29.09
South Elevation with albedo = 0.8															
Average	**36.19**	32.43	31.41	**32.69**	32.76	32.91	**29.75**	**31.42**	34.47	37.76	23.01	**28.88**	28.79	29.02	28.81
Max	**44.50**	41.81	39.63	**44.97**	44.50	45.69	**40.40**	**45.09**	50.50	59.47	28.90	**30.99**	29.93	30.26	32.94
Min	**25.06**	21.23	20.98	**21.32**	21.37	21.29	**20.15**	**19.62**	21.75	21.11	14.92	**26.66**	27.56	27.76	24.67
Median	**36.06**	32.02	31.61	**30.80**	31.92	31.68	**28.39**	**29.05**	31.96	32.43	23.00	**28.98**	28.83	28.94	29.22

Table 6. 28: The simulation results of South elevation with different albedo values

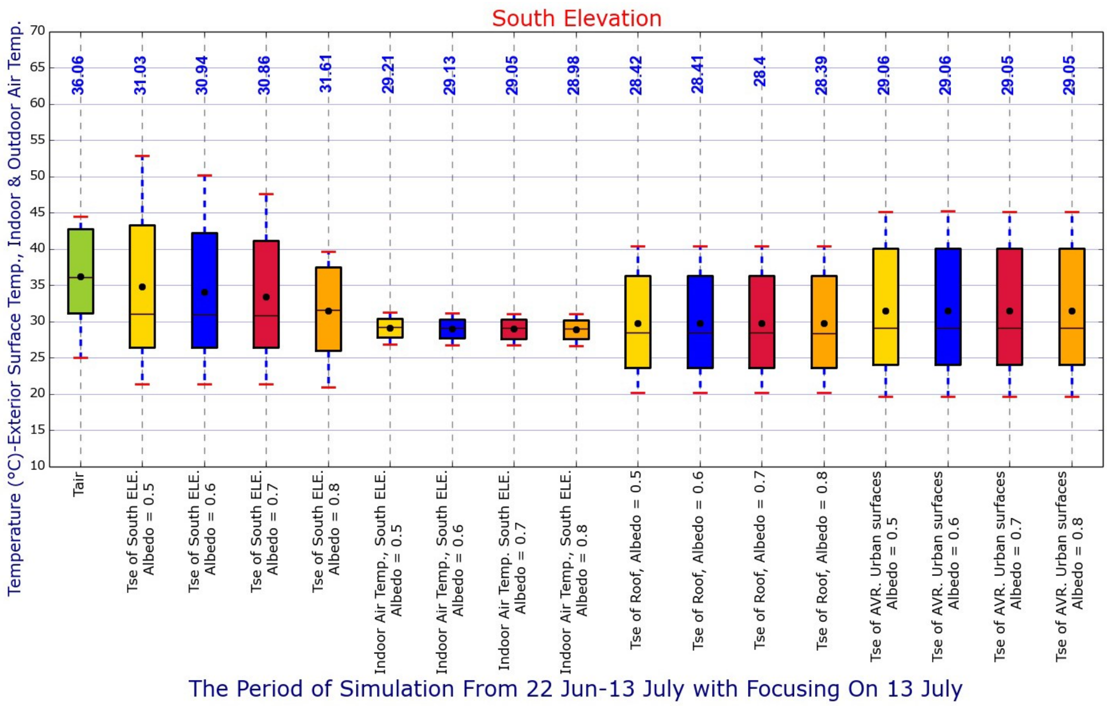


Figure 6. 64: The simulation results of South elevation with different albedo values

Sub-comparisons three – East elevation

i. The effect of increasing albedo value of East elevation on other elevations, roof and urban spaces..

According to Table 6.29 and table 6.65, we find that changing the albedo value of East elevation from (0.5) to either (0.6, 0.7), or (0.8) has no significant effect on the exterior surface temperature of other elevations (North, South, and West), roof and urban spaces exterior surface temperature where they nearly maintain the same level for all scenarios. The maximum exterior surface temperature for North, South. West elevations, roof, and urban spaces are, (39 ºC), (45 ºC), (46 ºC), (40 ºC), (45 ºC) respectively.

ii. The effect of increasing albedo value of East elevation on the indoor air temperature and exterior surface temperature of itself.

According to Table 6.29 and table 6.65, we find that changing the albedo value of East elevation from (0.5) to either (0.6, 0.7), or (0.8) has no significant effect on the indoor air temperature where the maximum indoor air temperature is about (31 ºC) for all scenarios. Whereas the exterior surface temperature of itself there is a significant effect. The maximum exterior surface temperature when albedo value is (0.5, 0.6, 0.7, 0.8), is (56.18 ºC). (52.16 ºC), (48.08 ºC), (44.50 ºC) respectively.

	Global air temperature	Average Exterior Surfaces Temperature	North ELE. Exterior Surfaces Temperature	South ELE. Exterior Surfaces Temperature	**East ELE. Exterior Surfaces Temperature**	West ELE. Exterior Surfaces Temperature	**Roof Exterior Surfaces Temperature**	**Urban Spaces Surfaces Temperature**	Spaces Surfaces Temperature	Roads Surfaces Temperature	Grass Surfaces Temperature	**Average Indoor Air Temperature**	Ground Floor Indoor Air Temperature	First Floor Indoor Air Temperature	Second Floor Indoor Air Temperature
East Elevation with albedo = 0.5															
Average	**36.19**	33.03	31.44	32.72	**35.12**	33.02	**29.78**	**31.43**	34.49	37.76	23.01	**29.09**	29.06	29.28	28.92
Max	**44.50**	43.03	39.64	44.99	**56.18**	45.72	**40.44**	**45.10**	50.53	59.48	28.91	**31.22**	30.23	30.52	33.05
Min	**25.06**	21.24	20.98	21.32	**21.38**	21.30	**20.17**	**19.62**	21.75	21.11	14.92	**26.82**	27.76	27.96	24.73
Median	**36.06**	32.82	31.67	30.81	**32.22**	31.93	**28.42**	**29.05**	32.01	32.44	23.01	**29.21**	29.14	29.27	29.17
East Elevation with albedo = 0.6															
Average	**36.19**	32.83	31.43	32.71	**34.34**	32.98	**29.77**	**31.43**	34.49	37.76	23.01	**29.02**	28.97	29.20	28.89
Max	**44.50**	42.39	39.64	44.98	**52.16**	45.71	**40.43**	**45.10**	50.52	59.48	28.91	**31.14**	30.13	30.44	33.01
Min	**25.06**	21.24	20.98	21.32	**21.38**	21.29	**20.16**	**19.62**	21.75	21.11	14.92	**26.77**	27.69	27.89	24.71
Median	**36.06**	32.55	31.65	30.81	**32.12**	31.85	**28.41**	**29.06**	32.00	32.44	23.01	**29.13**	29.04	29.16	29.13
East Elevation with albedo = 0.7															
Average	**36.19**	32.63	31.42	32.70	**33.56**	32.94	**29.76**	**31.43**	34.48	37.76	23.01	**28.95**	28.88	29.11	28.85
Max	**44.50**	41.86	39.64	44.97	**48.08**	45.70	**40.41**	**45.09**	50.51	59.48	28.91	**31.07**	30.03	30.35	32.97
Min	**25.06**	21.24	20.98	21.32	**21.37**	21.29	**20.15**	**19.62**	21.75	21.11	14.92	**26.72**	27.63	27.83	24.69
Median	**36.06**	32.29	31.63	30.80	**32.02**	31.76	**28.40**	**29.05**	31.98	32.44	23.01	**29.05**	28.94	29.05	29.09
East Elevation with albedo = 0.8															
Average	**36.19**	32.43	31.41	32.69	**32.76**	32.91	**29.75**	**31.42**	34.47	37.76	23.01	**28.88**	28.79	29.02	28.81
Max	**44.50**	41.81	39.63	44.97	**44.50**	45.69	**40.40**	**45.09**	50.50	59.47	28.90	**30.99**	29.93	30.26	32.94
Min	**25.06**	21.23	20.98	21.32	**21.37**	21.29	**20.15**	**19.62**	21.75	21.11	14.92	**26.66**	27.56	27.76	24.67
Median	**36.06**	32.02	31.61	30.80	**31.92**	31.68	**28.39**	**29.05**	31.96	32.43	23.00	**28.98**	28.83	28.94	29.22

Table 6. 29: The simulation results of East elevation with different albedo values

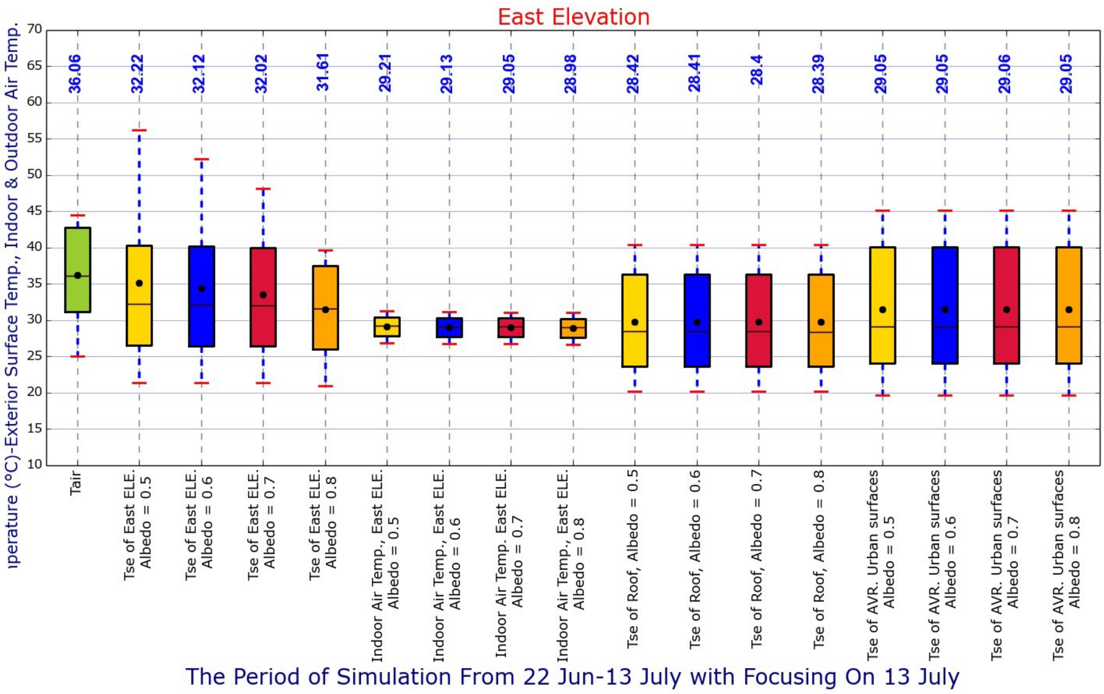


Figure 6. 65: The simulation results of East elevation with different albedo values

Sub-comparisons four – West elevation

i. The effect of increasing albedo value of West elevation on other elevations, roof and urban spaces.

According to Table 6.30 and Figure 6.66, we find that changing the albedo value of West elevation from (0.5) to either (0.6, 0.7), or (0.8) has no significant effect on the exterior surface temperature of other elevations (North, South, and East), roof and urban spaces exterior surface temperature where they nearly maintain the same level for all scenarios. The maximum exterior surface temperature for North, South, East elevations, roof, and urban spaces are, (40 ºC), (45 ºC), (45 ºC), (40 ºC), (45 ºC) respectively.

ii. The effect of increasing albedo value of East elevation on the indoor air temperature and exterior surface temperature of itself.

According to Table 6.30 and Figure 66, we fid that changing the albedo value of East elevation from (0.5) to either (0.6, 0.7), or (0.8) has no significant effect on the indoor air temperature where the maximum indoor air temperature is about (31 ºC) for all scenarios. Whereas the exterior surface temperature of itself there is a significant effect. The maximum exterior surface temperature when albedo value is (0.5, 0.6, 0.7, 0.8), is (57.43 ºC). (53.57 ºC), (49.66 ºC), (45.69 ºC) respectively.

	Global air temperature	Average Exterior Surfaces Temperature	North ELE. Exterior Surfaces Temperature	South ELE. Exterior Surfaces Temperature	East ELE. Exterior Surfaces Temperature	West ELE. Exterior Surfaces Temperature	Roof Exterior Surfaces Temperature	Urban Spaces Surfaces Temperature	Spaces Surfaces Temperature	Roads Surfaces Temperature	Grass Surfaces Temperature	Average Indoor Air Temperature	Ground Floor Indoor Air Temperature	First Floor Indoor Air Temperature	Second Floor Indoor Air Temperature
East Elevation with albedo = 0.5															
Average	**36.19**	33.10	31.43	32.73	32.87	**35.56**	**29.78**	**31.44**	34.50	37.75	23.01	29.11	29.11	29.31	28.93
Max	**44.50**	43.81	39.69	44.99	44.52	**57.43**	**40.42**	**45.10**	50.53	59.48	28.90	31.28	30.31	30.62	33.10
Min	**25.06**	21.24	20.98	21.33	21.38	**21.30**	**20.18**	**19.62**	21.75	21.11	14.92	26.87	27.83	28.02	24.75
Median	**36.06**	32.88	31.62	30.86	32.22	**32.44**	**28.43**	**29.10**	31.99	32.43	23.01	29.20	29.08	29.19	29.15
East Elevation with albedo = 0.6															
Average	**36.19**	32.88	31.43	32.71	32.83	**34.69**	**29.77**	**31.43**	34.50	37.76	23.01	29.04	29.00	29.21	28.89
Max	**44.50**	43.02	39.67	44.98	44.51	**53.57**	**40.42**	**45.10**	50.52	59.48	28.90	31.18	30.18	30.50	33.04
Min	**25.06**	21.24	20.98	21.32	21.38	**21.30**	**20.17**	**19.62**	21.75	21.11	14.92	26.80	27.74	27.93	24.72
Median	**36.06**	32.59	31.62	30.84	32.12	**32.18**	**28.41**	**29.09**	31.98	32.43	23.01	29.12	29.00	29.10	29.12
East Elevation with albedo = 0.7															
Average	**36.19**	32.65	31.42	32.70	32.80	**33.80**	**29.76**	**31.43**	34.48	37.76	23.01	28.96	28.90	29.12	28.85
Max	**44.50**	42.32	39.65	44.97	44.50	**49.66**	**40.41**	**45.09**	50.51	59.48	28.90	31.09	30.06	30.38	32.99
Min	**25.06**	21.24	20.98	21.32	21.38	**21.29**	**20.16**	**19.62**	21.75	21.11	14.92	26.73	27.65	27.85	24.70
Median	**36.06**	32.31	31.61	30.82	32.02	**31.93**	**28.40**	**29.07**	31.97	32.43	23.01	29.05	28.91	29.02	29.08
East Elevation with albedo = 0.8															
Average	**36.19**	32.43	31.41	32.69	32.76	**32.91**	**29.75**	**31.42**	34.47	37.76	23.01	**28.88**	28.79	29.02	28.81
Max	**44.50**	41.81	39.63	44.97	44.50	**45.69**	**40.40**	**45.09**	50.50	59.47	28.90	**30.99**	29.93	30.26	32.94
Min	**25.06**	21.23	20.98	21.32	21.37	**21.29**	**20.15**	**19.62**	21.75	21.11	14.92	**26.66**	27.56	27.76	24.67
Median	**36.06**	32.02	31.61	30.80	31.92	**31.68**	**28.39**	**29.05**	31.96	32.43	23.00	**28.98**	28.83	28.94	29.22

Table 6. 30: The simulation results of West elevation with different albedo values

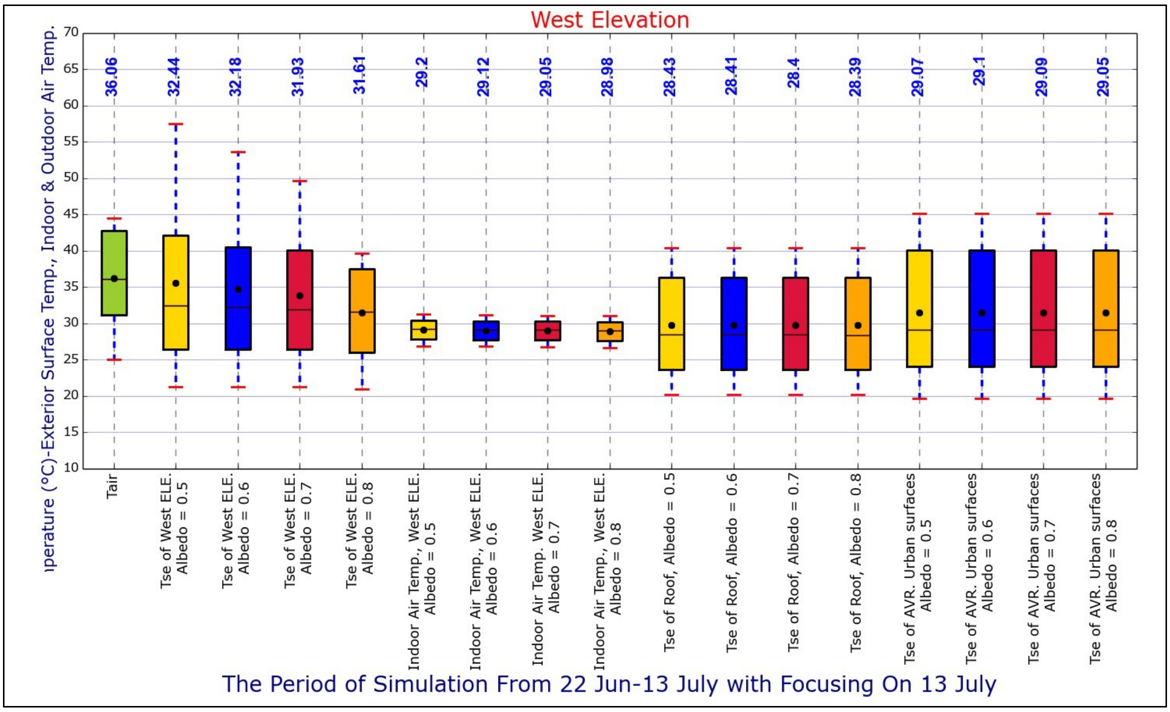


Figure 6. 66: The simulation results of West elevation with different albedo values

d. Conclusion of step four | sub-step one

Results have shown that there is a close relation between the amount of radiation falling on each elevation and the value of albedo required to lower temperature, higher radiation incident requires an increase in the albedo value. For the present case study, the north elevation receives about (45.16 W/m^2) flux, the change of the albedo value does not make big change in its exterior surface temperature compared to the other three elevations where there are clear impacts on their exterior surface temperature (Table 6.31).

	Diffuse Flux W/m^2	Direct Flux W/m^2	Total Flux W/m^2	% of total flux of all ELE.
North ELE.	17.79	27.37	45.16	11.7%
South ELE.	20.42	52.29	72.71	18.8%
East ELE.	21.90	108.59	130.49	33.8%%
West ELE.	23.85	114.46	138.32	35.8%
Total all ELE	***83.96***	***302.71***	***386.68***	

Table 6. 31: The mean flux over the day results of proposed scenario

According to the previous simulation results concerning the variation of albedo, the proposed scenario regarding the albedo value for urban typology will be as Table (6.32):

Components	**Albedo value**	**Components**	**Albedo value**
North elevation	0.5	*Roads*	0.6
South elevation	0.8	*Pavements and urban spaces*	0.7
Est elevation	0.8	*Roofs*	0.8
West elevation	0.8	*Green area*	0.28

Table 6. 32: Proposed scenario of albedo values

This scenario was Adapted in two directions and the difference was determined:

- Firstly: without insulation roof materials
- Secondly: With using holly clay block as roof insulation material

According to (table 6.33) and (Figure 6.67), we have found that using the insulation materials within the inner layer of the roof has improved the thermal performance regarding the indoor air temperature especially at the second floor which has a direct contact with the roof. In this situation, the maximum indoor air temperature of the second floor is reduced from (32.95 C) to (30.52 C). Therefore, we can say that using insulation materials can increase thermal comfort and help reduce energy consumption.

- In addition, the result shows that although the use of the insulation materials for the roof has enhanced the thermal comfort level but it has increased the surface temperature of the roof.

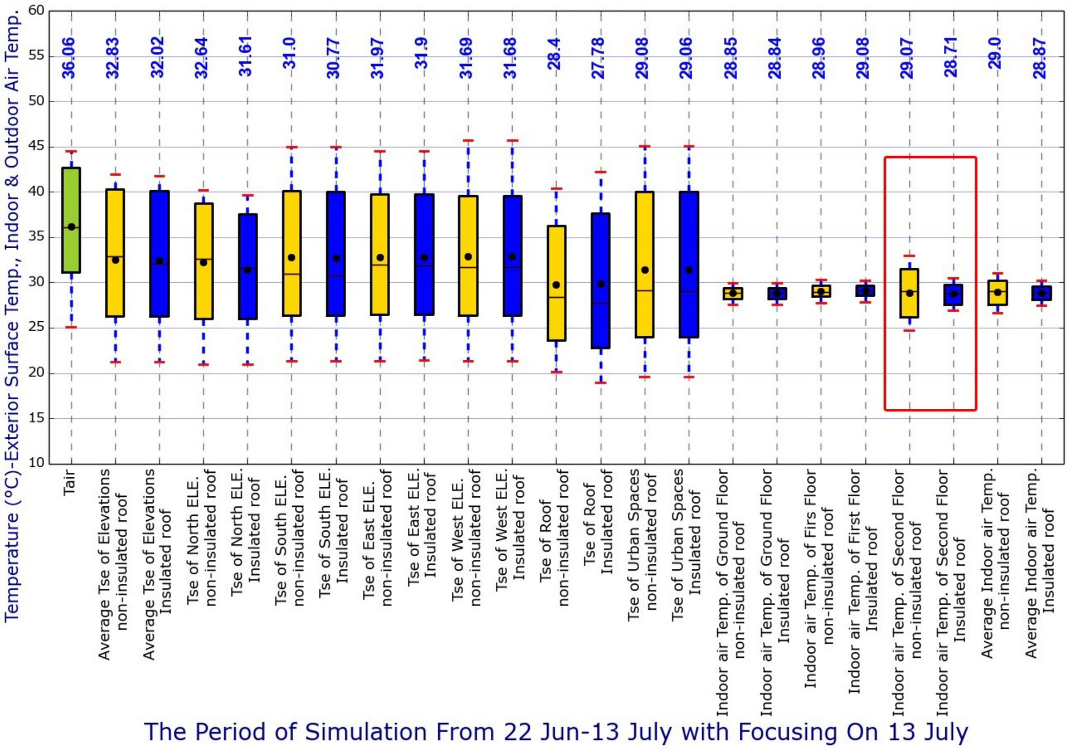


Figure 6. 67: The simulation results of proposed scenario, insulation and non-insulation roof

	Global air temperature	Average Exterior Surfaces Temperature	North ELE. Exterior Surfaces Temperature	South ELE. Exterior Surfaces Temperature	East ELE. Exterior Surfaces Temperature	West ELE. Exterior Surfaces Temperature	**Roof Exterior Surfaces Temperature**	Urban Spaces Surfaces Temperature	Spaces Surfaces Temperature	Roads Surfaces Temperature	Grass Surfaces Temperature	**Average Indoor Air Temperature**	Ground Floor Indoor Air Temperature	First Floor Indoor Air Temperature	Second Floor Indoor Air Temperature
Propose scenario : Without insulation roof materials															
Average	36.19	32.55	32.20	32.75	32.77	32.92	29.76	31.43	34.48	37.76	23.01	28.90	28.81	29.05	28.83
Max	44.50	41.98	40.20	45.01	44.50	45.70	40.41	45.10	50.52	59.48	28.90	31.01	29.95	30.29	32.95
Min	25.06	21.23	20.98	21.32	21.37	21.29	20.15	19.62	21.75	21.11	14.92	26.68	27.58	27.78	24.68
Median	36.06	32.83	32.64	31.00	31.97	31.69	28.40	29.08	31.99	32.45	23.01	29.00	28.85	28.96	29.07
Propose scenario : With using holly clay block as roof insulation material															
Average	36.19	32.43	31.41	32.69	32.76	32.91	29.81	31.43	34.48	37.76	23.01	28.88	28.80	29.08	28.76
Max	44.50	41.81	39.63	44.97	44.52	45.68	42.21	45.10	50.53	59.48	28.90	30.22	29.95	30.25	30.52
Min	25.06	21.24	20.98	21.33	21.39	21.30	18.96	19.62	21.75	21.11	14.92	27.45	27.57	27.84	26.93
Median	36.06	32.02	31.61	30.77	31.90	31.68	27.78	29.06	31.97	32.44	23.00	28.87	28.84	29.08	28.71

Table 6. 33: The simulation results of proposed scenario, insulation and non-insulation roof

According to the previous results, the roof insulation scenario will be selected

In this step, it is necessary to identify the difference between the proposed scenario with firstly the actual situation of the case study (ordinary concrete blocks), and secondly with the case study when using pumice blocks without complementary solution.

According to Figure 6.68 and Table 6.34 which describes the result of the comparison among these three scenarios, the proposed scenario has combined the good thermal performance of the two scenarios, in other words reducing the exterior surface temperature (as in the actual case-ordinary concrete blocks), in addition to its contribution to reduce the interior surface temperature and thus contributes to provide a good level of thermal comfort.

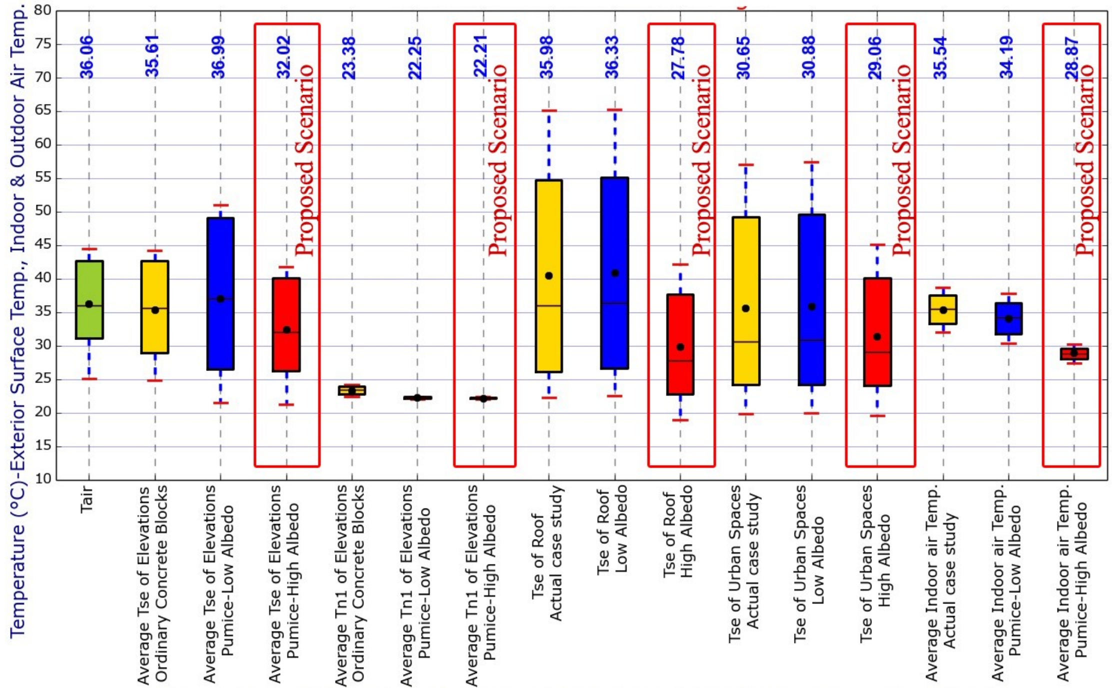


Figure 6. 68: Comparison of result from the proposed scenario, the actual situation, and pumice blocks scenario without a complementary solution

	Air temperature	Average exterior surface temperature	Average interior surface temperature	Roof surface temperature	Urban spaces surface temperature	Average indoor air temperature
Actual case study - Ordinary concrete blocks						
Average	36.19 ºC	35.34 ºC	23.33 ºC	40.52 ºC	30.78 ºC	35.37 ºC
Max	44.50 ºC	44.26 ºC	24.15 ºC	65.16 ºC	43.83 ºC	38.71 ºC
Min	25.06 ºC	24.89 ºC	22.43 ºC	22.21 ºC	19.38 ºC	32.04 ºC
Median	36.06 ºC	35.61 ºC	23.35 ºC	35.98 ºC	28.32 ºC	35.54 ºC
Proposed Materials – Pumice blocks						
Average	36.19 ºC	37.09 ºC	22.24 ºC	40.85 ºC	35.88 ºC	34.11 ºC
Max	44.50 ºC	51.02 ºC	22.41 ºC	65.31 ºC	57.47 ºC	37.85 ºC
Min	25.06 ºC	21.44 ºC	22.02 ºC	22.58 ºC	19.95 ºC	30.37 ºC
Median	36.06 ºC	36.99 ºC	22.25 ºC	36.33 ºC	30.88 ºC	34.19 ºC
Proposed Case – Pumice blocks-High Albedo						
Average	36.19 ºC	32.43 ºC	22.20 ºC	29.81 ºC	31.43 ºC	28.88 ºC
Max	44.50 ºC	41.81 ºC	22.35 ºC	42.21 ºC	45.10 ºC	30.22 ºC
Min	25.06 ºC	21.24 ºC	22.02 ºC	18.96 ºC	19.62 ºC	27.45 ºC
Median	36.06 ºC	32.02 ºC	22.21 ºC	27.78 ºC	29.06 ºC	28.87 ºC

Table 6. 34: Comparison of result from the proposed scenario, the actual situation, and pumice blocks scenario without a complementary solution

According to the symmetric chart that is provided by Ecotect software, indoor comfort conditions are located as follows:

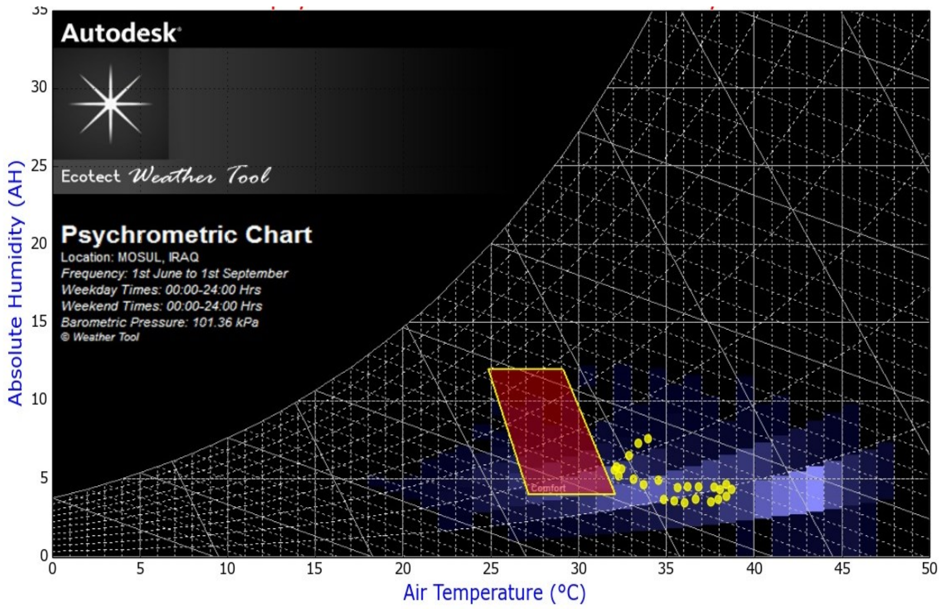


Figure 6. 69: Psychometric chart of actual case study

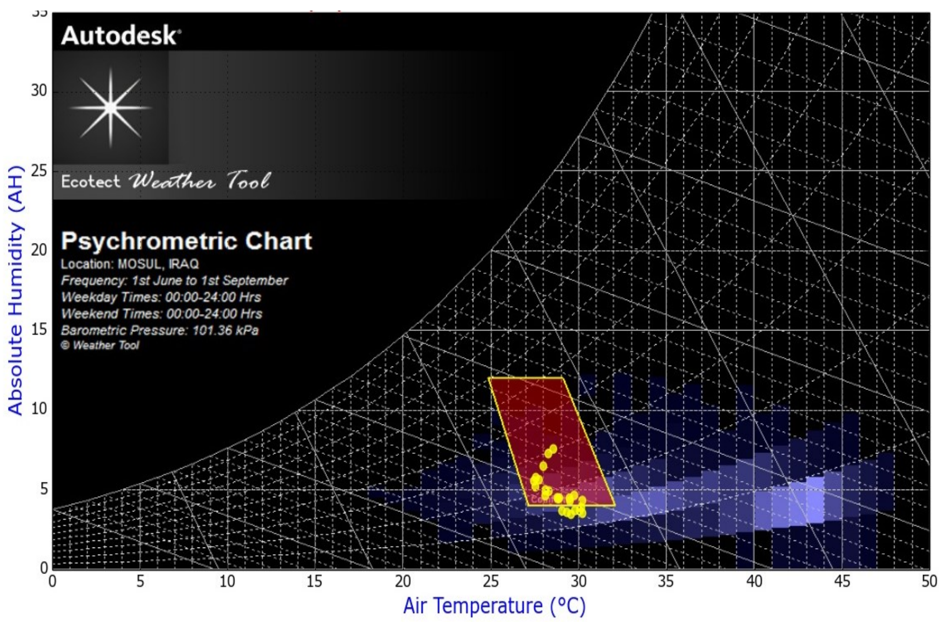


Figure 6. 70: Psychometric chart of proposed scenario

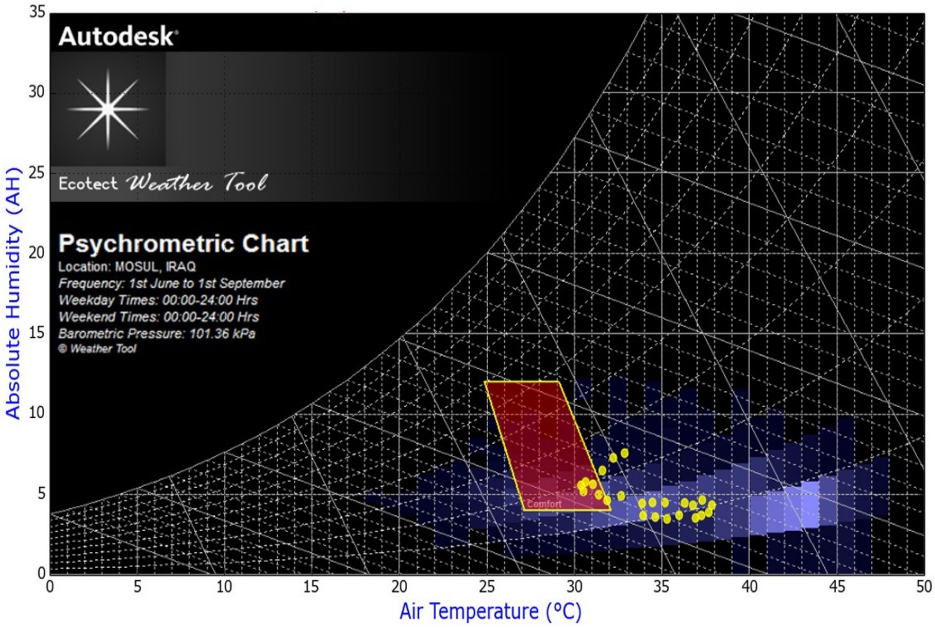


Figure 6. 71: Psychometric chart of pumice block scenario

6.6.2.2. Simulation results of step four | sub-step two

The result of this step is related to the energy needed to maintain the acceptable thermal comfort with a temperature set (26ºC) of the final high albedo scenario that has been selected in the previous step. A comparison has been done among the actual situation of the case study (ordinary concrete blocks), when using pumice block as a main material for the exterior walls, and finally, the case study when using pumice block and high albedo as a complementary solution.

From table (6.35) and Figure (72), we have found that the proposed scenario has contributed to maintain the thermal zone with minimum average amount of energy compared to Actual case and Pumice blocks-low albedo which do not exceed 7.45 W/m2 while the others scenarios consequently 55.75 W/m^2, 28.24 W/m^2 of all the building floor.

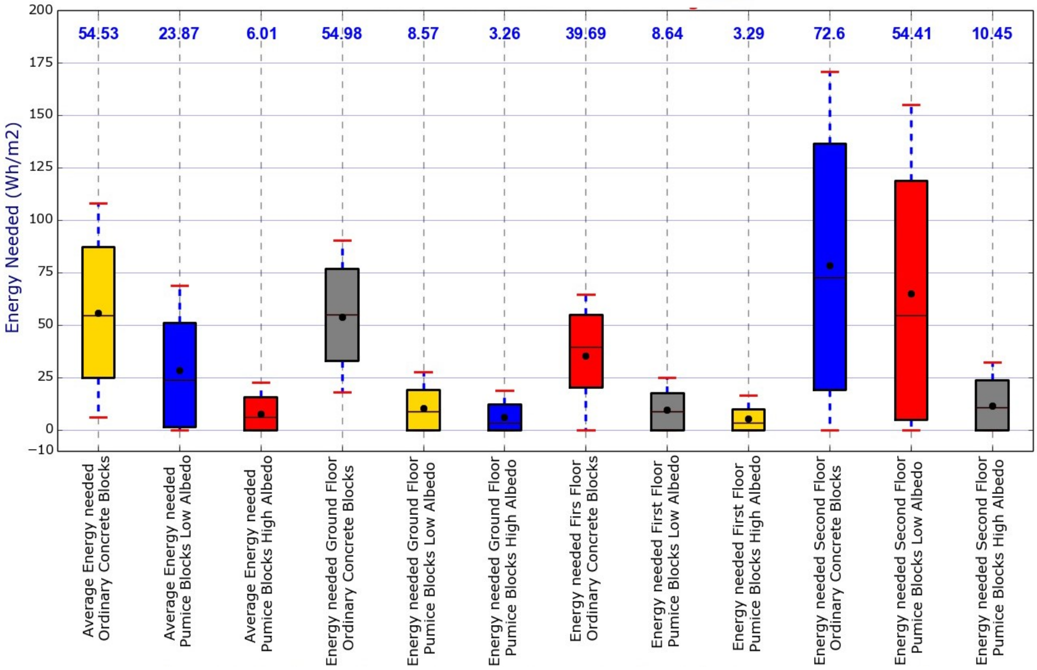


Figure 6. 72: The energy needed for proposed scenario compared with other scenarios

	The new situation of Indoor air temperature	Total Energy Nedeed	Energy Nedeed G.F	Energy Nedeed F.F	Energy Nedeed S.F
Actual case study - Ordinary concrete blocks					
Average		55.75 W/m^2	53.73 W/m^2	35.12 W/m^2	78.44 W/m^2
Max		107.89 W/m^2	90.44 W/m^2	64.37 W/m^2	170.97 W/m^2
Min		5.96 W/m^2	18.03 W/m^2	0.02 W/m^2	0.00 W/m^2
Median		54.53 W/m^2	54.98 W/m^2	39.69 W/m^2	72.60 W/m^2
Proposed Materials – Pumice blocks					
Average		28.24 W/m^2	10.21 W/m^2	9.55 W/m^2	64.96 W/m^2
Max		68.61 W/m^2	27.66 W/m^2	24.79 W/m^2	155.19 W/m^2
Min		0.00 W/m^2	0.00 W/m^2	0.00 W/m^2	0.00 W/m^2
Median		23.87 W/m^2	8.57 W/m^2	8.64 W/m^2	54.41 W/m^2
Proposed Case – Pumice blocks-High Albedo					
Average		7.45 W/m^2	5.86 W/m^2	5.10 W/m^2	11.39 W/m^2
Max		22.51 W/m^2	18.88 W/m^2	16.41 W/m^2	32.24 W/m^2
Min		0.00 W/m^2	0.00 W/m^2	0.00 W/m^2	0.00 W/m^2
Median		6.01 W/m^2	3.26 W/m^2	3.29 W/m^2	10.45 W/m^2

Table 6. 35: The energy needed for proposed scenario compared with other scenarios

6.6.3. Results Simulation using "Thermo-radiative model of building coupled with mean radiant temperature model"

The result of this step is closely related to the mean radiant temperature of actual case, pumice block scenario, and pumice block scenario with high albedo complementary solution.

Figure 6.74 is describe the measurement point of MRT. According to Figure 6.73 and Table 6.36 which describe the result of the comparison among these three scenarios, the proposed scenario (pumice block scenario with high albedo complementary solution) has achieved the minimum average MRT (27.60 ºC) while, sequentially, MRT of the actual case and pumice block scenario is (30.46 ºC), (31.35 ºC).

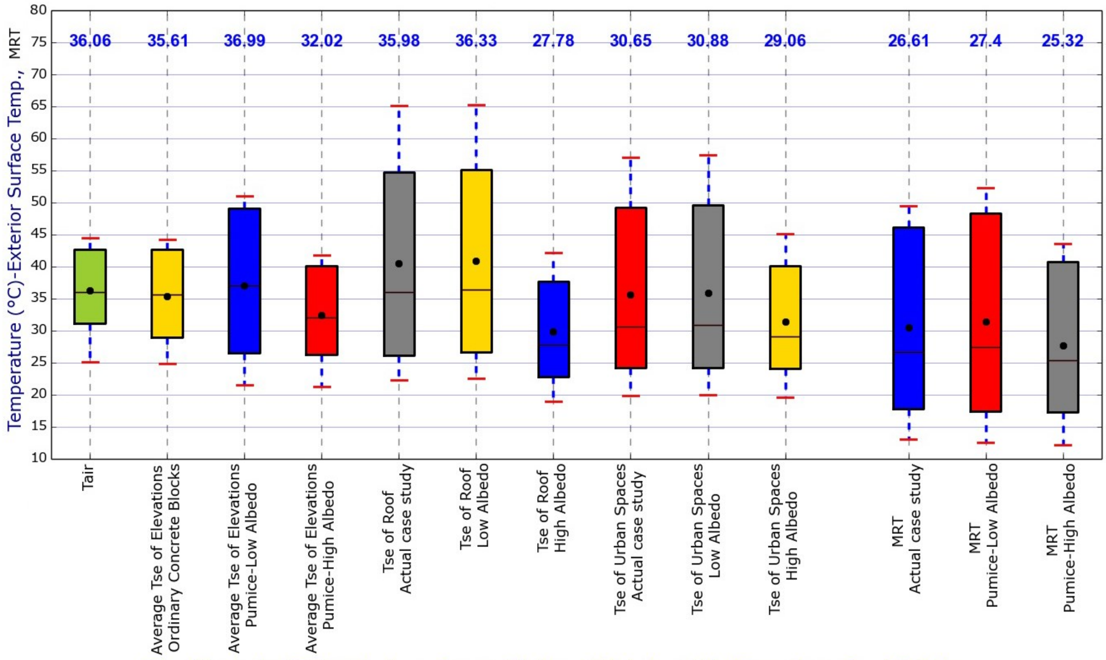


Figure 6. 73: The mean radiant temperature of actual case, pumice block scenario, and pumice block scenario with high albedo complement solution

	Air temperature	Average exterior wall surface temperature	Roof surface temperature.	Urban spaces surface temperature.	**MRT**
Actual case study - Ordinary concrete blocks					
Average	36.19 ºC	35.34 ºC	40.52 ºC	30.78 ºC	**30.46 ºC**
Max	44.50 ºC	44.26 ºC	65.16 ºC	43.83 ºC	**49.53 ºC**
Min	25.06 ºC	24.89 ºC	22.21 ºC	19.38 ºC	**13.04 ºC**
Median	36.06 ºC	35.61 ºC	35.98 ºC	28.32 ºC	**26.61 ºC**
Proposed Materials – Pumice blocks					
Average	36.19 ºC	37.09 ºC	40.85 ºC	35.88 ºC	**31.35 ºC**
Max	44.50 ºC	51.02 ºC	65.31 ºC	57.47 ºC	**52.29 ºC**
Min	25.06 ºC	21.44 ºC	22.58 ºC	19.95 ºC	**12.45 ºC**
Median	36.06 ºC	36.99 ºC	36.33 ºC	30.88 ºC	**27.40 ºC**
Proposed Case – Pumice blocks-High Albedo					
Average	36.19 ºC	32.43 ºC	29.81 ºC	31.43 ºC	**27.60 ºC**
Average	44.50 ºC	41.81 ºC	42.21 ºC	45.10 ºC	**43.58 ºC**
Max	25.06 ºC	21.24 ºC	18.96 ºC	19.62 ºC	**12.18 ºC**
Min	36.06 ºC	32.02 ºC	27.78 ºC	29.06 ºC	**25.32 ºC**

Table 6. 36: The mean radiant temperature of actual case, pumice block scenario, and pumice block scenario with high albedo complement solution

Figure 6. 74: The measurement point of MRT

6.6.4. Results of the Simulation by using "Thermo-radiative model coupled with energy balance equation".

The result of this step is related to the ambient air temperature within the urban city of the actual case, pumice block scenario, and pumice block scenario with high albedo complementary solution.

As mentioned previously, this study used the method proposed by Laurent MALYS, which already explained in chapter one. According to study of Ignatius et al., the air temperature was estimated at two level, firstly, base level (ground level-4m) and secondly, at altitude level; (see Figure 75) ; therefore the finally the outdoor air temperature is the average temperature between these two temperatures (see Figure 76 and Table 6.37) (Ignatius et al. 2015).

Figure 6. 75: The method of estimating air temperature at different altitudes proposed by Ignatius

Figure (6.76) and Table (6.37) described the comparison result among actual case (OCB material), pumice block scenario, and pumice block scenario with high albedo complementary solution (proposed scenario).

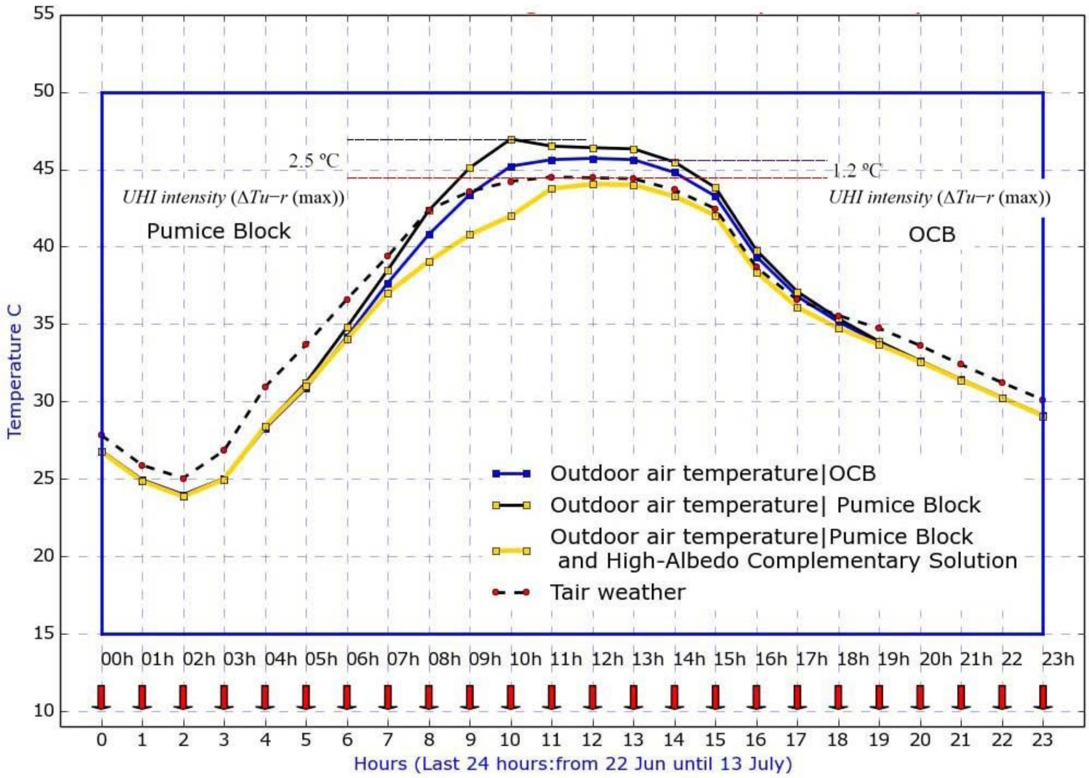


Figure 6. 76 : The outdoor air temperture of actual case, pumice block scenario, and pumice block scenario with high albedo complementary solution

Time step	Outdoor air temperature | Pumice-low albedo			Outdoor air temperature | OCB			Outdoor air temperature | Proposed case-high albedo			
	Tair Ground	Tair top	**Tair Final**	Tair Ground	Tair top	**Tair Final**	Tair Ground	Tair top	**Tair Final**	Tair weather
00h	26.109	27.478	**26.794**	26.151	27.487	**26.819**	26.046	27.465	**26.755**	27.833
01h	24.224	25.568	**24.896**	24.324	25.589	**24.957**	24.154	25.553	**24.853**	25.889
02h	23.169	24.670	**23.920**	23.296	24.698	**23.997**	23.081	24.651	**23.866**	25.056
03h	23.918	26.132	**25.025**	23.937	26.136	**25.037**	23.839	26.115	**24.977**	26.833
04h	26.919	29.910	**28.414**	26.677	29.856	**28.267**	26.902	29.906	**28.404**	30.944
05h	29.739	32.707	**31.223**	29.180	32.585	**30.882**	29.413	32.635	**31.024**	33.667
06h	33.727	35.876	**34.801**	32.721	35.656	**34.188**	32.441	35.593	**34.017**	36.611
07h	38.019	38.990	**38.504**	36.644	38.690	**37.667**	35.600	38.461	**37.030**	39.389
08h	42.482	42.197	**42.339**	39.944	41.638	**40.791**	37.106	41.007	**39.057**	42.389
09h	46.157	44.036	**45.097**	43.318	43.419	**43.369**	39.065	42.485	**40.775**	43.556
10h	48.734	45.159	**46.946**	45.854	44.536	**45.195**	40.565	43.382	**41.973**	44.222
11h	47.781	45.196	**46.489**	46.346	44.891	**45.618**	43.272	44.234	**43.753**	44.5
12h	47.644	45.136	**46.390**	46.512	44.892	**45.702**	43.775	44.302	**44.038**	44.444
13h	47.555	45.074	**46.314**	46.411	44.827	**45.619**	43.740	44.250	**43.995**	44.389
14h	46.610	44.316	**45.463**	45.505	44.078	**44.791**	42.974	43.531	**43.253**	43.667
15h	44.685	42.946	**43.816**	43.768	42.748	**43.258**	41.704	42.303	**42.004**	42.444
16h	40.438	39.099	**39.768**	39.767	38.954	**39.360**	38.129	38.601	**38.365**	38.667
17h	37.422	36.766	**37.094**	36.918	36.658	**36.788**	35.753	36.407	**36.080**	36.556
18h	35.220	35.493	**35.357**	34.868	35.418	**35.143**	34.210	35.276	**34.743**	35.556
19h	33.329	34.429	**33.879**	33.191	34.399	**33.795**	32.965	34.351	**33.658**	34.722
20h	31.986	33.271	**32.629**	31.948	33.263	**32.605**	31.873	33.247	**32.560**	33.611
21h	30.794	32.057	**31.425**	30.763	32.050	**31.406**	30.714	32.039	**31.376**	32.389
22h	29.633	30.890	**30.262**	29.617	30.887	**30.252**	29.567	30.876	**30.222**	31.222
23h	28.443	29.763	**29.103**	28.445	29.764	**29.105**	28.384	29.750	**29.067**	30.111

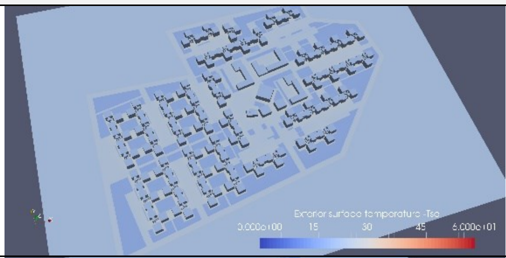
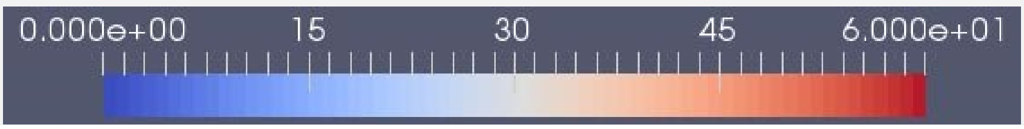
Table 6. 37: The outdoor air temperture of actual case, pumice block scenario, and pumice block scenario with high albedo complementary solution

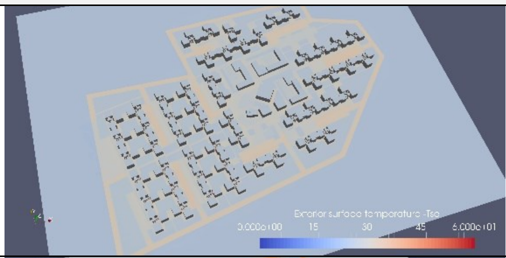
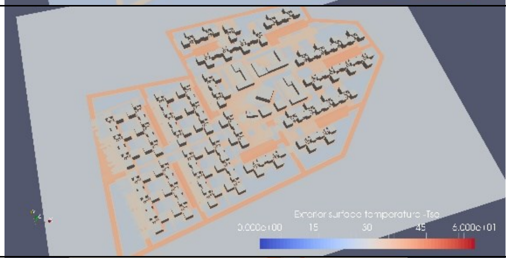
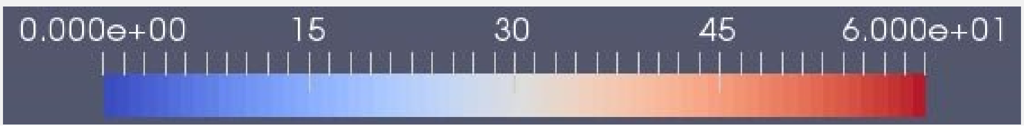
From this result, we can conclude that the used of pumice block materials and high albedo alternative helped effectively reducing the air temperature between the building for a period located between 00:06h -18:00h which reached its high difference (2 ºC) at 10:00h.

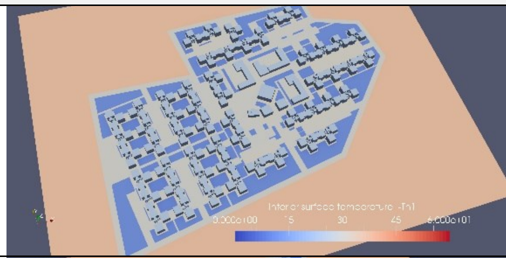
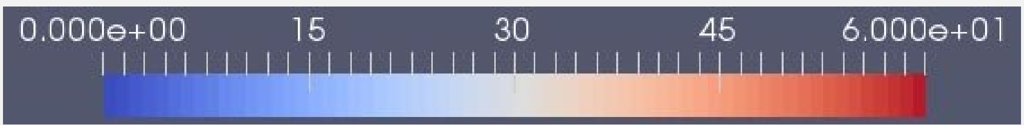
6.6.5. The virtual results of the final scenario selected

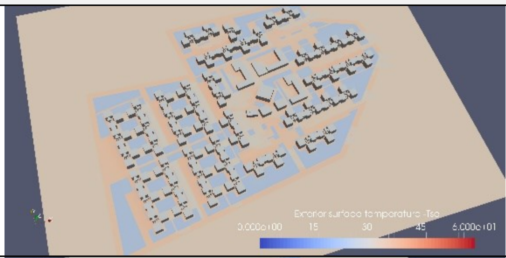
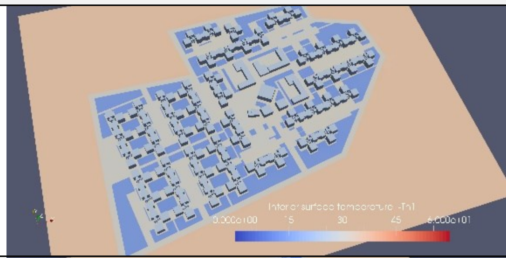
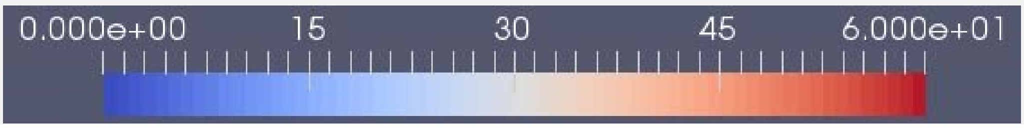
This result shows the exterior and interior surface temperature for the final scenario concluded, which consists of:

1. Square wall with thickness 20 cm constructed by using Pumice block as the main material.
2. High albedo coating materials as finishing materials for building envelope.
3. Insulation roof and high albedo tiles
4. Roads and parking constructed by using the type that developed by Synnefa (2011)
5. Pavements concrete with light gray color
6. Natural grass

Time Step	Exterior surface temperature (Tse)	Interior surface temperature (Tn1)
Time step= 00 h		
Time step= 01 h		
Time step= 02 h		
Time step= 03 h		
Time step= 04 h		
Time step= 05 h		
		

Time Step	Exterior surface temperature (Tse)	Interior surface temperature (Tn1)
Time step= 06 h		
Time step= 07 h		
Time step= 08 h		
Time step= 09 h		
Time step= 10 h		
Time step= 11 h		
		

Time Step	Exterior surface temperature (Tse)	Interior surface temperature (Tn1)
Time step= 12 h		
Time step= 13 h		
Time step= 14 h		
Time step= 15 h		
Time step= 16 h		
Time step= 17 h		
		

Time Step	Exterior surface temperature (Tse)	Interior surface temperature (Tn1)
Time step= 18 h		
Time step= 19 h		
Time step= 20 h		
Time step= 21 h		
Time step= 22 h		
Time step= 23 h		
		

Chapter 7

THE CONCLUSIONS AND RECOMMENDATIONS

Summary

Chapter 7 The conclusions and recommendations

7.1. Introduction

In this study, the influence of the selected construction materials on urban heat island and energy needed to sustain an acceptable level of indoor thermal comfort have been researched by simulation and comparative experiment under the summer climate conditions of Mosul city-Iraq. It's main originality lies on the simulatneous study of indoor and outdoor condition and the research for efficiency for both of them through the choice of materials' characteristics.

The final conclusions of the research will be determined through three aspects:

-The first aspect is related to the application part of the research and its results.

- The second aspect is related to the scientific sequence of the methodology to achieve the best building envelope environmental design which contributes to achieve the internal and the external thermal comfort besides reducing the difference in air temperature between the city and the surrounding rural areas.

- The third aspect is on tools and limitations to our study.

7.2. Application part of the research

These conclusions are linked with the results of the application and come within four axes:

- Conclusions of thermal performance of different building envelope design varying in material types, wall design, and wall shape
- Conclusions on the identification of the best strategy among double wall, vegetated system (green wall), and variation of the reflection coefficient (high albedo value) suitable for the region of the case study that can be applied to building envelope to achieve additional gains related to the exterior wall surface temperature.
- Conclusions on estimating the outdoor mean radiant temperature.
- Conclusions on estimating the outdoor air temperature.

7.2.1. Conclusions of thermal performance of different building envelope design varying in material types, wall design, and wall shape

Conclusion related to materials type and thickness

The results of the comparison of different building envelope materials types have revealed several aspects that can be summarized as follows:

For any materials type there are two possibilities:

The first possibility indicates that the materials lead to reduce the external surfaces temperature but adversely affected the indoor surfaces temperature and thermal comfort such as heavy weight concrete block materials or reinforcement concrete. Therefore, we are in need of finding some ways to reduce the interior surface temperature and finally maintain the high thermal comfort inside the building spaces e.g. natural venation, air conditioning, etc.

The second possibility indicates that the materials lead to reduce the internal surfaces temperature and finally maintain indoor thermal comfort such as pumice block.

This study has adopted the second approach, Therefore, as a next step, the effect of changing the thickness of the walls and using the cavity wall is examined, so the conclusions are as follows:

Conclusion related to wall design

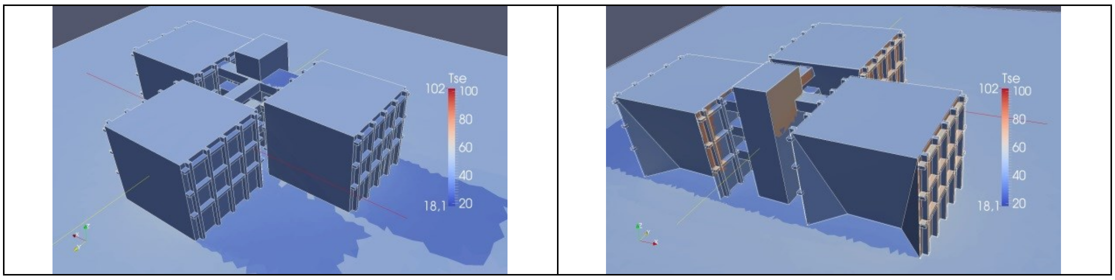
The main factor which dominates the formulation of thermal performance of the wall is the type of construction material. For example, when we use the pumice block as the main wall materials, we have found that these materials keep the same level of surface temperature even when there is a change in the wall thickness. From that, we can say that the materials having lower thermal conductivity, thermal diffusivity and absorptivity have less temperature swing on the inside surface of the walls compared to the materials with high thermal conductivity.

Concerning the cavity wall, the gap inside the inner layer of wall which is not related to the type of materials which is responsible for the formation of the thermal performance. Whereas, in the single layer wall, we have found that the materials types are responsible for the formation of the thermal performance.

Conclusion related to wall shape

The orientation of the building elevations towards the sun is a key parameter for selecting the exact shape of the building envelope. The reason is that each building elevation does not receive the same amount of solar radiation. Consequently, we can state that the wall design that is compatible to specific elevation can effectively affect the thermal performance and exterior surface temperature of the wall.

From that, it can be confirmed that the elevation which receives a large amount of radiation as the western façade is able to take advantage of the shapes of wall that provide self-shadow, as in the following suggested form:



7.2.2. Conclusions on the identification of the best strategy among double wall, vegetated system, and variation of the reflection coefficient.

Conclusion related to strategies to reduce exterior surface temperature

After the selection of the second approach of materials type we can say that although these types of materials have achieved high level of comfort inside the building, its exterior surface temperature is high and it will negatively influence the air temperature around the building.

Therefore, we have conducted a comparative study of the available complementary solutions to reduce the external surfaces temperature such as double wall, green wall and ceiling, and high albedo value. Out of the results of this comparison, the conclusions which may be drawn are as follows:

There are always the possibility of reducing the exterior surface temperature of building envelope by using one of the following strategies: double wall, green wall, and high-albedo materials. In spite of obtaining the best performance when we use the vertical greenery systems compared to the other solutions, the highly reflective materials are the most viable and the easiest strategy for the application.

To specify the albedo value of any surface, it is necessary to verify the amount of the direct solar radiation it receives. The surfaces that receive less radiation can be coated low albedo materials whereas the surface that receive more radiation require high albedo value.

For exterior wall, the gains that are obtained by increasing the value of reflectivity of an elevation are not limited to reducing the external surface temperature, but their benefit is to sustain a high level of thermal comfort inside the spaces.

For the roof, the gains that are obtained by increasing the value of reflectivity help reducing the surface temperature in addition to reduce the average indoor air temperature especially the floor is directly connected to the roof (last floor).

For exterior street and pavement, the gains that are obtained by increasing the value of reflectivity of these components are limited to reduce the surface temperature where there is no significant change recorded both in the roof surface temperature, indoor air temperature, and exterior surfaces temperature of the building exterior walls.

After reviewing these two axis of the conclusions, we can state that they are considered as the final statement of conclusions. For any city corresponding to the case study region, the integrating both high thermal insulation materials and high albedo strategy for the south, east and west walls can effectively be:

At the building level:

1. Reduce interior surface temperature in which the indoor air peak temperature in the building can be reduced in the day time.
2. Reduce exterior surface temperature
3. Reduce the roofs surface temperature
4. Provide high level of thermal comfort consequently reduce the energy conception

At the urban level

1. Reduce effectively outdoor main radiation temperature.
2. Reduce effectively the temperature of the outside air around the buildings.

2. Scientific sequence of the methodology

During this work, we have proposed and tested a methodology, adapted to urban and building design to achieve both indoor and outdoor comfort conditions.

This method, focusing on materials can be applied for different case study and supplementary steps on urban form could be added.

<table>
<tr><td colspan="3">To design any building envelope which contributes to providing high thermal performance regarding the exterior and interior surface temperature, high-level of indoor thermal comfort with minimum energy needed, reduce the air temperature difference between the city and its surrounding rural area, we should follow one of the following steps.</td></tr>
<tr><td colspan="3"></td></tr>
<tr><th>Alternative one</th><th>Alternative Two</th><th>Alternative Three</th></tr>
<tr><td>Find some type of materials that conduct the heat in one way</td><td>High thermal conductivity materials which lead to reduce the external surfaces temperature but adversely affected the indoor surfaces temperature and thermal comfort</td><td>Low thermal conductivity and effusivity materials which lead to reduce the internal surfaces temperature and finally maintain indoor thermal comfort</td></tr>
<tr><td>This possibility is one of the alternatives offered but it is limited to be used on the issues of electronic industries where the first materials developed by MIT team</td><td>For this alternative, we are in need of finding some ways to reduce the interior surface temperature e.g. natural venation, air conditioning, etc.</td><td>After selecting this type of materials, we should be searching some strategies to reduce the exterior surface temperature</td></tr>
<tr><td colspan="2">Future works</td><td>The alternative adopted and recommended in this study</td></tr>
</table>

	The alternative adopted and recommended in this study
First step	Based upon specific criteria, a range of materials that meet the desired purpose are selected.
Second step	Is using a specialized software to study the thermal behavior of materials selected when applied on buildings through calculation of the interior and exterior surfaces temperatures. Finally, the material that gives the lowest internal surface temperature is selected. This type of materials surely will help to provide an acceptable level of thermal comfort, but still its exterior surface temperature is high.
Third step	Based upon many criteria, A specific complementary solution that contributes reduce exterior surface temperature is selected. In this regard there are four alternatives:

1	Green strategy	*This alternative may not suitable for all climate zone, for example in hot or arid climatic regions most plants may not survive the heat.*	According to the conditions of the case study region, this study adopted the third and fourth probability
2	Double wall	*This alternative may not be suitable for low-cost construction*	
3	High albedo materials	*This alternative is suitable for application with minimum cost and It does not require high building technology, therefore it is suitable for many countries in the world.*	
4	Specific building envelope shape	*This alternative is suitable for application*	

Either, High albedo materials	**Or, Specific building envelope shape**
Fourth step, is using a specialized software to determine the appropriate albedo value for each elevation through searching the minimum exterior surface temperature	**Fourth step**, is using a specialized software to estimate the exterior surface temperature for all proposed envelopes shapes. Finally, select the appropriate shape for each elevation that gives the minimum exterior surface temperature.

In this step, the indoor air temperature is estimated and also the amount of energy required to maintain an acceptable level of thermal comfort.

Fifth step	Depending of the case study region, is finding the thermal comfort zone by using psychometric chart that provides by Ecotect software
Sixth step	Is using a specialized software to estimate the outdoor thermal comfort by estimating the outdoor mean radiant temperature.
Seventh step	Is using a specialized software or mathematical model to estimate the outdoor air temperature between the buildings.
Eighth step	Is finding the air temperature difference between city and its surrounding rural area (UHI = $T_{urban} - T_{rural}$). This difference represents the UHI temperature.

7.3. Limitations of Study

Although this research has been carefully prepared and reached important findings in the field of environmental design, but it has still some limitations and shortcomings. Either the methodology or the results and recommendations of this study could not be applied directly to all the projects because each one has its own design characteristics which may vary from one location to another and from one region to another.

In this study we have shown that to study simultaneously indoor and outdoor comfort, buildings' and urban materials so that to take into account the interactions, a tool allowing to simulate the urban and the building scale is necessary. We used SOLENE-microclimat which was available and one of the most adapted tool for our purpose. However it (and the way we used it) has some limitations which should not harm our global results but they worth been mentioned.

Limitations regarding the factors effecting the thermal performance of the building and urban area

The first limitation concerns the factors affecting the thermal performance of the building and urban area. To put it in another way, there might be some relevant factors which significantly influence such performance e.g. sky view factors, windows parameters (size and position of the windows), wall orientation, which is beyond the scope of this research where this study is limited to certain existing case. Future research may be more convincing if the research has been linked to more factors to the thermal performance of the building and urban area. It would also be very long and the results difficult to interpret because of their multiplicity.

Limitations regarding the building materials selected- pumice block:

According to the results of this study and to its context, the pumice block is chosen as a basic wall material, but this type of materials may not be able to be imported or produced in all regions of the world. Therefore, it is necessary to find another material similar to the pumice block in the thermal specifications in order to give similar effect.

Limitations regarding the complementary solution- high reflectivity materials:

The complementary solution which is proposed (high reflectivity materials) will certainly not be applicable to all cities in the world where in many countries the main environment design is capturing the sun as a passive solar heating, therefore, we can say that this strategy is suitable for application only in the hot climate region.

Limitations regarding the building morphology and design

In this study and as a case study, a low-rise residential building consisting of three floors is adopted. This type of building was the prevailing pattern in the region of Mosul. However, this design doesn't represent the majority buildings type all over the world. Therefore, when trying to apply the findings of this study to another high-rise project, this may be inappropriate as the heights of the buildings and the district densities which have significant impacts on many basic climatic factors such as wind, sunlight, etc.

Limitations regarding the analysis of case study

Since the analysis is conducted on a numerical case study, it is unavoidable that in this work, a certain degree of error may be found. In fact, it was a sort of objective to compare the results of simulation with the results of a set of measurements conducted in the case study location (Mosul city-Iraq). But the bad security situation of this city during the period of study led to the inability to make this comparison where the findings are limited to the results of the simulation.

Limitations regarding the tool of the simulation - Solene-microclimate

SOLENE-microclimat has been developed in CRENAU Laboratory. Just now, this too is used for a scientific purpose and it has not reached the commercial purpose yet. Therefore, any user of this tool faces difficulty in finding some specific tutorials. Each user's ability to use the model relies on it's own perseverance to understand and practice the tool and on one training courses held yearly by the CRENAU laboratory to learn all the basics related to conduct the analysis. The user group of SOLENE-microclimat also helps. However, even if this tool would be of great interest for urban and building design, it's use for professionals is still difficult. This tool has some limitations:

Concerning building

- The wall and ground models used in SOLENE-microclimat are rough and if they allows comparing different configurations, the dynamic behavior of heat flow is not well represented. New models have been developed but wasn't available during our work.
- The wall model is monodirectional, this means that the effect of different shapes concern only self-shading but neglect 3D conduction effects.
- The building model is partitioned in floors so that we had to take into account the internal loads as means for the level although they are heterogeneous as well as resulting comfort conditions.

Concerning external conditions

- SOLENE-microclimat allows complex thermo-aeraulic simulations. However, focusing on materials, we decided to concentrate on radiative and conductive exchanges. We calculated the outdoor temperature using a balance equation instead of CFD. This certainly lowers near ground or wall air temperatures whereas Malys (2012) has shown that using CFD could lead to local to high temperature due to the neglection of buoyancy effects). However, as we were most interested in a global effect, this was more appropriate for our work and this require less skill and thus is more adapted to design process.

- As we choose to focus on materials, we didn't change the urban form. However, this would have been possible but computer intensive as for different forms, the whole geometry must be changed.

Moreover, the use of comfort charts in complement to simulations is necessary and pertinent to render the conclusions related to comfort more comprehensible.

7.4. Recommendations:

The recommendations of this study can be intended for those who are highly interested in buildings and urban design, energy issues, and construction materials production companies in order to achieve architectural and urban projects in harmony with the requirements of the environment in general and the climate in particular. These recommendations will be stated according to the responsibilities of each party and as follows:

Architects and engineers

The best design cannot be achieved if the local environment is not interacted with all its dimensions such as local materials, climatic conditions, etc. because it will affect directly or indirectly the overall performance of the building and the user. From this principle all designers should:

- Benefit from the experiences offered by many countries in the world in how to adapt to the surrounding circumstances and exploit the available possibilities and keep pace with the development of civilization and the use of technological means and measure the extent of applicability locally.

- Improve the environmental performance of the existing architectural projects on the level of buildings and on the level of urban space which can be reconsidered in the light of the research findings especially with regard to the use of high-albedo coatings where the efficiency of this solution has been demonstrated by its effective contribution to enhancing thermal performance and thermal comfort at both the building and the urban levels.

The use of SOLENE-microclimat model. This tool offers a great potential to modeling urban microclimate and building thermal behavior based on the coupling of radiative, thermal and CFD models.

The possibility of using the scientific methodology which has been used in this study to achieve the same objectives for different projects in term of thermal behavior of building envelope.

Take advantage of what has been proposed regarding the construction materials, and the external finishing's for both buildings and urban areas in addition to the forms and designs of layers of buildings envelopes besides taking advantage of the specific indicators that are proposed and used in this study related to:

- The urban microclimate and thermal comfort, and
- The UHI and urban construction materials,

The possibility of having benefit from the information and data presented in this study including the data weather and the comfort level acceptable in Mosul city, the available types of building materials in Iraq, the alternative types that produce in France that can be used in Iraq.

Educational institutions

Taking the responsibility of training of the specialists and those who are interested in the field of environmental design and those who work in state institutions through providing a practitional and educational background and clarifying the importance of numerical simulation. This knowledge may provide information and future vision about the thermal behavior and energy consumption of the projects before the construction, consequently this helps make critical decisions regarding their designs.

The development of a curriculum model and encourage the use of modern techniques and simulation programs related to indoor and outdoor environmental assessment in the faculties of architecture that will ensure continuous adaptation to the climate change.

Taking the responsibility of spreading social awareness about the risks of climate change and the need for architectural designs firstly to meet environmental requirements, energy consumption, secondly aesthetic factors and others through hold non-scientific seminars, posters, and articles that related to some of the facts regarding the environmental issues facing our society today.

Governments

In many countries, and also in Iraq, most of the residential buildings and facilities are owned by the government or a related entity. Therefore, it is the duty of the government to actively contribute to the support and development of important strategies for building housing complexes in accordance with local environmental conditions, following some of the tools:

Issuing instructions and policies for the construction process to those who are related to the design and construction materials industry in order to achieve the best performance for the buildings and the urban area, so that the city is responsive to its climate and thus achieving the idea of a sustainable city.

Supporting their employees to participate in training and educational courses aimed at increasing their awareness of the risks of climate change and the need to work hard to alleviate them through, for example, the use of suitable alternatives construction materials for buildings and urban spaces which they have importance to overall sustainability and the appropriate envelope shape and design.

Creating community boards and commissions to study local environmental issues and provide guideline and brochures for the environmental design.

Cooperating with the universities to contribute effectively to solving problems and providing suitable solutions to the local environment and climate change by tackling these problems by researchers in their scientific works.

7.5. Future works

1. Publishing part of the results of this study which are related to the effect of building envelope shape and design on indoor and outdoor thermal comfort of Al-hadba residential complex.

2. Conducting a study regarding the verification of the new wall and ground models

3. Conducting a study related to the urban form and materials combinations

4. Conducting a study about the effect of internal loads and natural ventilation strategies

5. Conducting a similar study located in another country such as France to know the effect of climate characteristics on the choice of building materials.

6. Conducting a study that adopts the other trends presented in this study which have not been applied such as the development of a building material that conducts the heat in one way when using high thermal conductivity material, what passive design strategies that can be used to provide thermal comfort inside the building.

7. Conducting a field study for Al-hadba residential complex regarding the thermal performance of its buildings and urban open spaces by conducting a set of measurements and compare them with the results of the current study.

8. Establishing an educational research center for the purpose of giving courses and lectures on the use of computer techniques and numerical simulations in the field of climate and environmental analysis.

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Appendix

Appendix

The main aim of this chapter is explaining the details related to the simulation results for all steps, therefore it will consist of four sections

A. Section One: The details simulation results related to thermo-radiative model.
B. Section Two: The details simulation results related to thermal model (free thermal regime and force thermal regime).
C. Section Three: The details simulation results related to thermal model coupling with MRT Model.
D. Section Four: The details simulation results related to thermal model coupling with energy balance equation.

A. Section One: The details simulation results related to thermo-radiative model

A.1. Detail result related to initial assessment of surface temperate materials

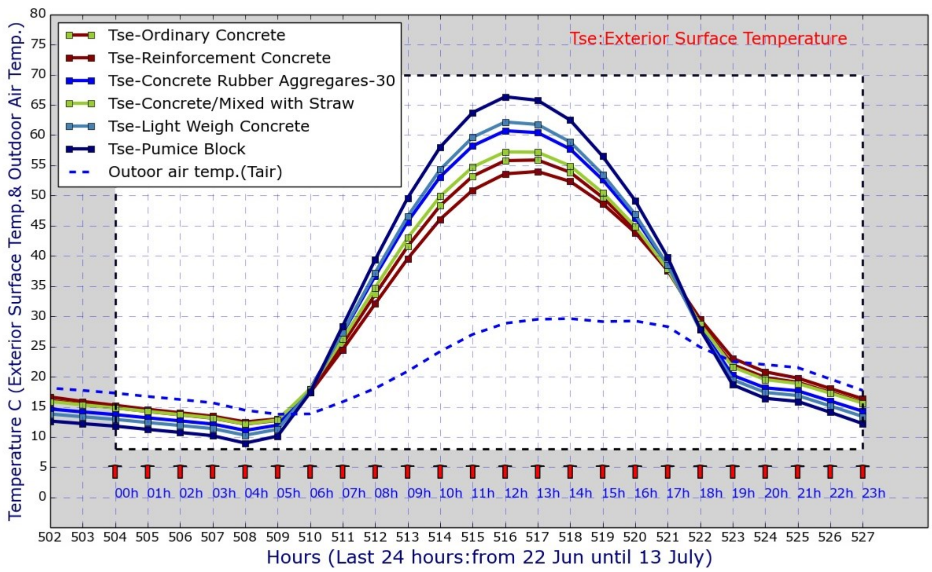


Figure 1, Appendix A.1: *The exterior surface temperate of different materials types*

Time	OCB	REFC	HClayB	SStone	Adobe	LWCBF	LWCBH	AeratedB	Cstraw	CrubberB	Pumice
0	20.954	21.197	19.353	20.005	19.626	19.187	18.82	18.927	20.765	19.85	18.655
1	19.693	19.931	18.07	18.772	18.361	17.883	17.48	17.592	19.507	18.552	17.248
2	18.929	19.147	17.415	18.063	17.691	17.236	16.81	16.935	18.837	17.937	16.543
3	19.231	19.391	18.132	18.519	18.318	18.014	17.687	17.792	19.347	18.656	17.5
4	20.403	20.484	19.898	19.906	19.949	19.875	19.729	19.787	20.805	20.4	19.704
5	22.375	22.359	22.599	22.121	22.48	22.699	22.754	22.771	23.181	23.152	22.933
6	27.921	27.686	29.852	28.203	29.323	30.25	30.83	30.73	29.565	30.412	31.535
7	35.353	34.868	39.209	36.242	38.217	39.944	41.112	40.884	37.982	39.804	42.416
8	43.148	42.446	48.679	44.599	47.289	49.706	51.396	51.053	46.588	49.265	53.227
9	49.888	49.044	56.519	51.736	54.867	57.742	59.783	59.363	53.862	57.124	61.984
10	55.315	54.396	62.552	57.407	60.753	63.889	66.148	65.68	59.53	63.145	68.59
11	59.111	58.181	66.464	61.262	64.628	67.84	70.171	69.688	63.432	67.148	72.732
12	60.988	60.108	68.043	63.071	66.264	69.387	71.692	71.213	65.079	68.702	74.261
13	60.964	60.183	67.389	62.882	65.746	68.645	70.842	70.382	64.519	67.902	73.321
14	58.962	58.327	64.373	60.554	62.953	65.479	67.44	67.03	61.931	64.857	69.722
15	55.043	54.595	59.081	56.158	57.969	59.975	61.573	61.243	57.395	59.653	63.545
16	48.81	48.602	51.066	49.342	50.366	51.667	52.779	52.552	50.204	51.584	54.289
17	41.989	42.009	42.529	41.966	42.236	42.834	43.459	43.333	42.369	42.892	44.47
18	34.86	35.094	33.719	34.264	33.831	33.725	33.826	33.813	34.405	34.042	34.3
19	29.064	29.436	26.778	28.037	27.17	26.572	26.273	26.351	28.126	27.123	26.328
20	26.653	27.015	24.384	25.542	24.774	24.168	23.81	23.908	25.808	24.759	23.781
21	25.372	25.69	23.389	24.279	23.713	23.212	22.869	22.973	24.815	23.854	22.839
22	23.963	24.254	22.119	22.891	22.418	21.951	21.603	21.709	23.58	22.626	21.539
23	22.611	22.883	20.856	21.57	21.144	20.688	20.324	20.433	22.341	21.384	20.214
A	36.733	36.55	38.43	36.97	37.92	38.85	39.55	39.422	38.081	38.95	40.48
MX	60.98	60.18	68.04	63.07	66.26	69.38	71.69	71.21	65.07	68.70	74.26
MI	18.92	19.14	17.41	18.06	17.69	17.23	16.81	16.93	18.83	17.93	16.54
MD	31.96	32.15	31.78	31.23	31.57	31.98	32.32	32.27	31.98	32.22	32.917
A	**Average**		**MX**	**Maximum**		**MI**	**Minimum**		**MD**	**Median**	

Table 1, Appendix A.1: *The exterior surface temperate of different materials types*

Time	OCB	REFC	HClayB	SStone	Adobe	LWCBF	LWCBH	AeratedB	Cstraw	CrubberB	Pumice
0	23.967	24.192	21.847	22.268	22.228	21.589	20.541	20.961	24.679	23.169	20.017
1	22.973	23.16	21.249	21.418	21.522	21.076	20.235	20.588	23.899	22.579	19.913
2	22.116	22.268	20.747	20.713	20.928	20.645	19.988	20.28	23.198	22.056	19.832
3	21.505	21.629	20.422	20.283	20.54	20.366	19.865	20.095	22.643	21.653	19.821
4	21.197	21.3	20.311	20.186	20.401	20.27	19.892	20.059	22.275	21.401	19.892
5	21.226	21.317	20.434	20.446	20.535	20.375	20.076	20.183	22.127	21.325	20.044
6	21.987	22.086	21.081	21.532	21.279	20.928	20.644	20.676	22.433	21.615	20.428
7	23.555	23.685	22.284	23.491	22.675	21.957	21.598	21.552	23.259	22.314	21.018
8	25.784	25.969	23.917	26.114	24.578	23.352	22.817	22.712	24.535	23.359	21.718
9	28.375	28.631	25.75	29.024	26.721	24.917	24.116	23.987	26.098	24.616	22.406
10	31.067	31.403	27.597	31.919	28.887	26.493	25.359	25.247	27.794	25.96	23.012
11	33.618	34.036	29.292	34.534	30.88	27.939	26.435	26.38	29.483	27.278	23.487
12	35.806	36.3	30.694	36.647	32.533	29.136	27.26	27.294	31.014	28.456	23.8
13	37.465	38.022	31.704	38.11	33.727	30	27.782	27.927	32.263	29.401	23.937
14	38.459	39.061	32.237	38.797	34.363	30.459	27.956	28.225	33.137	30.043	23.886
15	38.692	39.318	32.236	38.63	34.373	30.462	27.755	28.154	33.565	30.327	23.642
16	38.039	38.662	31.623	37.5	33.665	29.943	27.136	27.663	33.439	30.171	23.185
17	36.634	37.232	30.507	35.608	32.369	28.995	26.2	26.836	32.804	29.617	22.592
18	34.617	35.17	28.991	33.13	30.603	27.702	25.028	25.745	31.733	28.723	21.913
19	32.313	32.809	27.315	30.458	28.649	26.27	23.808	24.563	30.409	27.639	21.264
20	30.241	30.68	25.865	28.202	26.954	25.03	22.832	23.567	29.14	26.618	20.821
21	28.496	28.882	24.693	26.423	25.579	24.027	22.108	22.784	28.006	25.72	20.547
22	26.983	27.319	23.71	24.961	24.423	23.185	21.54	22.142	26.97	24.91	20.352
23	25.653	25.943	22.87	23.734	23.434	22.465	21.079	21.604	26.015	24.172	20.199
A	29.19	29.55	25.72	28.51	26.74	24.89	23.42	23.72	27.54	25.55	21.57
MX	38.69	39.31	32.24	38.79	34.37	30.46	27.97	28.23	33.56	30.33	23.94
MI	21.19	21.3	20.31	20.19	20.40	20.27	19.87	20.05	22.13	21.325	19.82
MD	28.44	28.76	25.22	27.31	26.15	24.47	22.83	23.18	27.38	25.32	21.14
A	**Average**		**MX**	**Maximum**		**MI**	**Minimum**		**MD**	**Median**	

Table 2, Appendix A.1: *The interior surface temperate of different materials types*

A.2. Detail result related to selecting the appropriate types of materials

A.2.1. Actual case study materials type – Wall thickness 12 cm

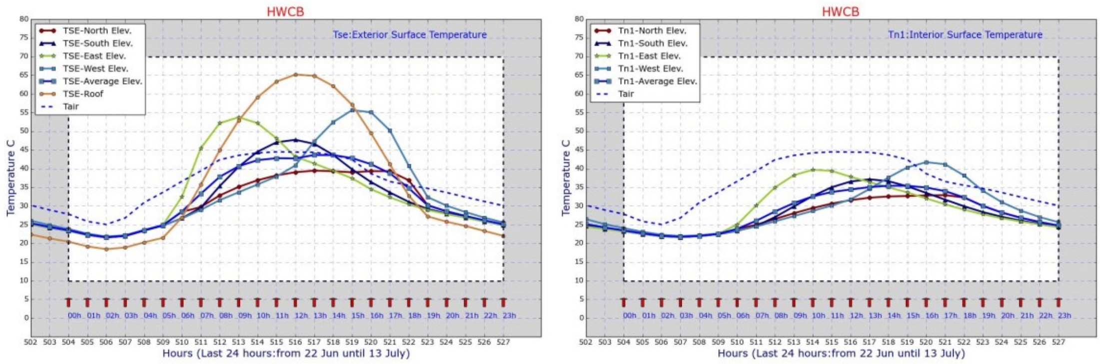
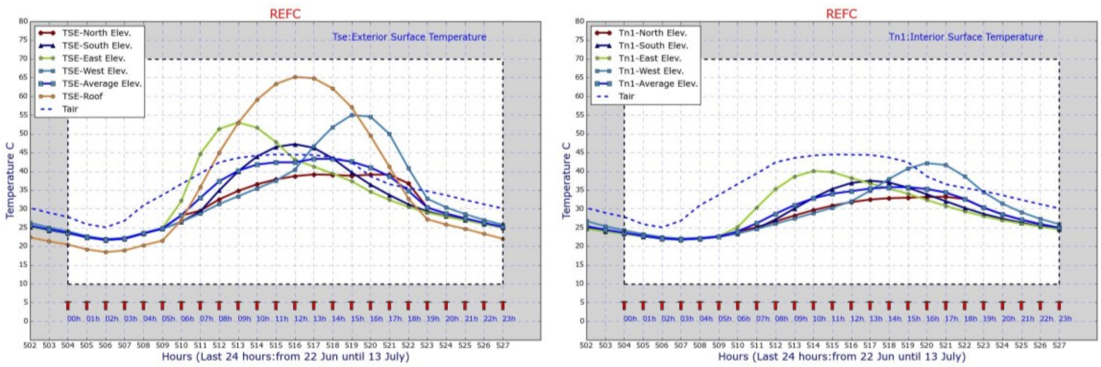
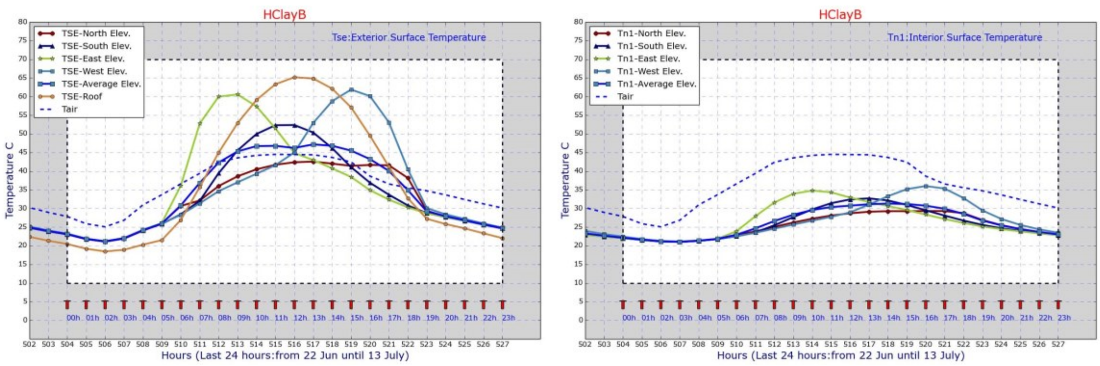


Figure 2, Appendix A.2: *The exterior (left side) and interior (right side) surface temperate of (ordinary concrete block)*

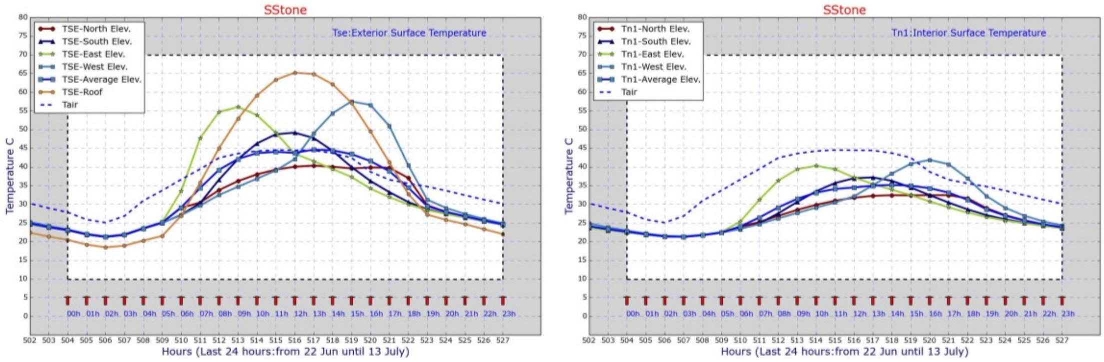
A.2.2. Alternative materials type available in Iraq – Wall thickness 12 cm



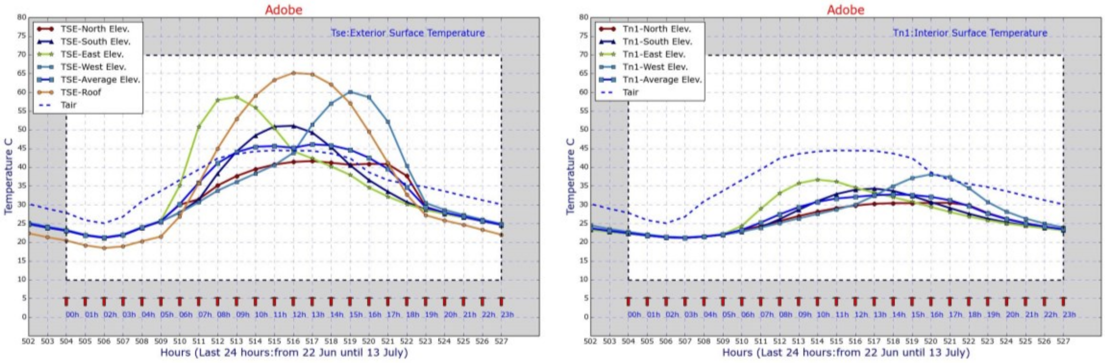
Reinforcement concrete materials



Hollow clay blocks



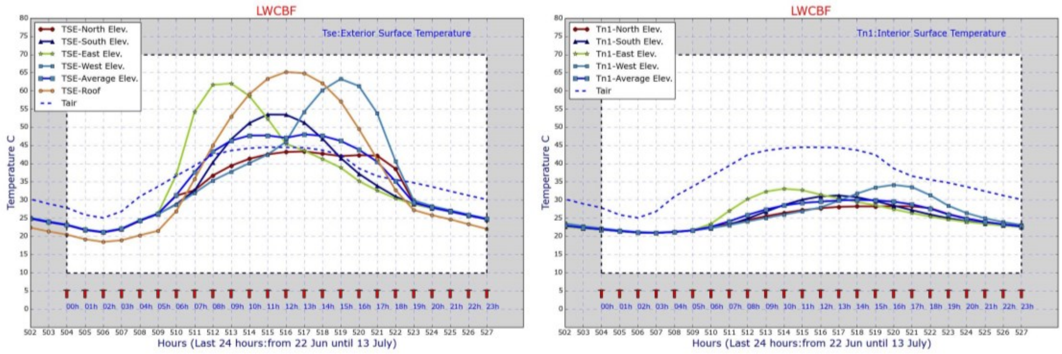
Sandstone materials



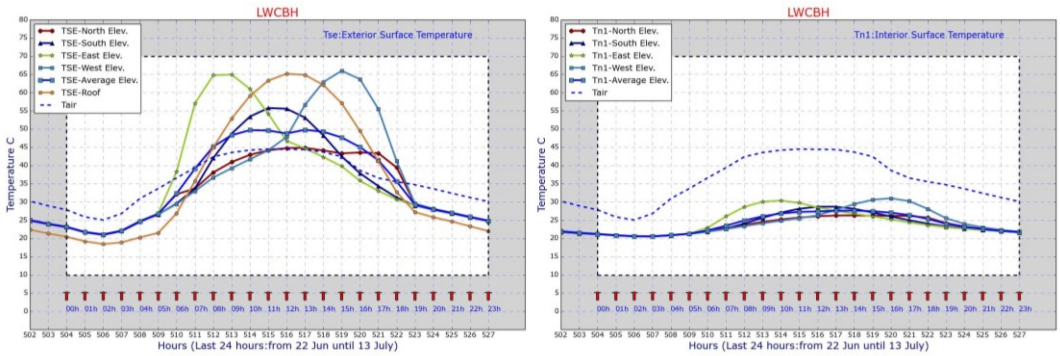
Adobe bricks materials

Figure 2, Appendix A.2: *The exterior (left side) and interior (right side) surface temperate of Alternative materials type available in Iraq – Wall thickness 12 cm*

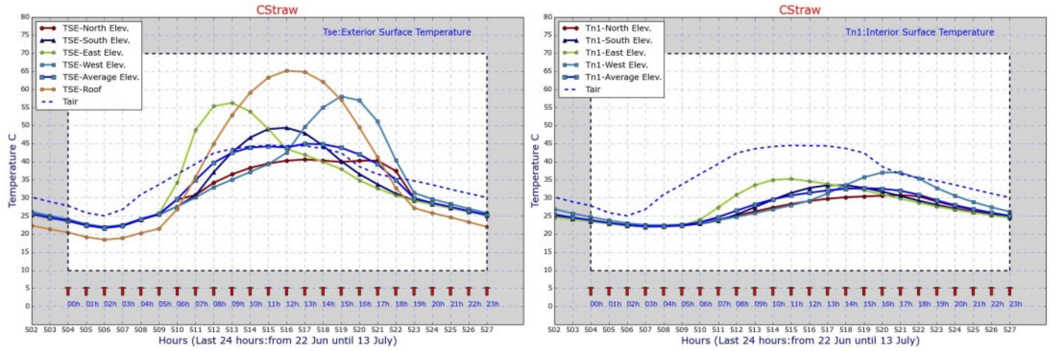
A.2.3. Alternative materials type available in France – Wall thickness 12 cm



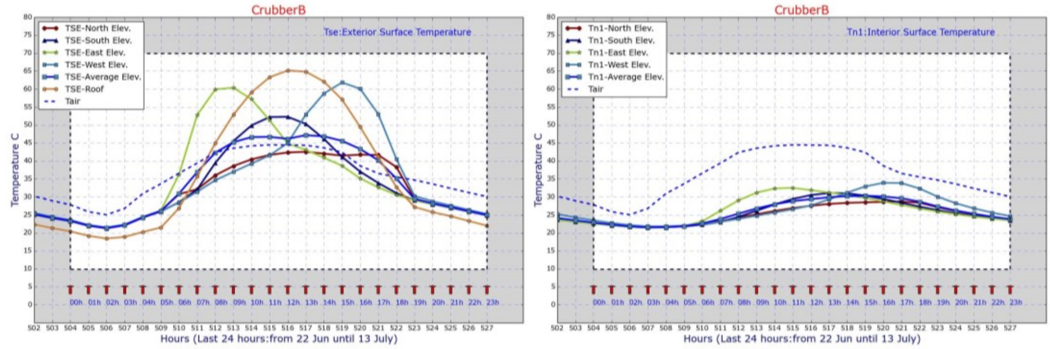
Lightweight concrete block – Filled materials



Lightweight concrete block – Hollow materials

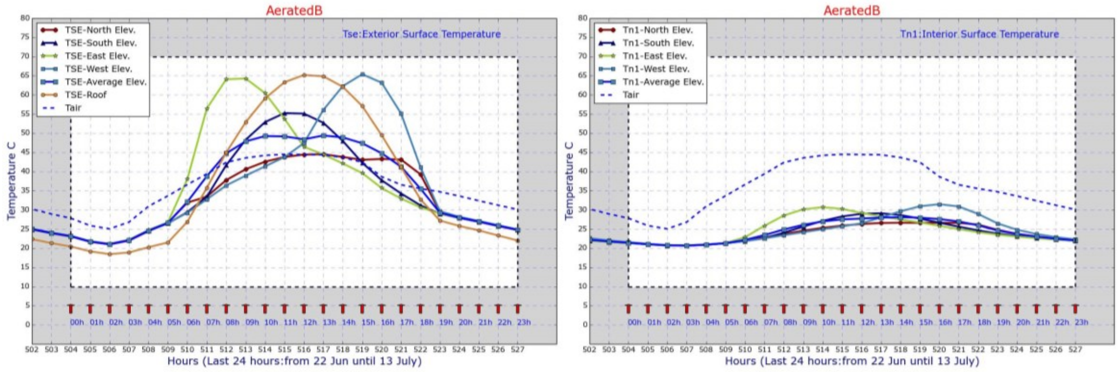


Concrete/mixed with straw materials

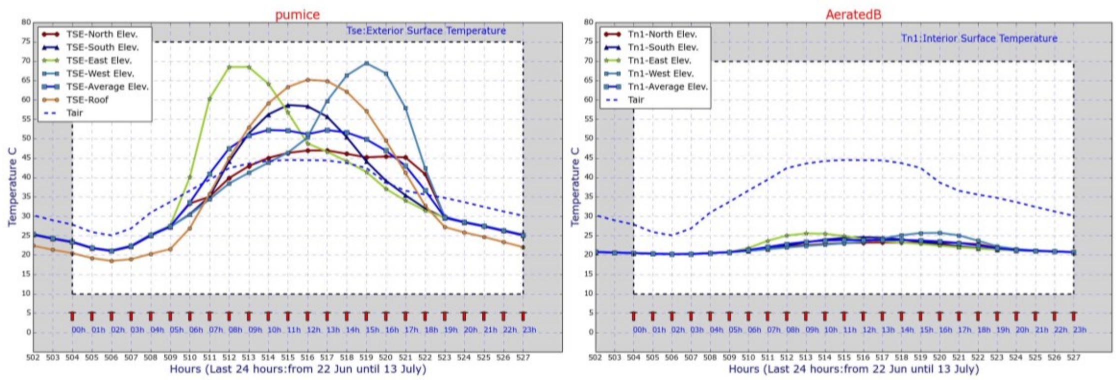


Concrete rubber aggregates materials

Figure 3, Appendix A.2: *The exterior (left side) and interior (right side) surface temperate of Alternative materials type available in France– Wall thickness 12 cm*



Aerated concrete blocks materials



Pumice block materials

Figure 3, Appendix A.2: *The exterior (left side) and interior (right side) surface temperate of Alternative materials type available in France– Wall thickness 12 cm*

A.2.4. Actual case study materials type – Wall thickness 20 cm

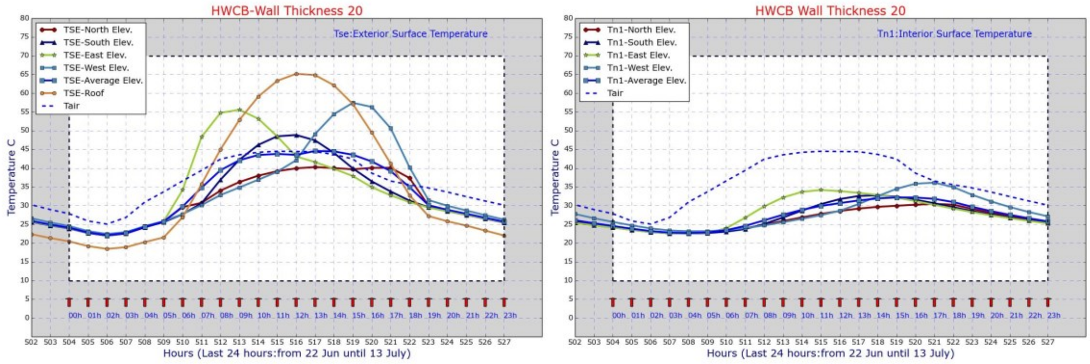
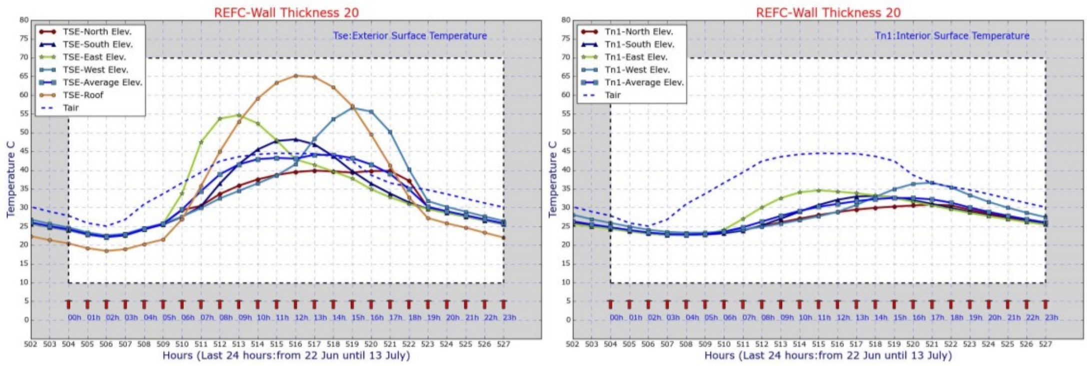
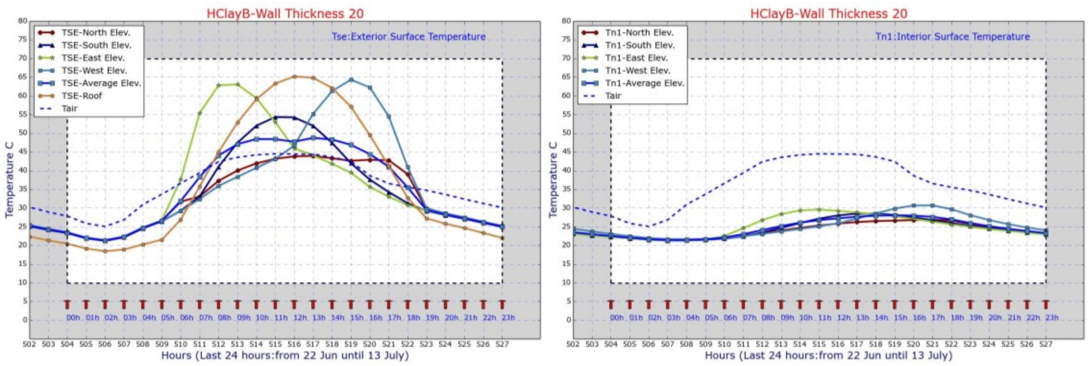


Figure 2, Appendix A.2: *The exterior (left side) and interior (right side) surface temperate of (ordinary concrete block)*

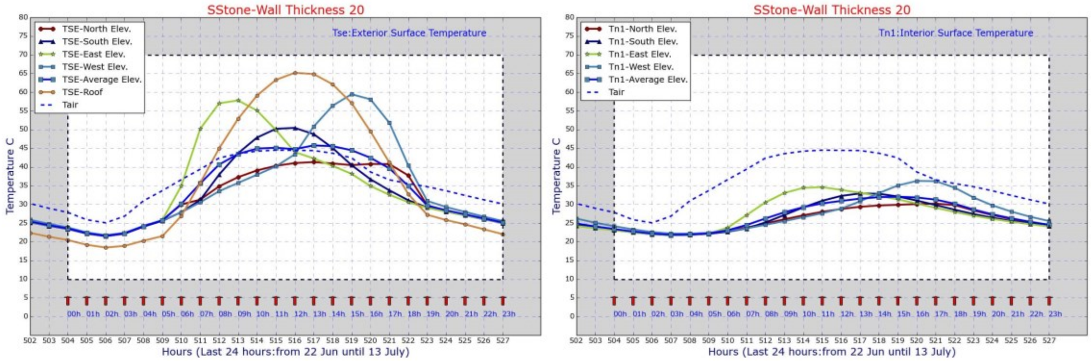
A.2.5. Alternative materials type available in Iraq – Wall thickness 20 cm



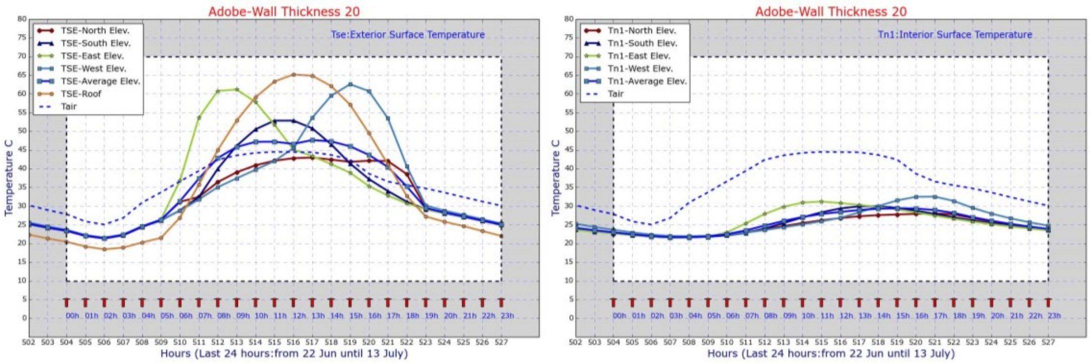
Reinforcement concrete materials



Hollow clay blocks



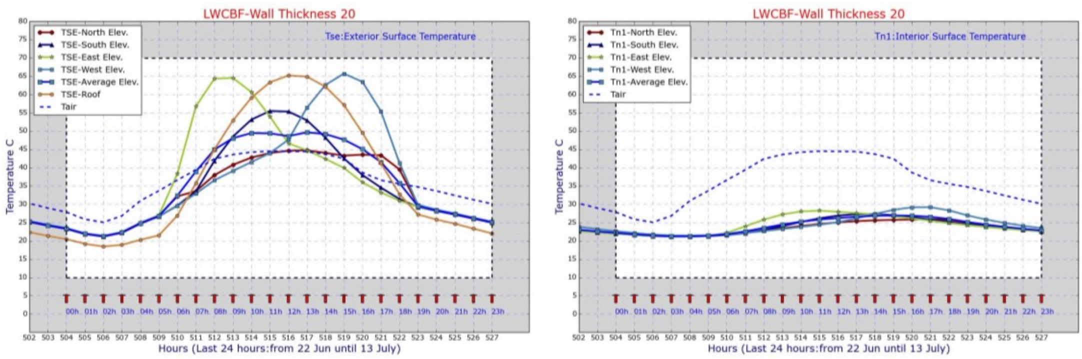
Sandstone materials



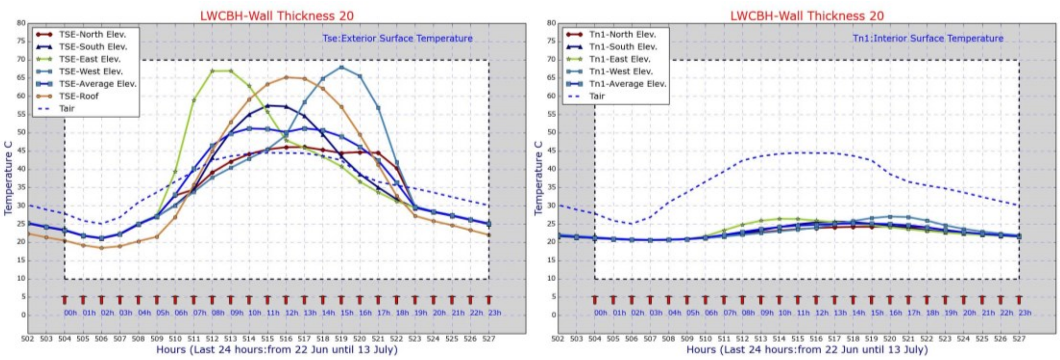
Adobe bricks materials

Figure 2, Appendix A.2: *The exterior (left side) and interior (right side) surface temperate of Alternative materials type available in Iraq – Wall thickness 12 cm*

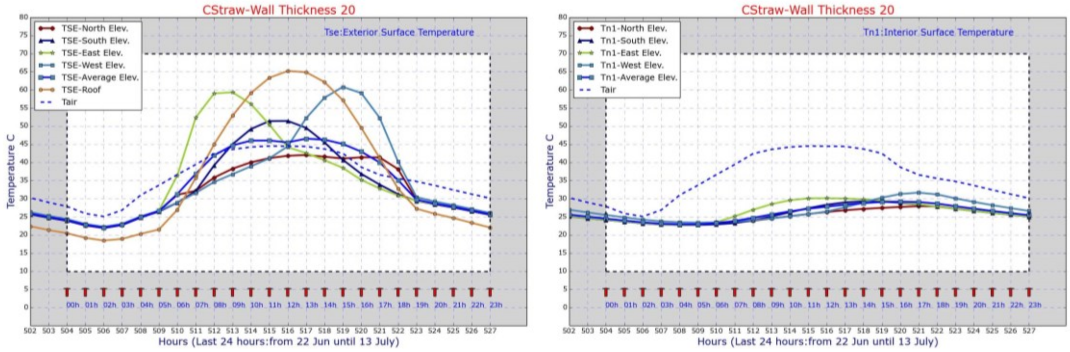
A.2.6. Alternative materials type available in France – Wall thickness 20 cm



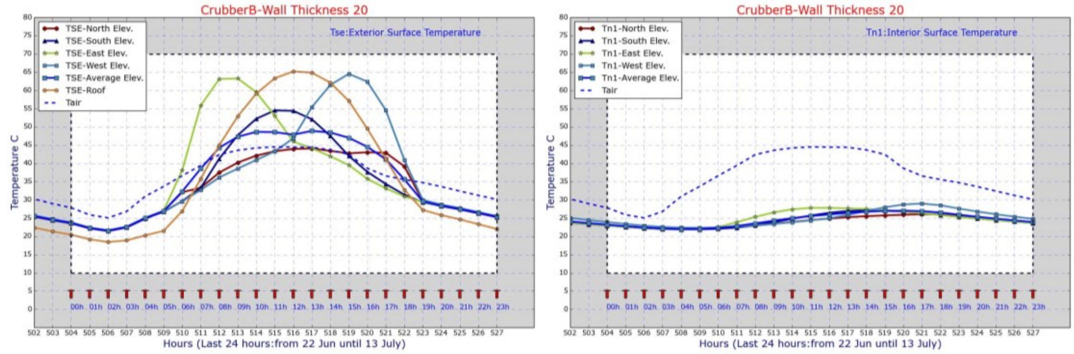
Lightweight concrete block – Filled materials



Lightweight concrete block – Hollow materials

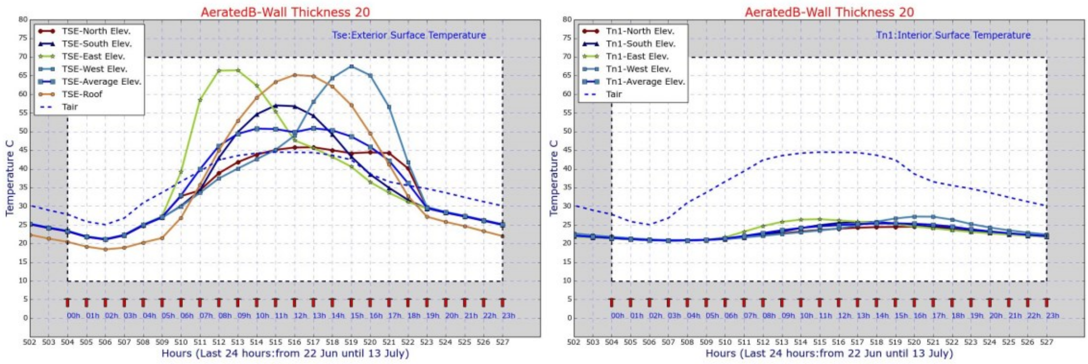


Concrete/mixed with straw materials

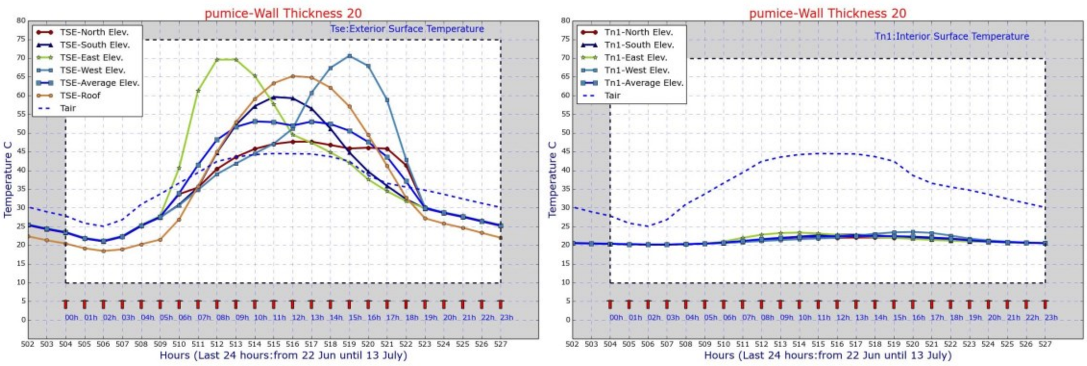


Concrete rubber aggregates materials

Figure 3, Appendix A.2: *The exterior (left side) and interior (right side) surface temperate of Alternative materials type available in France– Wall thickness 20 cm*



Aerated concrete blocks materials



Pumice block materials

Figure 3, Appendix A.2: *The exterior (left side) and interior (right side) surface temperate of Alternative materials type available in France– Wall thickness 20 cm*

A.2.7. Actual case study materials type – Cavity "air gap" wall

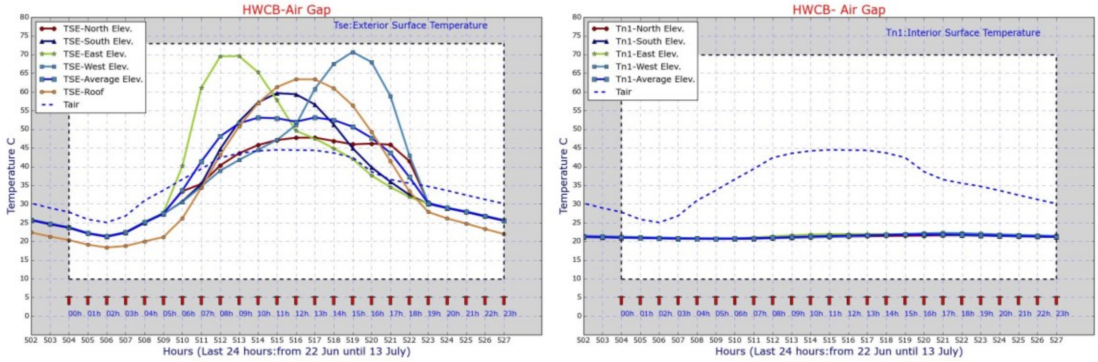
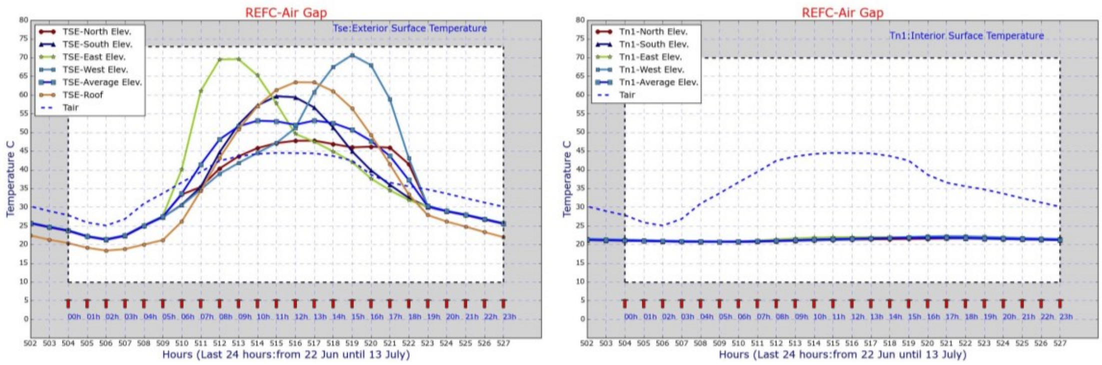
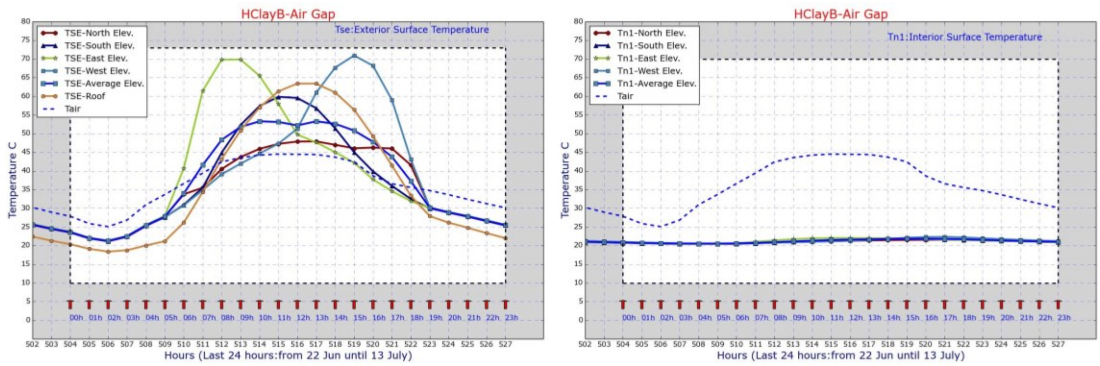


Figure 2, Appendix A.2: *The exterior (left side) and interior (right side) surface temperate of (ordinary concrete block- Cavity "air gap" wall)*

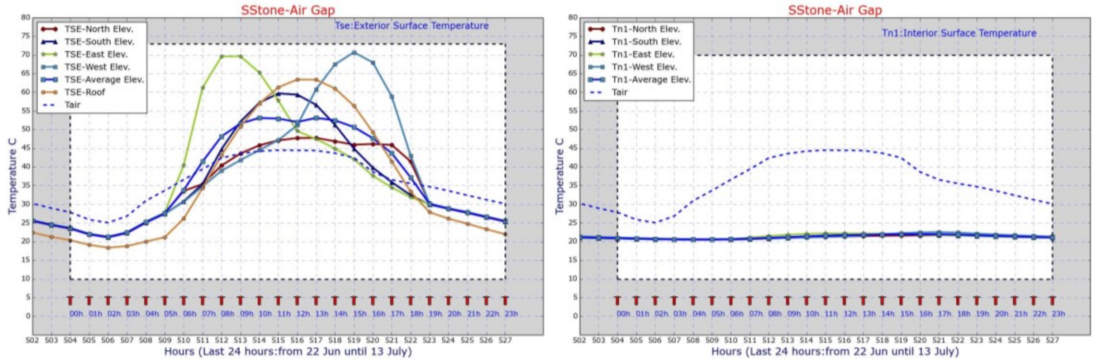
A.2.8. Alternative materials type available in Iraq – Cavity "Rockwool gap" wall



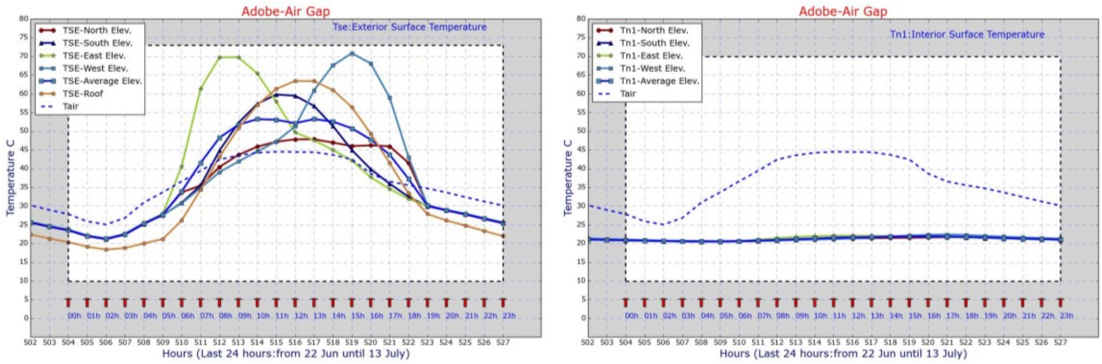
Reinforcement concrete materials



Hollow clay blocks



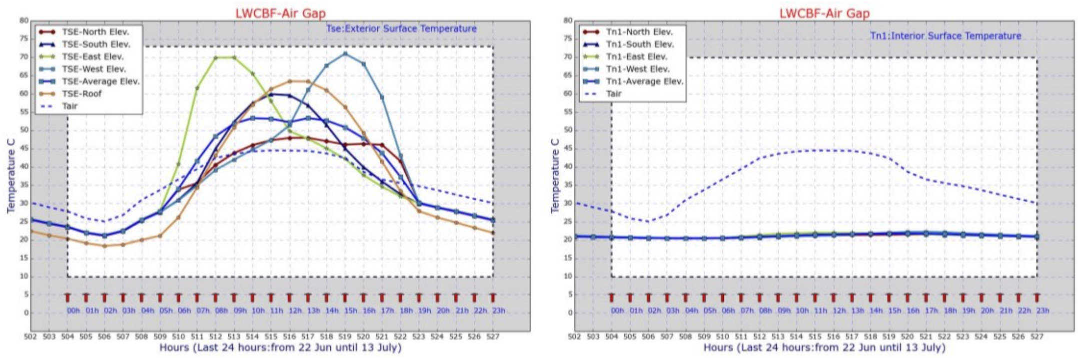
Sandstone materials



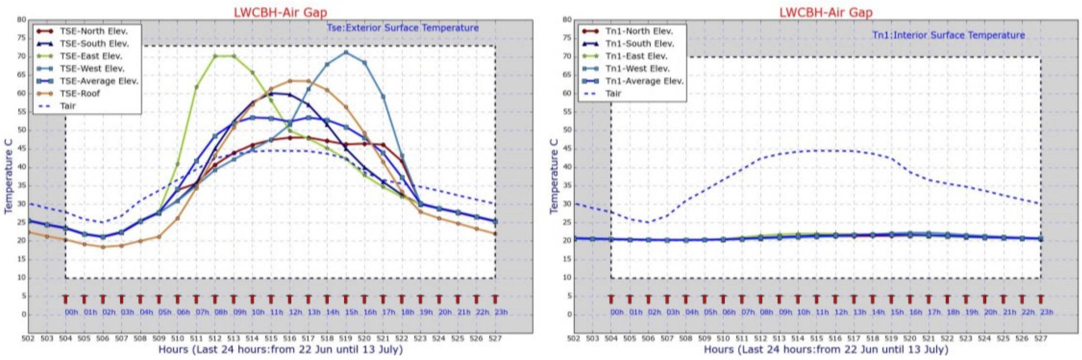
Adobe bricks materials

Figure 2, Appendix A.2: *The exterior (left side) and interior (right side) surface temperate of Alternative materials type available in Iraq – Cavity "air gap" wall*

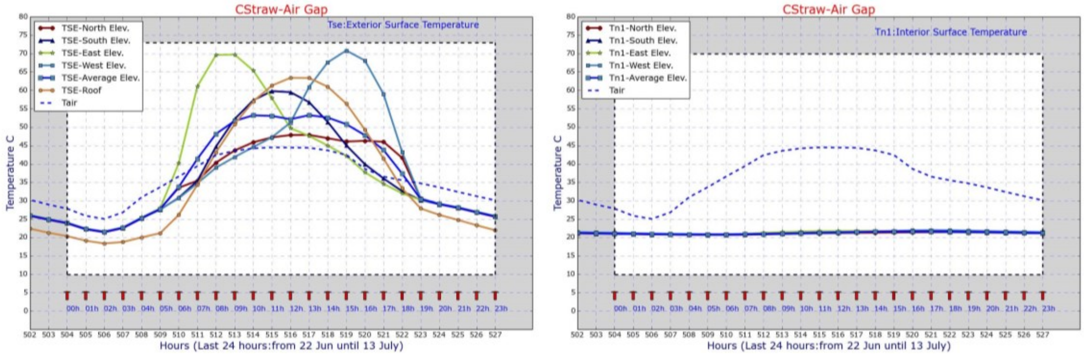
A.2.9. Alternative materials type available in France – Cavity "air gap" wall



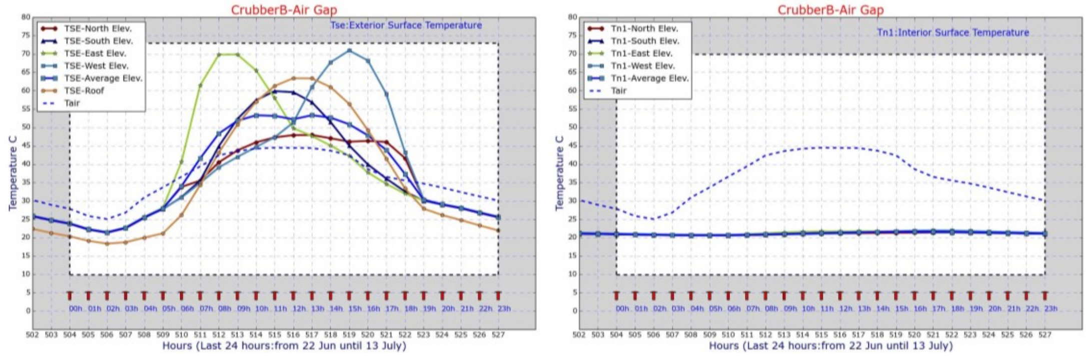
Lightweight concrete block – Filled materials



Lightweight concrete block – Hollow materials

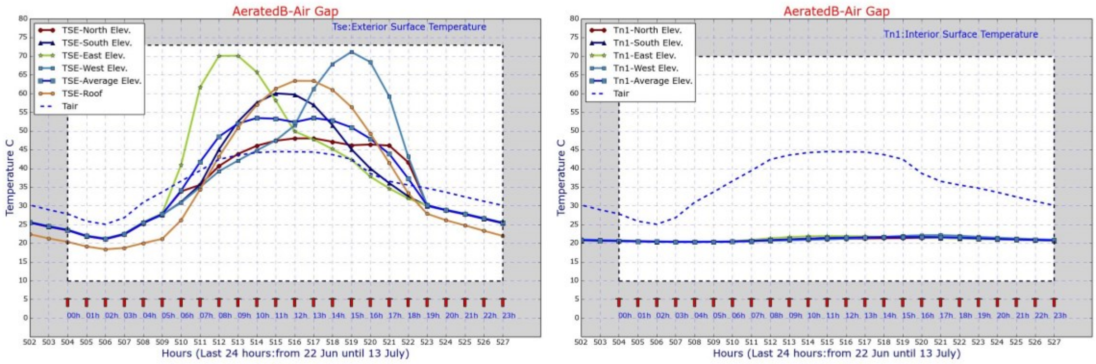


Concrete/mixed with straw materials

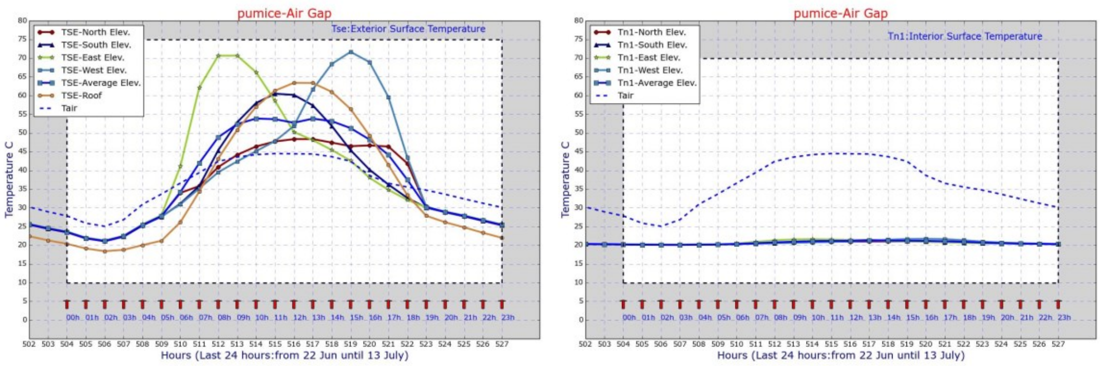


Concrete rubber aggregates materials

Figure 3, Appendix A.2: *The exterior (left side) and interior (right side) surface temperate of Alternative materials type available in France– Cavity "air gap" wall*



Aerated concrete blocks materials



Pumice block materials

Figure 3, Appendix A.2: *The exterior (left side) and interior (right side) surface temperate of Alternative materials type available in France– Cavity "air gap" wall*

A.2.10. Actual case study materials type – Cavity "Rockwool gap" wall

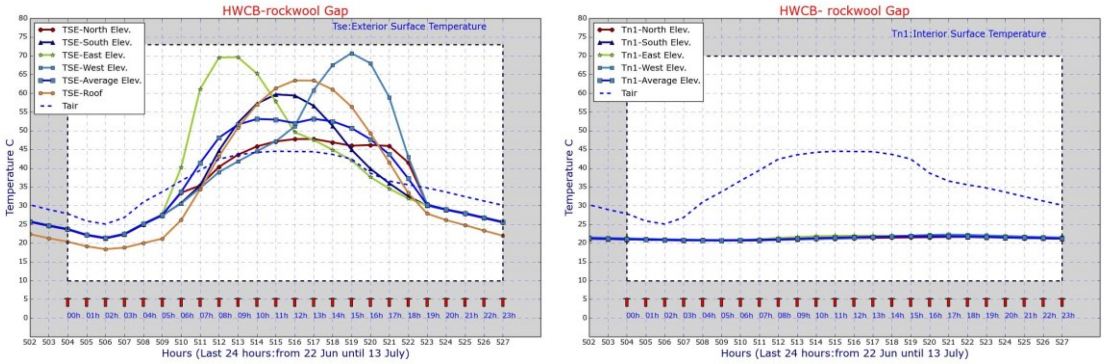
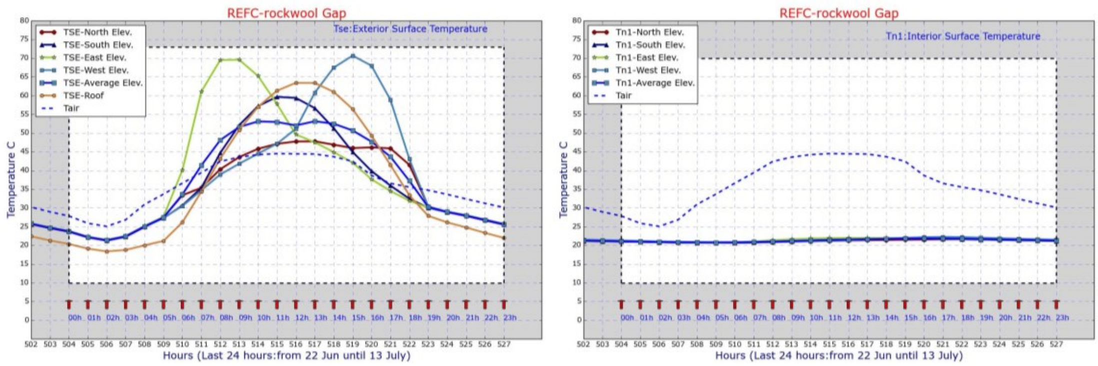
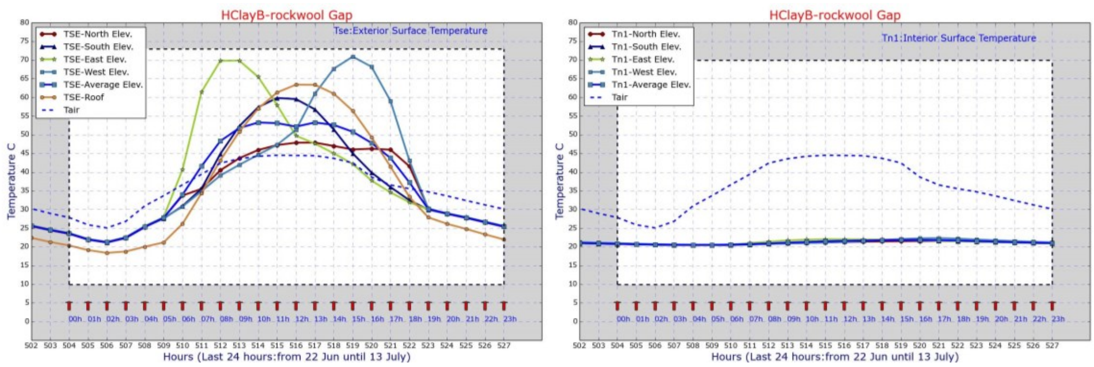


Figure 2, Appendix A.2: *The exterior (left side) and interior (right side) surface temperate of (ordinary concrete block- Cavity "Rockwool gap" wall)*

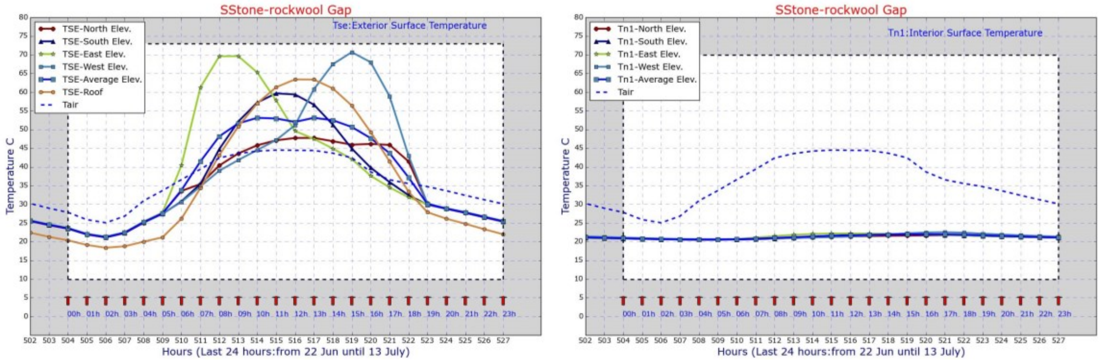
A.2.11. Alternative materials type available in Iraq – Cavity "Rockwool gap" wall



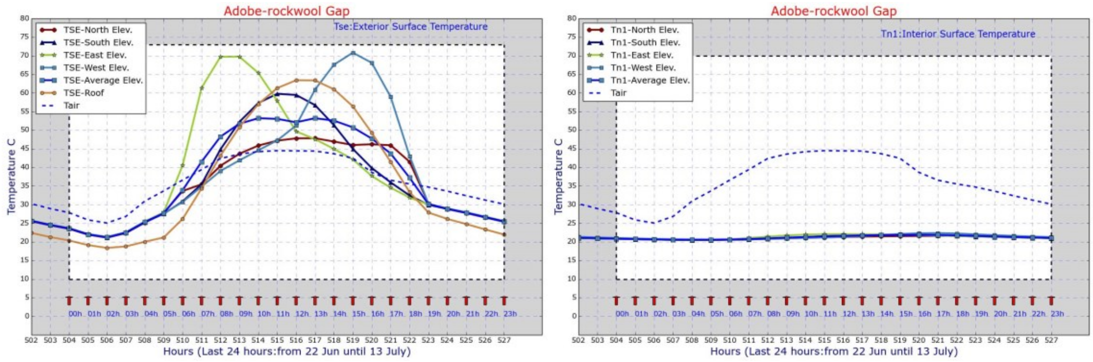
Reinforcement concrete materials



Hollow clay blocks



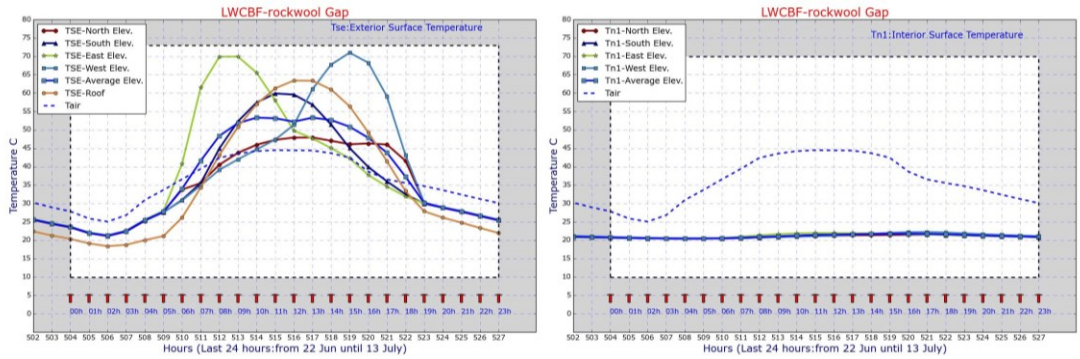
Sandstone materials



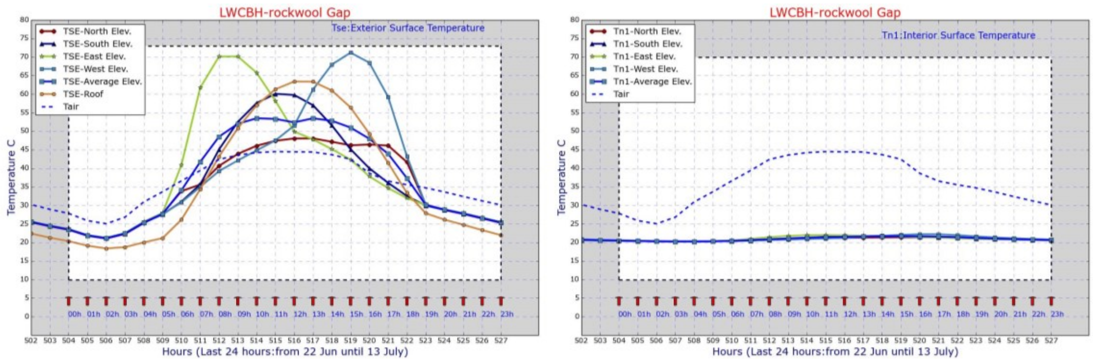
Adobe bricks materials

Figure 2, Appendix A.2: *The exterior (left side) and interior (right side) surface temperate of Alternative materials type available in Iraq – Cavity "Rockwool gap" wall*

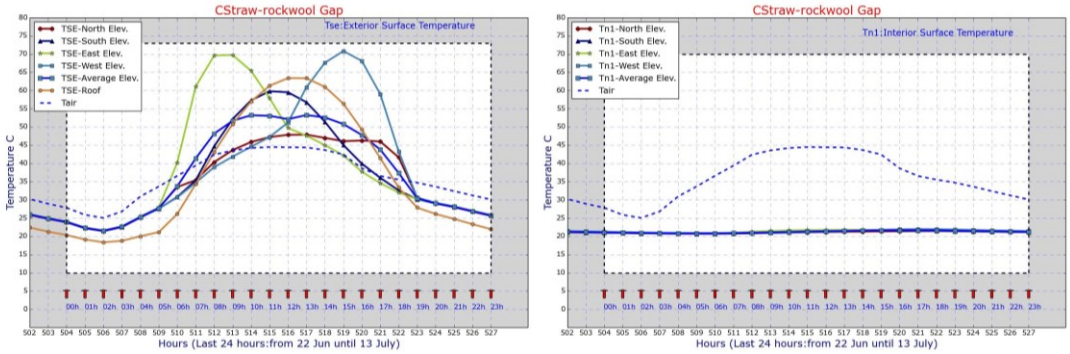
A.2.12. Alternative materials type available in France – Cavity "air gap" wall



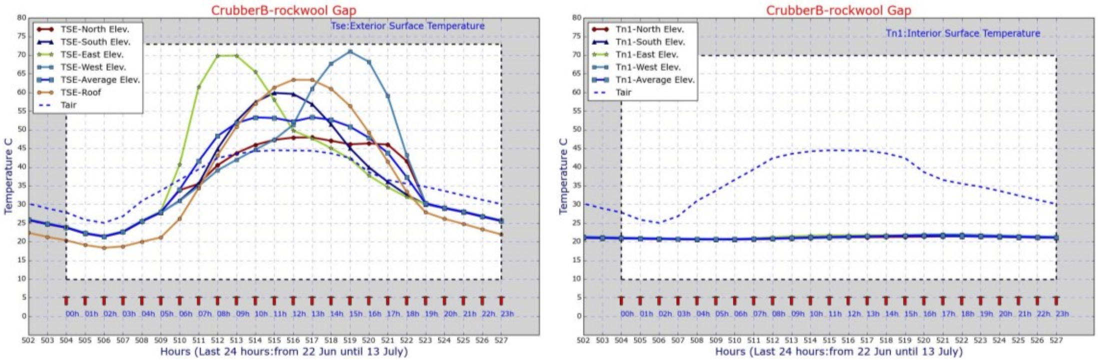
Lightweight concrete block – Filled materials



Lightweight concrete block – Hollow materials

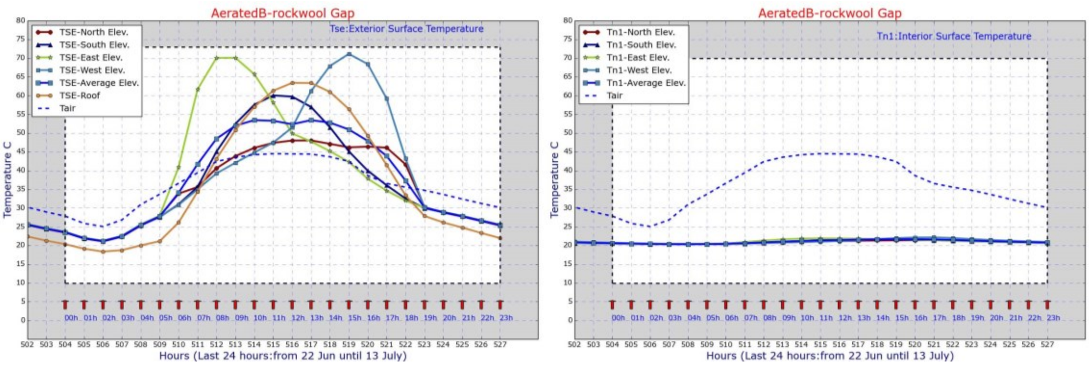


Concrete/mixed with straw materials

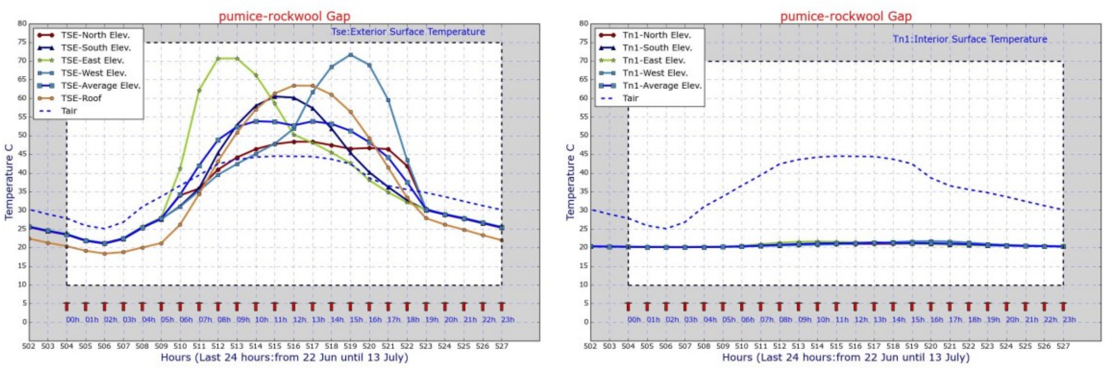


Concrete rubber aggregates materials

Figure 3, Appendix A.2: *The exterior (left side) and interior (right side) surface temperate of Alternative materials type available in France– Cavity "Rockwool gap" wall*



Aerated concrete blocks materials

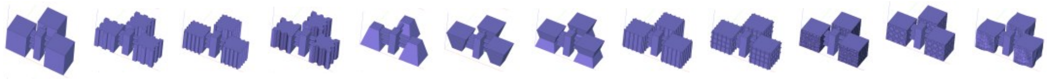


Pumice block materials

Figure 3, Appendix A.2: *The exterior (left side) and interior (right side) surface temperate of Alternative materials type available in France– Cavity "Rockwool gap" wall*

A.3. Detail result related to selecting the appropriate wall shape design

A.3.1. East Elevation- Low Albedo

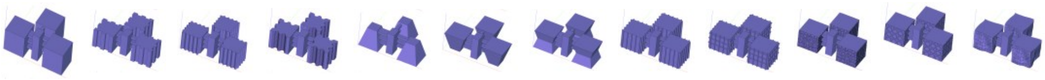


	Square shape	Irregular square shape	Zigzag shape	Serpentine shape	Pyramid shape	Inverted pyramid shape	Combine pyramids shape	Column expressed	Frame expressed	Irregular printed concrete	Ornament printed	Muli-surface shape
	23.05	23.95	23.67	23.68	21.89	24.22	23.15	24.15	24.46	24.02	23.73	23.29
	21.47	22.32	22.06	22.07	20.36	22.60	21.57	22.53	22.82	22.39	21.95	21.70
	20.67	21.53	21.26	21.27	19.58	21.80	20.77	21.73	22.03	21.60	20.68	20.90
	21.75	22.72	22.42	22.40	20.63	22.87	21.86	22.90	23.24	22.76	20.55	21.99
	24.32	25.49	25.16	25.13	23.07	25.54	24.45	25.73	26.16	25.58	21.44	24.56
	27.41	28.46	28.09	28.16	26.13	28.61	27.51	28.71	29.04	28.52	22.44	27.68
	50.34	48.04	47.07	48.20	49.47	49.72	49.90	46.85	45.62	46.91	27.00	50.11
	63.62	58.97	58.51	60.11	64.36	60.69	62.88	57.76	56.22	57.58	34.84	62.85
	69.15	63.40	63.68	65.35	71.80	64.15	68.29	61.99	59.27	62.27	43.86	67.94
	68.57	63.65	63.52	65.03	73.16	61.80	67.70	62.45	60.62	62.79	52.16	67.03
	63.80	60.65	59.83	61.00	70.10	55.74	63.01	59.35	57.42	60.22	59.31	62.03
	55.94	53.45	53.61	54.34	63.62	47.74	55.60	53.21	52.79	54.08	64.85	54.14
	46.00	46.75	47.28	47.13	54.50	47.17	46.56	46.94	46.83	46.93	68.30	46.76
	44.68	44.77	44.65	44.67	44.00	46.38	45.08	44.75	45.58	44.85	69.33	45.05
	43.28	43.10	43.23	43.05	41.79	44.95	43.50	43.25	43.66	43.27	67.96	43.45
	41.26	41.25	41.38	41.22	39.86	42.86	41.46	41.38	41.47	41.49	64.23	41.48
	37.70	37.67	37.78	37.65	36.41	39.11	37.81	37.79	37.79	37.83	57.77	37.84
	34.77	34.95	34.94	34.87	33.60	36.08	34.89	35.09	35.16	35.07	50.15	34.96
	32.23	32.73	32.59	32.56	31.00	33.51	32.35	32.89	33.06	32.82	42.08	32.45
	30.09	30.86	30.63	30.62	28.79	31.44	30.22	31.06	31.32	30.95	36.12	30.35
	28.75	29.58	29.33	29.32	27.47	30.06	28.87	29.78	30.07	29.66	33.17	29.00
	27.57	28.42	28.16	28.16	26.35	28.83	27.69	28.62	28.91	28.50	30.74	27.82
	26.24	27.13	26.85	26.86	25.01	27.48	26.35	27.34	27.64	27.21	28.43	26.49
	24.92	25.87	25.58	25.58	23.69	26.18	25.04	26.08	26.41	25.95	26.33	25.18
Ave	38.65	38.15	37.97	38.27	39.03	38.31	38.60	38.01	37.82	38.05	41.14	38.54
Max	69.15	63.65	63.68	65.35	73.16	64.15	68.29	62.45	60.62	62.79	69.33	67.94
Min	20.67	21.53	21.26	21.27	19.58	21.80	20.77	21.73	22.03	21.60	20.55	20.90
Med	33.50	33.84	33.76	33.72	32.30	34.80	33.62	33.99	34.11	33.94	35.48	33.70

A.3.2. North Elevation- Low Albedo

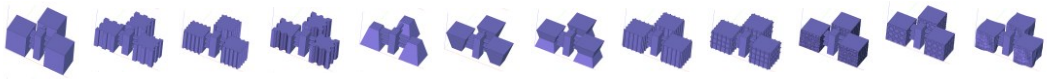
												
	Square shape	**Irregular square shape**	**Zigzag shape**	**Serpentine shape**	**Pyramid shape**	**Inverted pyramid shape**	**Combine pyramids shape**	**Column expressed**	**Frame expressed**	**Irregular printed concrete**	**Ornament printed**	**Muli-surface shape**
	23.16	24.03	23.76	23.77	21.99	24.35	23.27	24.25	24.57	24.27	23.51	23.6
	21.56	22.39	22.13	22.15	20.44	22.71	21.66	22.61	22.91	22.62	21.89	21.81
	20.75	21.58	21.32	21.34	19.65	21.89	20.85	21.80	22.10	21.81	21.08	20.98
	21.81	22.76	22.47	22.45	20.69	22.94	21.91	22.96	23.30	22.98	22.15	22.25
	24.36	25.52	25.20	25.16	23.11	25.58	24.49	25.78	26.20	25.81	24.80	24.81
	26.86	28.02	27.77	27.69	25.60	28.07	26.97	28.30	28.71	28.33	27.29	26.65
	36.35	36.96	35.94	36.16	36.05	36.16	36.28	36.82	36.45	36.22	35.98	29.42
	38.95	39.41	40.58	38.95	40.83	36.65	38.86	40.21	39.60	39.29	38.50	32.57
	38.81	39.60	41.17	39.90	42.99	39.31	40.32	40.62	40.63	40.32	38.82	36.09
	40.40	41.73	42.45	41.47	43.32	42.00	41.47	42.47	42.53	42.00	40.59	38.58
	42.30	43.04	43.35	42.89	43.31	43.76	42.81	43.29	43.81	43.14	42.38	40.81
	43.53	43.77	43.64	43.60	43.40	45.11	43.98	43.80	44.50	43.94	43.63	43.04
	44.23	44.04	44.22	44.09	43.70	45.67	44.41	44.20	44.79	44.26	44.26	44.26
	44.52	44.58	44.62	44.54	44.49	46.14	45.01	44.64	45.21	44.83	44.81	44.82
	44.24	44.48	45.02	44.57	45.33	45.82	44.85	44.74	45.00	44.60	44.72	44.72
	43.08	43.63	44.88	43.64	45.98	44.73	44.11	44.38	43.92	43.50	43.64	43.64
	40.70	40.40	42.68	41.05	44.89	41.28	42.22	41.42	40.69	40.87	41.03	41.03
	41.74	41.12	42.87	40.77	43.57	39.57	41.66	41.89	40.39	41.01	41.76	41.76
	39.84	39.57	38.80	39.03	39.45	39.80	39.76	39.34	38.24	38.97	39.69	39.03
	31.02	31.56	31.49	31.40	29.64	32.40	31.13	31.79	31.97	31.81	31.26	31.99
	29.05	29.80	29.57	29.57	27.72	30.41	29.17	30.03	30.31	30.05	29.35	30.41
	27.81	28.59	28.35	28.35	26.54	29.10	27.93	28.81	29.10	28.83	28.12	29.13
	26.42	27.26	27.00	27.01	25.17	27.70	26.54	27.49	27.80	27.51	26.76	28.73
	25.07	25.97	25.69	25.70	23.81	26.35	25.18	26.20	26.53	26.23	25.43	27.36
Ave	34.02	34.58	34.79	34.39	34.23	34.90	34.37	34.91	34.97	34.72	34.23	33.65
Max	44.52	44.58	45.02	44.57	45.98	46.14	45.01	44.74	45.21	44.83	44.81	44.82
Min	20.75	21.58	21.32	21.34	19.65	21.89	20.85	21.80	22.10	21.81	21.08	20.98
Med	37.58	38.18	37.37	37.55	37.75	36.40	37.57	38.08	37.35	37.60	37.24	32.28

A.3.3. South Elevation- Low Albedo



	Square shape	Irregular square shape	Zigzag shape	Serpentine shape	Pyramid shape	Inverted pyramid shape	Combine pyramids shape	Column expressed	Frame expressed	Irregular printed concrete	Ornament printed	Muli-surface shape
	23.17	24.04	23.92	23.78	21.98	24.38	23.28	24.27	24.64	24.10	23.59	23.05
	21.57	22.40	22.29	22.15	20.43	22.73	21.67	22.63	22.98	22.45	21.97	21.46
	20.75	21.59	21.48	21.34	19.64	21.91	20.85	21.82	22.17	21.65	21.15	20.64
	21.82	22.77	22.63	22.45	20.68	22.96	21.93	22.99	23.38	22.80	22.24	21.72
	24.38	25.53	25.37	25.18	23.12	25.62	24.51	25.81	26.31	25.61	24.92	24.25
	26.33	27.62	27.41	27.23	25.06	27.60	26.46	27.92	28.47	27.73	26.95	26.23
	29.40	30.77	30.93	30.33	28.10	30.75	29.55	31.44	31.95	31.64	30.05	29.34
	33.23	34.66	35.10	34.22	31.93	34.69	33.47	35.57	35.84	36.03	33.80	33.26
	37.67	38.95	40.16	38.83	41.00	39.14	39.35	40.33	40.36	40.30	38.13	38.88
	44.55	43.87	43.89	45.08	50.51	42.50	45.44	46.22	44.95	45.49	44.30	46.09
	51.05	50.35	49.97	50.56	58.15	45.39	50.96	50.05	49.89	50.79	50.31	52.36
	55.44	53.13	53.39	53.89	63.18	47.62	55.37	52.64	52.37	53.75	53.95	56.59
	57.28	54.44	54.99	55.39	65.15	48.76	56.90	53.89	53.27	54.44	55.17	58.22
	56.69	54.14	54.48	54.99	64.21	49.10	56.59	53.61	53.15	53.89	55.63	57.37
	53.34	52.14	52.20	52.52	60.09	48.00	53.20	51.74	51.28	51.25	53.39	53.88
	47.61	46.17	46.50	47.61	53.12	45.86	48.40	48.37	46.72	46.92	48.30	48.32
	39.87	40.09	41.40	40.28	42.59	41.30	41.17	41.05	40.65	40.38	41.12	40.55
	35.94	36.35	36.68	36.25	34.56	37.23	35.98	36.74	36.59	36.26	36.17	35.71
	32.81	33.26	33.19	33.11	31.39	34.19	32.90	33.36	33.55	33.29	32.99	32.60
	30.49	31.16	31.09	30.95	29.03	31.92	30.58	31.38	31.67	31.22	30.80	30.30
	29.06	29.82	29.73	29.59	27.67	30.44	29.16	30.05	30.38	29.88	29.42	28.90
	27.82	28.61	28.51	28.37	26.51	29.13	27.92	28.84	29.17	28.66	28.19	27.67
	26.43	27.28	27.16	27.02	25.14	27.73	26.54	27.51	27.87	27.33	26.83	26.29
	25.08	25.99	25.86	25.71	23.79	26.37	25.19	26.23	26.61	26.04	25.51	24.95
Ave	35.49	35.63	35.76	35.70	36.96	34.80	35.72	36.02	36.01	35.91	35.62	35.78
Max	57.28	54.44	54.99	55.39	65.15	49.10	56.90	53.89	53.27	54.44	55.63	58.22
Min	20.75	21.59	21.48	21.34	19.64	21.91	20.85	21.82	22.17	21.65	21.15	20.64
Med	31.65	32.21	32.14	32.03	30.21	33.05	31.74	32.40	32.75	32.47	31.89	31.45

A.3.4. West Elevation- Low Albedo



	Square shape	Irregular square shape	Zigzag shape	Serpentine shape	Pyramid shape	Inverted pyramid shape	Combine pyramids shape	Column expressed	Frame expressed	Irregular printed concrete	Ornament printed	Muli-surface shape
	23.18	24.06	23.77	23.80	21.97	24.38	23.27	24.25	24.56	24.35	23.51	23.07
	21.57	22.41	22.13	22.17	20.42	22.73	21.66	22.60	22.90	22.70	21.89	21.48
	20.75	21.60	21.32	21.35	19.63	21.90	20.84	21.79	22.09	21.88	21.07	20.67
	21.81	22.77	22.46	22.46	20.67	22.95	21.91	22.95	23.29	23.06	22.15	21.73
	24.37	25.53	25.19	25.18	23.10	25.60	24.49	25.77	26.20	25.92	24.80	24.25
	26.32	27.62	27.21	27.24	25.05	27.58	26.45	27.86	28.34	28.03	26.83	26.82
	29.14	30.42	30.02	30.04	27.90	30.37	29.28	30.66	31.13	30.82	29.65	37.27
	32.31	33.46	33.11	33.11	31.12	33.54	32.48	33.66	34.11	33.84	32.77	40.88
	35.88	36.83	36.59	36.55	34.64	37.17	36.04	37.06	37.44	37.22	36.27	41.77
	38.30	39.04	38.92	38.76	37.11	39.75	38.55	39.23	39.59	39.38	38.57	42.11
	40.59	41.02	41.04	40.87	39.52	42.07	40.81	41.30	41.88	41.30	40.80	43.41
	42.90	43.26	43.12	42.99	42.51	44.27	43.12	43.26	44.20	43.22	42.93	43.94
	45.23	46.08	46.73	46.45	54.15	46.16	45.86	46.33	46.23	45.48	45.14	44.34
	56.54	53.86	54.14	54.75	64.35	48.16	56.26	53.60	53.16	53.79	55.42	44.62
	65.47	61.89	61.26	62.32	71.71	57.47	64.71	60.55	58.47	60.22	63.66	44.23
	70.98	65.46	65.56	66.95	75.36	64.42	70.11	64.23	62.24	63.71	69.49	43.87
	70.96	64.29	64.87	66.45	73.45	66.13	70.06	62.79	59.79	62.20	68.75	42.33
	66.33	60.78	60.59	62.13	66.88	63.60	65.54	59.47	57.65	58.84	64.04	41.57
	53.82	50.76	50.00	51.11	52.73	53.42	53.32	49.79	48.11	49.24	52.26	39.13
	31.72	32.15	31.93	32.04	30.20	33.13	31.77	32.33	32.42	32.35	31.87	30.82
	29.13	29.90	29.63	29.67	27.71	30.53	29.21	30.09	30.35	30.18	29.41	28.92
	27.86	28.66	28.39	28.43	26.53	29.19	27.95	28.85	29.12	28.94	28.16	27.70
	26.46	27.31	27.03	27.06	25.15	27.76	26.55	27.51	27.81	27.61	26.78	26.32
	25.09	26.01	25.71	25.74	23.79	26.39	25.19	26.21	26.53	26.32	25.44	24.97
Ave	38.61	38.13	37.95	38.23	38.99	38.28	38.56	38.01	37.82	37.94	38.40	34.43
Max	70.98	65.46	65.56	66.95	75.36	66.13	70.11	64.23	62.24	63.71	69.49	44.62
Min	20.75	21.60	21.32	21.35	19.63	21.90	20.84	21.79	22.09	21.88	21.07	20.67
Med	32.02	32.80	32.52	32.58	30.66	33.34	32.12	33.00	33.27	33.10	32.32	38.20

A.4. Detail result related to selecting the complementary solution

a. Double Wall

Time steps	North ELE.	South ELE.	East ELE.	West ELE.	Average ELE.
00:00 h	23.64	23.62	23.56	23.78	23.65
00:01 h	22.50	22.51	22.45	22.56	22.51
00:02 h	21.84	21.87	21.83	21.87	21.85
00:03 h	22.37	22.42	22.43	22.40	22.41
00:04 h	23.98	24.06	24.13	24.02	24.05
00:05 h	25.41	25.46	25.59	25.42	25.47
00:06 h	29.02	27.46	32.40	27.27	29.04
00:07 h	30.23	30.13	42.66	29.56	33.14
00:08 h	33.08	34.98	50.29	32.12	37.62
00:09 h	34.88	38.64	50.28	33.77	39.39
00:10 h	36.09	41.29	46.54	34.92	39.71
00:11 h	36.76	42.59	41.60	35.88	39.21
00:12 h	37.28	42.43	38.19	37.04	38.73
00:13 h	37.71	41.50	37.12	41.78	39.53
00:14 h	37.75	39.71	36.22	47.32	40.25
00:15 h	37.48	37.65	35.15	51.43	40.43
00:16 h	37.34	34.80	32.95	51.01	39.03
00:17 h	37.96	32.55	31.24	47.18	37.23
00:18 h	36.37	30.51	29.80	39.70	34.09
00:19 h	29.91	28.93	28.57	31.31	29.68
00:20 h	28.36	27.87	27.64	29.31	28.30
00:21 h	27.23	26.94	26.77	27.83	27.19
00:22 h	26.16	26.00	25.89	26.54	26.15
00:23 h	25.16	25.09	25.02	25.40	25.17
Max	37.96	42.59	50.29	51.43	40.43
Min	21.84	21.87	21.83	21.87	21.85
Average	30.77	31.21	32.43	32.89	31.83
Median	30.07	29.53	30.52	30.43	31.41

b. Green Wall

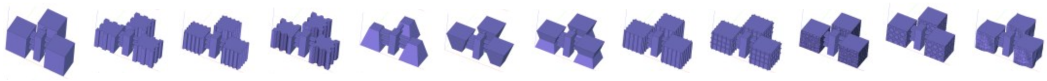
Time steps	North ELE.	South ELE.	East ELE.	West ELE.	Average ELE.
00:00 h	25.40	25.39	25.40	25.44	25.41
00:01 h	23.58	23.58	23.58	23.60	23.58
00:02 h	22.67	22.67	22.68	22.69	22.68
00:03 h	23.91	23.92	23.94	23.93	23.92
00:04 h	27.24	27.25	27.29	27.27	27.26
00:05 h	29.65	29.65	29.70	29.67	29.67
00:06 h	32.55	32.34	33.03	32.33	32.56
00:07 h	35.23	35.17	36.89	34.99	35.55
00:08 h	38.06	38.29	40.13	37.66	38.52
00:09 h	39.67	40.27	41.82	39.24	40.24
00:10 h	40.71	41.65	42.66	40.31	41.33
00:11 h	41.24	42.31	42.52	41.02	41.77
00:12 h	41.30	42.36	41.83	41.41	41.73
00:13 h	41.24	42.16	41.28	41.89	41.64
00:14 h	40.63	41.23	40.43	41.84	41.03
00:15 h	39.61	39.76	39.27	41.31	39.97
00:16 h	36.58	36.24	35.95	38.43	36.79
00:17 h	34.86	34.14	34.00	36.27	34.80
00:18 h	33.70	32.93	32.90	34.36	33.47
00:19 h	32.25	32.01	32.01	32.60	32.21
00:20 h	31.16	31.04	31.05	31.36	31.15
00:21 h	29.97	29.91	29.91	30.09	29.97
00:22 h	28.84	28.81	28.82	28.91	28.84
00:23 h	27.68	27.67	27.67	27.72	27.69
Max	41.30	42.36	42.66	41.89	41.77
Min	22.67	22.67	22.68	22.69	22.68
Average	33.24	33.36	33.53	33.51	33.41
Median	33.13	32.63	32.96	33.48	33.01

c. High albedo Wall

Time steps	North ELE.	South ELE.	East ELE.	West ELE.	Average ELE.
00:00 h	23.25	23.30	23.32	23.24	23.28
00:01 h	21.68	21.74	21.74	21.67	21.71
00:02 h	20.94	20.99	21.00	20.93	20.96
00:03 h	22.15	22.22	22.30	22.20	22.22
00:04 h	25.00	25.09	25.27	25.12	25.12
00:05 h	27.15	27.16	27.41	27.20	27.23
00:06 h	30.60	29.82	32.58	29.74	30.67
00:07 h	33.56	33.57	40.19	32.73	34.95
00:08 h	37.62	38.99	44.89	36.17	39.37
00:09 h	39.98	42.74	46.06	38.16	41.72
00:10 h	41.55	45.38	45.66	39.66	43.08
00:11 h	42.68	47.04	44.52	41.04	43.86
00:12 h	43.36	47.43	42.45	43.50	44.24
00:13 h	43.48	46.61	40.80	46.13	44.29
00:14 h	43.00	44.52	39.60	47.33	43.62
00:15 h	41.86	41.51	38.05	47.14	42.12
00:16 h	38.97	36.94	34.49	43.72	38.50
00:17 h	36.77	33.76	32.29	39.46	35.56
00:18 h	33.71	31.15	30.66	33.79	32.33
00:19 h	29.64	29.55	29.45	29.49	29.54
00:20 h	28.49	28.52	28.50	28.45	28.49
00:21 h	27.44	27.49	27.49	27.42	27.46
00:22 h	26.25	26.31	26.34	26.26	26.29
00:23 h	25.08	25.14	25.19	25.09	25.13
Max	43.48	47.43	46.06	47.33	44.29
Min	20.94	20.99	21.00	20.93	20.96
Average	32.68	33.21	32.93	33.15	32.99
Median	32.08	30.48	31.47	31.23	31.50

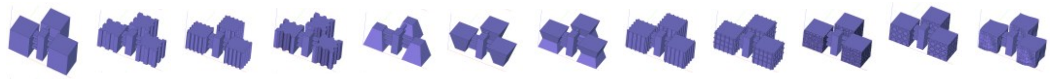
A.5. Detail result related to selecting wall shape and the complementary solution selected

A.5.1. East Elevation- High Albedo



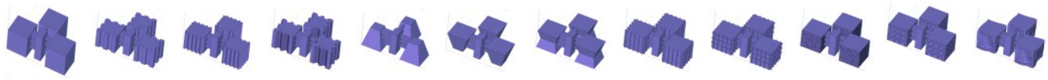
	Square shape	Irregular square shape	Zigzag shape	Serpentine shape	Pyramid shape	Inverted pyramid shape	Combine pyramids shape	Column expressed	Frame expressed	Irregular printed concrete	Ornament printed	Muli-surface shape
	22.83	23.78	23.48	23.50	21.72	23.95	22.94	23.99	24.32	23.85	23.22	23.07
	21.30	22.19	21.91	21.93	20.22	22.39	21.40	22.39	22.70	22.26	21.66	21.53
	20.53	21.42	21.14	21.16	19.47	21.61	20.63	21.63	21.93	21.49	20.89	20.76
	21.64	22.64	22.33	22.31	20.55	22.74	21.75	22.82	23.17	22.68	22.01	21.88
	24.23	25.42	25.05	25.06	23.00	25.43	24.36	25.66	26.10	25.51	24.70	24.47
	26.35	27.63	27.23	27.25	25.08	27.59	26.48	27.89	28.34	27.72	26.87	26.63
	34.14	34.57	33.96	34.29	32.94	34.90	34.11	34.41	34.46	34.33	34.11	34.29
	39.58	39.35	38.85	39.30	38.87	39.66	39.47	39.18	39.15	39.01	39.27	39.57
	42.96	42.45	42.13	42.60	42.82	42.43	42.83	42.22	41.87	42.18	42.63	42.80
	43.74	43.43	43.02	43.47	44.22	42.68	43.61	43.29	43.18	43.26	43.61	43.50
	43.15	43.29	42.72	43.07	44.15	41.70	43.05	43.13	42.98	43.25	42.93	42.84
	41.48	41.77	41.50	41.72	42.88	39.99	41.51	41.90	42.15	42.02	41.48	41.16
	38.99	40.14	39.99	39.96	40.58	40.10	39.24	40.37	40.70	40.26	39.32	39.38
	38.77	39.70	39.37	39.40	37.78	40.01	38.96	39.87	40.44	39.78	39.15	39.04
	38.13	38.96	38.70	38.67	36.93	39.37	38.27	39.16	39.60	39.06	38.48	38.35
	36.97	37.80	37.56	37.54	35.78	38.20	37.10	38.00	38.33	37.92	37.33	37.20
	34.20	34.89	34.68	34.67	33.10	35.33	34.30	35.07	35.32	34.98	34.49	34.40
	32.24	32.93	32.71	32.71	31.18	33.34	32.34	33.13	33.37	33.01	32.57	32.45
	30.56	31.42	31.15	31.14	29.43	31.71	30.67	31.60	31.89	31.49	30.94	30.79
	29.23	30.17	29.88	29.89	28.04	30.43	29.34	30.37	30.70	30.25	29.61	29.48
	28.18	29.13	28.83	28.85	27.02	29.37	28.29	29.33	29.68	29.21	28.57	28.43
	27.14	28.07	27.77	27.79	26.00	28.29	27.24	28.28	28.61	28.14	27.52	27.38
	25.89	26.86	26.55	26.57	24.74	27.06	26.00	27.05	27.41	26.93	26.28	26.14
	24.65	25.66	25.34	25.36	23.47	25.85	24.76	25.85	26.22	25.73	25.06	24.91
Ave	31.95	32.65	32.33	32.42	31.25	32.67	32.03	32.77	33.03	32.68	32.20	32.10
Max	43.74	43.43	43.02	43.47	44.22	42.68	43.61	43.29	43.18	43.26	43.61	43.50
Min	20.53	21.42	21.14	21.16	19.47	21.61	20.63	21.63	21.93	21.49	20.89	20.76
Med	31.40	32.17	31.93	31.93	30.30	32.53	31.51	32.37	32.63	32.25	31.76	31.62

A.5.2. North Elevation- High Albedo



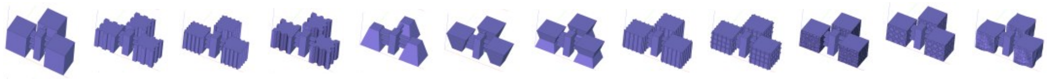
	Square shape	Irregular square shape	Zigzag shape	Serpentine shape	Pyramid shape	Inverted pyramid shape	Combine pyramids shape	Column expressed	Frame expressed	Irregular printed concrete	Ornament printed	Muli-surface shape
	22.87	23.80	23.51	23.53	21.76	24.00	22.98	24.03	24.36	24.04	23.24	22.80
	21.34	22.21	21.94	21.96	20.25	22.43	21.43	22.44	22.75	22.44	21.68	21.26
	20.57	21.44	21.17	21.18	19.50	21.64	20.66	21.66	21.97	21.67	20.91	20.50
	21.66	22.65	22.34	22.33	20.57	22.76	21.77	22.85	23.20	22.86	22.02	21.59
	24.25	25.43	25.06	25.07	23.01	25.44	24.37	25.69	26.12	25.72	24.69	24.14
	26.20	27.51	27.14	27.13	24.94	27.44	26.33	27.79	28.25	27.82	26.71	26.14
	30.26	31.51	30.92	30.98	29.22	31.16	30.34	31.67	31.95	31.57	30.57	30.47
	32.65	33.90	33.91	33.43	32.22	32.97	32.74	34.33	34.55	34.11	32.96	33.15
	34.43	35.81	35.90	35.52	34.62	35.51	34.95	36.30	36.70	36.25	34.87	35.18
	35.85	37.34	37.19	36.93	35.74	37.19	36.25	37.77	38.18	37.66	36.35	36.28
	37.18	38.44	38.19	38.08	36.59	38.43	37.41	38.73	39.24	38.71	37.62	37.44
	38.09	39.14	38.79	38.80	37.23	39.32	38.30	39.36	39.90	39.41	38.50	38.16
	38.54	39.42	39.17	39.16	37.60	39.72	38.68	39.66	40.16	39.70	38.92	38.53
	38.72	39.64	39.36	39.36	37.91	39.94	38.93	39.85	40.34	39.92	39.16	38.70
	38.36	39.30	39.17	39.06	37.87	39.57	38.61	39.56	39.95	39.54	38.84	38.32
	37.42	38.41	38.49	38.16	37.42	38.66	37.78	38.80	38.98	38.57	37.91	37.60
	34.98	35.60	36.01	35.57	35.39	35.88	35.47	36.05	36.10	35.91	35.35	35.39
	34.11	34.59	34.88	34.31	33.89	34.26	34.16	34.98	34.79	34.73	34.38	34.03
	32.62	33.27	32.85	32.90	31.72	33.41	32.67	33.37	33.31	33.29	32.86	32.38
	29.48	30.37	30.11	30.11	28.28	30.70	29.59	30.58	30.89	30.62	29.84	29.38
	28.27	29.20	28.91	28.92	27.09	29.47	28.38	29.41	29.77	29.45	28.64	28.19
	27.21	28.12	27.83	27.85	26.06	28.37	27.32	28.36	28.68	28.36	27.57	27.13
	25.95	26.90	26.60	26.62	24.79	27.13	26.06	27.11	27.47	27.14	26.33	25.87
	24.70	25.69	25.38	25.40	23.52	25.90	24.81	25.90	26.28	25.94	25.09	24.62
Ave	30.66	31.65	31.45	31.35	29.88	31.72	30.83	31.93	32.24	31.89	31.04	30.72
Max	38.72	39.64	39.36	39.36	37.91	39.94	38.93	39.85	40.34	39.92	39.16	38.70
Min	20.57	21.44	21.17	21.18	19.50	21.64	20.66	21.66	21.97	21.67	20.91	20.50
Med	31.44	32.39	31.89	31.94	30.47	32.07	31.51	32.52	32.63	32.43	31.71	31.43

A.5.3. South Elevation- High Albedo



	Square shape	Irregular square shape	Zigzag shape	Serpentine shape	Pyramid shape	Inverted pyramid shape	Combine pyramids shape	Column expressed	Frame expressed	Irregular printed concrete	Ornament printed	Muli-surface shape
	22.88	23.81	23.92	23.53	21.76	24.02	22.99	24.05	24.44	23.87	23.33	22.78
	21.34	22.22	22.29	21.96	20.25	22.44	21.44	22.45	22.82	22.28	21.76	21.24
	20.57	21.45	21.48	21.18	19.50	21.65	20.67	21.68	22.04	21.50	20.99	20.47
	21.67	22.66	22.63	22.33	20.57	22.78	21.78	22.87	23.28	22.69	22.11	21.58
	24.26	25.44	25.37	25.08	23.03	25.47	24.39	25.72	26.23	25.51	24.81	24.14
	26.07	27.42	27.41	27.01	24.82	27.35	26.22	27.72	28.28	27.51	26.72	25.99
	28.41	29.86	30.93	29.42	27.09	29.74	28.56	30.25	30.84	30.16	29.08	28.33
	31.13	32.64	35.10	32.16	29.82	32.49	31.31	33.11	33.65	33.05	31.80	31.08
	34.15	35.66	40.16	35.25	34.10	35.50	34.72	36.26	36.75	36.07	34.81	34.40
	37.00	37.93	43.89	37.93	37.74	37.35	37.36	38.82	38.94	38.44	37.47	37.37
	39.58	40.43	49.97	40.18	40.73	38.88	39.68	40.59	41.00	40.63	39.89	39.90
	41.35	41.69	53.39	41.60	42.76	39.99	41.47	41.78	42.13	41.93	41.42	41.63
	42.12	42.26	54.99	42.23	43.61	40.52	42.15	42.31	42.56	42.32	41.99	42.35
	42.05	42.24	54.48	42.20	43.44	40.71	42.15	42.30	42.58	42.24	42.19	42.20
	40.84	41.38	52.20	41.23	41.99	40.15	40.92	41.47	41.73	41.20	41.29	40.96
	38.65	39.10	46.50	39.25	39.41	38.96	38.97	39.90	39.81	39.36	39.26	38.80
	34.76	35.52	41.40	35.36	34.76	35.90	35.19	35.96	36.15	35.64	35.45	34.89
	32.55	33.30	36.68	33.08	31.44	33.65	32.63	33.60	33.82	33.32	32.92	32.42
	30.72	31.56	33.19	31.29	29.54	31.91	30.83	31.76	32.10	31.62	31.11	30.60
	29.34	30.26	31.09	29.98	28.12	30.58	29.45	30.49	30.88	30.32	29.78	29.22
	28.28	29.21	29.73	28.93	27.08	29.49	28.39	29.44	29.84	29.27	28.73	28.17
	27.22	28.13	28.51	27.85	26.05	28.39	27.32	28.38	28.76	28.19	27.65	27.11
	25.96	26.90	27.16	26.62	24.79	27.15	26.07	27.13	27.55	26.96	26.41	25.85
	24.71	25.70	25.86	25.40	23.52	25.92	24.82	25.93	26.36	25.76	25.18	24.60
Ave	31.07	31.95	35.76	31.71	30.66	31.71	31.23	32.25	32.61	32.08	31.51	31.09
Max	42.12	42.26	54.99	42.23	43.61	40.71	42.15	42.31	42.58	42.32	42.19	42.35
Min	20.57	21.45	21.48	21.18	19.50	21.65	20.67	21.68	22.04	21.50	20.99	20.47
Med	30.03	30.91	32.14	30.64	28.83	31.25	30.14	31.13	31.49	30.97	30.45	29.91

A.5.4. West Elevation- High Albedo



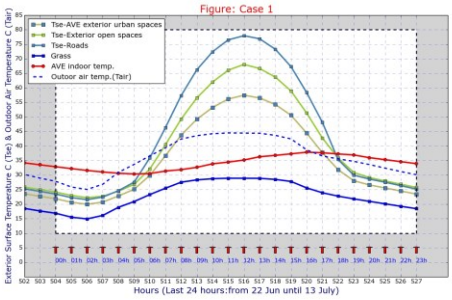
	Square shape	Irregular square shape	Zigzag shape	Serpentine shape	Pyramid shape	Inverted pyramid shape	Combine pyramids shape	Column expressed	Frame expressed	Irregular printed concrete	Ornament printed	Muli-surface shape
	22.87	23.81	23.50	23.54	21.74	24.00	22.97	24.01	24.35	24.12	23.23	23.11
	21.33	22.22	21.93	21.96	20.24	22.42	21.43	22.41	22.73	22.51	21.67	21.56
	20.56	21.44	21.15	21.19	19.49	21.63	20.65	21.64	21.95	21.74	20.90	20.78
	21.66	22.65	22.33	22.33	20.56	22.76	21.76	22.83	23.18	22.94	22.01	21.89
	24.25	25.44	25.05	25.08	23.01	25.44	24.37	25.67	26.12	25.82	24.69	24.48
	26.06	27.41	26.99	27.02	24.80	27.32	26.20	27.66	28.16	27.83	26.59	26.34
	28.32	29.76	29.31	29.34	27.02	29.61	28.47	29.99	30.53	30.21	28.87	28.62
	30.87	32.31	31.86	31.86	29.59	32.16	31.03	32.55	33.09	32.74	31.42	31.16
	33.67	35.09	34.66	34.65	32.37	34.97	33.82	35.33	35.87	35.53	34.21	33.93
	35.32	36.65	36.25	36.24	34.07	36.63	35.50	36.90	37.42	37.08	35.84	35.61
	36.75	37.93	37.58	37.57	35.59	38.01	36.91	38.20	38.75	38.33	37.22	37.01
	37.93	39.02	38.65	38.66	37.00	39.12	38.09	39.21	39.84	39.32	38.33	38.16
	38.80	39.98	39.85	39.80	40.49	39.85	39.07	40.22	40.56	40.10	39.15	39.12
	42.01	42.18	41.95	42.15	43.47	40.46	42.06	42.27	42.51	42.44	42.06	41.74
	44.27	44.11	43.63	43.97	45.33	42.76	44.17	43.89	43.65	43.91	44.10	43.96
	45.25	44.49	44.20	44.65	45.80	44.12	45.10	44.29	44.04	44.25	45.14	44.98
	43.50	42.27	42.15	42.65	43.54	42.82	43.32	41.98	41.38	41.90	43.13	43.29
	41.03	40.07	39.76	40.24	40.49	40.96	40.87	39.85	39.55	39.73	40.62	40.93
	36.49	36.35	35.90	36.21	35.40	37.17	36.43	36.22	35.99	36.16	36.32	36.57
	29.66	30.53	30.22	30.28	28.42	30.89	29.76	30.71	31.00	30.82	29.99	29.91
	28.29	29.22	28.91	28.95	27.08	29.49	28.39	29.41	29.76	29.54	28.65	28.54
	27.21	28.14	27.83	27.87	26.05	28.39	27.32	28.34	28.67	28.45	27.57	27.46
	25.95	26.91	26.59	26.63	24.77	27.14	26.06	27.10	27.46	27.23	26.32	26.20
	24.70	25.70	25.37	25.41	23.50	25.91	24.81	25.88	26.26	26.02	25.09	24.96
Ave	31.95	32.65	32.32	32.43	31.24	32.67	32.02	32.77	33.03	32.86	32.21	32.10
Max	45.25	44.49	44.20	44.65	45.80	44.12	45.10	44.29	44.04	44.25	45.14	44.98
Min	20.56	21.44	21.15	21.19	19.49	21.63	20.65	21.64	21.95	21.74	20.90	20.78
Med	30.27	31.42	31.04	31.07	29.00	31.52	30.39	31.63	32.04	31.78	30.71	30.54

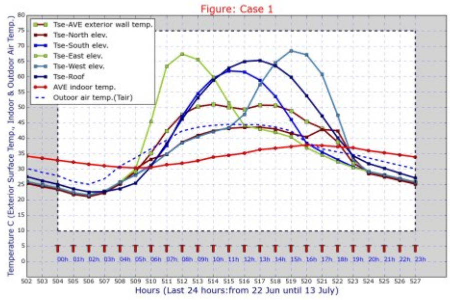
B. Section Two: The details simulation results related to Thermal model

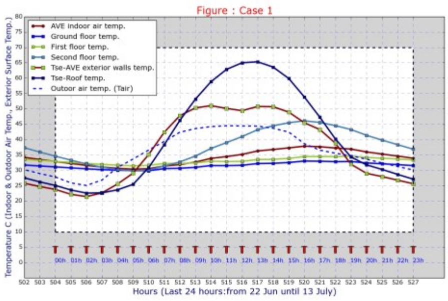
B.1. Detail result related to selecting the appropriate albedo value

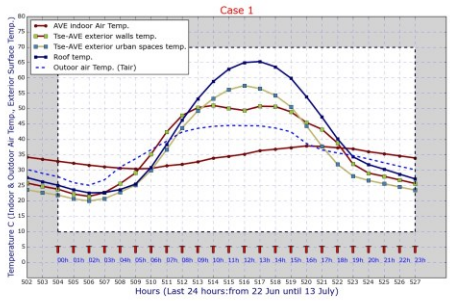
B.1.1. Scenarios one and two: Result related to roof albedo alternatives

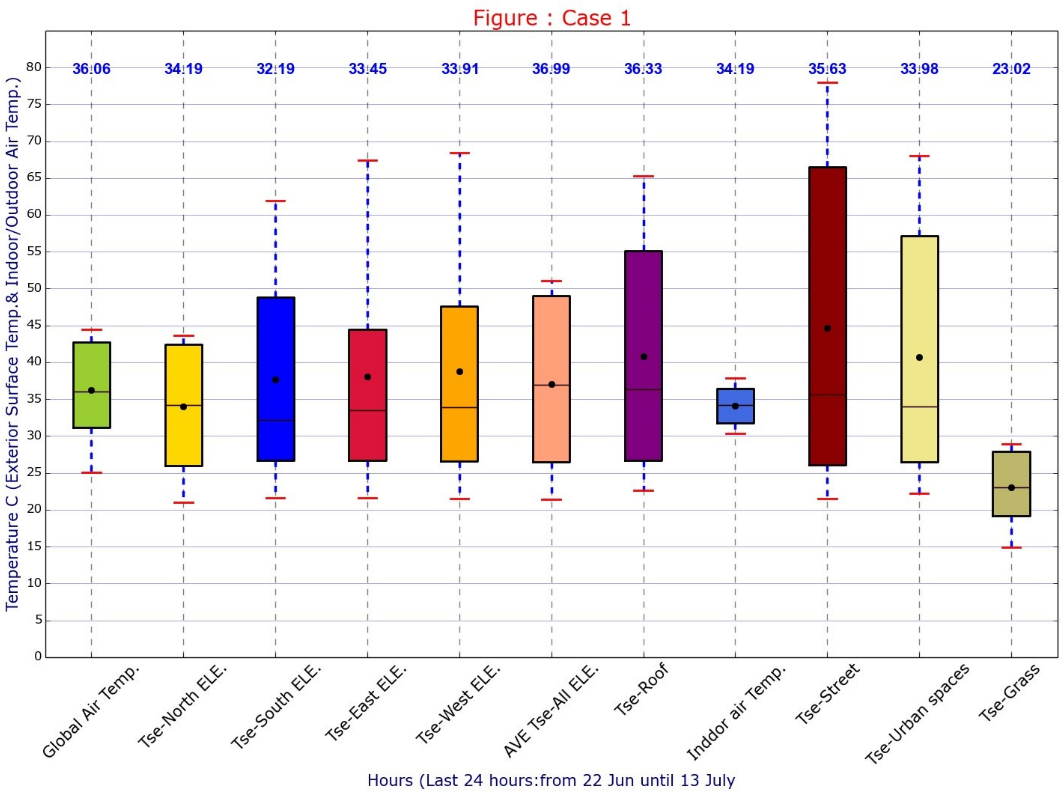
Scenario one



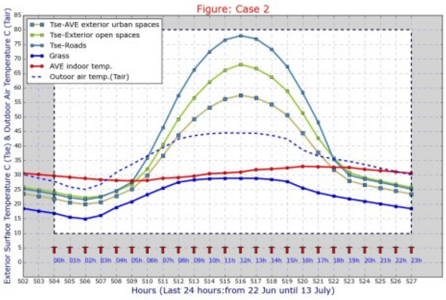


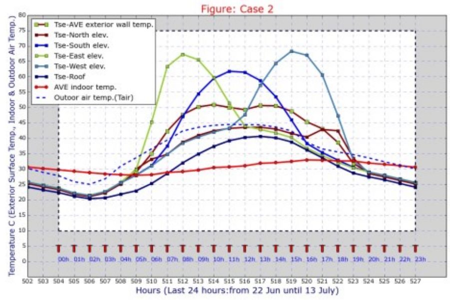


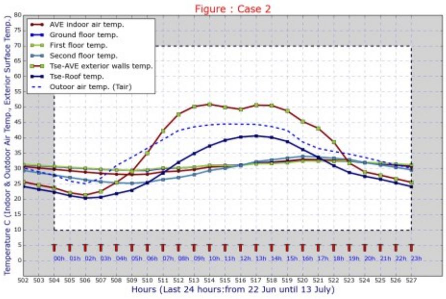


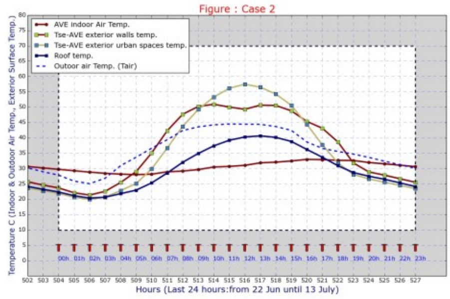


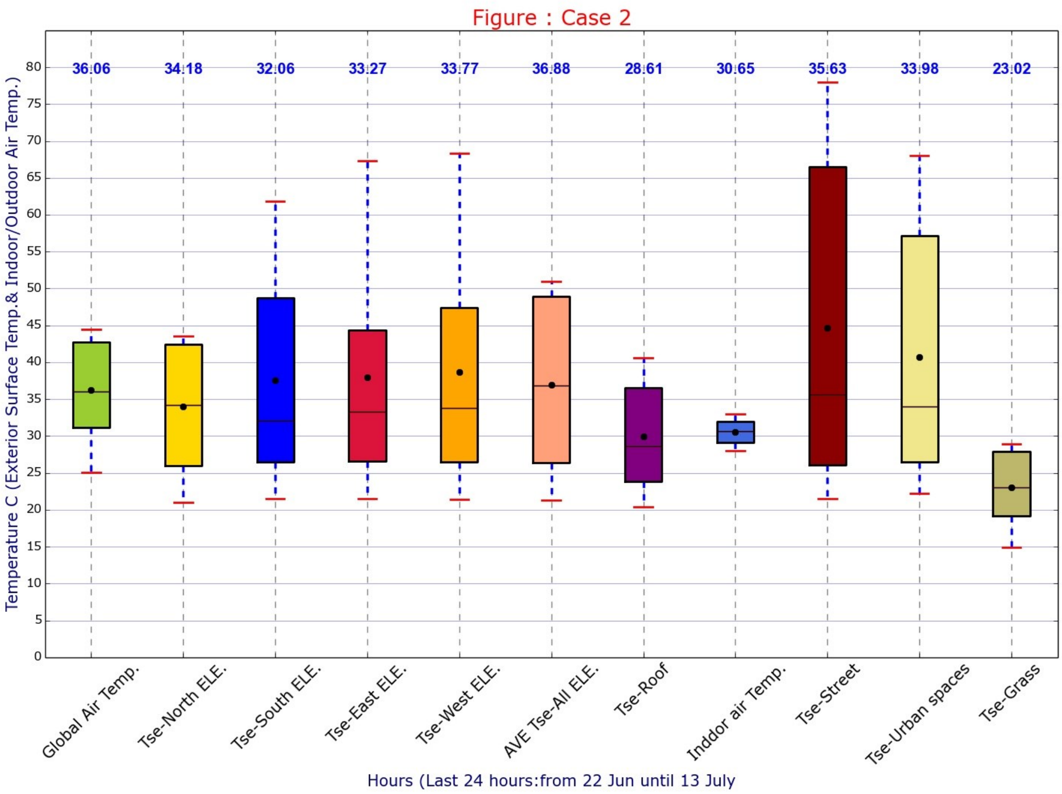
Scenario Two





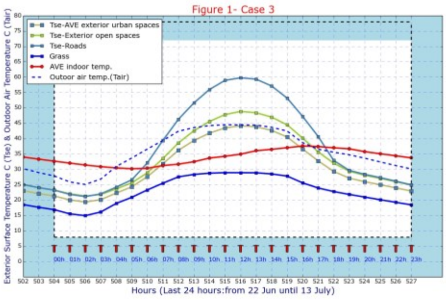


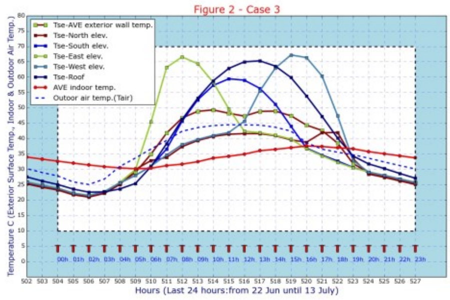


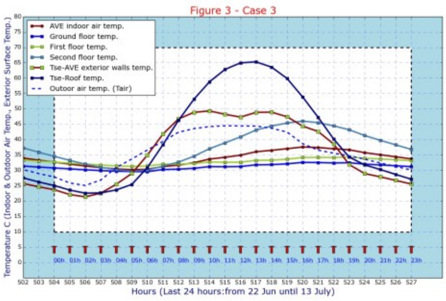


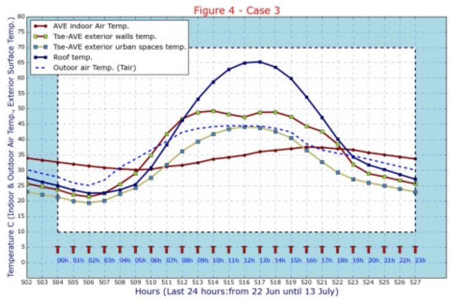
B.1.2. Scenario three: Result related to rood albedo alternatives

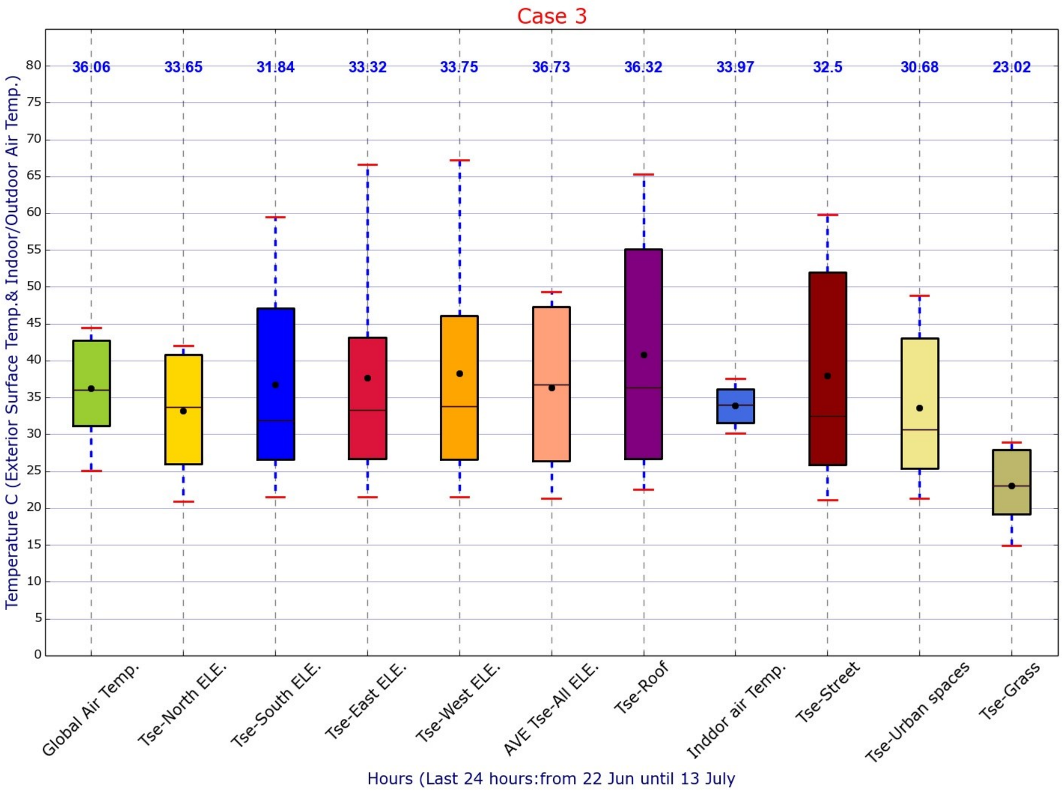
Scenario Three





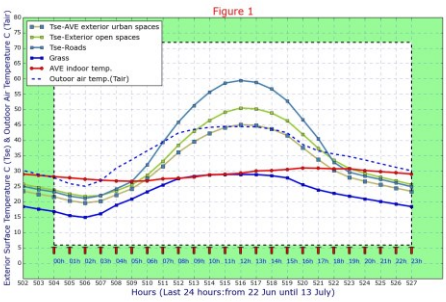


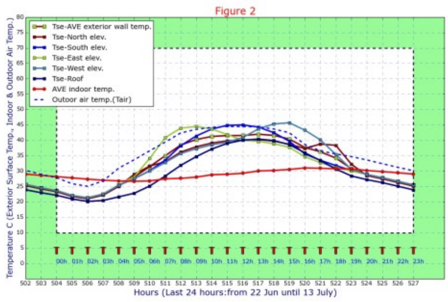


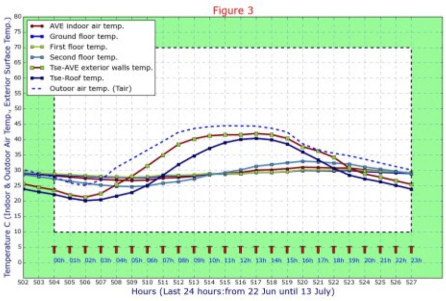


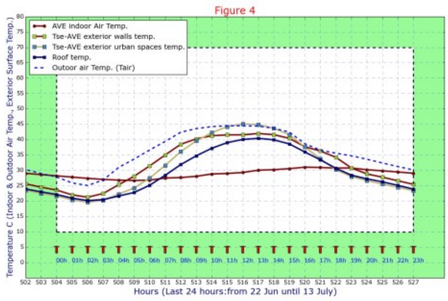
B.1.3. Scenario three: Result related to rood albedo alternatives

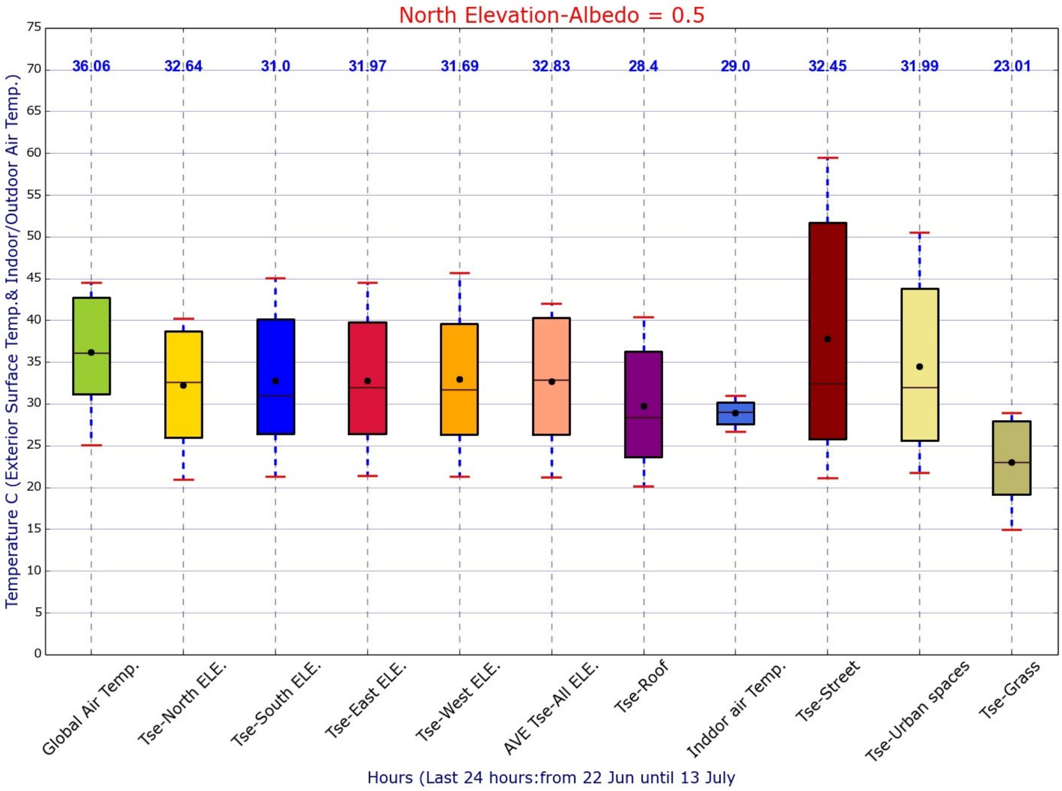
Scenario: North Elevation, Albedo Value = 0.5



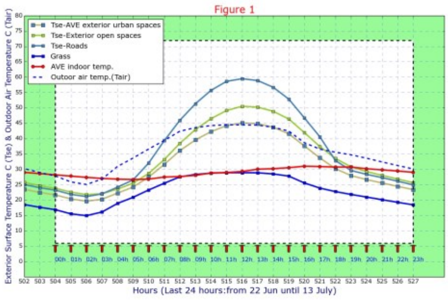


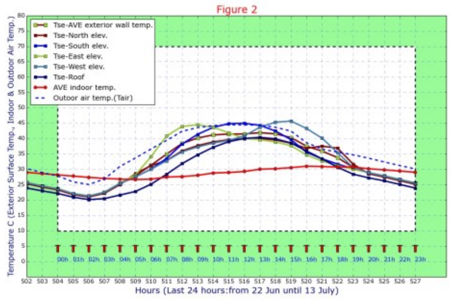


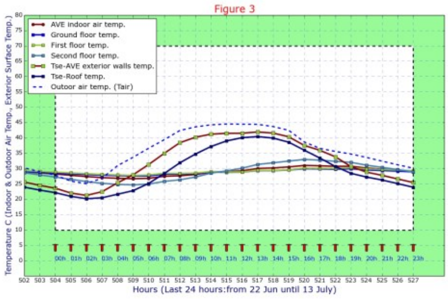


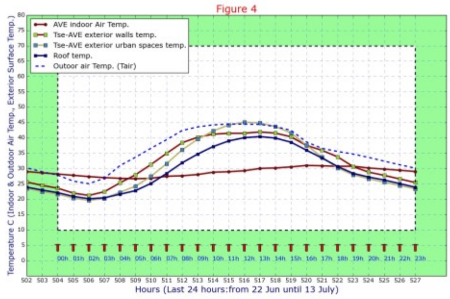


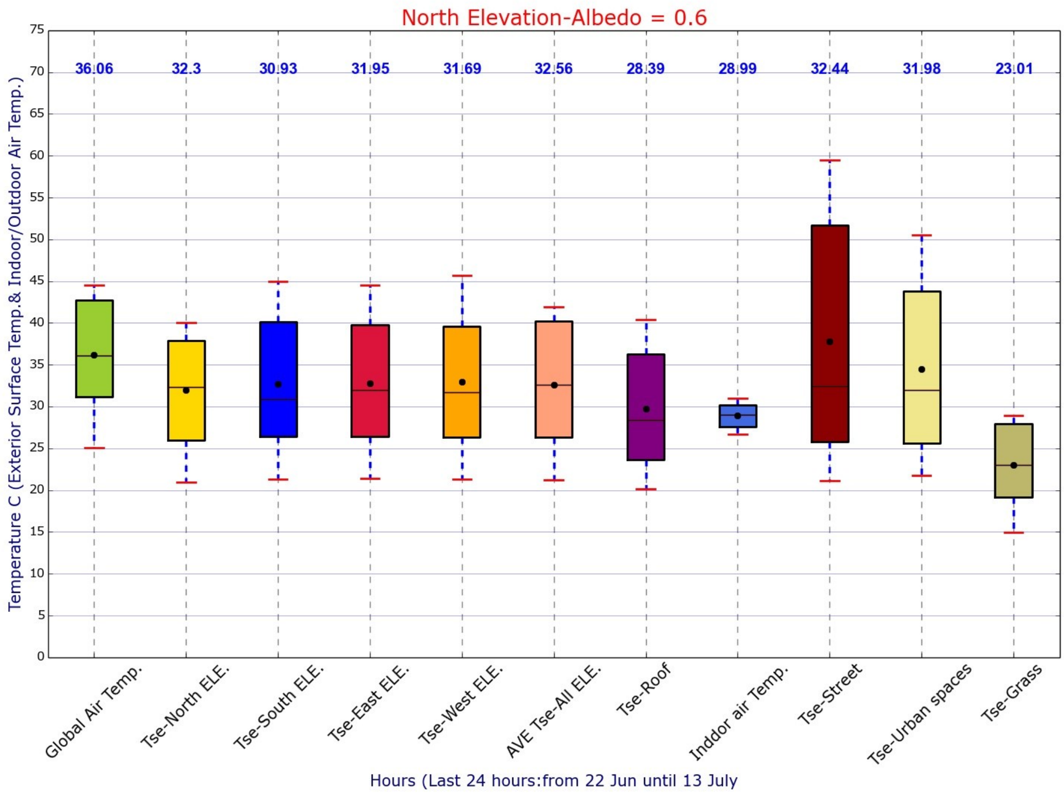
Scenario: North Elevation, Albedo Value = 0.6



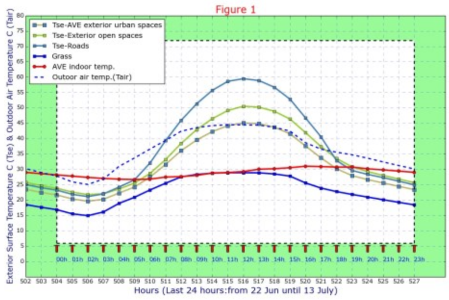


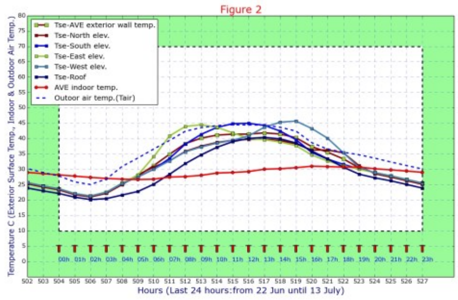


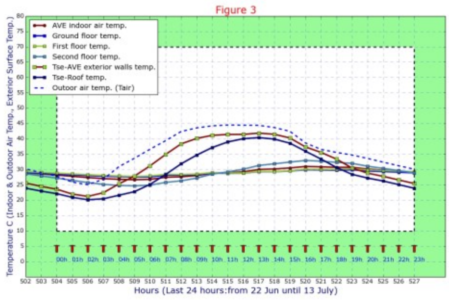


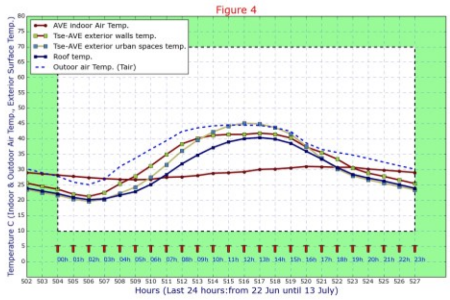


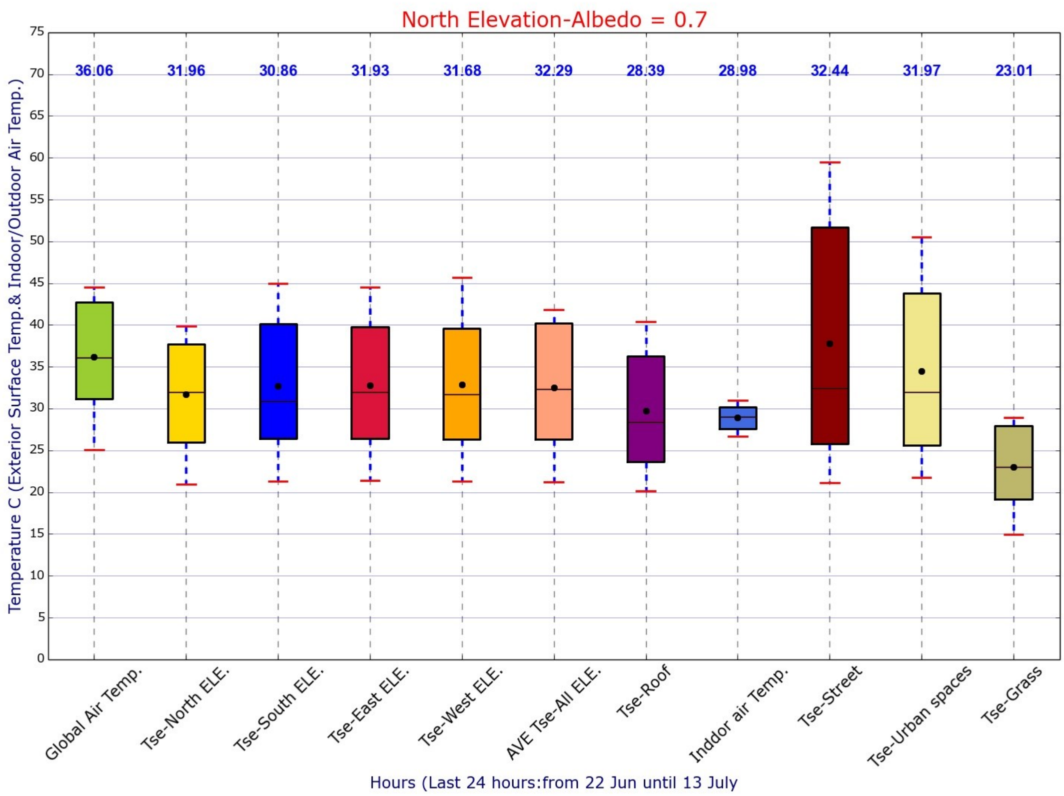
Scenario: North Elevation, Albedo Value = 0.7



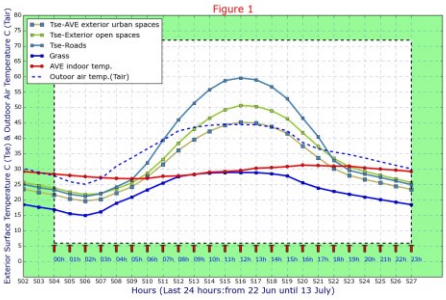


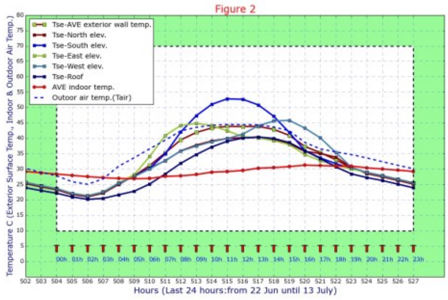


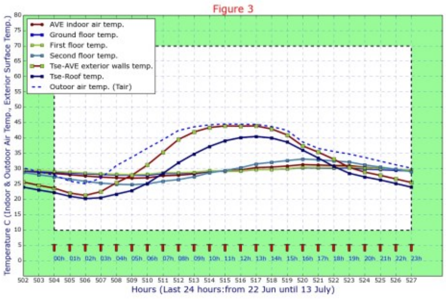


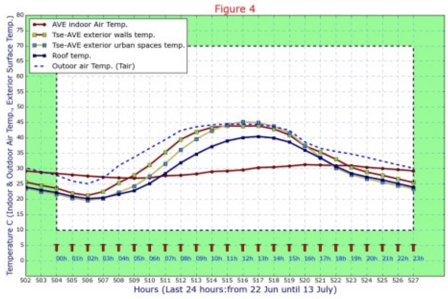


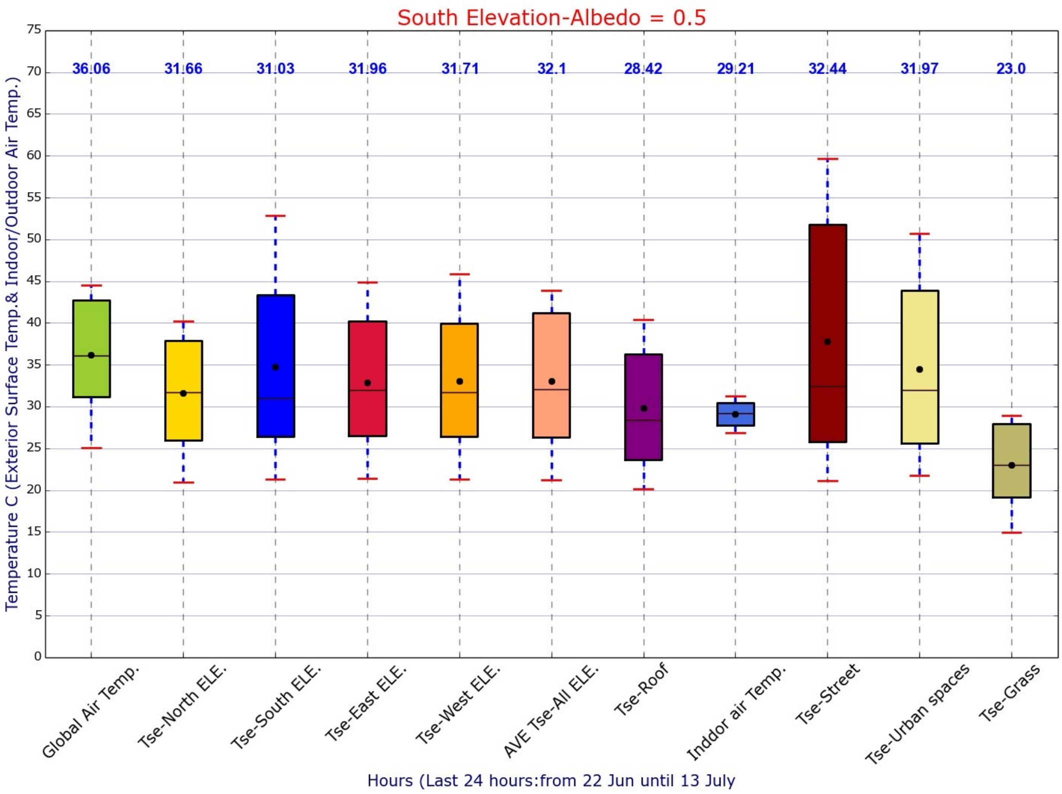
Scenario: South Elevation, Albedo Value = 0.5



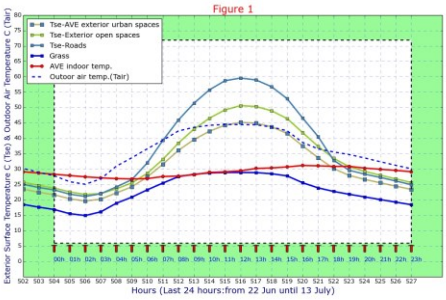


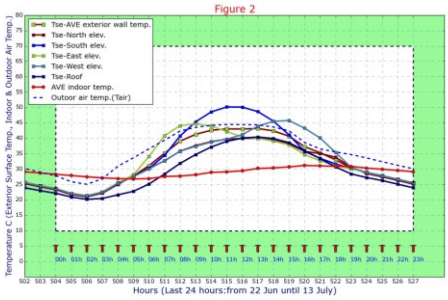


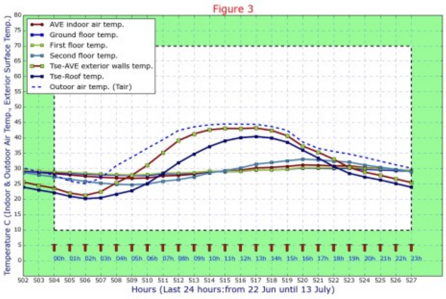


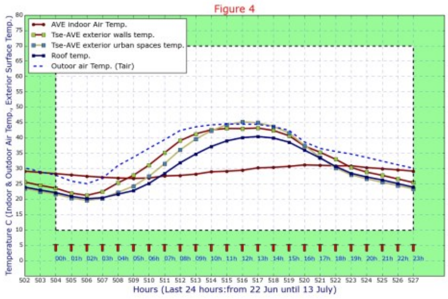


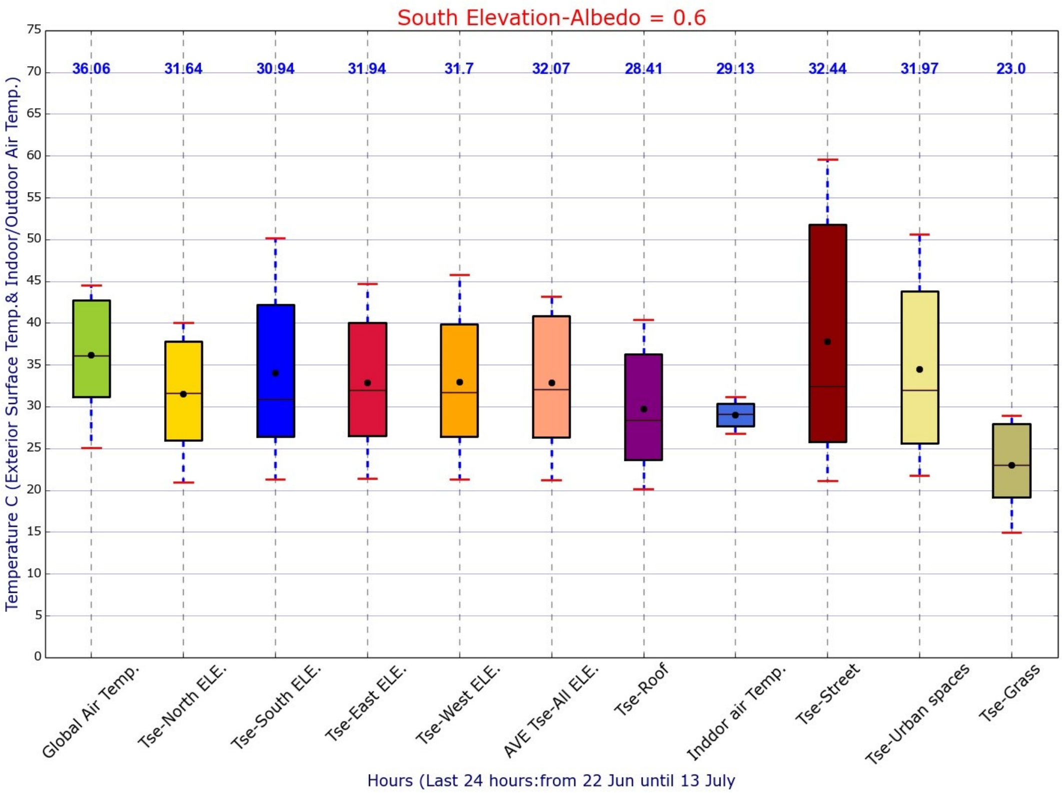
Scenario: South Elevation, Albedo Value = 0.6



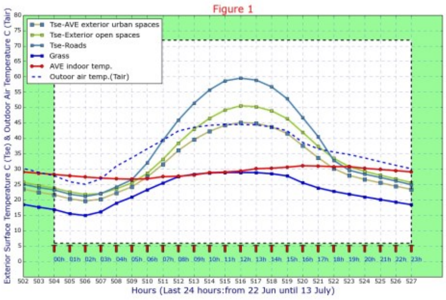


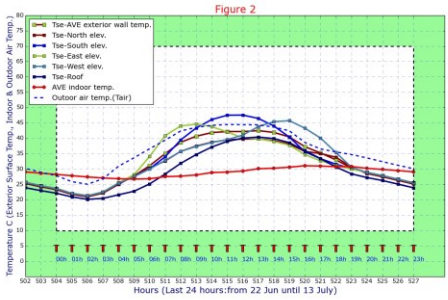


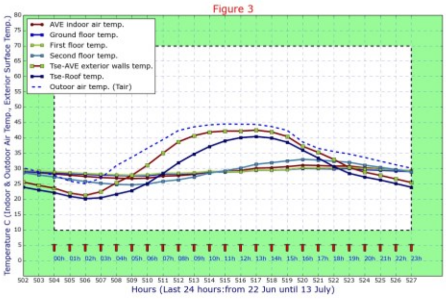


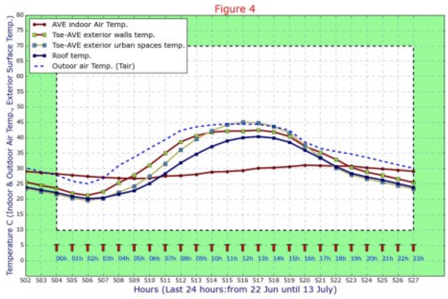


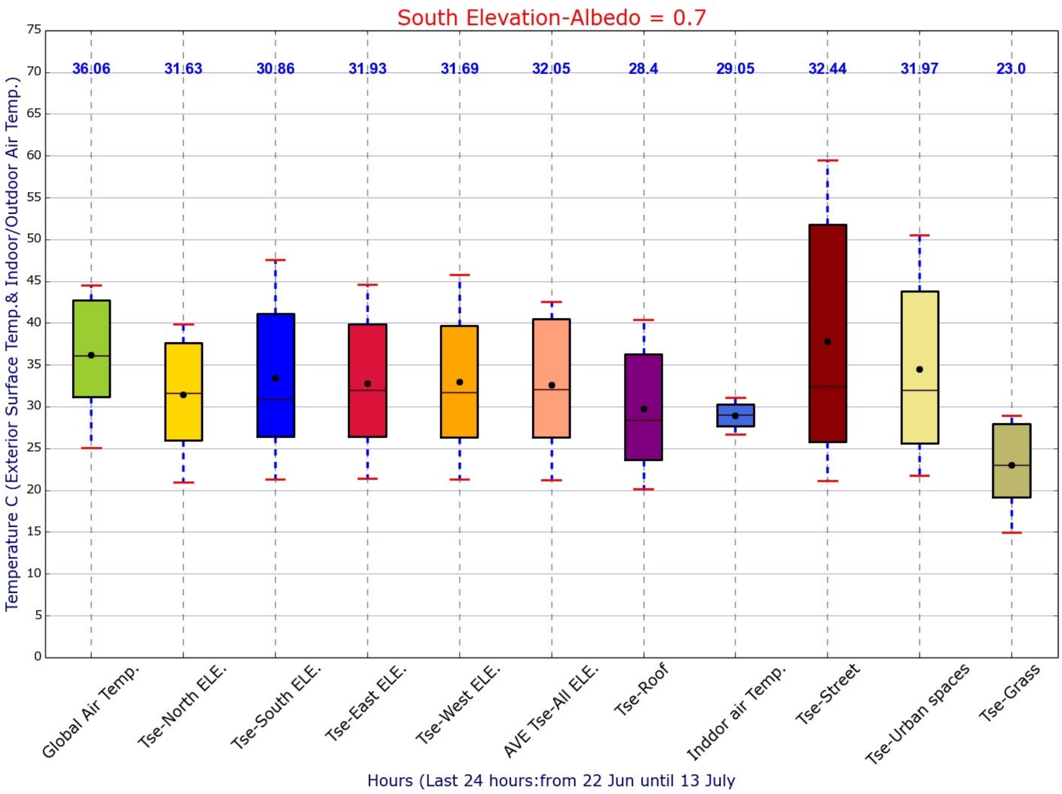
Scenario: South Elevation, Albedo Value = 0.7











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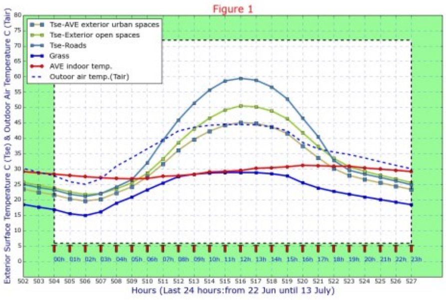

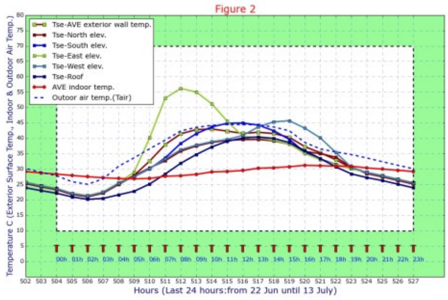

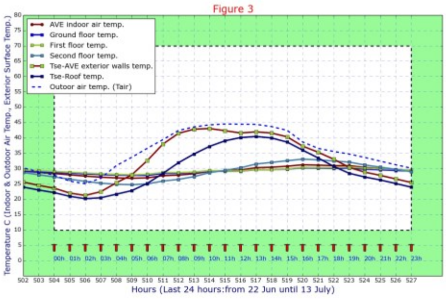

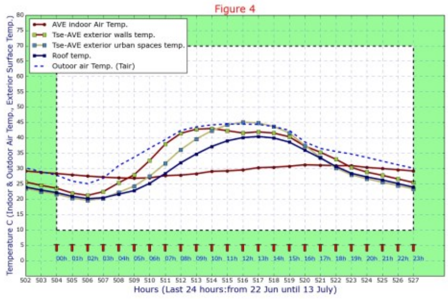

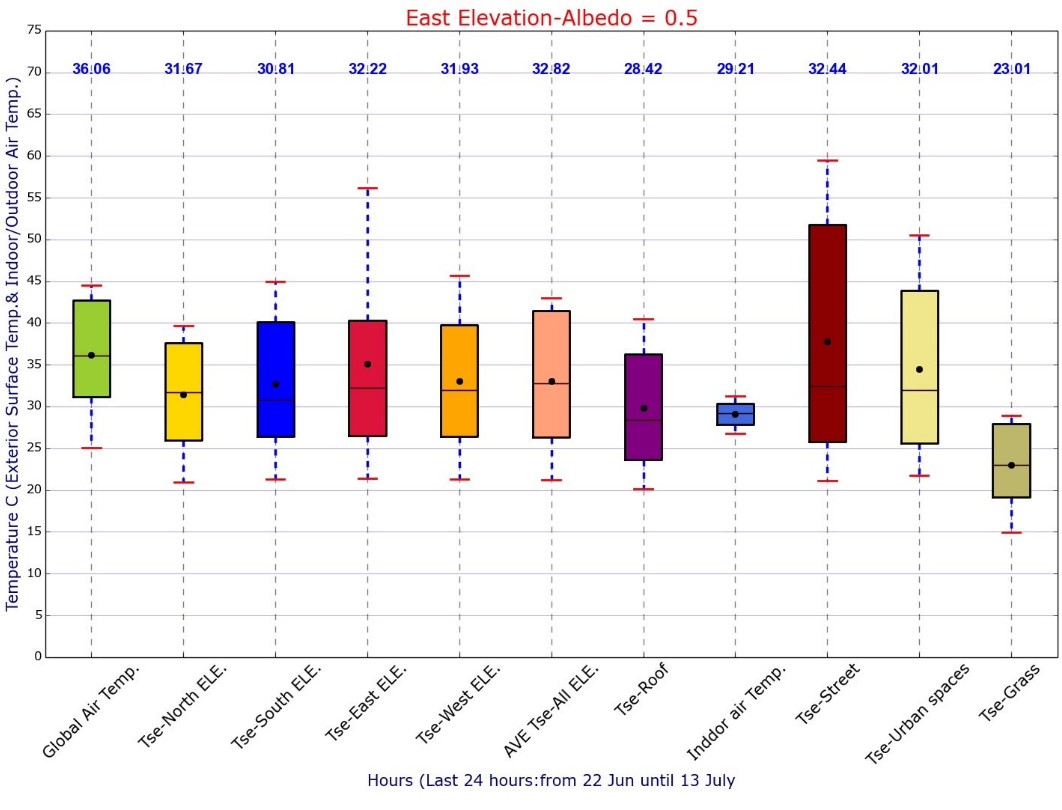

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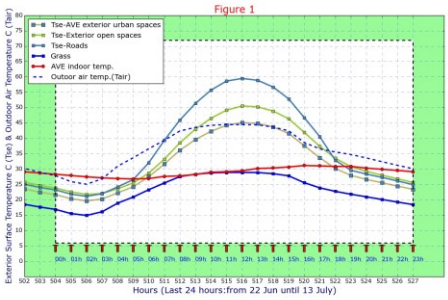

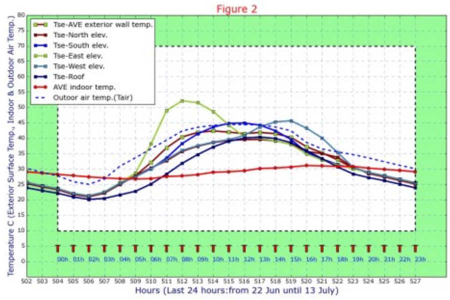

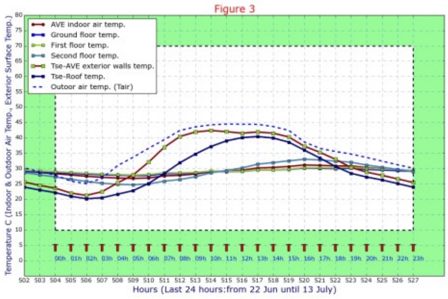

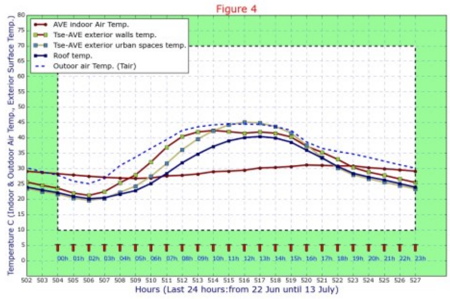

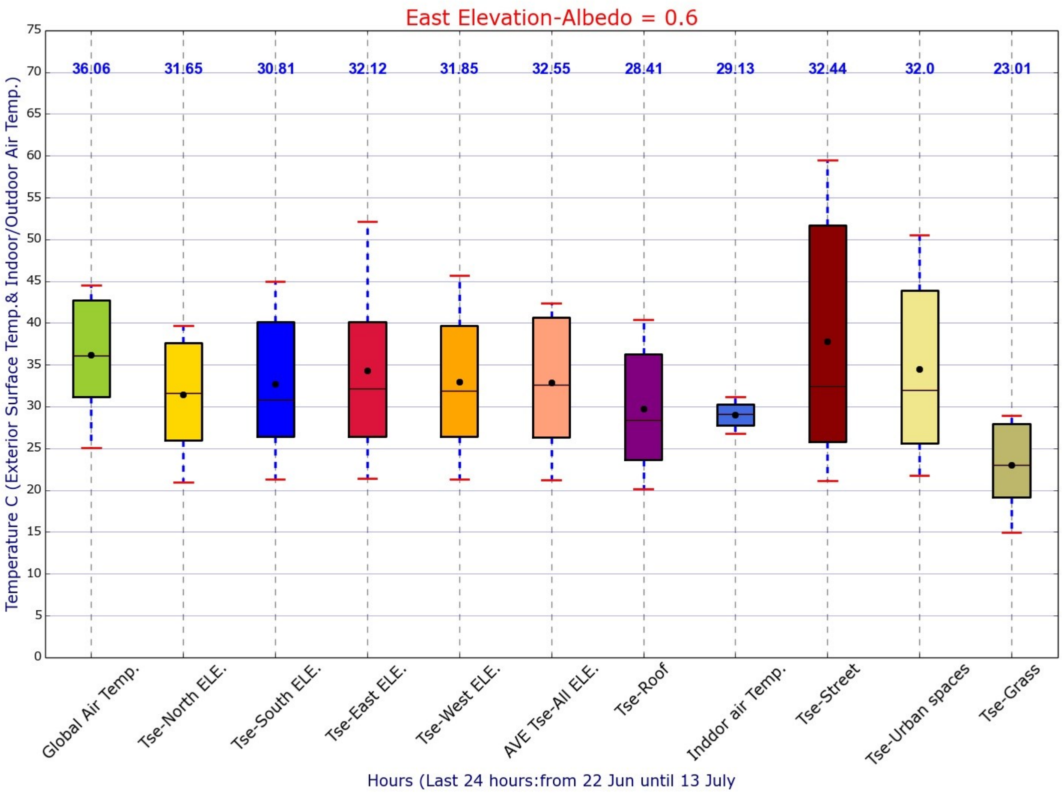

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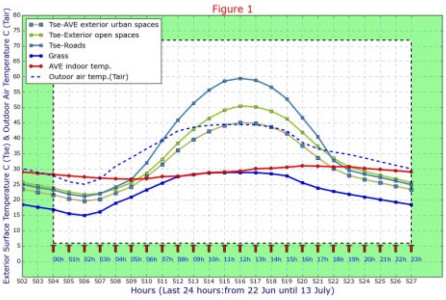

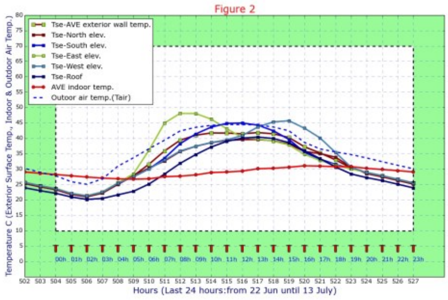

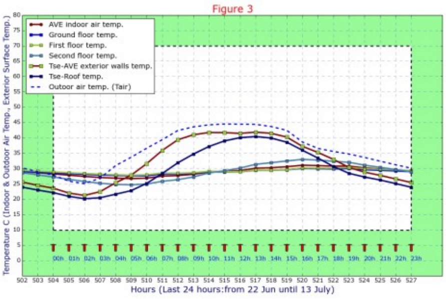

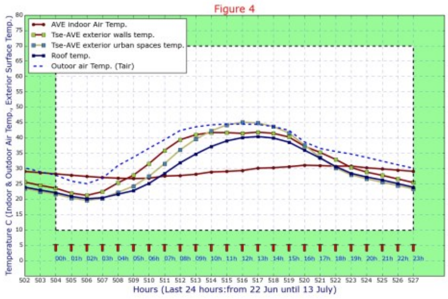

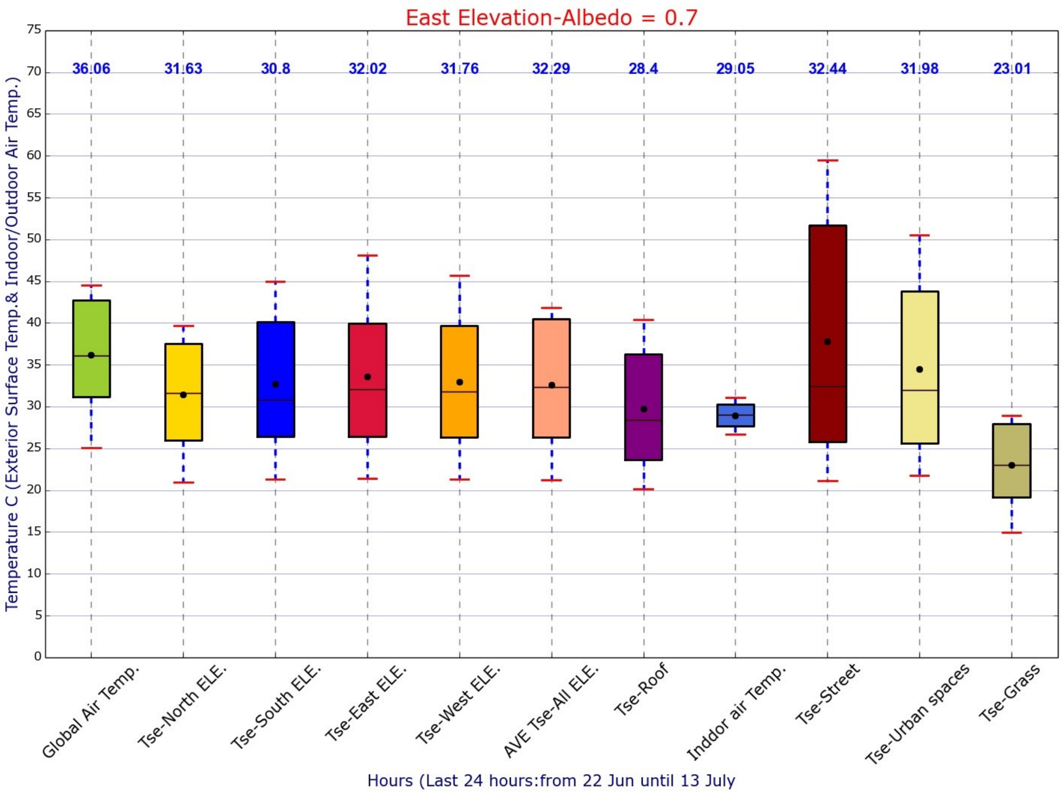

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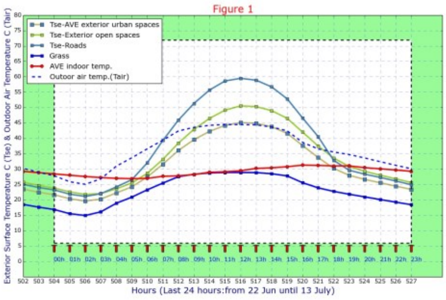
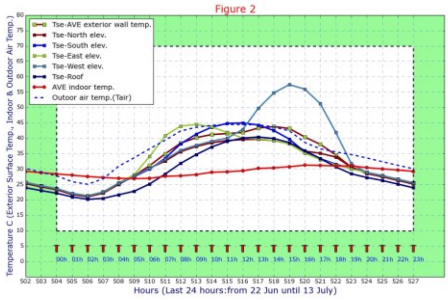
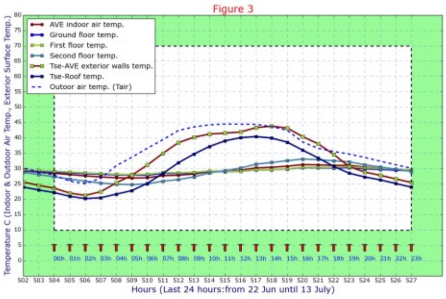
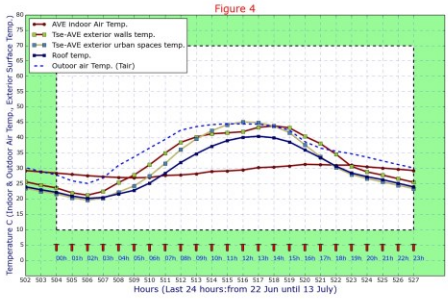
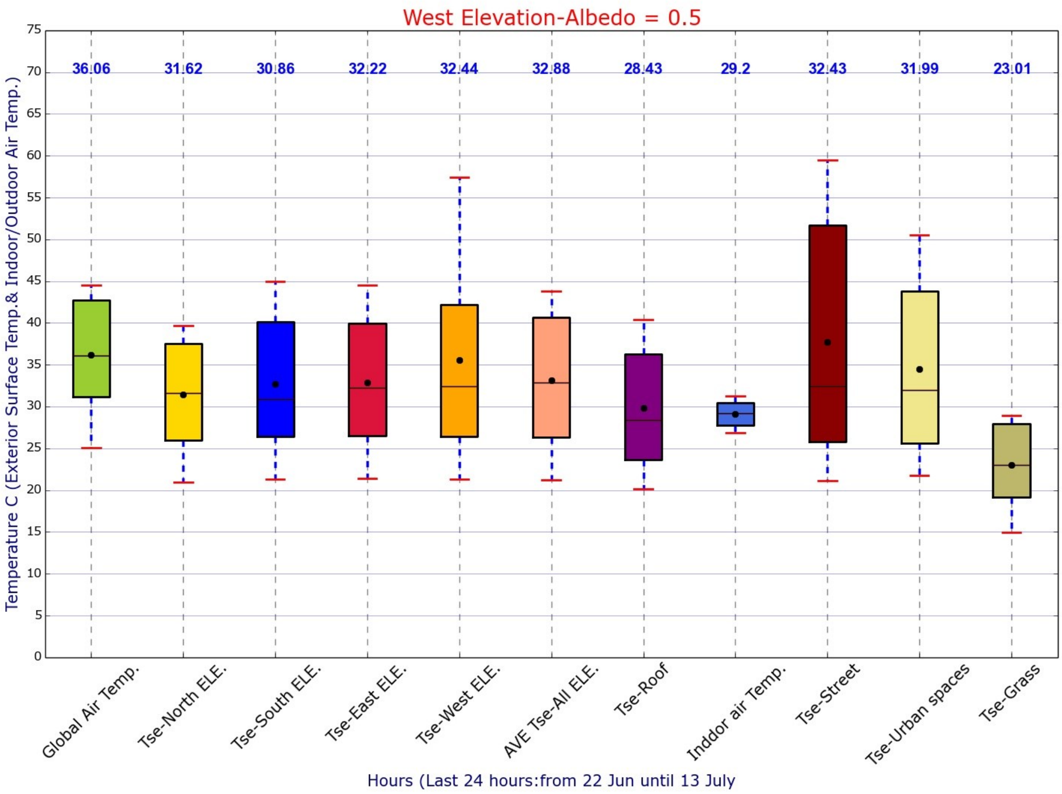


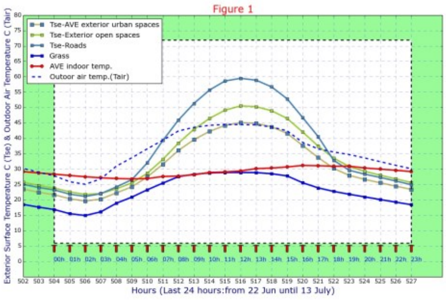


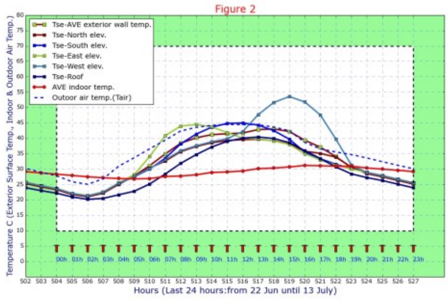


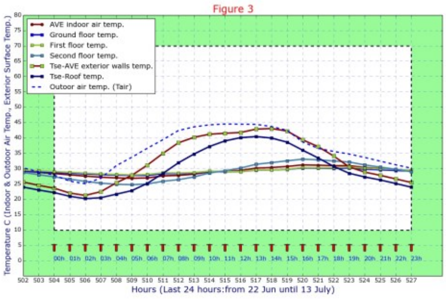


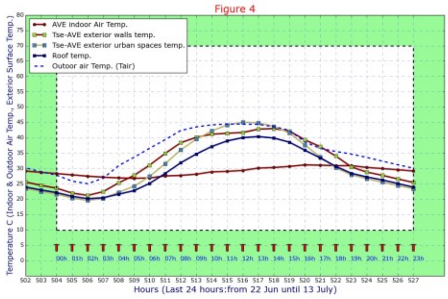


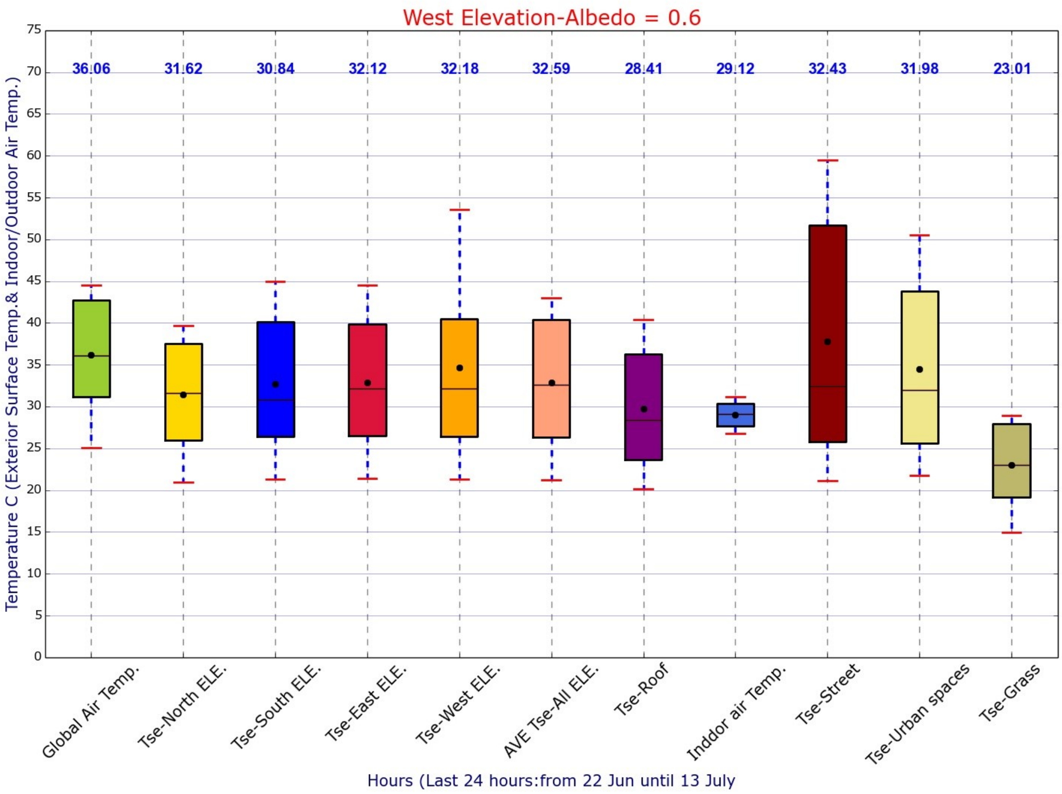
Scenario: West Elevation, Albedo Value = 0.6



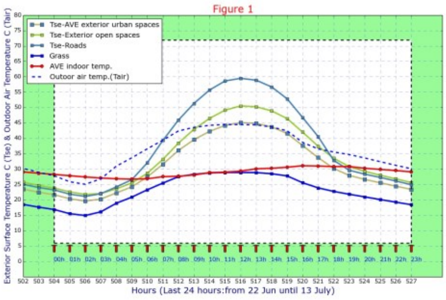


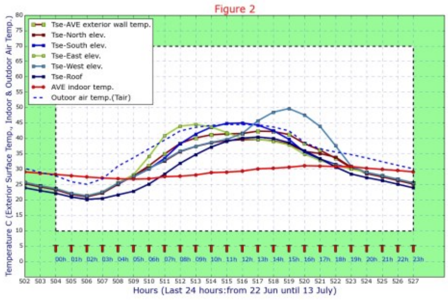


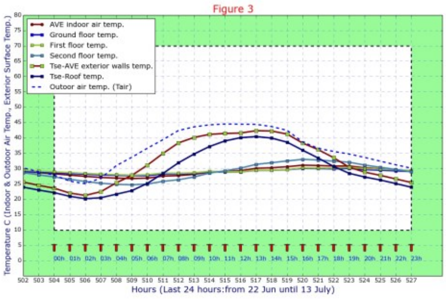


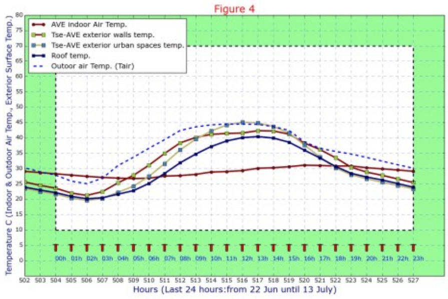


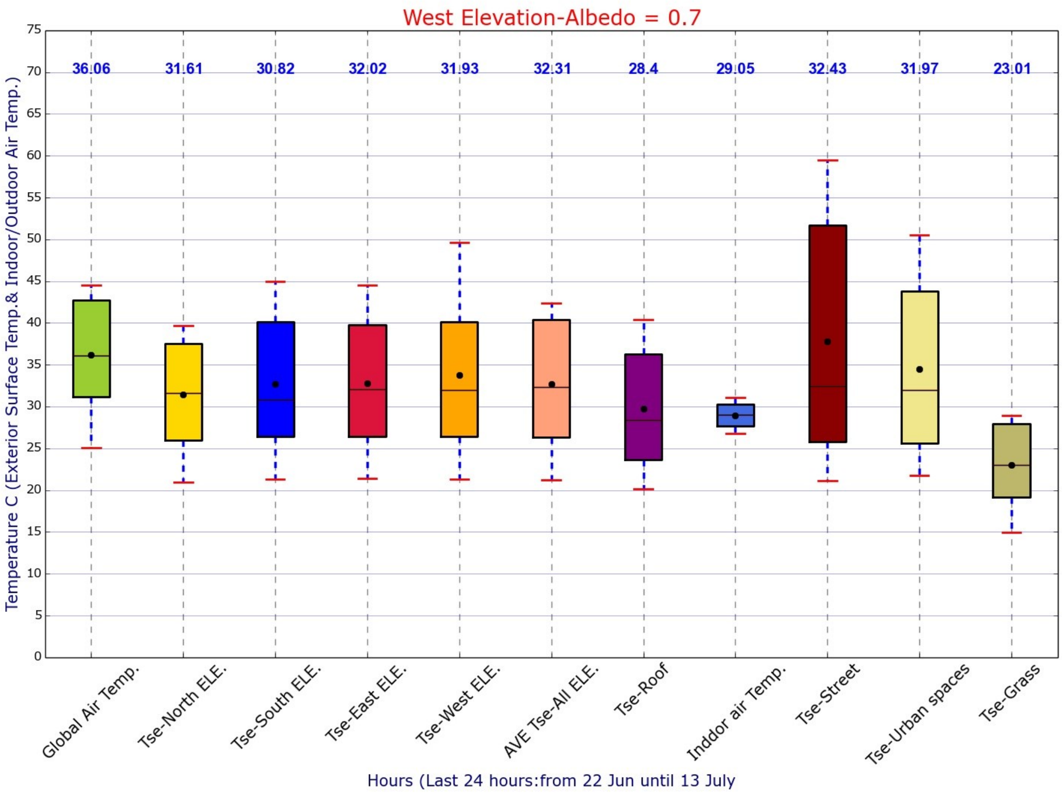
Scenario: West Elevation, Albedo Value = 0.7











C. Section Three: The details simulation results related to MRT

Time Stepe	T-air	Ordinary Concrete block	Pumice Block Low albedo	Pumice Block High albedo
00:00 h	27.83	15.23	14.75	14.54
00:01 h	25.89	13.81	13.23	13.00
00:02 h	25.06	13.04	12.45	12.18
00:03 h	26.83	13.92	13.56	13.22
00:04 h	30.94	16.32	16.39	15.95
00:05 h	33.67	19.00	19.52	18.76
00:06 h	36.61	26.53	27.55	25.22
00:07 h	39.39	35.51	37.21	32.18
00:08 h	42.39	45.49	47.76	40.71
00:09 h	43.56	48.53	51.13	43.00
00:10 h	44.22	49.53	52.29	43.58
00:11 h	44.50	47.45	50.23	41.02
00:12 h	44.44	47.98	50.59	40.93
00:13 h	44.39	49.25	51.65	42.01
00:14 h	43.67	49.33	51.34	42.41
00:15 h	42.44	45.65	47.16	39.76
00:16 h	38.67	39.06	40.03	34.46
00:17 h	36.56	32.88	33.72	29.79
00:18 h	35.56	26.69	27.26	25.43
00:19 h	34.72	21.74	21.66	21.56
00:20 h	33.61	20.14	19.85	19.90
00:21 h	32.39	19.07	18.77	18.73
00:22 h	31.22	18.02	17.70	17.57
00:23 h	30.11	16.98	16.59	16.44
Max	44.50	49.53	52.29	43.58
Min	25.06	13.04	12.45	12.18
Average	36.19	30.46	31.35	27.60
Median	36.06	26.61	27.40	25.32

D. Section Four: Summary of the thesis by French language

Résumé de la thèse de doctorat par langue française

Contribution à l'étude de l'impact des Matériaux de Construction sur l'îlot de Chaleur Urbain et la Demande Energétique des Bâtiments

Ce résumé contient:

1. L'introduction
2. La contexte de la préparation de la thèse et la problématique, le cas d'étude.
3. La délimitation du champ de recherche
4. L'objectif de la recherche
5. Les questions de la recherche
6. Les méthodes suivies et les résultats
7. La conclusion
8. Perspectives
9. Bibliographie

1. Introduction

Cette thèse intitulée **Contribution à l'étude de l'impact des Matériaux de Construction sur l'îlot de Chaleur Urbain et la Demande Energétique des Bâtiments** traite principalement de la problérnatique de l'effet des températures de surface de la scène urbaine sur le microclimat urbain et ceci essentiellement à travers le paramètre matériau de construction.

Il comprend 3 parties, avec un total de 7 chapitres qui sont:

Chapitre 1: "Fundamentals: Climate And Buildings", Fondamentaux: Climat Et Bâtiments.
Chapitre 2: "Current Problems Of Cities, Energy And Climate", Problèmes Actuels Des Villes, De L'énergie Et Du Climat.
Chapitre 3: "Role Of Construction Materials", Rôle des matériaux de construction.
Chapitre 4: "Research Case Study", Cas d'Étude De la Recherche.
Chapitre 5: "Research Methodology, Méthodologie De la Recherche.
Chapitre 6: "The Results And Simulation", Les Résultats Et La Simulation.
Chapitre 7: "The Conclusions And The Recommandations", Les Conclusions Et Les Recommandations.

Chapitre 1

Le premier chapitre debute par l'analyse de l'environnement urbain et plus exactement par expliquer l'impact de ce dernier sur le microclimat urbain. Ensuite, l'influence de la zone climatique sur la conception des bâtirnents et l'urbanisme est discutée avec comme suite logique, l'etude des facteurs affectant le microclimat urbain tels que la température et l'humitdité extérieures, le vent et le rayonnement solaire. Enfin, des éléments de rnodélisation en vue d'appréhender la performance énergétique des bâtiments sont abordés.

Chapitre 2

Ce chapitre est basé sur deux axes majeurs de l'intéraction intérieur/extérieur, à savoir le phénomèna d'llot de Chaleur Urbain (ICU) et le contort thermique. Après une définition générale de l'llot de Chaleur Urbain, les 3 types d'ICU sont présentés. Il s'agit de l'ICU de surface (températures de la surface urbaine), celui de sub-surface (températures à l'intérieur du sol urbain) ainsi que l'ICU de la canopee urbaine (températures atmosphériques). Les facteurs qui impactent l'ICU sont également détaillés de manière à montrer quels sont les leviers de la conception relatifs à la construction sur ce phénomène.

Concernant le contort thermique, l'analyse débute par une présentation des paramètres nécessaires à son evaluation. Tout ceci amène naturellement à présenter différents indicateurs ou indices de contort thermique tels que le PMV/PPD, l'indice SET, la temperature operative et le contort thermique adaptatif.

Chapitre 3

Dans le chapitre 3, le sujet majeur du travail de thèse est abordé, à savoir le rôle des matériaux de construction. Après une présentation des performances requises pour les rnatériaux de construction (notamment en terme de mise en œuvre et de résistance mécanique), un classement de leurs propriétes est effectué. Parmi celles-ci, on s'intéresse plus particutièrernent aux propriétes thermo-physiques (conductivite thermique, inertie, diffusivité et effusivité) et radiatives (albédo, emissivité et rugosité). Ensuite, les différents composants d'enveloppe, les materiaux associés ainsi que le revêtement des espaces exterieurs sont presentés et discutés.

Chapitre 4

Ce chapitre est dédié à la présentation du cas d'etude traité dans thèse. II s'agit d'un complexe résidentiel nommé Al Hadba et situé dans la ville de Mossoul en lrak dont la construction est achevée. Le complexe comprend 56 immeubles comportant chacun 3 étages avec 3 appartements par étage. Lee plan masse du complexe est donné, ainsi que les matériaux utilisés pour la construction. Par la suite, 10 matériaux alternatifs sont envisagés, ce qui avec le matériau original (béton) constitue 11 alternatives possibles pour la composition de paroi. Entin, les conditions météoroloqiques du lieu sont présentées et discutées. Une alayse de ces données permet de sélectionner une journée d'étude, le 13 juillet. Par la suite, les simulations seront réalisées sur les deux semaines précédant cette journée et les résultats comparés sur cette journée.

Chapitre 5

Le chapitre 5 est consacré à la méthodologie adoptée pour atteindre les objectifs affichés. Celle-ci est basée sur la modélisation qui repose sur un outil numérique principal, le logiciel SOLENE-Microclimat. Une présentation des différents sous-modèles et des possibilités offertes par ce logiciel est effectuée en detail. Au travers des différentes simulations proposées, plusieurs facteurs et paramètres liés au domaine de simulation sont etudiés. II s'agit tout d'abord de la densite urbaine et de la taille de la veine numérique. Ensuite, les paramètres qui intéressent directement la recherche, l'influence du type et des propriétes des matériaux utilisés, sont appréhendés. Enfin, l'effet de la forme de l'enveloppe des bâtiments est egalement integré à l'etude paramétrique.

Chapitre 6

Ce chapitre constitue le coeur de la thèse dans le sens ou c'est dans celui-ci que sont presentés et analysés les résultats obtenus à l'aide de la méthodologie de recherche définie dans le chapitre 5. Les principaux résultats pour la journée du 13 juillet sont presentés sous la forme de comparaison de box-plots, encore appelés « boîtes à moustache » et concernent majoritairement les temperatures de surface moyennes des surfaces intérieures et extérieures des surfaces du bâtiment étudié et de la scène urbaine. Pour certains cas, des resultats en termes de température d'air ou de flux sont également donnés afin d'affiner l'analyse.

Chapitre 7

Le dernier chapitre (chapitre 7) est consacré aux conclusions et preconisations. Les limites de l'etude ainsi que les perspectives sont aussi abordées dans ce chapitre.

2. La contexte de la préparation de la thèse et la problématique, le cas d'étude

Dans ce siècle, le monde à vu la plus grande croissance urbaine de ces dernières décennies. Plusieurs raisons ont conduit à cette croissance.

En Afrique et en Asie, l'une des raisons les plus importantes est l'urbanisation.

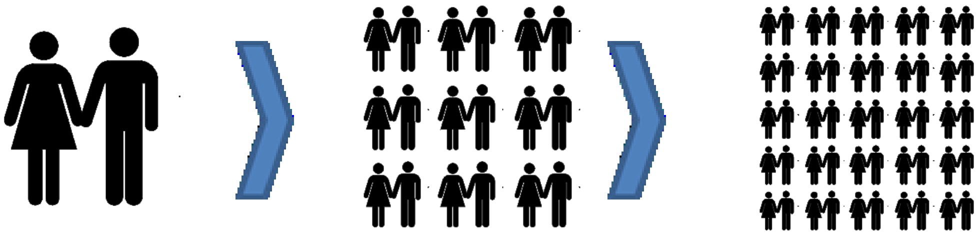


Figure 1: *l'urbanisation*

Dans les pays en développement, la raison principale de la croissance de la ville est l'augmentation des zones bâties et les améliorations le secteur des transports. Par conséquent, la quantité d'espace construit par personne a augmenté en proportion (Emmanuel and Krüger, 2012).

Figure 2: *Augmentation de l'espace, exemple du centre de Paris*

Aujourd’hui, plus de la moitié de la population mondiale (54%) vit dans les zones urbaines. D’ici 2050, cette proportion devrait passer à (66 %), selon un nouveau rapport des Nations Unies (United Nations 2014).

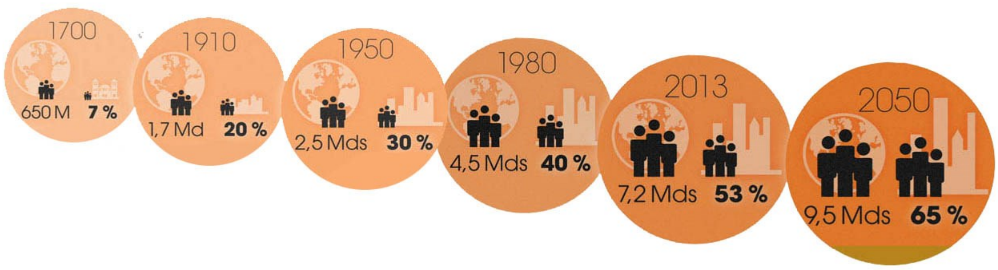
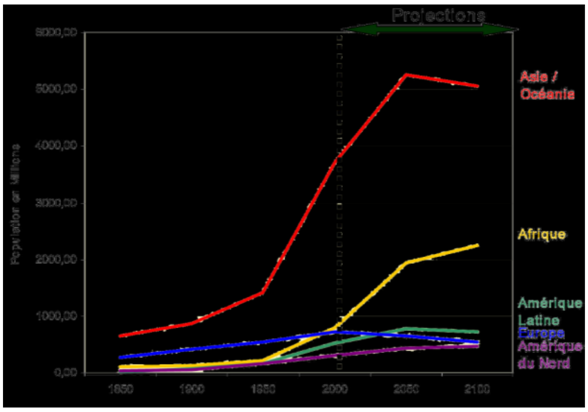


Figure 3: *La proportion de la population urbaine*

D'ici à 2030, la population urbaine mondiale avoisinera les 5 milliards, la croissance urbaine étant concentrée en Afrique et en Asie (voir figure 4) (**United Nations 2014**).

Selon le "International Monetary Fund" (2014), parallèlement à l'urbanisation, "les enjeux les plus importants sur le plan du développement se concentreront dans les villes, surtout dans les pays de la tranche inférieure des revenus intermédiaires, où le rythme d'urbanisation est le plus rapide. Les villes devront offrir de meilleures possibilités de revenu et d'emploi, assurer un accès égal aux services et améliorer les infrastructures dans les secteurs de l'eau et de l'assainissement, des transports, du logement, de l'énergie, ainsi que de l'information et des communications."(I.M.F.E., 2014)

En Asie, l'Irak est témoin d'une augmentation significative de la population, qui devrait atteindre environ 71.350 millions en 2050 (voir figure 5) ("Iraq", 2016)



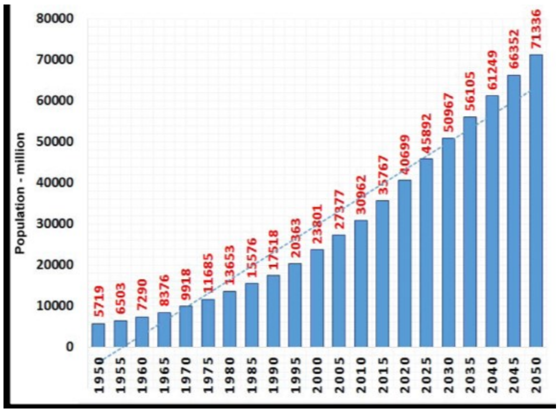


Figure 4:L*la population urbaine mondiale* **Figure 5:** *La proportion de résidents en Irak*

On constate que le climat de nos villes est plus chaud par rapport aux zones rurales, en raison des modifications progressives de la surface dont le remplacement de la végétation naturelle par des bâtiments, les rues et parkings. Cet effet sera augmenté par le réchauffement climatique (voir Figure 6). Ce phénomène est connu étant le phénomène d'îlot de chaleur urbain (ICU) (voir Figure 7).

Ce phénomène contribue à la réduction du confort thermique humain voire même à l'augmentation de la surmortalité en cas de canicule en plus de l'augmentation de la consommation d'énergie pour le rafraichissement des bâtiments.

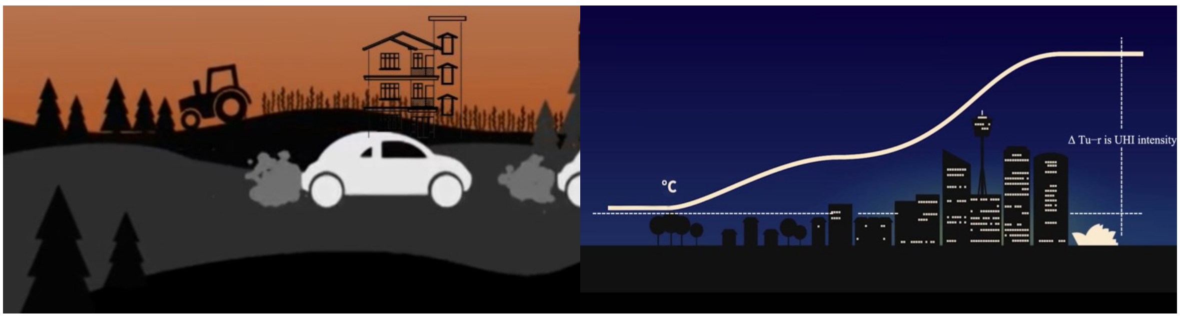


Figure 6: *Modifications de la surface* **Figure 7:** *L'îlot de chaleur urbain (ICU)*

Il existe trois types d'îlots de chaleur urbains (Voogt, 2000) :

1. L'îlot de chaleur surfacique : augmentation des températures de la surface du aux matériaux employés
2. L'îlot de chaleur souterrain : augmentation des température des sous-sols urbains due à leur occupation intensive et à l'augmentation de leur température de surface).
3. L'îlot de chaleur urbain atmosphérique qui peut être décompésé en deux parties : l'îlot de chaleur de la canopée urbaine et l'îlot de chaleur urbain de la couche limite urbaine.

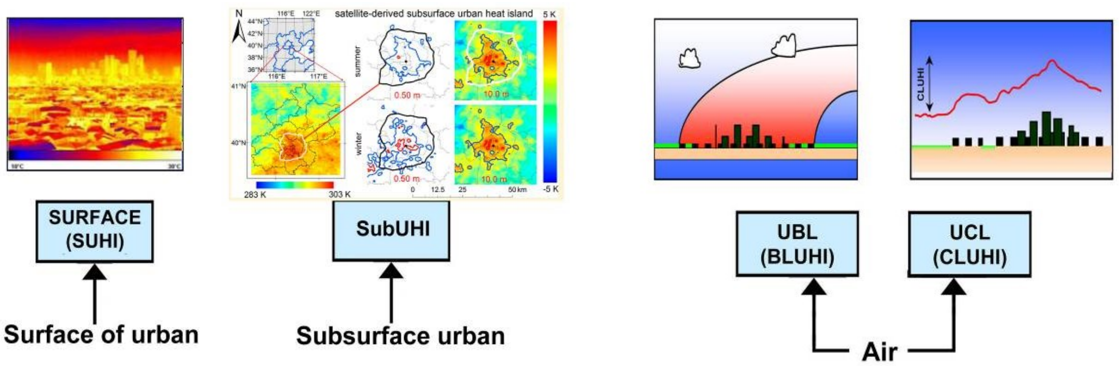


Figure 8: *Types d'îlots de chaleur urbains*

L'ICU résulte de la concordance de plusieurs phénomènes thermiques et de paramètres de composition urbaine :

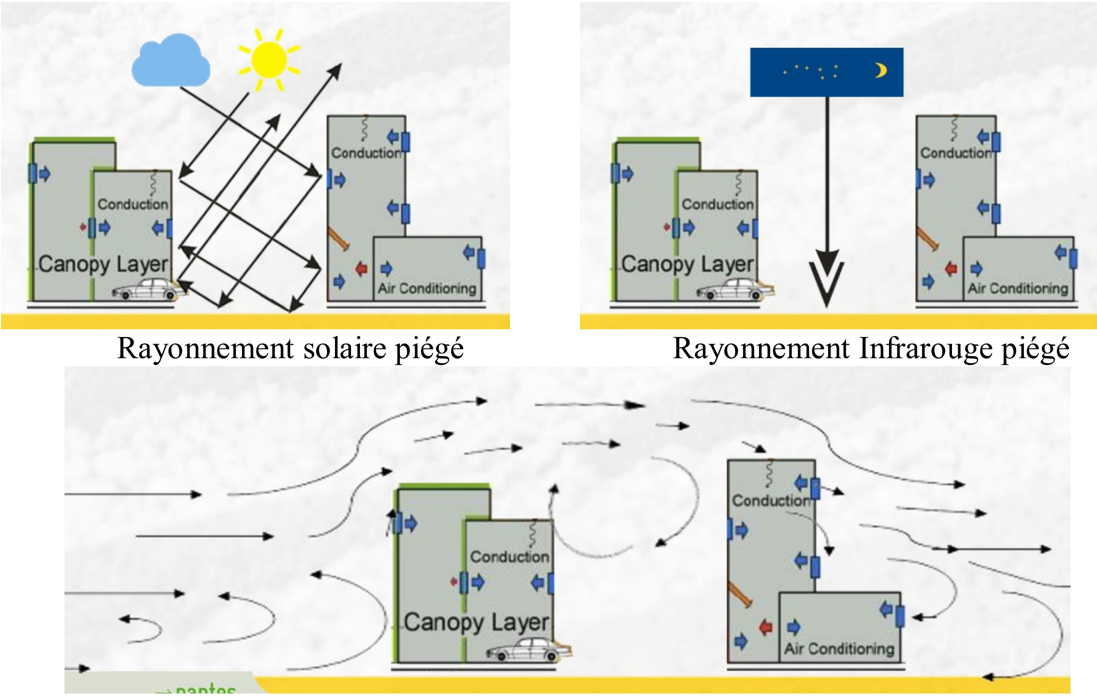
La géométrie urbaine, très dense et découpée (rugueuse),

- piège le rayonnement solaire incident
- limite les échanges par rayonnement infrarouge avec le ciel, principal puits de chaleur,
- réduit la vitesse du vent du fait de la présence de nombreux obstacles.

Le paysage urbain est essentiellement minéral, et de ce fait l'évaporation est faible, ce qui conduit à la d'avantage de stockage de la chaleur dans les matériaux et à sa restitition à l'air sous forme de convection.

Les différentes activités humaines (transports, équipements du bâtiment…) conduisent à des émissions de chaleur importantes (charges anthropiques).

La littérature sur l'ICU indique que les matériaux de l'enveloppe des bâtiments et aussi des surfaces urbaines sont un des principaux déterminants qui favorisent la formation de l'ICU. Ce leviers peut être facilement activé pour peu qu'on sache comment il intervient et quelles sont les caractéristiques sur lesquelles agir (Wong et al., 2008; Zarkesh et al., 2012).



Rayonnement solaire piégé

Rayonnement Infrarouge piégé

Vitesse du vent

Figure 9: *Raisons de la formation des îlots de chaleur urbains*

Problématique de recherche

Le travail de thèse repose sur trois enjeux auxquels il faut répondre pour assurer le confort intérieur et extérieur dans les villes irakiennes :

1. Trouver les stratégies appropriées pour développer les industries de matériaux de construction adaptés à l'Irak pour éviter ou réduire les problèmes environnementaux.

2. Développer d'autres stratégies complémentaires, qui contribuent à fournir un confort thermique extérieur et intérieur

3. Mettre en place des connaissances et des outils adaptés à la conception pour la sélection des matériaux de construction en évaluant leur effet sur:

- La température des surfaces urbaines,
- La température de l'air dans la zone urbaine,
- Le confort thermique intérieur / extérieur,
- L'énergie nécessaire pour assurer le confort thermique dans les bâtiments.

3. La délimitation du champs de recherche

Cette étude porte sur la conception de l'enveloppe du bâtiment avec une approche environnementale sur l'un des quartiers résidentiels importants dans la ville de Mossoul, en ce qui concerne:

- Les matériaux de construction
- Le forme de mur
- La design de mur

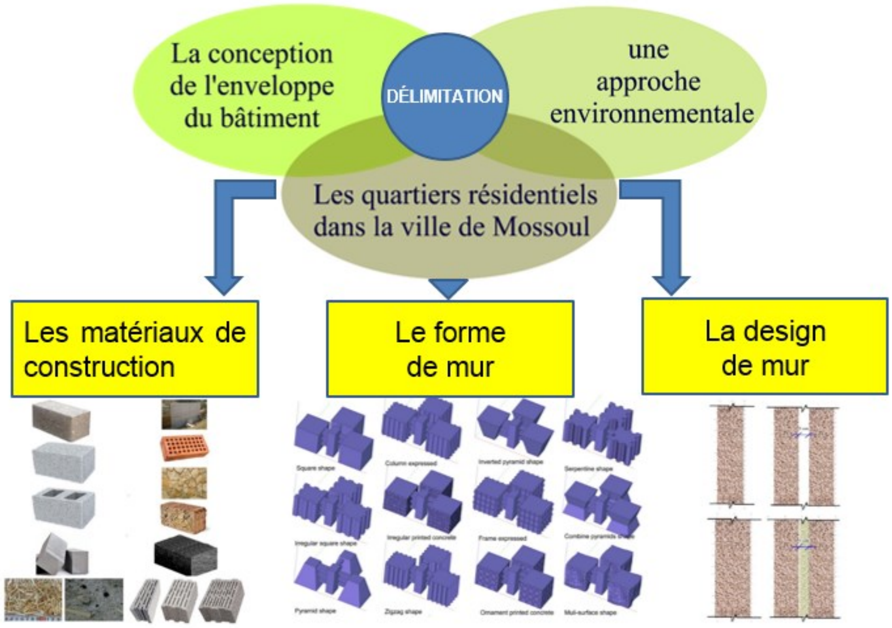


Figure 10: *La délimitation du champs de recherche*

Cette étude a été appliquée à un projet résidentiel dans la ville de Mossoul (Irak - région Nineveh). Celui-ci a été proposé par le ministère de la construction et du logement Il est considéré comme un projet typique et est susceptible d'être construit dans d'autres régions.

Figure 11: *Cas de étude de recherche*

4. L'objectif de la recherché

L'objectif principal de cette recherche est:

De montrer qu'une conception d'enveloppe du bâtiment appropriée permet d'atteindre de bonnes performances thermiques, c'est-à-dire :

- D'assurer dans le même temps, les conditions de confort thermique à l'intérieur des bâtiments et à l'extérieur
- De réduire la consommation d'énergie nécessaire à maintenir les conditions de confort à l'intérieur
- De déuire l'impact de la construction sur le phénomène d'ICU

5. Les questions de la recherche

Cette recherche pose les questions suivantes :

Quelle est la relation entre le design des enveloppes des bâtiments et:

1 - La température de surface extérieure des parois, qui cause l'augmentation de la température de l'air extérieur et contribue donc la formation d'ICU?

À cet égard, nous rechercherons comment choisir

- Les types de matériaux
- La forme de la façade
- Les caractéristiques de la surface

2. La température de la surface intérieur qui affecte le confort thermique intérieur et l'énergie nécessaire au maintient de conditions de confort acceptables ?

À cet égard, nous étudierons les apports d'alternatives qui sont:

- La double paroi,
- Le système végétalisé (mur végétalisé),
- La variation du coefficient de réflexion (albédo).

3. Les indices de confort intérieur et extérieur et la contribution à l'ICU ?

À cet égard nous étudierons

- Comment optimiser les caractéristiques des surfaces.

6. Les méthodes utilisées et la simulation

La méthodologie adoptée est basée sur l'outil numérique SOLENE-Microclimat. Les simulations ont été réalisées après des études préalables de sensibilité (sur la taille du domaine à simuler) et le choix de la période de simulation pour garantir la représentativité des résultats.

SOLENE-microclimat est un ensemble d'outils logiciels de simulation du microclimat urbain (bilans radiatifs, thermiques, aérauliques, etc.) construits sur la base du logiciel SOLENE développé entre 1990 et 2000 au sein du CRENAU à l'école nationale supérieure d'architecture de Nantes et initialement dédié aux calculs d'ensoleillement, d'éclairement et de rayonnement thermique des projets architecturaux et urbains.

La plateforme SOLENE-microclimat permet aujourd'hui de simuler l’influence des divers choix d’aménagement urbain à l’échelle d'un quartier sur :

- Les températures de surface,
- Le confort extérieur,
- La consommation énergétique des bâtiments,
- L'effet de l'ilot de chaleur urbain,
- La transformation des lieux et des paysages urbains (par des analyses systématiques des visibilités).

De nombreuses études ont été menées avec cet outil : influence de la végétation en ville, de l’eau, du choix des matériaux de construction, de l'évolution de la forme urbaine… apportant des éléments de réponses aux problématiques liées au changement climatique [15].

6.1. Méthode d'affichage des résultats

Pour afficher les résultats, les diagrammes suivants seront utilisés:

a. Diagramme de quartiles

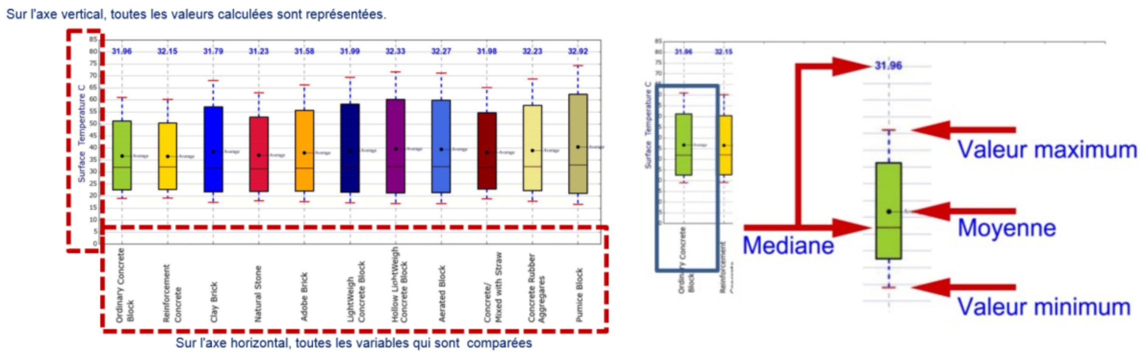


Figure 12: *Diagramme de quartiles*

[15] https://solene2016.sciencesconf.org/

b. Diagramme psychrométrique

Ces diagrammes produits en utilisant le logiciel Ecotect sont utilisés pour identifier la zone confort pour une région spécifique. Les points correspondant aux valeurs des conditions d'ambiance (température, humidité de l'air) heure par heure sont positionnés sur le graphe et leur concordance avec la zone de confort peut être analysée.

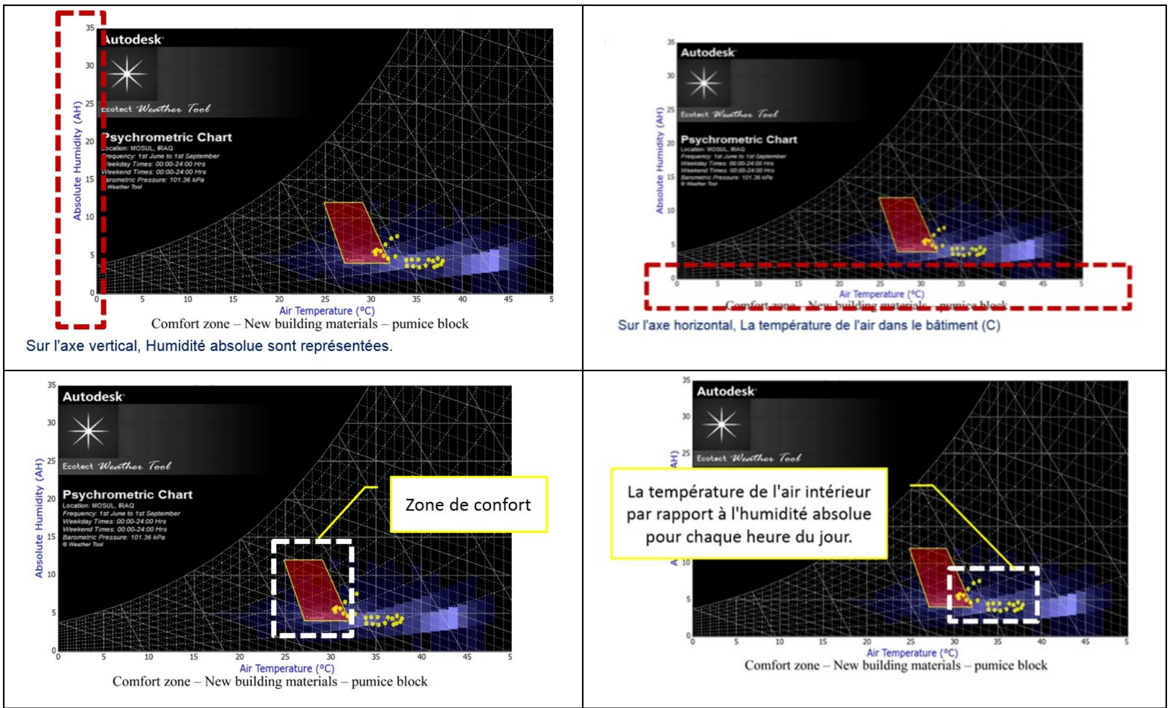


Figure 13: *Diagramme psychrométrique*

6.2. Les flux solaires incidents

Sur la figure 14, nous montrons les flux solaire incidents moyens calculés heure par heure sur les surfaces de différentes orientations du bâtiment étudié. Ils tiennent compte du masque des bâtiments environnants.

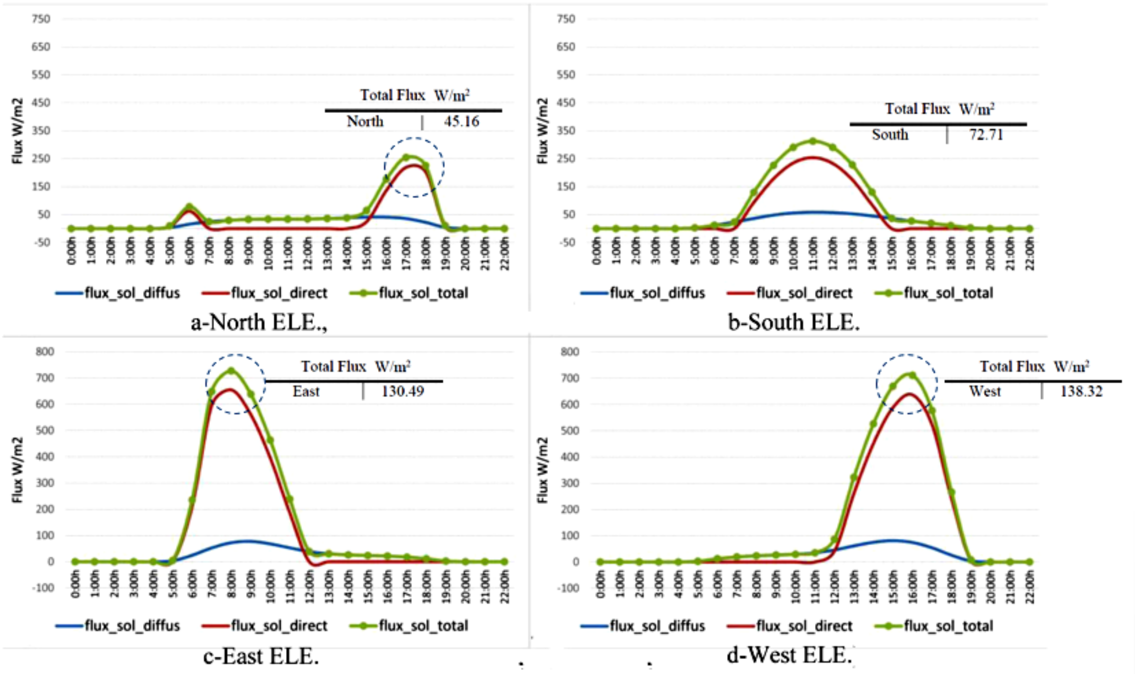


Figure 14: *Les flux solaires incidentssur chacune des surface du bâtiment d'étude*

Comme le montre la figure 14, ces flux solaires incidentsmoyens de chaque façade (surfaces verticales) présentent des différences dans leur dynamique temporelle et leur valeur maximale.

- La surface Nord reçoit une quantité minimale de fluxsolaire (maximum de 45.16 W/m^2);
- Les surfaces Est et l'Ouest reçoivent la quantité maximale de flux incidents (130.49 W/m^2 pour l'EST, 138.32 W/m^2 pour l'Ouest), avec des dynamiques temporelles symétriques,
- La surface Sud reçoit un incident moyen avec un maximum de 72,71 W/m^2.

6.3. Les étapes de simulation

Dans cette étude, nous utilisons différentes options offertes par ce logiciel avec 6 étapes principales.

1. Simulation en utilisant le modèle thermo-radiatif SOLENE[16]

Évaluation initiale des matériaux avant utilisation dans le bâtiment.

Etape 1	Matériaux

Évaluation des matériaux après utilisation dans le bâtiment

Etape 2	sous étape 1. | Matériaux, composition
	sous étape 2. | Forme
Etape 3	sous étape 1. | Solution complémentaire (Tse)
	sous étape 2. | Solution complémentaire (Tse) et Forme

2. Simulation en utilisant le modèle thermique du bâtiment de SOLENE-microclimat[17]

Etape 4	sous étape 1. | Différent scénario de Solution complémentaire (Tsi)
	sous étape 2. | Solution complémentaire (les besoins d'énergie)

3. La simulation en utilisant le modèle thermo-radiatif de SOLENE couplé avec le modèle température radiante moyenne à l'extérieur.

Etape 5	Estimation de température radiante moyenne (confort extérieur)

4. La simulation en utilisant le modèle thermo-radiatif de SOLENE couplé avec l'équation du bilan énergétique sur un volume d'air extérieur (évaluation de l'impact sur l'ICU)[18].

Etape 6	Estimation de température d'air extérieur

---

[16] Le logiciel SOLENE est utilisé pour calculer les flux solaires et infrarouges, réaliser le bilan de surface et d'en déduire le flux convectif et les températures de surface et aux nœuds des parois.

[17] A l'approche précedente, l'utilisation du modèle de thermique du bâtiment est ajoutée. Celle-ci permet soit d'imposer la température intérieure et donc de calculer les besoins, soit de considérer qu'il n'y a pas de système de conditionnement des ambiances intérieures et donc de calculer l'évolution libre de la température intérieure.

[18] Il s'agit d'une alternative au couplage avec Code-saturne (Computational Fluid Dynamics) developpée par (Malys, 2012) pour calculer la contribution de l'aménagement au phénomène d'ICU.

6.3.1. Simulation en utilisant le modèle thermo-radiatif SOLENE

Étape 1, Évaluation initiale des matériaux avant utilisation dans le bâtiment

Le but est ici de construire une connaissance initiale concernant le comportement thermique des matériaux de construction sélectionnés avant leur utilisation dans les bâtiments. Ceux-ci sont rassemblés en trois catégories :

- Les matériaux de construction utilisés dans le cas d'étude
- Les matériaux de construction utilisés en Irak, qui pourraient apporter des performances différentes
- De nouveaux types de matériaux produits en France, et qui pourraient être utilisés en Irak. Ces matériaux ont été sélectionnes non seulement pour leurs caractéristiques thermiques mais aussi en fonction de la possibilité de les produire et mettre en œuvre en Irak.

Pour une connaissance initiale du comportement thermique des ce matériaux, une petite pièce de chaque matériau ayant une dimension 100 * 100 * 10 cm a été testée (voir figure 15). Pour la simulation, la surface, positionnée horizontalement est soumise sur sa surface supérieure aux conditions météorologiques (rayonnement, température d'air) et sur sa surface intérieure à une température constance correspondant aux conditions interne d'un bâtiment (voir schéma de droite de la fugure 16).

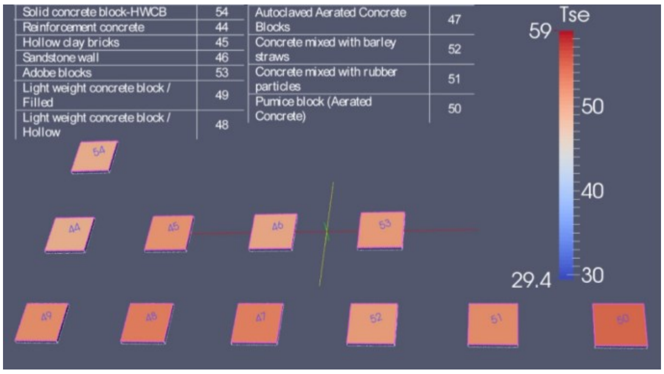


Figure 15: *Évaluation initiale des matériaux : température de surface extérieure des échantillons testés.*

Comme le montre la Figure 16, le matériau qui a une effusivité thermique élevée, a enregistré sa température de surface la plus basse. À l'inverse le matériau qui a une effusivité thermique faible, a enregistré sa température de surface la plus élevée.

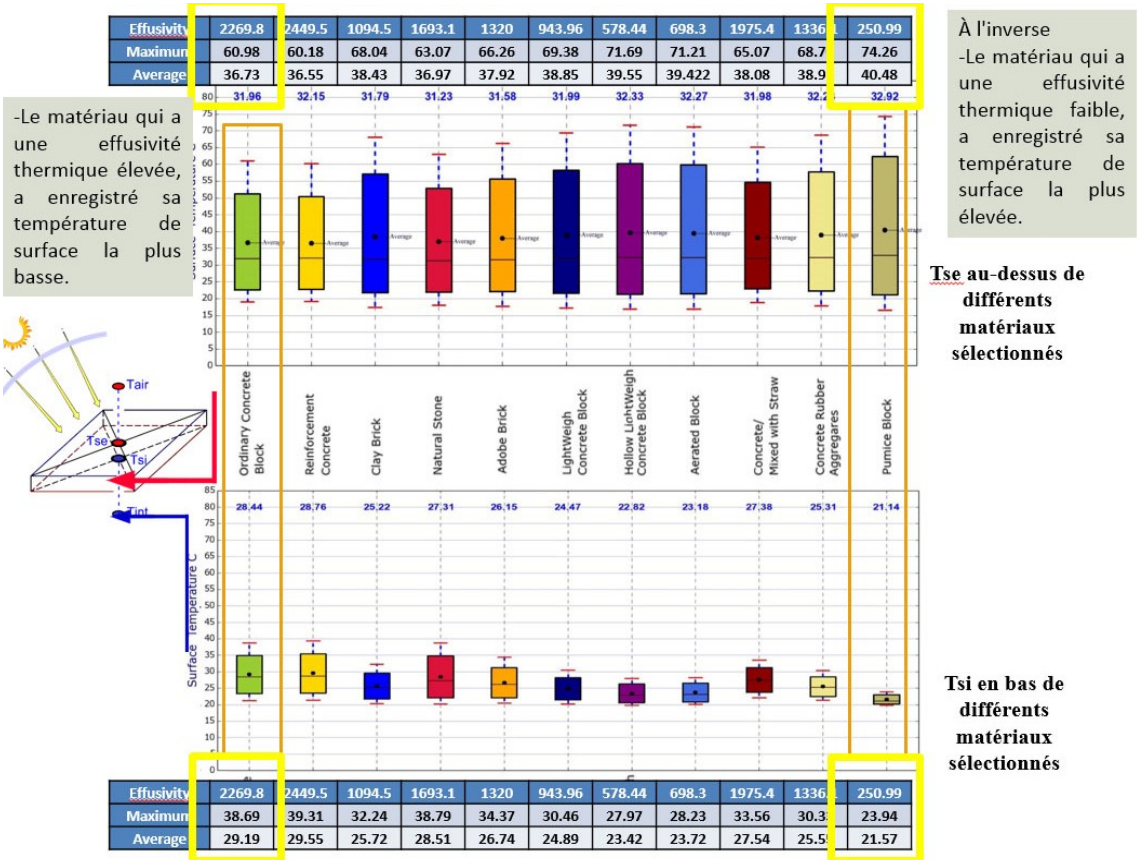


Figure 16: *La température de surface Tsi et Tse*

De là, nous pouvons conclure que l'effusivité thermique nous permet de bien caractériser le comportement thermique des matériaux vis-à-vis de l'élévation de la température de surface extérieure (voir figure 17):

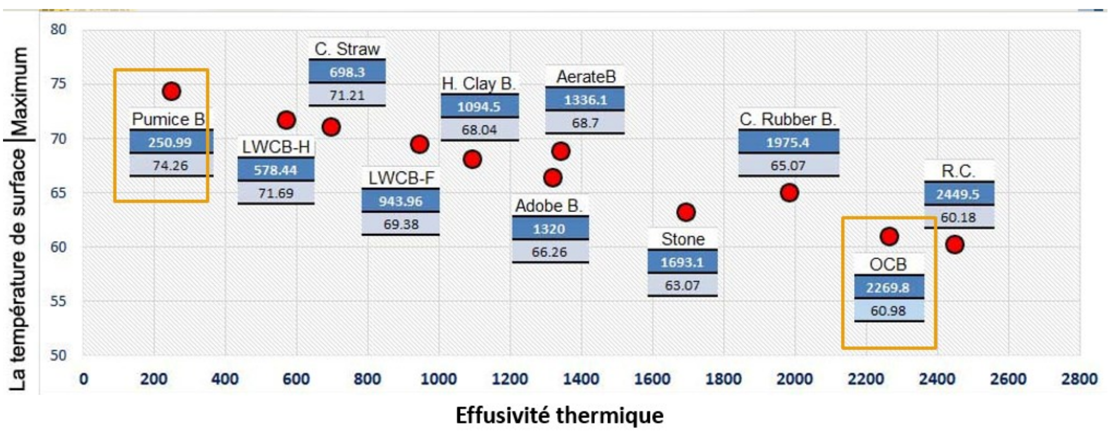


Figure 17: *La relation entre l'effusivité thermique et la température de surface extérieure maximale*

Plus l'effusivité thermique est faible, plus la température maximale de surface extérieure est élevée. Les matériaux de forte effusivité ne permettent pas à la chaleur de passer de l'extérieur à l'intérieur du bâtiment, en raison de leur capacité à conserver la chaleur dans ses couches.

Plus l’effusivité thermique est élevée, plus la température de surface extérieure maximale est basse. Les matériaux de faible effusivité conduisent la chaleur de l'extérieur à l'intérieur plus rapidement.

Étape 2, Évaluation des matériaux après utilisation dans le bâtiment

Cette étape concerne le comportement thermique des matériaux de construction utilisés dans les bâtiments du cas d’étude. Elle a pour objectid de sélectionner :

-le matériau de construction approprié,
-La composition de mur,
-le forme de mur

En estimant la température de surface intérieure et extérieure pour différents scénarios.

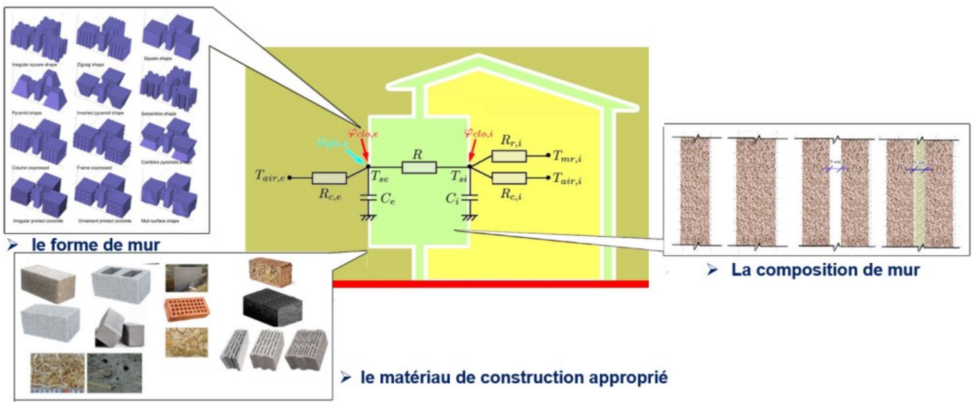
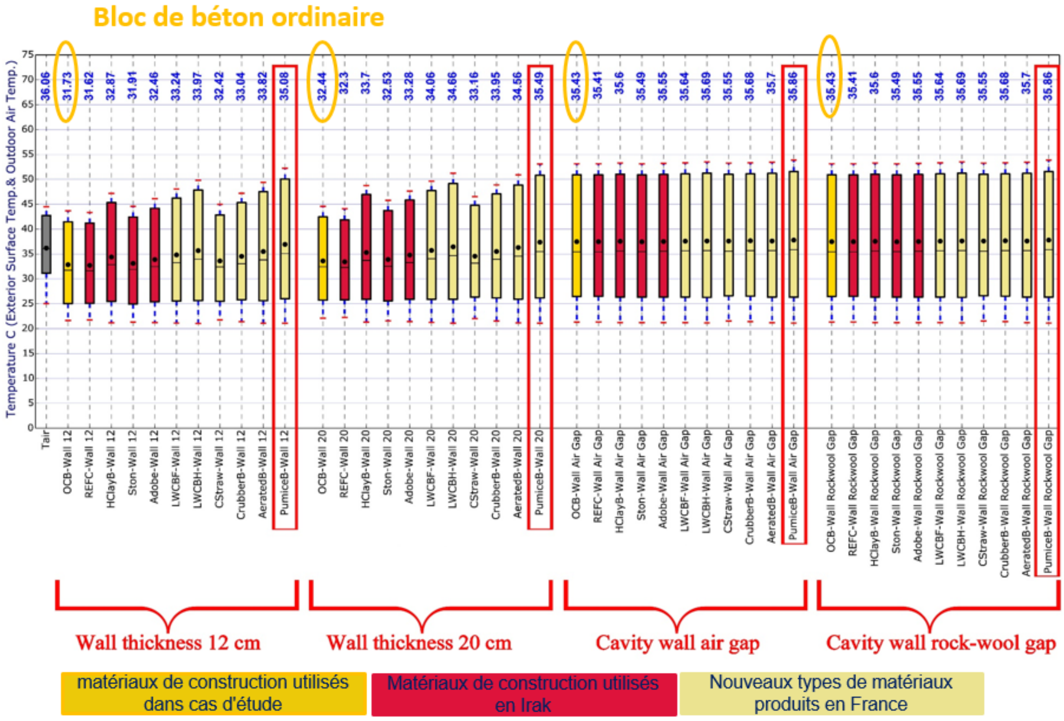


Figure 18: *Étapes pour évaluer la performance thermique du mur*

Les résultats de étape 2, Sous-étape 1

Comme le montre la Figure 19, il est possible d'augmenter le niveau d'isolation en augmentant l'épaisseur du mur ou en ajoutant un espace d’air dans la couche du mur. Mais, pour le bloc de pierre ponce, la situation est diffèrente. En effet, nous trouvons que ce matériau conserve le même niveau de température de surface même s'il y a une modification de l'épaisseur de la paroi ou l’ajout d’une cavité dans la couche de la mur.



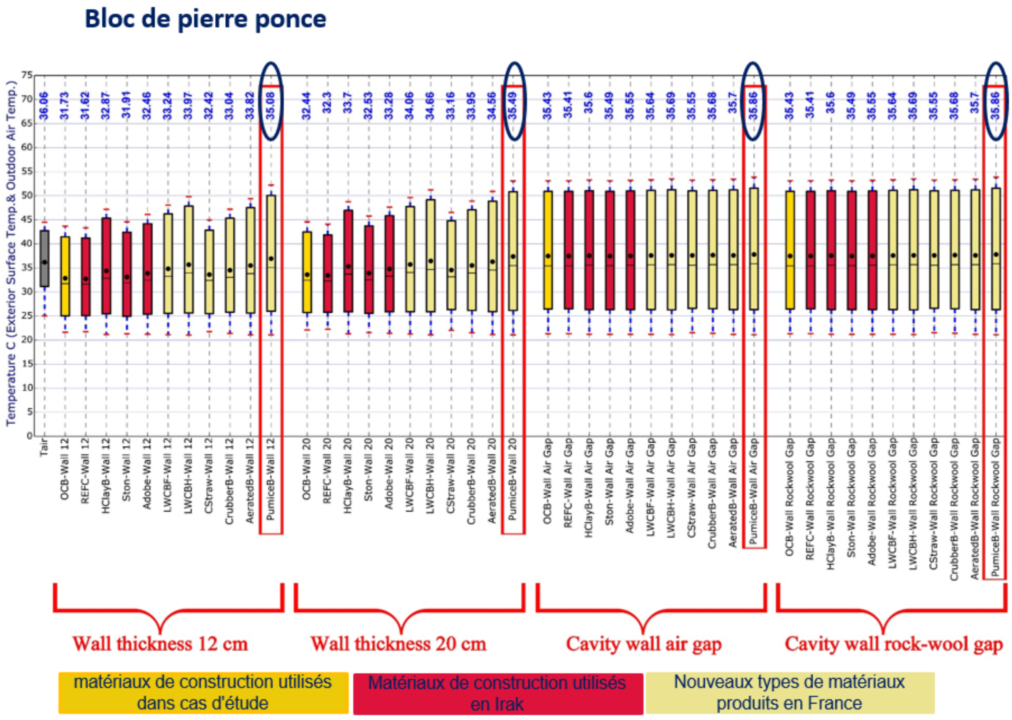


Figure 19: *Les résultats de étape 2, Sous-étape 1 | Tse*

Conclusion de l'étape 2, Sous-étape 1

Les résultats indiquent que :

- Dans le cas du mur à une seule couche, les types de matériaux sont responsables de la formation des performances thermiques.

- En ce qui concerne le mur à cavité, la cavité est responsable de la formation des performances thermiques, sauf pour les matériaux qui avaient déjà une bonne perfomance thermique (matériaux à isolation répartie).

Finalement, nous pouvons dire que pour tout matériel, il existe deux possibilités.

La première possibilité

Choix de matériaux qui contribuent à réduire la (Tse) mais affectent négativement:

- la (Tsi),
- le confort thermique intérieur (blocs de béton lourd ou béton armé).

Dans ce cas, il est nécessaire de trouver des stratégies pour réduire la température de la surface intérieure et finalement assurer le confort thermique intérieur, par exemple en ajoutant une couche d'isolation intérieure, par la ventilation naturelle, la climatisation.

La deuxième possibilité

Choix de matériaux qui contribuent à réduire (Tsi) et finalement à fournir un confort thermique intérieur mais qui augmente (Tse) (par exemple, le bloc de pierre ponce).

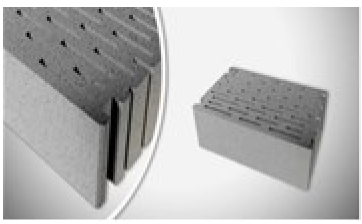
Dans ce cas, il est nécessaire de trouver une stratégie pour réduire la température des surfaces extérieures et finalement de manière à impacter positivement la température de l'air extérieur (la double paroi, un système végétalisé, la variation du coefficient de réflexion).

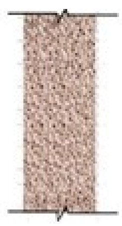
Pour cette étude, la deuxième possibilité a été sélectionnée

Et, finalement et après avoir comparé les résultats, nous sélectionnons:

-Le bloc pierre ponce comme principal type de matériau pour le mur.

-Une couche avec une épaisseur (20 cm).





Étape 2, Sous-étape 2

Le but de cette étape d'édudier limpact de différentes forme des façades et de trouver celles plus appropriée en fonction de l'orientation de la façade. Douze formes ont été étudiées comme indiqué dans Figure 20. Ces formes consistent soit en un modélé de surface (motif), soit en un inclinaison générale de la surface. L'impact essentiel porte sur l'auto-ombrage de la surface, qui modifie les flux solaires incidents et les échanges radiatifs avec la scène.

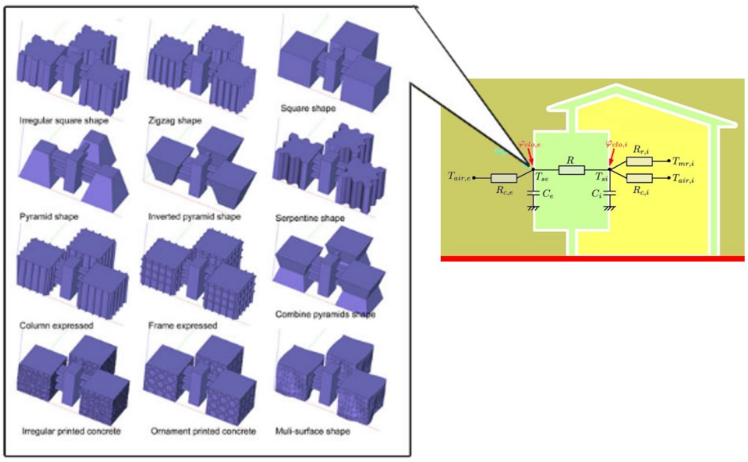
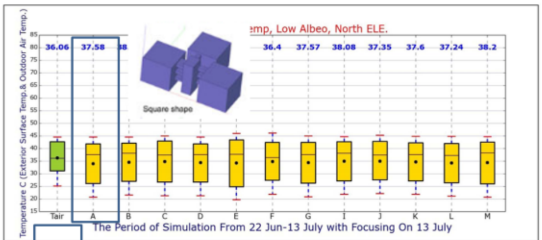


Figure 20: *Différentes forme des façades.*

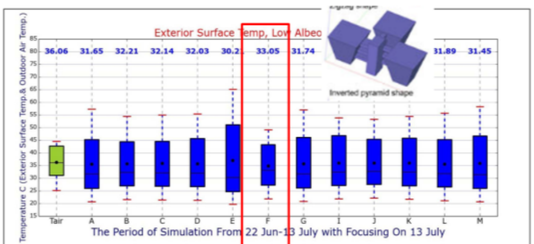
Les résultats de étape 2, Sous-étape 2

Les résultats de étape 2, Sous-étape 2 sont présentés dans la Figure 21, pour chaque façade: Nord, Sud, Est, et Ouest.



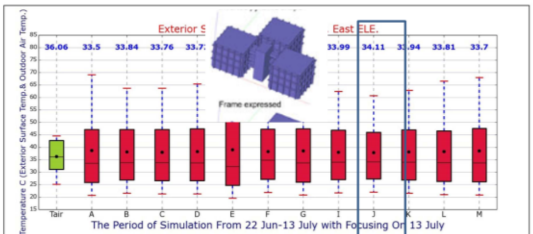
	A	B	C	D	E	F	G	I	J	K	L	M
	Square shape	Irregular square shape	Zigzag shape	Serpentine shape	Pyramid shape	Inverted pyramid shape	Combine pyramids shape	Column expressed	Frame expressed	Irregular printed concrete	Ornament printed	Muli-surface shape
AVE	34.02	34.58	34.79	34.39	34.23	34.90	34.37	34.91	34.97	34.72	34.23	33.65
MAX.	44.52	44.58	45.02	44.57	45.98	46.14	45.01	44.74	45.21	44.83	44.81	44.82
MIN	20.75	21.58	21.32	21.34	19.65	21.89	20.85	21.80	22.10	21.81	21.08	20.98
MED.	37.58	38.18	37.37	37.55	37.75	36.40	37.57	38.08	37.35	37.60	37.24	32.28

Table 6. 15: The exterior surface temperature of different wall shapes | North elevation



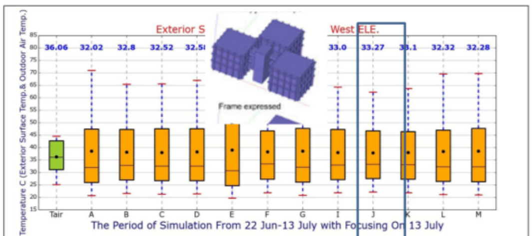
	A	B	C	D	E	F	G	I	J	K	L	M
	Square shape	Irregular square shape	Zigzag shape	Serpentine shape	Pyramid shape	Inverted pyramid shape	Combine pyramids shape	Column expressed	Frame expressed	Irregular printed concrete	Ornament printed	Muli-surface shape
AVE.	35.49	35.63	35.76	35.70	36.96	34.80	35.72	36.02	36.01	35.91	35.62	35.78
MAX.	57.28	54.44	54.99	55.39	65.15	49.10	56.90	53.89	53.27	54.44	55.63	58.22
MIN.	20.75	21.59	21.48	21.34	19.64	21.91	20.85	21.82	22.17	21.65	21.15	20.64
MED.	31.65	32.21	32.14	32.03	30.21	33.05	31.74	32.40	32.75	32.47	31.89	31.45

Table 6. 16: The exterior surface temperature of different wall shapes | South elevation



	A	B	C	D	E	F	G	I	J	K	L	M
	Square shape	Irregular square shape	Zigzag shape	Serpentine shape	Pyramid shape	Inverted pyramid shape	Combine pyramids shape	Column expressed	Frame expressed	Irregular printed concrete	Ornament printed	Muli-surface shape
AVE.	38.65	38.15	37.97	38.27	39.03	38.31	38.60	38.01	37.82	38.05	41.14	38.54
MAX.	69.15	63.65	63.68	65.35	73.16	64.15	68.29	62.45	60.62	62.79	69.33	67.94
MIN.	20.67	21.53	21.26	21.27	19.58	21.80	20.77	21.73	22.03	21.60	20.55	20.90
MED.	33.50	33.84	33.76	33.72	32.30	34.80	33.62	33.99	34.11	33.94	35.48	33.70

Table 6. 17: The exterior surface temperature of different wall shapes | East elevation



	A	B	C	D	E	F	G	I	J	K	L	M
	Square shape	Irregular square shape	Zigzag shape	Serpentine shape	Pyramid shape	Inverted pyramid shape	Combine pyramids shape	Column expressed	Frame expressed	Irregular printed concrete	Ornament printed	Muli-surface shape
AVE.	38.61	38.13	37.95	38.23	38.99	38.28	38.56	38.01	37.82	37.94	38.40	34.43
MAX.	70.98	65.46	65.56	66.95	75.36	66.13	70.11	64.23	62.24	63.71	69.49	44.62
MIN.	20.75	21.60	21.32	21.35	19.63	21.90	20.84	21.79	22.09	21.88	21.07	20.67
MED.	32.02	32.80	32.52	32.58	30.66	33.34	32.12	33.00	33.27	33.10	32.32	38.20

Table 6. 18: The exterior surface temperature of different wall shapes | West elevation

Figure 21: *Comparaison des effets des différentes formes et sélection de la forme la plus appropriée pour chaque façade.*

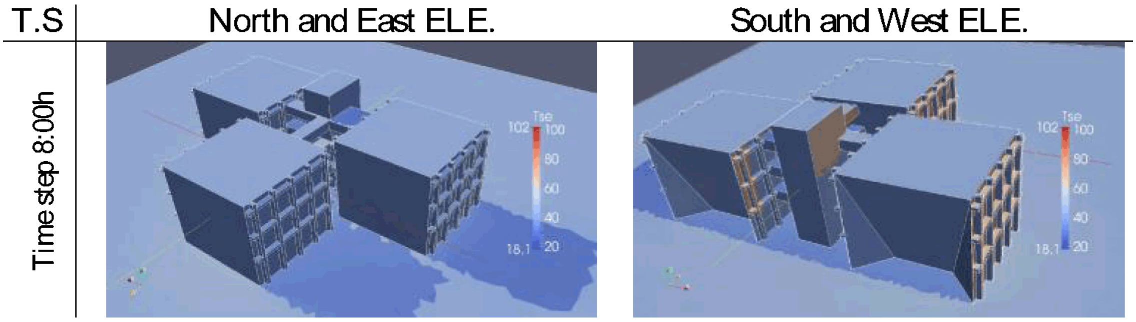


Figure 22: *La forme de bâtiment proposée pour optimiser les températures de surface extérieure*

Étape 3: Solution complémentaire Tse et la forme appropriée de bâtiment

Le but de cette étape est:

- De sélectionner une solution complémentaire qui contribue à réduire la température de surface extérieure (Sous-étape 1).
- Suite au choix de cette solution complémentaire, d'étudier l'impact du changement de la forme de mur sur cette réduction de la température de surface extérieure (Sous-étape 2).

Les solutions complémentaires étudiées sont : le double mur, la façade végétale, les matériaux à albédo élevé.

Les résultats de l'étape 3, Sous-étape 1

Les résultats de l'étape 3, Sous-étape 1 sont présentés dans la Figure 23.

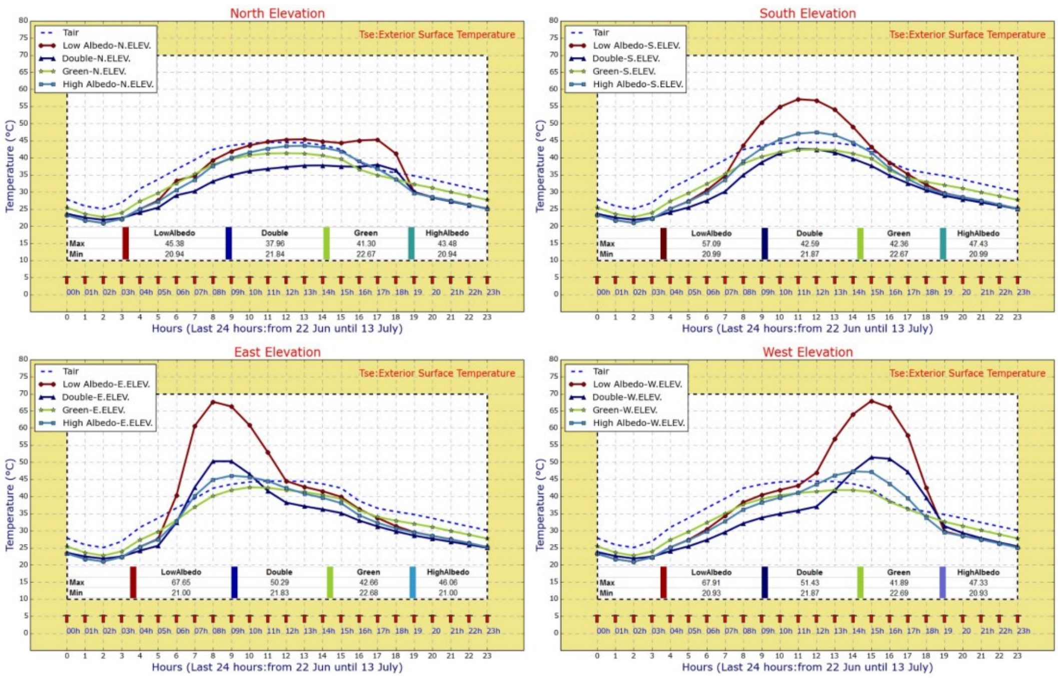


Figure 23: *Evolution des Tse pour les différentes solutions complémentaires*

Conclusion d'étape 3, Sous-étape 1

Selon les orientations, les deux solutions qui apparaissent comme meilleures sont le système végétalisé et la double paroi.

Cependant, le système végétalisé, n'est que difficilement pas applicable en Irak pour des raisons de gestion de la disponibilité en eau et de la nécessité d'entretien de la plupart des solutions.

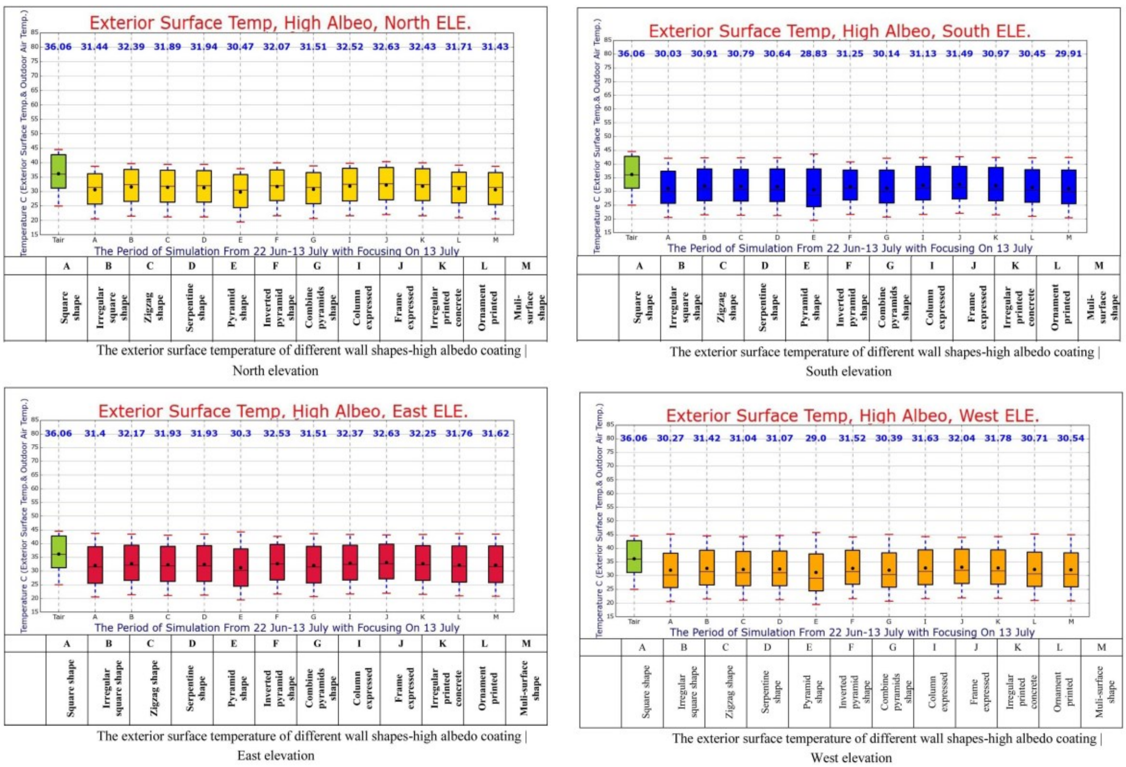
La «double paroi», elle est appliquée seulement aux maisons individuelles privées, en raison de son coût.

Finalement, la troisième stratégie complémentaire, en terme de performance vis-à-vis de la température extérieur, les "matériaux à albédo élevé" peuvent parfaitement être appliqués en Irak pour tous les types de projets nouveaux, par le choix de couleur et traitement de surface appropriés et de projets anciens, lors de réhabilitation.

Les résultats de l'étape 3, Sous-étape 2

Forme et albédo

Le but de cette étape est d'étudier l'impact du changement de la forme de mur après l'utilisation de la stratégie complémentaire choisie : matériaux à albédo élevé. Les résultats sont discutés pour chaque façade: Nord, Sud, Est, et Ouest (Figure 24).



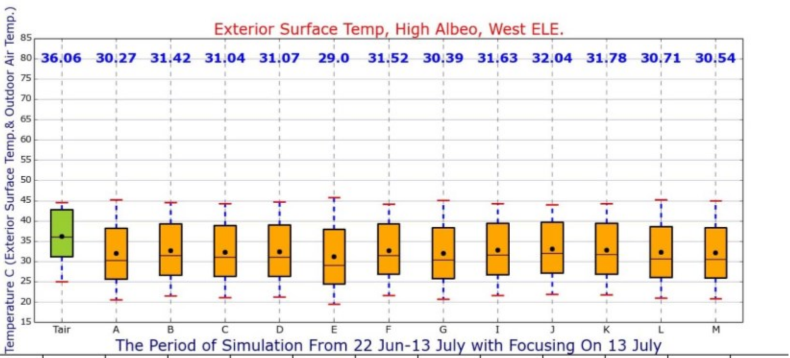
The exterior surface temperature of different wall shapes-high albedo coating | North elevation

The exterior surface temperature of different wall shapes-high albedo coating | South elevation

The exterior surface temperature of different wall shapes-high albedo coating | East elevation

The exterior surface temperature of different wall shapes-high albedo coating | West elevation

Figure 24: *Tse, des différentes formes de façades par orientation*



	A	B	C	D	E	F	G	I	J	K	L	M
	Square shape	Irregular square shape	Zigzag shape	Serpentine shape	Pyramid shape	Inverted pyramid shape	Combine pyramids shape	Column expressed	Frame expressed	Irregular printed concrete	Ornament printed	Muli-surface shape
AVE.	31 ºC	33 ºC	32 ºC	32 ºC	31 ºC	33 ºC	32 ºC	33 ºC	33 ºC	33 ºC	32 ºC	32 ºC
MAX.	44 ºC	44 ºC	44 ºC	45 ºC	46 ºC	44 ºC	45 ºC	44 ºC	44 ºC	44 ºC	45 ºC	45 ºC
MIN.	21 ºC	21 ºC	21 ºC	21 ºC	19 ºC	22 ºC	21 ºC	22 ºC	22 ºC	22 ºC	21 ºC	21 ºC
MED.	31 ºC	31 ºC	31 ºC	31 ºC	29 ºC	32 ºC	30 ºC	32 ºC	32 ºC	32 ºC	31 ºC	31 ºC

Table 6. 23: The exterior surface temperature of different wall shapes-high albedo coating | West elevation

Figure 25: *Tse de différentes formes pour la façade ouest*

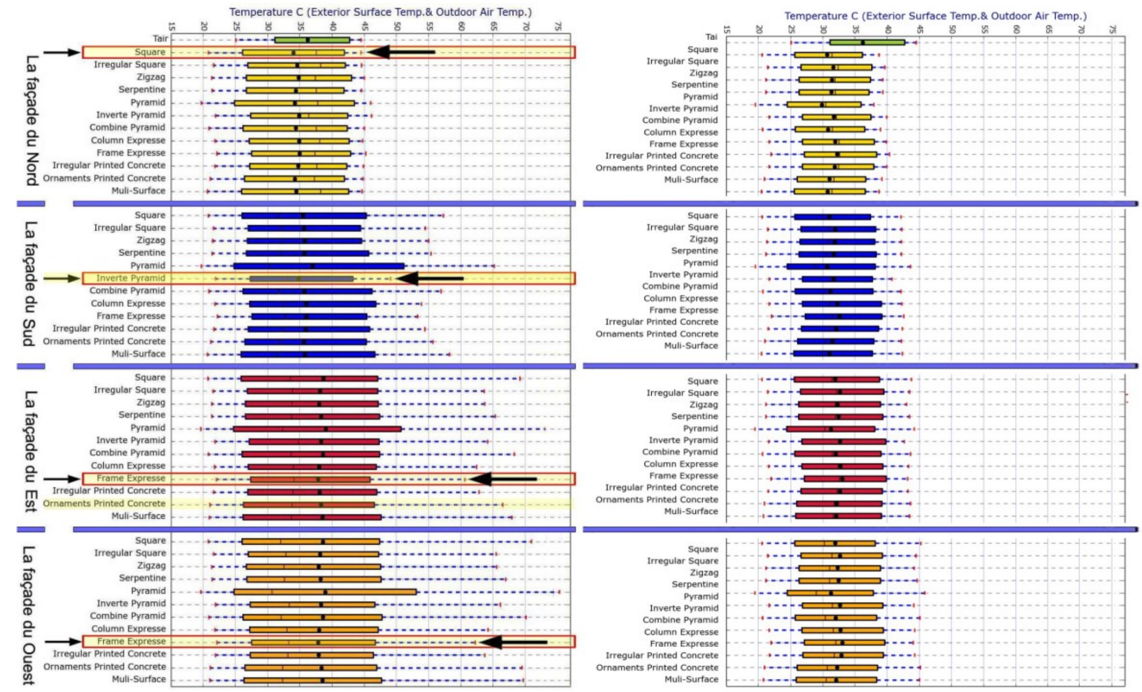


Figure 26: *Comparaison entre différentes formes de façades, comparaison de l'effet de l'albédo (faible à gauche, élevé à droite)*

Conclusion de l'étape 3, Sous-étape 2

Les résultats de simulation précédents indiquent qu'il n'y a pas de variation significative de la température de surface extérieure parmi toutes les formes de parois testées quel que soit le changement de forme.

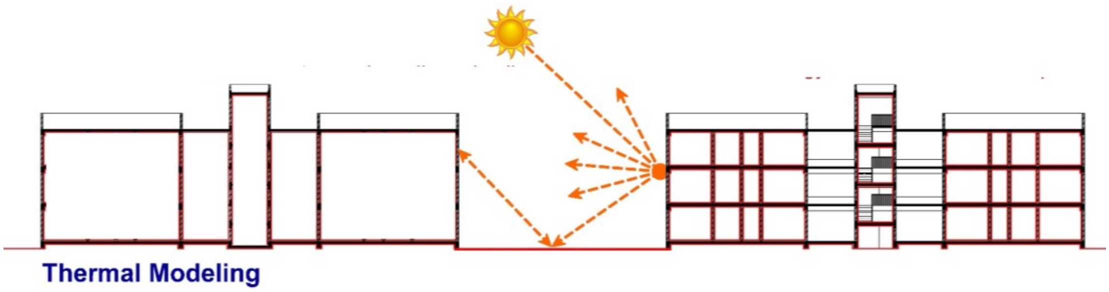
On en conclut que c'est certainement principalement le résultat de l'augmentation de la réflectivité des surfaces extérieures du bâtiment qui a affecté la température de la surface du bâtiment.

Par conséquent, nous pouvons dire que l'augmentation de la valeur de réflectivité des surfaces extérieures des bâtiments est le pricnipal levier pour les architectes. En utilisant des revêtements ou matériaux à fort albédo, ils se réservent de larges possibilités de conception de la forme de la façade pour répondre à leurs préférences esthétiques.

Pour la suite, nous considèrerons le mur carré comme forme de paroi pour les raisons suivantes:

- Cette forme n'augmente pas les temps de simulation,
- Le mur carré est similaire à la forme d'origine de notre le cas d'étude,
- A performances environnementales similaires, cette forme n'implique pas de cout financier supplémentaire.

6.3.2. La simulation en utilisant le modèle de thermique du bâtiment de Solene-microclimat



Etape 4, "Albedo, confort thermique et énergie"

Le but principal de cette étape de la simulation est de sélectionner la valeur appropriée de l'albédo de chaque façade du bâtiment qui contribue à offrir un haut niveau de confort intérieur et réduire la consommation d'énergie

Les résultats de étape 4, Sous-étape 1:

a. Impact de l'albédo du toit

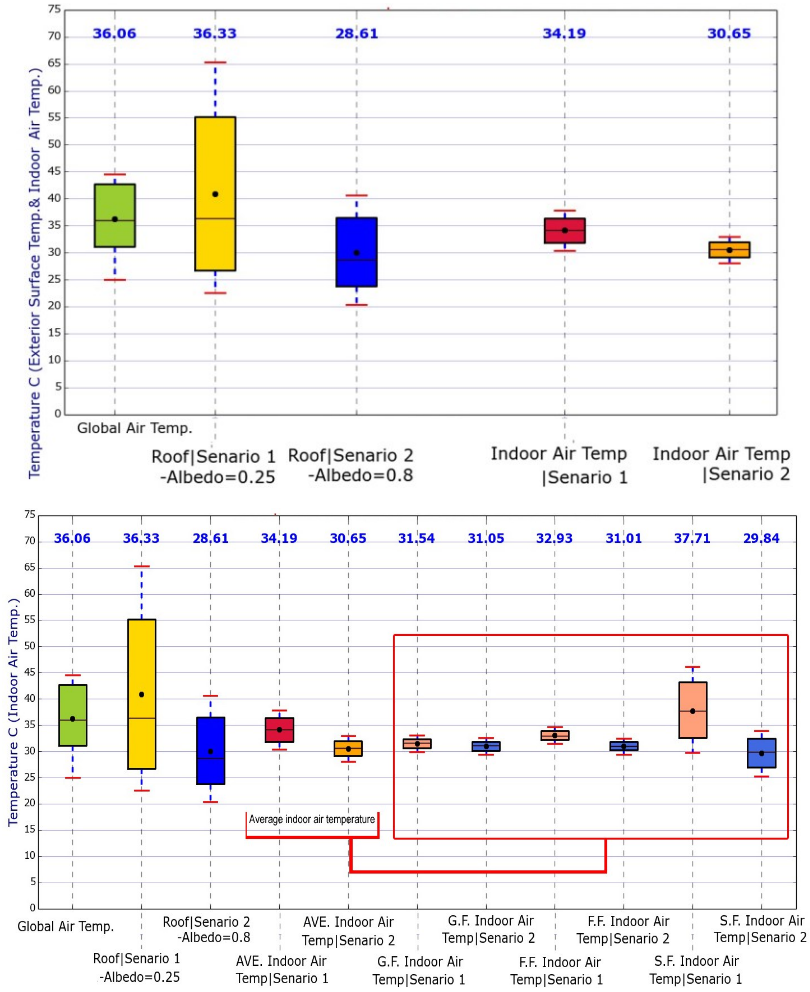
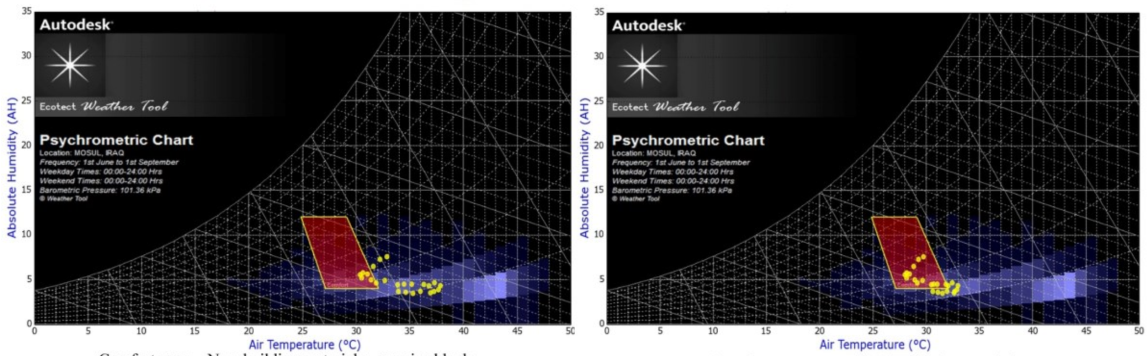


Figure 27: *Dans chacun des deux graphes, sont représentés* :

- *A gauche : la température de toit – pour chaque alternative albédo faible/élevé,*
- *A droite : la température de l'air intérieur – pour chaque alternative albédo faible/élevé*



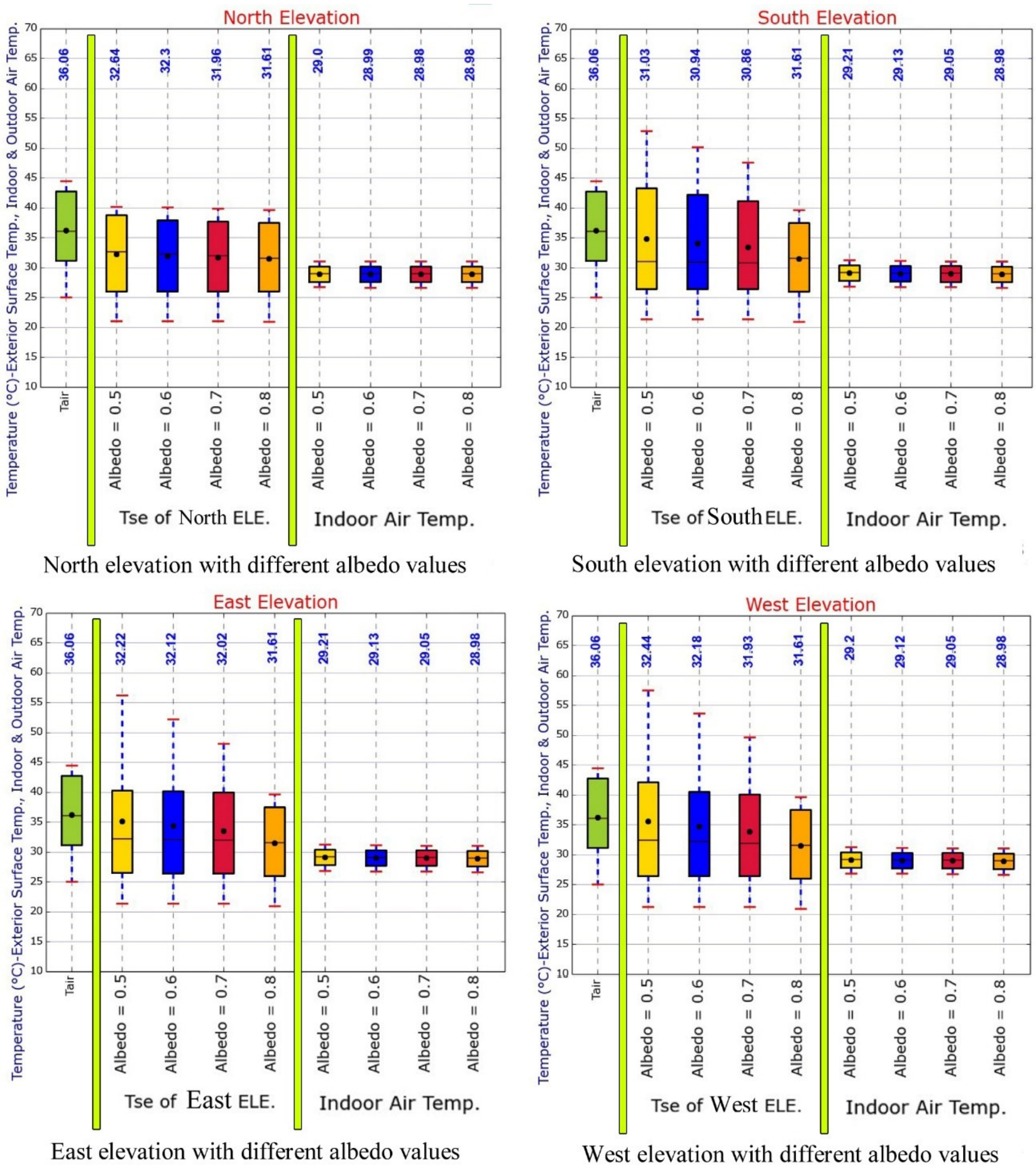
Comfort zone – New building materials – pumice block

Comfort zone – Roof high albedo materials

Figure 28

À gauche. Diagramme psychrométrique – bloc de pierre ponce, toit albédo faible,
À droite. Diagramme psychrométrique – bloc de pierre ponce, toit albédo élevé

b. l'impact d'un changement de l'albédo des murs extérieurs



North elevation with different albedo values

South elevation with different albedo values

East elevation with different albedo values

West elevation with different albedo values

Figure 29: *Comparaison de différents scénarois d'albédo*

Conclusion des étapes 3, 4, 5

- Les résultats ont montré qu'il existe une relation entre la quantité de rayonnement arrivant sur chaque façade et la valeur de l'albédo nécessaire pour réduire la température, une augmentation de du rayonnement incident nécessite une augmentation de la valeur de l'albédo.

- Pour le cas d'étude actuel, la façade nord reçoit la quantité minimale de flux, donc l'utilisarion d'un albédo élevé ne modifie pas grandement sa température de surface extérieure par rapport aux trois autres façades.

-La combinaison proposée sera celle donnée ci-dessous :

Components	Albedo value	Components	Albedo value
North elevation	0.5	*Roads*	0.6
South elevation		*Pavements and urban spaces*	
Est elevation	0.8	*Roofs*	0.8
West elevation		*Green area*	

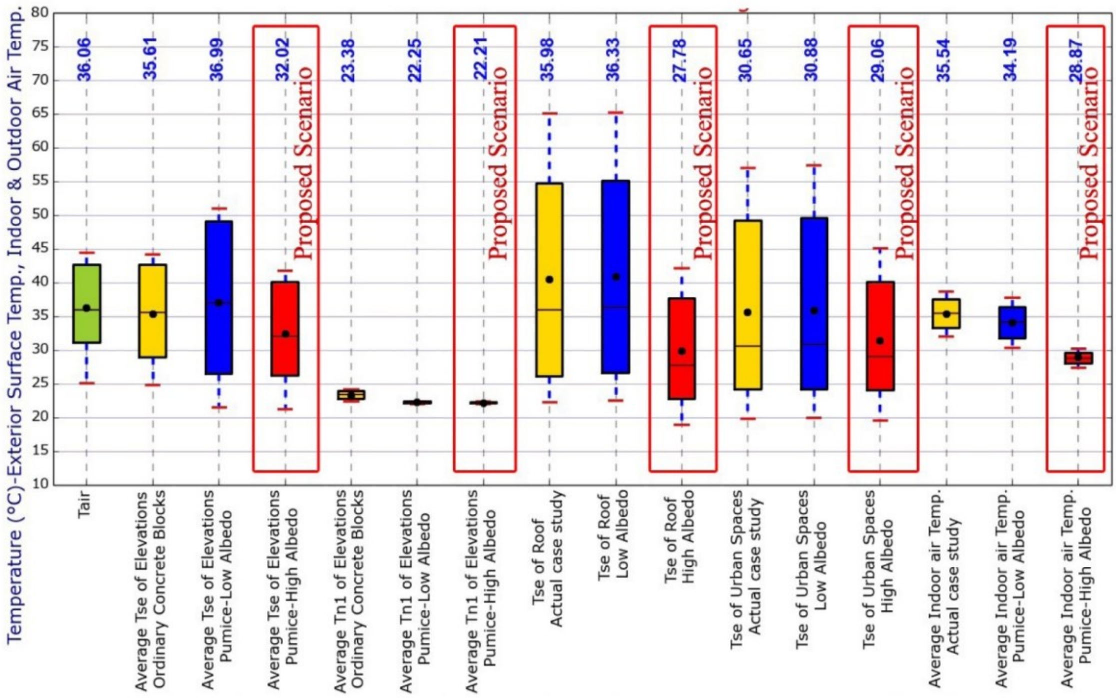
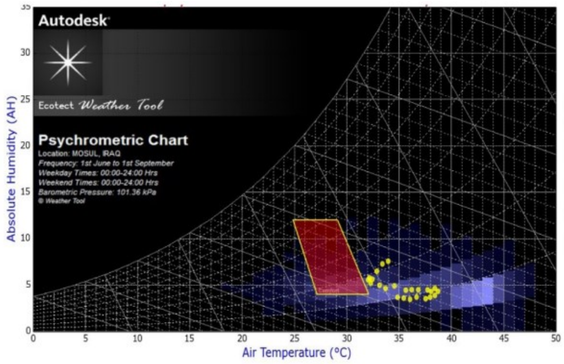
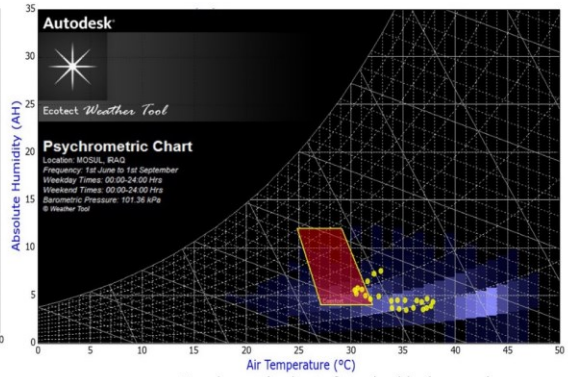


Figure 30: *Comparaison de la température de surface extérieure moyenne pour -le scénario proposé, - le cas d'étude réel - la pierre ponce scénario sans solution complémentaire*

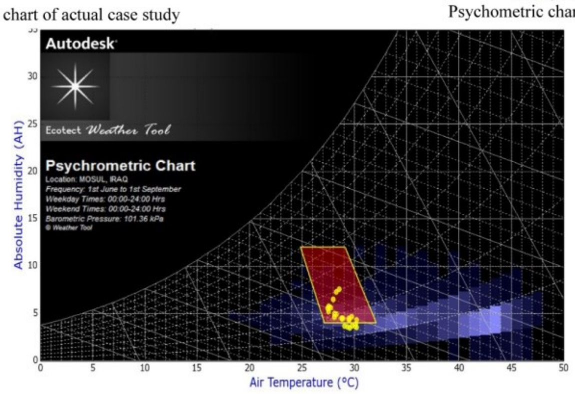
On constate que le scénario proposé améliore non seulement la température moyenne des surfaces extérieures des bâtiments et des espaces extérieurs, la température moyenne de surface intérieure et la température d’air intérieure.



Psychometric chart of actual case study



Psychometric chart of pumice block scenario



Psychometric chart of proposed scenario

Figure 31: *Diagramme psychrométrique du scénario proposé, du cas d'étude réel et de la pierre ponce sans solution complémentaire*

On constate que le scénario proposé améliore fortement les conditions de confort intérieur puisque presque tous les points sont inscrits dans la zone de confort.

Les résultats de l'étape 4, Sous-étape 2:

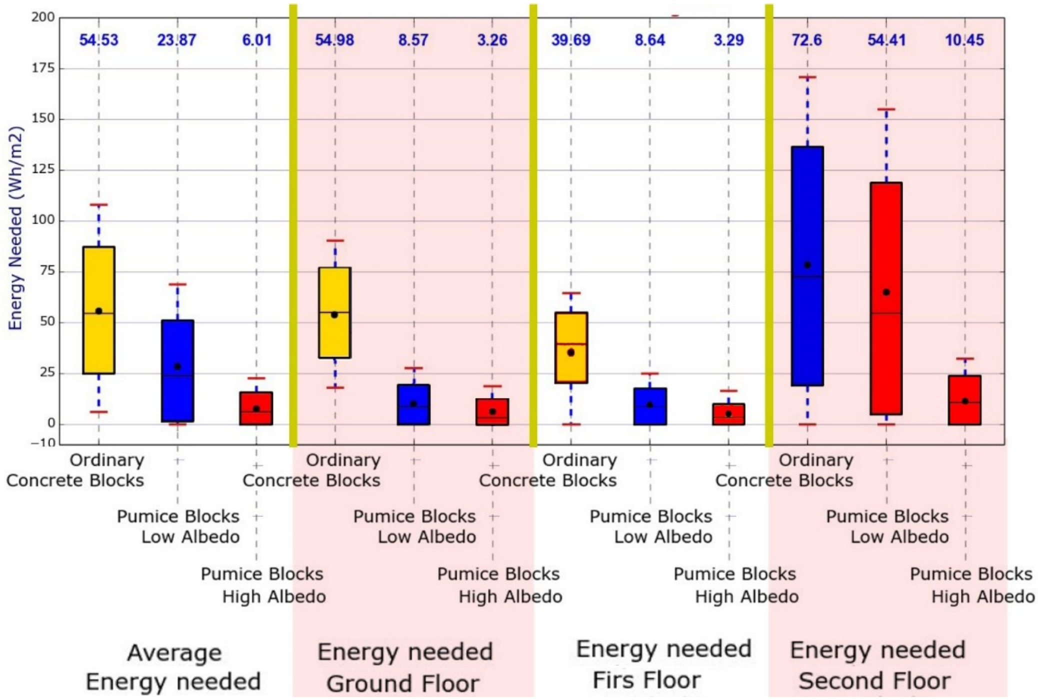


Figure 32: *L'énergie nécessaire au maintien des conditions de température intérieure pour le scénario proposé par rapport à d'autres scénarios*

On constate que la proposition permet de réduire les besoins énergétiques moyens du bâtiment. L'analyse par étage montre que cette réduction concerne tous les étages mais est plus forte sur le dernier étage, qui subit des apports solaires très élevés.

La simulation en utilisant le modèle thermo-radiatif de Solene couplé avec le modèle de calcul de la température moyenne radiante (Tr)

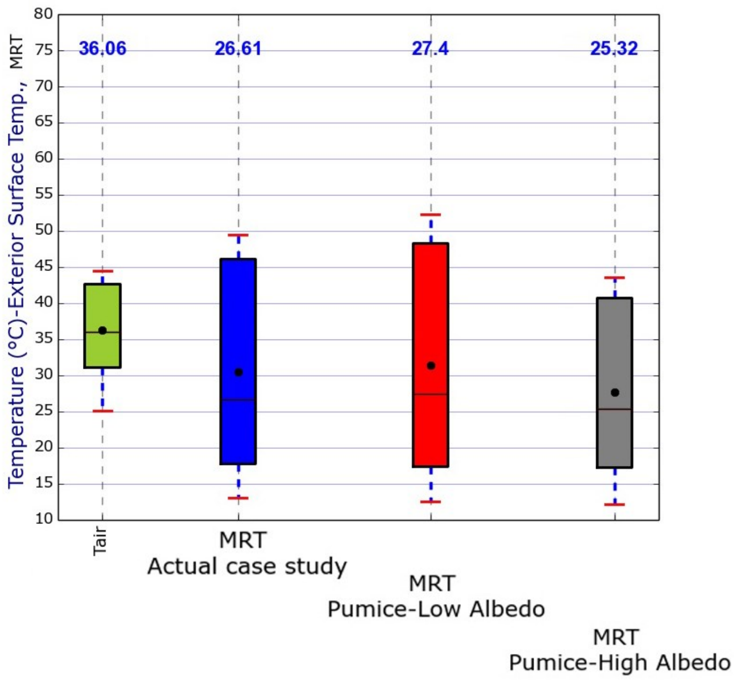


Figure 33: *Comparaison de la température moyenne radiante du cas d'étude réel, de la pierre ponce sans solution complémentaire et de la pierre ponce avec solution complémentaire*

Le calcul de la température moyenne radiante dans l'espace extérieur permet d'évaluer l'impact de la solution sur le confort extérieur. En effet, nos solutions ne modifient pas l'humidité de l'air ni les vitesses du vent. La température moyenne radiante donne donc une première idée de l'impact sur le confort qui sera ensuite complétée par l'impact sur la température d'air.

On constate que la solution baisse de quelques degrès la température moyenne radiante ce qui représente une amélioration conséquente des conditions de confort.

La simulation en utilisant le modèle thermo-radiatif de Solene couplé avec l'équation du bilan énergétique

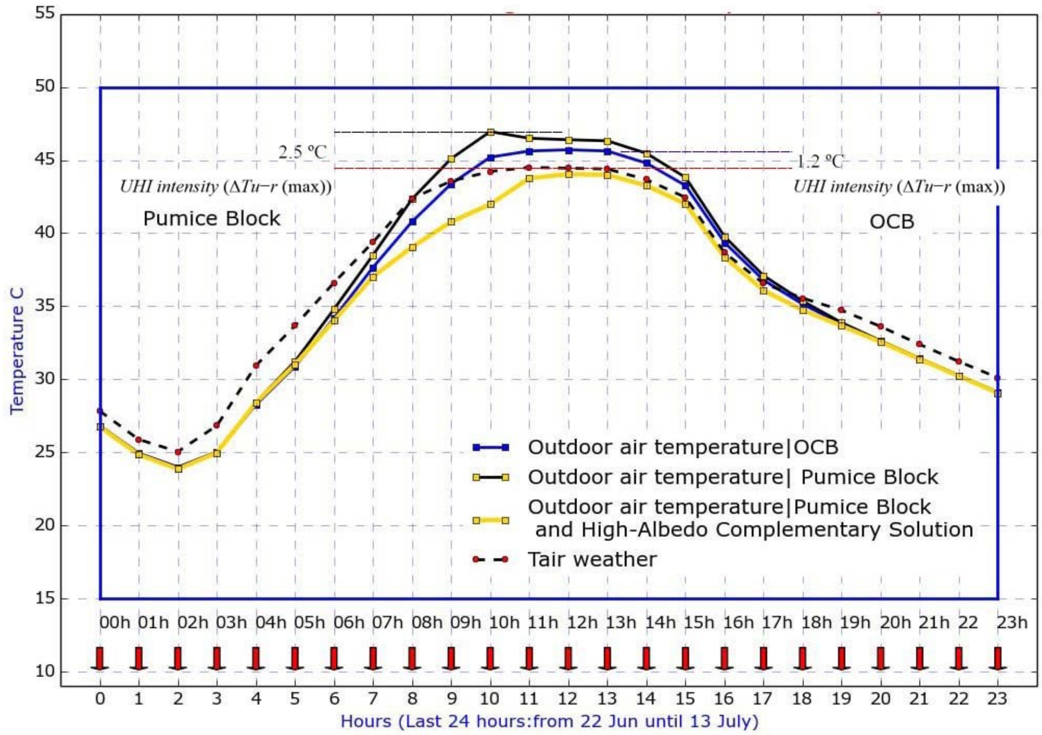


Figure 34: *Comparaison de Tair du cas d'étude réel, de la pierre ponce scénario sans solution complémentaire et de la pierre ponce scénario avec solution complémentaire*

L'impact sur la température d'air extérieur est calculé de manière moyenne, par le biais des flux convectifs. L'utilisation de la solution proposée permet de limiter l'augmentation de la température de 1,2°C par rapport à la solution initiale alors que la solution pierre ponce augmente la température maximale de 1,3°C.

7. Conclusion

Nous avons proposé une méthode pour sélectionner une stratégie de matériau, de composition, de forme et de surface pour chaque orientation de façade pour une forme urbaine donnée pour atteindre les conditions de confort intérieur et extérieur.

Cette méthode pour concevoir les enveloppes a été appliquée au cas de l'IRAK et ses résultats sont directement utilisables par les architectes pour la conception de leurs bâtiments dans ce contexte climatique.

La méthode, elle, peut aussi être utilisée pour d'autres contextes, afin d'adapter les caractéristiques obtenues.

Nous montrons aussi qu'une bonne connaissance des phénomènes thermiques est nécessaire pour comprendre les résultats et s'orienter dans la recherche de solution. L'outil solene-microclimat permet ensuite d'évaluer et comparer les solutions afin de choisir celles qui permettent d'atteindre de meilleures performances par rapport aux ambiances intérieures et extérieures.

8. Perspectives

Du point de vue de la poursuite de ces travaux en recherche, des améliorations méthodologiques peuvent être apportées.

Notre méthodologie a été très progressive pour bien comprendre l'impact de chaque élément dans la performance finale. Une fois cette compréhension acquise, elle pourrait être simplifiée en utilisant des outils d'optimisation pour lesquels il faudrait dans un premier temps sélectionner les caractéristiques à optimiser et les gammes de variation possible.

Par ailleurs, notre travail ne concernait que les parois opaques. Il serait aussi nécessaire d'étudier également les vitrages et les protections solaires avec toujours un objectif d'amélioration des conditions de confort intérieur et extérieur.

Du point de vue de la valorisation de ce travai de recherche, un objectif s'impose. Il s'agit de la proposition d'outils simplifiés pour les architectes qui pourraient prendre la forme de la rédaction de guides ou de formations. Des outils simplifiés permettant de tester rapidement des solutions sont nécessaires. Ceux-ci pourraient être construits pour des formes urbaines simplifiées par l'exploitation de resultats de plans d'expériences.

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