Modeling and thermal optimization of residential buildings using BIM and based on RTS method: application to traditional and standard house in Sousse city

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MODELING AND THERMAL OPTIMIZATION OF RESIDENTIAL BUILDINGS USING BIM AND BASED ON RTS METHOD: APPLICATION TO TRADITIONAL AND STANDARD HOUSE IN SOUSSE CITY"

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Abstract

The thermal quality of the contemporary building tends to be deteriorated due to aesthetic and economic considerations. Cheap materials which are thermally inappropriate are still rising in new buildings. Actually, the architectural design has been changed. Hence, the orientation is poorly investigated. The interior height of the new buildings is defectively compared to those of traditional houses. In addition, the patio is replaced by a corridor and different parts have already become communicating. Accordingly, the heating and cooling space becomes more and more important. The traditional dwelling, in fact, has a bioclimatic architecture which allows to provide naturally minimal comfort.

In our work, we tend to exploit the REVIT software in the residential building simulation in Tunisia and to optimize the modern housing model. Following the REVIT validation of the obtained results and comparing them to TRNSYS and SPREADSHEET ASHRAE, we have already relied on them to assess both housing models (contemporary and traditional). Using REVIT, the evaluation results show that traditional housing are more efficient than contemporary ones particularly during summer period. Then, we optimize the modern models making use of the passive strategies of traditional bioclimatic architecture and the improvement measures in the previous investigations. Numerous tests have been generated applying REVIT software in order to determine various models of contemporary housing which are able to be integrated into the Mediterranean climate. In fact, these tests indicate that REVIT efficiency is based on RTS method in thermal simulation of residential buildings

Keywords:

REVIT, Radiant Time Series, Thermal comfort, Heating and cooling loads, Building Information(data) Modeling, Improvement measurement, Bioclimatic design strategies

Contents

Abbreviation

A	Surface area expressed on (m²)
a	Surfaces absorbed coefficient for short wavelength
AEC	Architecture, energy and construction industry
$A_{s,b}$	Brut solar heat gain energy (Wh)
$A_{s,u}$	Useful solar heat gain energy (kWh/m².year)
A_v	Glazing surface (m²)
BIM	Building information modeling
CAD	Computer Aided- Design
E	Thickness (m)
ΔE	Overall energy saving %
ΔR	Difference between long-wave radiation incident on surface from sky and surroundings and radiation emitted by blackbody at outdoor air temperature, (W/m²)
Δt	Heating or cooling number hours that exceeded set point temperature (hours).
CDD	Cooling degree-days
C_i	Specific Heat
CLTD/CLF	Cooling Load Temperature Difference/Cooling Load Factor
COS	
CTF	Conduction Transfer Function
CTSF	Conduction time series factors
c_n	Conduction time series factors for n hours
CTS	Conduction Time Series
CH	Collective housing
DB	Dry Bulb
DB/MWB	Dry Bulb and coincident Mean Wet temperatures
E	Energy consumption for overall period of heating and cooling. (KWh/m².year)
EC	Energy Cost
E_C	Energy consumption for cooling period (kWh/m².year)
Ef	Expectancy Factor to corrected PMV index
E_H	Energy consumption for heating period (kWh/m².year)
E(t,b)	Beam component expressed on (W/m²)
E(t,d)	Diffuse component expressed on (W/m²)
E(t,r)	Ground-reflected component expressed on (W/m²)
Et	Total solar radiation incident on surface, (W/m²)
EUI	Energy Use Intensity (KWh/m².year)
FAI	Full Automated Interface
f(s,i)	fraction of absorbed solar flow by surface
G	Ground reflectance
GBS	Green Building Studio
GBXML	Green Building XML, exchange format between CAD and/or engineering software
H	Elevation expressed in (m)
h0	Coefficient of heat transfer by long-wave radiation and convection at outer surface, (W/(m².K))

H	Street height
H/M	Aspect ratio (Street height/street width)
HB	Heat Balance
HBM	Heat Balance Method
HC	High class social
Hc	Heat capacity expressed on (kJ/ m²K)
Hce	Outside convective coefficient which is expressed in kJ/hm²K
Hci	Convective exchange coefficient which is expressed on kJ/hm²K
HDD	Heating degree-days
$\mathrm{H_h}$	Overall solar irradiation received by window for overall heating season (Wh/m²)
IAC	Inside shading attenuation coefficient
IDF	Input Data File, format data used by building energy analysis tools
IFC	Industry Foundation Classes , format data used by design tools
IH	Individual housing
K	Thermal Transmission Coefficient
K_f	Window transmission coefficient (W/m²K)
LCC	Life cycle cost
$\mathrm{L_H}$	Energy needed to maintain indoor steady temperature without contribution of solar heat gain (kWh/m².year)
LST	Local Standard Time
MC	Middle class
MCV	Mean Comfort Vote
NBST	National Building Company of Tunisia
$\mathrm{N_s}$	Fraction of useful solar heat gain energy by brut solar heat gain energy
PMV	Predicted mean vote
PPD	Predicted percentage of dissatisfied
PPS	Predicted percentage of satisfied
PRF	Periodic Response Factors
PRF/RTF	Periodic response factor/Radiant time factor Generator software
$\mathrm{P_w}$	Heating or cooling equipment power (W)
RH	Relative Humidity, expressed on (%)
RHB	Residential Heat Balance.
RLF	Residential Load Factor
r_n	Radiant time factors for n hours
RTF	Radiant Time Factors
RTS	Radiant Time Series
SAI	Semi-Automated Interface
SHGC	Solar Heat Gain Coefficient
Solar Taub	Clear sky optical depth for beam irradiance
Solar Taud	Clear sky optical depth for diffuse irradiance
ST	Set point Temperature
t0	Outdoor air temperature, (°C)
te	Sol-air temperature
T	Temperature, (°C)
TETD/TA	Total Equivalent Temperature Difference/Time Average
TFM	Transfer Function Method
TRNSYS	Transient System Simulation Program
TZ	Time Zone

U	Thermal transmittance
UTC	Coordinated Universal Time
W	Humidity Ratio, expressed on (g/kg)

Greek letters

α	Absorptance of surface for solar radiation
ε	Hemispherical emittance of surface
ρ	Density
τ_f	Glazing transmission coefficient (W/m²K)

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Preface

The urban landscape is constantly growing. It does correspond to the rigid transition from defined outlines to undefined outline of agglomeration. During the last century, urban growth has become excessive. The emergence of urbanization and low thermal efficiency buildings in cities were thanks to a new urban movement. In fact, this phenomenon resulted in deterioration of the thermal quality of new buildings and the degradation of the climate and natural environment. In Tunisia, this phenomenon is also present in the residential sector show that the housing stock has a growth rate of 45% from 1984 to 2009. The Tunisian thermal quality of new housing is poor to meet comfort atmosphere in residential buildings. It resorts that the use of heating and cooling equipment has increasingly moved from 7% in 1989 to 20% in 2009 of final energy consumption. In 2016, these percentages are perpetually growing. This increase represents a significant waste of energy and leads to a major environmental pollution. In Tunisia, projections show that in 2020 energy consumption of the building sector will become the largest energy consumer. This increase in energy consumption is the result of various social changes and architectural transformations taking into account shortly term economic considerations. Coming up an excessive urbanization the excessive increased energy consumption and depletion of renewable energies, the Rio conference in 1992 was held to produce Agenda 21. This Agenda is a framework for reflection which resulted in changing the planning in order to promote a sustainable development concept. The latter is based on two developmental strategies as "think globally and act locally."

Agenda 21, as framework actions, open the way to hierarchical reflections from politicians to scientists in order to enhance a development policy of green building. In Tunisia, 2009 Act of the thermal regulation of residential buildings is imposed establishing the minimum of technical specifications for energy saving in buildings. Hence, there is a complementary work between institutions and building actors to develop the green building policy in Tunisia and to apply these regulations. The green building is a scientific project that has an urban policy scope, the interrelationship between the two entities allows the emergence of sustainable cities with high energy efficiency in Tunisia. A first entity controls a law application and the second entity uses scientific knowledge to meet the sustainable development of buildings. In this thesis, we will discuss two key solutions. The first solution consists of using a new technology as Building Information Modeling (BIM) for sustainable building. The second solution uses the passive design strategies relying on the climate as an old source of a cheap passive energy. As well as, Tunisian traditional architecture is a bioclimatic model. During the last century, traditional house was able to meet the climatic requirements, especially in summer, in accordance with the lifestyle of its inhabitants. This kind of dwelling appears as bioclimatic architecture. Starting from the independence period, the original inhabitants left ancient city to stay in a new one seeking comfort. In the medina, non-connecting rooms and open air patio have a major problem in winter. Therefore, this typology causes a big transformation at the level of the construction materials and the architectural design. Many contemporary houses have not benefited from passive design strategies which are presented in traditional houses. These passive design strategies, in fact, are clearly shown in the patio which represents itself a micro-climate. In a contemporary house the atrium is changed by a lobby or hallway which allows to access into different rooms. Hence, the heated zone becomes wider. These transformations are brutal and with no transitions. They are unable to provide appropriate solutions to Tunisian climatic conditions. Therefore, the main interest of this research is to improve the thermal quality of contemporary houses. The passive design strategies, found in the literature review and in traditional house were identified and provided improvements. The improvement variants were simulated using REVIT which represents the tool of BIM. This popular tool focused on non-residential buildings to calculate the heating and cooling loads. Therefore, we need to verify a REVIT performance on a thermal simulation in residential buildings. Finally, this research work uses REVIT for geometric design and for creating an energetic model in order to achieve thermal effective variants for contemporary house model. Subsequently, the originality of this work appears in two aspects:

- REVIT is based actually on the steady state for heating and cooling load calculation of non-residential buildings. In this case, the verification of REVIT efficiency for residential building simulation consists of comparing its results to those found in the literature review. We choose, therefore, the simulation results which are depended on transient state as TRNSYS

- The majority of Tunisian buildings do not take account of bioclimatic design parameters as used in traditional houses to reduce energy consumption. As a result, the assessment of the climate responsive of these dwelling is based on a qualitative and quantitative investigation. Hence, traditional houses are not equipped with heating and/or cooling systems. They provide a minimal comfort especially in the summer. In this case, the evaluation of the performance will be based on the note of comfort. If the house is conditioned, the investigation will be based on assessment of heating and cooling loads. The climatic characteristics of Tunisia require a supply of heating and cooling equipment in winter and in summer respectively. A suitable design inspired from vernacular architecture can ensure and reconcile climate in both seasons. Our research work is composed of 4 chapters: literature review, check REVIT performance, analysis of meteorological data, evaluation and optimization of study models.

The first chapter of this thesis examines deeply the improvement parameters found in the literature review that are based on BIM and not based on BIM. Thus, heating and cooling load calculation were identified. As well as, the calculation method as the thermal balance and the Radiant Time Series method (RTS) were explained in detail. This last method is used by REVIT which is popular, multidisciplinary and used by architects and engineers in the preliminary design phase to improve durability and thermal efficiency of new buildings. Therefore, our work aims at exploiting REVIT the efficiency in residential buildings.

In the second chapter, we expose the methodology adopted in this research for the thermal improvement of traditional and modern house in Sousse city using BIM technology. Firstly, the identification of housing types (traditional, contemporary, unconditioned and conditioned) is used for our study. Secondly, we define the various tools that are chosen for climatic data, analysis, thermal comfort evaluation and heating and cooling load calculations. Furthermore, we identify the characteristics of each mode used by REVIT for analysis energy and for sizing heating and cooling equipment in order to promote energy saving in the preliminary design phase.
As we have seen before, REVIT focused on heating and cooling load calculation of non-residential buildings.

Thus, chapter III exploits the efficiency of REVIT in heating and cooling load calculations for residential buildings using RTS method. As a result, we selected three steps to validate the results of calculation of REVIT. The first step refers to the obtained results by Ouertani in his doctoral thesis using TRNSYS. The second step uses SPREADSHEET ASHRAE and REVIT to the same conditions as those used by Ouertani. The last part compares the achieved results to those found in the literature review.

In chapter IV, we perform a detailed analysis for meteorological data. This analysis enables us to identify passive bioclimatic design strategies which are suitable to our study site. Thereby, in this chapter, we check REVIT efficiency compared to ECOTECT software which is specialized in climate data analysis.

The chapter V is divided into two parts. The first part is based on a qualitative and quantitative of two study samples of traditional and contemporary dwellings located in traditional and new city of Sousse region. The second part enables to improve a thermal quality of contemporary house. The combination of the various improvement measures leads to a wide range of variants. Therefore, a sensitivity analysis is conducted for each improvement measures, where the first is adapted to climate and the second is cited in literature review. This optimization study seeks thermal efficient variant of a contemporary house which is close to the optimum. As well as, it identifies energy saving percentage using bioclimatic design parameters in contemporary house model. This work aims at preserving and revalorizing our architectural heritage in Mediterranean region using a new technology which is designed for a sustainable development of new construction.

Chapter I : Thermal Building Study (International and national)

The key challenge of the 21st Century is the effective achievement of more sustainable buildings [1].This major emerging issue is due to both the exhaustion of non-renewable energy resources and climate change. To mitigate climate change, the process of building design is currently undergoing some major changes. Therefore, design methods are being replaced by the concept of Building Information Modeling (BIM). According to the literature review, it seems that research in thermal building is divided into the following parts:

- Literature review of thermal Building based on BIM
- Literature review of thermal Building non-based on BIM

I.1 Literature review of thermal Building based on BIM:

In fact, BIM is a virtual model enables to store the whole data of a building project. The term "Building Information Model" first appeared in a 1992 paper written by G.A.van Nederveen and F.P.Tolman [2]. At that time, they presented BIM as an approach where the aspects of the models are used to store specific information view. BIM actually defined by The International Standard as "The shared digital representation of physical and functional characteristics of any built object and a reliable basis for decisions [3, 4]". Since, the second half of 2002, the adoption of BIM has become a trend just as its publication has been continued and the range of published topics has been increased significantly as displayed in the figure (I-1).

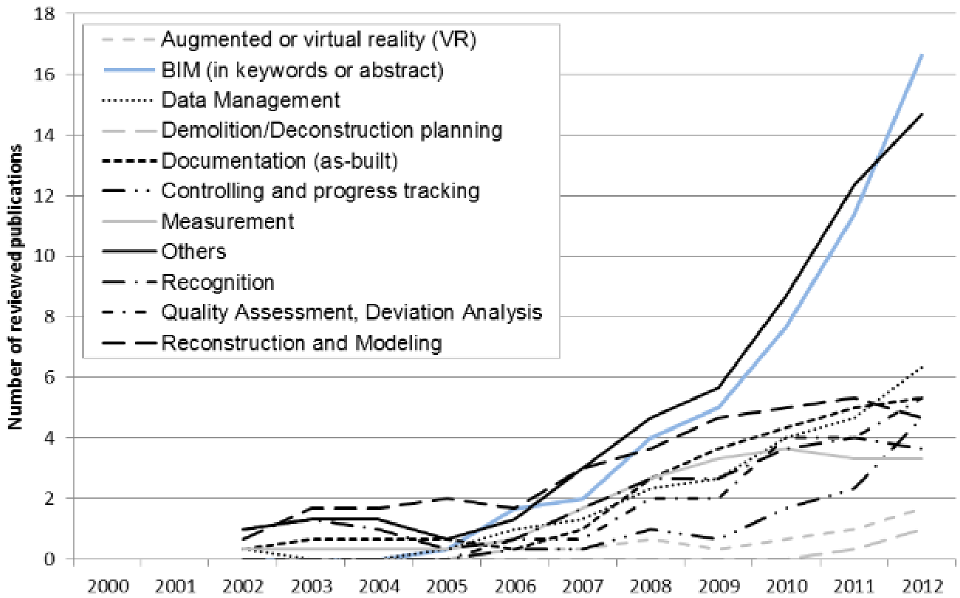


Figure I-1 Number of reviewed publications with designated BIM topics per year (multiple naming possible), depicted with moving average on 3 periods (Source: Volk et al (2014) [4])

This new technology is recorded and led to many benefits. It shares the interoperability and reduces information losses among the whole building actors. Gerber et al [5] present three on lines-surveys. These surveys are carried out to assess industrial and student interests on various BIM topics of research. The investigation, therefore, shows that BIM technology can be used to sustain Architecture, Energy and Construction Industry (AEC). In addition, these surveys prove that: 44 out of 110 practitioners are interested in using BIM in AEC. Only 79 students' school of architecture and civil engineering department of the Southern California University acquire some BIM knowledge. The below diagram figure (I-2) shows that practitioners are more interested in BIM topics than students except for energy innovation topic where students seem more interested in BIM technology than practitioners.

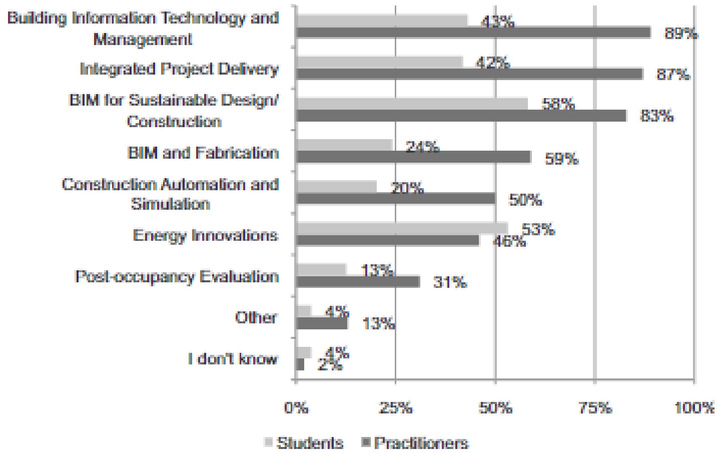


Figure I-2 Areas of research where practitioners are interested in, and the areas of research where students think will be the most important in their professions after graduating. (Source: Gerber et al (2010) [5]).

Kanters et al [6] carried out a survey in 14 internationals countries (Australia, Austria, Belgium, Canada, Denmark, France, Germany, Italy, Norway, Portugal, South-Korea, Spain, Sweden, and Switzerland). Subsequently, the responses of 350 professional architects are considered in this analysis. The obtained results show that REVIT architecture is among the most commonly used Computer Aided- Design (CAD) tools in building solar design process. The latter is classified as the third after AUTOCAD and SKETCHUP. A few years ago, AUTODESK Company added new thermal features to REVIT software as 'Energy Analysis' and 'Heating and Cooling' tools .These tools aim at improving the sustainability of building design process and assessing thermal quality in early phase of conception. Generally, they are used for residential and non-residential building. For instance, 'Heating and cooling tools' are deduced especially for a non-residential building load calculation using Radiant Time series (RTS) method. Ahn et al [7] show that BIM allows to identify the interoperability between CAD tools and dynamic energy simulation software. Their study suggests, thereafter, two approaches: Full Automated Interface (FAI) and Semi-Automated Interface (SAI). These two approaches enable information transition from CAD tools like ARCHICAD13 which used Industry Foundation Classes (IFC) to ENERGYPLUS Input Data File (IDF). They realized that SAI was not only more reliable and transparent but also ensured the quality better than FAI. This is simply because SAI allows the user to enter more accurate and variable input in ENERGYPLUS. Bahar et al [8] exhibit the most applicable tools to the BIM such as REVIT, ARCHICAD, SKETCHUP. These tools support Green Building XML (GBXML) format and can be used at many stages of the life-cycle. In addition, they can be used for energy analysis and constructional engineering. They also provide other functionalities to exchange data with other application tools. The figure I-3 displays basically the possibility of interoperability between BIM design tool and thermal application tool as: DPV, DESIGNBUILDER, ECOTECT, ENERGYPLUS, EQUEST, ECODESIGNER, GREENBUILDING STUDIO, IDA ICE, IES VE, and RIUSKA. Figure I-3 visualizes clearly the links between interfaces based on add-on or plug-in. The data exchange is conducted in various formats, primarily by GBXML. In addition, this interoperability exchange is mostly documented in literature. As prior seen, REVIT tool is used at various stages and performs energy calculation in a steady state. Therefore, we will focus on assessing REVIT efficiency compared to transient state software as Transient System Simulation Program (TRNSYS) in chapter (III).

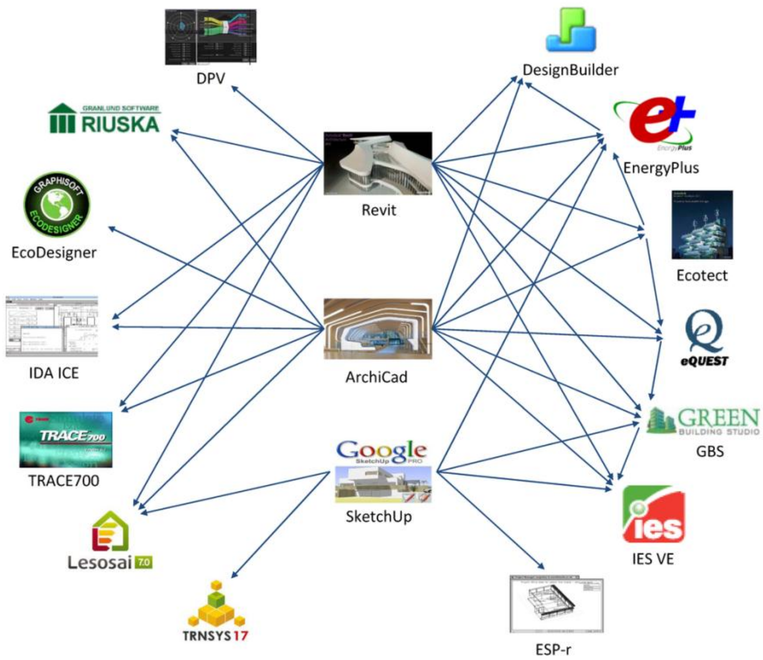


Figure I-3 Summary of data exchange between modeling tools and thermal simulation tools (Source: Bahar et al (2013) [8])

I.2 Literature review of a non -based BIM thermal Building:

Many international and national studies have been taken into consideration to reduce energy consumption of buildings. For this reason, Calculation methods were used and software were generated to evaluate the thermal performance of buildings. These studies lead to achieve the reality of energy simulation like Nelson Fumo's [9] study which is based on the comparison of an hourly thermal simulation using ENERGYPLUS software and the utility of electricity and fuel invoices. The methodology was applied in two buildings of the climate zone in United States (placed at Atlanta and Meridian). In both cases, the errors between hourly energy simulation and hourly energy consumption using utility electricity and fuel invoices are estimated at about 10%. For this reason, Shady et al [10] presented two typical habitations of three Egyptian cities of energetic models such as Alexandria, Cairo and Assiut. These models resulted in two types of construction.

Type1: While energy consumption per apartment is 22.4kWh/m²/year in Alexandria, whereas 26.6kWh/m²/year in Cairo is and 31kWh/m²/year in Assiut.

Type2: The average energy consumption for a typical apartment in Alexandria is 11kWh/m²/year, 14kWh/m²/year in Cairo and 18kWh/m²/year in Assiut. We notice that the energy consumption depends totally on the type of construction. The used tool for simulating the two parametric models reference is ENERGY PLUS. The results show that electrical energy consumption in residential buildings is substantially dominated by the seasonal use of air conditioners along summer season (April-October) in Egypt. Ouartani et al [11] in their thesis selected National Building Company of Tunisia (NBST) which represented three different types of buildings: Social housing, Economic housing and High standing houses. They also considered five regions of climate zones, Tunis, Bizerte, Jendouba, Gafsa and Gabes. To evaluate a thermal quality of conditioned houses the criteria are based on energy consumption and Energy Cost (EC). Therefore, they relied on TRNSYS14.2 for thermal simulation. On the contrary, the criteria, to evaluate a thermal quality of unconditioned houses are focused on a minimum comfort naturally obtained and did not based on energy saving. Thus, for the simulation, they combined “human body design tool” with TRNSYS. Hence, a standard assessment of comfort sensation is based on Mean Comfort Vote using the following equation according to Ouertani [11]:

$$\mathbf{MCV = [1 - PPD] \times 100} \quad (1)$$

The Predicted Percentage of Dissatisfied person (PPD) is the expected percentage of unsatisfied persons who do vote -3, -2, +2, and +3. The PPD is related also to Predicted Mean Vote (PMV) index and is given by psychophysical vote scale of Fanger [[12]] as the following table:

Table I-1 PMV Psychophysical vote scale of PMV (Source: Ouertani et al (2001) [11])

PMV	Thermal sensation	Interpretation
-3	So cold	Unsatisfied because so cold
-2	Cold	
-1	Fresh	Satisfied
0	Agreeable, neutral	
+1	Slightly hot	
+2	Hot	Unsatisfied because so hot
+3	So hot	

We note and according to the above table, the votes -1, 0, +1 correspond to Predicted Percentage of Satisfied (PPS). Ouertani et al [11] found that MCV was equal to 65.2 in July and 74.4 in January for an economic house in Tunis. But, they realized elsewhere that it was equal to 61.1kWh/m² in heating period (November to March) and 67.3kWh/m² in cooling period (June to September). According to the literature review, it appears that the most improved measures to enhance the thermal efficiency of the building in heating and cooling periods are divided in two parts as following:

-First part is related to a passive heating system like skylight and Trombe wall [[13], [14]].
-Second part represents the improved parameters variation such as [11,[15]]:
-Variation in slab inertia
-Variation in roof and wall insulation thickness.
-Variation in percentage of glass surfaces relatively to the south facade and the impact of shading system in this face.
-Variation in building orientation.
-Variation in building materials (brick, stone).
-Variation in form (simple, complex).
-Variation in roof (horizontal, cross void).
-Variation in shading system in the south facade.
-Variation in ventilation.

I.2.1 Variation in Skylight system and comfort condition

While, Skylight or Solarium represents a passive heating system [[16]], Muller [[17]] shows that thermal gains through skylight system are profitable during the heating period. But during the cooling ones, it increases the cooling load and consequently the temperature of the room. Therefore, windows need light and thermal control, particularly for conditioning with a clear sunny sky. These are defined by the percentage of reduction factors of light transmission and solar heat gain. Glare control and heat gains should not reduce daylight level. These emphasize the problem of comfort and energy consumption which represent a challenge for the design of integrated building. The skylight system is commonly used in order to provide natural lighting to an interior courtyard area, which is usually related with a lateral opening to create naturally ventilation inside. In this way, Sadafi et al [18] investigate the impacts of indoor courtyard with double terrace which is located in warm humid climate on passive cooling. Their studied model is presented by a family house located in Khuala Lampur, Malaysia. In the first step, they apply for three field-day measurement (from 10th to 13th April) in the central part of the family area. Meanwhile environmental factors have been already taken into account like air and globe temperatures, relative humidity and air velocity. Therefore, the existing house represents a baseline model (A). The thermal performance of the last one along the survey period is investigated using ECOTECT software which is known as simple, fair and accurate. The achieved simulation results from ECOTECT are compared with field survey measurements for validation. In addition, the reached findings show that the average temperature between simulation and field measurement is 0.4 °C. After that, they use the survey measurements results so as to evaluate inside thermal comfort which is based on Fanger and deDear [19,20] results. Unlike Fanger [20] proposed PMV factors range between -3 and +3, the comfortable thermal sensations have been determined to be in the region of PMV −1.5 to+1.5 for the majority of people. Some researchers found discrepancies results within PMV Fanger's range. Thus, they proposed an expectancy factor for non-air-conditioned buildings, which will be multiplied by PMV value. For instance, deDear found PMV of Fanger can predict indoor thermal comfort sensation for air-conditioned buildings more accurately than naturally ventilated buildings. It is simply because people in free-running buildings will accept higher internal temperatures. Sadafi et al applied the expectancy factor of 0.9 for PMV calculation. The results, of comfort condition of baseline house model (A) along three days of field measurements, show that a case study terrace house is thermally comfortable for about 15h as displayed in the following table:

Table I-2 Summary of thermal comfort condition according to PMV variations (Source:Sadafi et al (2011) [18])

Time	Number of hours	Comfort condition	PMV
11:30 pm to 6.30 am	7	Comfortable	$-1.4 \leq PMV \leq 1.5$
8:30-11:30 pm	3		
6:30-9:30 am	3		
9:30-11:30 am	2	Almost comfortable	$PMV \approx +1.5$
6:30-8:30 pm	2		
11:30 am-6:30	7	Uncomfortable	$+1.7 \leq PMV \leq +2.7$

In the second step, they introduced a rectangular courtyard with 2.5m × 2.2m which taken as a model (B). The attained results prove that the modified house with internal courtyard can improve interior thermal conditions better than courtyard's surrounding spaces. In this case, it is necessary to provide sufficient and efficient openings for natural ventilation, suitable materials for walls of internal courtyard and shading devices to attain satisfactory results.

I.2.2 Variation in Trombe wall system

A study is carried out using TRNSYS for the simulation of a simple typical Tunisian building [21] which has 16m² area. This survey shows that Trombe wall system saves 77% of energy demand for a non-insulated house by 8m^2 vented Trombe wall. It also reaches 97% reduction of the annual heating load based on 6m² Trombe wall areas and double wall with 5cm insulation thickness of expanded polystyrene. In mild and subtropical climates, the integration of Phase Change Materials (PCMs) in the inside surface of the intermediate partition of a Trombe wall helps to reduce the superficial temperature variability [22].

I.2.3 Variation in slab inertia

Ouertani et al [11] found that the increase of the floor thermal inertia of the floor is not beneficial to energy saving. Florides GA et al [23] have presented an analysis of the various measures used to decrease building energy consumption and showed their cost-effectiveness. Despite the use of TRNSYS, they found that increasing thermal mass of roof and wall is not enough for energy saving. In this way, Ghrab [24] assumed that an increasing wall thermal capacity is more decisive than choosing the benefits of several wall arrangements in summer conditions.

I.2.4 Variation in roof insulation and wall thickness

In maritime environment (Tunis, Bizerte, Gabes), Ouartani et al [11] noticed that a 5 cm thickness of an insulation roof creates a significant reduction in cooling load by 66%. Ucar [25] found out that the insulation thickness of an outside surface in a Turkish building is 6cm with an internal temperature of 18°C which corresponds to a 77.2% reduction in energy consumption.

Jaber et al [15] developed three different points of view to optimize energy in typical residential buildings in Jordan. These points of view correspond to an energetic, technical and economic study of the building. The simulation results which rely on TRNSYS reduce 23.54% of initial energy cost and 11.67% of Life Cycle Cost (LCC) of energy. Meanwhile, the design parameters are optimal windows, optimal shading device and respectively 20cm ceiling insulation, as well as 13cm. However, Florides et al [23] show that the thickness insulation of 50 mm for the wall. Ghrab et al [26] present an experimental evaluation of the thermal performance of a pavilion solar roof. The latter illustrates a passive solar house with a total area of 66m2 located in the ENIT (National Engineering School of Tunis). The study involves the thermal simulation of various parametric designs. The applied tool for this simulation is the version of TRNSYS 12.1. Ghrab et al [26] demonstrate eventually that the insulation of the roof and walls reduce energy consumption. Ghrab [24] propose 23 layers arrangements of walls for a thermal simulation in another article. The purpose of this study is to design an efficient wall in summer period. First, the obtained results show that the heat flow through the wall is not directly related to the Thermal Transmittance (U) value. Second, the most favorable thickness of the double wall insulating is between 5 and 7 cm which seem more suitable for both heating and cooling conditions. Finally, we can deduce that the double wall insulation is a further supplementary investment that will be replaced by energy savings.

I.2.5 Variation in percentage of glass surfaces relative to the south facade and the impact of shading system in this face.

Ouertani et al [11] show that 60% of the south wall glazing surface with 4cm insulation thickness reduces the heating needs. This investment is quite profitable because it permits a 66% reduction of energy consumption during the heating period of Gabes in Tunisian South Region. As seen prior, Samar Jaber et al [15] assess a thermal performance of typical residential building in Amman region in Jordan at the initial design stage using TRNSYS. This tool which used to identify an optimal orientation of passive façade of model house is composed of a guest and living room. Construction materials used in this house are double-glazed windows with an aluminum frame, envelope insulation and an optimal percentage glazing and shading device in South façade. In this study, three levels are taken into account as following:

- **Energetic level**

Simulation results show that a wall is composed of 40% surface glass requires the following total energy:

- West façade: 14,001kWh.
- East façade: 13,833kWh.
- North façade: 13,761kWh.
- South façade: 13,565kWh.

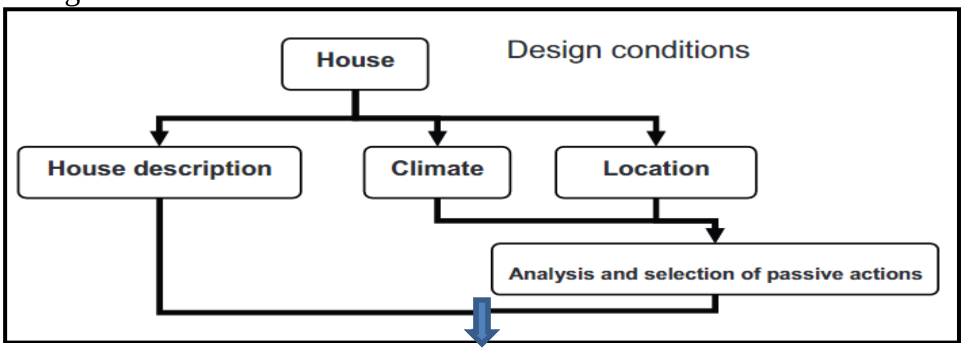
Consequently, the South facade represents the most efficient orientation.

- **Technical level**

The optimal percentage of glazing area in North orientation is 10%, 20% for the West orientation and 40% for the Southern and Eastern orientations.

- **Economic level**

The results show that the decrease of life cycle cost of buildings occurs only if window area represents 30% of south facade, 20% of the east wall and 10% of the North and West facades. In addition, a shading device which is located on the South façade allows to save energy and money. Nonetheless, the results reveal that the reduction of energy consumption is nearly equal to 25.31% and the LCC is decreased by 11.67% using the optimal window size accompanied by shading system, ceiling and walls insulation with a thickness of 0.2m and 0.13m respectively. Ruiz and al [[27]] are interested in improving energy performance of residential building in Spain. In this study, the applied methodology is based on different steps (figure (I-4)). The first step is based on identifying passive actions suited for the location and the climate of the project. In the second step, it is limited to the performance of the thermal demand of original building. In third one, it applies a passive technique to the original building. In the last one, it identifies the percentage of energy saving among both the original and final buildings in which it includes all favorable actions.



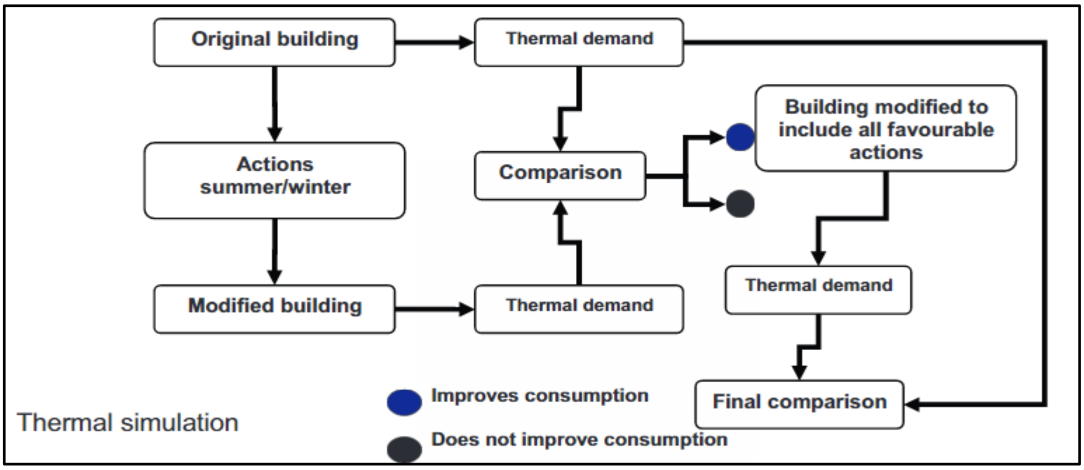


Figure I-4 Study methodology (Source: Ruiz et al (2011) [27])

Ruiz et al [27] studied a family house in Cantabria. This original house complies with energy requirements in the HE-1 document of Cordigo Technico de Edificacion using LIDERIT software for ensuring regulatory compliance and CALENER Spanish building certification software [27]. It is occupied by 6 people and its equipment is spread over 3W/m² bathroom and 32W/m² in kitchen. As far as the energy calculation is concerned, comfort levels are set using B.Givoni's psychometric diagram with Tmin=21°C, Tmax=26°C, Hmin=20% and Hmax= 75%. The calculation results show that energy consumption of original building in heating and cooling periods are respectively: 20.06kWh/m² and 14.69kWh/m². Hence, this calculation results uses ENERGY PLUS software. Research groups identify particularly 7 months for heating period and 4 months for cooling period because, the thermal consumption of original building takes place in summer as well as in winter. Therefore, the adapt design practices to the original building and passive strategies according to the climate and the location in order to reduce energy needs in winter and summer periods. However, the following passive techniques are displayed in the figures (I-5) and (I-6). They bring into consideration the orientation, 20% the increase of South and North facade openings, 2cm wall insulation, lintel to glazed openings, a light color facade, a shade creation after building a 6m wall parallel to the East facade. Each building modification is simulated separately in order to estimate energy saving, the researcher members combine subsequently the favorable actions. For instance they add a 20% glazing in North and South facade, a 35cm lintel window and 2cm façade insulation thickness. Finally, they find that annual thermal consumption is equal to 17.10kWh/m² and 13.23kWh/m² respectively for heating and cooling periods. These values represent actually energy saving while 15% in winter and 10% in summer season compared to original building as in the following equation [27]:

$$\Delta E\% = \frac{\left[\boldsymbol{E}_{(\boldsymbol{original\ building})} - \boldsymbol{E}_{(\boldsymbol{modified\ building})}\right] \times \mathbf{100}}{\boldsymbol{E}_{(\boldsymbol{original\ building})}} \qquad \textbf{(2)}$$

Where: ΔE= overall energy saving, (%)

E=energy consumption = $\boldsymbol{E}_{\boldsymbol{heating}} + \boldsymbol{E}_{\boldsymbol{cooling}}$(KWh/m².year).

As a result, these simple bioclimatic actions are beneficial and do save nearly almost 13% of energy saving in this study.

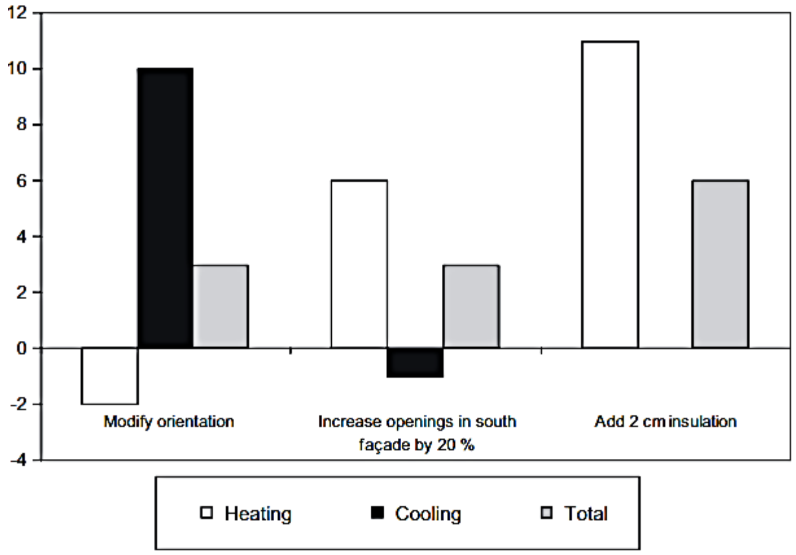


Figure I-5 Energy saving after applying winter strategies to the building (Source: Ruiz et al (2011) [27])

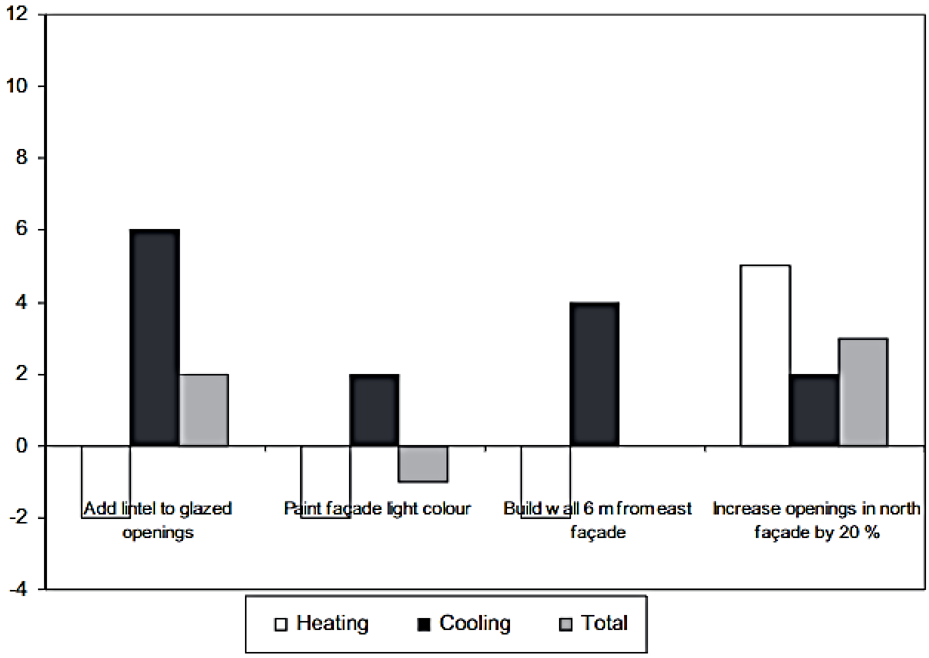


Figure I-6 Energy saving after applying summer strategies to the building (Source: Ruiz et al (2011) [27])

In our research work, we will refer to the study of methodology chart used by Ruiz et al [27] to improve design parameters of the building. In this way, Kaklauskas [28] has developed a model of quantitative and qualitative analysis of a passive house as well as intelligent system of Passive House with smart windows to control solar gain. Florides et al [23] found that double-glazed windows with a low emissivity can save 24% of the annual cooling load. Hence, the overhangs of a 1.5m length on the window can save 7% of the annual cooling load. Ghrab [24] recommended that the south and north facades are longer than the east and the west ones. As the south side glass should be 80%, the other sides must be provided with small windows as much as possible. The results show that the best solutions to save energy and money are quite different. It is possible to combine the two problems, and then to perform a multi-objective optimization approach. For Bambrook et al [29], the framework is focused on energy optimization with much respect to LCC residential buildings in Sydney. Their

study indicates that it is possible to reduce up to 94% of the conditioning cost with the requirements prescribed by legislation BASIX (5MJ/m².an).
These energy savings are thanks to:
-Wall insulation R =5.2m²K/W and roof R =6.5m²K/W
-Windows low thermal transmittance
-South facade with a shading System
-Optimal size of windows.
-Reduction of infiltration
- Using the thermal mass of the internal wall.
-Concrete slab insulation
-Summer night ventilation
The results state that the optimized model is more efficient than the original model which responses to the BASIX standard. They are obtained by taking into consideration the construction, HVAC, electricity costs, over a period of 20 years.

I.2.6 Variation in building orientation

Ucar [25] concluded that the south facade is the most effective orientation because it provides 11.67% less of energy consumption.

Ruiz et al [27] in ENGREPO research group found that the best orientation is the South facade. The final thermal simulation of an improved building attains an annual consumption of 17.10kWh/m² for the heating and 13.23kWh/m² for the cooling. This grants, indeed, a saving of 15% in winter and 10% in summer. As a result, these simple bioclimatic actions improve energy use and lead to 13% reduction in energy consumption. Through simple practices, these investments have barely increased building cost.

I.2.7 Form variation of (simple, complex)

Florides et al [23] exhibited that rectangular shape enables to increase the annual heating load between 8.2% and 26.7%, compared to a square-shaped building which is located in its four cardinal points. For this reason, they recommended that rectangular house should orient its longest side to the south.
Ghrab et al [26] pointed out that the rectangular shape of the building is the optimal configuration for reducing energy consumption. From an economic point of view, the compact shape of the building is the most optimal solution, although this shape increases the conditioned energy.

I.2.8 Ventilation variation

In summer, Florides and al [23] assumed that ventilation leads to a maximum reduction in annual cooling load of 7.7% to maintain the house at 25°C. After evaluating the profitability, they urge to use the ventilation when outdoor temperature is lower than internal one.
According to the literature review, it appears that several softwares are used such as: REVIT, LIDERIT, TRNSYS and ENERGYPLUS in order to optimize design variables. These softwares enable to determine thermal performance, load calculation and improve design variables.

I.3 Analysis and calculation types

Literature review shows that these design parameters are used in:
- Conceptual Energy Analysis (CEA).
- Dynamic thermal simulation (simplified and detailed)

- Steady state thermal simulation(thermal simulation of Steady state)
- The regulatory calculation

I.3.1 Conceptual Energy Analysis:

It is used in the preliminary design phase. We are only interested in the building envelope. The conceptual analysis allows us to analyze the influence of different design measures according to energy economy of the building such as orientation, the percentage of the glass surface, the environmental impact, shadow and sunshine.

I.3.2 Dynamic Thermal Simulation (DTS):

The simplified dynamic thermal simulation gives an hourly building load. This hourly simulation across the entire time study is based on design data (weather, occupancy, areas ...). The detailed dynamic thermal simulation is used for the building with a highly energetic performance. This kind of simulation involves a detailed modeling of the building (thermal bridges, solar masks), and employs a Heat Balance Method (HBM) for the load calculation.

I.3.3 Steady State Thermal Simulation (SSTS):

A steady-state approach is a simplified method and derived from HBM. It is used to evaluate the energy demand whether monthly or yearly with a constant indoor temperature and moderately outdoor climate.

I.3.4 Regulatory calculation:

This type of analysis is not oriented to building design but it is generated by a regulatory imposition. Using regulatory tool, we can check the thermal performance of the building compared to the standard regulatory imposition. We notice several softwares are used for building thermal simulation as each has its own interface, and its own engine for modeling, for calculating and for analyzing. Dynamic thermal simulation state is exerted in the detailed phase of design. However, the user refers to thermal simulation of steady state especially at an early phase of the design. This latter provides a rapid decision at preliminary phase of design simply because he needs rapid decisions.

I.4 Heating and cooling load calculation method:

I.4.1 History

Cooling load calculation methods have been developed, improved and published in ASHRAE handbook for decades as following:

- 1980, ASHRAE published Cooling and Heating Load Manual Calculation that included Cooling Load Temperature Difference/Cooling Load Factor (CLTD/CLF) procedure for load calculation developed by Rudoy and Duran.
- 1992, ASHRAE published 2nd Edition of Cooling and Heating Load Calculation Manual by McQuiston and Spitler. In this edition CLTD/CLF, Transfer Function Method (TFM) and Total Equivalent Temperature Difference/Time Average (TETD/TA) procedure for heating and cooling load calculation are presented.
- Middle 1990's, despite revisions to all the methods, ASHRAE Load Calculation Technical Committee remained "dissatisfied" with the previous methods.
- Then, in 1996 ASHRAE technical committee replaced the existing method by Heat Balance (HB) and RTS method. The first method was developed by Pederson et.al, 1997 as well as, the second method appears by Spitler et.al, in 1997.
- Besides, from 1997 until now ASHRAE Handbook Fundamentals is appearing in revised versions.

In this work, we will focus on using ASHRAE 2009 [30], 2005 [31] and 2001 [32] editions.

I.4.2 Generality:

In steady state, the energy balance of the building equalizes the sum of the heat gains and the losses. This is clearly explained in the following equation:

$$\sum(\textbf{internal gains} + \textbf{solar gains} + \textbf{heating or cooling load}) = \sum \textbf{heat losses} + \textbf{ventilation} \qquad (3)$$

Where, the sum of the heat losses is produced by the conduction, the convection and the losses of radiation. The purpose of heating and cooling load calculation is to determine the maximum heating and cooling load in each period.

- In winter, we determine the necessary heating energy rate. We need this energy in order to keep a comfortable atmosphere inside.
- In summer period, we determine the cooling energy rate to get rid of the inside continuous heating. We need this energy to maintain a comfortable temperature and humidity inside the building.

I.4.2.1 Cooling load principle:

The building components which affect the cooling load are:
-External input (walls, roof, floor, window, and ceiling)
-Internal supply or internal load (lighting, occupants, appliances, equipment)
-Infiltration (air leaks, moisture migration)
-System (duct leakage, heating, ventilation)

I.4.2.2 Heat gain by space

It is the heat rate produced in the space. It is classified either by sensible heat load or latent heat load.

- <u>Sensible heat load</u>:

In this case, the heat is added to air-conditioned space by conduction, convection and radiation

- <u>Latent heat load</u>:

In this condition, humidifying or dehumidifying air from the space contributes to its heat load. These input modes are similarly useful in heating and cooling period.

I.4.2.3 Radiant heat gain:

The radiation heat gain will be absorbed by the building surfaces and the furniture. Then, this gain will be divided in two.
-The first portion will be instantly transferred by heat convection after increasing the temperature of the inside surface.
-The second portion will be stored within building walls thanks to thermal capacity and materials of construction. The stored portion will be transferred to the air in the interior of the space by heat radiation and convection.

I.4.3 The method of Heat Balance calculation:

HBM is considered as the most fundamental and general method. In other words, it takes accurately into account the heat transfer rates to interior, exterior areas and air zone [33]. This method is totally based on the building type residential or nonresidential. Therefore, we use for residential building calculation a detailed method called Residential Heat Balance (RHB). Pederson and al derived a new simplified method from RHB called Residential Load Factor (RLF). However, for non-residential buildings, we refer also to accurate building calculation method HB (Heat Balance). Although we can use a simplified calculation method such as RTS which is derived from HBM [31], the users can generate RTS method for residential heating and cooling load calculations making use of SPREADSHEET ASHRAE tool or program as REVIT software. Further details will be presented afterwards in chapter (II).

I.4.3.1 Assumptions:

These assumptions are cited as following:
-Air temperature is uniform all over the zone.
-Uniform surface temperatures
- Long waves (LW) and short waves (SW) irradiation uniforms.
-Diffuse radiating surfaces
-One-dimensional heat conduction.

I.4.3.2 Heat Balance processes

The HB method takes into consideration four distinct processes like the heat balance of the outside-face and the inside-face, wall conduction process and the air heat balance as shown in figure (I-7). It displays the relationship between these processes in a single opaque surface. In fact, these processes are classified successively from outside face to interior space. The previous processes are repeated for opaque and transparent surfaces. However, the absorbed solar component appears in the conduction process part instead of the outside face, where the absorbed component splits inwards and outwards flowing fractions. These components, indeed, participate in the surface heat balances.

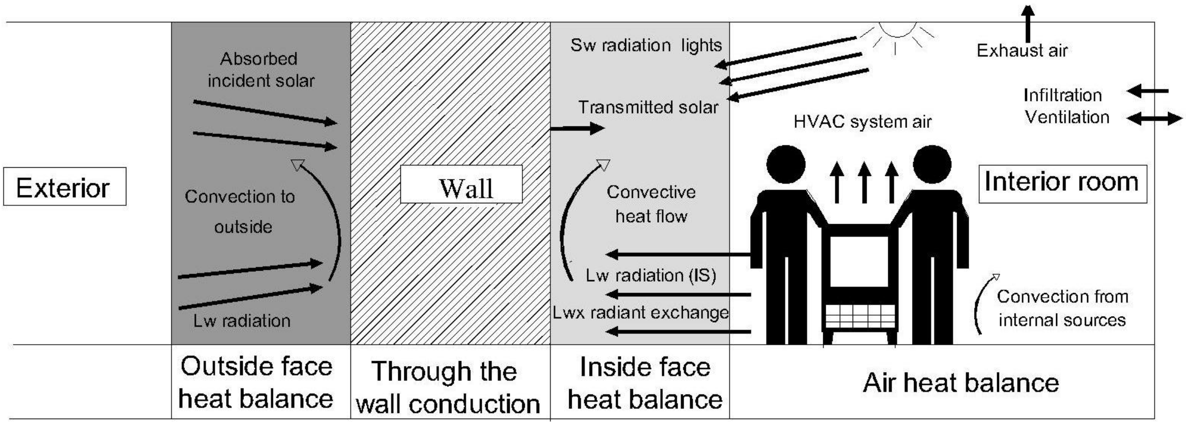


Figure I-7 Heat balance process in zone

- The heat balance of an outside surface

$$q''_{asol} + q''_{LWR} + q''_{conv} - q''_{ko} = 0 \quad (4)$$

Where
q''_{asol}= direct absorbed and diffused solar radiation flow (q/A), (W/m²).
q''_{LWR} =net long-wave radiation exchange with the surroundings, (W/m²).
q''_{conv}=convective heat flow exchanged with outside air, (W/m²).

q''_{ko}= wall conductive flow, (W/m²).

- The heat balance of an inside surface

$$q''_{LWX} + q''_{SW} + q''_{LWS} + q''_{ki} + q''_{sol} + q''_{conv} = 0 \qquad (5)$$

Where
q''_{LWX}=net long-wave radiant heat flow exchange between zone surfaces, (W/m²).
q''_{SW} =net short-wave radiation heat flow to surface from lights, (W/m²).
q''_{LWS} =long-wave radiation heat flow from equipment in zone, (W/m²).
q''_{ki} =conductive heat flow through wall, (W/m²).
q''_{sol} =transmitted solar radiant heat flow absorbed at surface, (W/m²).
q''_{conv} =convective heat flow to zone air, (W/m²).

- **Wall conduction process**

Wall conduction process is linked to outside and inside heat balances as it is shown in fig (I-8). Wall conduction is formulated using Conduction Transfer Functions (CTF), which relates conductive heat flow to current and past surface temperatures and past heat flows. The general form of the inside heat flow is:

$$q''_{ki}(t) = -Z_0(T_{si,\theta}) - \sum_{j=1}^{nz} Z_j T_{si,\theta-j\delta} + Y_0 T_{si,\theta} + \sum_{j=1}^{nz} Y_j T_{so,\theta-j\delta} + \sum_{j=1}^{nq} \emptyset_j q''_{ki,\theta-j\delta} \qquad (6)$$

For outside heat flow, the form is as following:

$$q''_{ko}(t) = -Y_0(T_{si,\theta}) - \sum_{j=1}^{nz} Y_j T_{si,\theta-j\delta} + X_0 T_{so,\theta} + \sum_{j=1}^{nz} X_j T_{so,\theta-j\delta} + \sum_{j=1}^{nq} \emptyset_j q''_{ko,\theta-j\delta} \qquad (7)$$

where
$\mathbf{X_j}$=outside CTF,j = 0,1,…nz, (j=1 to 24 hours in the day)
$\mathbf{Y_j}$ =cross CTF,j = 0,1,…nz
$\mathbf{Z_j}$=inside CTF, j = 0,1,…nz
$\emptyset_j$ =flux CTF, j = 1,2,…nq
θ =time
δ=time step
$T_{si,\theta}$ =inside-face temperature, (°C), (i=1 to 12 zone surfaces)
$T_{so,\theta}$=outside-face temperature, (°C).
$q''_{ki,\theta}$ =conductive heat flux on inside face, (W/m²).
q''_{ko} =conductive heat flux on outside face, (W/m²).

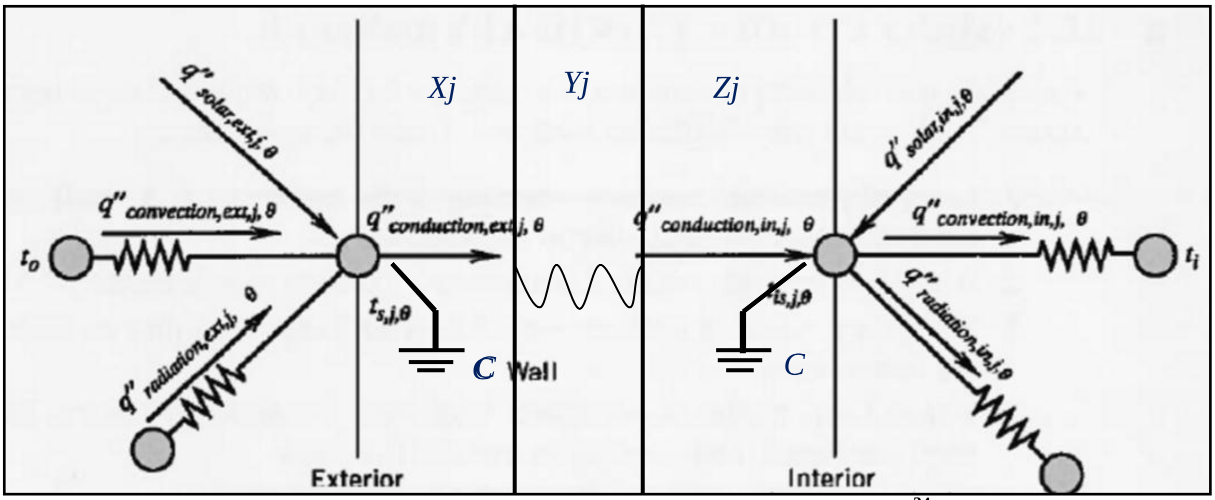


Figure I-8 Graphical representation of the heat balance[34]

- The heat balance of the air zone

In HB, formulations aim at determining cooling loads, the capacitance of air in the zone is neglected and the air heat balance is done quasi steady balance in each time periods. Four factors contribute to the air heat balance:

$$q_{conv} + q_{CE} + q_{IV} + q_{sys} = 0 \quad (8)$$

where

q_{conv} =surfaces convective heat transfer, (W).

q_{CE} =convective parts of internal loads, (W).

q_{IV} =sensible load caused by infiltration and ventilation air, (W).

q_{sys} =heat transfer to/from HVAC system, (W).

We note that HBM requires detailed input and computer implementation to solve hourly simultaneous heat balance equations cited before.

I.4.4 Radiant Time Series (RTS) calculation method:

RTS calculation method aims to provide a simplified method based directly on a HB method. Thus, it is found on the assumption of steady periodic conditions. This method is suitable for peak design load calculation in heating and cooling periods. However, it should not be used for annual energy simulation due to its inherent limited assumptions [32]. We can use a manual calculation in order to estimate cooling loads. In fact, this method is tedious and repetitive for multiple design conditions. Therefore, we can generate this method using Spreadsheet ASHRAE tool or REVIT program which contains “Heating and Cooling Load” tool. More details will be after all presented in chapter II.

I.4.4.1 Cooling load calculation

Computing the cooling load by RTSM does not solve the equation of heat balance. The simplification from HB procedure consists of taking advantage from the Steady Periodic Nature of cooling load calculation. In1999, Spitler et al [33] demonstrated that Conduction Transfer Function (CTF) was determined by transient conduction calculation which could be reformulated on Steady Periodic Response Factors (PRF). The last one is called Conduction Time Series (CTS) and RTS method in steady-periodic heat input. Spitler et al [33] set a second predetermined simplification for Steady Periodic Zone Response Factors called Radiant Time Factors (RTF). RTF are called time series which represent the chronological thermal response of an adiabatic zone (does not exchange heat to outside) to a single steady periodic pulse of radiant energy incident on the internal surface zone. Besides, to generate accurate coefficients, we can use Periodic Response Factor/Radiant Time Factor (PRF/RTF) Generator software. These coefficients are known as errors source. So, if these coefficients are determined, the RTSM can be implemented in a SPREADSHEET ASHRAE for peak cooling load calculation and thus for assess components contribution to the hourly cooling loads. The third previous simplification divides heat gain of local on convective and other radiant portions. In fact, RTSM is based on three simplifications as following:

I.4.4.1.1 First simplification

First simplification is used to divide the 24 Periodic Response Factors (PRF) by the respective overall wall or roof U-factor and to form the conduction time series. Conduction heat gain depends on PRF and temperatures as described in the following equation:

$$\boldsymbol{q_\theta = p_{r0} A\left(t_{e,\theta} - ST\right) + p_{r1}\, A\left(t_{e,\theta-1} - ST\right) + \cdots + p_{r23}\, A(t_{e,\theta-23} - ST)} \tag{9}$$

Where:
$\boldsymbol{q_\theta}$ = hourly conductive heat gain for the surface, (W).
$\boldsymbol{p_{r0}}, \boldsymbol{p_{r1}}$, etc. = periodic response factors, (W/ (m².K)).
$\boldsymbol{U}$ = global heat transfer coefficient for the surface, (W/ (m².K)).
$\boldsymbol{A}$ = area, (m²).
$\boldsymbol{t_{e,\theta-n}}$ = Temperature"$\boldsymbol{\theta - n}$".
$\boldsymbol{ST}$ = presumed constant room air temperature, (°C).
According to ASHRAE Manual, the sol-air temperature is shown by the following equation:

$$\boldsymbol{t_e = t_0 + \frac{\alpha E_t}{h_0} - \frac{\varepsilon \Delta R}{h_0}} \tag{10}$$

Where
$\boldsymbol{t_e}$ = Sol air temperature,(°C).
$\boldsymbol{\alpha}$ = radiation absorption coefficient by the surface.
$\boldsymbol{E_t}$ =total solar radiation incident on surface, (W/m²).
$\boldsymbol{h_0}$ =coefficient of heat transfer by long-wave radiation and convection at an outer surface, (W/ (m².K)).
$\boldsymbol{t_0}$ =outdoor air temperature, (°C).
$\boldsymbol{\varepsilon}$ = hemispherical emittance of surface.
$\boldsymbol{\Delta R}$ =difference between long-wave radiation incident on a surface from sky and surroundings and radiation sent out by blackbody at outdoor, (W/m²).

In the RTS method, conduction through exterior walls and roofs is calculated using conduction time series. Wall and roof conductive heat input at the exterior is defined by the familiar conduction equation as

$$\boldsymbol{q_{i,q-n} = UA\left(t_{e,q-n} - ST\right)} \tag{11}$$

Where
$\boldsymbol{q_{i,q-n}}$ = conductive heat input for the surface in *n* hours ago, (W).
$\boldsymbol{U}$ = global heat transfer coefficient for the surface, (W/ (m².K)).
$\boldsymbol{A}$ = area, (m²).
$\boldsymbol{t_{e,q-n}}$ = sol-air temperature in *n* hours ago, (°C).
$\boldsymbol{ST}$ = Set point temperature, (°C).
Also, PRF can be written in terms of CTSF. In the following equation (12), we assume that last term will be written on $(\boldsymbol{c_n})$ term as following:

$$\sum_{n=0}^{23} p_{rn} = U \times \left(\sum_{n=0}^{23} C_n\right) \qquad \textbf{(12)}$$

Conductive heat gain through walls or roofs can be calculated using conductive heat inputs for the current hour and over 23h and conduction time series as written by the following equation:

$$\boldsymbol{q_q = c_0 q_{i,q} + c_1 q_{i,q-1} + c_2 q_{i,q-2} + c_3 q_{i,q-3} + \cdots + c_{23} q_{i,q-23}} \qquad \textbf{(13)}$$

Where

$\boldsymbol{q_q}$ =hourly conductive heat gain for the surface, (W).
$\boldsymbol{q_{i,q}}$= heat input for the current hour.
$\boldsymbol{q_{i,q-n}}$= heat input n hours ago.
$\boldsymbol{c_0}, \boldsymbol{c_1}$, etc. =conduction time series factors.
The heat transfer by conduction through the walls made from external surface envelope to interior area is caused by the temperature difference between the inside and the outside. This heat gain will be transferred to the inside late. This delay is due to the heat capacity and the construction materials envelope, where the Heat Capacity (Hc) or surface heat capacity is the ability of construction assembly to absorb or to release thermal energy. It is a significant parameter which represents a thermal propriety of construction material. Hence, it relies on Density $(\boldsymbol{\rho})$, Thickness $(\boldsymbol{e})$ and Specific Heat (C_i). The assembly heat capacity is calculated using the following equation:

$$\boldsymbol{Hc = \sum_{i=1}^{n} (C_i \times \rho_i \times e_i)} \qquad \textbf{(14)}$$

Where:
$\boldsymbol{HC}$ = the heat capacity layer (KJ/ (m².K°)).
$\boldsymbol{n}$ = the total number of layers in the assembly.
C_i = the specific heat of i th layer (KJ/ (Kg K°)).
$\boldsymbol{\rho_i}$ = the density of i th layer (Kg/m³).
$\boldsymbol{e_i}$ = the thickness of i th layer (m).

Therefore, the conduction time delay leads to a division of heat gain over 24h time series. Series coefficient is called conduction time. This conduction time factors reflect the percentage of earlier heat gain at the exterior either of a wall or a roof which becomes by the way heat at the inside during the current hour such as:

- CTS at current hour = earlier conduction time sum at current hour.

I.4.4.1.2 Second simplification

In appears, in the following equation (15), a time delay of radiant heat gain represents a radiant pulse heat gain over 24 hours. It shows that multiplying 24 Radiant Time Factors RTF by radiant heat gains for current hour and n hours ago lead to a radiant cooling load at current hour. The load charge at this time is similar along thirty-day per month.

$$\boldsymbol{Q_{r,\theta} = r_0 q_{r,\theta} + r_1 q_{r,\theta-1} + r_2 q_{r,\theta-2} + r_3 q_{r,\theta-3} + \cdots . + r_{23} q_{r,\theta-23}} \quad \textbf{(15)}$$

Where

$\boldsymbol{Q_{r,\theta}}$ =radiant cooling load (Q_r) for current hourθ, (W).

$\boldsymbol{q_{r,\theta}}$ =radiant heat gain for current hour, (W).

$\boldsymbol{q_{r,\theta-n}}$=radiant heat gain n hours ago, (W).

$\boldsymbol{r_{0,}.r_{1,}}$etc. =radiant time factors.

In the next chapter, we will focus on conduction and radiant factors in order to investigate the heating and cooling loads in Tunisian dwellings applying RTS calculation method.

I.4.4.1.3 Third simplification

HB procedure does not only solve the instantaneous convective and radiant heat transfer from each surface but also splits internal load into convective/radiant ones. Yet, RTS simplifies further the HB procedure which is based on an estimated radiant/convective heat gain. The convective and radiant portions represent the third simplification set for RTSM. These convective and radiant percentages can be viewed in the below table:

Table I-3 Convective and radiant percentages of total sensible heat gain, (Source: ASHRAE Handbook 2005 [31]).

Heat gain source	**Radiant heat, %**	**Convective heat, %**
Transmitted solar, with no inside shade	100	0
Window solar, with inside shade	63	37
Absorbed by fenestration solar	63	37
Fluorescent lights, suspended, unvented	67	33
Recessed, vented to return air	59	41
Recessed, vented to return air and supply air	19	81
Incandescent lights	80	20
People		
Conduction, exterior walls	63	37
exterior roofs	84	16
Infiltration and ventilation	0	100
Machinery and appliances	20 to 80	80 to 20

Assumptions:

The RTS method is based on the following assumptions:

- Design conditions are periodic, regular and steady (inside temperature and humidity, climate, building management, occupation).
- Outdoor climatic design conditions are periodic in both heating and cooling periods.

To determine cooling load calculation, we assume that a daily cooling load for each component is repeated along 30 days of the month and which corresponds to 24 hours (one day) heat gain. Then, to calculate peak cooling load, we need to generate 288 times design hours. Hence, the temperature profile in this period is made by the following equation:

$$288\ \boldsymbol{Annual\ design\ temperature} = \mathbf{24}\ (\boldsymbol{Dry\ bulb\ or\ wet\ bulb})\ \boldsymbol{temperature} \times \mathbf{12}\ \boldsymbol{months} \quad \textbf{(16)}$$

In addition, a monthly design temperature in hot period is based on annual percentiles frequency of occurrence by the following value: 0.4%, 1%, and 2% in the 2009 edition of ASHRAE Handbook-Fundamentals. However, 2005 edition listed 1%, 2.5% and 5% annual cumulative frequency of occurrence. To determine heating load calculation, we need to repeat 12 times design conditions which correspond to 1 hour per month. Thus, the heat gain for a particular component at a specific hour per month is the same as the previous 24h, which seems similar as the previous 48h, etc. For this period a temperature design relies on a 99.6% and 99.0% annual cumulative frequency of occurrence (more details in the next chapter).

We notice that heat gain of remain components such as: internal loads, infiltration, ventilation and windows are based also on the prior simplification.

I.4.4.1.4 Lighting heat gain:

Lighting Heat gain is expressed as the following equation:

$$\boldsymbol{q_{el}} = \boldsymbol{W F_{ul} F_{sa}} \quad \textbf{(17)}$$

Where

$\boldsymbol{q_{el}}$ =heat gain, (W).

$\boldsymbol{W}$ =total light wattage, (W).

$\boldsymbol{F_{ul}}$ =lighting use factor.

$\boldsymbol{F_{sa}}$ =lighting special allowance factor.

ASHRAE reference presents $\boldsymbol{F_{sa}}$ as the special allowance factor which is the ratio of the power consumption of lighting fixtures, including lamps and ballast, to the nominal power consumption of the lamps. We will use, thereafter, one factor for incandescent lights.

I.4.4.1.5 Equipment heat gain:

As a previous internal gain, heat gain equipment may be calculated by:

$$\boldsymbol{q_s} = \boldsymbol{q_{s\ input} F_U F_R} \quad \textbf{(18)}$$

$\boldsymbol{q_s}$= sensible heat gain, (W).

$\boldsymbol{F_U}$=usage factor.

$\boldsymbol{F_R}$=radiation factor.

$\boldsymbol{q_{s\ input}}$=rated energy input, (W).

I.4.4.1.6 Occupants heat gain

Occupants release sensible and latent heat at metabolic rate depending on the activity state [35]. Table (I-4) gives a typical metabolic generation of heat for various activities. This heat generation emits a sensible and latent heat. An example of representative rate, at which sensible and latent heat are given by occupants being in different states of activities, are reported on table (I-5).

Table I-4 Typical metabolic heat generation for various activities (Source: ASHRAE Handbook 2001) [31]

Degree of activity (Resting)	W/m²	met
Sleeping	40	0.7
Reclining	45	0.8
Seated, quiet	60	1.0
Standing, relaxed	70	1.2

(1met=58,15 W/m²)

Table I-5 Representative rates at which heat and humidity are given off by human beings in different states of activity (Source: ASHRAE Handbook 2005) [32]

Degree of activity	Location	Total heat, W		Sensible heat, W	Latent heat, W
		Adult Male	Adjusted M/F		
Seated at theater	Theater, matinee	115	95	65	30
Seated at theater, night	Theater, night	115	105	70	35
Seated very light work	Offices, hotels, apartments	130	115	70	45
Moderately active office work: walking	Offices, hotels, apartments	140	130	75	55
Standing, light work, walking	Departments store, retail store	160	130	75	55
Walking, standing	Drug store, bank	160	145	75	70
Sedentary work	Restaurant	145	160	80	80

I.4.4.1.7 Infiltration or ventilation heat gain

Air-conditioning design often requires the following information which are given by the below equation:

$$q_t = 1.2 \times Q_s \Delta h \qquad (19)$$

Where

1.2 = air density (dry air), (Kg/m³).

q_t =total heat gain, (W).

Q_s =standard flow rate, (m³/s).

Δh =difference enthalpy, J/Kg.

The sensible heat loss corresponds to a sensible heat gain. It is explained by the following equation:

$$q_s = 1.2(1.006 + 1.84W)Q_s \Delta t \quad (20)$$

Where
$\mathbf{1.006}$=specific heat of dry air, kJ/ (kg K).
$\boldsymbol{W}$= ratio of the humidity, kg (water)/kg (air).
$\mathbf{1.84}$=specific heat of water vapor, kJ/ (kg K).
$\Delta \boldsymbol{t}$=difference of temperature between interior design and outdoor temperature

We can notice that we are able to determine W value using a psychometric chart, if we know the dry air temperature and the relative percentage of humidity. In addition, we can calculate infiltration or ventilation air flow (Q_s) as following:

$$Q_s = \frac{ACH \times volume \times 1000}{3600} \quad (21)$$

Such as: $\boldsymbol{ACH}$=air change per hour for infiltration or ventilation air flow (Q_s) = l/s

I.4.4.1.8 Windows heat gain

For fenestration heat gain, Total fenestration heat gain Q:

$$Q = q_b + q_d + q_c \quad (22)$$

Where:
$\boldsymbol{q_b}$ = Gain of direct solar heat.
$\boldsymbol{q_d}$ = Gain of diffused solar heat.
$\boldsymbol{q_c}$ = Gain of conductive heat.

The direct beam and solar heat gain is expressed as following:

- Direct beam and solar heat gain is presented by the following equation:

$$q_b = A\, E_{t,b}\, SHGC\,(\theta)\; IAC\,(\theta, \Omega) \quad (23)$$

Where
$\boldsymbol{A}$ = window area, (m²)
$\boldsymbol{E_{t,b}}$ = direct irradiance, (W/m²)
$\boldsymbol{SHGC\,(\theta)}$=beam or direct solar heat gain coefficient is a function of incident angle $\boldsymbol{\theta}$
$\boldsymbol{IAC}$ = coefficient of inside shading attenuation .It becomes equal to 1, if there is no inside shading device. It is a function of shade type and may also be an equal function of beam solar angle of incidence $\boldsymbol{\theta}$ and shade geometry [30, 31].

- Diffuse solar heat gain is determined by:

$$q_d = A\,(E_d + E_r)\;(SHGC)_D\, IAC_D \quad (24)$$

Where
$\boldsymbol{E_d}$ = Diffuse irradiance,
$\boldsymbol{E_r}$ = Ground-reflected irradiance,
$\boldsymbol{(SHGC)_D}$= diffuses solar heat gain coefficient and is also called a hemispherical $\boldsymbol{SHGC}$.

- Conductive heat gain is defined by the familiar conduction equation as following:

$$q_c = UA\,(T_{out} - T_{in}) \quad (25)$$

T_{out}= outside temperature, (°C)
T_{in}= inside temperature, (°C)
U= overall U-factor, including frame and mounting (W/ (m²K))

- **RTS procedure**

The calculation procedures of cooling load are based on RTS method for each component such as occupants, equipment, lights, windows, walls and roofs. In fact, these components are based on various steps displayed in figure (I-9) and (I-10). Therefore, we can divide calculation process using RTS method in the following steps:

1) Determine hourly solar intensities such as direct beam radiation ($E_{t,b}$) which helps to find out the transmitted solar heat gain and diffused radiation ($E_{t,d}$). Whereas, the diffused ground radiation determine the solar heat gain for a window. The diffused and conductive heat sum represents the total solar radiation (E_t) which depends actually on a sol-air temperature (T sol-air).
2) Calculate hourly sol-air temperature which is used to determine the conduction heat gain through opaque surfaces like walls and roofs.
3) Calculate the heat gain profile heat gain of each component along 24 hours.
4) Divide the heat gain into radiant and convective portions. The convective portion is converted into an instantaneous cooling load, although the radiant portion is transformed into a cooling load after a time delay.
5) Apply an appropriate radiant time series to a radiant part of heat gains to consider at the time delay in conversion to a cooling load. For this activity, we need to select “solar radiant series coefficient” (solar RTS) or “non-solar radiant time series” (non-solar RTS). We will use solar RTS for direct beam heat gain and to calculate only solar beam cooling load and the contribution on window with no inside shading. For the remaining components heat gain, we will apply non-solar radiant time series in order to determine the contribution of each radiant heat gain to cooling load.
6) Determine infiltration heat gains adding all convective hourly portions.
7) Compute the total radiant, convective and infiltration heat gains to determine full cooling load of each component for an hour design.
8) Repeat the above steps during multiple hours and along one year (12 months) in order to determine the monthly peak load occurrence.

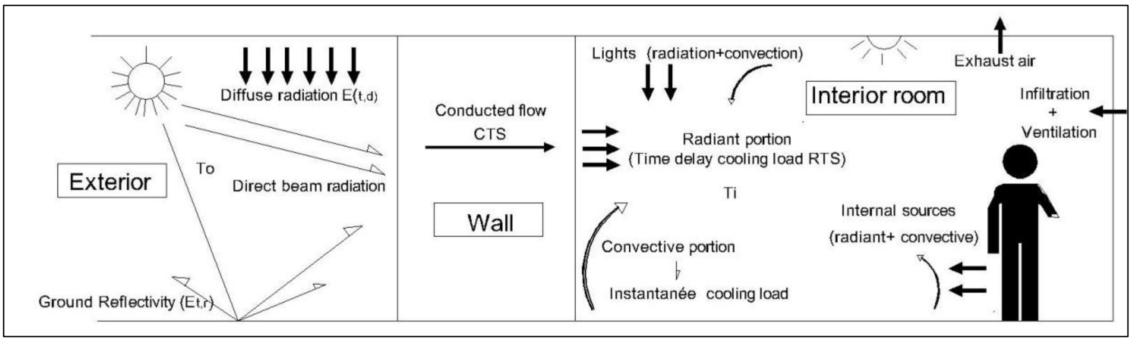


Figure I-9 RTS approach in zone

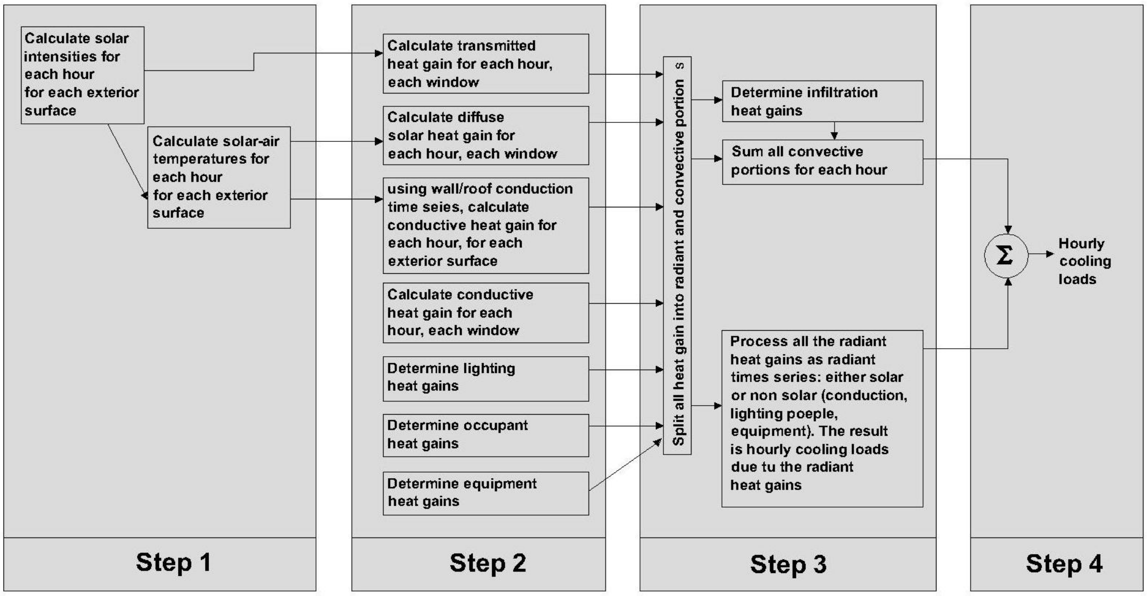


Figure I-10 Overview of different steps based on RTS method (Source: ASHRAE Handbook version 2005) [32].

I.4.5 Energy estimation

The daily estimation degree is a steady method for an energetic analysis. It enables us to estimate annual loads if the interior temperature and gains are constant and a HVAC system operate along the whole season. This method is based on indoor and balance point temperatures which are called also base temperatures.

- **Cooling and heating degree days:**

A simplified method used to estimate heating and cooling degree-days relying on the temperature base or ST is varied from 10 to 18°C for analyzed period. The HDD (heating degree-days) and $\boldsymbol{CDD}$ (cooling degree-days) are calculated as following equations [31]:

$$\boldsymbol{HDD} = \sum_{i=1}^{N} (\boldsymbol{ST} - \overline{\boldsymbol{T}}_i)^+ \quad \textbf{(26)}$$

$$\boldsymbol{CDD} = \sum_{i=1}^{N} (\overline{\boldsymbol{T}}_i - \boldsymbol{ST})^+ \quad \textbf{(27)}$$

Where daily**:**

$$\overline{T}_i = \frac{T_{i,max} + T_{i,min}}{2} \quad (28)$$

$$X^{+} = Max\,(X, 0) \quad (29)$$

And,
N=is the number of days in a month
ST =is the set point temperature
$\overline{T}_i$ =Mean daily temperature
X^{+}=only positive quantities are taken into account

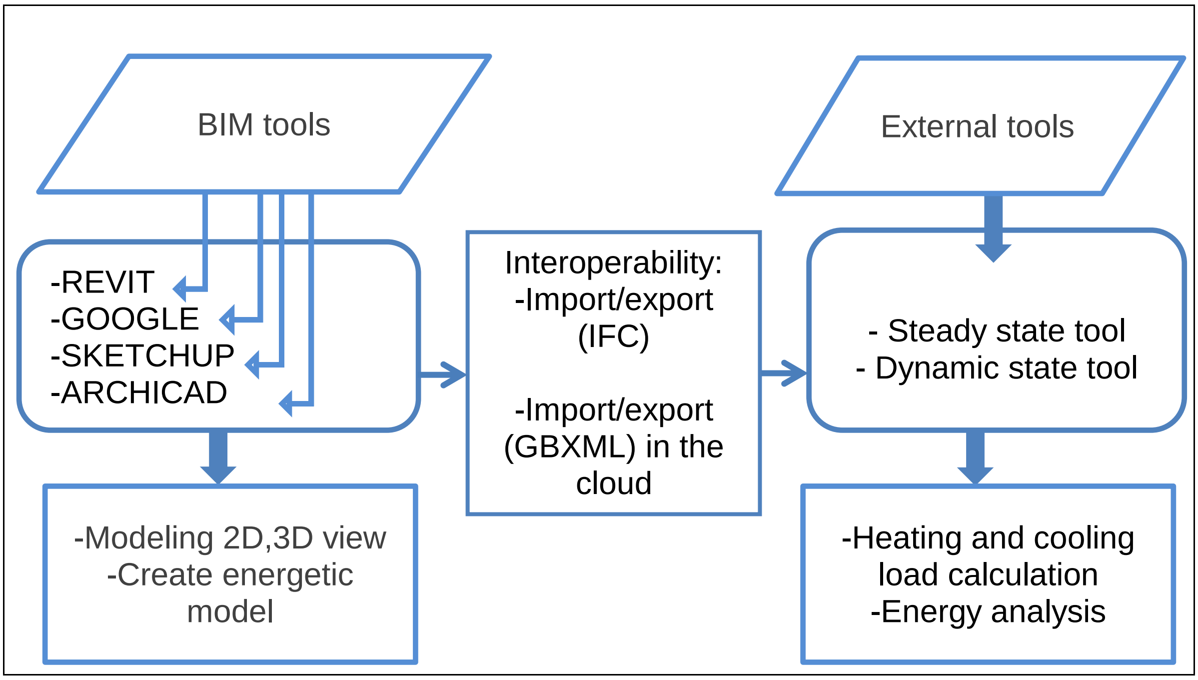


Figure I-11 BIM environment workflow

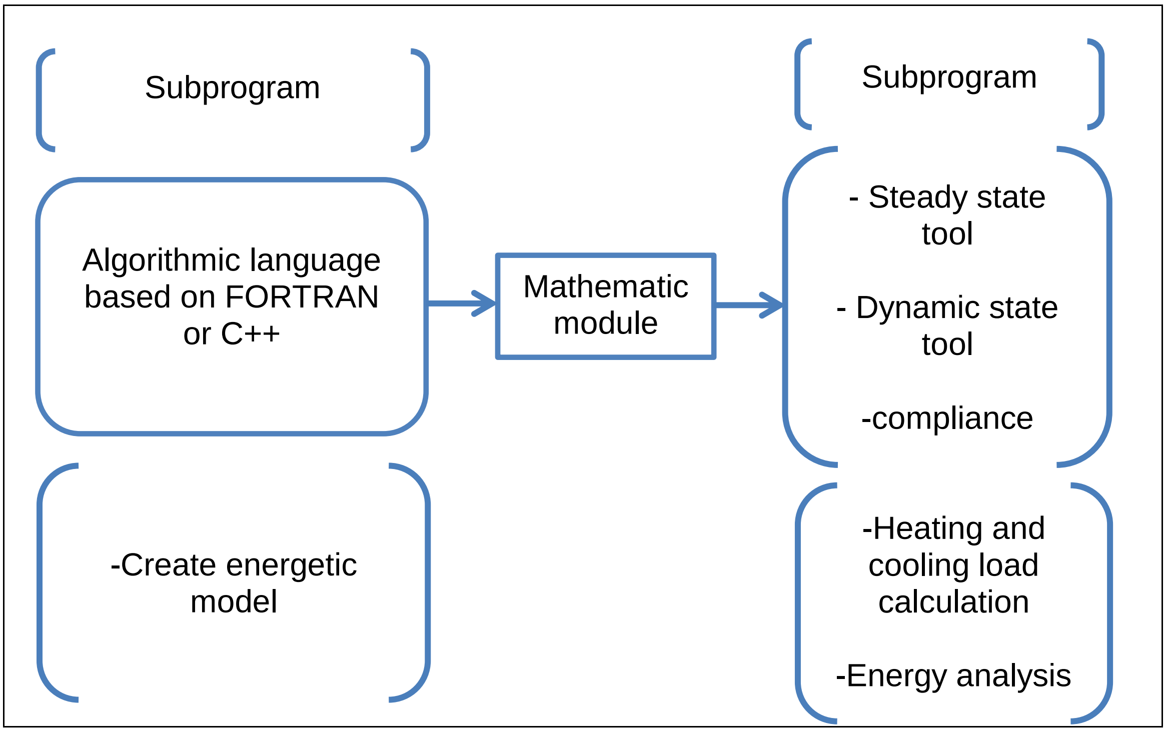


Figure I-12 Non-BIM based for energy simulation

I.5 Conclusion:

We can sum up that the literature review is relying on the two above graphs. Hence, the first Graph (I-11) represents the workflow of energy simulation based on a Building Information Modeling (BIM). Therefore, it is divided into three main parts: The first part contains a geometric design tool in 2D and 3D. The second one creates an energetic model (EM) tool. Whereas, the third part contains an energy analysis or a heating and a cooling load calculation based on engine calculation in the cloud such as DOE-2 which linked to REVIT (BIM tool) by GBXML format. This interoperability allows exporting the results from DOE-2 to REVIT in the cloud. Thus, the previously described method RTS is used for load calculation. In addition, for a detailed load calculation, we can export energetic model using IFC or GBXML format for a more detailed load calculation. The last operation permits a more advanced energy analysis using steady, dynamic state or compliance regulatory software. However, the second graph (I-12) displays a familiar simulation tools which is not based on BIM. These programs are autonomous based on a mathematic module and the subprograms are written as FORTRAN language. In the next chapter, we will focus on BIM environment workflow using REVIT tool based on RTS method. The last one allows reducing computing time and provides some physical insight to the nature of the calculation. As seen prior, REVIT is multidisciplinary tool used by architects and engineers; likewise, it is the most popular tool in building design process. Although it focuses on a nonresidential cooling and heating load calculation, it is used for a residential and non-residential building. Therefore, we will center, in the next chapters, on investigating the efficiency of RTS method and REVIT software to calculate cooling and heating loads in Tunisian houses.

Chapter II : METHODOLOGY AND SIMULATION TOOLS

II.1 Introduction:

Our main purpose is to operate BIM tools of REVIT software in order to improve the thermal efficiency of Tunisian house. Like described before (figure (I-11)), this software is based on BIM environment workflow. The improvement measurements in our thesis are founded on climatic response and improvement parameter cited in literature review to reduce energy consumption. As seen before, REVIT is designed to calculate the cooling and heating loads in non-residential buildings. It is also used essentially by both the architects and engineers for the thermal simulation whether in residential or non-residential buildings. A further focus will be given to the following steps:

- Validation of the load calculation for both the heating and the cooling in residential buildings, by REVIT software.
- Climate data analysis in Tunisian Coast and select passive techniques of the local design.
- Evaluation of the thermal demand by the Coastal Tunisian dwellings.
- Optimization of thermal demand using REVIT.
- Comparison of the original and modified dwellings based on REVIT software.

II.2 Methodology:

In this study, the adapted methodology is shown in figure (II-1). In the first step, we will refer to house model used in literature review by Ouertani [11] for validation. This house is a standing type selected from houses of Tunisian Building National Society (TBNS) which are located in Tunis City. In the second step, we will reuse modern and traditional house in Sousse city which has been already studied in Master research [36] in order to deepen the founding results. Then, we will use field survey of climatic parameters (humidity and temperature) of test site 1 and 2 in chapter (V). Test site 1 is characterized by traditional architecture with a patio (central courtyard); it is located in a historical site called Medina which is characterized by dense urban tissue with an organic and spontaneous town planning. However, test site 2 is consists of a contemporary house which is located in dense urban tissue with orthogonal grid [36]. This kind of house is a standard house which is actually the most common in Tunisian Coast. We will use existent houses of 2 sites for the description, evaluation and optimization respectively in chapter (IV), (V) and (VI). These houses, as in figure (II-1), are called original houses. Their thermal quality study is based on virtual meteorological data of study site (more details of study site in chapter (IV)). As well as, we will rely on these houses for thermal simulation. The used tools in our study are divided into four parts. The first part tools will aim to validate RTS method as well as, to assess REVIT program efficiency for energetic calculation of residential building. For that, we will refer to the obtained results by Ouertani [11]. Thus, its achieved results are based on dynamic state software such as TRNSYS. These results are compared to our simulation results which are based on steady state tools like REVIT as SPREADSHEET ASHRAE tool. The second part tool will be based on ECOTECT WEATHER TOOL for the climatic analysis data and identification of favorable design passive actions. These actions are chosen from percentage comfort chart. The third part tools will allow to evaluate climatic thermal responsive of house1 and house2. They are referred respectively to traditional and contemporary house in Sousse city as will be displayed in figure (II-1). On the one hand, we will use image and comment as tools for qualitative evaluation. On the other hand, a quantitative evaluation will be referred in the field survey which was carried out in master work [36] and then we opt for solar radiation simulation, shade simulation and assessment of comfort condition. In this part, we will assume that the original houses are unconditioned. Furthermore, we will apply Thermal Comfort tool (CBE) for ASHRAE 55 in order to Predict Mean Vote (PMV) index in chapter (V). Concerning, the evaluation of thermal demand, we will use REVIT and we suppose that the original houses are conditioned with the same heating and cooling equipment as will be seen in figure (II-1). In the final part, REVIT software will be used to save energy consumption of the original houses. We rely on this last part to improve thermal quality of original houses according to the following actions:

- Beneficial passive design techniques related to climate.
- Improvement measurements found in a literature review

Modified house models will contain combination of all improvement parameters related to climate and to previous literature review. They will provide several simulation variants which are difficult to exploit. For that, improvement levels will be investigated for each parameter in chapter (VI) in order to reduce workspace.

II.2.1 Unconditioned lodgment:

Unconditioned lodgment is based on a minimal comfort achieved naturally without any heating or cooling equipment. Thus, this house type does not rely on energy saving to realize thermal quality improvement. The inside temperature is always fluctuating in unconditioned building as the case of Tunisian traditional house which is response to bioclimatic and vernacular architecture. In further chapter (IV, V, VI) our study rely on traditional lodgment located in Sousse Medina. These houses are based on principles of bioclimatic architecture. Thus, they are designed according to passive strategies which are adapted to its climate and to their social and physical environment. In chapter (V), we will proceed to a qualitative and quantitative response to the climate of this model. In this study part, we are inspired by the evaluation method which is used by Ngugen et al [[37]]. Therefore, thermal performance evaluation of this unconditioned lodgment needs to calculate indoor temperature and humidity. These climatic parameters allow to determinate felt sensation of inside comfort. The last one is described by MCV which is developed in the previous chapter. According to our literature review, a Mean Comfort Vote is expressed by PPD. According to Fanger [13], the last term can be related in first, to heat flow exchange of human body with given environment and secondly to emit heat flow for specific activities for an optimal comfort.

II.2.2 Conditioned lodgment

Conditioned lodgment uses heating and cooling equipment in order to provide a steady temperature inside during the overall conditioning period. In this thesis, the evaluation of the thermal efficiency as to determine the maximal heating and cooling loads of original and conditioned houses using REVIT. Then, it will be used to evaluate and optimize the traditional and contemporary houses in Sousse city (chapter (IV and V)).

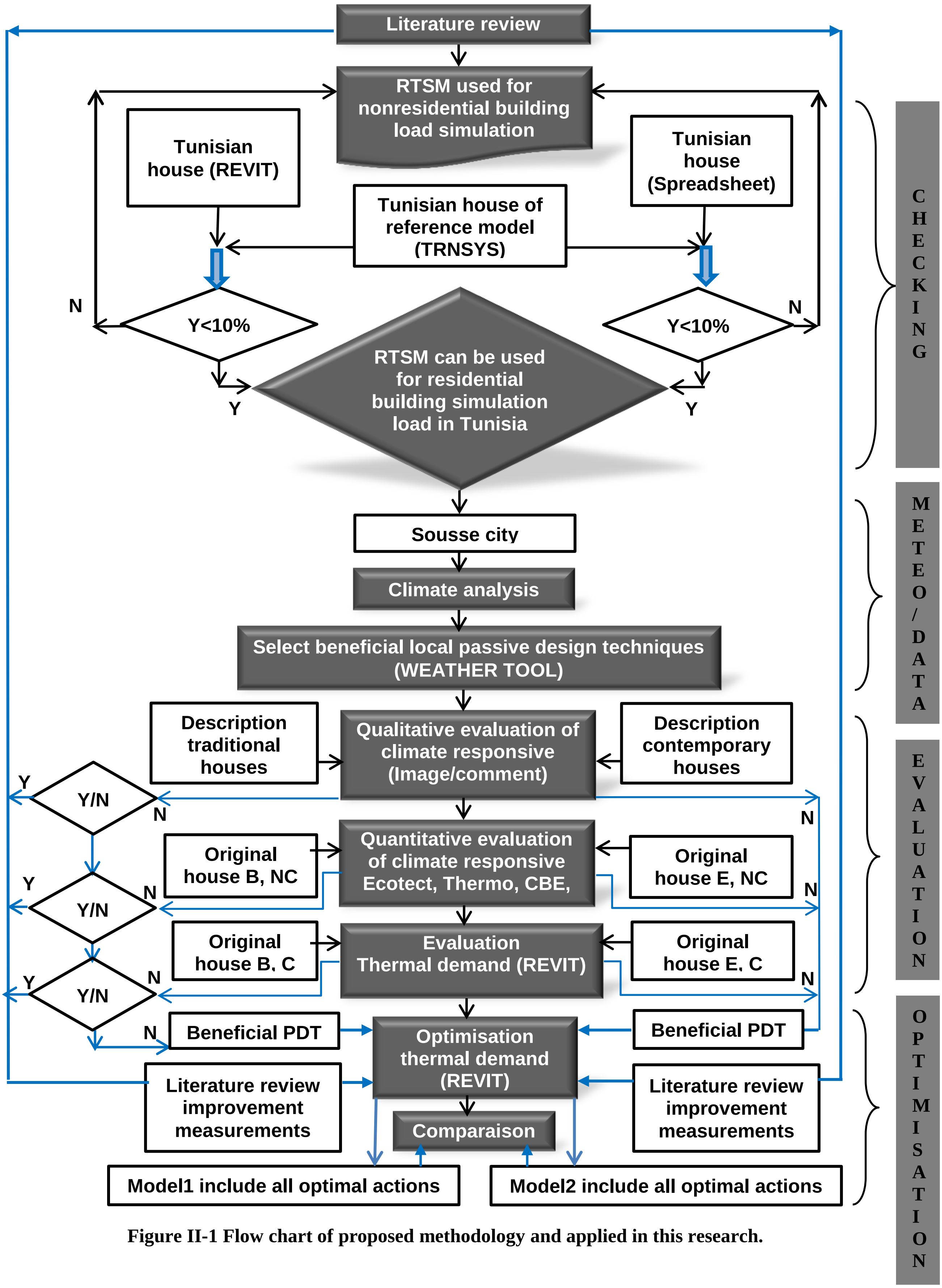


Figure II-1 Flow chart of proposed methodology and applied in this research.

II.2.3 Lodgment types

The Tunisian habitat mode has gone through several architectural styles. In our study, we will base our research on two Tunisian house styles as traditional and contemporary houses. While the first is designed with a patio, the second is covered. In this thesis, we will consider a study sites located in Tunisian climatic zoning ZT1 which corresponds to Mediterranean region.

II.2.3.1 Traditional lodgment

In our study, we will rely on a traditional lodgment which has already been studied in Master research [36] which represents a patio bioclimatic house. This house type is unconditioned and situated in ancient city (Medina) of Sousse. It is characterized by a high weight envelope and ancient construction materials. In fact, our ancient house was underwent a transformation of its roof from barrel vault to horizontal concrete slab. Traditional house architecture is to its climate to achieve a minimal natural comfort. Hence, this house will be used in chapter (V) to qualitative and quantitative evaluation on its climate responsive. Then, we will identify passive design techniques of our traditional house which are related to Sousse climate.

II.2.3.2 Contemporary lodgment

In our study, a contemporary house represents an open building with no patio and is located outside the Medina and built by modern construction materials. We will refer to two study sites. The first corresponds to a reference model used by Ouartani [11] and is located in Tunis. The second is studied in Master research [36] and represents a second floor apartment located in Sousse city. We will refer to a contemporary house model by Ouartani [11] to validate the thermal load calculation using REVIT. And then, we will reuse a contemporary house which has been already studied in Master research [36] for a thermal quality assessment and improvement using REVIT.

II.2.4 Climatic parameter

Our work is based on climatic parameters as dry bulb temperature, wet bulb temperature, relative humidity, wind speed and solar radiation. We will refer to these data in three forms as following:

II.2.4.1 Typical Year

A typical Year is based almost on thirty years for historical weather data. We will rely on Typical Year of weather data from ASHRAE climatic data base which are given by World Meteorological Organization (WMO). We will also use typical year in SPREADSHEET ASHRAE and REVIT to energy use heating and cooling load calculation. To determinate the first one, we will base on CDD and HDD which corresponds to cumulative average temperatures. Then, to calculate the second we will rely on extreme climatic design conditions as displayed in the chart (figure (II-2)).

II.2.4.2 Actual Year

We will use Actual Year which represents a real weather data to analyze meteorological data of Sousse location. For this analysis, we will base on ECOTECT WEATHER tool. This tool allows us to use a Comfort Percentage chart which enables us to select beneficial passive design techniques related to Sousse climate. These passive actions will improve a thermal quality of traditional and contemporary house in Sousse city. As well as, we will rely on Actual Year. In the first step, we will refer to the year 2006 (CSV) file of GBS and convert it to WEA file to identify climate type of Sousse. In the second step, we select a beneficial passive design techniques related to Sousse climate to assess a climate responsive of our study models.

II.2.4.3 Field survey

We will reuse the obtained results in Master research [36] of traditional and contemporary houses. These results, indeed, represent a field survey of indoor climatic parameters as temperature, and relative humidity. We will rely also on these parameters to determinate a PMV vote and to evaluate a thermal comfort.

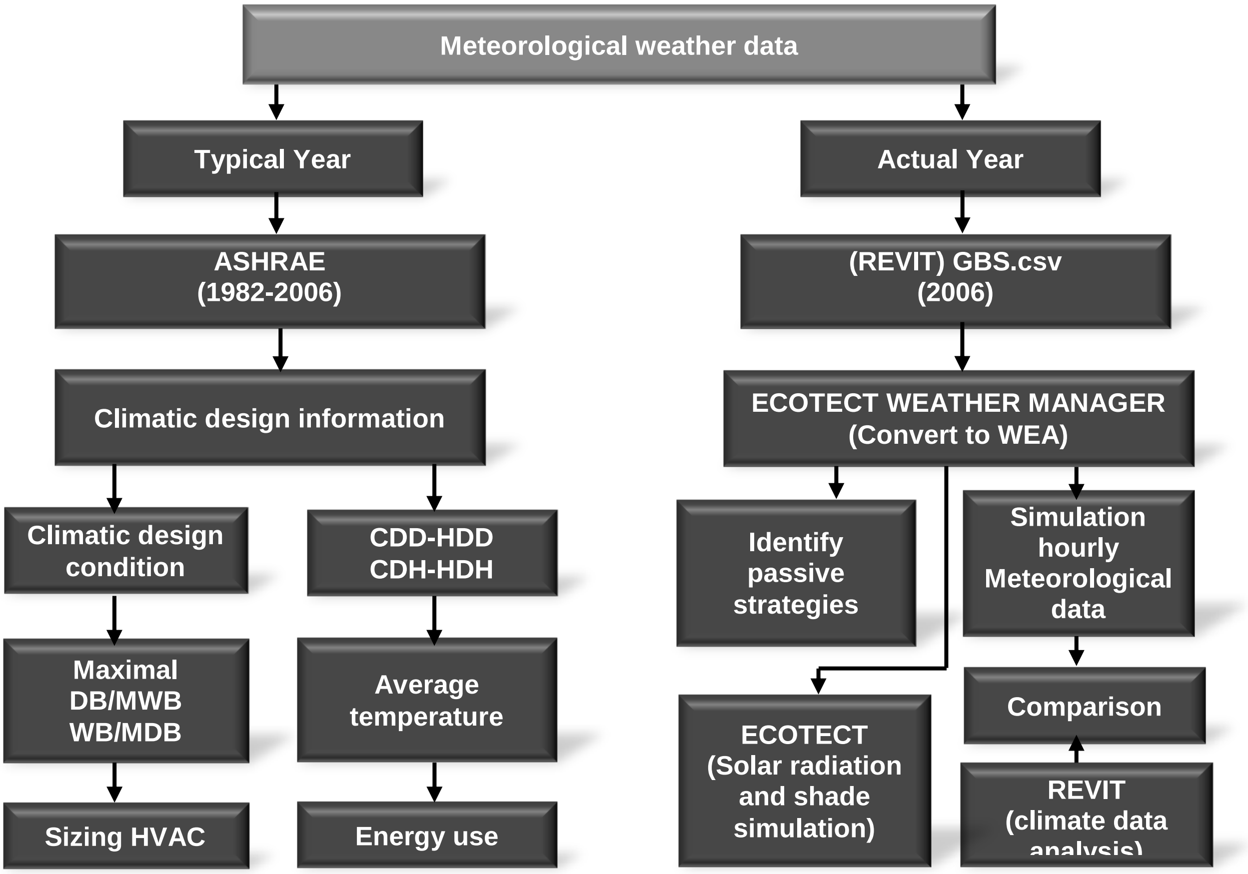


Figure II-2 Workflow chart of weather data used in our study

II.3 Tools

II.3.1 : Tool for climate analysis

Many tools for weather data analyses are used as ECOTECT WEATHER tool and REVIT AUTODESK tool. The first tool is an old and specialized but the second is new in weather data analysis. In chapter (IV), we will identify the REVIT efficiency in this field.

II.3.1.1 ECOTECT WEATHTER tool

ECOTECT is a specialized tool for Meteorological data and environmental analysis with a highly visual and interactive display. Research results show that ECOTECT can provide a scientific basis for energy efficiency [38, 39] and climatic parameters analysis for passive designs [40]. It includes a wide range of detailed analysis. Then, we opted for ECOTECT and for its integrated tool as WEATHER TOOL. We use therefore the last tool to hourly simulation of dry bulb temperature, relative humidity percentage and solar diffuse quantity.

As well as, we opt for this tool to select beneficial passive design techniques based on Best Orientation chart, Psychometric chart and Percentage Comfort chart. We rely on ECOTECT tool to quantitative evaluation of beneficial passive strategies as direct solar radiation. The last is considered as a passive solar heating.

II.3.1.2 REVIT AUTODESK tool

REVIT, in fact, allows a climate data analysis for building passive and sustainable design. It analyzes the climatic parameters as: wind speed, wind frequency, humidity, dry bulb and wet bulb temperatures. It provides charts like the wind rose, monthly design data, diurnal weather averages and humidity. Furthermore, we will reckon on these charts to validate climate data analysis by REVIT with the obtained analysis results by ECOTECT WEATHER tool for Sousse city.

II.3.2 Tool for thermal efficiency assessment:

II.3.2.1 Simulation tools for indoor thermal quality

In chapter (V), we will focus on the traditional house (B) and the contemporary one (E) found in a Master research [36]. Therefore, the used tools for the survey of indoor temperatures and humidity center on a sensor of climatic parameters. In this investigation, we used Hydro button for temperature and humidity survey and Thermo button for temperature survey.

II.3.2.2 Tool for comfort sensation prediction

Thermal Comfort CBE tool is conformed to ASHRAE Standard 55-2013. It is simple, accurate and free online tool. We select this tool to assess comfort condition of original houses 1 and 2. As well as, we opt for this tool because we can easily get a wide range of input data as: air temperature, mean radiant temperature, air speed, clothing level and relative humidity. Besides that CBE tool can generate these data in the cloud and enable to calculate automatically the output results of PMV, prediction comfort sensation PPD.

II.3.3 Tool for load calculation:

II.3.3.1 Periodic Response Factor and Radiant Time series Factors tool (PRF/RTF)

The purpose of our thesis is to validate REVIT results for heating and cooling load calculation in residential building. REVIT is based on RTS method for load calculation. Thus, for the validation, we need to compare the obtained results by REVIT with those achieved by TRNSYS [12] and by SPREADSHEET ASHRAE which is focused on RTS method for load calculation. We need to PRF, RTS and RTF coefficient to put into SPREADSHEET ASHRAE. Then, we select PRF/RTF generator which is presented as a graphic user interface program. It is also used to calculate Periodic Response Factor (PRF), Conduction Time Series (CTS) and Radiant time Factor. PRF/RTF generator tool is based on ASHRAE loads toolkit algorithm for calculation.

II.3.3.2 SPREADSHEET ASHRAE

SPREADSHEET ASHRAE is prepared similarly with the development of the ASHRAE for Non Residential Cooling and Heating Load Calculation of the 2005 ASHRAE Handbook Fundamentals. The available version is SPREADSHEET ASHRAE 2009 which is an updated version with new procedures defines in 2009 ASHRAE Handbook Fundamentals. As well as, this version is based on the new climatic design condition as 0.4, 2, 5 and 10 percentiles cumulative frequency of occurrence. We select this tool to simplify tedious handling calculation in chapter (III) in order to determine heating and cooling load calculation using RTS method for reference house [12]. The achieved results from SPREADSHEET ASHRAE and TRNSYS validate REVIT results for heating and cooling load calculation.

II.3.3.3 REVIT

REVIT software is a BIM tool. It is a parametric and sustainable software tool that enables architects and engineers to collaborate and interact more effectively. Then, we opt for Autodesk REVIT Version 2014 for thermal simulation. As previously REVIT has got multidisciplinary features in the same software. These features allow collaboration between building actors. It plays the role of information centralizer and contains the information about:

- Localization (altitude, latitude)
- Climatic and weather information
- Building geometry with 2D and 3D view.
- Building composition (materials, type condition spaces, occupancy schedule, operation schedule, internal heat gains.
- Technical systems (ventilation, cooling and heating).

REVIT workflow as displayed in figure (II-3) is relied on 3 paths. Paths 1 and 2 represent Conceptual Energy Analysis (CEA) workflow for energy analysis which is based on 'Conceptual Mass' and 'Building Elements Mode' tools. It is usually used by architect to estimate the annual energy consumption. Path 3 represents a methodology flow for 'Heating and Cooling tool' which used for heating and cooling load calculation and based on RTS calculation method. It is usually used by engineer. Path 1 needs a mass design it allows creating a general energetic model. However, path 2 is based on architectural plan for geometric design. It enables to regulate a detailed energetic model. But, path3 workflow allows us to get a detailed report about the necessary electric load to size up the heating and cooling equipment.
All paths are based on a calculation engine such as Revit which proposes to import and export calculation results in the cloud from model via GBXML. It recovers all information that have been calculated in third-party by specialized software as DOE-2. This is very important concerning the workflow and calculation process. In addition, REVIT provides tools for comparing, emailing and exporting analysis results. REVIT can also compare analysis results within or between projects. It can mail results and comparisons, or export mail them in common formats such as PDF. For the dynamic state simulation, the user can also export energy model information in GBXML, DOE2 and ENERGYPLUS formats as displayed in figure (I-11). Using path 1 and 2, we can export data charts as graphics presentation and create custom graphics. Besides, we can download weather data file from Green building Studio (GBS) software to generate in the third the specialized tool in weather data analysis as ECOTECT software. We refer in the last operation in further chapter (IV, V) to a detailed weather data analysis and assessment.

II.3.4 Tools available in Revit

Generally, REVIT provides an integrated calculation. It can share information between the overall building actors. It can set HVAC system for the engineer and the architect to determine energy consumption. REVIT has used analytical and calculation tool to communicate these decisions since the early design phase. Among these tools of analysis, we find the "Conceptual Energy Analysis" tool usually used by architect and "Heated and Cooling tool". These tools are mostly used by engineer.

- **Heating and cooling tool:**

"Heated and Cooling tool" is Mechanical, Electrical and Plumbing (MEP) of REVIT. It is not designed for the thermal calculation or residential building calculation but to simulate the overall building type [7]. It is used usually used by engineers to calculate the needed power for heating and cooling. "Heating and Cooling" tool is a native tool thanks to the integration of American Carmel Software Revit Mep. The calculation is based on RTS method calculation and done according to ASHRAE Handbook 2005 edition which is directly based on design condition of a monthly cumulative frequency of occurrence equals to 1%. 'Heating and cooling' tool gives needs for heating and cooling period using monthly calculation. The calculation is similarly made for various areas and zones which are based on RTS method for heating and cooling calculation. This method is developed previously in chapter (I) for the load calculation. We will base on 'Heating and Cooling' tool in the next chapter to validate REVIT efficiency for thermal calculation of residential building.

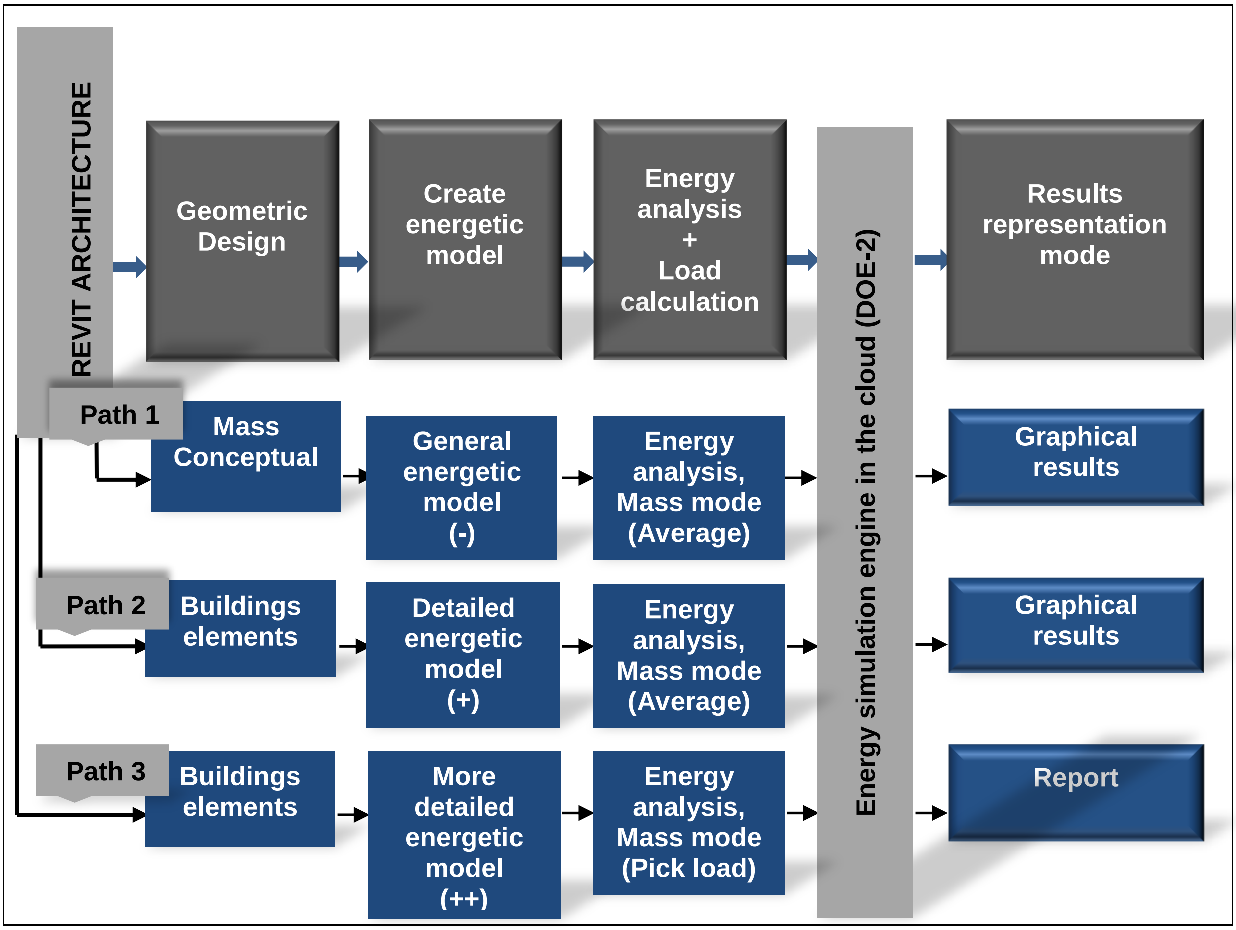


Figure II-3 REVIT Workflow

- **Conceptual Energy Analysis (CEA) tools:**

CEA is a tool used by architect for an overall conceptual analysis to compare several variants. It works in the cloud and enables to analyze without disrupting the workflow. This thermal analysis is firstly done from the draft phase. It consists of two modes: conceptual mass mode and building elements mode. Initially, we set energetic model then we run energy simulation. In this step, the model will be sent into the cloud to servers that will make the calculations displayed in figure (II-3). As soon as, the calculation is done, we are informed and therefore.

We can react to receive and compare the obtained results of the same models. The Conceptual mass mode is based on HDD and CDD for energetic load calculation.

II.3.5 Conceptual Mass Mode and Building Elements Mode

We use Conceptual Mass Mode or Building Elements Mode to perform conceptual energy analysis at the preliminary design stage design.

II.3.5.1 Conceptual Mass Mode tool

Conceptual Mass mode is used to generalize energetic analysis. We need after all to set in Energy Setting dialogue box percentages of glazing, shading and building materials in order to prepare energy model for the analysis.

- **Methodology to prepare energy model for analysis**:

Actually, we need to make a model of geometric design to prepare an energetic simulation. Thus, we rely on Mass design for Conceptual Mass Mode and set energetic parameters. The used methodology for this purpose of Conceptual Mass Mode and to prepare energy model for analysis is divided into two parts as following:

a) Quick start method:

A quick start method is based on several steps as following. The first step consists of adjusting the different mass floor of the project. The second one needs to connect directly to Autodesk account and to define the chosen mode and to activate the energetic model. The third, allows setting the energetic parameters in 'Energy Settings' dialogue box. The fourth, aims to run energy simulation in 3D view and select "Results and Compare" panel to visualize them.

b) Detailed workflow method

The detailed workflow method relies on the same previous steps. However, in the third step, we personalize design condition of each zone separately such as glazing percentage and 'Condition Type' (Heated and/or Cooled, Vented). Consequently, to personalize the characteristics of openings, we need to customize the "Mass Surface" and select the show Mass surface. Finally, we need to set Target percentage of glazing and Target Still Height.

II.3.5.2 Building Elements Mode tool

Building Elements Mode, we need for a detailed energy analysis. Using Building Elements Mode, users can define the parameters of the energy (location, type of construction) and use GBS to analyze and compare the different results. Building Elements Mode provides more information at an early phase of the design process.

- **Methodology to prepare energy model for analysis**:

For Building Elements Mode, we need to make a geometric design of building elements as roof, windows, doors, floors, walls. As previously seen, the Conceptual Mass Mode is based on two simulation methods as.

a) Quick start method:

Quick start method for Building Elements Mode has the same steps as Quick method for Conceptual Mass Mode. But, in the first step, we need to make a geometric design of building elements.

b) Detailed workflow

Detailed workflow method for Building Elements Mode has the same steps as detailed method for Conceptual Mass Mode. But in the third step, we need to include thermal propriety of building elements and to set in 'Energy model- Building services' panel and we need to add information concerning: ‘Building Operating Schedule’, HVAC system kind and Outdoor Air Information.

II.3.6 Heating and cooling load calculation

1) Methodology to prepare for heating and cooling load calculation:

For heating and cooling load calculation, we need to use ‘Heating and Cooling’ tool. Before, we run thermal calculation, it is necessary to create a geometric model of building elements, we should also create conditioned spaces in order to set energetic model. This model is made by ‘Operation and Occupancy Schedule, HVAC system kind, outdoor air flow exchange, indoor set point and thermal propriety of construction materials.

2) Calculation method

For “Heating and cooling” tool, the engine DOE-2 in the cloud examines each space from the months of April to November during 24hours. Then, it calculates cooling loads for each component for each hour using RTS method for load calculation. Thus, the engine sums up the overall loads to determine the total cooling load for each time and select the time of the peak load for design of the air-conditioning system. The engine repeats similarly this process for several months of design to determine the peak load month. The simulation results represent the peak power of heating and cooling system to maintain a steady set point temperature inside. In heating load calculation, we note that REVIT does not include heating solar and internal load because it is based on extreme condition in load calculation as RTS method.

II.4 Conclusion:

Energetic model design by REVIT needs to assign at least one conditioned space for unconditioned building to perform thermal simulation. This does not represent a reality of unconditioned (free running) houses. As well as, energetic model design using RTS method of conditioned buildings with non-residential type represents a good compromise. This compromise is between building information modeling, reduction calculation time and accuracy load calculation in steady state. In case of traditional houses, the temperature fluctuates in relation with internal and external heat gain and losses. Its criterion of thermal quality evaluation is a comfort vote which based on thermal sensation index PMV and satisfaction persons number PPS. We will obtain these indexes by CBE tool and refer to the last tool because it conforms to requirements in ASHRAE STANDARD 55. Thus, in case of conditioned houses, a local temperature is maintained steadily to a set point value. Then, we will consider to thermal quality evaluation of the last kind as energetic consumption level and a necessary system power of heating and cooling. We will base for thermal quality assessment on Conceptual Energy Analysis and Heating and Cooling tools. We will propose in further chapter to use REVIT tool for the following actions as evaluation, improvement and comparison of Tunisian houses. Hence, we will need to validate REVIT results in heating and cooling load and its RTS method calculation for residential building. As well as, we will investigate calculation results using Heating and Cooling tool and Building Elements tool. Therefore, we will try to find a compromise of results between the last tools used respectively by engineer and architect.

Chapter III : CHECKING REVIT PERFORMANCES IN HEATING AND COOLING LOAD CALCULATION OF A LOCAL USING RTS METHOD

III.1 Adopted approach for validation:

Our main purpose is to compare a thermal quality of a traditional house to a contemporary one. In order to achieve this goal, we will use REVIT for heating and cooling load calculation. We call back that REVIT is adapted by engineer work in order to size HVAC system. As well as, it is used by architect to estimate the contribution of each component in energy use. As seen before, this tool is developed for a non-residential building using RTS method calculation. But in reality, it is used similarly for residential building. Then, we will adopt REVIT tool and RTS method calculation to Tunisian house. Hence, we will propose to use REVIT for assessment, improvement and comparison of thermal quality of traditional and contemporary houses in Sousse. Therefore, we need to validate the results and the methods of load calculation used by REVIT. After a long reflection concerning validation process, we decide that we need to investigate REVIT results by steady state and dynamic state. Therefore, we propose the following steps:

- In the first step, we will opt to find results of standing house using TRNSYS by Ouertani [11] which is based on dynamic state for energy consumption calculation. Her study is a part of project which led to set up a thermal regulatory for Maghreb countries.
- In the second step, we will use SPREADSHEET ASHRAE to generate RTS calculation method of standing house model from Ouertani.
- In the third step, we will calculate energy load of heating and cooling load calculation using REVIT, so we will rely respectively on 'Building Elements' tool and 'Heating and Cooling' tool.

Indeed, for validation using SPREADSHEET ASHRAE and REVIT tools, we need to use the similar design condition as used by Ouertani [11].

III.2 Description of reference model:

Our model reference is a standing apartment built by NBST and located in Tunis region. A building has a ground level and three floors each level has 2 symmetrical apartments with respect to an axis (A) as displayed in figure (III-1). Living room and room 1 and 2 are situated in the principal facade with a South direction. As well as, room 3, the kitchen and the bathroom are situated in North façade. A covered area for each apartment is 140m². Ouertani [11] relies on South zone to calculate energy consumption which has 100 m². In this zone, the glazing area represents 24% of principal facade. In this chapter, our study is limited to room1 in order to simplify calculation process. This room has 4m length and 3.5m width and is located in third floor as displayed in figures (III-2). It has as well a window with 2.16m² areas which is opened on principal façade as shown in figure (III-2). While, the reference model is equipped by a central heating and air-conditioner respectively in winter and summer, the central heating equipment is used continuously in winter. Ouertani [11] assumes that the set point Temperature (ST) is equal to 20°C. But in summer period, the ST temperature is equal to 26°C and the central air-conditioning is 'heat pump air/water' equipment. For the study thermal performance, she focuses on occupancy, operation schedule and construction materials of high standing house of NBST and considered two simulation cases:

- In the first case, she fixed a heating and cooling period respectively for January and July.
- In the second case, she opted for an entire real year of meteorological data such as heating and cooling period which are extended respectively from November to March and from June to September.

III.2.1 Partitions composition

For the load calculation, we depend upon a reference model used by Ouertani [11] which represents a high standing house. This model is made up by insulation roof and double partitions. The last one has 35cm thickness included 5cm air space. The openings are on a single glazing with aluminum frame; these components are characterized by low air loss. Further table taken from Ouertani [11] shows thermal properties of high-standing house model as following:

Table III-1 Composition of standard house partitions (Source : Ouartani, 2001)

Material	Ep (cm)	K (W/m/k²)	Cp (kJ/m².K)
Exterior wall			
Mortar	2		
Plastered brick	6.5		
Air space	4	1.21	240.2
Brick 12T	15		
Cement mortar	2.5		
Slab on the ground:			
Tiles floor	2		
Mortar	2	2	
Sand	3		444.6
concrete	5		
hedgehog	15		
Roof terrace :			
Mortar (batard)	2		
Hourdie Block	15		
Concrete	5		
Sloped form	10	2.16	551
Cement mortar	2		
Sealing	0.5		

III.2.2 Building operating and occupancy strategies

III.2.2.1 Internal load and strategies:

Actually, lighting, equipment and occupants represent the internal loads. Ouertani [11] takes account of these heat gains especially in summer for the simulation. In fact, these factors contributed to cooling load. The occupancy strategies of these components are as following:

- Occupancy schedule:

According to Ouertani [11] occupancy schedule of residential building in Tunisia differs from summer to winter as following:

Table III-2 Occupancy schedule of Tunisian house (Source: Ouertani, 2001)

Hourly band	Persons number
Summer	
7h to 15h	3
15h to 7h	5
Winter	
8h to 18h	1
18h to 8h	5

- Metabolic energy

Metabolic energy is emitted by occupants and is almost constant along the year. Ouertani [11] considered a metabolic of 125W (total heat) or (1.2 met) during a day and 75W (total heat) or (0.7 met) at night. According to table (I-4) in chapter (I) the last values present respectively the relaxing and sleeping person activities.

- Clothing insulation:

The thermal insulation provided by clothing depends on season and daytime. In the Tunisian Coast region, the clothing insulation can be considered as 1 clo during the day and 3 clo at night especially in winter season (Nov to March). Whereas, in summer (July to September), the clothing insulation is generally equal to 0.5clo during the day and 1 clo at night. Moreover, in June, it is from 0.8 clo during the day and 2 clo at night. Through mid-seasons (from April, May and October) thermal resistance is probably equal to 0.8 during the day and 2.5 clo at night [11].

- Lighting:

Residential buildings, in Tunisia, use almost 350w lighting power for 140m² house areas [11]. Occupants illuminate their lodgments from 7h to 8h, then from 18h to 22h in winter but they light from 19h to 23h in summer.

- Equipment:

The television (TV), the cooker and the refrigerator represent the most important equipment in Tunisia. Ouertani [11], assumes that the refrigerator works the whole day; a cooker works 3 hours per day and TV is lighted up 6 hours per day. The below table (III-3) provides power values and recuperation fraction. The last one corresponds to heat gain portion provided by equipment which contributes to house heating accordingly. These values are based on 140m² house areas.

Table III-3 Power and recuperation fraction of Tunisian house (Source: Ouartani, 2001)

Equipment type	Standing house	Recuperation fraction	Operating time
	Watt power		Hours
TV	112	1	6
Cooker	3000	1/2	3
Refrigerator	189	1/4	24

III.2.2.2 Building management

Window openings provide lighting to the inside. These openings are subsequently managed differently according to the seasons. The following table (III-4) describes the opening scenario in winter and summer determined by Ouertani [11]. According to Ouertani [11] a contemporary house is conditioned in summer and winter. For the simulation, she assumed that air flow exchanged with outdoor is equal to 1.6volumes/hour [11].

Table III-4 Management of windows opening

Hourly band	Opening conditions
Summer	
6h to 20h	Rolling window shutters are open and glazing are closed
20h to 6h	Rolling window shutters and window glazing are closed
Winter	
8h to 18h	Rolling window shutters are open and glazing are closed
18h to 8h	Rolling window shutters and glazing are closed

Figure III-1 Backend in North direction (Source: REVIT)

Figure III-2, 3D view oriented on principal façade of building reference (Source: REVIT)

III.3 TRNSYS application:

The reference model is conditioned model with a constant ST during the heating and cooling periods. In fact, TRNSYS contains numerous modules. Hence, Ouertani [11] used the model

Type 56 for a thermal dynamic modeling of the building and a subprogram called BID which generates 3 files:

- The first file is to create the thermal zones.
- The second is to determine the response factors of overall building.
- The third describes the building characteristics.

These files are generated by a subprogram of TRNSYS called BID which has contained building description, envelope and opening description, thermo physical properties of construction materials. As well as, it refers to the following characteristics as: occupancy mode, operation mode, internal heat gain, ventilation and infiltration.

III.3.1 TRNSYS modeling

- Modeling of Thermal transmission coefficient of windows:

As Ouertani model [11], they are done by aluminum frame with a low infiltration rate and their rolling shutters are made by PVC material. Along the whole year, the rolling shutters are opened and the panes are closed. She considered a percentage value of outdoor design temperature as used in Thermal Regulatory Code. Hence, she assigns outdoor temperature value that corresponds to 5% of cumulative frequency of the cooling period and 97.5% of the heating period and considers an indoor relative humidity to 50% for the cooling.

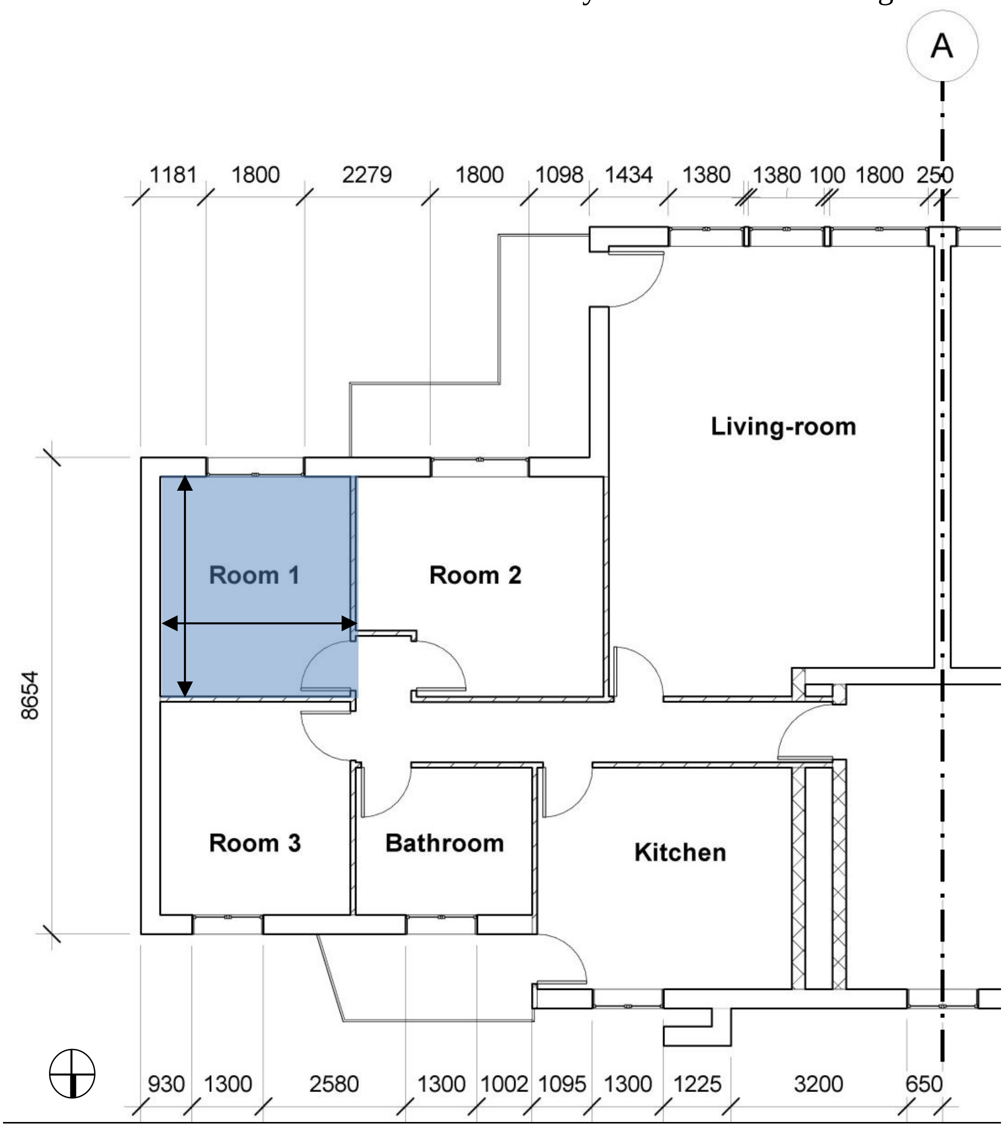


Figure III-3 Level third of reference lodgment designed by REVIT

These assumptions allow calculating the necessary power for the heating and cooling equipment.

- Modeling of Superficial exchange coefficient:

TRNSYS needs a convective heat coefficient (hci) for the inside face of walls which is equal to 9.6kJ/hm²K, whereas the convective heat coefficient (hce) for the outside equals to 60.8kJ/hm²K.

- Sunspot modeling:

Generally, TRNSYS ignores the multiple reflections of solar radiation on surfaces. It assumes that the absorbed radiations are distributed according to surface area and absorption coefficient. In fact, $\boldsymbol{f_{s,i}}$ is the fraction of the absorbed solar flow by surface $\boldsymbol{i}$ is equal to the following equation [11]:

$$f_{s,i} = \frac{(\mathrm{a_i} A_i)}{(\sum \mathrm{a_i} A_i)} \quad \textbf{(30)}$$

Where:
a_i = coefficient of short wavelength.
A_i= area of i surface.

- Calculation of fictive absorption coefficient:

Ouertani [11] assumes that the overall envelope is painted in clear color for load calculation.

III.3.2 Simulation results of reference model by TRNSYS

According to Ouertani [11] energy consumption per surface unity is obtained by dividing the amount of the consumed energy by the conditioned area which is equal to 100m². Moreover, to determine the annual consumption of the heating energy, she considers the gain of the useful solar heat:

$$E_H = L_H - A_{s,u} \quad \textbf{(31)}$$

Where:
E_H = energy consumption for heating period (kWh/m².year).
L_H = the needed energy to maintain indoor steady temperature without contribution of solar heat gain. This energy represents the overall heat losses through partition walls and windows (kWh/m².year).
$A_{s,u}$ = useful solar heat gain energy (kWh/m².year).
Ouertani [11] relied on the following equations to determine the useful solar energy ($A_{s,u}$). Hence, she selects N_s which is equal to 0.7 and based on Roulet [41] formula to determine glazing transmission coefficient in equation (III-34). Furthermore, to determine the last coefficient, she fixes the following coefficients as τ_0 = 0.6 and x= 0.04 m²K/W

$$A_{s,u} = N_s \times H_h \times \tau_f \times A_v \quad \textbf{(32)}$$

$$N_s = \frac{A_{s,u}}{A_{s,b}} \quad \textbf{(33)}$$

$$\tau_f = \tau_0 + x \times K_f \quad \textbf{(34)}$$

N_s= fraction of useful solar heat gain energy by brut solar heat gain energy.
H_h = overall solar irradiation received by window for overall heating season (Wh/m²).
τ_f = glazing transmission coefficient (W/m²K).
A_v = glazing surface (m²).
$A_{s,b}$ = brut solar heat gain energy (Wh).
τ_0 = 0.6.
x = 0.04 m²K/W.
K_f = window transmission coefficient (W/m²K).

Therefore, Ouertani [11] used the equation (35) to determine energy consumption during the heating and cooling periods. This amount is equal to heating and cooling equipment power multiplied by conditioning hour number as displayed in the following equation:

$$E = P_w \times \Delta t \quad \textbf{(35)}$$

E = Heating or cooling energy consumption (kWh/m².year).
P_w = Heating or cooling equipment power (W).
Δt = Heating or cooling number hours that exceeded set point temperature (hours).
We recall to calculate energy consumption (E) for living zone which located in south orientation; On the one hand, Ouertani [11] considered January and July respectively for heating and cooling period as displayed in below table.

Table III-5 Heating and cooling energy for reference lodgment for January and July as respectively heating and cooling months

Description	Heating	Cooling
Third level	17.1(kWh/m²)	22.9(kWh/m²)
Month	January	July
Conditioned hours number	240	210

On the other hand, she considered an entire real year of meteorological data to calculate E as indicated in the below table.

Table III-6 Heating and cooling energy for reference lodgment for entire real year

Description	Heating	Cooling
Third level	61.1(kWh/m²)	67.3(kWh/m²)
Conditioned period	November to March	June to September
Conditioned hours number	1200	630

In fact, SPREADSHEET ASHRAE and REVIT determine the heating equipment power regardless of the obtained Heat Gain from the Solar Energy ($A_{s,u}$). In addition, these tools calculate only the Total Heat Loss (L_H). In order to validate the obtained results by TRNSYS, we need to estimate both amount of L_H and $A_{s,u'}$. Futhermore, we rely on the equation (III-32), equation (III-34) and respectively the values K_f (6.98 W/m².K and 532.7kWh/m²) and H_h so as to determine the value of $A_{s,u}$ through glazing. According to figure (III-3), Ouertani [11] finds a heating gain through the window equals to 31.794kWh/m² during heating period. Subsequently, we have noticed that L_H is equal to 92.894kWh/m² in winter. In addition, a necessary Heating Power Equipment (P_w) equals to 77.41 W/m² in winter but is 106.8W/m² in summer season.

III.4 Room 1 modeling for radiant time series method calculation

We recall that we need to take several assumptions compared to TRNSYS in order to calculate cooling and heating loads of room1 using REVIT and SPREADSHEET ASHRAE. Since, these last tools are based on RTS method calculation; they are related to steady design conditions. On the one hand, we assign building management, occupancy and climate data in heating and cooling period are regular and steady. On the other hand, to determine cooling load calculation, we assume that a daily cooling load for each component is repeated over 30 days. Then, we need to generate 288 times over design hours in order to calculate the peak cooling load.

III.4.1 Surface data

Room1 is chosen to validate actually the calculation of cooling and heating loads relying on REVIT and SPREADSHEET ASHRAE. In fact, it is 14m² room area where the length is 4m, the width is 3.5m and the height is 2.8m. To do the duty, input data have been selected: carpeted floor, a concrete slab roof painted with a clear color, the K coefficient which is equal to 2.16W/m²K as in table (III-1), double indoor walls painted as well with acrylic white color with a coefficient K equal to 1.21W/m²K. The simple glazing window with 6 mm of thickness and a gray outside panel has a Solar Heat Gain Coefficient (SHGC) equals to 0.59. Hence, its frame is aluminum made without thermal break and the global K is equal to 6.98W/m²K. The south oriented window has got 1.8m wide and 1.2m height and a total area of 2.16m² areas.

III.4.2 Design conditions

As seen prior, the required design conditions for the cooling and the heating load calculations are the climatic conditions, the occupancy and the operative schedules.

III.4.2.1 Occupancy and Operation Planning

According to the operational schedule in table (III-2), 40% of persons stay at home from 8:00 am to 2:00 pm and 100% of them from 2:00 pm to 8:00 am.

The lighting operation is from 7: am to 8: am in the morning and from 6:00 pm to 10:00 pm of afternoon with fluorescent lights (2.5W/m²). Consequently, the global power use of the equipment is estimated to 90% between 11:00 am to 1:00 pm and 100% from 6:00 pm to 7:00 pm, 10% from 7:00 pm to 12:00 pm and finally 3% in the rest of the day.

III.4.2.2 Climatic design conditions adopted in our study

The initial step in load calculation is choosing indoor and outdoor design conditions:

- Outdoor climatic design condition:

We need to use RTS method calculation to assume one steady day (24 hours) monthly. The climatic condition includes values of Dry bulb, Wet Bulb, Dew point temperature and Wind speed with direction at various frequency of occurrence. These designs conditions are developed according to ASHRAE research group from 1993 to 2009. Our study is interested only in 2005 and 2009 percentiles from ASHRAE Fundamentals as displayed in table (III-7). Each tool as REVIT, SPREADSHEET ASHRAE and TRNSYS has its data base for the simulation. Then, for the validation we need to get as close as possible to the same design condition used by Ouertani using TRNSYS [11]. In table (III-7), we expose design condition and localization according to the selected tools for simulation. We note that climatic design data are very close but not totally identical.

Table III-7 Climatic design condition of simulation tools

Simulation tools	Weather data	Latitude (North)	Longitude (East)	h(m)	Climatic design information		
					Heating	Cooling	HR
TRNSYS	Real Year 2000	36° 50’	10° 14’	4	97.5%	5%	52%
SPREADSHEET	1982-2006	36° 83’	10° 23′	4	99.6%	5%	50%
REVIT	2006	36° 85’	10° 22′	7	99%	1%	46%

- Indoor climatic design condition:

We select the same climatic design conditions in the indoor as Ouertani [11]. They are 26°C in cooling period and 20°C in heating period. In fact, sizing HVAC system using RTS allows us to ensure a continuous comfort for occupants because it is adapted at extreme circumstances with a percentile design conditions. The below figure (III-4) displays the evolution of maximal dry bulb temperature at the cooling design conditions for SPREADSHEET ASHRAE and REVIT. We note that 1% cumulative frequency of temperature design by REVIT exceeds those used by SPREADSHEET ASHRAE and TRNSYS as displayed in figure (III-4).

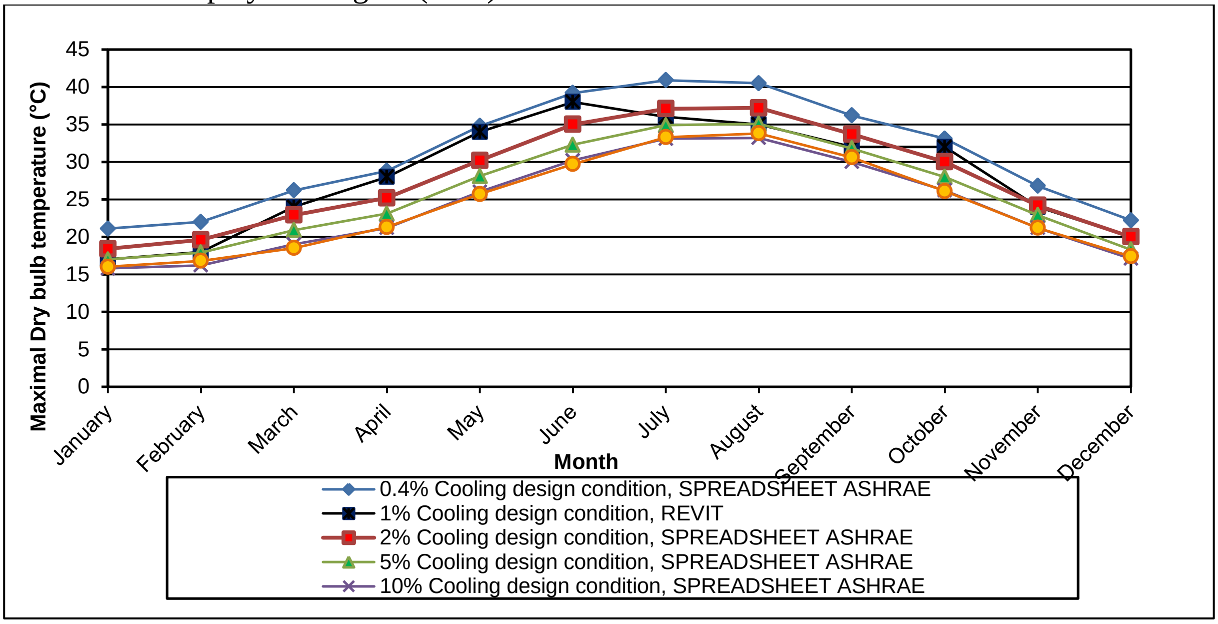


Figure III-4 Evolution of dry bulb temperature in the cooling design conditions according SPREADSHEET ASHRAE and REVIT Design condition

- Reference model location according to SPREADSHEET ASHRAE:

SPREADSHEET displays 15 Tunisian localizations (Tunisia, Bizerte, Djerba, Mellita, Gabes, Gafsa, Habib Bourguiba International, Jendouba, Kairouan, Kelibia, Monastir Skanes, Sfax-El Maou, Tabarka, Thala, Tozeur, Tunis Carthage distributed to 56 stations. The name of the closest observing station to reference model is TUNIS-CARTHAGE station. This station has 36.83 N° latitude and 10.23 E° longitudes as displayed prior in table (III-7). As well as, its altitude is equal to 4m. The below figure (III-5) exposes a Time Zone (TZ) of this location which is equal to +1 hour ahead Coordinated Universal Time (UTC). These base data are derived from Integrated Surface Data Set (ISD) for stations from around the world provided by National Climatic Data Center (NCDC) for the period 1982-2006.

Figure III-5 Time zone of Tunisia location compared to UTC

III.4.2.3 Modeling using RTS method

We recall as seen in chapter (I) that RTS method calculation is based on two time delays:

- Radiant time delay for 24 hours represented by 24 coefficients series which correspond to radiant time factors (RTF). These RTF are used to convert radiant portion of hourly heat gains to hourly cooling. As well as, the heat gain by conduction through external surface to interior area occurs after a time delay is calculated using Conduction Time Series Factor (CTF) which can also called Conduction Time Series (CTS) coefficients.

- Time delay by conduction for 24 hours represented by 24 coefficients series which corresponds to radiant time factors (RTF).

<

Then, we need to select CTS, RTF solar and non-solar RTF in order to generate RTS method in SPREADSHEET ASHRAE. Then, we will model room1 zone using PRF/RTF generator in order to determine the last coefficients. We will call in this thesis respectively ‘Typical wall’ and ‘Typical roof’ which correspond to Finding CTS coefficients related to walls and roof of room1. As well as, we will entitle ‘Typical solar RTF’ and ‘Typical non-solar RTF’ for RTF coefficients. After that, we will select accurate RTS and RTF data from ASHRAE Handbook of Fundamentals 2009 which are the closest to our reference model as displayed from figure (III-6) to figure (III-11). Figure (III-6) displays CTS percentage for external surfaces as walls, floor and roof. The South, North, East, and West walls have the similar percentage factors because they have a similar material construction and even the same thermal property. We notice, as seen before, that the heat gain is distributed differently according to the heat capacity of each component envelope as displayed in table (II-2) such as:

- The exterior wall with the lowest heat capacity (Hc), it has almost 231.5 kJ/ m²K distributes 11% CTS factors heat gain at 5 hours.

- The floor with a medium thermal capacity distributes 7.8% CTS coefficient heat gain at 5 hours by conduction progressively throughout 24 hours which is equal to 444.6 kJ/ m²K°.
- The roof with the highest thermal capacity as 551 kJ/ m²K displays 6.2% CTS factors heat gain at 9 hours.

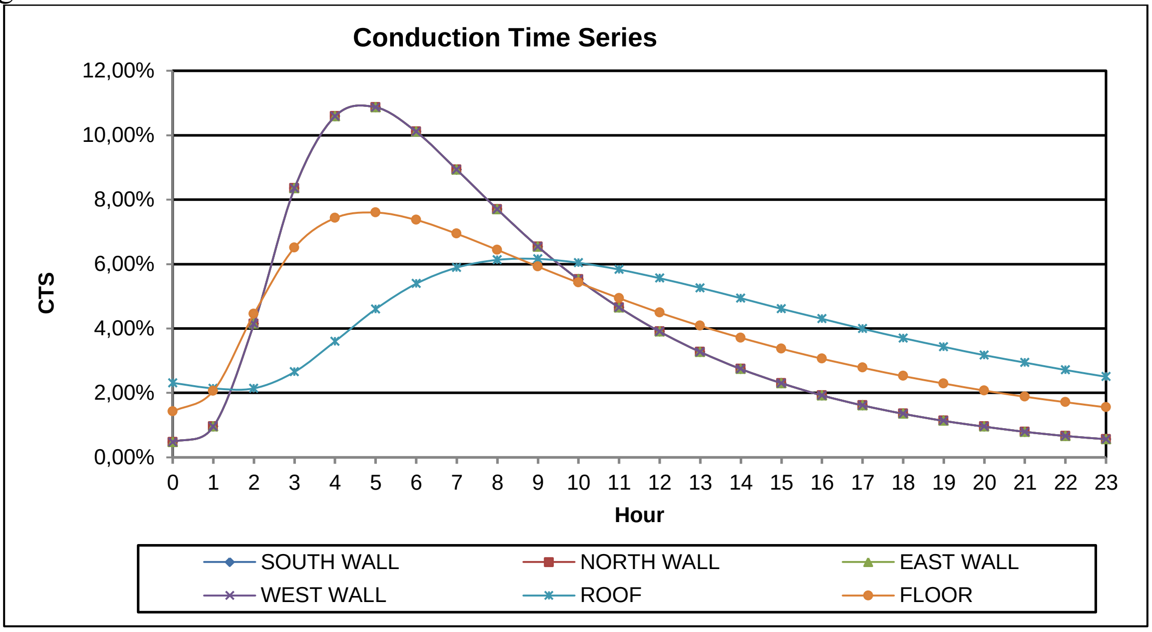


Figure III-6 CTS values for external surface of reference model

We call back that Periodic Response Factors (PRFs) are related to conduction heat gains. The conduction time series are the results of dividing the 24 periodic response factors respectively by the global thermal transmission of l wall or roof. Then, we can base on PRFs in order to assess the efficiency of the external surfaces as displayed in figure (III-7) which proves that the roof is more efficient than South wall surface because it has a higher thermal capacity. According to figure (III-8), we choose CTS coefficients of 'wall 10' which has the same path to our 'Typical wall'. Moreover, we select CTS coefficients of 'roof 16' to determine heat gain through roof of our study model. Thus, the evolution of 'roof 16' CTF for 24 hours is so close to our 'Typical roof' in figure (III-9). Besides, we use RTS called 'Type 14' for non-solar and solar RTF data which corresponds to a Heavy Weight Construction, assuming 50% glass with carpeted-floor. Then, the evolution of this kind of RTF for 24 hours concerning non-solar and solar is so close to our 'Typical roof' as displayed respectively in figure (III-10) and (III-11).

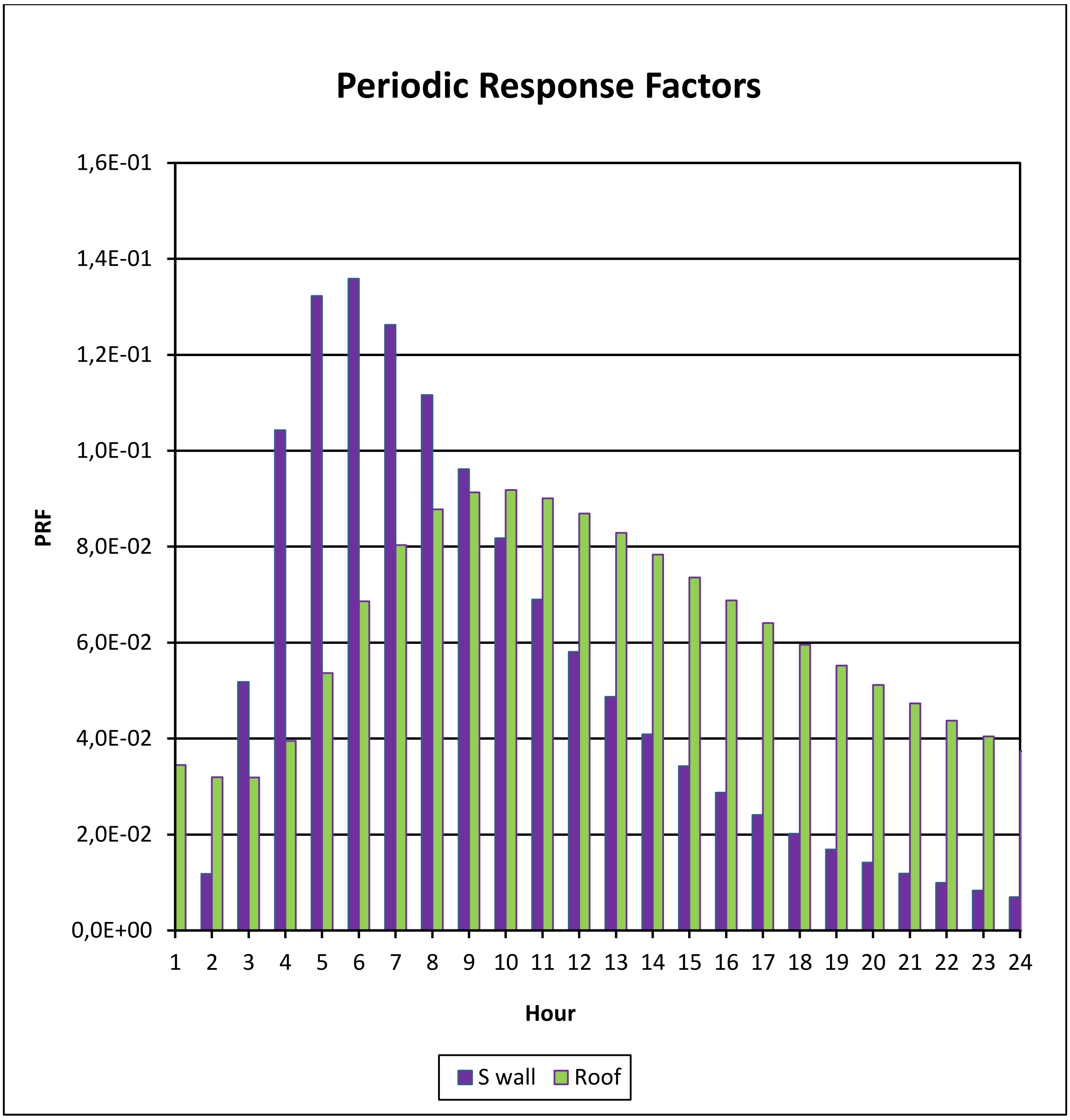


Figure III-7 Hourly PRF evolution of South wall surface and roof

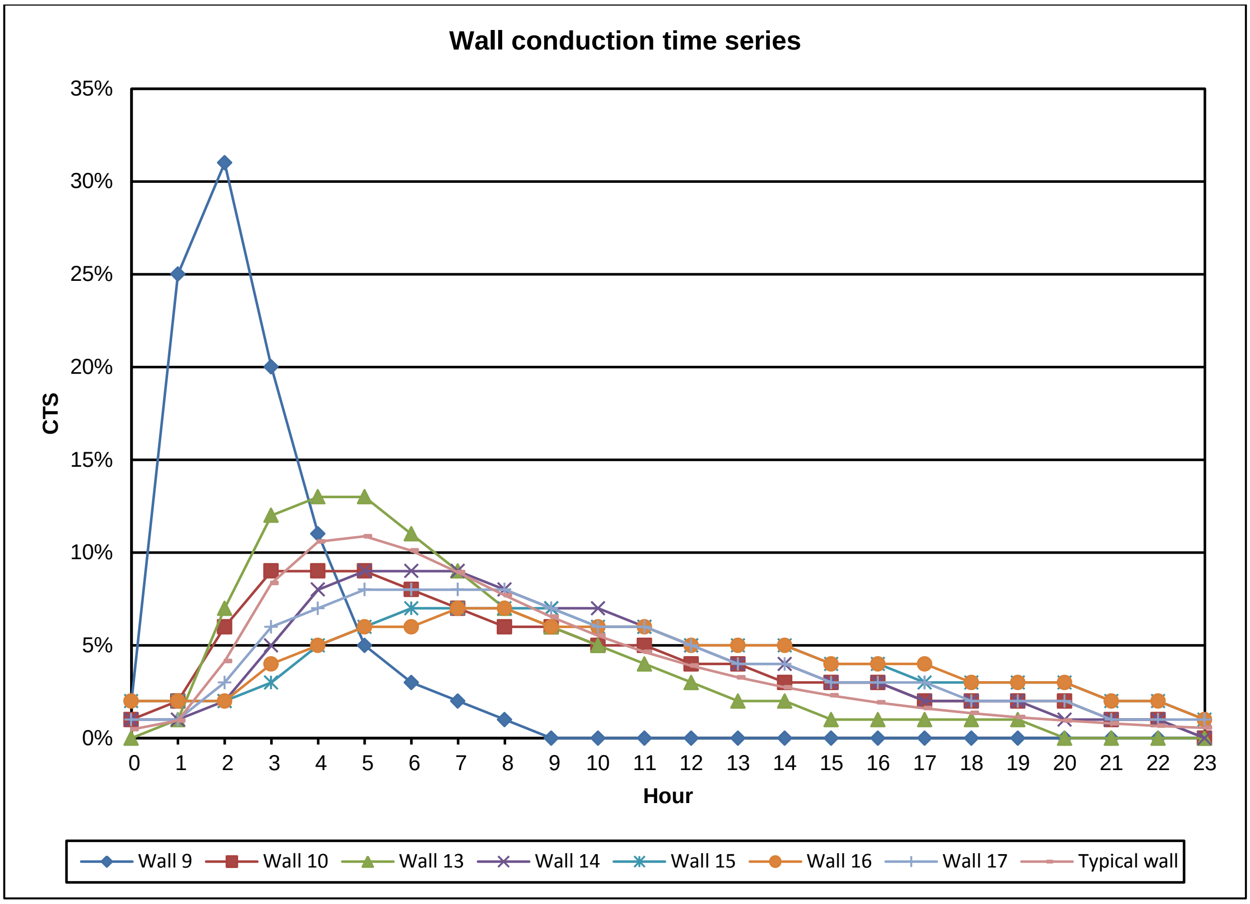


Figure III-8 Evolution of CTS of typical wall and ASHRAE construction walls

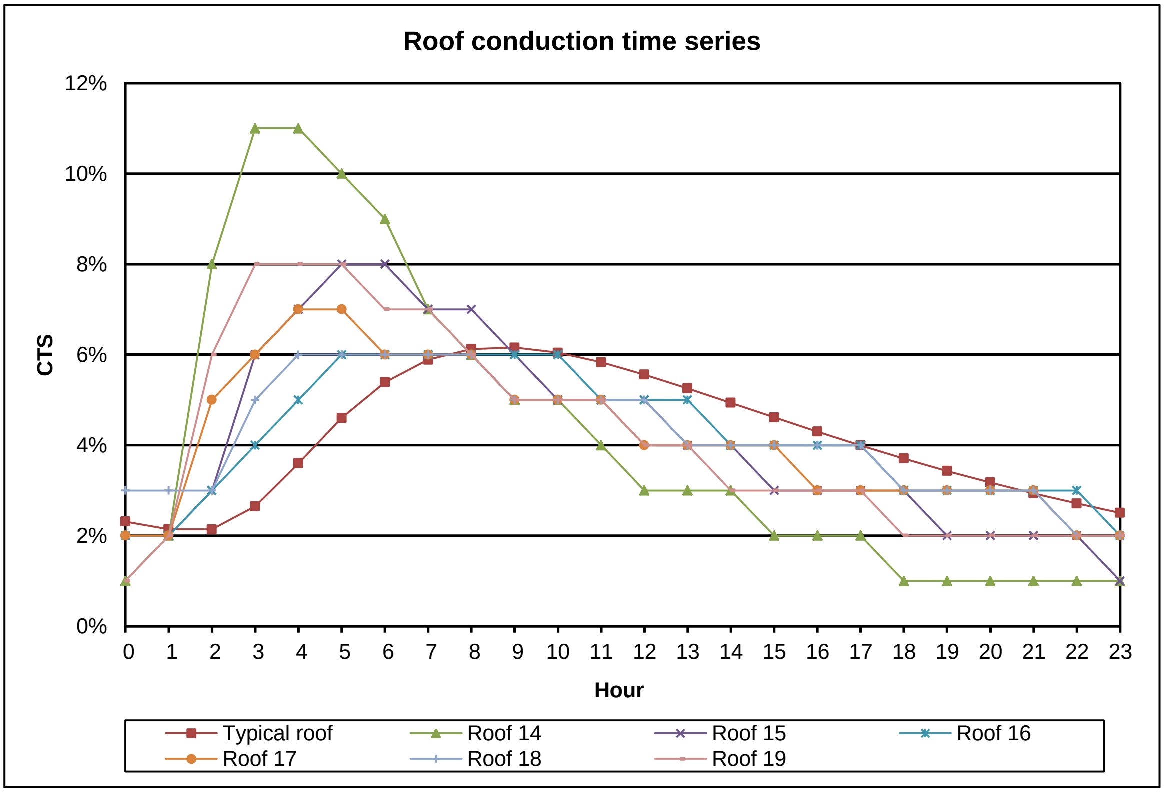


Figure III-9 Evolution of CTS of typical roof and ASHRAE construction roofs

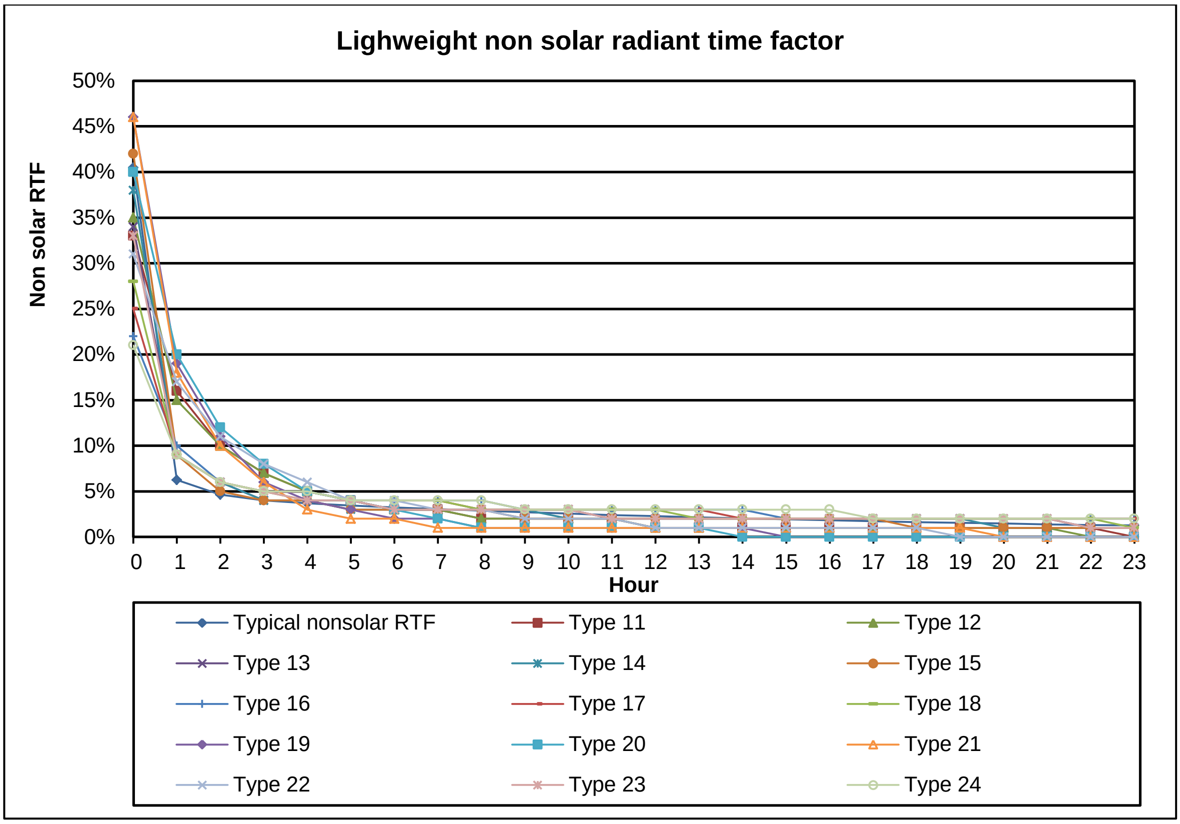


Figure III-10 Evolution of Typical Non solar RTF and ASHRAE RTF Non solar data

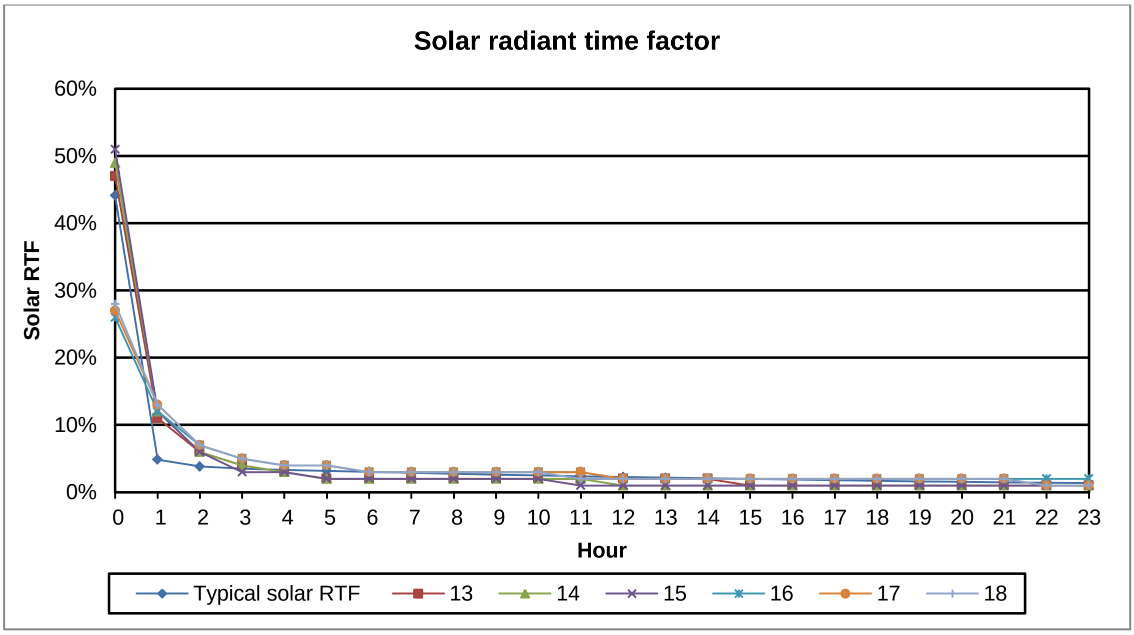


Figure III-11 Evolution of Typical solar RTF and ASHRAE RTF solar data

III.5 SPREADSHEET ASHRAE Application

III.5.1 Room cooling load calculation

Relying on RTS, we need to generate 288 time Dry bulb/ Coincident Wet-bulb temperature to calculate the cooling load. For the simulation, we choose a 5% frequency of occurrence for climatic design condition in order to remain in the same conditions as TRNSYS. These extreme conditions determine the time and the amount of peak cooling load to size the cooling load in room1. Hence, in this part we will be limited only to calculate cooling load in July at 2:00 pm. And after that, we will rely on SPREADSHEET ASHRAE computer to simulate the remaining hours. We select this date because it represents a maximal outdoor temperature as 33.1°C in July. Therefore, we will determine a contribution of each component to the total cooling load at this specific date. The next paragraphs are based on different steps of RTS procedure described earlier in chapter (I).

III.5.1.1 Internal cooling load

III.5.1.1.1 Lighting cooling load

To determinate cooling load of our lighting kind as Fluorescent lights [11], we rely on the following step. Firstly, we need to calculate the 24 h heat gain profile for lighting based on the equation (I-17). We take into account, of course, the occupancy schedule indicated previously. Secondly, we split those heat gains into 67% radiant and 33% convective portions as displayed in chapter I (table (I-3)). Thirdly, we apply in the equation (I-15) a radiant portion of lighting heat gain profile with non-solar RTF as ‘Type 14’ coefficients. Fourthly, we sum the convective and radiant cooling load components up to determine the contribution of lighting in the overall cooling load as displayed in the following figure (III-12). This figure shows that peak sensible cooling load of lighting occurs at a maximal heat gain at 7:00 am and 9:00 pm. These hours represent 225W/lighting Watt and 250 W/lighting of sensible cooling load.

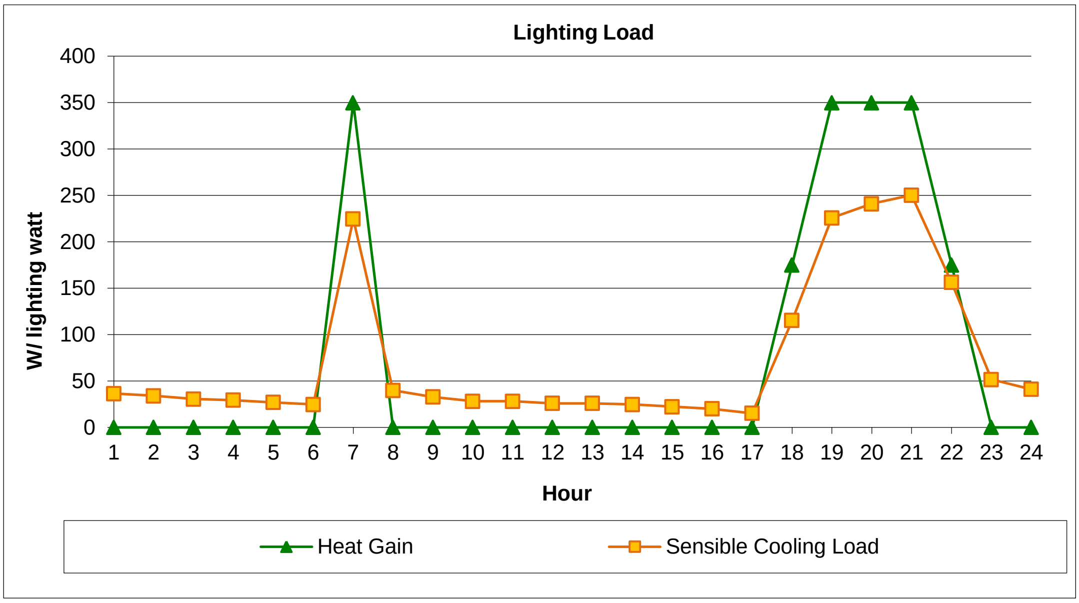


Figure III-12 Evolution for 24 hours of peak load for lighting component using SPREADCHEET ASHRAE in July at 5% design condition

III.5.1.1.2 Equipment cooling load

The above steps are often repeated in order to determine the contribution of equipment to overall cooling load. But to calculate the 24 h heat gain profile for equipment, we refer to equation (I-18) taking into account the equipment schedule indicated prior. After that, we need to split those heat gains into 30% radiant and 70% convective portions as displayed in table (I-3). Therefore, the results of the equipment cooling load are displayed in the following chart. This chart displays the maximal sensible cooling loads and the maximal heat gain of equipment component which are produced respectively 2735W and 3301W of equipment power. These peak values are occurred at 7:00 am, 12:00 am and 7:00 pm. We notice that at these specific hours the maximal heat gains are contributed to an instantaneous cooling load.

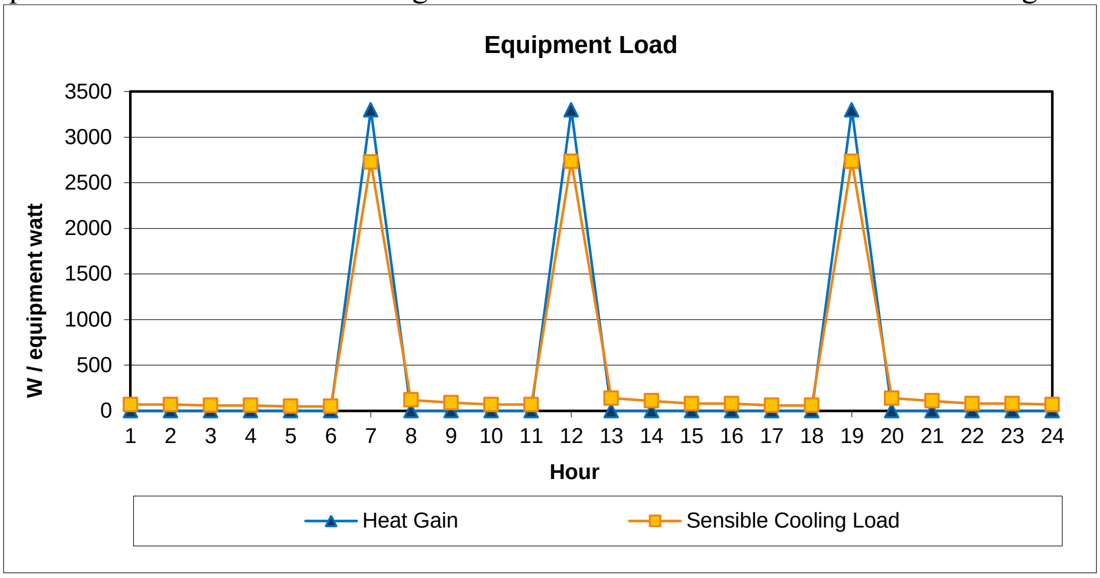


Figure III-13 Evolution for 24 hours of peak load for equipment component using SPREADCHEET ASHRAE in July at 5% design condition

III.5.1.1.3 Occupant cooling load

The above steps are repeated in order to find out the contribution of the occupants to the overall cooling load. Therefore, we select 70 W/person for sensible heat gain and 35 W/person for latent heat gain as given by Ouertani [11]. We insert these data according to table (I-4). As well as, we split sensible heat gains into 60% radiant and 40% convective portions as displayed in table (I-3). Hence, the results of heat gain contribution by occupant on cooling load are displayed on the following chart (figure III-14). This chart displays the maximal sensible cooling load of people component occurs at a maximal heat gain by equipment at 7:00 am to 6:00 pm. The last hours correspond respectively to 54W and 62 W of sensible cooling load per person.

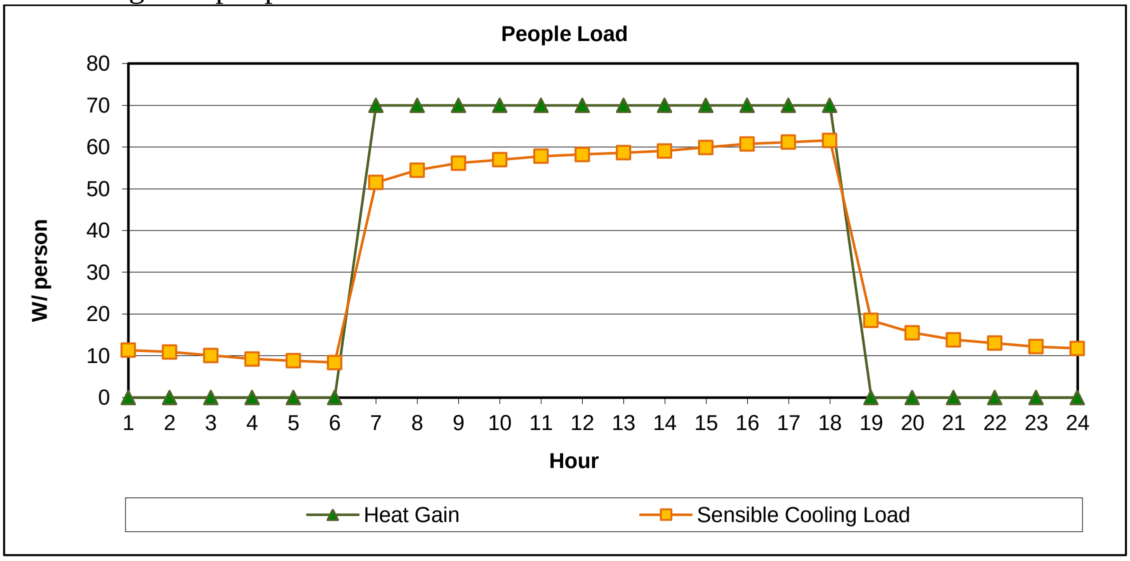


Figure III-14 Evolution at 5% design condition through 24 hours of peak load per person using SPREADCHEET ASHRAE

We call again that our purpose in this part is to estimate the internal and the external surfaces load using RTS at 2:00 pm in July method. As seen before, SPREADSHEET ASHRAE computer is used to generate RTS method. Hence, it is used in this chapter to simplify the tedious handling calculation load and to estimate a peak cooling load during whole year.

III.5.1.2 External surfaces

We will focus on calculating the contribution of the external surfaces like south-oriented wall, roof and south windows in the cooling load.

III.5.1.2.1 Wall cooling load:

In this short part, we count on these steps to work out the cooling load of a double partition wall of room1. Firstly, we apply the equation (I-10) in order to fix the sol-air temperature ***(*te)** of external surfaces in July 21st at 2pm (local standard time). Thereby, the data of meteorological station are considered for the calculation by ASHRAE. This wall surface is painted on white-colored such as **α /ho** = 0.01, and **ε ΔR/ho** = 0. It is located in Tunis-Carthage such as latitude is equal to 36.83 E° and longitude is 10.2 N°. As well as, for the calculation we select accurate clear sky optical depth for Beam Irradiance (Solar Taub) and for Diffuse Irradiance (Solar Taud) which are respectively 0.545 and 1.73 value. These values which correspond to our meteorological stations are taken for July from monthly weather data in Ashrae. Outdoor design temperature in July at 2:00pm is 34.9°C. The Ground Reflection (**g**) is assumed equal to 0.4. Table (III-8) summarizes the climatic design information related to our location in order to calculate Solar-air Temperature **(te)** and the total solar irradiance.

Table III-8 Design condition from SPREADSHEET ASHRAE

Design condition	Information
Location	Tunis Carthage station
Latitude	36.83
Longitude	10.2
Time Zone	+1hour/UTC
Month	7th month (July)
Indoor Air Temperature	26°C
Ground reflectance	0.4

The total solar irradiance "$\mathbf{E_t}$" reaches the receiving surface is given by the sum of three components: the beam component "$\mathbf{E_{t,b}}$" occurs from solar disc, the diffuse component "$\mathbf{E_{t,d}}$ " originating from the sky dome and the last term is the ground-reflected component "$\mathbf{E_{t,r}}$" which occurs from the ground in front of receiving surface. Thus, the total solar irradiation is expressed in the following equation:

$$E_t = E_{t,b} + E_{t,d} + E_{t,r} \quad (36)$$

$\mathbf{E_{t,b}}$= the beam component expressed on (W/m²)

$\mathbf{E_{t,d}}$=the diffuse component expressed on (W/m²)

$\mathbf{E_{t,r}}$=the ground-reflected component expressed on (W/m²)

In fact, we need to compute solar angles as solar altitude, solar azimuth, surface solar azimuth, and incident angle to calculate the last values. We will base further on these procedures to calculate the total solar radiation for roof. Figure (III-15) shows that maximal incident flow for beam component "$\mathbf{E_{t,b}}$" and total solar radiation "$\mathbf{E_t}$" for south wall is occurred at 11:00 am. As well as, the total solar irradiance of wall rises between 5:00 am and 7:00 pm which corresponds to sunrise and sunset in July.

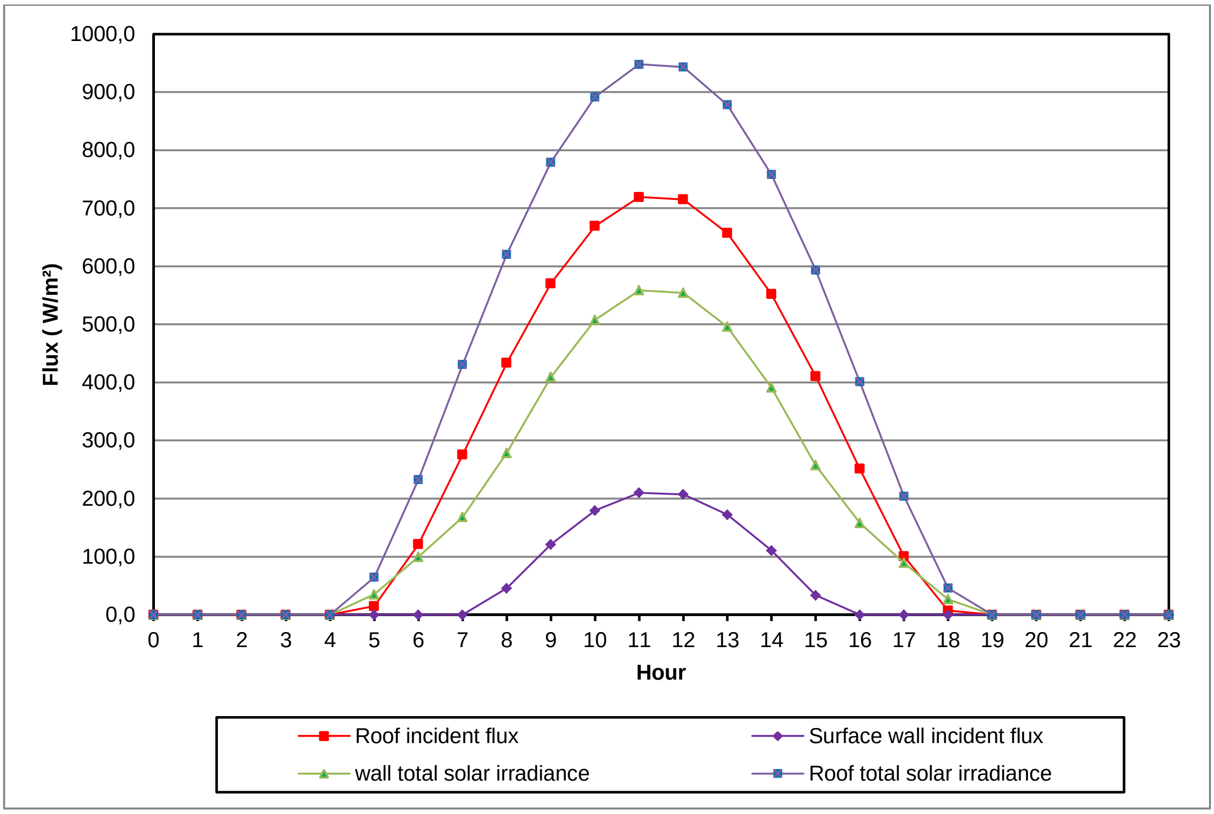


Figure III-15 Flow incident and total solar irradiation of roof and wall through a design day in July at 5% design condition

If we apply outdoor temperature value, "E_t" value, absorbance and emittance coefficient in equation (I-10), we will find that sol air temperature **(te)** for south wall is equal to 42.7°C at 12:00 am Local Standard Time (LST). This hour corresponds to 34.2°C outdoor temperature as displayed in figure (III-16). We base on SPREADSHEET ASHRAE to simplify tedious method calculation of sol air temperature through 24 hours in July as displayed in figure (III-16). This chart shows that outdoor temperature and sol-air temperature of roof and wall have similar oscillations. These temperatures rise between 5:00 am and 7:00 pm which correspond to sunrise and sunset in July.

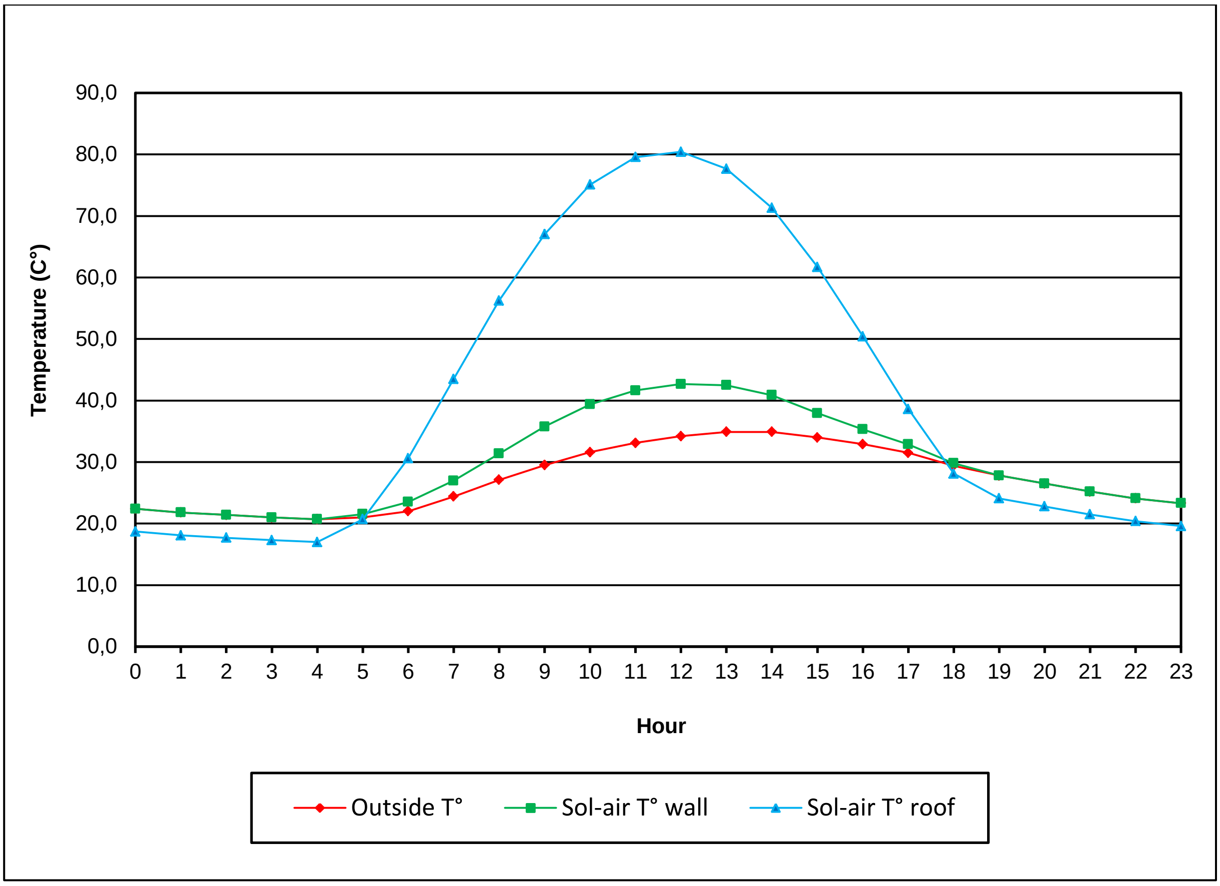


Figure III-16 Evolution of outdoor air temperature and sol-air temperature related to wall and roof external surface through a design day in July at 5% design condition

Therefore, sol air temperature value is applied firstly with an overall heat transfer coefficient of south wall in equation (I-11) to determinate 24 h heat input profile for south wall. Second, we use CTS of 'wall 10' coefficients with heat input profile in equation (I-13) to find out conduction heat gain in 2:00 pm and past 23 hours. Third, we split this heat gain on 63% radiant and 37% convective portion. Then we apply to radiant portion heat gain in equation (I-15) with non-solar RTS for heavy weight construction with carpeted floor and we assume 50% glass. We sum up the convective cooling load with radiant cooling load to determinate total cooling load of south wall components in order to calculate the radiant cooling load. The obtained results are displayed below for 24 hours in July and show that wall conduction heat gain and wall cooling load have the same fluctuations. We notice according to figure (III-17) that maximal heat gain and cooling load of south wall components is occurred at 7:00 pm at sunset time. This one corresponds to 8 hours delay of a wall maximal sol air temperature. Then, it conforms also to 9 hours delay of a maximal solar heat flow which is achieved by wall as displayed in figure (III-15).

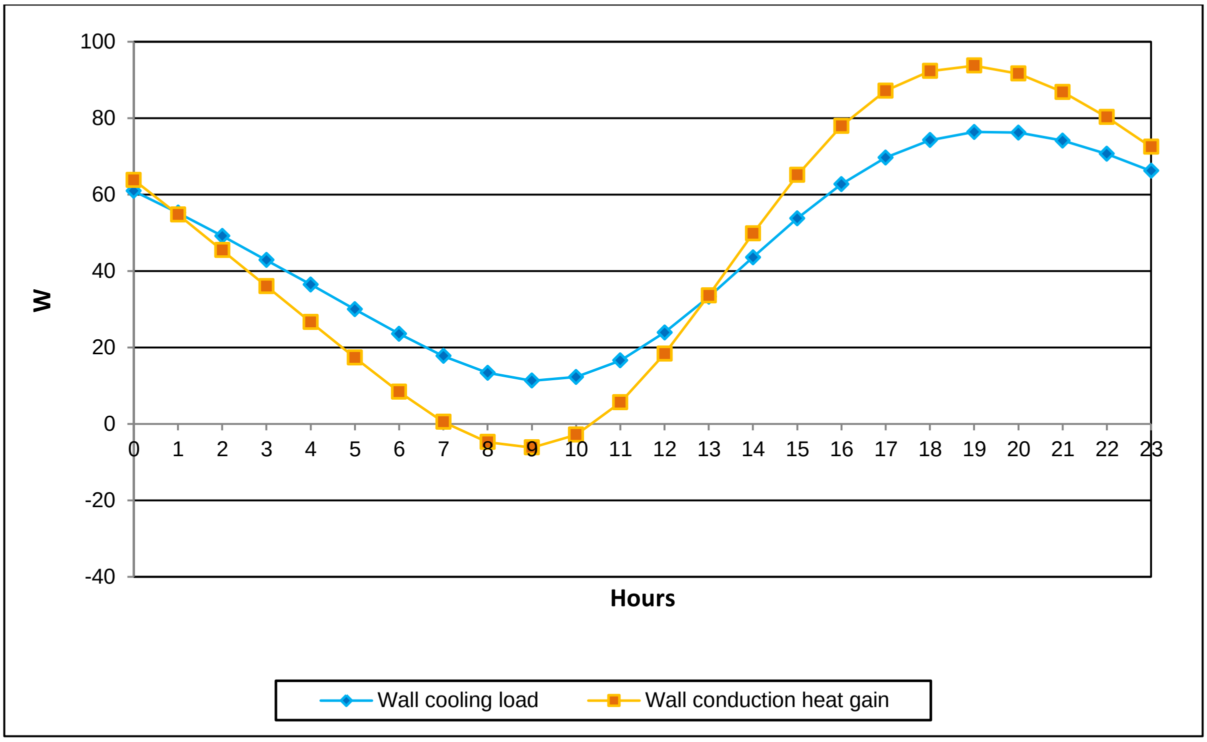


Figure III-17 Evolution for 24 hours of peak load for south wall component using SPREADCHEET ASHRAE in July at 5% design condition

III.5.1.2.2 Roof cooling load

The proceeding procedures are repeated to calculate the contribution of a roof component in cooling load. In the first step, we need to calculate the heat gain profile for the roof component. So, the procedure described above is repeated to determine the roof sol air temperature at this design time. Figure (III-15) shows that the maximal incident flow of solar beam component "$\mathbf{E}_{\mathbf{t,b}}$" and total the solar radiation "$\mathbf{E}_{\mathbf{t}}$" for roof is occurred at 11:00 am which corresponds respectively to 719W/m² and 947W/m². Figure (III-16) shows "**te**" of roof is equal to 80.4°C at midday. In the second step, we refer to CTS of 'roof 16' type coefficients to calculate conduction heat gain in 2:00 pm and past 23 hours. Thirdly, we split this heat gain on 84% radiant and 16% convective as displayed in table (I-3). Then, we repeated the same procedures described above to calculate the roof cooling load. The obtained results are displayed below (figure III-18) for 24 hours in July and show that the amount of roof conduction heat gain and roof cooling load have the same oscillations. We notice that the maximal heat gain and the cooling load of south wall components are respectively 654W and 556W in July. These values are occurred similarly at 8:00 pm and 9 pm after sunset. A maximal cooling load of south roof component is occurred at 9 hours delay compared to the maximal "**te**" of roof, although it corresponds to 8 hours delay compared to "$\mathbf{E}_{\mathbf{t}}$" which reached the roof.

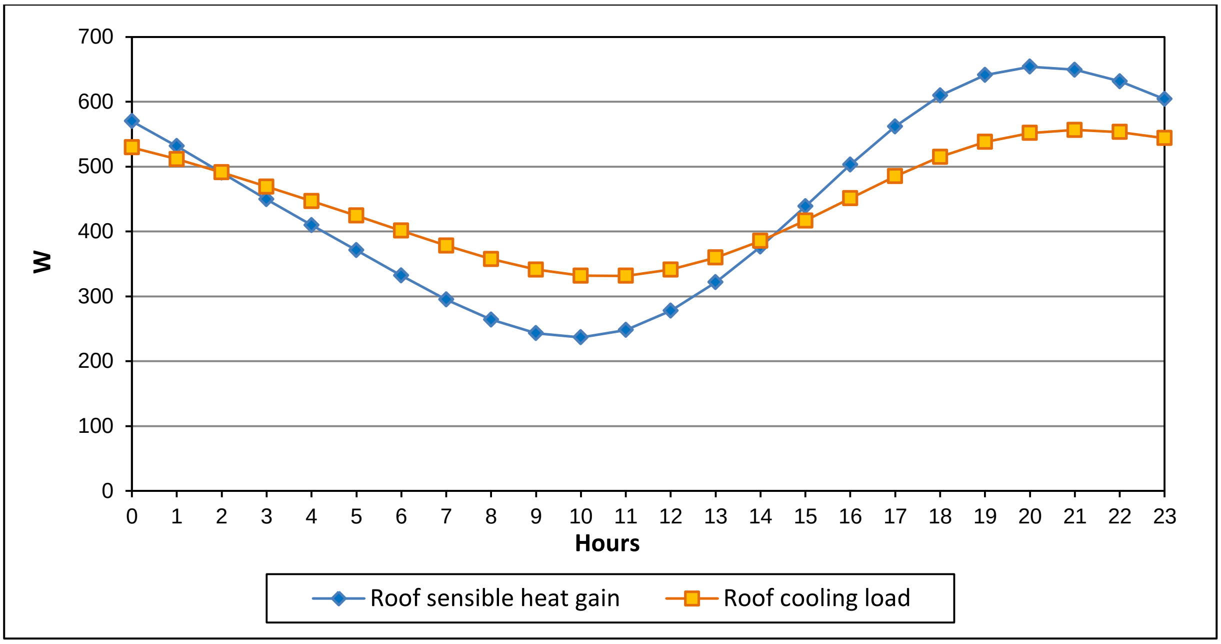


Figure III-18Evolution for 24 hours of peak load for south roof component using SPREADCHEET ASHRAE in July at 5% design condition

III.5.1.2.3 Window cooling load

The window is located in south wall of room1. It is composed of an aluminum frame with no thermal break. The window has an operable single glass, its U coefficient is 6.98 W/m²K, and its Interior Solar Attenuation Coefficients (**IAC**) is equal to 1, although this window glazing is SHGC (0) = 0.59 and. Therefore, to calculate the contribution of window component to cooling load, we use the displayed process in figure (III-19). Hence, we need to calculate 24 hours heat gain profile in July using equation (I-22). Therefore, it is necessary to determine the following terms: the direct beam solar heat gain (**qb**) according equation (I-23), the diffuse solar heat gain (**qd**) relying on the equation (I-24) and the conductive heat gain (**qc**) referring to the equation (I-25). Consequently, for direct beam solar heat gain, we need to take into account **IAC** value which is equal to 1. Then, we split the diffuse heat, conduction and direct gain on radiant and the convective portion as following:

- Total heat gain (diffuse and conduction) is divided on 54% convective and 46% radiant.
- Direct solar heat gain is entirely radiant (100%) because of IAC=1.

Thereafter, we apply non-solar RTF coefficients to the first portion. But, we apply solar RTF coefficients to second portion. Fourth step consists of sum beam radiant portion and (conductive + diffuse) radiant portion in order to determinate total cooling load of window component at 2:00 pm in July. Eventually, we use SPREADSHEET ASHRAE to estimate the cooling load of south window component for the remaining hours.

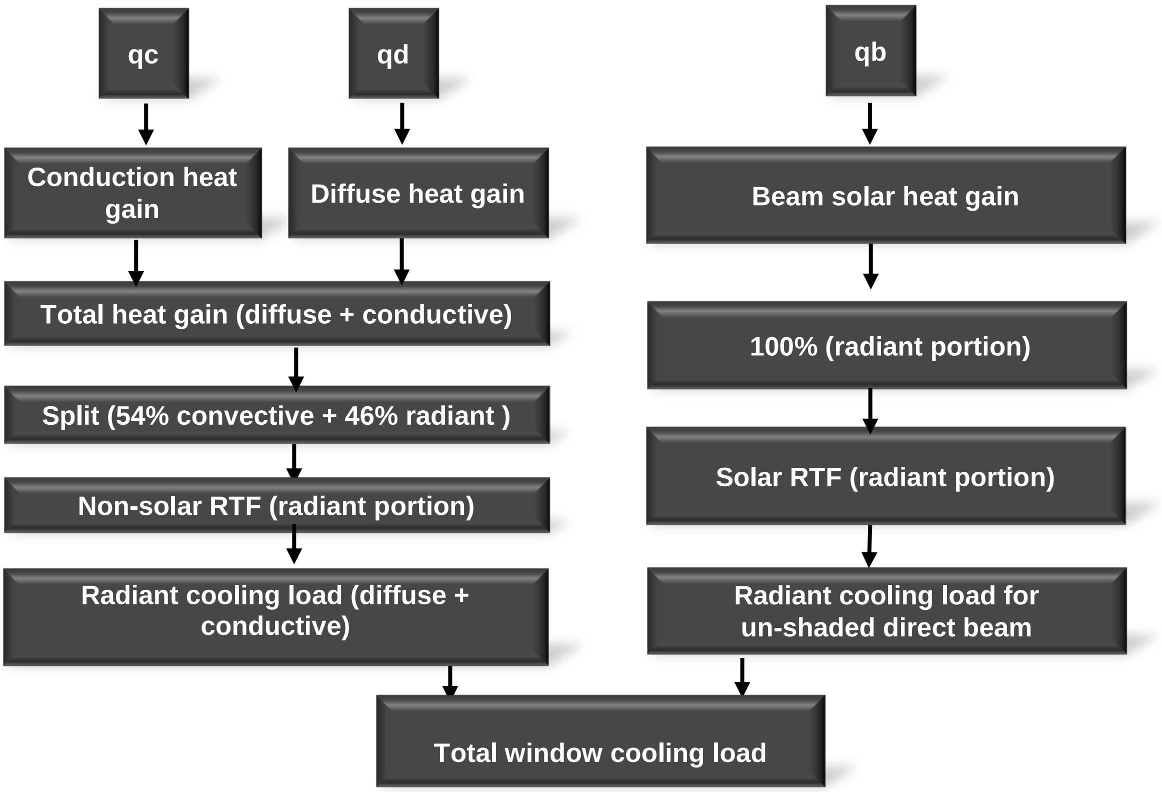


Figure III-19 Workflow cooling load calculation of window component using RTS method calculation

Figure (III-20) displays that the beam, the diffuse solar heat gain, and conductive heat gain are occurred respectively on 172W, 391W and 134W. Although the beam and diffused solar heat gain are occurred at 11:00 am, the conductive heat gain are taken place at 1:00 pm and 2:00 pm. Figure (III-21) shows that a peak and overall cooling load is 597W at 12h00 for window component. This load is the sum of two maximal loads through window:

- Load of direct un-shaded solar gain.
- Load of shaded solar gain (diffuse and conductive).

These loads expose respectively 132W and 464W at 12h00.

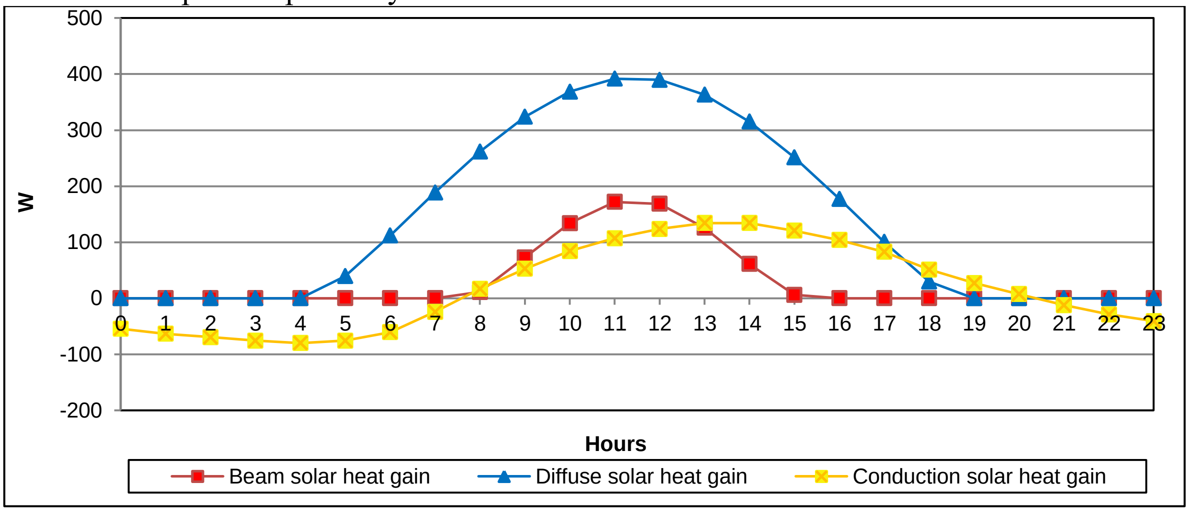


Figure III-20 Evolution for 24 hours of beam and diffuse solar heat gain of south window using SPREADCHEET ASHRAE in July at 5% design condition

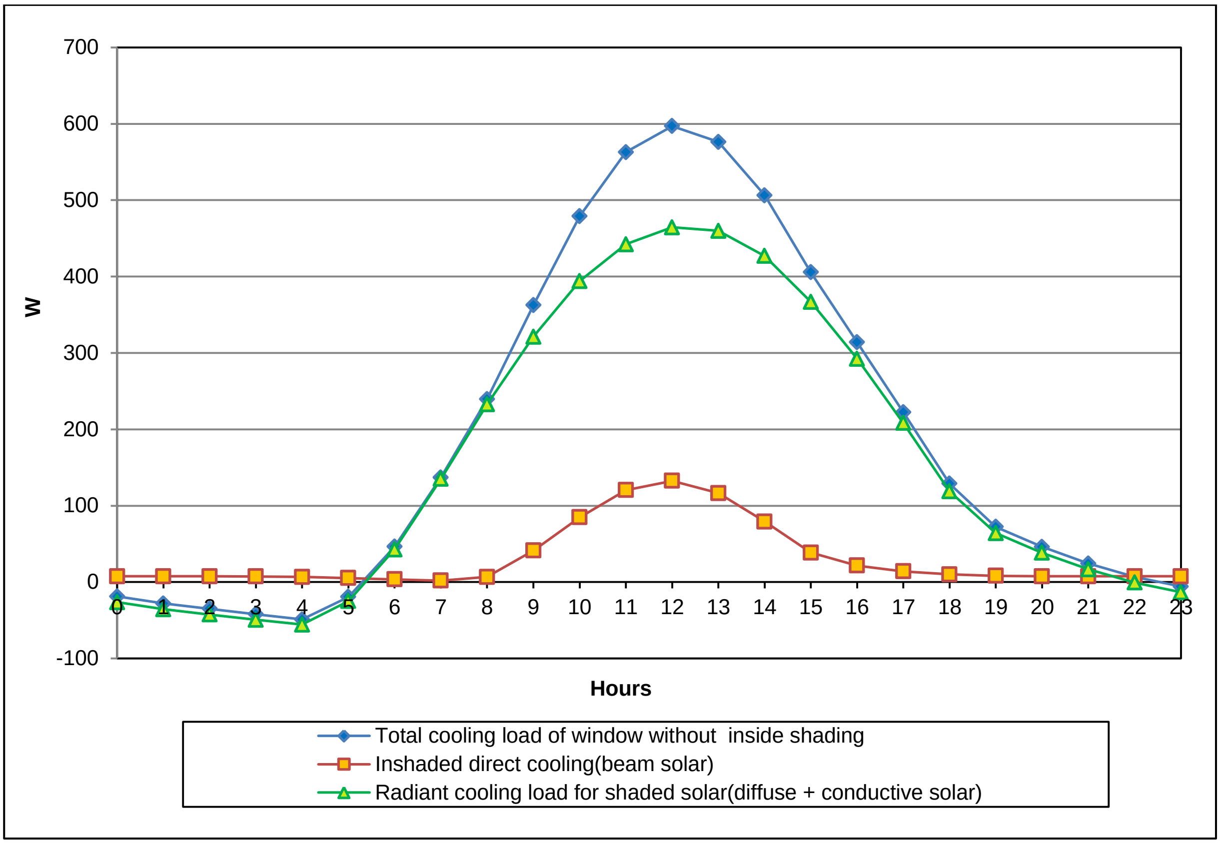


Figure III-21 Evolution for 24 hours of peak load for south window component without inside shading using SPREADCHEET ASHRAE in July at 5% design condition

III.5.1.3 Total cooling load of room1

In our study, the room1 has 2.8 m ceiling and its volume is equal to 39.2m³. We referred to the same condition as used by Ouertani [11] in order to calculate the overall cooling load of room1 using SPREADSHEET ASHRAE. Thereby, we adopted the following assumptions:

- The air change is equal to 1.6 volumes airflow/hour.
- The infiltration airflow represents 16.88 l/s using equation (I-21).
- Design Dry bulb temperature of the outside for cooling is 34.9°C at 5% frequency of occurrence in July (figure III-4).
- Indoor Relative Humidity (RH) is equal to 50% (III-7).

- Infiltration cooling load:

Generally, the latent load of room is composed of persons and infiltration latent loads. The below equation exposes that the room total load using RTS method calculation is equal to the sum of the sensible and latent cooling load of the room.

$$Room\ total\ \ load = \sum Room\ sensible + \sum Room\ latent\ load \qquad (37)$$

The obtained results of sensible and latent cooling load infiltration using equation (I-20) the obtained results are exposed in figure (III-22). The last figure explains that the peak cooling loads whether sensible or latent infiltration loads are respectively equal to 185W and 91W at 2:00 pm in July. This infiltration heat gain is occurred by Humidity Ratio (W) which is equal to 18.1g/kg. We determine the last value by psychometric chart and using 50% RH.

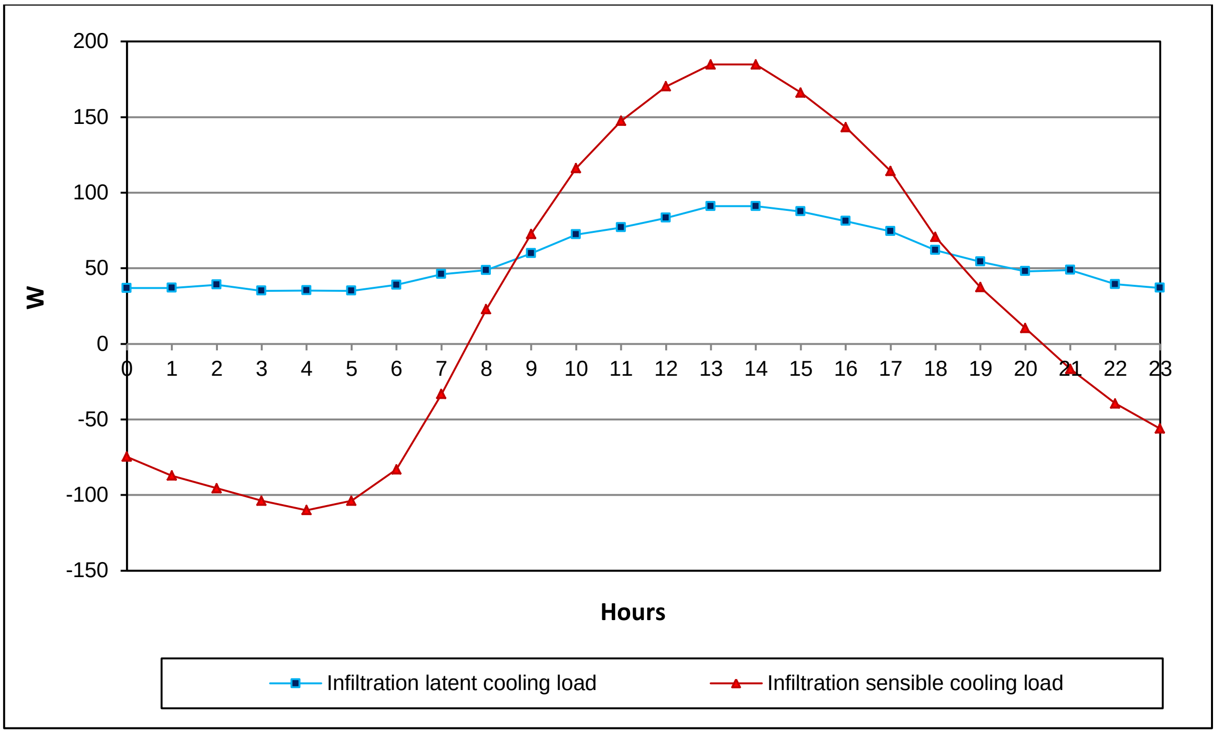


Figure III-22 Evolution for 24 hours of peak sensible infiltration load and latent infiltration load for room1 using SPREADCHEET ASHRAE in July at 5% design condition.

Figure (III-23) displays the evolution of each component for sensible cooling loads along 24 hours in July at 5% outdoor dry bulb temperature design in room1. The cooling load components are internal loads, envelope loads and infiltration. Figure (III-24) shows that the roof and the south window loads are the main components which contribute to the highest load in July. However, it displays that lighting, south wall, equipment, person latent load and infiltration sensible loads contribute to the lowest cooling load in July. We notice that the figure (III-23) reveals that a maximal of total sensible cooling and overall cooling load are occurred respectively on 1191W and 1282W at 11:00 am in July. We remind that this hour corresponds to a maximal incident flow and to a peak solar irradiance heat gain of south wall surface and roof surface (figure III-15). Besides, this hour corresponds to a beam and diffuse solar heat gain through south window of room1 (figure III-20).

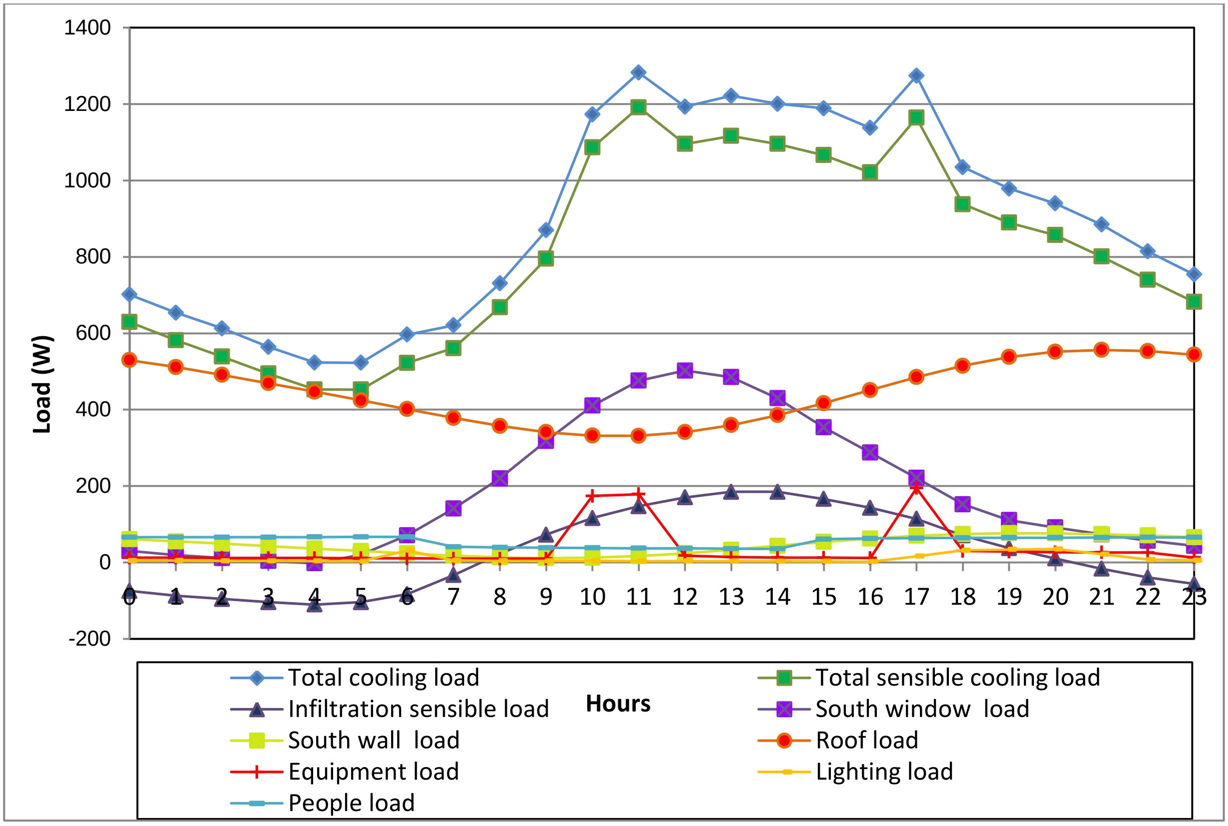


Figure III-23 Evolution for 24 hours of peak load of each component, total sensible load and overall cooling load using SPREADCHEET ASHRAE in July at 5% design condition

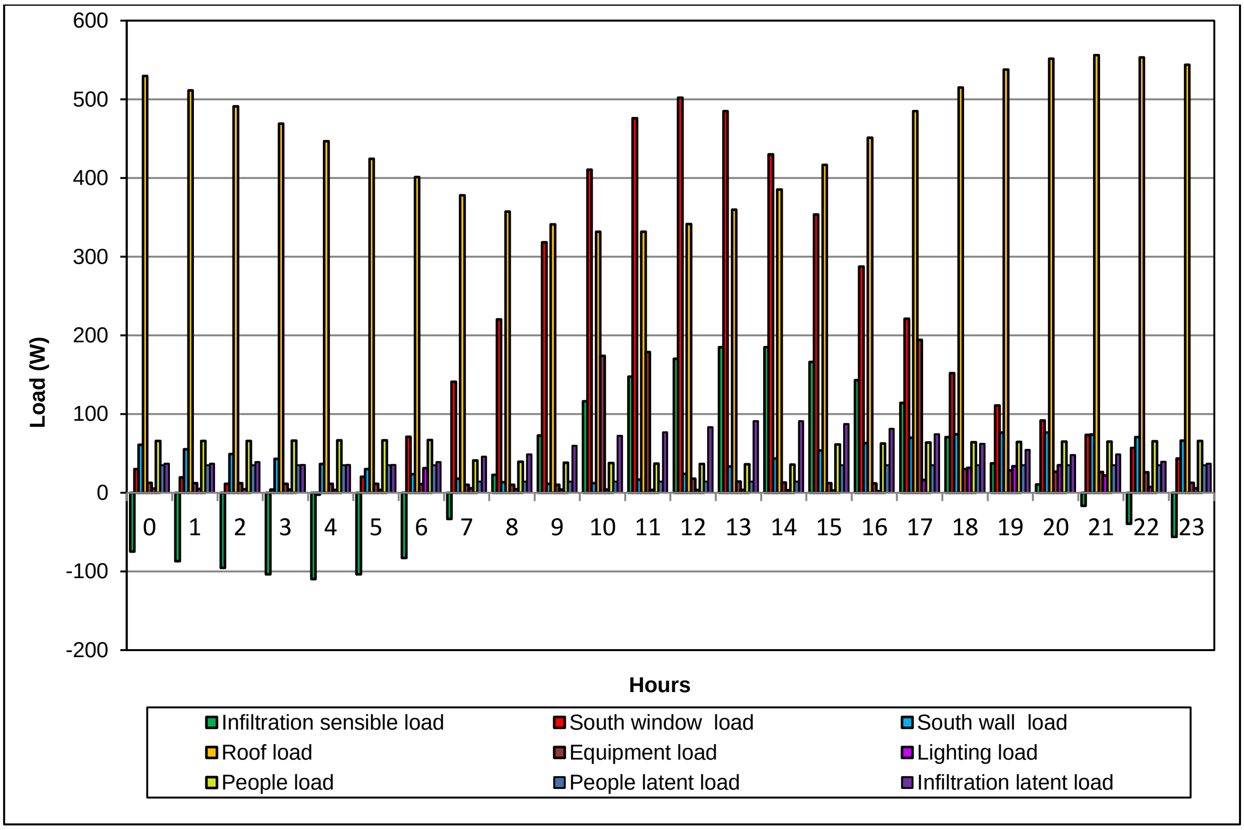


Figure III-24 A contribution for 24 hours of each component to peak load using SPREADCHEET ASHRAE in July at 5% design condition

The achieved results using SPREADSHEET ASHRAE computer (for 288 design hours of dry bulb temperature at 5% percentile frequency of occurrence) show that a peak cooling load is occurred at 12:00 am in August. At that time, the total cooling load of room1 is 1443W. This amount of load is split into two quantities as was displayed later in equation (III-37). The first amount is a total sensible cooling load which is equal to 1291W. It is equal as well as to internal envelope and infiltration loads as displayed in table (III-9). The second amount is a total latent cooling load which is equal to 152W. It is also equal to latent persons load and latent infiltration as displayed in table (III-10). Table (III-9) shows that the peak cooling loads are 586W and 301W which occurred successively by the south window and then by the roof.

Table III-9 A peak sensible cooling load of each component using SPREADCHEET ASHRAE at 12:00 am in August at 5% design condition

Room loads	**Room1 sensible cooling load (W)**
Internal loads	
People	37
Lighting	4
Equipment	179
Envelope loads	
Roof	301
Walls	30
South window	586
Infiltration loads	
Infiltration	154
Total	1291

Table III-10 A peak latent cooling load of each component using SPREADCHEET ASHRAE at 12:00 am in August at 5% design condition

Room loads	**Room1 latent cooling load (W)**
Internal loads	
People	14
Infiltration loads	
Infiltration	138
Total	152

III.5.2 Heating load calculation of Room1

Heating load calculation using RTS method is based on an extreme design condition. It also assumes unique outside temperature. Heat losses calculation is not replaced by solar and internal heat gain. Thus, the required heating load is a result of heat losses released by:

- Infiltration.
- Different envelope components.

III.5.2.1 Results of heating load calculation

This part is just to calculate heating load of room1 which is described before using RTS method calculation and SPREADSHEET ASHRAE computer. We have already referred to the same conditions as those of Ouertani [11] to the total heating load of room1 relying on SPREADSHEET ASHRAE. Therefore, we turn to the following suppositions:

- Inside temperature 20°C as Ouertani [11].
- Air change is 1.6 air volume /hour.
- Infiltration airflow is 16.88 l/s.
- Dry temperature is 5°C outdoors and occurrence frequency of the heating period is 99.6%.
- Indoor relative humidity is 50%.

Using the equation (I-20), the humidity rate (*W*) is equal to 9.5g/kg and the sensible heat gain of the infiltration during the heating period is 311W. To calculate actually the heating loads, we have used the U-factors which had been already applied for conditioning the cooling. According to the below table (III-11) the total sensible heating of room1 is equal to 1169W. This amount is composed by the envelope and infiltration loads as displayed in table (III-11). We notice that the peak heating loads are occurred by roof then by infiltration.

Table III-11 A peak sensible heating load of each component using SPREADCHEET ASHRAE at 99.6% design condition

Room loads	**Room1 sensible heating (W)**
Envelope loads	
Roof	454
Walls	178
Window	226
Infiltration loads	
Infiltration	311
Total	1169

III.6 REVIT application

As previously seen, REVIT allows to share building data among the interested actors. Hence, this part of the study aims to:

- Validate the thermal simulation using REVIT.
- Compare the obtained results of TRNSYS [11] and SPREADSHEET to validate REVIT.
- Investigate the achieved results by the building actors (architect, engineer) using REVIT software.

The two building actors lead to provide comfort inside lodgment for users. On the one hand, the main purpose of architect is to design sustainable building. Briefly, he needs to identify most passive strategies suitable for a study site. The architect analyzes the meteorological data, and then, he can estimate the contributions of each passive design technique for energy save. Then, REVIT engine, in this step, needs to determine the cooling and heating hours and the monthly cumulative load. It displays above all the graphic results of a monthly heating load. Finally, it exposes yearly the cooling energy consumption of each component.
On the other hand, the engineer workflow, REVIT permits to determine the maximal heating and cooling loads so as to design an efficient HVAC system.

III.6.1 REVIT climatic conditions

The initial step in cooling and heating load calculation is composed of select indoor and outdoor design conditions [32]. REVIT is based on climatic design information for load calculation and energy use calculation. These data are taken from extreme climatic data and mainly from National Data Center (NDC) for 1982-2006 recorded periods. The extreme climatic conditions are assured according an annual percentile for cold season and monthly percentile for warm season. These percentile values have the same probability of occurrence in any climate. According to, ASHRAE Handbook Fundamentals [32], the X% design condition is the condition that exceeds an average of X% of time. Besides, it shows that exist a relation between annual and monthly cooling designs as described in the following equation:

$$X\%\ annual\ cooling\ design = 5\ \times X\%\ \ monthly\ cooling\ condition \qquad \textbf{(38)}$$

Such as:

$X\%$= percentile value of cumulative frequency of occurrence of design condition.

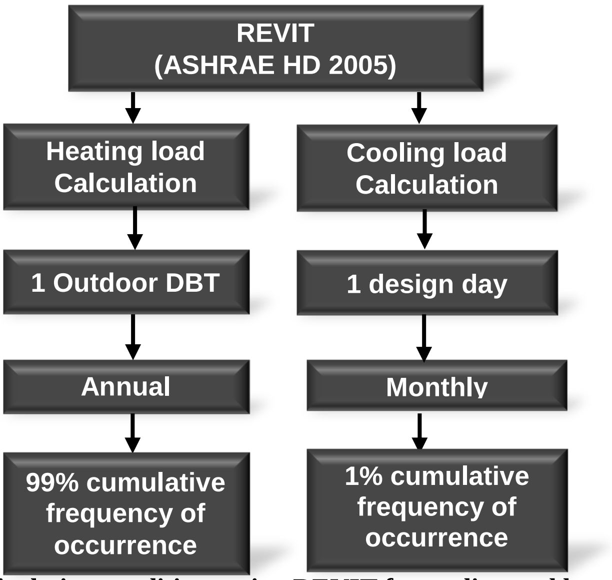


Figure III-25 Climatic design conditions using REVIT for cooling and heating load calculation

Therefore, we choose HVAC design data from weather station ID (156609-2006) which represents the closest data to our location. This ID station is located in 36.85 N° latitude and 10.22 E° longitude based on those of ASHRAE Fundamentals 2005. And, they are derived from REVIT Manage and World Meteorological Organization (WMO) database. The closest WMO weather station is picked along with its weather data which provide climatic design condition for load calculation. Then, a design day is derived to represent a month with a maximum dry-bulb temperature as well as its coincident wet bulb temperature. A temperature values correspond to 1% monthly temperature for this location. This is the temperature that exceeds monthly an average of 1% of the time as displayed in table (III-7) and figure (III-4). According to the equation (III-38), these temperature values are taken at 7.2 hours in a month which correspond to 438 hours from 8760 hours per year. As well as, the climatic conditions for heating load calculation are based on 99% percentile value of frequency of occurrence. We attain a 6°C design temperature only if we use REVIT for load calculation at 99% percentile.

III.6.2 Adopted method for calculation using REVIT

REVIT software is used for heating and cooling load calculation. We have only one interface to set both winter and summer design conditions. In this part, we will investigate the efficiency of architect and engineer tools for thermal simulation.

- In the first step, we will use 'Heating and Cooling' tool set up by the engineer. Thus, we need to set only 24 hours/day to define operating schedule of the annual building. Because REVIT is based on a steady operating, occupancy and climatic design conditions along the whole year.
- In the second, we will rely on 'Building Elements Mode' tool used by the architect to estimate the energy use.

III.6.3 Simulation based on 'Cooling and Heating' tool:

Heating and cooling load calculation method in REVIT is based on RTS method. This method relies on two times delay. The first is by conduction and the second time delay is by radiant. We use Ashrae Handbook of Fundamentals as reference to validate REVIT results. A 'Cooling and Heating' tool from REVIT is to calculate a total peak cooling load for all spaces in the zone (ventilation, pipe and duct gains, and sensible and latent loads). In our study, we will concentrate only to calculate a total cooling and heating loads using 'Cooling and Heating' REVIT tool.

Before, REVIT displays the heating and cooling load results, we need to prepare an energy model. Consequently, we require setting up the space and zone properties.

III.6.3.1 Space and zone properties

After designing a geometric model using REVIT, we need to assign a space area where we apply in the HVAC zone. Furthermore, we need to establish an energetic model of room1 in the suitable dialog box of Space and Zone properties.

- Zone properties:

In the zone properties of the dialogue box as it is displayed in figure (III-26), we need to regulate cooling information. So, we assign 26°C for cooling set point temperature and 16°C for cooling supply air temperature. Although we assign 20°C for the heating set point temperature and 30°C for supply air temperature. We affect an air exchange equal to 1.23l/(s.m²) as well.

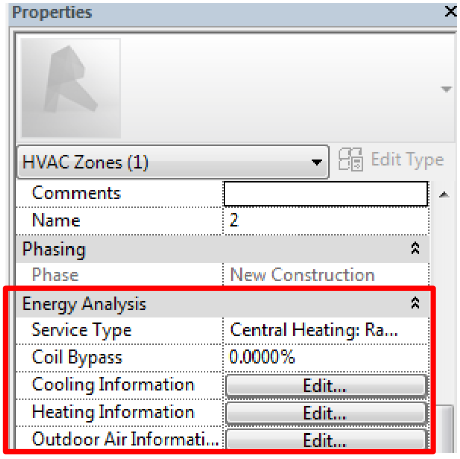


Figure III-26 Dialogue box of the zone properties.

- Space properties:

We need to define 'Properties Spaces' in dialogue box the characteristics of room1 as used by Ouertani [11] for the simulation. We notice that the input data using REVIT are similar to SPREADSHEET ASHRAE computer because both are based on RTS method calculation. Although using REVIT, we can't select RTS and CTS types accurately to room1 data. In below dialogue box, we set the following spaces properties of room1:

- 40% ceiling reflectance.
- 40% walls reflectance.
- 40% ground reflectance.
- Alimentation flow air = 16.88 l/s.
- Type of conditioning: heated and cooled.
- Lighting power =2.5W/m², (tableau III-3).
- Artificial lighting (7h à 8h et de 18h à 22h), (figure III-29).
- Equipment power 23.57W/m² for 140m² areas.
- Occupancy (2 peoples presents from 8h to 16h and 5 peoples presents from 16h to 8h), (figure III-28).

Heat gains released by occupant are 70W for the sensible heat and 35W for latent one. These values of metabolic energy are interpolated from table (I-4), (I-5) in chapter (I).

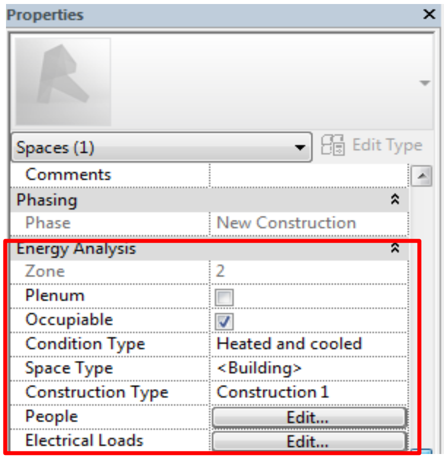


Figure III-27 Space properties dialog box

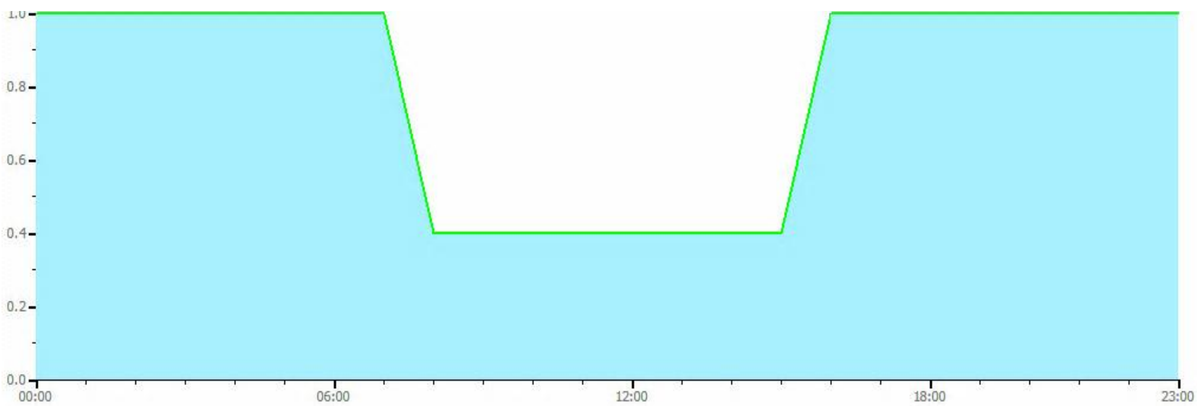


Figure III-28 Occupancy schedule for our study model using REVIT

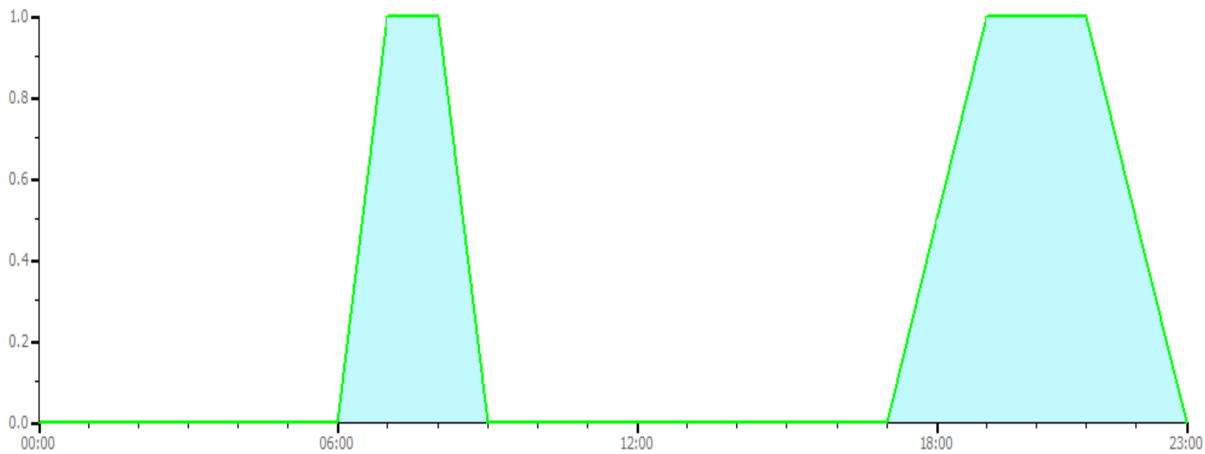


Figure III-29 Setting of lighting schedule for our study model using REVIT

Finally, in 'Construction Type' dialogue box, we need to specify the same thermal properties (roof, exterior wall, floor and south window) as used in SPREADSHEET ASHRAE. We note that in 'Construction Type' using REVIT, we can insert data for the construction properties or RTS and CTS types. After simulating several tests, we notice that these input parameters are the real error sources. Finally, we select two types of tests such as roofs and walls construction materials differently for each test.

-In the first test, we apply a similar CTS type from Ashrae Handbook Fundamentals [32]. Then, we use 'Roof 16' Type (Membrane Sheating insulation board 200mm and light-weight concrete). Besides, we use as well as a similar CTS type for exterior wall like 'Wall 10' Type (EIFS Finish insulation Board Sheating 200mm).

- In the second test and in 'Building Construction' dialogue box, we select a similar U coefficient for roof and wall as used by Ouartani [11]. In addition, we use accurate construction material to 1.21W/m²K for the south wall and 2.16 W/m²K for the roof. Thereby, we assign for roof the "asphalt, screed, dense cast concrete, dense plaster (U=2.0240 W/(m²·K))" then, we affect for exterior wall a "4 in face brick, 8 in common brick (U=1.2100 W/(m²·K))". Moreover, we maintain the same shading factor which represents IAC equals to 1 for south window in the 2 tests. As well as, we specify that the door is on solid wood storm, the floors in Wilton carpet and the slab is made up with standard construction such as (U=0.2499 W/(m²·K)). After that, we select a similar construction of window as used prior in SPREADSHEET ASHRAE. Then, we affect Uncoated single glazing with 6mm thick and gray glass color as (U =5.9050 W/(m²·K)) and (SHGC =0.59). Finally, we assume that the slab is made up with concrete and false ceiling as (U=1.0411 W/ (m²·K)).

III.6.3.1.1 First test results

- Cooling:

Cooling load results of test 1 using REVIT computer are based on 288 design hours of dry bulb temperature at 1% percentile frequency of occurrence. It shows that a peak cooling load is occurred at 13:00 am in October. At that time, a total cooling load of room1 is 1283W (table III-12). This amount is composed of internal envelope and infiltration loads. According to the below table a peak cooling load is occurred by south window.

Table III-12 A peak total cooling load (sensible and latent) of each component using REVIT at 13:00 am at 1% design condition

Room loads	**Room1 total cooling load (W)**
Internal loads	
People	48
Lighting	2
Equipment	15
Envelope loads	
Roof	6
South wall	208
Window (south)	873
Infiltration loads (Ventilation)	
Infiltration	131
Total	1283

- Heating:

In our case, room1 is located in 36° 85' latitude and 10° 22' longitude. For heating load calculation, the results of the first test 1 using REVIT computer are based on 5°C for 99.6% design dry-bulb exterior temperature and 20°C set point temperature. RTS method of load calculation using SPREADSHEET ASHRAE or REVIT is similar. But, we can choose 'Use Load Credit' which allows to consider internal heat gain but it does not take into account the solar heat gain to calculate the heating load using REVIT. Thus, the heating load 'Without Use Credit' is determined by calculating the sum of heat transfer through the envelope components and the required load from infiltration. Consequently, the report results of the heating load calculation show that room1 has got a 610W without load credit. The latter means that internal loads compensate an amount of heating load only if we interpolate an amount of 545W. We notice that the peak heating loads without using the load credit is occurred respectively by the south window and the wall.

Table III-13 A peak heating load of each component using REVIT at 99% design condition (without load credit)

Room loads	**Room1 total heating load (W)**
Envelope loads	
Roof	64
South wall	78
Window	179
Infiltration loads (Ventilation)	
Infiltration	289
Total	610

III.6.3.1.2 Second test results

- cooling

Cooling load results of test 2 using REVIT computer shows that a peak cooling load is occurred at 17:00 am in June. At that time, a total cooling load of room1 is 1344W with 46% RH at 1% percentile frequency of occurrence. A cooling load contribution of each component is displayed in below table (III-14) where we notice that the envelope loads has a peak cooling load contribution. Besides, a peak cooling loads are occurred successively by the roof and the south window.

Table III-14 A peak cooling total load of each component using REVIT at 13:00 am at 1% design condition

Room loads	Room1 total cooling load (W)
Internal loads	
People	48
Lighting	2
Equipment	15
Envelope loads	
Roof	844
Wall (south)	113
Window (south)	191
Infiltration loads (Ventilation)	
Infiltration	131
Total	1344

- Heating:

Yet, the total heating load in room1 is equal to 1045W to 99% percentile of frequency occurrence mainly in test2. The below table (III-15) displays the peak cooling loads which are occurred successively by roof, ventilation and south window.

Table III-15 A peak heating load of each component using REVIT at 99% design condition (without load credit)

Room loads	Room1 total heating load (W)
Envelope loads	
Roof	437
South wall	140
Window	179
Infiltration loads (Ventilation)	
Infiltration	289
Total	1045

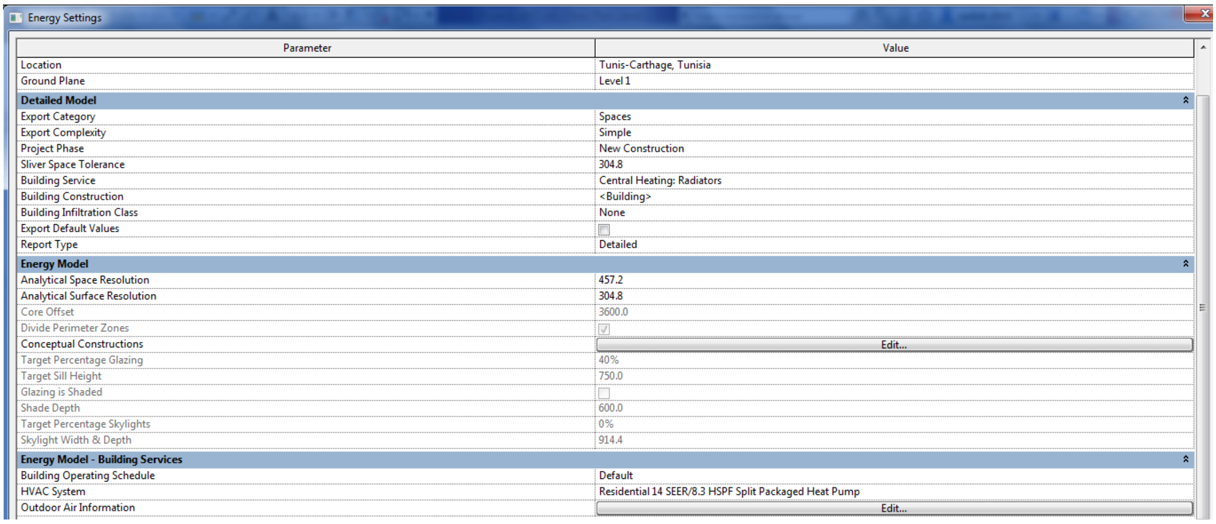
After a long reflection, the selection of test1 or 2 results using 'Heating and cooling' tool from REVIT is to validate REVIT software in residential building load calculation. Then, we further focus only on test 2 because of its closest results to SPREADSHEET ASHRAE.
Our decision relies on the components which occur at a peak cooling and heating load contribution.

III.6.4 Simulation based on 'Conceptual Energy Analysis' tool

The CEA tools are based on the cumulative cooling and heating loads of the monthly analyzing model. We will deal with the efficiency of 'Building Elements' tool from CEA one represent a detailed tool and adaptable tool to the architect work for energy analysis at the early phase of the design.

III.6.4.1 Energy setting

Actually, we require preparing the energy model before the energy simulation using REVIT software. In addition, we have to create firstly the building geometric design of room1. Then, we become able to determine the energy data and at least we can run the energy simulation. Finally, this model will be sent into the cloud to determine the calculation. As soon as, we receive the results, we can reuse them.


Energy Settings

Parameter	Value
Location	Tunis-Carthage, Tunisia
Ground Plane	Level 1
Detailed Model	
Export Category	Spaces
Export Complexity	Simple
Project Phase	New Construction
Sliver Space Tolerance	304.8
Building Service	Central Heating: Radiators
Building Construction	<Building>
Building Infiltration Class	None
Export Default Values	☐
Report Type	Detailed
Energy Model	
Analytical Space Resolution	457.2
Analytical Surface Resolution	304.8
Core Offset	3600.0
Divide Perimeter Zones	☑
Conceptual Constructions	Edit...
Target Percentage Glazing	40%
Target Sill Height	750.0
Glazing is Shaded	☐
Shade Depth	600.0
Target Percentage Skylights	0%
Skylight Width & Depth	914.4
Energy Model - Building Services	
Building Operating Schedule	Default
HVAC System	Residential 14 SEER/8.3 HSPF Split Packaged Heat Pump
Outdoor Air Information	Edit...

Figure III-30 Energy setting workflow

- <u>Common parameter</u>
  In this part, we determine the station location ID156609 and we specify a "single family" building type.
- <u>Detailed model</u>
  We export spaces for simulation and specify a 'Central heating radiators' as building service.
- <u>Energy model</u>
  In 'Energy model' subpart, we use the same construction design as used prior in test 2
- <u>Energy model Building Services</u>

We select a system which on a continuous system such as (24/7). It means that a conditioned system worked 24 hours per 7 days alone in the heating period. As well as, we assume that a conditioned system as 'Residential 14 SEER/8.3 HSPF Split Packaged Heat Pump'. Then, we fix the outdoor air amount which is equal to 1.23l/ (s.m²).

III.6.4.2 Results of Building Elements Mode calculation

As seen prior, SPREADSHEET ASHRAE and REVIT are based on ASHRAE data base and RTS method calculation. We recall that we need to compare results of 'Building Elements' with SPREADSHEET ASHRAE computer and TRNSYS [11], in order to validate REVIT results which are found by the architect. Hence, the overall Energy Use Intensity (EUI) using 'Building elements' tool from REVIT are 184.7kWh/m²/yr. This amount represents the annual heating and cooling load. It is split on both fuel (EUI) and electricity (EUI) which represent respectively 41.3kWh/m²/yr and 143kWh/m²/yr. Due to information insufficiency of numbers hours in heating and cooling period which are used to estimate the annual EUI using REVIT, we can't compare EUI (kWh/m²/an) founded by REVIT with total load calculated by SPREADSHEET ASHRAE computer because the last amount is expressed by Watt. For that we will base on two cases:

- In the first case, we will rely only on monthly cumulative load results of each room1 component using "Building Element" tool from REVIT for heating and cooling periods. These charts are not only used for sizing HVAC system, but they also give information about heat gain needed to remove and the lowest heat losses. Nevertheless, we cannot compare the EUI (kWh/m²/an) obtained by REVIT with the peak maximal loads calculated by SPREADSHEET ASHRAE computer due to the shortage of the information numbers in heating and cooling period to estimate the annual EUI using REVIT. The reliable evaluation components are the following: various equipment, lighting devices, the inhabitants, window solar gains, window conduction, outdoor and indoor surroundings, walls and roofs. Figure (III-31) represents a monthly cooling load of room1, it exposes that the widest cooling load is occurred in July. Besides, it displays that peak cooling load is produced respectively by roof and walls. These results denote that in an early phase of conception, we need to improve the thermal quality of roofs and walls in order to add thermal insulation.

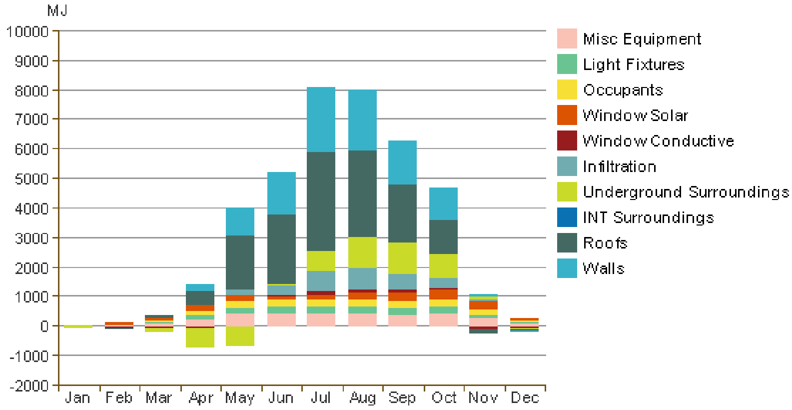


Figure III-31 Monthly cooling load chart using 'Building elements' tool from REVIT

Actually, figure (III-32) stands for a monthly cumulative load of heating. It indicates likewise the largest heating load occurred in January and its peak is achieved thanks to roofs and walls. Consequently, the roof does contribute to the heating and cooling loads enormously.

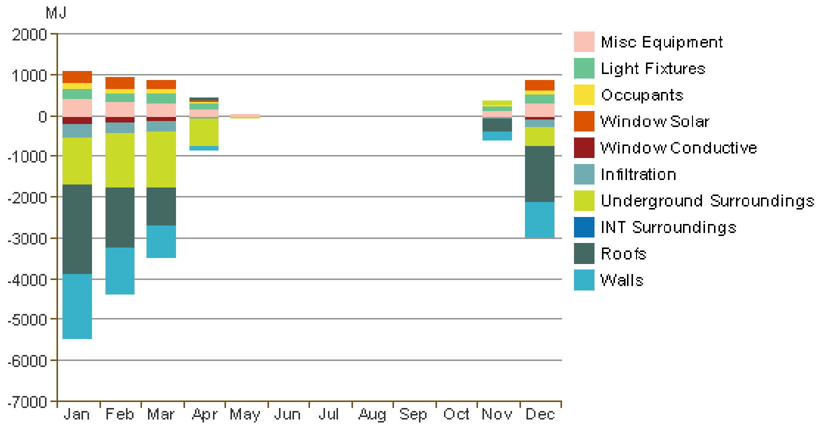


Figure III-32 Monthly heating load chart using 'Building elements' tool from REVIT

- In the second case, we will rely only on a cumulative peak cooling load calculation to investigate the relationship between 'Building elements' tool from REVIT results with SPREADSHEET ASHRAE computer results. Hence, we will base on 288 results of peak cooling load calculation of each component along 12 months as displayed in figure (III-33). The last figure demonstrates that the maximal cooling load is realized successively by the window and the roof in August at 5% of the design dry bulb temperature applying the SPREADSHEET ASHRAE computer. The attained results are considered as the engineer duty.

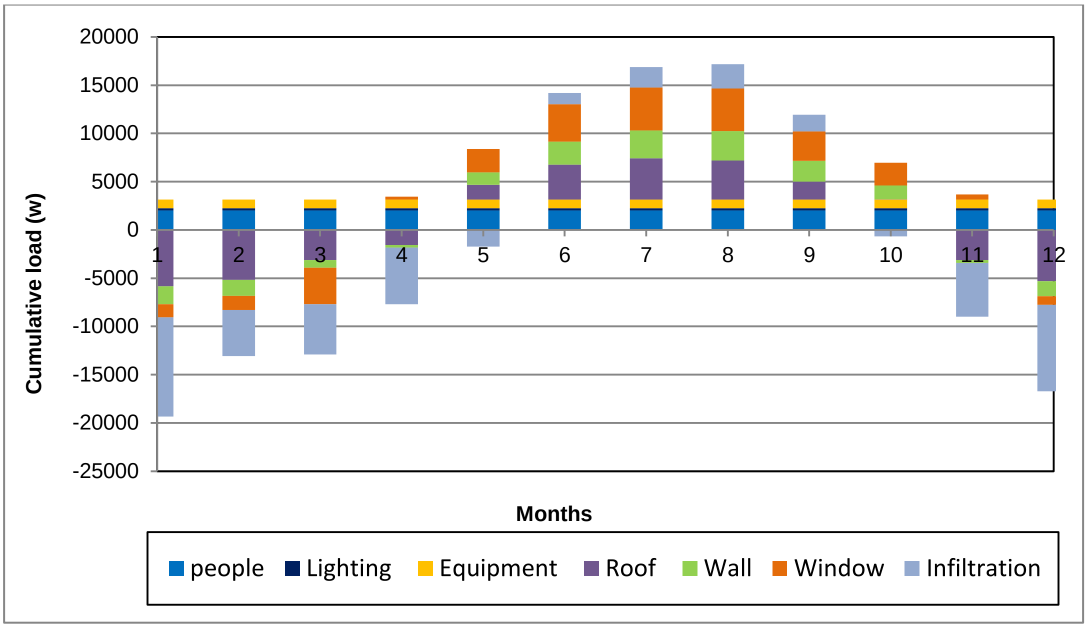


Figure III-33 Monthly cooling chart of peak cumulative load using SPREADSHEET ASHRAE computer at 5% design dry bulb temperature

III.7 Comparison

III.7.1 Annual heating and cooling load

Despite the data shortages, we do rely upon various software and calculation methods as TRNSYS, SPREADSHEET ASHRAE and REVIT. Thus, we will bring into play some assumptions in this comparison to keep the same basis as Ouertani [11].

- We opt the term L_H (W/m²) described in paragraph (III-3-2) because of its available values in the three investigation tools.
- We will focus on test 2 results from REVIT which seem similar to SPREADSHEET ASHAREE.

III.7.1.1 Cooling

The below table (III-6) displays the peak cooling load results of room1 using TRNSYS, SPREADSHEET ASHRAE and REVIT. These tools are generated using various percentiles of design conditions. The results of table (III-6) show that TRNSYS and SPREADSHEET ASHRAE have the same magnitude respectively at 5% and (0.4%, 2%, 5%). According to the chart, the cooling load using REVIT at 1% of design condition is slightly less than those found by TRNSYS and SPREADSHEET ASHRAE. This is justified because we can't arrange all the input data as RTS, CTS and U coefficients of study model. However, SPREADSHEET ASHRAE has an interesting interface which allows us to enter in the necessary coefficients to generate RTS calculation method.

We notice that the amount of peak cooling load using SPREADSHEEET ASHRAE increases when the design conditions percentiles decrease which chicks the RTS principle that considers extreme conditions of occurrence. Besides, we can analyze at 13% of error percentage between reference value (106.8W/m²) from TRNSYS and approximate value (121.14W/m²) from SPREADSHEET ASHRAE which are respectively at 5% and 0.4% design condition. Although we found a 10% error percentage between reference value as (106.8 W/m²) from TRNSYS and approximate value (96W/m²) from REVIT these values are resultantly at 5% and 1% design condition.

Table III-16 Peak cooling load for reference model (room1) using TRNSYS, SPREADSHEET ASHRAE and REVIT at various percentiles of design condition.

Tools	Latitude	Longitude	Percentile	Peak cooling load (W/m²)
TRNSYS	36° 50’	10° 14’	5%	106.8
SPREADSHEET ASHRAE	36.83	10.2	0.4%	121.14
			2%	109.8
			5%	103.03
REVIT	36° 85’	10° 22’	1%	96

III.7.1.2 Heating

The table (III-17) displays the results of peak heating load corresponds to room 1 using TRNSYS, SPREADSHEET ASHRAE and REVIT. These tools are generated equally the following percentiles of design conditions: 97.5%, 99.6% and 99%.
The results show that TRNSYS and REVIT have the same magnitude fitly at 97.5% and 99%. However, the heating load value using SPREADSHEET ASHRAE at 99.6% of design condition is slightly less than those obtained by TRNSYS and REVIT. According to the results exposed in the following table (III-17), we can interpret that 0.7% error percentage between reference value (77.41W/m²) from TRNSYS and approximate value (83.5W/m²) from SPREADSHEET ASHRAE. These values are duly at 6°C and 5°C dry bulb design temperature, although we find that 0.3% error percentage between reference values (77.41W/m²) from TRNSYS and approximate value (74.6W/m²) from REVIT. These values are respectively at 6°C and 5°C dry bulb design temperature.

Table III-17 Peak heating load for reference model (room1) using TRNSYS, SPREADSHEET ASHRAE and REVIT at various percentiles of design condition.

Tools	Latitude	Longitude	Percentile heating temperature	Peak heating load, L_H (W/m²)	Temperature (°C)
TRNSYS	36° 50’	10° 14’	97.5%	77.41	6
SPREADSHEET ASHRAE	36.83	10.2	99.6%	83.5	5
REVIT	36° 85’	10° 22’	99%	74.6	5

III.7.2 Energy use (annual)

The table (III-18) sums up the overall Energy Use Intensity (EUI) depending on REVIT, ‘Building Elements’ tool’s and TRNSYS [11] are greatly close.

Table III-18 Energy use intensity for reference model (room1) using TRNSYS and REVIT

Tools	EUI (kWh/m²)
TRNSYS	171kWh/m²/yr
REVIT	184.7kWh/m²/yr

III.8 Conclusion

Heating and cooling load calculation method using SPREADSHEET ASHRAE computer and REVIT are based on RTS method. This method is widely explained in Ashrae Handbook. It focuses on load calculation of non-residential building. Thereby, this chapter has investigated REVIT efficiency for residential buildings. Our investigation was based on the acquired results in literature review by Ouertani using TRNSYS software. The fulfilled study, in this chapter, is to validate REVIT efficiency for heating and cooling load calculation of conditioned room1. It leads us to some relevant conclusions as following:

Cooling load results of room1 using SPREADSHEET ASHRAE in July corresponds to a maximal outdoor dry bulb temperature as 33.1°C. Then, the peak cooling load is occurred at 2:00pm in this month at 5% design condition. We will try to investigate the peak cooling load of various room components in this month. The sensible peak cooling load of lighting component is occurred at a maximal heat gain by lighting in July. These peaks are produced at 7:00am and 9:00pm which corresponds to a peak operation schedule relative to the occupant at these hours. Even, the sensible peak loads for equipment are occurred at a maximal heat gain by the equipment. These peaks are produced at 7:00am and 9:00pm which corresponds to a peak equipment use during these hours. Moreover, a sensible peak cooling load of occupant is produced at 7:00am and 6:00pm which corresponds respectively 54W and 62W of sensible cooling load per person. The sensible cooling load of south wall component is 94W. It is, occurred at 7:00 pm when sunset corresponds to 8 hours delay of a wall maximal sol air temperature. Likewise, it corresponds to 9 hours delay of a maximal surface wall incident flow. In addition sensible peak of cooling loads of roof is 556W. It is produced equally at 9:00pm after sunset which corresponds to 9 hours delay of a roof maximal sol-air temperature. Furthermore, it corresponds to 10 hours delay of a maximal roof incident flow. A peak cooling load of south window component is 597W; it is achieved at 12:00am which corresponds to a maximal beam and diffuse solar heat gain falling on south window. The overall cooling load of infiltration component is 185W at 2:00pm. We notice that times of peak cooling loads are varied from 7:00am to 7:00 pm. According to SPREADSHEET ASHRAE cooling load calculation, south window and roof components contribute fitly to a maximal cooling load although the roof and south window components contributed equally to the maximal cooling loads in this period using REVIT.

SPREADSHEET ASHRAE computer and REVIT are based on RTS method calculation. These tools generate 288 design hours of dry bulb temperature respectively at 5% and 1% percentile frequency of occurrence. To achieve 26°C indoor design temperature, the sizing of cooling equipment are required as the following: 103.03W/m² cooling load by SPREADSHEET ASHRAE, 96W/m² cooling load by REVIT and 106.8W/m² cooling load by TRNSYS.

The heating period relying on SPREADSHEET ASHRAE computer and REVIT generate one design hour of dry bulb temperature respectively as 5°C at 99.6% and 99% percentile frequency of occurrence. To attain 20°C indoor design temperature, sizing heating equipment need as the following: 83.5W/m² cooling load by SPREADSHEET ASHRAE, 74.6W/m² heating load by REVIT and 77.41W/m² heating load by TRNSYS. According to SPREADSHEET ASHRAE and REVIT, the peak heating load is occurred suitably by roof, infiltration and south window. Therefore, the south window and roof components of standing house in Tunisia needs to improve their thermal quality at the preliminary phase of design.

For heating and cooling period, the load calculation results using SPREADSHEET ASHRAE and REVIT are close to TRNSYS reference tool. Consequently, we check that RTS method calculation and REVIT are efficient to heating and cooling load calculation for residential buildings. Therefore, we can use REVIT in the further chapter for evaluation and optimization of residential building in Sousse region

We notice that the heating period SPREADSHEET ASHRAE is based on the most extreme condition using RTS does not take into account a load credit as an internal load which is beneficial in winter period.

REVIT interface is limited to create an energetic model because of we can't insert all necessary for each component of room1. Whereas, RTS, CTS and U coefficients have major impact on cooling loads results. However, SPREADSHEET ASHRAE has an interesting interface which allows us to enter the necessary coefficients to generate RTS calculation method. But, SPREADSHEET ASHRAE calculator needs a specific knowledge concerning RTS method calculation. Therefore, we can summarize that REVIT is a simple and efficient at an early phase of design building and sizing equipment respectively for architect and engineer similarly. Hence, heating and cooling load tool from REVIT be will used in chapter V for quantitative investigation of traditional and contemporary houses in Sousse city.

Chapter IV : METEOROLOGICAL DATA STUDY RELATIVE TO SOUSSE REGION

IV.1 Methodology approach (purpose of this part)

Our main purpose in the first step is to compare a thermal quality of traditional and contemporary house in Sousse city. The second step is to improve a thermal quality of these houses using REVIT for optimization. Then, we will suggest selecting the efficient strategies of passive design as improvement parameters of Sousse city. Hence, this chapter aims to understand the climate of Sousse city in order to identify the passive design strategies related to its climate. In this part, we will analyze meteorological data of our research site related to traditional house and contemporary house. Then, we choose the actual year of 2006 which is taken from the Green Building Studio (GBS) weather file. This file can be converted into other format for more detailed meteorological analysis data. In this way, meteorologist Malkin [42] showed that using 'Typical Year' does not provide accurate prediction for the change of climatic conditions. But this data is limited only for Monastir airport location and does not provide accurate weather in the area of the project. Malkin [46] emphasizes that using weather data of GBS which represents a virtual weather station allows having very well observation over the entire year of actual Dry Bulb (DB) temperature. It is previously noted that this study is essentially based on the analysis of a bioclimatic parameters. Therefore; the weather data from 2006 year is extracted from GBS on CSV format data. And, we used ECOTECT WEATHER MANAGER to convert CSV weather file on Weather ECOTECT Analysis (WEA) format. The last format is readable by ECOTECT for meteorological data analysis. This method of conversion will be more developed in this chapter. Several studies [19, 44] note that ECOTECT has made beneficial exploration in preliminary design phase. Then, we will base on ECOTECT WEATHER MANAGER to convert weather data format from GBS to ECOTECT and to analyze meteorological data.

IV.1.1 Topography

Tunisia is a multi-climatic conditions territory, as indicated in the Thermal and Energy Reglementation Code of New Buildings in Tunisia (ANME) [43]. The last one divides Tunisian territory into 3 climatic zones to formulate temperature requirements for buildings in Tunisia: ZT1 is the coastal zone extending from the region of Bizerte to Medenine; ZT2 covers the Western area, from Jendouba to Gafsa, Zone ZT3 covers the south area as Tozeur, Kebili and Tataouine [48,44]. ZT1 has semi-arid climate (World map of koppen-Geiger) marked by hot summer and mild and wet winter. Our study is totally limited to the region of Sousse. The last one is situated in 10° 38′ 24″ East longitude, 35° 49′ 34″North latitude and an altitude of about 25 m above the sea level. It is bounded by Hammam-Sousse city from the north and Monastir city from the south.

IV.1.2 Climate

The old Medina of Sousse has Mediterranean climate. According to the division of the climate zone shown above, Sousse city has got a hot-summer and a mild and humid winter. TERC [48] shows the possibility to achieve 18°C and 20°C base temperature. The annual Heating Degree Days (HDD) are respectively equal to 745 degrees days and 1112 degrees days. Additionally, to attain 26°C temperature base the annual Cooling Degree Days (CDD) correspond equally to 180 degrees days. Likewise, the thermal code **[48]** shows that Sousse and Mahdia have the same climatic base condition as Monastir region. Then, the heating period of Sousse region is wider than the cooling period. The building thermal code **[48]**, considers cooling period is correspondingly between June 1st to September 30th, has 164 degree-hours for 26°C. However, the heating period is from December 1st to February 28th

and has 647 degree-hours for 20°C. Besides, the ECOTECT WEATHER tool, will be base our tool to analyze at the same time the weather data in winter and summer periods. The summer period is extended from June 1st to August 30th. According to the thermal code, represents 135 degrees hours for 26°C. Yet, the winter period is ranged from December 1st to February 28th. In the next paragraph, we will analyze additionally the climatic parameters of climate**:**

Table IV-1 Climatic data of Monastir city (1983-1997) modified from (Source: Thermal and Energy Reglementation Code of New Buildings in Tunisia)

Monthly temperature average (°C)	Maximal temperature Average (°C)	Maximal temperature Average (°C)	Average minimal temperature (°C)	Global daily insolation received by the horizontal plane (Wh/m²/day)
January	12.2	16.4	7.9	2950
February	12.9	17.3	8.6	3730
March	14.4	18.7	10.2	4990
April	16.6	21.1	12.1	5790
May	20.3	24.9	15.7	6860
June	23.9	28.4	19.3	7350
July	26.9	31.9	21.9	7580
August	27.9	32.6	23.3	6860
September	25.6	29.9	21.3	5340
October	22.0	26.0	17.9	4270
November	17.3	21.5	13.0	3260
December	13.5	17.7	9.4	2950
Year	19.5	23.9	15.0	5161

Table (IV-1) shows the monthly climatic data of Monastir city which is the nearest city to Sousse located about 20 km far away from the Medina. Henceforth, the average maximal temperature of August is 32.6 °C and it drops down to 16.40°C in January. The summer period represents the largest sunlight especially in July. It shows a global daily insolation is equal to7580Wh/m²/day. In fact, the data displayed in the above table are not enough to analyze and to choose passive design strategies. Therefore, we need hourly weather data in order to generate in ECOTECT WEATHER TOOL. We try hardly to use the weather data of real time as those in Monastir Meteorological station which are taken from ENERGYPLUS. Despite, the shortage of data in this file, we have decided to rely on GBS for Monastir case. We tried to use Real Time Weather data file of meteorological Monastir station from ENERGYPLUS Weather Data source but unfortunately this file has got insufficiency of data. Then, we decide to use GBS weather file for Sousse location.

IV.2 Weather data conversion: analysis and assessment

Weather data of Actual Year will analyze the meteorological data of the real time in order to identify the passive strategies adapted in Sousse climate and validate the data of REVIT. Due to shortage of meteorological data of Sousse city, the weather file (2006 year) will be taken from GBS in (CSV) format which corresponds to meteorological REVIT station ID 157077. We note that REVIT and GBS software share the same weather data for a given location because they belong to BIM environment. Then relevant (CSV comma. delimited) file is used to convert weather data from (CSV) format to (WEA) format readable by ECOTECT and ECOTECT WEATHER MANAGER. The CSV format will be used as well as the hourly simulation of dry bulb temperature, humidity, solar radiation and wind speed. Then, we will identify the best orientation and select passive design techniques. Furthermore, theses passives actions will be used in chapter (VI) to improve the thermal quality of both traditional and contemporary houses in Sousse city. As well as, ECOTECT software will be used to simulate a solar radiation and shade distribution of two original houses in summer and winter periods. In fact, the achieved results of the weather data analysis by REVIT will be compared to the obtained results by ECOTECT WEATHER TOOL.

IV.2.1 Weather data Conversion:

Both the traditional and the contemporary houses of our research are located exactly at 10.59°east longitude, 35.85°north latitude and an altitude of about 30 m above the sea level according to the internet mapping service from REVIT. The weather data of Monastir seen above are not accurate and even there are some shortages. So, the weather data of the closest station are 9km away of our study site such as 157077 from REVIT and GBS06M12-02-149005 from GBS. As far as REVIT is concerned, our studied location is close to station ID 157077 which is located in **10° 59′** east longitude, **35° 85′** north. Then, the Actual Year in CSV weather file is used by WEATHER MANAGER to convert it into (WEA) format and becomes legible by ECOTECT software. To convert weather data parameter, we need to add in the WEATHER MANGER dialog box as displayed in figure (IV-1) from ECOTECT WEATHER tool the following weather parameters:

- Year
- Month (1-12)
- Day (1-31)
- Hour (0-23)
- GlobHorizRad(Wh/m2)
- DirNormRad (Wh/m2)
- DiffHorizRad (Wh/m2)
- TotalSkyCover (tenths covered)
- DryBulbTemp (deg C)
- DewPointTemp (deg C)
- RelHumidty (%)
- Pressure (mb)
- WindDir (degrees)
- WindSpeed (m/s)

After that, we import file to load these data into the WEATHER TOOL. Finally, we add precipitation data on the ‘Monthly Data’ of Panel Selector concerning rainfall. The last operation consists to add a location then we fill in the Location Data field latitude, longitude, altitude and time zone. Finally, we save weather data file on WEA format.

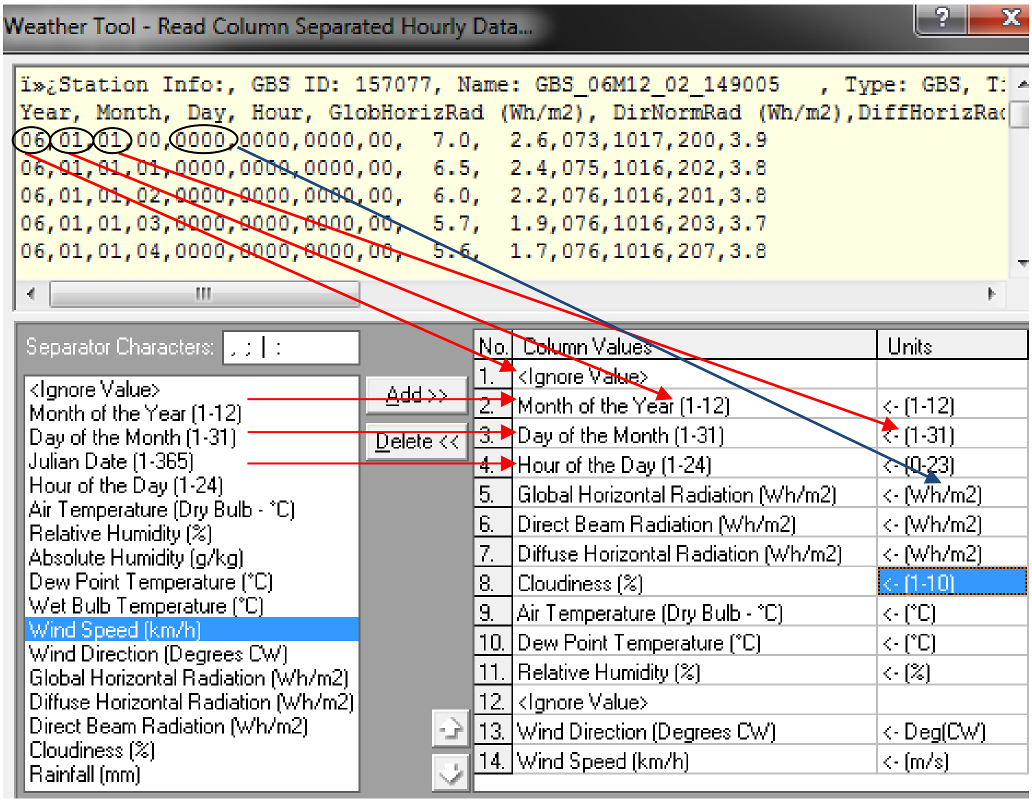


Figure IV-1 Dialog box ECOTECT WEATHER MANAGER Tool, 'Read Column Separated Hourly Data'

The figure (IV-2) exposes the temperatures from 0:00 hours to 20:00 hours on CSV format (comma. delimited) file downloaded from GBS and related to Sousse city. These data are similar to the conversion data output taken from ECOTECT WEATHER tool as displayed in figure (IV-2). Then, we can validate the conversion operation from GBS to ECOTECT WEATHER tool that corresponds to Sousse region weather data. In the next parts, these data will be used for climate data analysis.

```
06,07,21,00,0000,0000,0000,00, 22.8, 20.6,087,1013,010,2.5
06,07,21,01,0000,0000,0000,00, 22.2, 20.3,089,1013,358,2.5
06,07,21,02,0000,0000,0000,00, 21.6, 19.8,089,1013,339,2.5
06,07,21,03,0000,0000,0000,00, 21.1, 19.2,088,1013,312,2.4
06,07,21,04,0000,0000,0000,00, 20.6, 18.5,087,1013,296,2.5
06,07,21,05,0000,0000,0000,00, 20.2, 17.8,085,1013,287,2.6
06,07,21,06,0048,0015,0033,00, 20.3, 17.5,083,1013,279,2.7
06,07,21,07,0179,0346,0067,00, 24.4, 15.8,058,1014,285,2.5
06,07,21,08,0360,0541,0082,00, 26.8, 12.0,039,1014,298,2.6
06,07,21,09,0543,0667,0088,00, 28.5, 12.3,036,1013,321,2.4
06,07,21,10,0699,0742,0091,00, 30.1, 11.8,031,1013,347,2.5
06,07,21,11,0810,0786,0092,00, 31.4, 12.0,029,1013,004,2.7
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06,07,21,13,0859,0803,0092,00, 33.0, 15.5,034,1013,047,2.9
06,07,21,14,0793,0779,0092,00, 33.3, 15.7,033,1013,067,3.7
06,07,21,15,0672,0731,0091,00, 33.1, 15.4,033,1013,071,4.3
06,07,21,16,0509,0647,0087,00, 32.5, 14.7,033,1013,068,5.2
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06,07,21,18,0147,0298,0062,00, 30.8, 14.2,035,1012,071,5.2
06,07,21,19,0032,0008,0023,00, 29.3, 16.1,044,1012,071,4.2
06,07,21,20,0000,0000,0000,00, 27.7, 18.2,055,1012,073,3.3
```

Figure IV-2 CSV (comma. delimited) file download from GBS related to Medina Sousse city

Hour	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00
Temp.	22.8	22.2	21.6	21.1	20.6	20.2	20.3	24.4	26.8	28.5	30.1	31.4	32.3	33.0	33.3	33.1	32.5	31.8	30.8	29.3	27.7

Figure IV-3 Output file from ECOTECT WEATHER tool that corresponds to input on CSV file

IV.2.2 ECOTECT: meteorological data analysis

Actually, there are several useful tools to analyze weather data but the most fairly, specialized and accurate is ECOTECT software. In this part, we will expose hourly simulation results of climatic parameters using ECOTECT WEATHER tool. Then, we will rely on the last results to assess REVIT efficiency for the climate data analysis. The analyzed climatic parameters are temperature, solar radiation, wind and relative humidity as following:

IV.2.2.1 Temperature and humidity analysis:

Humidity and temperature are the most important climatic parameters for the comfort prediction. ECOTECT WEATHER enables to analyze all the weather data cited above. However, we will focus only on Dry Bulb temperature and relative humidity percentage in this part.

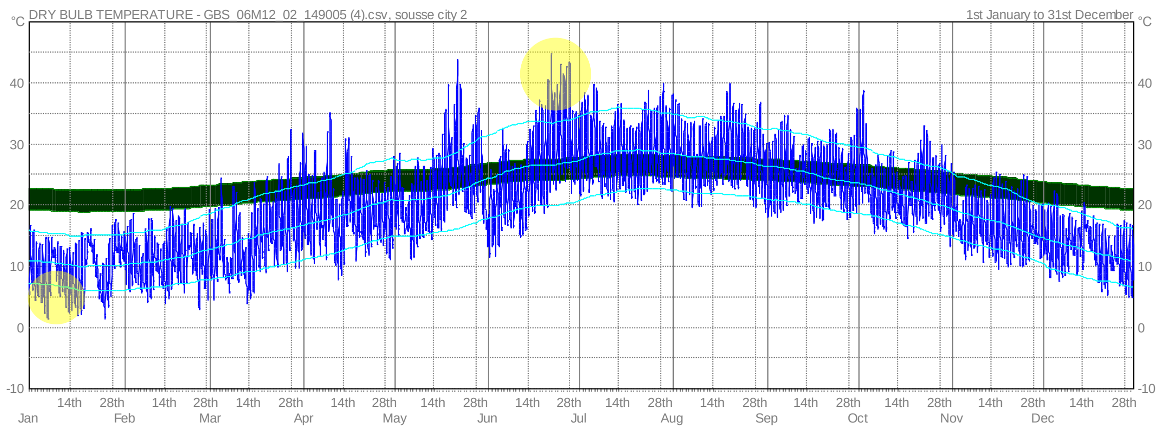


Figure IV-4 Distribution of annual hourly dry-bulb temperature generated by ECOTECT WEATHER TOOL

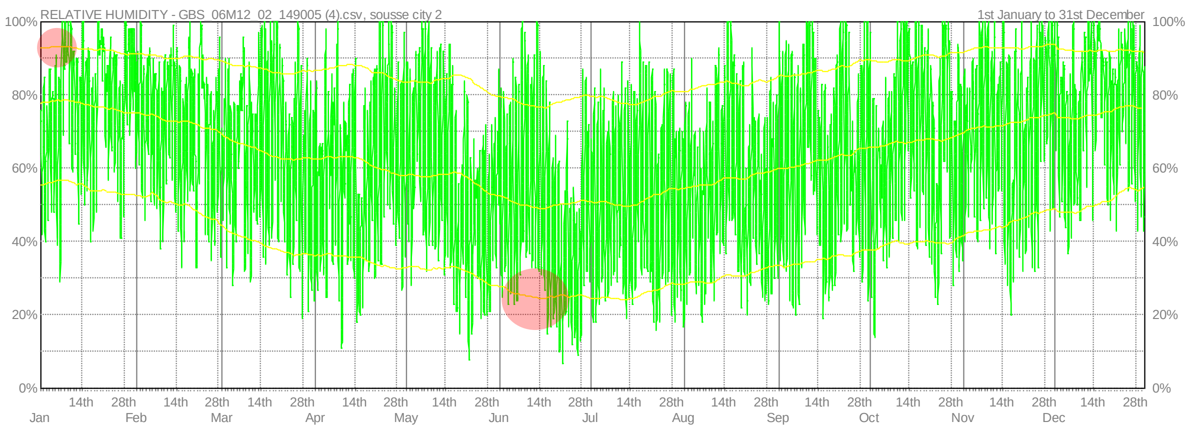


Figure IV-5 Distribution of annual hourly humidity percentage generated by ECOTECT WEATHER TOOL

Table IV-2 Climatic data of meteorological station 'GBS06M12-02-149005' based on ECOTECT WEATHER tool analysis.

Month	Monthly temperature average (°C)	Maximal temperature Average (°C)	minimal temperature Average (°C)	RH at 9am (%)	RH at 3pm (%)	CHH(26°) (degree-hours)	HHH(18°) (degree-hours)	Daily Solar radiation (Wh/m²/day)
January	9.3	16.8	1.9	79	57	0	6090	3859
February	11.1	19	4.6	74	50	0	4336	5097
March	14.3	25.1	4.1	61	41	320	3148	6368
April	18.9	34.1	9.2	52	35	1021	972	7505
May	22.8	34.9	11.5	48	34	2731	292	7461
June	25.7	35.7	11.6	38	26	4405	192	8495

July	28.8	39.4	20.8	40	28	6249	0	8528
August	28.1	38.9	20.1	45	33	5747	0	7946
September	24.8	34	17.7	57	37	3309	0	7134
October	22.5	38.6	15.6	68	40	2135	64	5623
November	16.8	26.6	10.7	73	44	323	1455	4580
December	12.8	22.1	7.2	83	56	10	3595	3565
Year	19.65			60	40			

According to the Table (IV-2) the annual average of dry-bulb temperature is about 19.65℃, the coldest month is January with an average temperature equals to 9.3℃. It exposes that the hottest month is July when the average temperature is 28.8℃. The hourly data in figure (IV-4) show that the hottest day in the year is the 22^{th} of June and the peak temperature is 44.8°C at 2pm. The last figure displays the year's coldest day which is January 7^{th} and its lowest temperature is 1.4°C at 7:00 am. Referring to the hourly data in figure (IV-5), the annual humidity of Sousse medina is high. The annual average of Relative Humidity (RH) is range between 50% and 78%, the RH in summer period (June to September 30^{th}) is 54.8% and the RH in winter period (December 1st to February 28^{th}) is 75.64%.
According to the table (IV-2), figure (IV-4) and (IV-5), the monthly temperature average increases when the Relative Humidity (RH) percentage decreases and vice versa. Hence, we can determine that Sousse region has both a typical hot dry summer and mild wet winter climate. To ensure the thermal comfort of living environment, energy-saving design must give considerations to thermal insulation in heating period and to promote ventilation in cooling period.

IV.2.2.2 Wind speed

Unlike, wind promotes natural ventilation and represents a passive cooling strategy in summer period. In this paragraph, we will investigate the role of the prevailing winds in Sousse location during summer and winter season. Figure (IV-6) shows that the main winds direction in summer are east-northeast and northeast direction. The last one corresponds to the Mediterranean wind as Gregale which is the prevailing wind in summer period. It persists actually for 81hours. As well as, this chart figures out eastern wind, which corresponds to 'Levante' wind as 40km/h. It blows from western Mediterranean Sea and has the highest velocity. Thus, it has about 40km/h velocity and a frequency below 9 hours in summer period. Although figure (IV-7) exhibits the most prevailing wind in winter period as west-northwest and west-southwest, it represents respectively 20km/h and 15km/h. These winds persist for more than 116 hours. We notice accordingly in figure (IV-7) that Sousse climate has also a Mistral wind which stands for a wind in winter period. It blows from northwest direction with 45km/h as velocity.

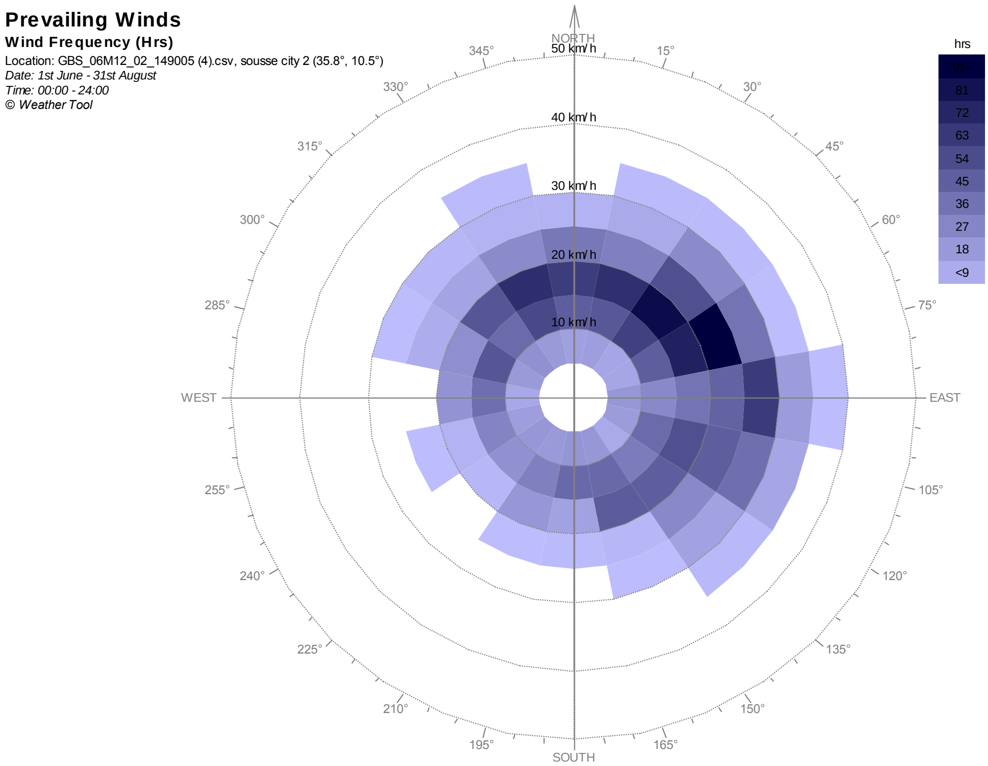


Figure IV-6 Distribution of wind rose /wind frequency in summer period

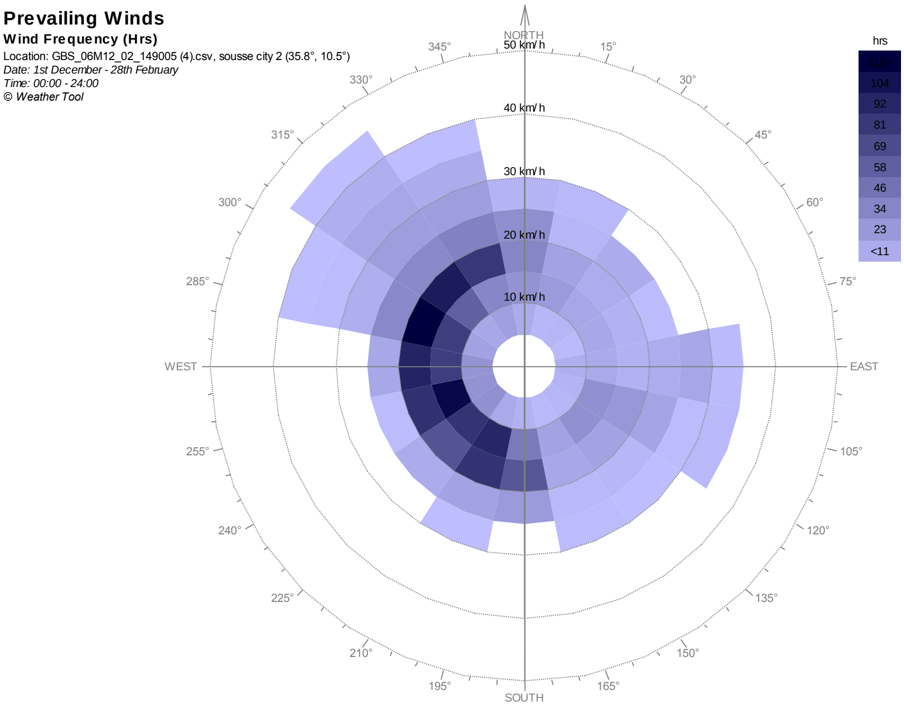


Figure IV-7 Distribution of wind rose /wind frequency in summer period

IV.2.2.3 Solar radiation:

The solar radiation represents a passive heating strategy in winter period. The below figure (IV-8) exposes the distribution of annual hourly direct solar generated by ECOTECT WEATHER TOOL in Sousse location.

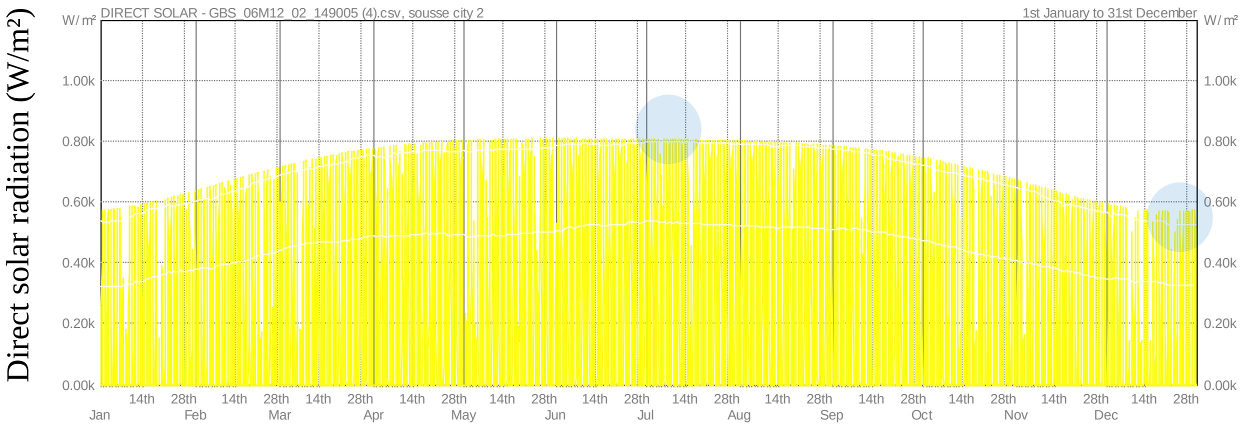


Figure IV-8 Distribution of annual hourly direct solar radiation generated by ECOTECT WEATHER tool

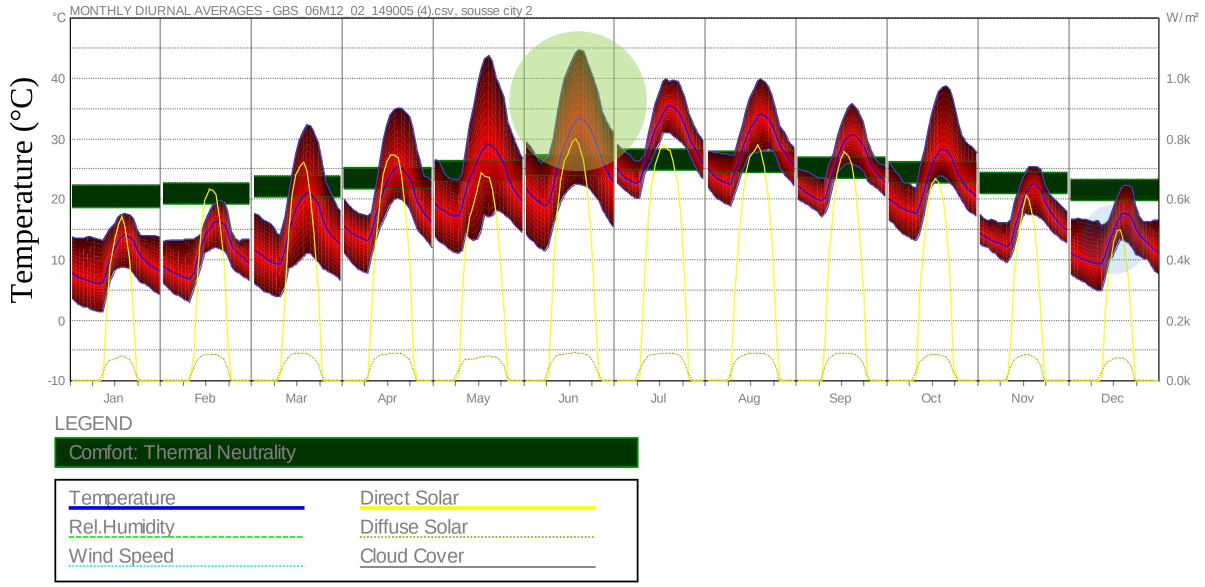


Figure IV-9 Monthly Diurnal Averages of temperature, relative humidity, wind speed, direct solar, diffuse solar and cloud cover using ECOTECT WEATHER tool

It shows that the maximal direct solar radiation is achieved 800 W/m² in summer, although the minimal .direct solar radiation is less than 600 W/m² in winter. Figure (IV-9) diplays that the evolution of both the monthly average diurnal temperature and the direct solar radiation. It displays that the maximal and the minimal direct solar radiation are occurred respectively 800W/m² in June 17th at 12:30am and 540W/m² in 17th December between midday and 1:00pm.As well as, we note that the maximal temperature occurs after two hours from a maximal direct solar radiation. Furthermore, there is a quite important interaction between climatic parameters.

IV.2.2.4 Weather parameter interaction:

Many types of weather data are very dynamic; they vary not only seasonally and daily but also hourly. Figure (IV-10) shows that a maximal dry bulb temperature occurs between 12:00am and 4:00pm in summer period. The time lag of 2hours occurs after the sun reaches its maximum altitude at midday and when the absolute solar radiation intensity reaches the peak (figure (IV-11)). Figure (IV-10) and (IV-11) display the lowest temperatures which appear before sunrise. Figure (IV-12) exhibits that the lowest RH% corresponds to a maximal dry bulb temperature and solar radiation. Figure (IV-13) and (IV-15) show also that the maximal dry bulb temperature and the most violent wind occur in summer period (24 to 32 weeks). Figure (IV-14) reveals that the wind direction is between 16h and 18h in summer. Then, Sousse location is suitable for a night-purge ventilation system. According to figure 14, a quick wind located in North-West direction is beneficial for night-purge ventilation system and natural ventilation. Consequently, the designer needs to exploit the previous direction for his passive design strategy.

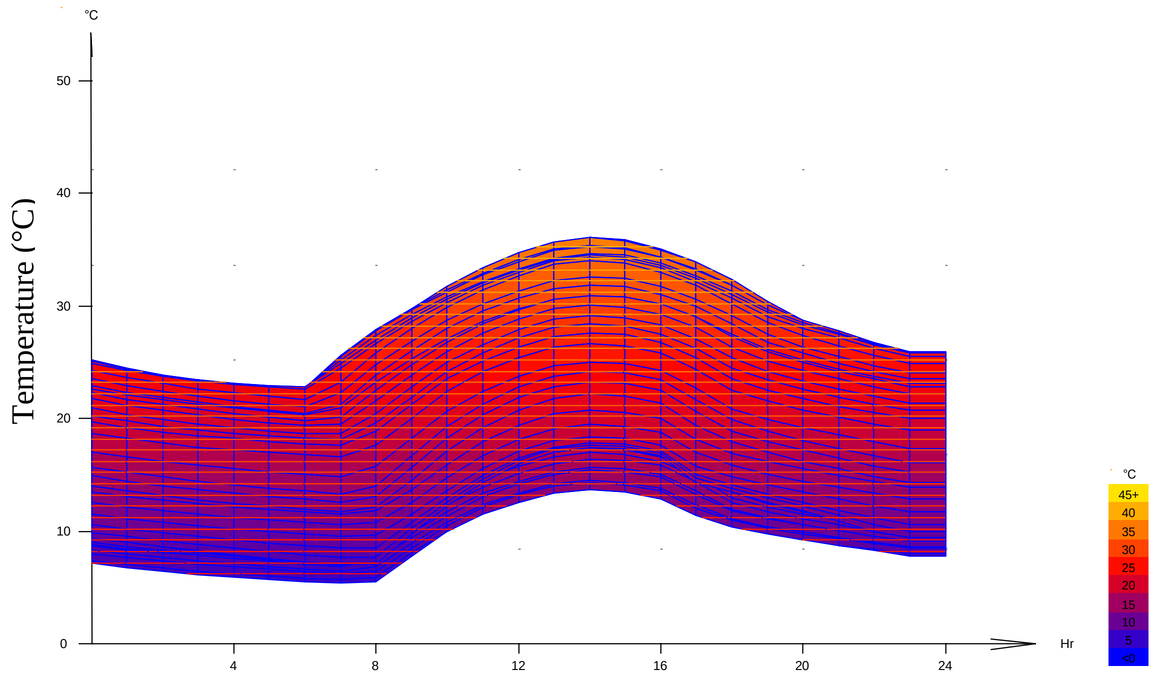


Figure IV-10 Average weekly dry bulb temperature (max T°, 12h-16h)

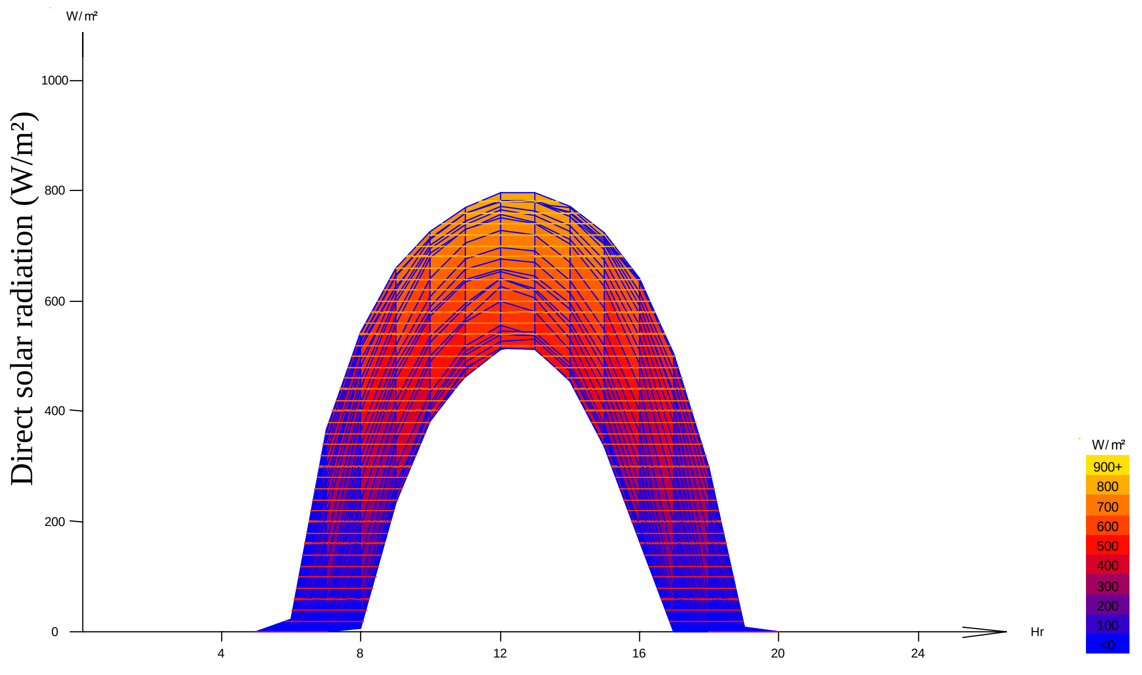


Figure IV-11 Average weekly direct solar radiation (max solar radiation at 12h)

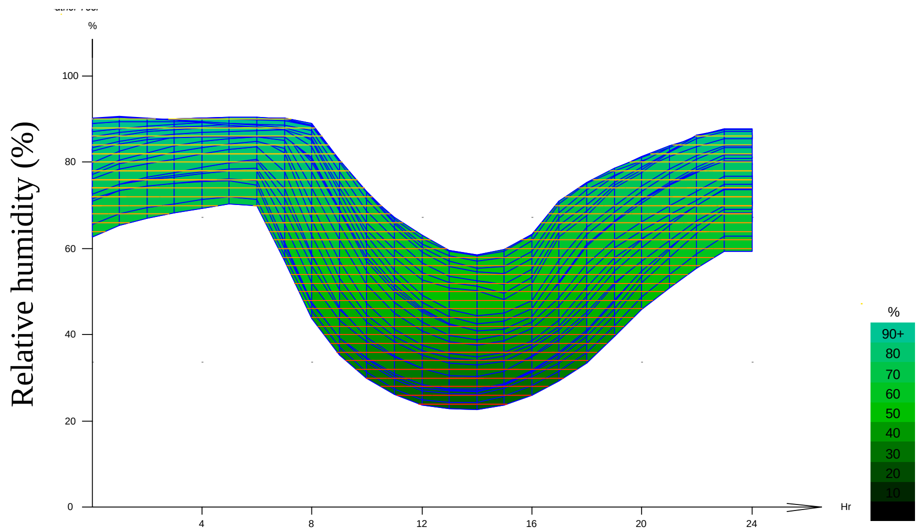


Figure IV-12 Average weekly relative humidity in summer (max RH%, 12h-16h)

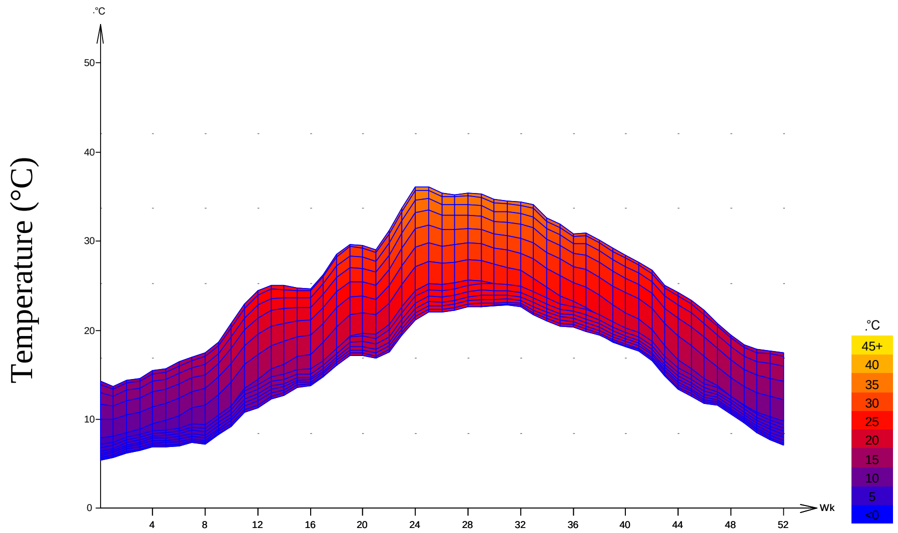


Figure IV-13 Avearage weekly dry bulb temperature in summer (max on 24 to32 weeks)

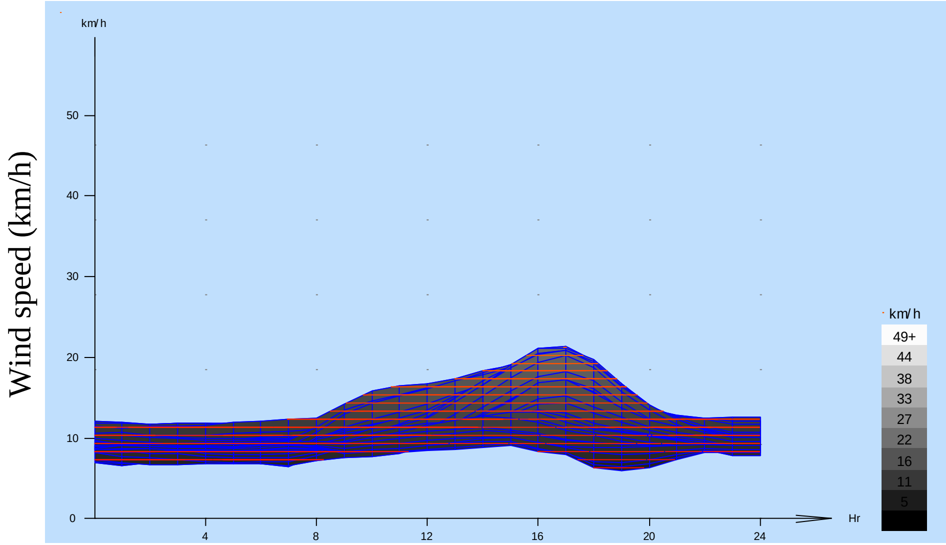


Figure IV-14 Average hourly wind speed in summer (max 16h-18h)

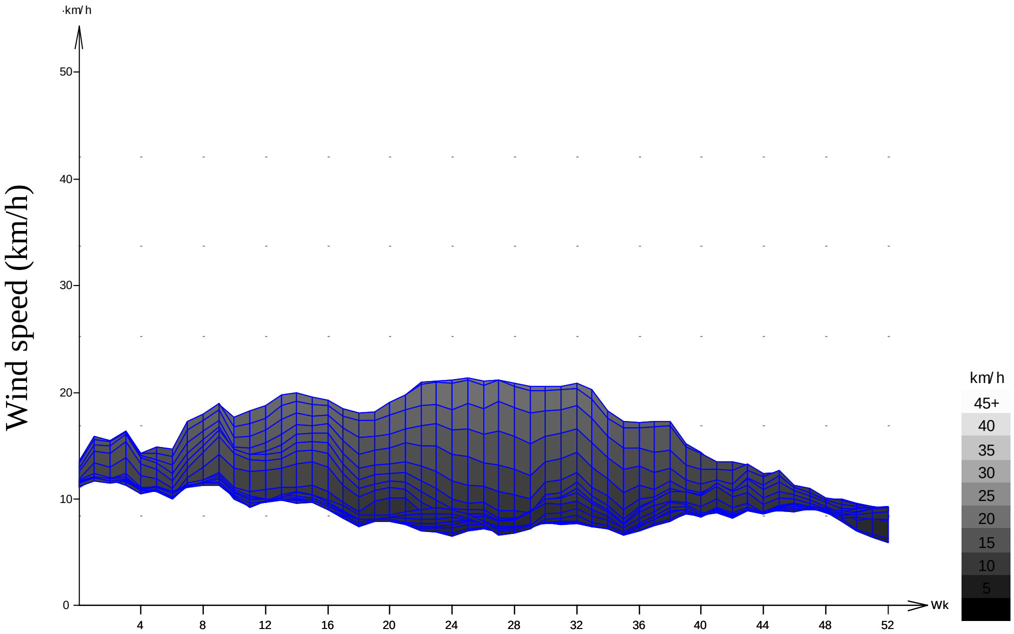


Figure IV-15.Average weekly wind speed in summer (max on 24 to32 weeks)

IV.2.3 REVIT climate data analysis

Few years ago, Autodesk technical community added a new feature to REVIT Energy Analysis tool such as weather and climate data analysis. REVIT provides climatic data for passive building design and emphasizes BIM concept. The climatic parameters used by REVIT to analyze weather data are the following: dry bulb and wet bulb temperature, direct and diffuse solar, relative humidity and prevailing winds. Also, we will rely on the last parameters to compare and analyze the obtained results of Sousse climatic data which are based on REVIT and ECOTECT WEATHER tool.

IV.2.3.1 Temperature and solar radiation

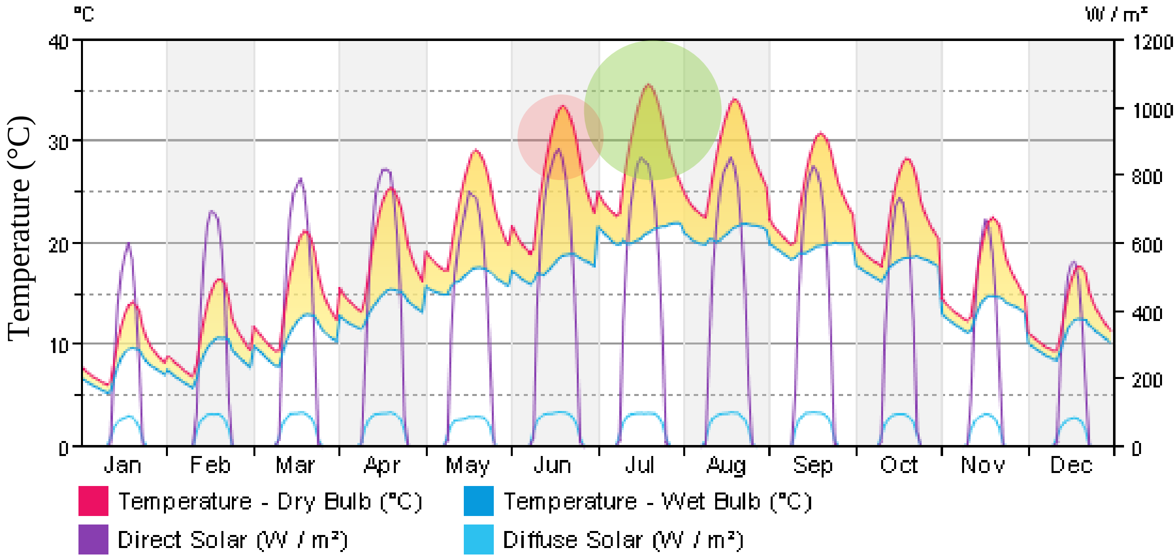


Figure IV-16 Monthly diurnal averages using REVIT weather data analysis

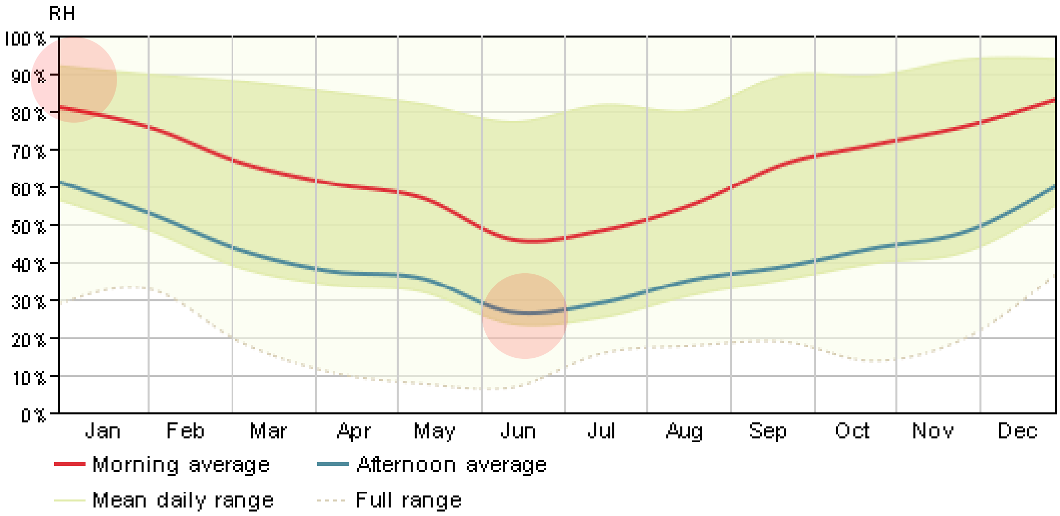


Figure IV-17 Monthly relative humidity using REVIT weather data analysis

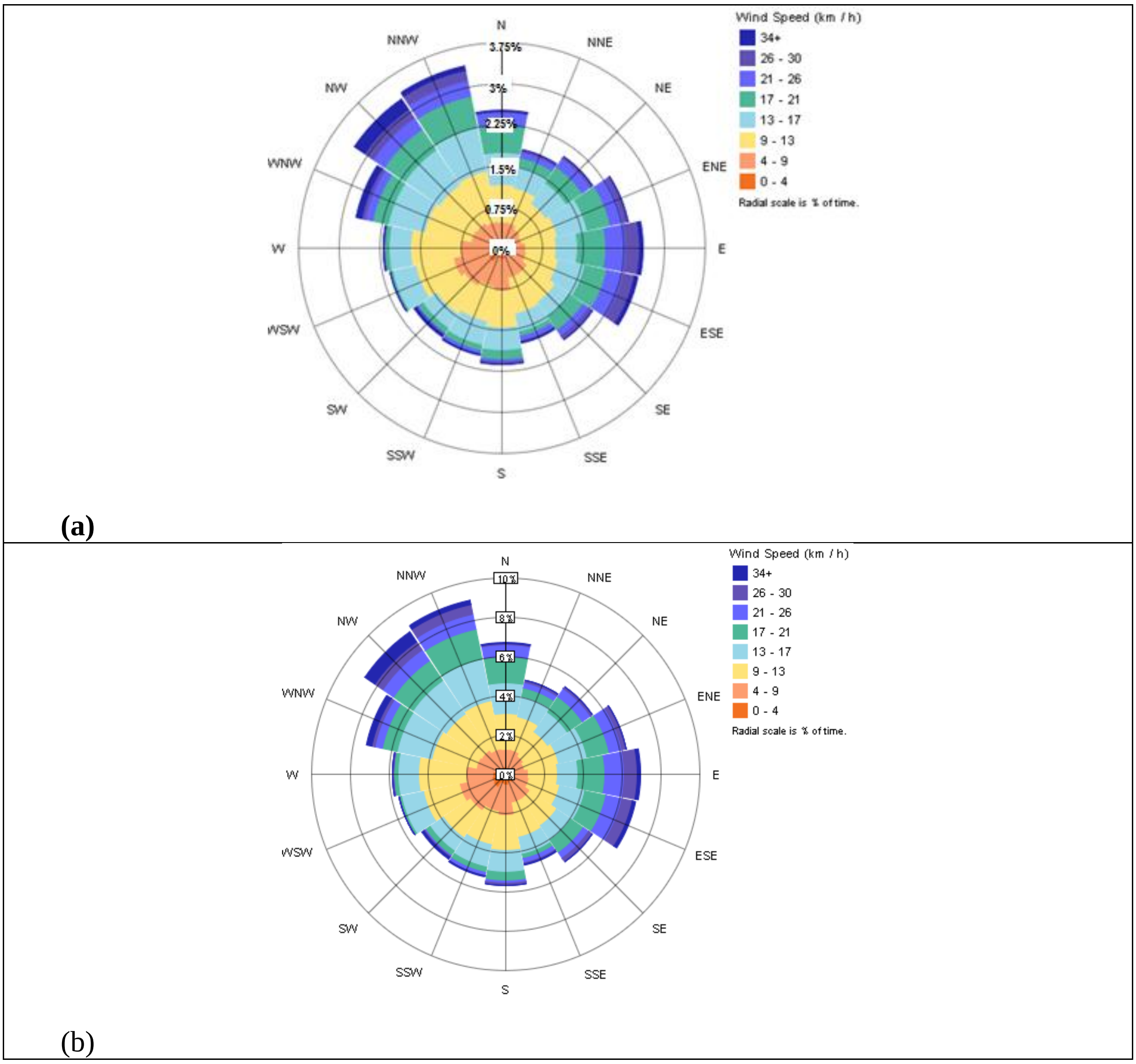


Figure IV-18 Distribution of annual wind rose /wind speed are displayed in above figure (a) and (b) are interpolated using respectively ECOTECT and REVIT

Figure (IV-18) from REVIT sets out the annual wind speed in function of time percentage in radiant scale for Sousse location. As well as, the figures (IV-6) and (IV-7) from ECOTECT WEATHER tool show the frequency and the speed of dominant winds respectively in summer and winter. We can determine out that REVIT and ECOTECT WEATHER tool have almost the same results as displayed in figure (IV-18, IV-6, and IV-7). Figure (IV-16) exposes that the maximal diurnal dry bulb and wet bulb temperature are in July and a minimum temperature is displayed in January. However, figure (IV-9) from ECOTECT WEATHER tool displays a maximal diurnal dry bulb temperature is in June. As well as, REVIT and ECOTECT WEATHER tool show respectively in figure (IV-16) and figure (IV-9) that a maximal direct and diffuse solar radiation occurs in June. Using REVIT and ECOTECT for weather data analysis, we find that the first one shows a minimum relative humidity 23% in June. Furthermore, ECOTECT WEATHER tool exhibits a similar value as 25% in June. Besides, they expose the closest of a maximal RH in January as 93%. As a result, REVIT and SPREADSHEET ASHRAE have the same analysis results of Sousse climate, then, we can validate the obtained results of climate data analysis by REVIT.

IV.2.4 Passive strategies analysis

We put in mind that our main purpose is to improve a thermal quality of traditional and contemporary houses in Sousse city. We will base on psychometric chart, comfort percentage and optimum orientation chart to identify the efficient passive design techniques which are related to Sousse climate.

IV.2.4.1 Psychometric chart

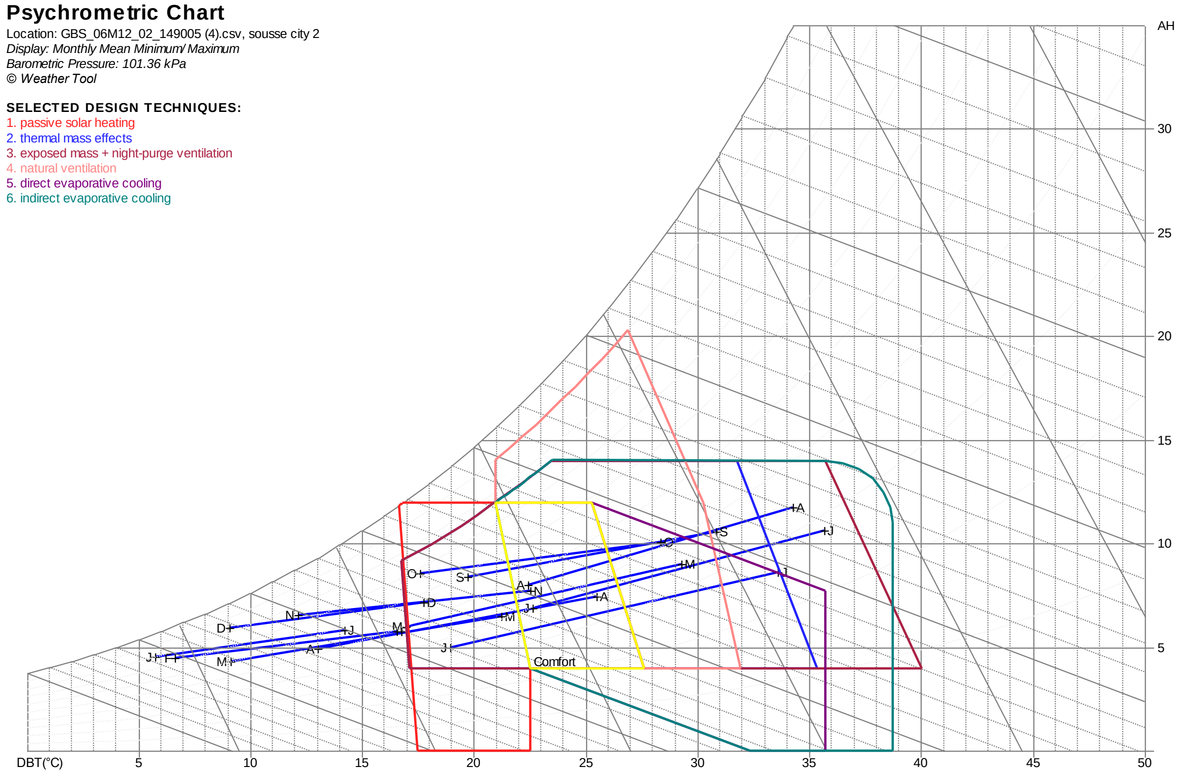


Figure IV-19 Effects of six passive strategies passive as solar heating, thermal mass effects, exposed mass & night purge ventilation, natural ventilation direct, evaporative cooling, and indirect evaporative cooling in Sousse city.

Psychometric chart can provide the corresponding analysis and the optimization for various passive strategies according to the local meteorological characteristics. These strategies refer to the bioclimatic design elements. Enthalpy-humidity chart is a very useful meteorological analysis method provided by ECOTECT WEATHER TOOL [[45]]. It displays a comfortable and reliable area for the most of people. The comfortable area depends on analysis location. In Figure (IV-19), the yellow colored region is the most comfortable area. It is determined by air temperature, relative humidity, airflow velocity and radiation temperature of the surrounding environment. In this area, the occupant lives naturally in comfort with a sedentary activity and without mechanical system. As well as, the blue lines in this chart represent monthly ranges which expose the monthly average weather data for each month. Then, this chart shows that the comfortable area is tried up with a small period compared to monthly weather data. Therefore, we must use the appropriate passive strategies in order to expand comfortable area through a year. Li Yang [44] uses the appropriate passive strategies which reduces the running cost of the mechanical methods. Hence, figure (IV-19) displays the effects of six passive strategies as follows: passive solar heating (red), thermal mass effects (blue), exposed mass & night purge ventilation (deep red), natural ventilation (orange red), direct evaporative cooling (purple) and indirect evaporative cooling (green) ([46],[47],[48]). Figure (IV-19) indicates that the combination of the four passive strategies have the best effect to improve human body comfort. Eventually, we will rely on ‘Comfort percentage’ chart from ECOTECT in order to identify the efficiency of passive design techniques.

IV.2.4.2 Comfort percentage chart

The figure (IV-20) presents the yellow and red areas which allow identifying respectively the percentage of comfort before and after using passive design techniques. This chart indicates also that Sousse city has a dry semi-arid climate. We use currently several tests of passive design techniques to identify efficient combination to improve indoor thermal comfort. For example, we use the study of each passive technique on energy save. The acquired results, using comfort percentage chart, show that these techniques (passive solar heating, thermal mass, exposed mass & night purge ventilation and natural ventilation) represent the optimal combination. This chart displays that before the improvement we have only 10% of inside annual comfort, although these design techniques occur 38% annual energy save. As seen in Sousse location, the cooling period is from June to September, and the heating period is from December to February. The figure (IV-19) shows that the mentioned passive design techniques are more efficient in the cooling period. As well as, the mentioned passive design four techniques emphasize that the best comfort period is occurred in July. The below table (IV-3) displays the sensitive study of each technique in order to improve indoor comfort.

It exposes that the thermal mass represents level 1 and gives the best comfort percentage. Though, the exposed mass with night purge ventilation represents level 4, it displays the lowest comfort percentage, that’s why we assume that Sousse region has a typical hot and dry summer. Therefore, night purge ventilation with high inertia is efficient to improve the inside comfort. Besides, we should put into consideration the appropriate orientation of the exposed mass and enhance its inertia. According to the ‘level 4’ of the passive technique, we need to promote solar mask in south orientation and we should use the optimal percentage glazing in suitable orientation. These strategies will be developed in the further chapter.

Table IV-3 Sensitivity study based on comfort percentages of passive solar heating, thermal mass, exposed mass & night purge ventilation and natural ventilation using comfort percentage chart.

Passive design techniques	Comfort percentage	Comfort level
Passive solar heating	10%	Level 2
Thermal mass	20%	Level 1
Exposed mass+ night purge ventilation	3%	Level 4
Natural ventilation	5%	Level 3

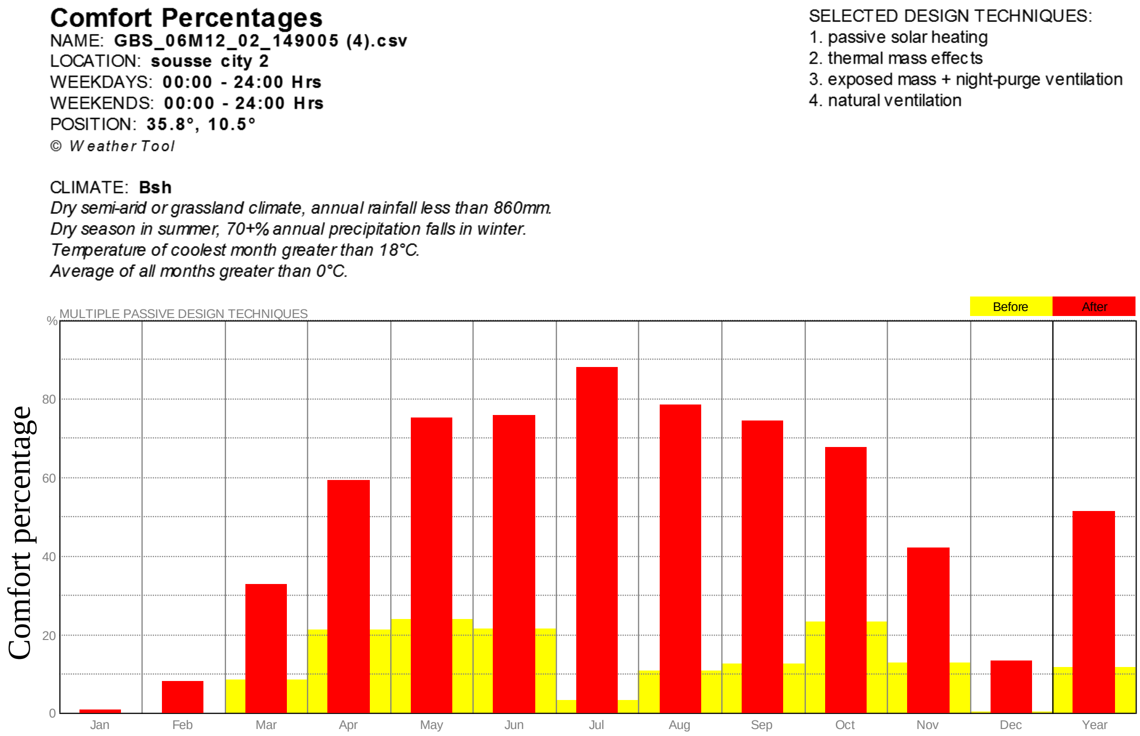


Figure IV-20 Analysis chart by ECOTECT illustrating improvement monthly comfort percentage before and after using four design techniques as following: solar heating, thermal mass, exposed mass & night purge ventilation and natural ventilation

IV.2.4.3 Orientation

ECOTECT WEATHER tool enables to analyze the amount of solar radiation according to its location. Then, it allows to calculate the relative best building orientation in accordance with solar heat absorbed in the annual super-heated period (hottest time) and under-heating period (coldest time). These usually correspond respectively to summer and winter periods. Good orientation means a lot to the thermal comfort and energy conservation of the building. Theoretically, the south orientation is the best. It can let building make full use of sunlight, it can also keep off the main wind direction in winter and make south exterior wall get the best heating conditions. However, the best building orientation will have approximate south angle thanks to the differences of longitude and latitude and the natural ventilation condition in different places. The ECOTECT WEATHER can analyze the solar radiation and calculate the relative best building orientation according to the solar heat absorbed during the annual super-heated period and under-heating period.

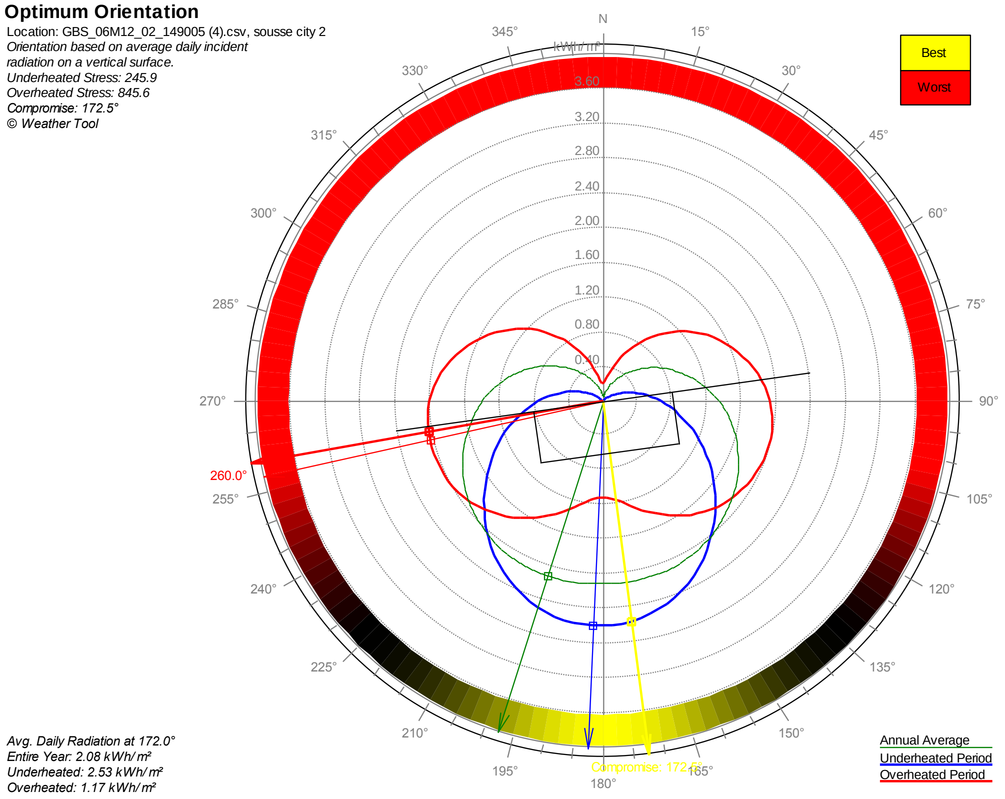


Figure IV-21 Analysis chart illustrating the best orientation of the building

Figure (IV-21) analyzes the best building orientation. For instance, the blue line represents the orientation that the building can get the most solar radiation during the under heated season (December, January, February), the red line represents the orientation because the building can get the least solar radiation during the overheated seasons (June, July, August). Shortly, the yellow line represents the best orientation after a comprehensive consideration of local meteorological condition. The best orientation of our planning area is 7.5 degrees south to east or 172.5 degrees from north. The daily average radiation incident on a vertical surface for the optimal orientation is 2.08KWh/m² in the entire year. However, in the hottest period is 2.53 KWh/m² and in the coldest period is equal to 1.17KWh/m². In a further chapter, we will base on 172.5° degree from north to assess a climate response of traditional and contemporary houses in Sousse city.

IV.2.4.4 Conclusion

The purpose of actual work in this chapter is to determine the bioclimatic improvement measurements which are related to Sousse climate. These measurements will be adopted in the next chapter. The selection of bioclimatic improvements is based on climate analysis of Sousse city and sensibility study. This sensibility is determined depending on the inside saved energy and comfort percentage graphic (chart). Thus, the achieved results show that the efficient bioclimatic design techniques of Sousse climate are limited to:

- 1) Thermal mass
- 2) Passive solar heating.
- 3) Natural ventilation.
- 4) Exposed mass & night purge ventilation

The cited techniques represent four comfort levels. Then, in further chapter, we will rely on these techniques to assess the climate response of the traditional and contemporary houses. In these assessments, therefore, we will base on comfort note and we assume that these houses are unconditioned. After that, we will refer to these passive strategies to optimize a thermal quality of these houses using REVIT and to assume that these houses are conditioned. For our research, the first comfort level represents a high inertia which allows storing the solar heat gain and then, it gives it back progressively at night. Although this strategy is efficient in winter, it causes an over cooling load in summer that's why we need to combine it with comfort level 3. This combination is obvious for comfort level 4. Getting benefits from these strategies, we need to take account of a good orientation to promote a prevailing wind in summer period and to encourage solar radiation access in winter. According to the prevailing winds chart from ECOTECT WEATHER tool, we can note that prevailing winds in Sousse blow from the east-northeast and 'Gregale'. They promote as a result natural ventilation in summer period. Although the prevailing winds in Sousse climate as west-northwest, west-southwest and 'Mistral' wind give additional load in winter, we require improving the opening insulation in order to reduce infiltration through openings. Then, we necessitate a compromise of these design strategies during cooling and heating periods. In order to ensure the second comfort level (passive solar heating) we need to promote directly or indirectly sunlight access. The last comfort level consists of an intermediary access of space as patio or atrium. Although be direct sunlight conduct is ensured through clear opening into habitable space. Sousse region has a typical hot and dry summer so these passive design bioclimatic strategies of Sousse city are more sufficient to ensure a thermal comfort in summer period. They can promote energy conservation as well. On the contrary, these techniques are insufficient in heating period because of Sousse city has a mild and wet winter climate. We need to promote directly or indirectly the sunlight access in order to ensure the second level of comfort as the passive solar heating and promote ventilation in cooling period. Afterwards, we will investigate the efficiency of the fourth level of comfort cited above. Hence, to improve this efficiency of these latter design techniques, we will rely on other improvements measurements exist in the literature review. In the next chapter, we will explore the efficiency of each technique using REVIT in order to improve an indoor thermal quality of traditional and contemporary houses.

Chapter V EVALUATION AND OPTIMIZATION

V.1 Methodology for evaluation and optimization

As described prior, our main purposes in this thesis are:

- 1) Investigate and compare thermal efficiency of traditional and contemporary houses.
- 2) Identify the efficient responsive strategies available in traditional house in Sousse city.
- 3) Recommend and improve the thermal quality using the appropriate solutions for both contemporary and traditional houses.
- 4) Rely on REVIT for thermal assessment and improvement.

Then, we will propose to adopt two kinds of improvements measurements as:

- Improvement measurements based on literature review.
- Improvement measurements correspond to passive design techniques.

Our strategy is to adapt the lodgment to the climate which consists of:
First, we investigate the climate of traditional and contemporary houses. Second, we propose to improve the thermal quality of these houses. Later in figure (II-1), we presented traditional and contemporary houses. Consequently, we aim to develop deeply these assumptions in this chapter.

V.2 Evaluation of climate responsive

V.2.1 Introduction

The special feature of habitat is to provide an appreciable thermal comfort to user. Tunisian habitat is composed by two kinds: a house with or without courtyard. The first one represents a traditional house which is expanded in Mediterranean region. It is Ifriqiyen house with central courtyard is available almost overall the Tunisian areas as in figure (V-1) [49]. Actually, this kind of house is located in ancient city (Medina).

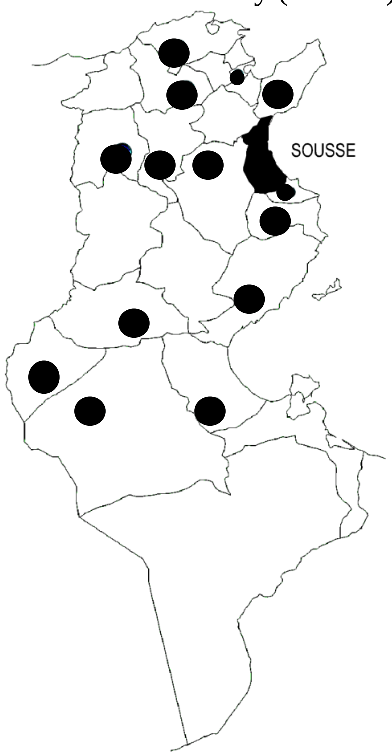


Figure V-1 Many localization of "Ifriqiyen" house with central courtyard in the map of Tunisia

It is adapted to its climate and social environment but provides a minimal comfort to users. This problem persists especially, in winter period because of the non-connecting rooms and the uncovered patio. A new phenomenon appears because the occupants left their dwellings to settle in new luxurious and comfortable cities out of the medina that's why the building system (design) has already changed from a traditional-patio house to modern house with no patio. So construction system is transformed from traditional house with patio to contemporary house without patio.

Figure V-2 Current unfavorable state of some houses in Medina, Dar 'Bou Achour' as example

V.2.2 Transformation and mutation

Modern mutations are occurred with no transition from traditional to contemporary house in Tunisia. Among these mutations, we notice that (1) family relationships are changed, (2) new spatial organization without courtyard is replaced by the corridor, (3) transformation from introverted space to extroverted space, (4) a change of construction material from stone to brick and from wood opening frames to aluminum frames, (5) cross vault ceiling transform to plaster ceiling, (6) traditional squares wood roof becomes concrete slab, (7) the orientation is poorly studied, (8) ceiling height in contemporary house is lower than the height in the traditional house, (9). These mutations are essentially occurred for the sake of modernism. As a result, some of traditional houses are forsaken by their owners as exposed in figure (V-2) and a new buildings have a poor thermal quality because the aesthetic and economic points are considered short term. Then, in order to provide an indoor thermal comfort, the occupant uses excessively heating and cooling equipment. In recent years, this new phenomenon increases energy consumption which allows enhancing economic crisis in Tunisia. As seen in the literature review in chapter (I), bioclimatic actions improve nearly 13% of energy saving [28]. These bioclimatic actions are used from ancestral period and present major solutions as demonstrated by Nguyen [40]. Coach [[50]] described vernacular architecture as a construction method which uses locally the resources for specific needs. Although Vissilia [[51]] defines bioclimatic design as a method which allows to satisfy the needs of occupants. She shows that bioclimatic architecture is relied on climatic conditions, techniques and material in-situ and knowledge benefits climate in building physics. According to the vernacular and bioclimatic characteristics of the dwellings described by Nguyen, Coach and Vissilia, we notice that these features are presented in Tunisia traditional house. This dwelling represents Ifriqiyen house [54] with a central patio which is suitable with the lifestyle and the behavior of Tunisian residents. It represents also the Tunisian culture, urban and climatic environment image. In the further part, we will investigate climate responsive of the available dwellings (traditional and contemporary) in Sousse region.

V.2.3 Environmental description (Macro scale)

Our study is limited to two sites in Sousse city. The first represents a dwelling in the old city and the second is in the new city.

V.2.3.1 Climate:

This part is a result from the last chapter (IV) which summarizes the climatic data analysis. We will rely on the following data in table (V-1), table (V-2) and table (V-3) for qualitative and quantitative investigation of climate responsive design.

Table V-1 Summary of the climatic data analysis (temperature, humidity, solar radiation, rainfall) of Sousse region

Climatic data	Maximal			Minimal		
	Time		Value	Time		Value
	Date	Hours		Date	Hours	
Temperature	22 July	2pm	44.8(°C)	7 January	7am	1.4(°C)
Humidity	December	9am	82%	June	3pm	26%
Solar radiation (diurnal average)	17July	12:30am	800W/m²	17December	12am-13am	540W/m²
Rainfall	October		63mm	July		1mm

Table V-2 A Summary of the prevailing wind analysis of Sousse region

Prevailing winds	Wind orientation	Frequency (hours)	Velocity (Km/h)
Wind (frequency and velocity in winter)	Northwest (Mistral)	92	45
	West-(northwest)	116	20
	West-(southwest)	116	15
Wind (frequency and velocity in summer)	Northeast (Gregale)	81	20
	East (Levante)	<9	40
	East- northeast	91	25

Table V-3 Efficient levels of bioclimatic design of Sousse region

Levels	**Level 1**	**Level 2**	**Level 3**	**Level 4**
Efficient levels of the bioclimatic design	**thermal mass**	**passive solar heating**	**Natural ventilation**	**exposed mass + night purge ventilation)**

V.2.3.2 Environment in Site 1 (Medina)

- **History and topography:**

The Ancient city of Sousse dates back to three thousand years. It is called "Medina" which represents a vernacular Tunisian settlement. It is built on the eastern flank of hills. Its setting is too close to the Sea. Since, December 9th, 1988, has been classified as World Heritage.

- **Urban morphology:**

This urban morphology is characterized by an organic frame [52]. The medina is bounded by rampart on all sides. It occupies a 32-hectare area, its perimeter is 2.2km and its wall has a 2m thick. The medina is formed by commercial, religious and residential areas. Our study focused on residential neighborhoods. The planning state of Medina settlement is dense and compact. Although souks are in Medina center, the residential neighborhoods are located between the main paths and the ramparts. They have a dense and homogeneous tissue with low houses and narrow streets baffles. The ancient morphology represents a segregation between residential and commerce areas and between the main and the private pathways [36].

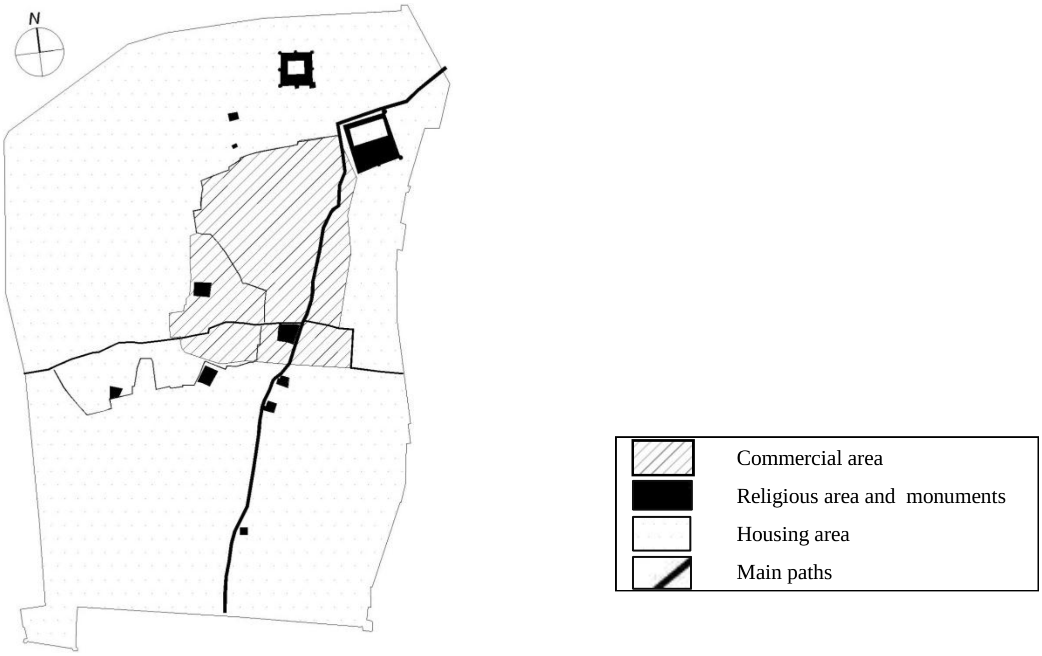


Figure V-3 Location of the various areas in traditional settlement of Sousse region

V.2.3.3 Environment in site 2 (New city)

- **History and topography:**

The new city is located outside the Medina and far from the sea as 'Bouhsina' city which has been built since the 70's.

- **Urban morphology:**

This new city represents a new urban morphology which is characterized by orthogonal grid. This planning is dense and takes account of 4m regulatory withdrawal. These dwellings are made up by modern construction materials. This new morphology is for the non-patio houses. Finally, these new settlement vary from one-floor building to five floor building.

V.2.4 Materials and methods:

Generally, we need to consider four major parameters to evaluate the real adaptation of the old and the new houses of Sousse city to the climate and the environment. These parameters are subsequently the occupant's behavior, the dwelling types, the site morphology and the natural resources. In this way, various approaches are employed in the literature as Bennadji in Algerian [[53]] context show that the thermal comfort within a traditional dwelling depends mainly on the behavior of the residents, the characteristics of the building, the site and the occupation mode in living space. Li Yang et al. [44] discover a new method of ecological planning relying on ECOTECT to analyze meteorological data and passive design strategies in China. He relies on solar radiation analysis and solar orbit. These analyses plan new sustainable residential state buildings. Manioglu et al [[54]] are carried out field survey measurements and investigation over 100 buildings in Turkey. They found that a traditional house is thermally more efficient than contemporary house. Although in Tunisia, researche studies concerning this special construction as Ghrab [[55]] have shown that comfort condition were acceptable during the hot season. She used TRNSYS (Transient system simulation) software for dynamic thermal simulation. Then, according to Ouertani [11] traditional architecture was able to respond to minimal comfort conditions of its occupants especially in cooling period. Gou et al [56] conducted a study to assess a climate responsive of typical ancient dwellings with a patio in China. Such as ‘three wings’ and ‘Folio shape’ building. They used analysis based on three basic steps: (1) description of the study sites and the traditional dwelling (topography, climate, building forms, construction materials, activity area), (2) quantitative analysis of climate responsive strategies (internal space, orientation, buffer space, envelope features, ventilation) and (3) quantitative analysis of indoor environment based on thermal comfort and thermal performance simulation using ENERYPLUS software. The obtained results show that traditional Chinese building is based on natural ventilation, sun shading, thermal buffering and heavy thermal mass providing a better thermal comfort in hot summer [58]. Although Nguyen [37] proposes other approaches which is based on six steps: (1) climate analysis, (2) collecting data (architectural houses typologies), (3) qualitative evaluation (analysis bioclimatic strategies), (4) quantitative evaluation (in-situ survey for 2 day); (5) quantitative evaluation through overall year (natural ventilation, shading effectiveness, indoor thermal environmental, (6) analysis and recommendation. Vissilia [51] analysis study is based on two major parts, (1) evolution of built environment and (2) assessment bioclimatic design strategies of vernacular dwellings. The investigated bioclimatic design strategies in literature review are exposed in table (V-4). Our assessment methodology is described prior in figure (II-1) which represents our main steps for assessment. Figure (V-2) expose our approach, steps and methods used in this chapter (V) to investigate the climate responsive of traditional and contemporary houses in Sousse city.

Table V-4 Examined bioclimatic design strategies in literature review

Authors	Bioclimatic solutions examined	Journal	Publication year
Vissilia [51]	- Layout (orientation, aspect ratio) - Spacing - Air movement - Opening size and shading device - Building envelope physical characteristics	Building and Environment	2009
Nguyen et al [37]	- Building orientation and shape - Solar shading - Natural ventilation type - Natural lighting techniques - Lightweight construction - High thermal mass - Evaporative cooling - Earth cooling by using color - Thermal insulation by material - Thermal insulation by design - Passive solar energy - Storm prevention - Flood prevention - Rainwater discharge - Moisture and condensation prevention	Energy and Buildings	2011
Li Yang et al [40]	- Orientation - Site radiation - Site sunlight distribution	Energy and Buildings	2014

	- Natural ventilation		
Gou et al [56]	- Internal space setting - Opening design - Orientation - Buffer space - Double layer envelope - Raised ventilation floor - Use vegetation and water	Building and Environment	2015

Table V-5 Methodology approach and steps proposed for climate responsive evaluation

Steps	Methods	Tools	Materials	
Beneficial bioclimatic design techniques	Climate analysis	ECOTECT WEATHER	Sousse region (meteorological data(.csv) file)	
Environmental description	Macro-scale description	Features of the studied sites	Traditional site	New site
Dwellings description	Micro-scale description	Architectural graphic documents	IH (MC, HC); CH	CH; IH (HC, MC)
Qualitative evaluation	Systematic analysis	Image/ comments	Investigation on housing bioclimatic actions (Indoor and outdoor environment)	
Quantitative Evaluation (indoor and outdoor environment)	Natural lighting Analysis	ECOTECT	Daylight and insolation simulation micro-climate (hottest and coldest day	
Quantitative Evaluation (indoor environment)	Field survey in-situ	Hydro button + Thermo button	Measurement in indoor environment (15 days in winter and 1 month in summer)	
	Indoor thermal comfort	CBE comfort prediction tool	Comfort note in indoor environment (hottest and coldest day)	
	Thermal demand simulation	REVIT	Heating and cooling load calculation (full year)	
			Conditioned traditional model	Conditioned contemporay model
Comparison	Simulation results	REVIT	Improvements measurenments bioclimatic (local)	Improvements measurenments (literature review)

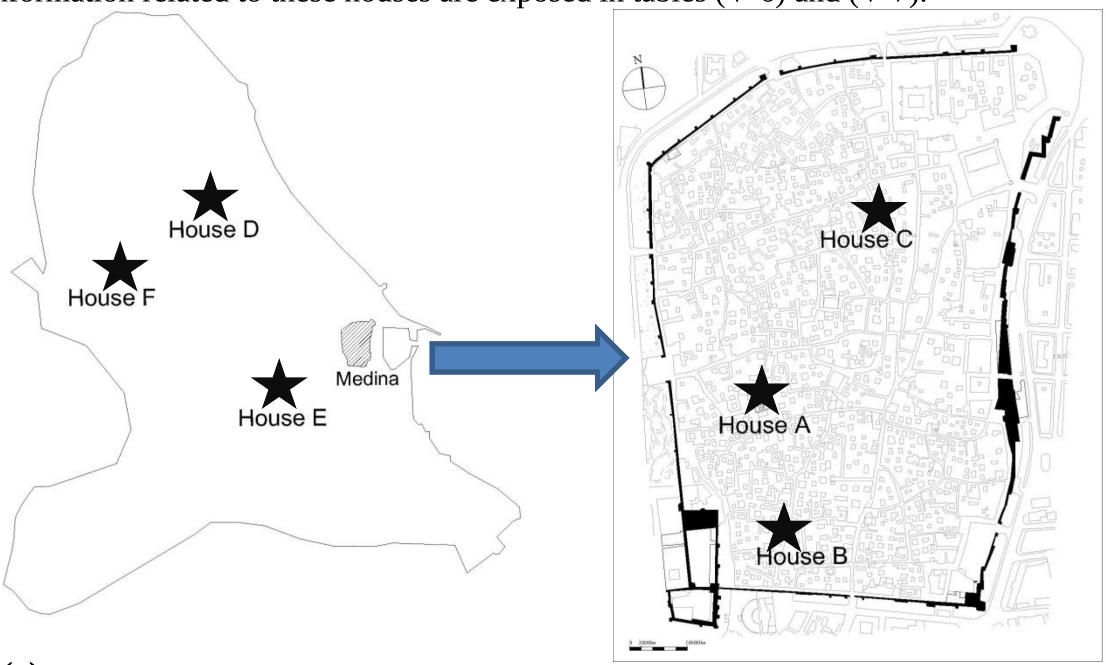
IH: defines individual houses in traditional site as houses B and C; individual houses in contemporary site as house E and F.
CH: sets out collective houses in traditional site as house A, collective individual house in contemporary site as D.
MC: exposes middle class houses as house B in traditional site and house E in contemporary house
HC: represents high class houses as house C in traditional site and house F

V.2.5 Description of micro scale environment

V.2.5.1 Collecting data

V.2.5.1.1 Selected houses

Our study is based on six typical houses in Sousse region. Our choice selection is made according to the social class and the type of use (private or public). Each site is represented by three houses: ‘house A’ represents a collective housing (public); house B and C are private housing. ‘House B’ belongs to middle class and ‘house C’ represents high class. More information related to these houses are exposed in tables (V-6) and (V-7).



(a) (b)

Figure V-4 Location of selected houses in the present study; (a) on the left, the map of Sousse region which shows the (house D, house E, house F) in outer Medina and (b) on the right, the selected houses (house A, house B, house C) in inter Medina site Dwelling in site 2

Table V-6 Information about study dwellings in site 1(Medina)

Code	House name	Type/Social class	Location	Year of construction	Surface (m^2)	Function
House A	Dar Echarae	Collective/public	Street Dar El Bey/Street April 9th	1705	716	Collective living space

House B	Dar Gachem	Private/ middle-class.	Street Sidi Baaziz	1930 (a)	166	Individual living space
House C	Dar Bou Achour	Private/ high class.	Street El Aroussi Zarrouk	End 18th century (a)	459	Individual living space

(a) Estimation (construction year)

Table V-7 Information about the studies houses in site 2 (new city)

Code	House name	Type/Social class	Location	Year of construction	Surface (m²)	Function
House D	building	Collective/public	Street Yasser Arafet	Under construction	716	Commercial/ office/ living space
House E	Dar Ghedas	Private/ middle-class.	Street Dar Essalem	2009	177	Living space
House F	Dar Guirat	Private/ high class.	Street Rue Imam Boukhari	2008	459	Living space

V.2.5.2 Construction materials

The traditional house is composed of stone walls characterized by a high thermal inertia associated with horizontal roof and wood frame openings. However, the modern house is made of brick walls with 35 cm thickness including 5cm air. These walls are accompanied by horizontal roof as displayed in chapter (III) and in paragraph (2-1). The openings in the contemporary house are made by aluminum frame. Construction materials of the two studied sites are exposed as in table (V-8) and table (V-9). The data about the opening in house B and E are displayed in table (V-10) and (V-11).

Table V-8 Construction materials in the studied site 1

Code	Wall	Structure	Roof service areas	Roof living areas	Floor	Openings
House A	Stone coated with 'khadel'	Load bearing wall +arch form	groin vault and barrel vault	horizontal roof with square wood	Marble floor	wooden panel, glass, forged iron
House B	Stone coated with 'faience'	Load bearing wall+ arch form	groin vault	Transformed to horizontal roof of concrete	Mixed (reinforced concrete and fired clay brick)	Timber, glass and forged iron
House C	Stone coated with 'khadel'	Load bearing wall+ arch form	groin vault	Mixed (horizontal roof with square wood	Mixed (Marble floor and fired clay	wooden panel, glass and forged iron

	and faiance			and barrel vault	brick)	

Table V-9 Construction materials in studied site 2

Code	Wall	Structure	Roof	Floor	Openings
House D	double partitions (brick)	Load bearing (reinforced cement concrete columns)	horizontal roof with reinforced concrete	Mixed (Marble floor and Porcelain Stoneware Tiles)	aluminum frame, glass and store
House E	double partitions (brick)	Load bearing (reinforced cement concrete columns)	horizontal roof with reinforced concrete	Tiles floor	aluminum frame, glass and store
House F	double partitions (brick)	Load bearing (reinforced cement concrete columns(	horizontal roof with reinforced concrete	Mixed (Marble floor and Porcelain Stoneware Tiles)	aluminum frame, glass and store

Table V-10 Data about opening in house B

Interior walls on the patio orientation	Percentage glazing	Height (m)
East side	13%	0.5
South side	20%	0.5
West side	20%	0.5
North side	21%	0.5

Table V-11 Data about opening in house E

Exterior walls orientation	Percentage glazing	Height (m)
North-east	39%	1 and 0.7
South-west	1%	1.6
North-east	12%	1
North-west	9%	1.2 and 1

V.2.5.3 Spaces repartition

The house in site1 is composed of a living room, 3 rooms, kitchen and 2 buffer spaces called 'Skifa' 1 and 2. Those spaces are designed around a patio as displayed in figure (V-5), although the houses in site2 are included by living room, dining room, parent room, 2 rooms for children and Bathroom. Those spaces are served by a corridor and hall entry as shown in figure (V-6).

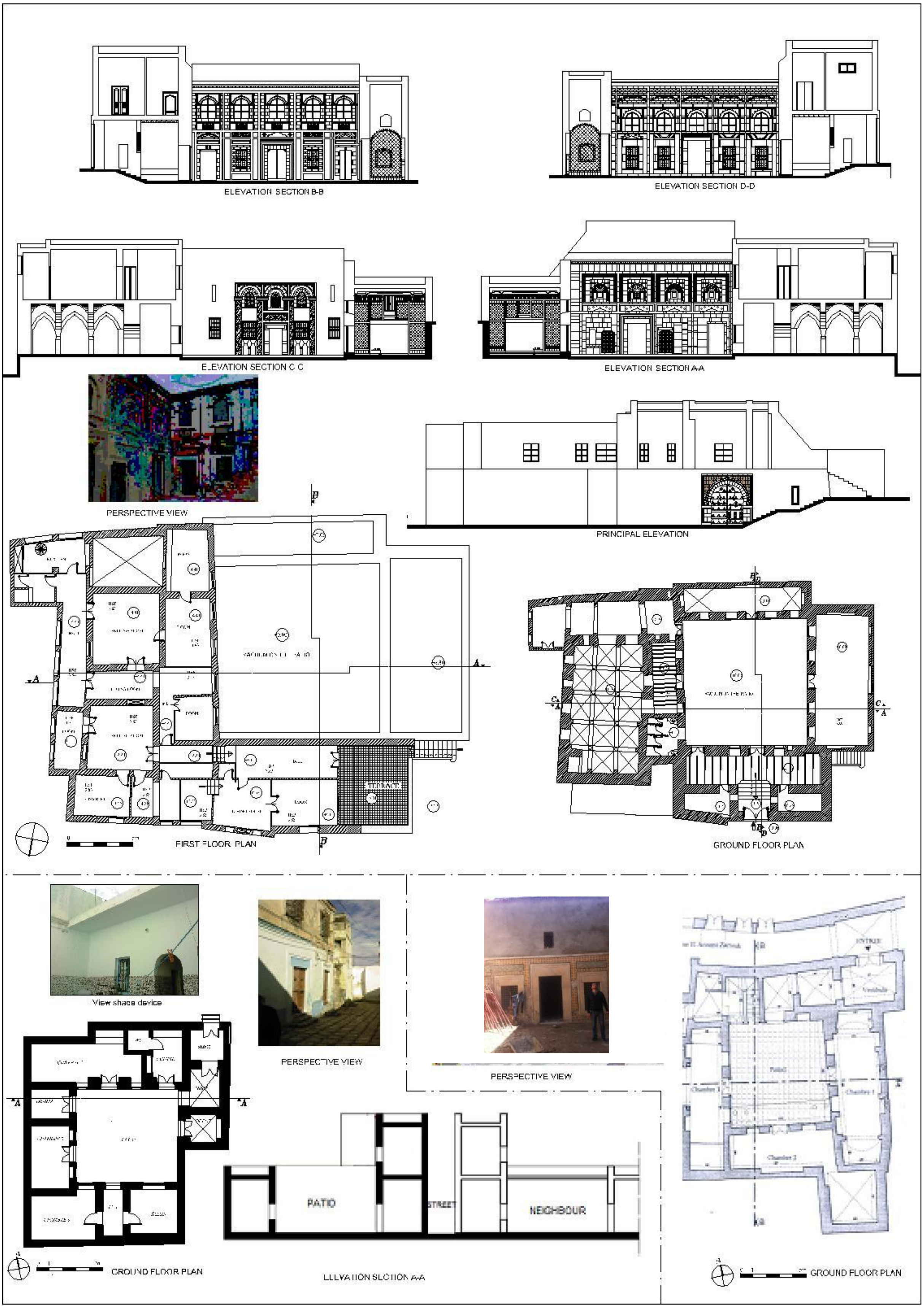


Figure V-5 Architectural details of the selected houses in site 1: house A; house B; house C (from upper to lower and left to right respectively).

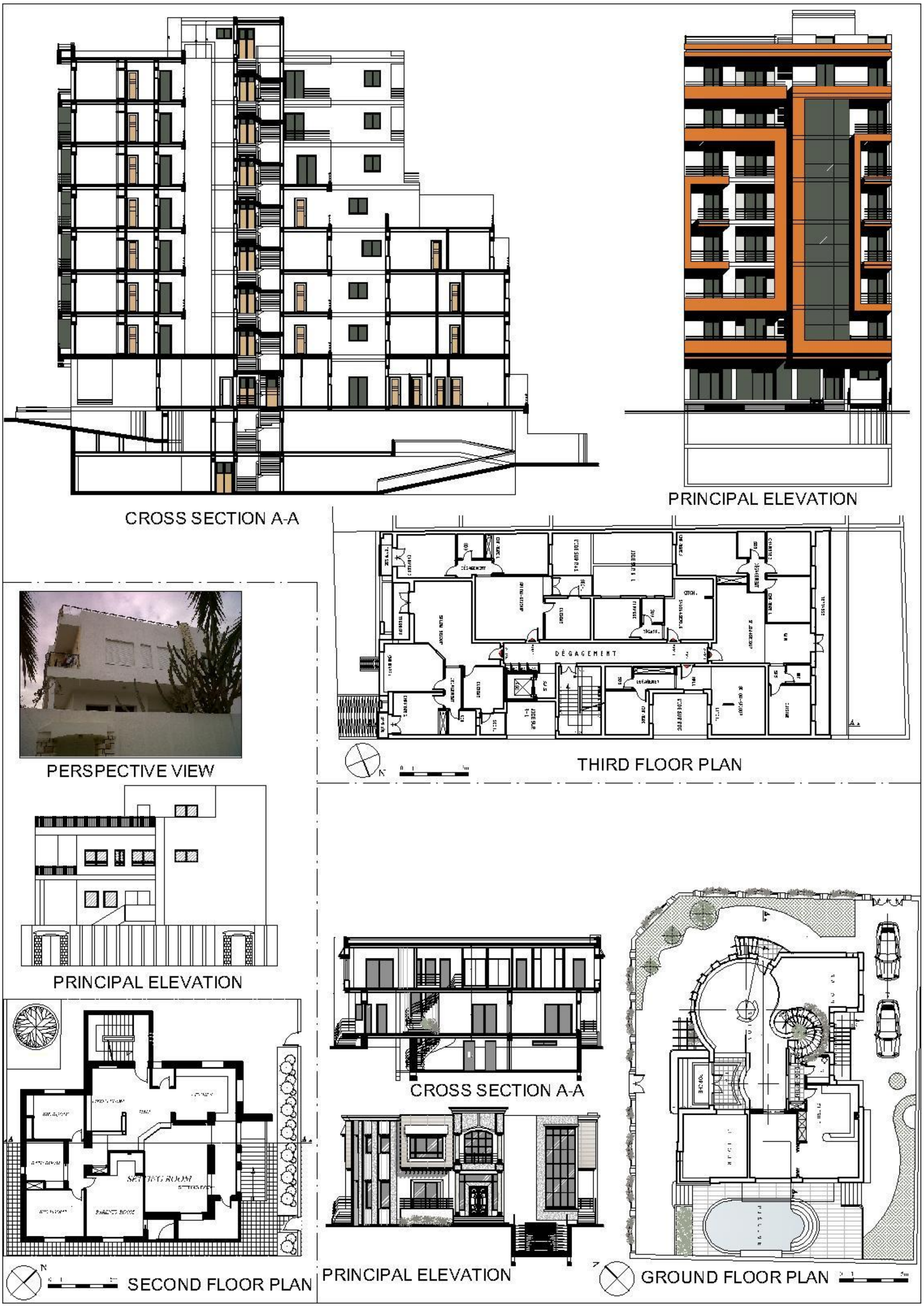


Figure V-6 Architectural details of the selected houses in site 2: house D; house E; house F (from upper to lower and left to right respectively).

V.2.6 Qualitative analysis of climate responsive techniques

V.2.6.1 Introduction:

The obtained results from chapter (IV) show that Sousse region has a typical hot and dry summer and mild and wet winter climate. Moreover, according to the last chapter, we found that the efficient design techniques of Sousse climate are divided as following: thermal mass (level1), passive solar heating (level 2), natural ventilation (level3), exposed mass and night purge ventilation (level 4). These levels represent the estimated comfort in the last chapter by ECOTECT WEATHER tool.

V.2.6.2 Investigation of climate responsive design strategies for houses in site1 and 2

The below table (V-12) exposes various bioclimatic design strategies which are examined in the literature review. Thus, we classify these strategies according to the fourth comfort levels relative to local climate. Our investigation is based on image/comment as displayed in tables (V-13) and (V-14). Our approach for investigation consists of assigning a vote for each strategy applied in the selected houses (A, B, C, D, E, and F) which is complied with the obtained solutions in the literature review. Thereby, we assign vote=1 if this strategy is entirely presented; vote=0.75 if this strategy is checked at 75%; vote=0.5 if this strategy is verified at 50% of conditions; vote=0 if this strategy is Not Available (NA) in a specific house. The acquired results of investigation show that the selected houses are neither fully adapted nor completely unsuitable for all passives design solutions but they are usually within this range [37]. Subsequently, the following points are carefully examined: using urban and architectural photos. The components of the studies houses are analyzed to identify the type of the climate response.

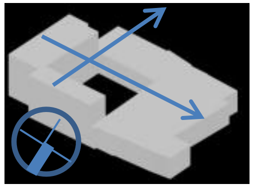
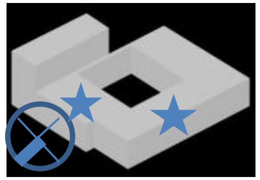
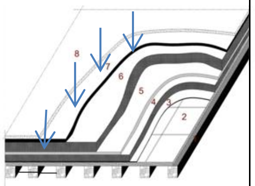
These responses determine compatibility between the passive design actions in the local climate and the design strategies available in the original traditional and contemporary houses in our study sites. Following a deep analysis, we admit that the evaluation of both traditional and contemporary houses must be done in relation to their urban environment as in tables (V-13) and (V-14). These last tables show that ventilation action is available for two study sites such as traditional houses are based on double ventilation over one single side and cross ventilation as well. But, the chosen houses in site2 rely only on cross ventilation. This natural ventilation is thanks to Gregale and Levante winds which provide fresh air and humidity to adapted dwellings during the hottest days without energy consumption. The localization of ancient city (site1) which is too close to sea provides sea breeze and allows atmospheric temperature reduction. Thus, it can improve the indoor thermal comfort and provide fresh air without energy consumption. Natural ventilation, in fact, presents in the hottest period an effective passive strategy in Sousse climate. Ventilation represents an old strategy that emphasizes the knowledge of ancient habitants to their particular climate especially in the hottest days. We note according to table (V-13) and (V-14) that traditional dwellings are characterized by 2 buffers spaces differently from the contemporary ones as following: the principal buffer is linked with the entrance and the second space by baffle access. These buffer spaces can improve indoor environment in summer through a cross ventilation. Besides, traditional dwellings enhance indoor environment through double ventilation with one single side opened in the patio. This process facilitates the entry of cool air through bottom opening thus hot air comes out through top opening. The top opening reinforces equally thermal leakage through exterior façades in winter period. High street with deep street canyon in traditional city provides shade and protection against excessive solar radiations in summer. Moreover, high inertia does exist for overall houses in the vernacular settlement (Medina). Natural lighting using window glazing is present in overall investigated houses.

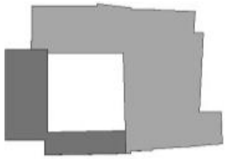
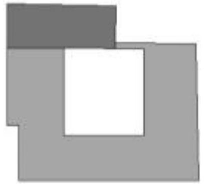
Besides, purge ventilation with high inertia are founded only for the vernacular houses. The buffer spaces are also identified in the last houses. We note that bedrooms and living areas of contemporary houses are badly oriented. However, these houses have shading device promoting passive cooling in summer period.

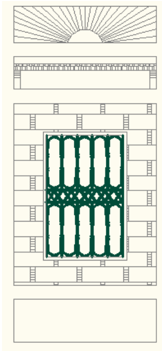
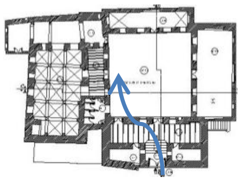
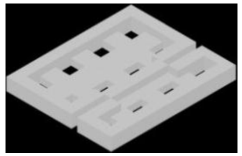
Table V-12 Classification of passive design solutions in literature review according to the four comfort levels for Sousse climate

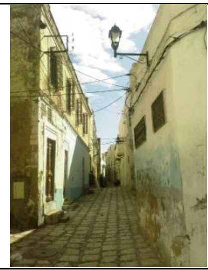
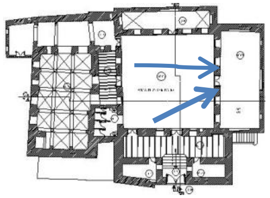
Efficient design levels	**Level 1 (thermal mass)**	**Level 2 (passive solar heating)**	**Level 3 (natural ventilation)**	**Level 4 (exposed mass + night purge ventilation)**
Bioclimatic solutions	- Orientation - Site radiation and sunlight distribution - construction materials - Passive cooling using color and/or shading system	- Shape - Passive solar energy (natural lighting technique and opening size)	- Buffer space - Spacing (site planning) - Street canyon (deep) - Ventilation type (single side for double ventilation and/or cross ventilation - orientation	- Inertia + Ventilation + orientation

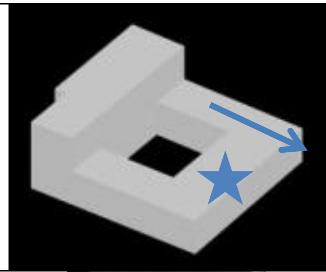
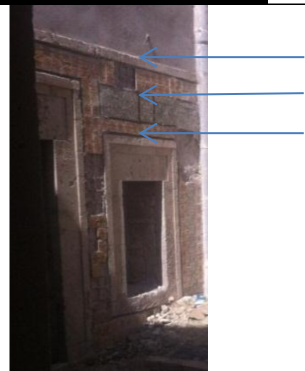
Table V-13 Qualitative investigation of bioclimatic design strategies used in traditional site1

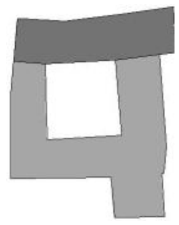
Strategies levels of bioclimatic design	Bioclimatic design solutions	Houses typology			
		House A (collective traditional house)		House B (individual traditional house with middle social class)	
		Description of the used strategies	Images	Description of strategies used	Images
Level 1	Orientation	- Highest walls opened in the patio are oriented in east and south to encourage thermal gain radiation in winter.		- East and south oriented rooms to promote thermal mass and natural day lighting in the patio.	
	Site radiation and sunlight distribution	- Vertical partitions with high thermal inertia benefit from horizontal solar radiation. - Horizontal partitions with high thermal inertia benefit from vertical solar radiation.		- Vertical partitions with high thermal inertia get benefits from the horizontal solar radiation. - Horizontal partitions with a high thermal inertia get benefits from vertical solar flow.	
	Construction materials	- Patio exterior envelope with 83cm wall thickness. - Exterior envelope opened on the street with 1m wall thickness. - First floor exterior envelope with 0.5m wall thickness. - Stone wall covered with natural stone ('Kadhel'). These materials represent local resources for		- Stone wall is built by local material as 'Hajer Swafa'. - Groin roof with solid brick.	

		construction which promote storage solar heat gain. - Groin roof with solid brick.			
	Passive cooling (using color or shading device)	- NA[a]	- NA	- Exterior envelope is painted by lime wash. It reflects solar radiation and presents passive cooling solution.	
Level 2	Shape	- Central courtyard - Ground Occupancy Coefficient (COS) represents 76% of the overall surface. - Patio area represents 23% which resemble to urban regulations in Medina settlement exceed 3m for solar daylight - This model is a first floor thus 160m² patio areas allows to solar daylight to enter the ground floor according to urban regulations in Medina.		- Lateral courtyard - COS represents 76% of overall surface areas. - Courtyard area represents 23% which is resembles to urban regulations in Medina such as patios areas almost equal to ¼ parcel area to promote solar daylight - This model has a first level thus 55 m² of patio area allows solar daylight of the ground level according to urban regulations in Medina.	 

	Passive solar energy (natural lighting technique and opening size).	- The east orientated glazing percentage is 11% in for bedrooms and living spaces. - Window target is still 1m high and the wall with 4m height to promote sunlight access directly in winter season.		- East oriented glazing percentage is 19% for bedroom 1. - South orientated glazing percentage is 17% for bedroom 2. - Window target is still 0.5m high and the wall with 5m height to promote sunlight passage directly.	
Level3	Buffer space	- 2 buffer spaces allow cross ventilation. - Buffer spaces called strong solar radiation and provide fresh air with ventilation in summer.		- Cross ventilation is occurred by doors of 'Skifa1' (exterior opening) and 'Skifa2' (interior opening).	
	Spacing (site planning)	- Linear block houses with courtyard are jointed with continuous order. These linear houses with courtyard produce autonomous and compact cluster with high urban density. - This morphology reduces heat losses through exterior envelope and promotes ventilation in micro-climate area (patio). - For house A and B green spaces are not available. - Each house A and B is designed with a well to exploit either groundwater or water cistern 'Magel' to benefit from rainwater. Natural resources are included in architectural design.			

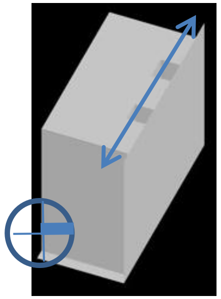
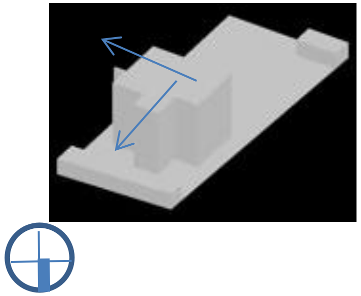
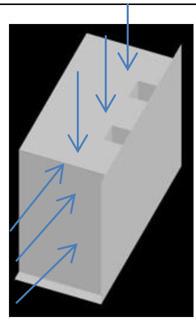
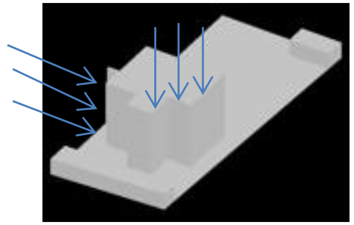
	Street Canyon	- Deep canyon with Aspect ratio (H/W) is equal to 2^{b}, it creates an outside turbulent air flow which promotes wind ventilation in summer season.			
	Ventilation types (cross, double ventilation of one single side)	- The ventilation is based on a double ventilation of one single side because the two openings are in the same wall. - The highest opening is located above the window or a door.	 	- Cross ventilation - A double ventilation of one single side is not available for the house B because of the highest opening is removed above door.	
	Orientation	- East-façade D-D is east oriented which allows prevailing wind ventilation as Levante and Gregale wind. These winds brow from Mediterranean Sea which promotes fresh air in summer.		- Living area and room3 are north -oriented to promote Gregale wind for natural ventilation.	
Level 4	Inertia+ ventilation+ orientation	- Combination of high density ventilation and the orientation which reduces swing back and forth of indoor temperature.	-	- High inertia which allows to store solar heat gain and then. It can re-establish progressively this heat gain at night with large opening.	-

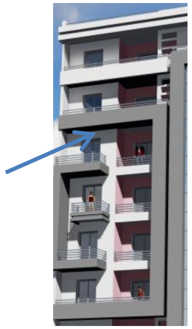
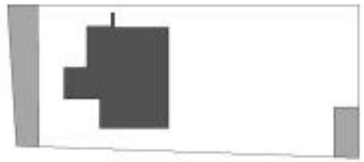
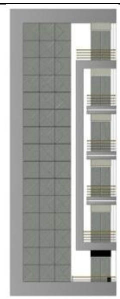
Efficient design levels (climatic features)	Bioclimatic design solutions	House C (collective traditional house)	
		Description of strategies used	**Image**
Level 1	Orientation	- The highest walls in the patio are south oriented. - Room 3 is oriented in east orientated in the patio.	
	Site radiation and sunlight distribution	- Vertical partitions with high thermal inertia benefit from horizontal solar radiation. - Horizontal partitions with high thermal inertia benefit from vertical solar radiation.	
	construction materials	- Stone wall allows to absorb diurnal solar heat and to restitute heat gain at night. - Groin, barrel roof with solid brick. - Horizontal roof with square wood is used for load bearing and is reduced infiltration.	
	Passive cooling by using color and/or shading system	NA	NA

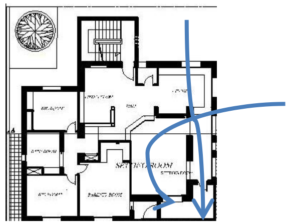
Level 2	Shape	- Central courtyard. - COS represents 80% of overall surface areas. - Courtyard area represents 20% which is conform with Medina settlement parameters such as the patio area which is almost equal to ¼ of the parcel area to promote the solar daylight. - This model has a first level thus 172 m^2 patio areas allows solar lighting to reach the ground level according to Urban Medina Regulatory in Sousse region. - This courtyard allows indirectly sunlight passage.	
	Passive solar energy (natural lighting techniques and opening size)	- Solar path is from the east towards the west, solar heat gain directly using efficient window glazing in winter period. - Solar heat gains pass indirectly via intermediary space as a patio.	
Level 3	Buffer space	- seen for house A and B	- seen for house A and B
	Spacing	- seen for house A and B	- seen for house A and B
	Street Canyon (deep)	- seen for house A and B	- seen for house A and B
	Ventilation types	- Double ventilation of single side create an indoor air movement such as the cold air enters through the lowest opening then the warm air goes up and comes out through the highest opening. - Cross ventilation.	
	Orientation	- The north oriented façade in the patio benefits from the Gregale wind which brows from the northeast Mediterranean Sea. The east oriented façade in the patio benefits from the Levante wind which brows from the eastern Mediterranean sea.	

Level 4	Inertia + ventilation + orientation	- seen for house A and B	

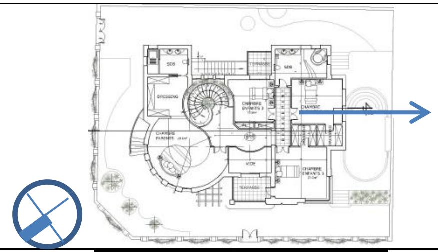
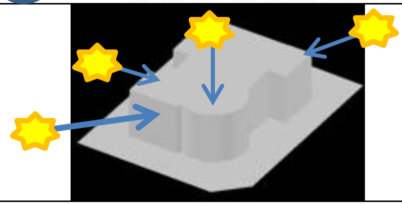
Table V-14 Qualitative investigation of bioclimatic design solutions used in traditional site2

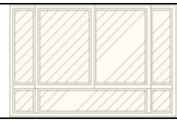
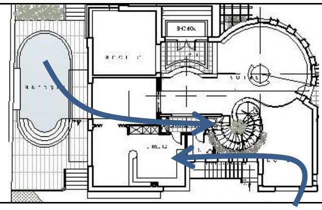
Efficient design levels (climatic features)	**Bioclimatic design solutions**	**Houses typology**			
		House D (collective contemporary house)		**House E (individual contemporary house/middle social class)**	
		Description of the used strategies	**Images**	**Description of strategies used**	**Images**
Level 1	Orientation	- Some bedrooms and living areas are either north-east or south-west oriented. - Other rooms are badly orientated.		- Living areas and 2 bedrooms are oriented respectively south-east and north –east oriented. - 1 rooms is badly oriented	
	Site radiation and sunlight distribution	- Vertical partitions with medium thermal inertia benefits from horizontal solar radiations which is a south-east fall. - Roofs with medium thermal inertia benefits from vertical solar radiations		- Exterior wall and roof surfaces benefits respectively from horizontal and vertical solar radiations.	

	Construction materials (with high inertia)	- NA	- NA	- Exterior envelope is combined with stone and brick 12T.	
	Passive cooling (using color or/and shading system)	- South-east shading device provides a diurnal shading with a high solar radiation		- A white painted exterior envelope reflects solar radiation and reduces solar heat gain in summer. - A south east oriented overhang with 1.5m as a device system provides shading.	
Level 2	Shape (compact, courtyard)	- Collectif housing block (perimeter block) - Double lateral courtyard (perimeter block) is on continued band - - Global courtyard areas represent 4% of the overall areas		- Single house with Individual housing block.	
	Passive solar energy (natural lighting techniques and opening size)	- Glazing percentage promotes directly solar radiation using curtain wall. - Overall exterior openings are on glazing.		- Glazing percentage promotes directly solar radiation.	

	Buffer space	NA	NA	- Vertical opening in stairwell encourages cross ventilation.	-
	Spacing (natural ressources, site planning)	(the Construction is a continued band, the natural ventilation is limited).	-	- Construction is an isolated- band construction promote natural ventilation. - Garden with olive trees provides air breeze.	
Level3	Street Canyon (deep)	- Deep canyon with aspect ratio (H/W) is superior to 2^b. It creates whirl semi-permanent related to a prevailing wind and provides indoor and outdoor comfort in summer season.	- NA	- NA	- NA
	Ventilation types	- Cross ventilation such as air flow circulation is occurred through a single opening.		- Cross ventilation such as air flow circulation is occurred through two openings; the opposite and the adjacent walls.	
	Orientation (exposed to Gregale, Levante)	- Opening oriented in south-east to promote wind ventilation as Levante wind.		- Northeast, southeast and northwest oriented windows just to promote wind ventilation.	 -

Level 4	Inertia+ ventilation+ orientation	- NA	- NA	- The walls which built on a slow stone with high glazing percentage encourage ventilation purge.	- NA

Efficient design levels (climatic features)	**Bioclimatic design solutions**	**House F (individual contemporary house/high social class)**	
		Description of used strategies	**Image**
Level 1	Orientation	- A north-east oriented living room. - First level bedrooms are south-ouest oriented.	
	Site radiation and sunlight distribution	- The solar path direction is from east to west. Although the solar radiations are vertical in midday, they are horizontal the rest of day.	
	Construction materials	- Like house D and E.	- The same as in house D and E.
	Passive cooling by using color or/and shading system	- An exterior envelope is painted on white color to reflect solar radiation and to reduce solar heat gain in summer. - An overhang 1.5m as device system has a south-east orientation to provide the shading.	-
Level 2	Shape	- Seperated construction is on isolate band, compact mass block without courtyard.	

	Passive solar energy (natural lighting techniques and opening size)	- Glazing of living room is oriented in south-east to promote directly solar radiation.	
Level 3	Buffer space	- NA	- NA
	Spacing (site planning)	- Separated morphology. - Swimming pool area to allow fresh air.	
	Street Canyon (deep)	- NA	- NA
	Ventilation types (cross ventilation, double ventilation of one single side)	- Only cross ventilation. - Swimming pool combined with air movement to provide fresh air to indoor area during the day in summer.	
	Orientation	- Northeast and southeast oriented windows in order to promote respectively the Gregale and Levante winds for passive ventilation.	
Level 4	Inertia+ ventilation+ orientation	- NA	- NA

a: NA, means that this strategies are applied in the selected houses do not comply with bioclimatic solutions of the local climate.
b: This aspect ratio is defined by Brebbia[57]

Table V-15 Results of the qualitative investigation of the climate responsive of site 1

Levels	Investigated Strategies	HouseA	HouseB	HouseC	Total votes
Level1	Orientation	1	1	1	3
	Site radiation	1	1	1	3
	Construction materials	1	1	1	3
	Passive cooling	0	0,5	0	0,5
Level2	Shape	1	1	1	3
	Passive solar energy	1	1	1	3
Level 3	Buffer space	1	1	1	3
	Spacing	0,75	0,75	0,75	2,25
	Street canyon	1	1	1	3
	Ventilation types	1	0,5	1	2,5
	Orientation	1	0,5	1	2,5
Level4	Inertia+ ventilation + orientation	1	1	1	3
Total votes of bioclimatic levels in A, B and C houses					**31 votes**

Table V-16 Results of the qualitative investigation of the climate responsive of site 2

Levels	Investigated Strategies	House D	House E	House F	Total votes
Level1	Orientation	0,5	0,75	0,5	1,75
	Site radiation	1	1	1	3
	Construction materials	0	0,5	0	0,5
	Passive cooling	0,5	1	1	2,5
Level2	Shape	0,5	0,5	0,5	1,5
	Passive solar energy	1	1	0,5	2,5
Level 3	Buffer space	0,5	0,5	0	1
	Spacing	0,5	0,5	0,5	1,5
	Street canyon	0,5	0	0	0,5
	Ventilation types	0,5	0,5	0,5	1,5
	Orientation	0,5	1	1	2,5
Level4	Inertia+ ventilation + orientation	0	0,5	0	0,5
Total votes of bioclimatic levels in D, E and F houses					**19 votes**

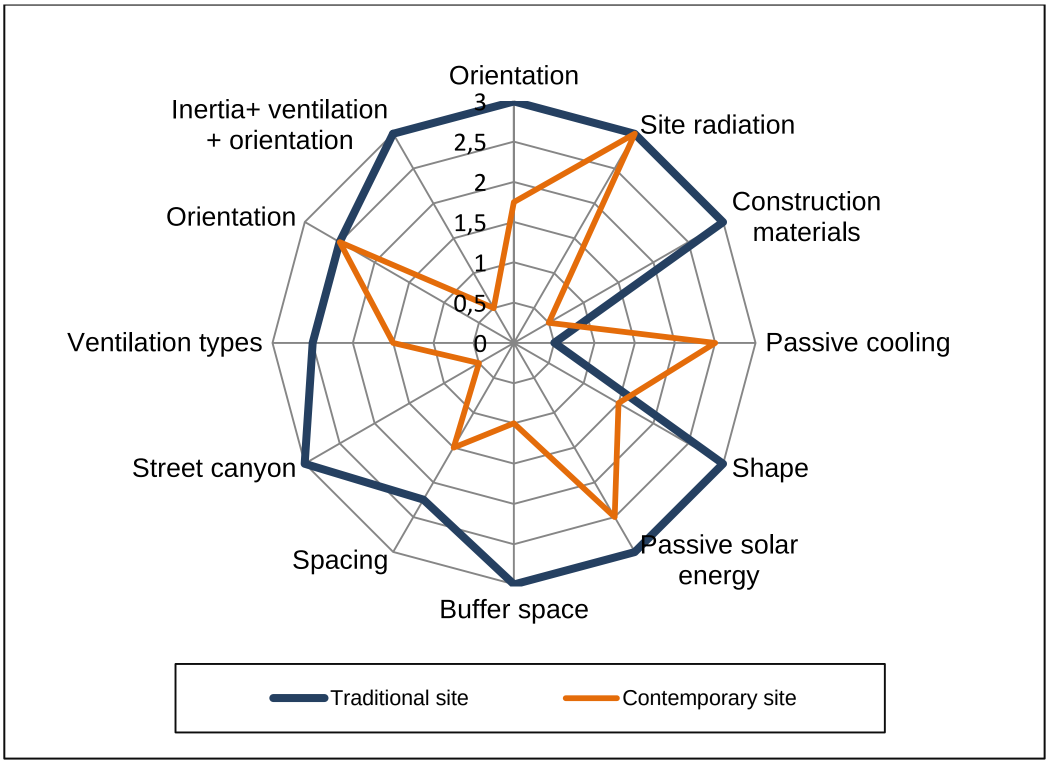


Figure V-7 Graphic results of qualitative investigation of climate responsive in traditional and contemporary sites

The survey results of table (V-13) and (V-14) are exposed in table (V-15) and (V-16) respectively for traditional and contemporary sites. Table (V-15) shows that the total votes of bioclimatic levels in A, B and C houses are **31votes**. However, the Table (V-16) displays that the total votes of bioclimatic levels in D, E and F houses are **19 votes**. Hence, the results of qualitative investigation show that traditional houses (A, B and C) are more efficient than contemporary houses (D, E and F). These results are also inserted in Radar graph (V-7) to compare climate responsive of two study sites. Radar plot summarizes that climate responsive area in site 1 is more important than climate responsive area in site 2. Hence, vernacular houses (house A, B, C) are more adapted to local climate than contemporary houses (house D, E, F). Therefore, the brutal transformations without transition from bioclimatic houses to contemporary houses in Sousse region are not efficient. For more accurate details, we will adopt a quantitative investigation in the next part.

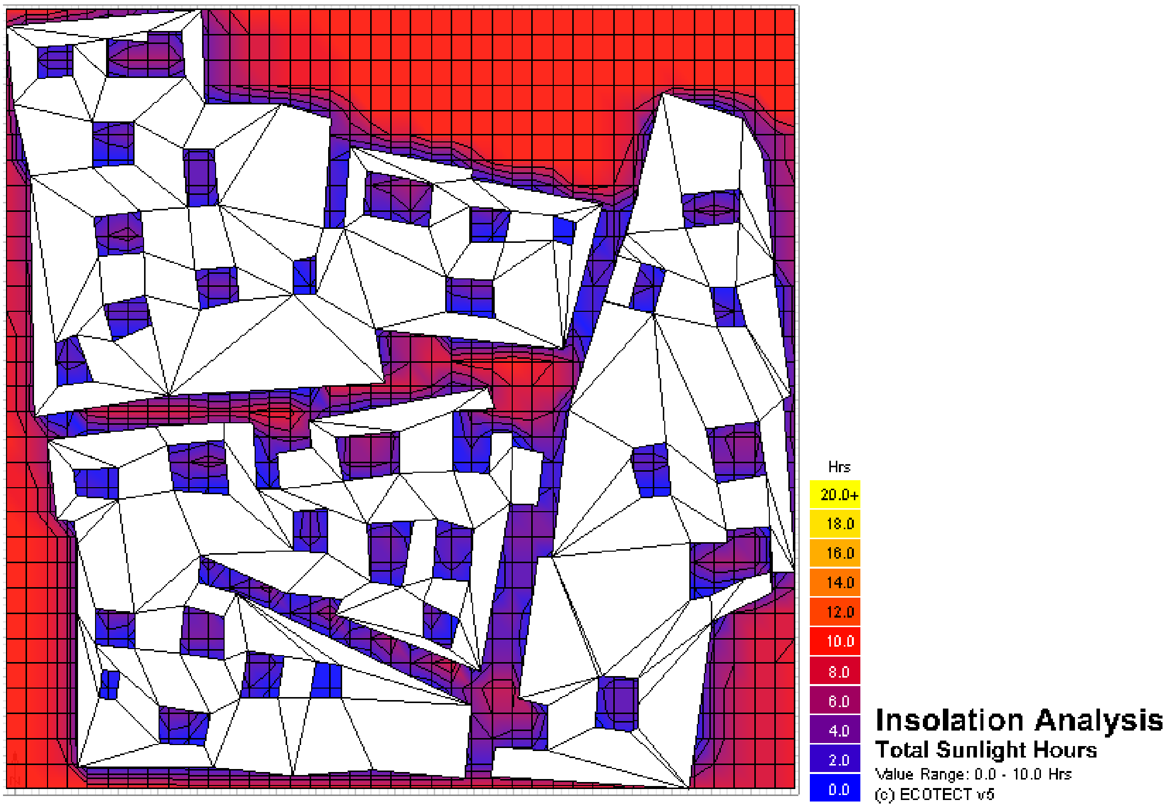
V.2.7 Quantitative evaluation of climate responsive

According to the literature review [41, 42], a thermal comfort in traditional house depends on the following parameters the occupancy mode, the behavior and the clothing of the occupant's resistance towards the climatic change and the bioclimatic design strategies. In this part, we will assess the climate responsive of the original traditional and contemporary houses in order to identify the efficiency of vernacular and contemporary architectures. As it is exposed in table (V-2), our quantitative investigation of climate responsive will be based on an indoor and outdoor environment using ECOTECT software. Otherwise, we will be limited to an indoor environment simulation as the authentic saving which is done by Hydro and Thermo-button.

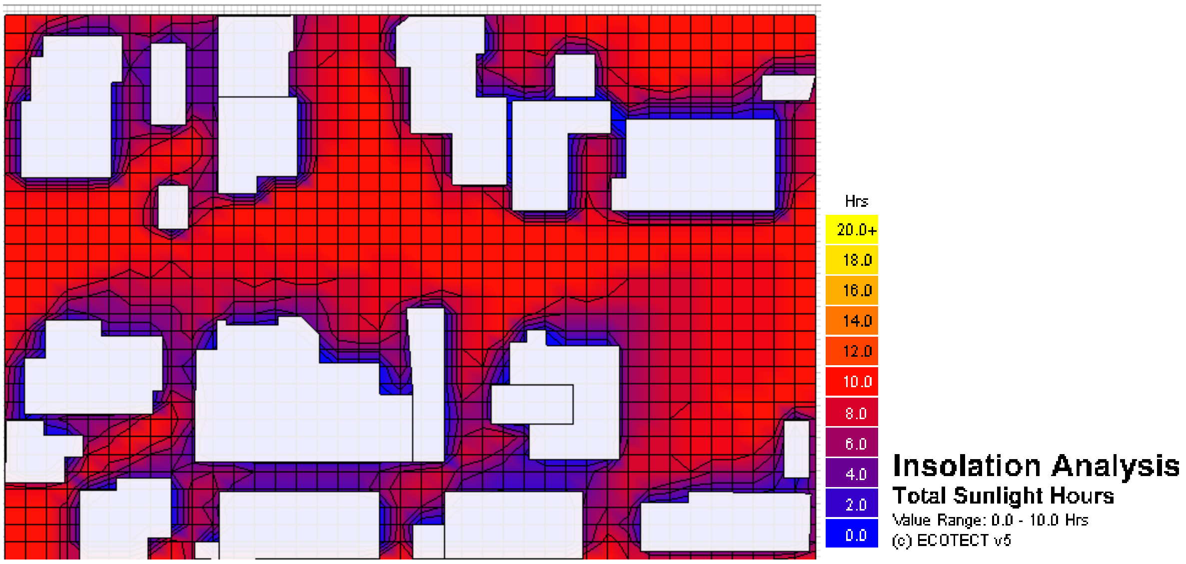
The prediction of the indoor thermal comfort using comfort prediction tool (3), the calculation of the thermal load relying on REVIT during both periods of heating and cooling load calculation. For the simulation, we select ultimately the original house B and E in traditional and contemporary sites with equals surfaces.

V.2.7.1 Site radiation

Actually, we need to calculate solar radiation distribution of the planning area in site 1 and 2 in order to evaluate efficiency of ancient and new urban morphology. Subsequently, we opt for ECOTECT software to investigate solar radiation distribution respectively during the coldest and the hottest days. Therefore, we rely on the grid calculation method and the location and orientation on the right. Figure (V-8a) displays the total solar radiation distribution of south-west clusters relatively to the Medina settlement (site1) on July 17th. Whereas, figure (V-8b) exposes the distribution of south cluster in Sousse region which is relative to contemporary site at that specific date. We notice that our investigation, in this part, is limited to the inside urban clusters. These last figures show that the solar radiation which is based on an hourly recorded direct radiation data from the file of Sousse weather. Thus, the total sunlight hour calculation is relied on average hourly value on July 17th. We can see from figure (V-8a) and (V-8b) that the total prevailing sunlight hours are 4 hours and 10hours respectively for the ancient and the contemporary study sites. Hence, the color blue is dominating in figure (V-8a) which indicates that the south-east cluster in site 1 gives a beneficial indoor and outdoor micro-climate. These advantageous results from the ancient urban morphology are based on a deep street canyon and joined houses with courtyard. Afterwards, the narrow streets and courtyard facades provide consequently mutual shading to the outside and the inside environments in the hottest days. Theoretically, the south is the best orientation for buildings. Figure (V-9a) and (V-9b) show similarly that wide streets in site2 have more radiation than narrow ones in site1 during the coldest day. Besides, courtyard area in site 1 has a poor sunlight in this specific date. The amount of solar absorption is mainly depended on the residential building layouts and south windows. Consequently, we calculate the horizontal incident solar radiation intensity to identify the impact of urban morphology on the occupants comfort during the winter period. That’s why we select southern façade of the patio for house B and southern-east façade for house E as displayed respectively in figure (V-10b) and (V-10a). According to the last figures, the cumulative direct solar radiation of vertical surfaces is almost 1680Wh and 202Wh for the southern-east exterior façade of house E and southern façade of courtyard of house B. Then, the solar exposure on site B results has poor solar heat gain energy on December 17th. Therefore, we can deduce that the thermal quality of external ambience in Medina is uncomfortable during winter seasons.

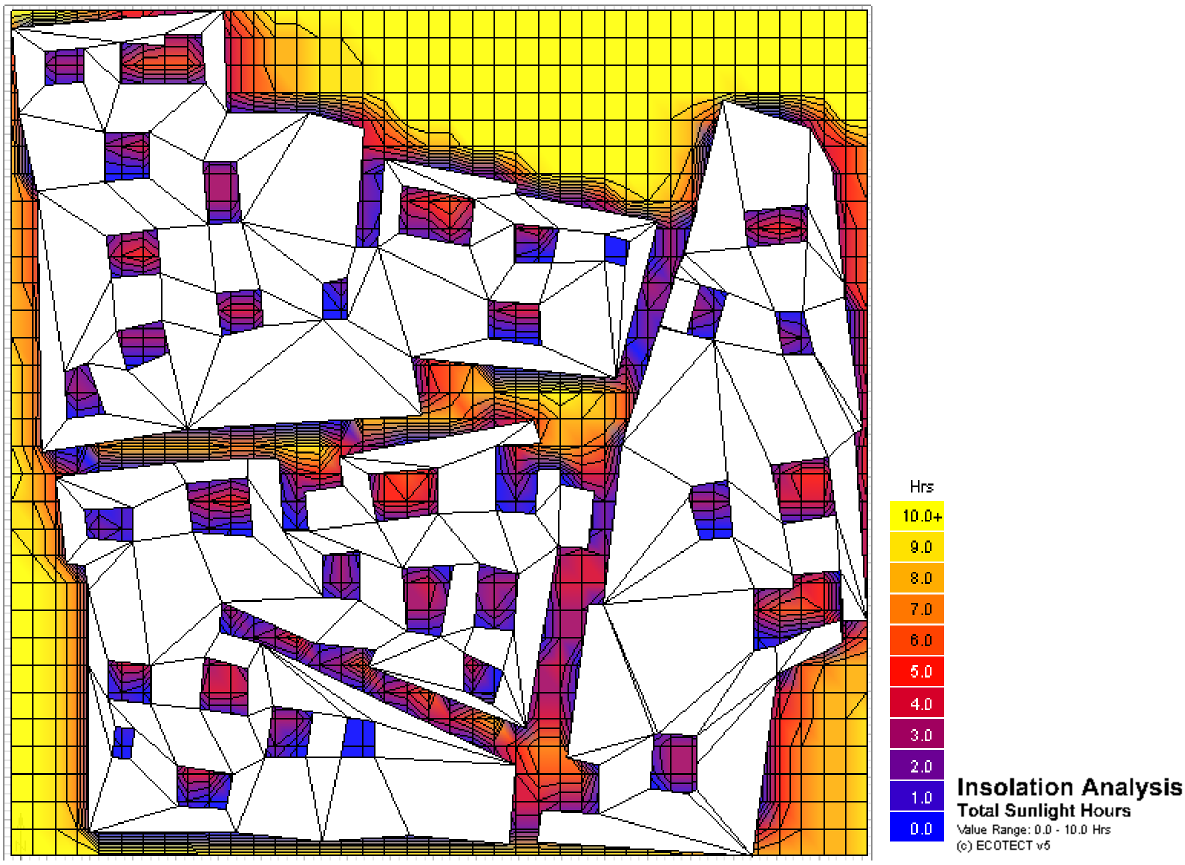


(a)

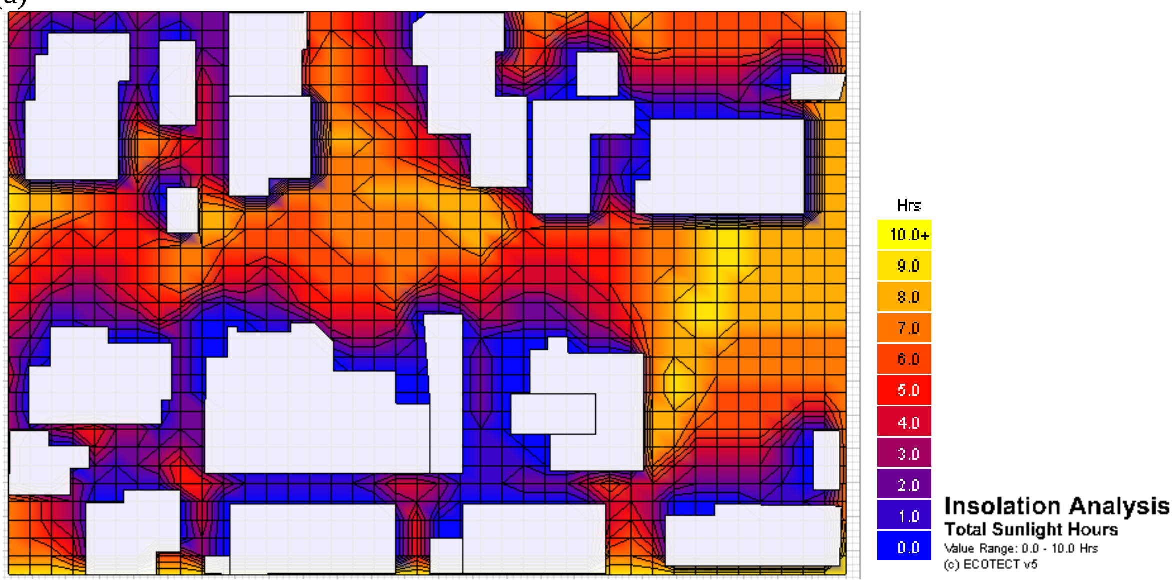


(b)

Figure V-8 Cumulative insolation relative to the total sunlight hours of direct radiations in the hottest day, on July 17th for the ancient study site (a) and for new study site (b)

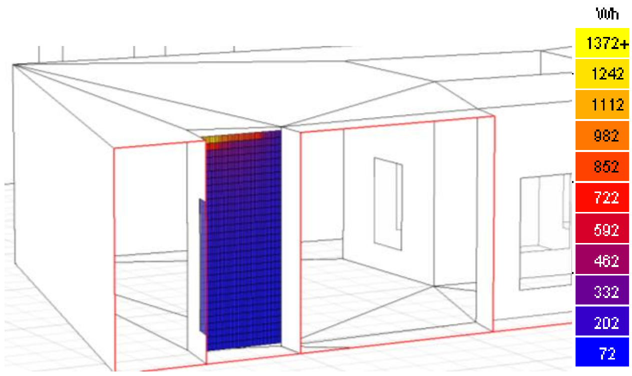


(a)

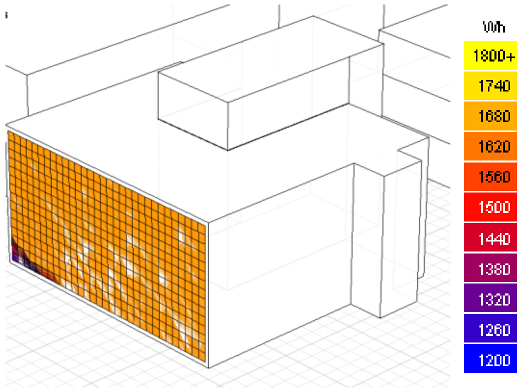


(b)

Figure V-9 Cumulative insolation relative to the total sunlight hours of direct radiations in the coldest day, on December 17th for the ancient study site (a) and for the new study site (b)



(a)- South façade of the courtyard in house B



(b)- South-east façade of house E

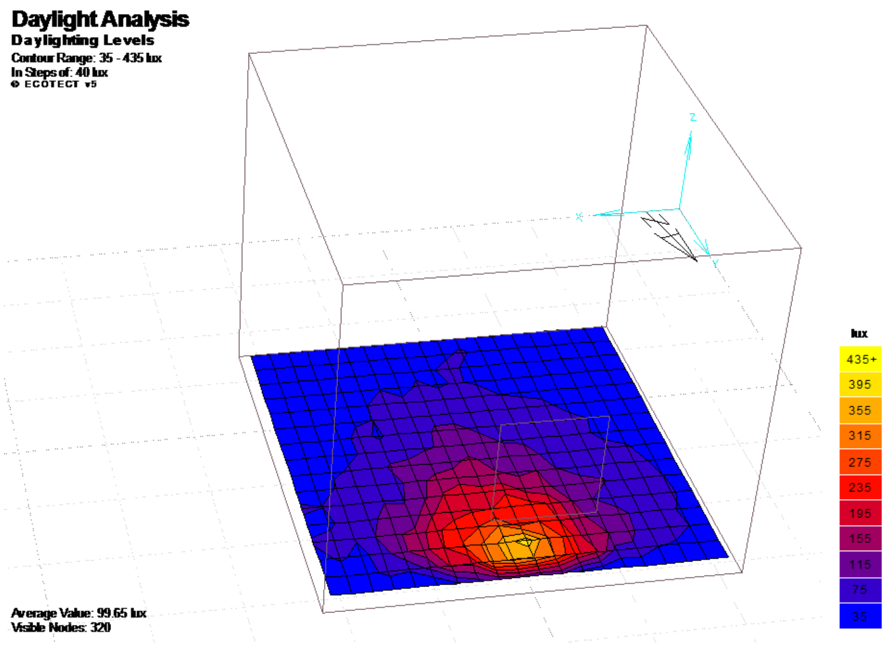
Figure V-10 Cumulative direct solar radiation in the coldest day on December, 17th for (a) and (b) models.

V.2.7.2 Natural lighting analysis

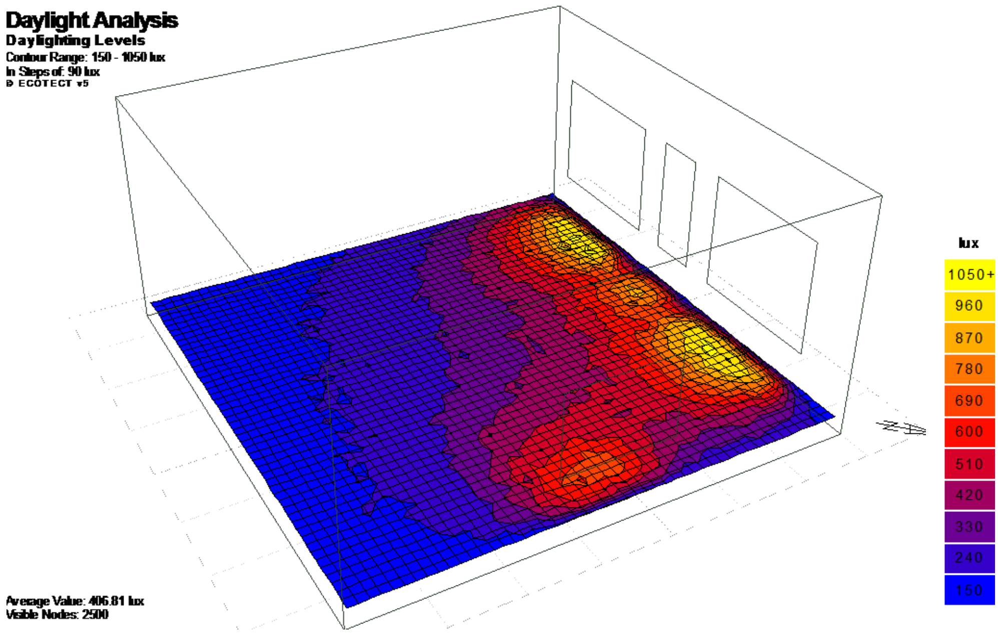
Passive solar heating is considered as beneficial passive design strategy for the local climate. In this work, this strategy is the second level of passive design techniques of Sousse climate. According to the literature review [11], the increasing percentage of the glazing allows a direct entrance of solar radiation. As a result, it decreases the energy consumption in winter period. Therefore, we will base firstly on calculating daylight factors in house B and E. Then, we will rely on calculating the daylight levels of the selected houses B and E.

V.2.7.2.1 Daylight levels

Actually, the direct solar radiations are enhanced thanks to the increase of the glazing percentage. The radiations, indeed, interfere into the inside space through windows. In this part, we proceed to evaluate the ratio windows of living area which allow useful solar heat gain energy at the coldest day in houses B and E. For more investigation, we select the original house B; otherwise, we don't take into account of shading device for house E. In fact, we choose this way to identify the contribution of windows on daylight levels. According to ECOTECT, our location sky illumination is 7500lux. The below figures (V-12a) and (V-12b) display daylight levels for living area of house B and E. these figures show that average value of daylight is 99.65 lux and 406.81 lux respectively for living area in house B and E.



(a) living area in house B

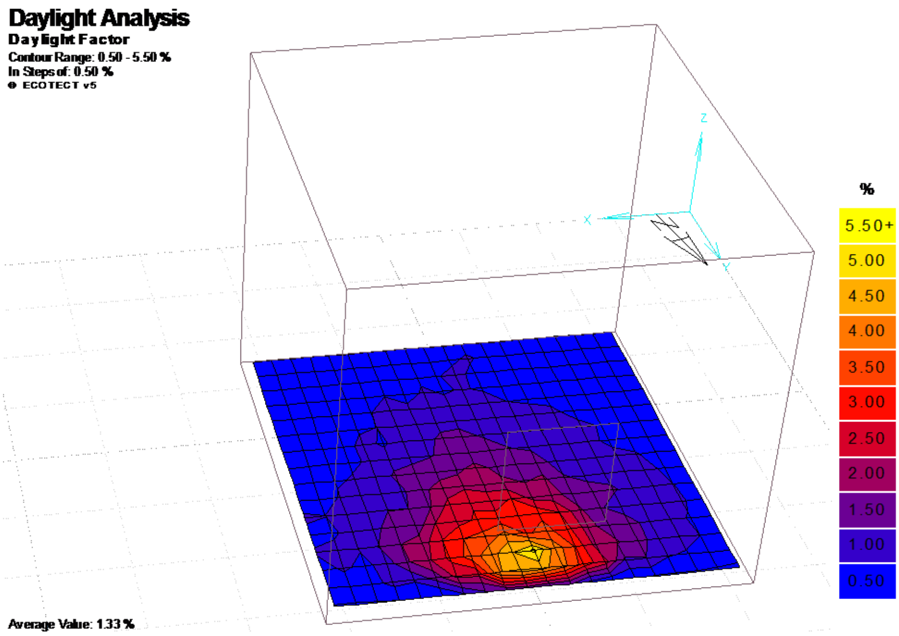


(b) living area in house E

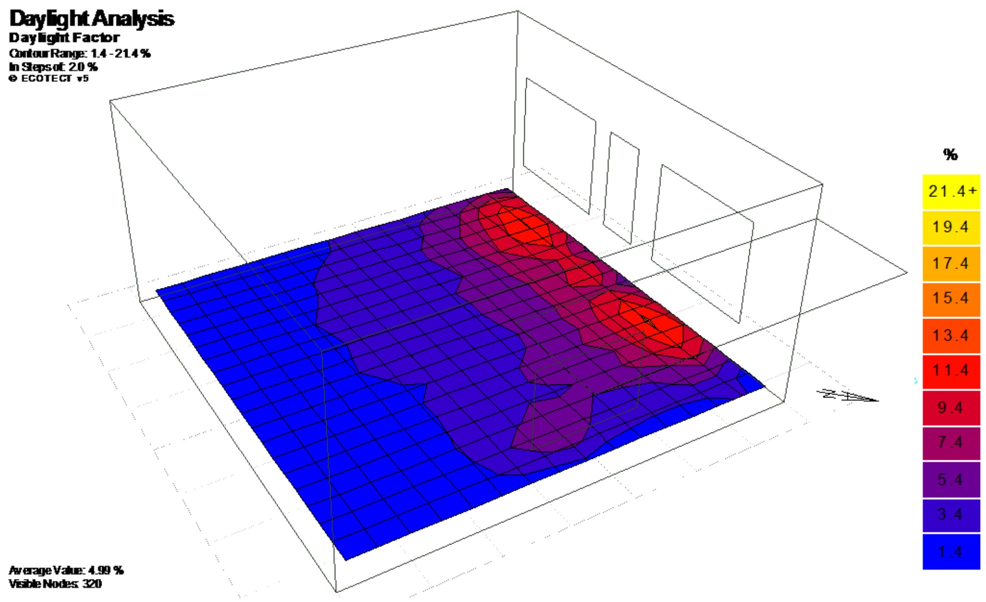
Figure V-11 Distribution of daylight level on December 17th at 14:00 am in the living area of the houses B and E which are respectively called by (a) and (b) of the sky illumination is 7500lux.

V.2.7.2.2 Daylight factors

As far as the calculation of daylight factors is concerned, ECOTECT takes into account the following features: sky illumination design, internal and external solar components and glazing percentage for each area. In this part, we will focus on assessing daylight factors of original houses B and E. Hence, simulation results show that the average of daylight factors are 1.33% and 4.99% where the first value corresponds to daylight factor of northern window of living area in house B. As well as, the second value determines the daylight factor of northern-east and southern-east of windows of living area in house E. Although the living area in house E has a shading device which is the south-east façade it remains lighter than living area in house B. Therefore, windows ratio of living area in E is more efficient than in house B.



(a)

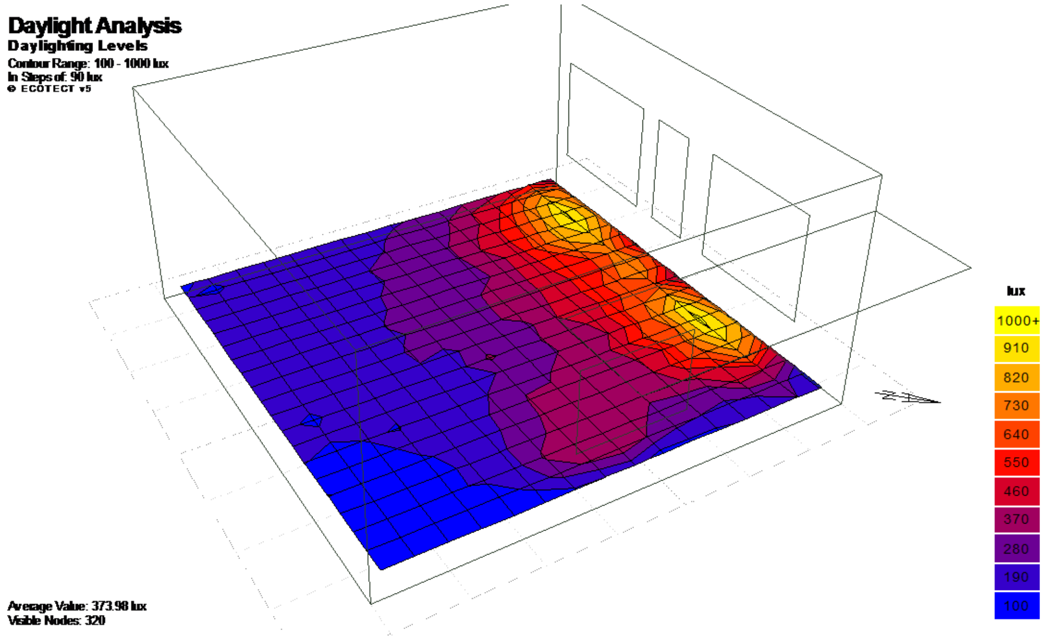


(b)

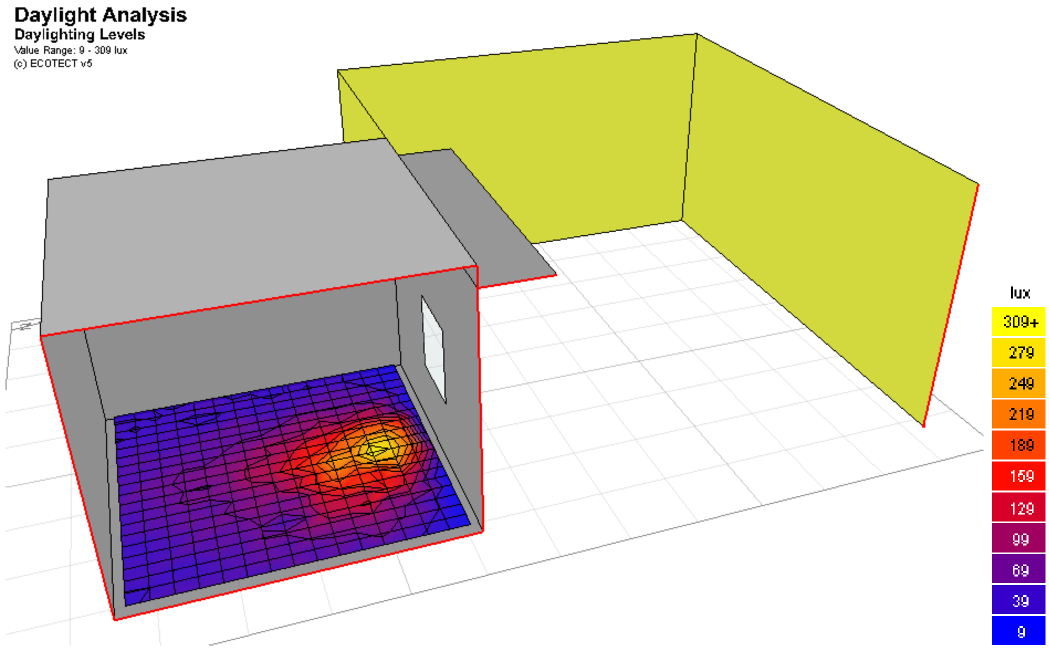
Figure V-12 Distribution of daylight factors on December 17th in living area of the houses B and E which are respectively called by (a) and (b)

V.2.7.2.3 Device shading:

In summer, the shading system should be used to stave off the penetration of much solar radiation into the inside. House B and E use north and south-east shading device. Hence, the shading system represents a passive cooling strategy. This part aims at evaluating the application of this strategy in houses B and A. The figures (V-13) and (V-14) display the impact of this strategy on indoor and outdoor environments of house B and E. Figures (V-13a) and (V-13b) show also that the shading device of living area reduce the daylight levels in house E better than house B on July 17th at 14:30. However, in house B shading system is badly orientated. Figure (V-14) analyses the interaction of shading device of living area with its surrounding on July 17th at 12:00 am of houses B and E. the obtained results show that the device system in house B with courtyard walls produce more shade than the shading device in house E. In house B, the patio atmosphere has a better thermal quality than indoor ambience because it creates a benevolent microclimate in summer period. The traditional house B interacts with its urban surrounding to adapt to its local climate.

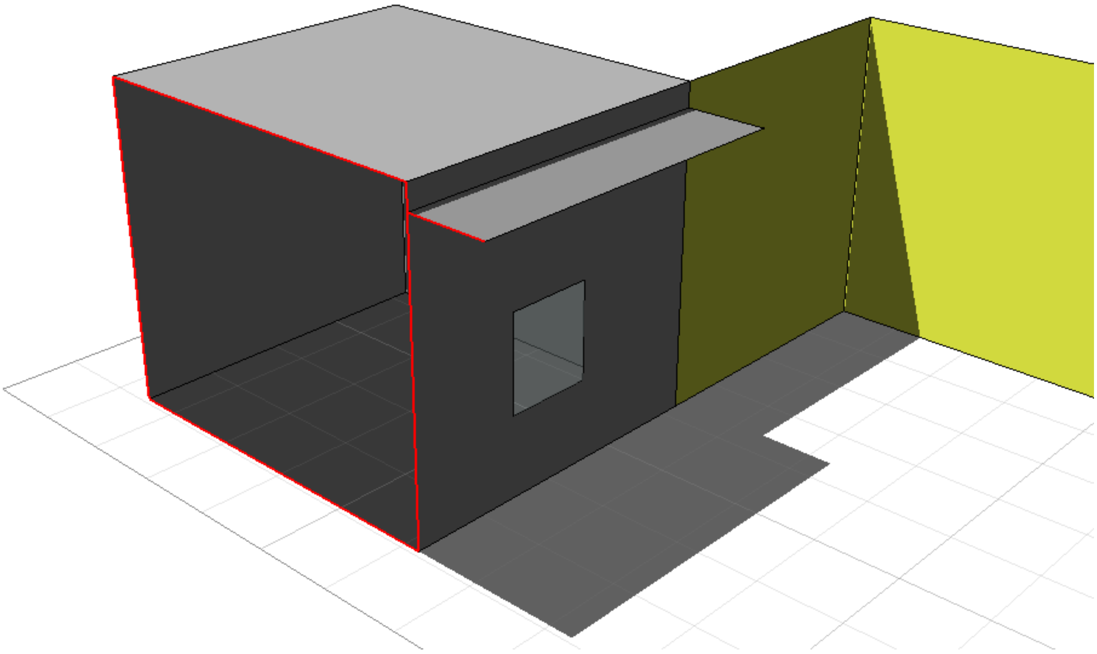


(a) living area in house E

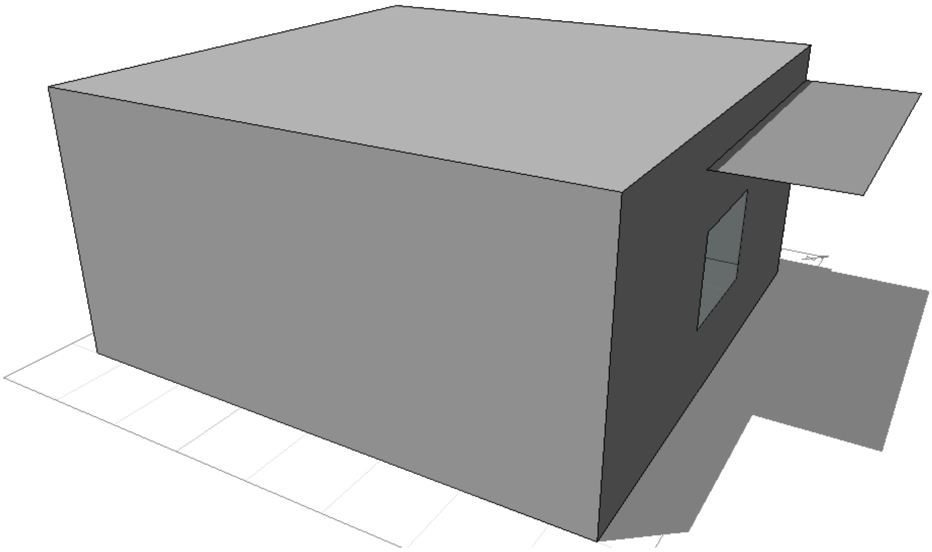


(b) living area in house B

Figure V-13 Distribution of daylight level on July 17th at 14:30 of living area of the houses E and B which are respectively mentioned above by (a) and (b)



(a) living area in house B

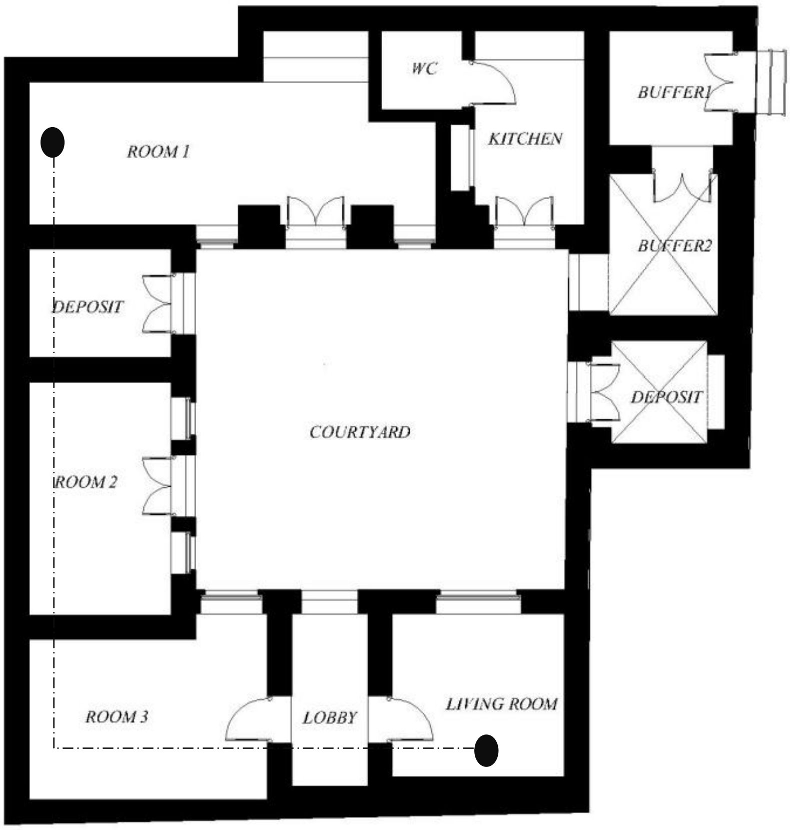


(b) living area in house E

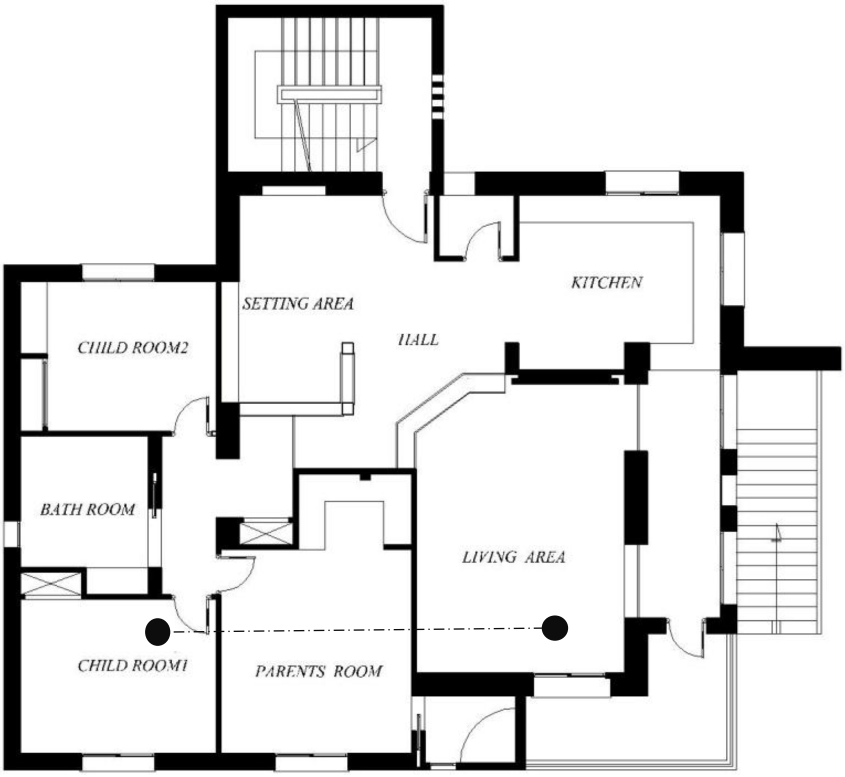
Figure V-14 Analysis of interactive shadow using ECOTECT on July 17th at 12:00 am of living area of houses B and E which are respectively called above by (a) and (b)

V.2.7.3 Field survey

In our master research, we equipped the study models B and E by a Thermo and Hydro—buttons. These instruments are respectively equal to 0.1°C and 1% of humidity. That's why we have already proposed to rely on the obtained measures in order to evaluate the indoor thermal comfort of these houses. The owners of house B have changed the slabs of the living room and the bedrooms. The buffer spaces are built with groin vault, we assume that the other slabs of the contemporary as well as the traditional models are similar and have the same thermal proprieties. Consequently, their differences are at the level of the urban morphology, the shape and the vertical partitions. For the field survey, we use Thermo-button and Hydro-buttons as displayed in figure (V-15a) and (V-15b). In 2010, Hydro-buttons are set in room n°1 to record the indoor temperature and the relative humidity in house B and E from March 19th, 2010 to April 04th, 2010 and from May 28th to June 09th. Although the Thermo-buttons are located in living areas of house B and E to record the hourly indoor temperatures from March 19th to April 04th. The average air temperature and the relative humidity during the survey periods are shown in the following figures to compare the indoor thermal comfort of original houses B and E. Figure (V-16) shows that the average of the indoor air temperature of room n°1 in house E is fluctuating, although it is a conditioned space. However, room n°1 in house B produces much indoor comfort than room n°1 in house E alternating periods from March 27th to March 30th and March 31st to April 2nd. While figure (V-17) shows that the percentage of relative humidity is fluctuating in the unconditioned houses B and E, figure (V-18) exhibits that room1 in the control site B provides much interior comfort than room 1 in house E along the unconditioned periods. According to the last figure, the greatest temperature range between two spaces in control houses is occurred at June 05th. Figure (V-19) displays the hourly interior average temperature along 24 hours of unconditioned room's in house B and E models at the last specific date. Actually, the obtained results show that the interior temperature of room1 in B model at 2pm is very close to the indoor temperature of room1 in E model. However, figure (V-20) clearly reveals that the indoor average temperature of the living rooms of B and E is fluctuating from March 19th to April 14th. It is simply because of its north orientation. Subsequently, we can assume that model B provides much comfort than E model especially during the hot period.



(a)


SETTING AREA
KITCHEN
HALL
CHILD ROOM2
BATH ROOM
LIVING AREA
CHILD ROOM1
PARENTS ROOM

(b)

Figure V-15 Thermo-button and Hydro-button localization in control site 1 and 2 are exposed in figures (a) and (b).

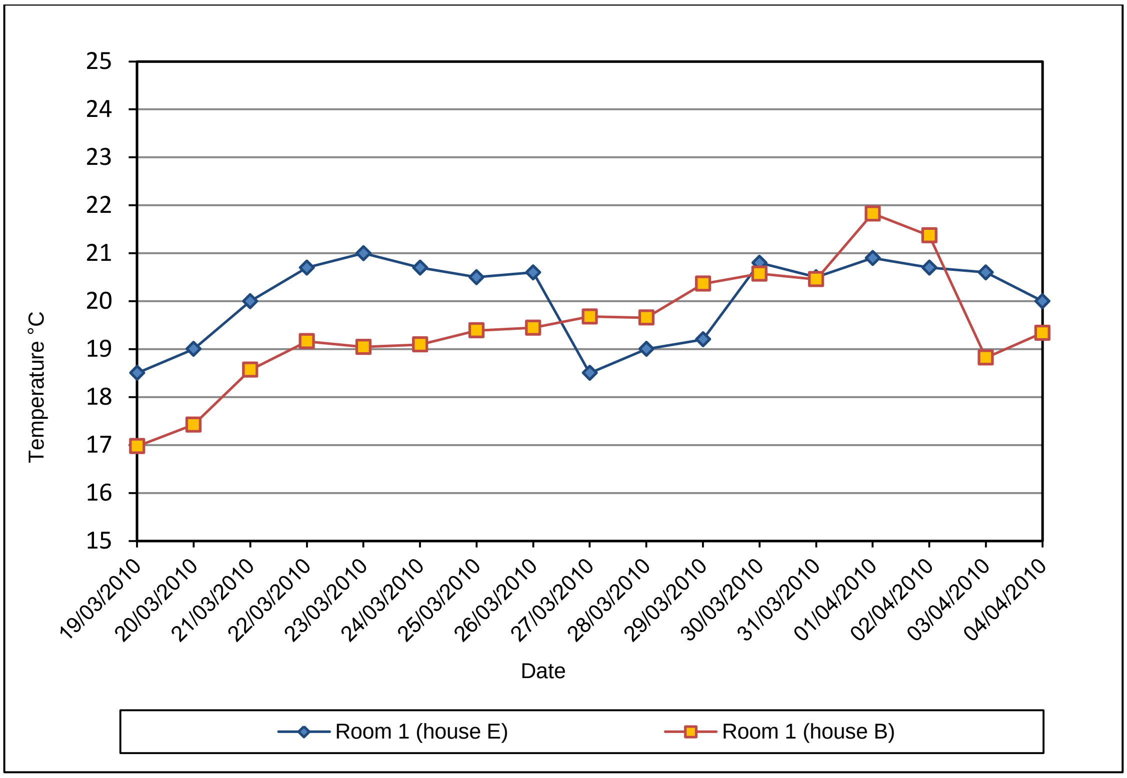


Figure V-16 Daily average of indoor air temperature at unconditioned room called 1 in house B and at conditioned room 1 in house E. These surveys are carried out from March 19th to 04th April.

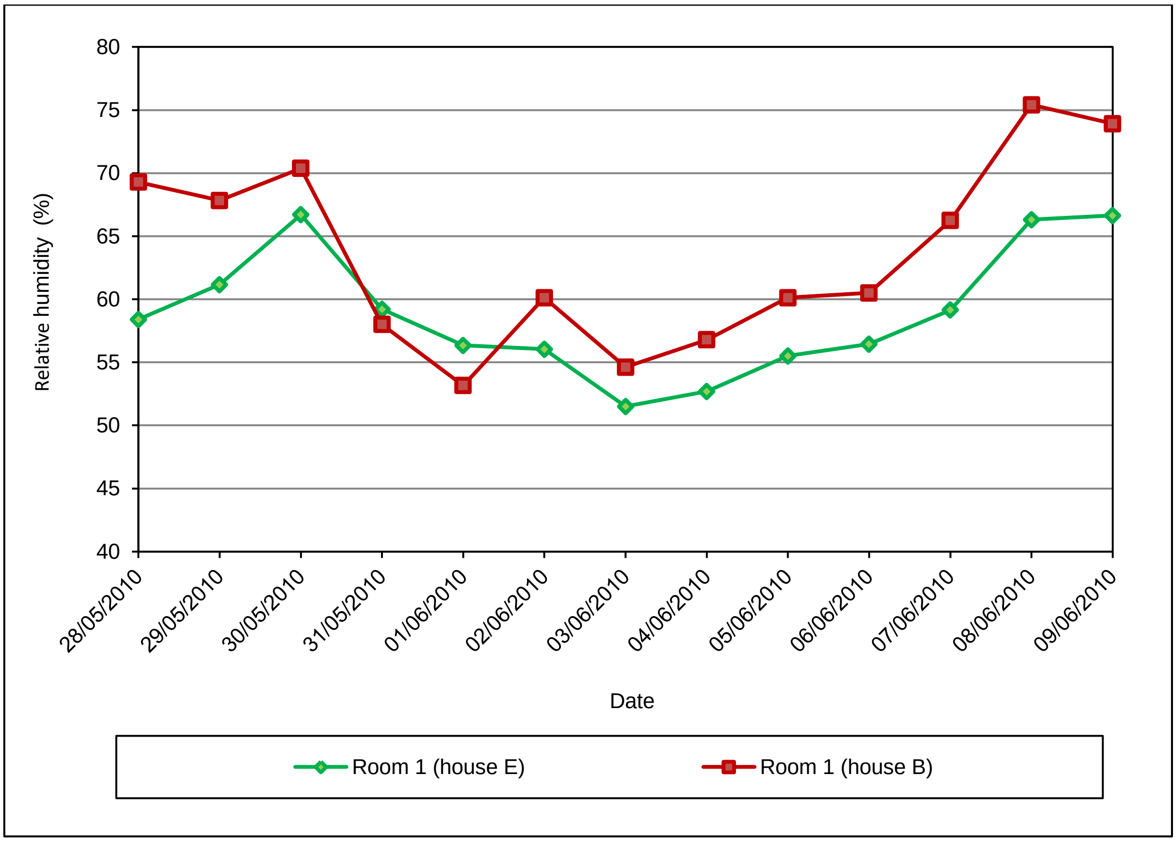


Figure V-17 Daily average of indoor relative humidity at unconditioned rooms 1 in house B and E carried out from May 28th to June 09th.

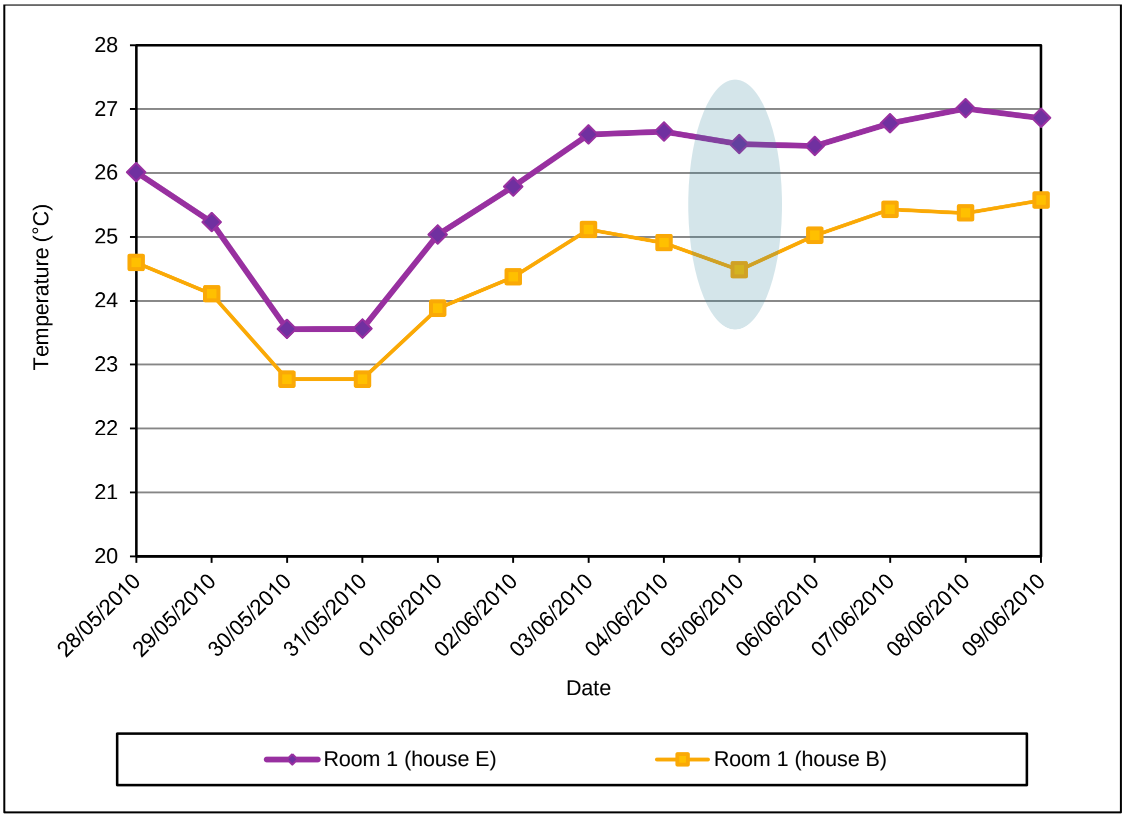


Figure V-18 Daily average of indoor temperature at unconditioned rooms 1 in house B and E performed from May 28th to June 09th.

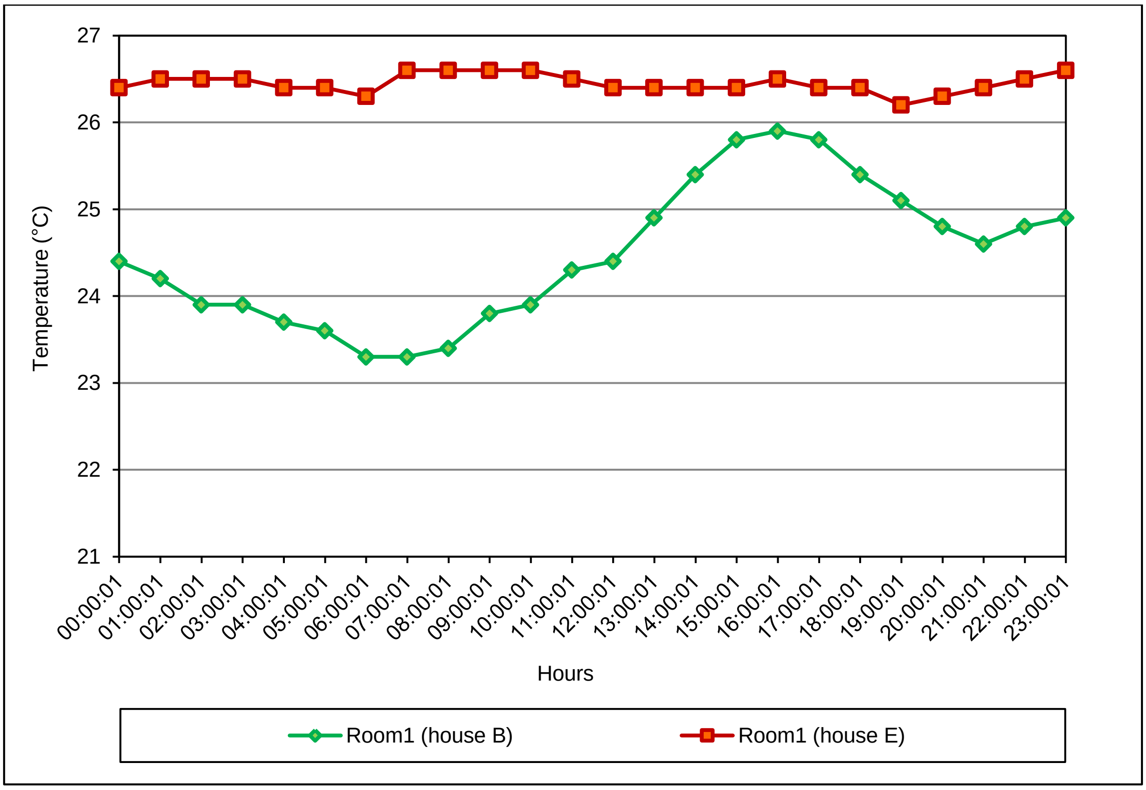


Figure V-19 Hourly average of indoor temperature for 24 hours at unconditioned room 1 in house B and at conditioned room 1 in E carried out on June 05th.

Figure V-20 Daily average of indoor temperature of living area called 1 in unconditioned house B and at conditioned living area called 1 in house E. These surveys are carried out from March 19th to April 04th.

V.2.7.4 Thermal comfort condition

This part is to evaluate the indoor thermal comfort which is based on the Predicted Mean Vote index (PMV) and Predicted Percentage of Dissatisfied persons (PPD). Our assessment is carried out in room1 of each model B and E. As seen in literature review, Fanger (1982) [12] gives incorrect prediction of indoor thermal comfort of the building with natural ventilation and during warm climate. Then, in 2002 Fanger and Toftum [60] estimated an Expectancy Factor (ef). This factor is equal to 1 of air-conditioned buildings and varies from 0.5 to 1 for unconditioned buildings as displayed in the below table (V-17). Our evaluation is normally carried out from May 28th to June 09th in rooms1 for unconditioned houses B and E. Subsequently, we choose the value 0.7 as moderate '**ef**' factor to correct PMV index for Sousse region as exposed in table (V-17). Otherwise, some assumptions are needed to predict thermal sensation of our chosen houses in a specific period. Some of these assumptions however are used by Ouertani [11] in part (III-2-21). Furthermore, we assign 1.65clo insulation clothing from May 28th to May 31st which corresponds respectively to 0.8 clo at day and 2.5 clo at night. We select 1.4 clo insulation clothing from 01 June to 09 June which corresponds to 0.8 clo at day and 2clo at night as well.

In addition, we assume that the metabolic activities provide 0.95clo per person. While the results correspond equally to 1.2met for a relaxed and seated person during the day, it corresponds to 0.7met for a sleeping person at night. According to Dubois, the necessary physical surface for a standard person of 1.7hight and 70kg weight is 1.8m². Indeed, we assume as well as that the mean radiant temperature is equal to the air temperature but the air speed is equal to 0.1m/s the chosen models. For the calculation, we set temperatures and humidity extracted from the field survey [36] in Thermal comfort tool as CBE Tool to generate PMV index and PPD estimations. Hence, the calculation method of CBE Tool is a non-commercial tool, and created by Built Environment Center at University of California

Berkeley. It is complies with ASHRAE Standard 55-2013. We assume as well as that CBE Tool is not accurate to predict a thermal sensation for a non-conditioned building. The achieved results are clearly explained in figures (V-21) and (V-22). But, we consider that the expectancy factor is 0.7 to correct the PMV index only for the first figure. According to the literature review, a psychophysics scale of PMV votes in table (I-1). Fanger [20] exposes efficiently that the comfort sensation range is located between -1, 0 and +1 of PMV index. Figure (V-20) shows that the thermal sensations at rooms1 are located in neutral comfort range. However, figure (V-21) explains that the majority of people in room1 of house B are more satisfied than those in room1 of E model.

Table V-17 Expectancy factors (ef) for non-air conditioned buildings in warm climates. (Source: Fanger 2002[[58]]).

Expectation	Classification of buildings	Expectancy factor (ef)
High	Non-air-conditioned buildings located in regions where air-conditioned buildings are common. Warm periods occur briefly during the summer season.	0.9-1.0
Moderate	Non-air-conditioned buildings located in regions with some air-conditioned buildings. Summer is a warm season.	0.7-0.9
Low	Non-air-conditioned buildings located in regions with few air-conditioned buildings. Warm weather during all seasons.	0.5-0.7

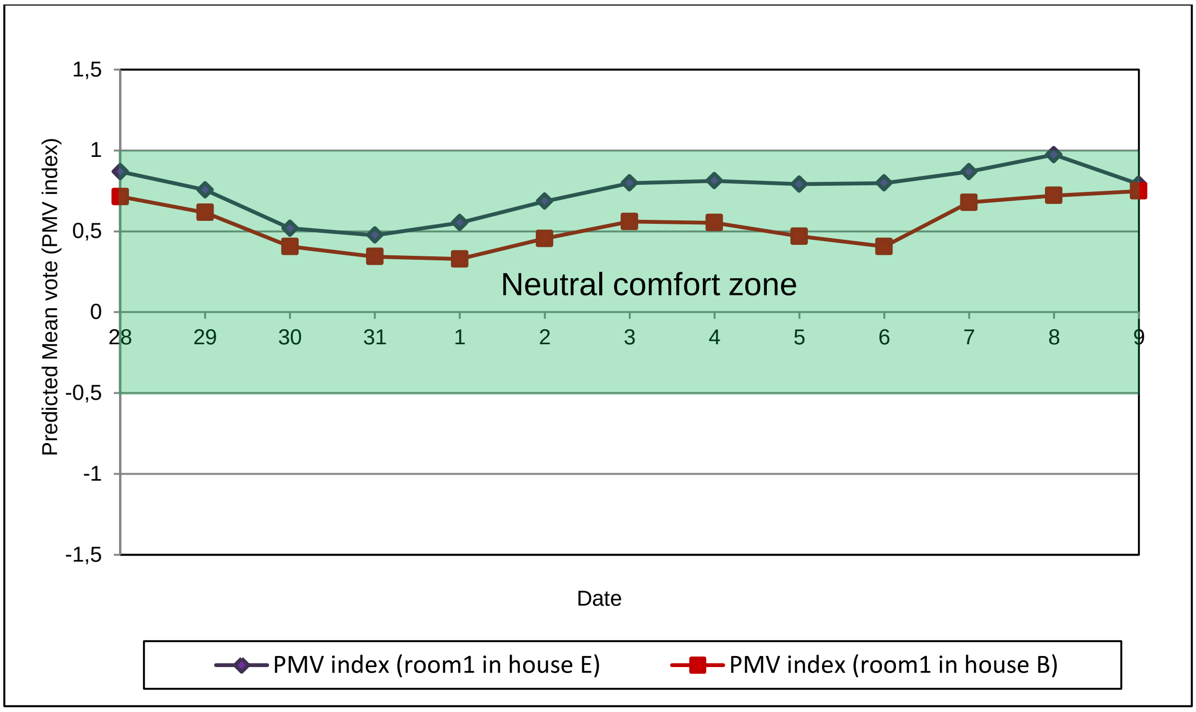


Figure V-21 Indoor thermal comfort comparison based on PMV index which is relative to room1 in house B and E from May 28th to June 09th.

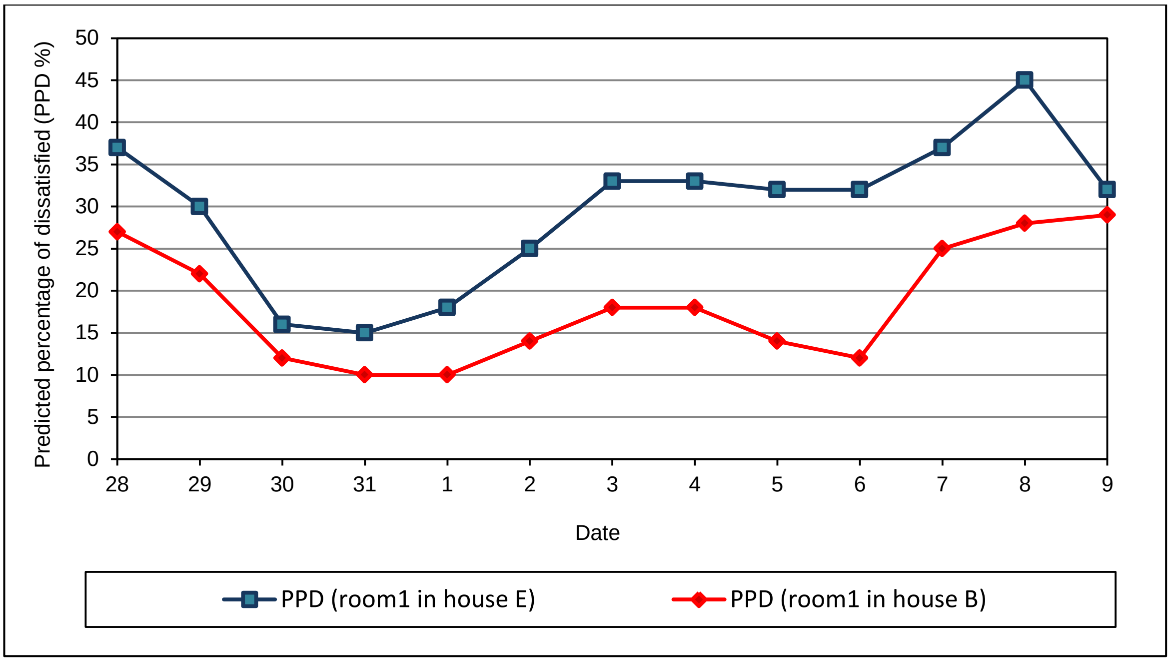


Figure V-22 Indoor thermal comfort comparison of room1 in houses B and E which are based on PPD percentage from May 28th to June 09th.

V.2.7.5 Heating and cooling load calculation

V.2.7.5.1 Assumptions for evaluation

In traditional house, the occupants use only the natural ventilation in cooling period. However, in heating period, they use ecologic heating system. In the last period, occupants have a special behavior because they heat space that will be used during the evening. Thus, all family members will come together in the same space. This behavior is related to traditional house morphology and the Arab-Islamic culture. For this reason, we assign two hypotheses which are related to occupant behavior in order to assess the thermal demand of a conditioned traditional house using REVIT. In the first hypothesis, we assume that traditional and contemporary houses have the same occupancy strategies in order to compare thermal efficiency of two reference models. Thus, we need to use a similar occupancy condition for the houses B and E and relying on the building operation and occupancy which are applied by Ouertani [11] as defined prior in chapter (III-2-2). It seems clearly that these strategies of occupancy and building management are the most widespread in Tunisian. As cited before, the traditional house is always unconditioned. However, we assume, in the first hypothesis, that the traditional house is conditioned to have an equitable comparison with the contemporary one so as to determine the required heating and air conditioning loads and the thermal performance of the two models. If simulation results, in this case, show that the heating and the cooling load in traditional house is less than contemporary house. Therefore, we can conclude that traditional house is more efficient than standard house. As a result, the traditional envelope needs less heating and cooling than contemporary one. If the last hypothesis is not valid we can conclude that thermal efficiency of traditional house is relied only on the occupant behavior.

Hence, we moved to the second assumption to assume that the conditioning strategies in traditional house are totally different from that in the contemporary. Thus, for the purpose of energetic modeling of the house E, we assign conditioned and unconditioned zones accordingly. Consequently, if the results of the first hypothesis are too satisfactory, they indicate that the envelope of house B is more efficient than that of E relying on REVIT.

V.2.7.5.2 Modeling of conditioned houses:

From here onwards, REVIT software will be our base for the geometric modeling, the creation of energetic models and the simulation of our chosen houses B and E which have respectively 166m² and 177m² areas. Modeling of selected houses B and E are analogous or similar to the standing house model used in last chapter III for validation with a few differences. Among, these differences, house B and E are located in Sousse city and use Water Loop Heat Pump as heating equipment. We take for granted 20°C and 30°C respectively for the set point temperature and supply air to calculate the heating load of the chosen B and E. In cooling period, we assign 26°C and 16°C respectively for set point temperature and supply air. We set 1.6 air flow change per hour for the two study models. Unlike, REVIT can't provide hourly and monthly cooling or heating load calculation; it is only used for extreme condition of heating and cooling. Therefore, for modeling, we consider overall zones are heated and cooled as displayed in figure (V-23) and (V-24) for modeling surface data of two houses B and E are as following. The openings areas are exposed clearly in table (V-10) and (V-11) and they have a medium infiltration class. The partitions composition of house E is displayed on details evidently in table (III-1). Although the vertical partitions of house B are characterized by high inertia with stone, the overall exterior and interior walls in house B have almost 80cm and 50cm thickness. Due to shortage data in 'Building Construction' interface from REVIT which correspond to construction materials of our study, we consider the following assumption for house B and E as exposed in below tables (V-18) and (V-19). Evaluation results show that the peak cooling and heating loads in house E are respectively 170 W/m² and 76.4 W/m² as displayed in table (V-20). However, the peak cooling and heating loads in house B are respectively 136.46W/m² and 82.12W/m². Hence, the traditional house B is more efficient than contemporary house E. We notice that the results are definitely satisfactory from the first hypothesis, Thereby; we repress ourselves only to this part to identify the thermal performance of house E and B. Hence, in next paragraph, we will apply enhancements only for the contemporary house E.

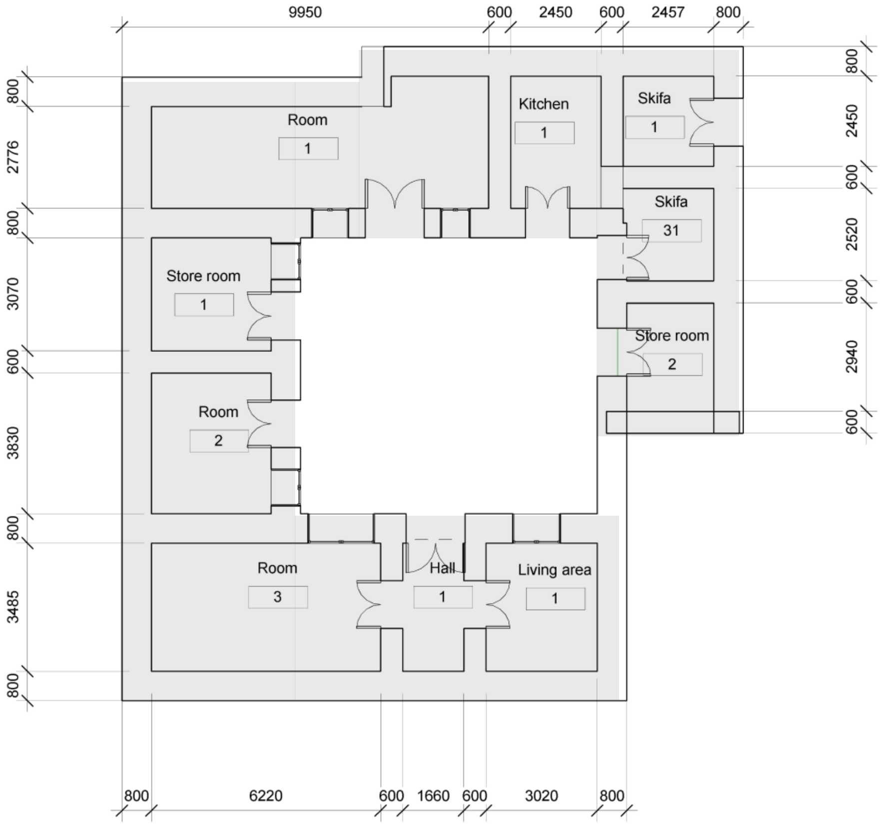


Figure V-23 Building model B for the simulation on heating and cooling load calculation using REVIT

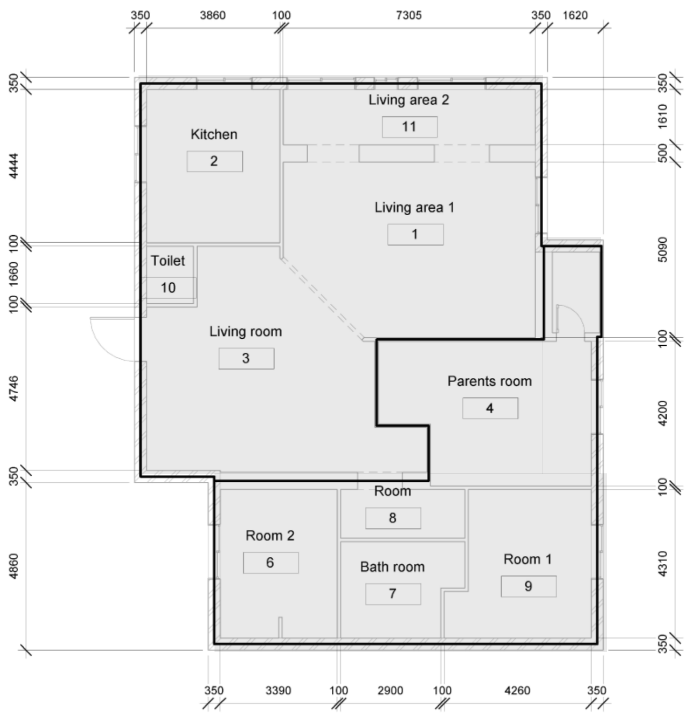


Figure V-24 Building model E for the simulation on heating and cooling load calculation using REVIT

Table V-18 Building construction properties which are input in REVIT interface relative to house E

Building components	Construction materials	Thermal properties U(W/m².K)
Roofs	Un-insulated flat roof	1.55
Exterior walls	4 in face brick 4 in lightweight concrete block and air space	1.23
Interior walls	8 common brick	1.853
Ceilings	8 in lightweight concrete	1.36
Floors	Carpet, underlay, screed, concrete, insulation, building board	0.28
Slabs	Standard slab construction	0.25
Doors	Solid core wood	2.61
Exterior windows	Uncoated single glazing, ¼ thick, gray glass, (SHGC=0.59)	5.90

Table V-19 Building construction properties which are input in REVIT interface relative to house B

Building components	Construction materials	Thermal properties U(W/m².K)
Roofs	Un-insulated flat roof	1.55
Exterior walls	Stone, insulation, plasterboard	0.65
Interior walls	Solid partition	1.16
Ceilings	8 in lightweight concrete ceiling	1.36
Floors	Carpet, underlay, screed, concrete, insulation, building board	0.28
Slabs	Standard slab construction	0.25
Doors	Solid core wood, wood storm	1.64
Exterior windows	Uncoated single glazing, ¼ thick, clear glass, (SHGC=0.81)	5.90

Table V-20 Peak Heating and cooling total load for house B and E expressed on W/m²

Study houses	Cooling	Heating (use load credits)	Heating (without load credits)
House B	136.46	73	82.12
House E	170	69.39	76.4

V.3 Optimization

The passives design solutions exposed in the literature review and in traditional Tunisian houses (A, B and C) according to figure (V-12) and (V-13) will be used in this paragraph to assess the REVIT efficiency and to enhance the thermal quality of house E.

V.3.1 Introduction

The investigation results of the qualitative and quantitative evaluation show that bioclimatic passive design strategies of local climate are applied in the traditional house as orientation, passive cooling using whitewash, shaped courtyard, buffer space, cross, single side and double ventilation, the direction of the prevailing wind and the exposed mass combined with night purge ventilation. Our main intention is to reduce energy use in house E. Therefore, we will assess the contribution of bioclimatic passive design presented in traditional Tunisian house review (table V-15) and literature review (table V-12). We emphasize that REVIT is limited by the thermal simulation.

V.3.2 REVIT efficiency

In this work, we carried out so many simulation tests to identify REVIT efficiency using Heating and Cooling tool. Investigations results are exposed in the below table (V-21) which summarizes the thermal simulation of traditional and contemporary houses. The strategies used in the table (V-12) are taken from table (V-12) and (V-15) which represent respectively the passives design strategies found in our literature review and in traditional houses in Sousse city. We will assign 'Yes' vote which corresponds that the mentioned strategy can be used by REVIT for the thermal simulation. Besides that we set 'No' vote if REVIT not take account of the designed strategy for the thermal simulation. According to the table (V-21), we emphasize that REVIT is limited to the thermal simulation because of it can't take into account the following:

- Physics parameters of envelope.
- Free running houses characterized by unconditioned zones and natural ventilation (in this case REVIT don't work and dialogue box displayed errors for simulation).
- Passive strategy of cooling as well as natural ventilation.
- Create energetic model of 'Trombe wall' device.
- Types of natural ventilation (single side double ventilation, cross ventilation).
- Oriented to prevailing wind.
- Passive cooling using color.

Table V-21 REVIT efficiency for thermal simulation based on the investigation results found in this work

Condition type of the building	**Building type**	**Condition used by REVIT**	**Physics parameters of envelope**	**Observation**
Conditioned	Contemporary house	Yes	Roof, walls, window frame	Missing data[a]
Unconditioned (free running)	Vernacular house	No	Roof, walls, window frame	No[b]
REVIT calculation	**Load type**	**Condition used by REVIT**	**Without a credit of loads**	
Heating load	Peak	Yes	Yes	
Cooling load	Peak	No	Not available	
Bioclimatic design solutions in Sousse climate	**Strategies used in traditional house**	**Strategy used by REVIT**	**Strategies used in literature review**	**Strategies used by REVIT**
Thermal mass	Orientation bedrooms to south	Yes	Trombe wall	Not effective
	Orientation living room to south	No	Orientation living room to south	Yes
	Construction	Yes	Slab inertia	Yes

	materials			
	Passive cooling using color	Not effective	Roof and wall insulation	Yes
Passive solar heating	Shape with courtyard	Yes	Device shading system	Yes
	Natural lighting (glazing percentage)	Yes	Skylight system	Yes
Natural ventilation	Buffer space	Yes	Buffer space	Yes
	Cross ventilation	Not effective	Ventilation flow rate variation	Yes
	Single side double ventilation	Not effective	-	-
	Orientation to prevailing winds	Not effective	-	-
Exposed mass + purge ventilation	Inertia+ ventilation + orientation	Yes	-	-

(a): The data are not available in ‘Energy and Setting’ interface of REVIT.
(b): It means that REVIT does not work within this condition for a thermal simulation.
Not effective: It means that REVIT is not efficient, and does not take into account the chosen strategy for load calculation.
Yes: REVIT is able to take into consideration the selected strategy for load calculation.

V.3.2.1.1 Improvement measurements correspond to passive design techniques applied in vernacular house

We noticed from the precedent paragraph (V-2-7-5-2) that the traditional house is more efficient than the contemporary house. Subsequently, we will apply the improvement measures found in traditional houses (A, B, and C) in order to improve the thermal quality of model E.

Hence, the improvement measurements applied in vernacular house will be implemented in the contemporary house. However, these measurements are limited to improvement parameters which are exposed in table (V-21). According to literature review [27] the equation (I-2) related to energy saving percentage represents the difference between the original and modified houses for overall energy saving period where ΔE is equal to the overall energy saving (%). Besides, E term represents a sum of energy consumption in heating and cooling periods. We will derive two terms as: $\Delta \boldsymbol{E}$ **heating** and $\Delta \boldsymbol{E}$ ***cooling*** which represent respectively energy saving percentage in heating period and energy saving percentage in cooling period. On the one hand, we will refer to this equation in our optimization study which investigated the initial model E without any improvement of its thermal quality, represented by (V0). On the other hand, it represents the enhanced model E using the local bioclimatic improvement measures taken from the traditional Coastal architecture (table (V-21)). Using these strategies, the optimized variants are represented by (V1, V2, V3 and V4) which are respectively south-west oriented window, wall with high inertia, courtyard shaped, high Inertia combined with natural ventilation and south oriented window.

$$\Delta \boldsymbol{E}\% = \frac{\left[\boldsymbol{E}_{(original\,building)} - \boldsymbol{E}_{(modified\,building)}\right] \times \mathbf{100}}{\boldsymbol{E}_{(original\,building)}} \quad \textbf{(39)}$$

House E has two south-east oriented bedrooms which are room1 and parents room. The variants 1 are made up to shift the west window to a better south orientation. Variants 4 represents exposed mass with purge ventilation as shown in above table (V-22). For this reason, we take into account V1+V2+V11. The last variant (V11) represents the increase of ventilation flow rate which in turn needs 2.5 air flow change per hour. The obtained results take into account credit load are exposed in the following table.

Table V-22 Thermal improvement results of house E taking into account the bioclimatic design solutions applied in vernacular house

N° variants	Improvement measurements	**Peak cooling load (W)**	**Energy saving in cooling period (%)**	**Peak heating load (W)**	**Energy saving in heating period (%)**
V1	Orientation (move west window to south)	167.86	1%	69.42	NS
V2	Construction materials (wall with high inertia)	164.53	3%	61.56	11%
V3	Shape with courtyard	NS	-	NS	-
V4	Inertia+ ventilation + orientation	N	-	N	-
V1+V2	Orientation + wall high inertia	162.42	5%	61.56	11%
NS: results are not satisfactory because of using REVIT this strategy does not contribute to energy saving. N: We can't apply this strategy because of ventilation. According REVIT does not contribute to passive cooling; it is considered as heat losses.					

Table (V-22) shows the combination of variants 1 and 2 provide the biggest energy saving in heating and cooling periods. We notice that V3 is not totally satisfactory due to the continuous heat losses which are proportional to the increase of exterior surface of the envelope. We can't calculate variant4 (V4) because the natural ventilation strategy, according to REVIT does not contribute to passive cooling. It is considered also as heat losses. Whereas the natural ventilation is beneficial in free running buildings.

V.3.2.1.2 Improvement measurements based on literature review

In this part, we suggest to improve the model $\boldsymbol{E}_{(modified\,building)}$ by bioclimatic improvement measures of design found in our literature (table (V-4)). However, the optimization results are represented by (V5, V5+2, V6, V7, V6+V7, V8, V9, V10, V11 and V12).

The below table (V-23) shows that the improvement measurements used in a vernacular dwelling does not provide a wide energy saving. Among of the used improvement measurements in the literature review, is skylight system. Hence, this system is represented by Variant10 (V10). For this device, we assign a simple transparent (clear) glazing, ¼ inch thickness and clear glass (U=5.9050 W/m²·K, SHGC=0.81).

Table V-23 Improvement measurements results based on literature review for house E

N° variants	Improvement measurements	**Peak cooling load (W)**	**Energy saving in cooling period (%)**	**Peak heating load (W)**	**Energy saving in heating period (%)**
V5	Slab inertia	126.15	26%	56	19%
V5+V2	Increase inertia (Slab + wall)	109.5	35%	48.7	30%
V6	Roof insulation	102.12	40%	47.27	32%
V7	Wall insulation	165.2	3%	63.93	8%
V6+V7	Roof and wall insulation	96.8	43%	41.8	40%
V8	Device shading system (louver)	170.06	NS	69.39	NS
V9	Device shading system (overhang 50cm)	164.53	3%	61.56	11%
V10	Skylight system	170	NS	69.39	NS
V11	Ventilation flow rate variation (2.5 air flow change per hour)	191.7	NS	81.39	NS
V12	Ventilation flow rate variation (2 air flow change per hour)	179.66	NS	74.72	NS

Besides, that Variants 5 (V5) represents increase slab inertia using 2 inch heavyweight concrete with 1 inch insulation (U=0.7632 W/(m²·K)). Furthermore, variants 6 (V6) corresponds to apply a Super-insulated flat roof such as U is equal to 0.1769 W/ (m²·K. Moreover, Variants 7 (V7) represents exterior wall with insulation Thus, the used material construction are brick, polystyrene insulation, light-weight concrete, dense plaster. In this case, the exterior wall has U=0.5700 W/(m²·K). For variants V8, we assign 0.8 shading factor which represent louvered shaded. According to ASHRAE Handbook the selected louver has 0.15 louver reflection with 45° tilt from outside glazing surface. The table (V-23) proves that roof and the wall insulation produce the largest amount of energy saving in cooling and heating periods. The below chart (V-25) summarizes the efficient improvement measurements in order to improve a thermal quality of contemporary house E in our study site. Hence, we are limited to variants which give a compromise in energy saving in cooling and heating periods. The obtained results, in this figure show that the improved variants which are based on literature review provide more energy saving percentage than the improved variants based on vernacular strategies in cooling and heating period. Moreover, this chart displays the improved variants in heating period which are based on vernacular strategies provide much energy saving than cooling period.

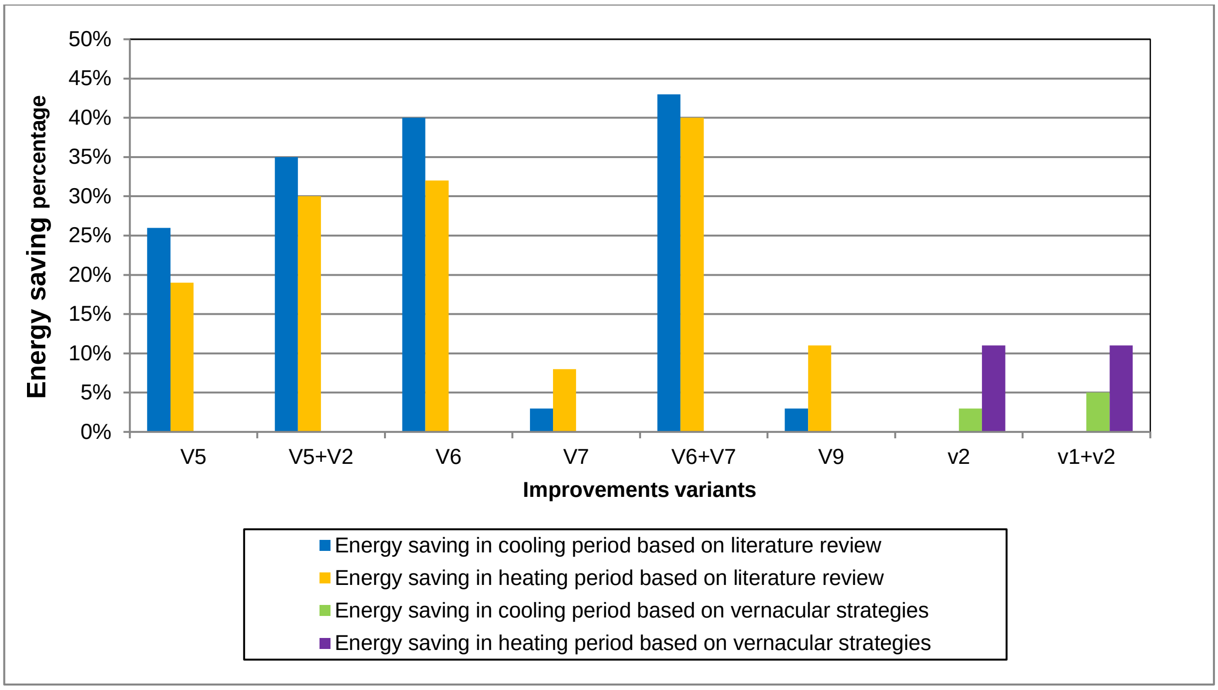


Figure V-25 Energy saving percentages of improvements variants in heating and cooling period and based on literature review and vernacular strategies

V.3.3 Conclusion

A qualitative and quantitative investigation concerning climate responsive of traditional and contemporary house models are carried out in this chapter. The achieved results are the following:

- Qualitative investigation based on image/comment show that traditional house is more efficient that contemporary house in heating and cooling period.
- Quantitative investigation of thermal quality efficiency relied on REVIT show that traditional house B is more efficient than contemporary house E in cooling period while, the last one contribute to less heating load in winter period.

  Besides, we perform improvement measurements of house E which are taken by literature review and passive design strategies of vernacular architecture. The realized results show as following:

The variants which are based on improvements measurements found in literature review as (V6+V7). They represent they combination of roof and wall insulation which allow the biggest energy saving for contemporary house in winter and summer seasons. They enable to save energy of 43% in summer season and 40% in winter period. Whereas, variant (V1+V2) which are based on improvements measurements given by vernacular local strategies. The variant represents a combination of orientation and wall high inertia; it enables to enhance 11% energy saving for contemporary house in winter and 3% in summer season.

V.4 General conclusion and perspectives

Actually, the challenge of this research is to improve the thermal quality of the new buildings and to put forward solutions in order to lessen the energy consumption of the urban landscape. Besides, it aims at enhancing a sustainable building with a low energy consumption taking into consideration our territory and architecture for our future generations. Hence, this work targets to reduce the heating and the cooling loads relying on passive design strategies. These last strategies depend, indeed, on the bioclimatic solutions of the local climate. In fact, we do refer in this study to determine REVIT efficiency for heating and cooling load calculation of residential building.

In the first chapter, a study leads to identify different improvement measures in the literature review as well as to clarify the simulation tools using BIM and non-BIM bases. Moreover, the calculation of the heating and the cooling loads relying on RTS and HB method has been already determined. Our work is, indeed, based on the BIM technology which depends on building sustainability. REVIT is clearly one of its tools, can provide a quick decision at a preliminary design phase. Clearly, SPREADSHEET ASHRAE and REVIT computers are based on the RTS method. However, the RTS method is widely explained in fundamentals Handbook of Ashrae for non-residential cooling and heating load calculations.

In third chapter, we actually propose to refer to RTS calculation method for the residential building. Consequently, we rely on the obtained results of the dynamic state for energy consumption of the conditioned standing house using TRNSYS software according to Ouertani. The simulation results of test 1 as well as test2 have exhibited that RTS, CTS and U coefficients had a major impact on the results of cooling load. Besides that, the achieved results show that relying on REVIT and SPREADSHEET ASHRAE, the thermal simulation results are very close to reference tool TRNSYS for both summer and winter periods. Hence, RTS method can be used and relying on REVIT and SPREADSHEET ASHRAE to determine the load of the residential building.

Thanks to chapter four, we have able to analyze the meteorological data of Sousse region using ECOTECT WEATHER tool. Hence, these obtained results reveal clearly that summer season is typically dry and hot whereas winter season is certainly mild and humid in Sousse region. However, within this part, we identify bioclimatic design strategies relative to local climate using comfort percentage chart based on bioclimatic design technique. Actually, the founded passive strategies are thermal mass, passive solar heating, natural ventilation and exposed mass with a night purge ventilation. These bioclimatic strategies have been used to investigate the sensitive climate of the traditional and contemporary houses in chapter five.

In the last chapter, the investigation study relies on a quantitative and qualitative evaluation of the responsive climate of the chosen houses of both sites1 and 2. The control sites 1 and 2 represent respectively the traditional houses in Medina and contemporary ones in the new city of Sousse region. The qualitative survey of the thermal quality using REVIT shows that traditional house B is more efficient than the contemporary house E during the summer season. However, during the winter season, this house requires a thermal quality improvement. In addition, the optimization of house E using the improvement measures in the literature review have shown that roof and wall insolation contribute deeply to the energy saving. The percentage of the energy saving reaches 35% during cooling period (summer) and

30% during heating period (winter). However, the optimization of house E using the bioclimatic strategies of the local design has revealed that the increase wall inertia and the change of window orientation participate to the economy of energy. Therefore, this percentage of energy saving is 5% and 11% respectively in the cooling and the heating periods. We have already noticed that the natural ventilation does not represent any passive cooling strategy for the thermal simulation using REVIT. This strategy is considered by REVIT as a load generated by a thermal loss.

In addition, the obtained results show that the traditional bioclimatic design strategies produce a light reduction of the heating and cooling load consumption compared to the other strategies found in the literature. Hence, the applied design parameters in traditional architecture are insufficient for improving the energy saving in the contemporary house. However, the bioclimatic design solutions utilized in vernacular house are more interesting as they are not expensive for the owner himself. Therefore, we recommend using the high inertia of walls combined with south windows and natural ventilation.

Our research work has a technical tendency; the economic and environmental aspects will be a future research study taking into consideration the REVIT interface.
The thermal comfort evaluation of the two models B and E was achieved using traditional investigation equipment neglecting the BIM environment.

Thereafter, we will intend to increase the optimization sample and make use of the interoperability between REVIT and ENERGYPLUS for the evaluation of the thermal comfort of our study models to deepen our research work.

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