SUSTAINABLE RENOVATION OF RESIDENTIAL BUILDINGS IN SUBTROPICAL CLIMATE ZONE

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APPROVAL SHEET

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Sustainable Renovation of Residential Building in Subtropical Climate Zone

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Abstract

Climate has a major impact on the thermal comfort and energy consumption in the buildings. Traditional buildings have been a good example of responding to the local climates, which were the results of centuries of materials construction techniques and climate considerations that achieved through a trial- and error process. In current buildings, some technologies and building materials used were inverted from western countries without careful consideration for the local climates in the region. In addition, most of the new building envelopes made of a thin layer of high thermal mass, such as cement block, which include no overhang or any shading devices, resulting in easy solar radiation penetration into inside the building. As a result, buildings were very hot without the assistance of an air-conditioner; this caused an excessive energy consumption of the built environment.

The building sector is known to be the largest energy consumer, based on the analysis of previous studies, the residential building is the first largest energy consumer. In Sulaimani governorate, the consequences of high energy consumption in residential sectors are becoming a major concern. According to the annual report of the Ministry of Electricity and Energy in Kurdistan Region of Iraq in 2014, the residential buildings consumed 70% of the total energy consumption. One of the best opportunities to improve the energy and thermal comfort performance in the existing buildings can be attained through the renovation of buildings in a sustainable manner. Thus, the main goal of sustainable renovation is improving the thermal comfort, increasing the indoor air quality, while minimizing the energy consumption .

The research to achieve its objectives tried to identify the residential buildings typology through field surveys based on their compositional and morphological properties analysis of the residential buildings in Sabunkaran district in Sulaimani city. In order to reduce energy consumption and improve indoor environment in the typical residential buildings, the study addressed the most appropriate passive and active strategies and tried to apply them, as traditional and contemporary techniques on the existing buildings during the optimization process. Furthermore, the dynamic simulation software IDA ICE 4.7.1 was used to assess the energy and thermal comfort performance, and Excel tool has been applied as a decision-making tool to decide on the appropriate passive and hybrid strategies for getting the optimum modes for the residential building typologies.

Keywords: Sustainable renovation, Residential building, Climate classification, Passive strategies, Hybrid strategies, Energy consumption, Thermal comfort performance.

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1. Background of the Study

1.1 Introductions

Currently, human communities are facing many problems, including decreasing natural resources, increasing environmental pollution and changes in global climate. These issues have contributed to the global emergence of protecting the environment and sustainability as a theme that occupies a special importance at all levels. In the past few decades, the discussion about green and sustainable architecture has increased significantly, as a modern trend in the architectural thought which interested in the relationship between the buildings and the ambient environment. In response to such threats, the term sustainability has been targeted to minimise the impacts of these issues and defined as the needs of the current generation without compromising the ability of next generations to meet their requirements (Brundtland, 1987).

Moreover, Iraq is a rich country in the solar radiation through the season of the year that could play a significant role in reducing energy consumption. In addition, the study focused on taking advantage of natural ventilation to improve indoor air quality for their occupants through using passive strategies. The passive strategy is considered as one of the most effective strategies for energy and thermal comfort efficiency, in new construction or renovation of existing buildings. Furthermore, renovation schemes should include the environmental protection, conservation of architectural, heritage and social values of traditional residential buildings. The research concentrated on depending strategies for interventions of the sustainable renovation of residential buildings in the subtropical climate zone, with the awareness that reusing existing residential buildings allows reducing the energy consumption and affecting the environment.

However, the research consists of two parts; the first part is a conceptual framework that includes literature reviews which relevant to the research topic with surrounding to find the required data for sustainable renovation in the residential building. It also deals with the analysis the existing residential building through field surveys to identify typical residential building typology to evaluate the performance of energy and thermal comfort. While the second part related to study appropriate strategies to create the optimum solutions for the selection model types as an air-conditioned model for subtropical climate.

1.2. Literature review

The majority of literature review on the research topic which helped to identify the missing data, found to cover two fields; the first field related to the renovation existing buildings in a sustainable perspective, whether residential, commercial, or office buildings, based on providing a balance between preserving the cultural heritage and fulfill the requirements of their occupants. While the second field covers the optimization for the existing building based on the passive strategies, through taking advantage of the microclimate, in order to allocate thermal comfort requirements for its inhabitants and minimizing energy consumption.

1.2.1. Studies on sustainable renovation buildings

The residential buildings account for a large proportion of the building sector, which have a direct relationship with the human's life and environment, therefore, the renovation of these buildings lead to benefit environmental, economic, and energy aspects. Several European countries, managed successfully in restoring the old building sustainability, and to maintain its identity, and was able to achieve it, not only in urban side, but also overtaken by a social, environmental, occupational and economic levels, and can be aware that, through research and studies that discuss the possibilities of renovation building sustainability.

1.2.1.1. Gao W., Zhang P, 2011, Sustainable renovation projects of residential building in Austria, Master thesis, Austria;

This study focused on the five examples of sustainable renovation projects in residential buildings which including; single-family and multi-family residences in various cities in Austria. The study presented the recent practice of sustainable renovation in residential buildings through highlighting on the decreasing the environmental impact and increasing the comfort of life. In addition, provided a checklist to analyse the examples of sustainable renovation projects and develop the cases study. The results were compared and the experiences were summarized for the future renovation project in the existing and new residential buildings.

This study showed appropriate architectural solutions for renovation in the various types of residential buildings including single-family and multi-family residences in a sustainable way through presenting and analysing the wonderful five renovated projects in

Austria. It will be advantageous to find solutions to renovate residential buildings in Europe, which have a similar climatic condition.

1.2.1.2. Botta M., 2005, Towards sustainable Renovation, Three research projects, Doctoral dissertation, Stockholm;

This is a review study, based on empirical material and further reflections from previous research projects dealing with Swedish housing renovation including private old single-family, and large housing areas, which mainly owned by housing companies. Additionally, the study focused on analysing and examining the concept of careful renovation, environmentally friendly renovation, and sustainable renovation, as different and necessary approaches to sustainable renovation. It also identified the main issues that may be faced renovation process, which has a relevant to the impact on the environment architecture or resident. Furthermore, the study indicated the relationship between man and environment, which discussed from a phenomenological perspective, were assumed as the theoretical background to interest and attitude towards the renovation of housing. Lastly, it concluded positive results and challenges that may be found in the sustainable renovation project.

The study is a sum up of theoretical review on three previous research projects for the author, for the house's renovation in sustainable perspectives in Sweden, in order to transfer some knowledge and inspiration to sustainable residential housing care, without analysing or presenting the architectural solutions for the projects that will take benefit from similar renewable projects.

1.2.1.3. Cristina M., 2013, Strategies for Sustainable Renovation of Existing Buildings, Doctoral dissertation, Italy;

The study focused on developing strategies for the intervention of sustainable renovation with the knowingness of reusing existing building allow reducing the impact on the environment, energy consumption, and economies, through analyses the restoration projects of two industrial buildings in a sustainable perspective in Trento, Italy. In order, to understand how different material choices could affect the environmental savings which coming from building retrofitting and reuse. In the study, the synthetic indicators and life-cycle tools have been proposed and investigated for assessing the environmental benefits in restoring existing buildings. Furthermore, the life-cycle tools have been integrated and developed for comparing different designing intervention of renovation which can be sustained under multiple aspects. Moreover, the application of the developed methodology to a case study emphasized how the use of a multi-criteria approach is useful for comparing different design alternatives, especially when there is a huge number of parameters involved in the analysis, all characterized by different units of measurement.

The study focused on two aspects: First, the appropriate strategies for the sustainable renovation of the industrial buildings in cold climate. Thus, it presented the benefits from reusing instead of demolition in several aspects. Second, the assessing of the environmental and economic benefits for restoring the buildings based on the synthetic indicators and life-cycle tools. The different design alternatives for renovation were compared. Thus, due to the complexity of the topics and used methods, included in the renovation and evaluation process, it might be the information confusion for readers.

1.2.1.4. Alison H., 2007, Barriers to Sustainable Renovation and Incentive that Local Government Can offer, published paper, New Zealand;

This study presented the barriers that were faced sustainable renovation of residential buildings, and addressed the survey of the residents who undertook renovations on private houses in North Shore and Waitakere city, and examined the findings results on. It also covered the role of local government to encourage the householders to renovate their houses more sustainable, by offering them the incentive and the rate of awareness people towards sustainable renovation .

This study focused on the most important barriers that faced residential buildings during the sustainable renovation process, in two cities in New Zealand, and mentioning the appropriate procedure for solutions to tackle these barriers, or potential possibilities, to resolve those obstacles during the renovation process of residential buildings.

1.2.1.5. Thuvander L., et al., 2012, Unveiling the Process of Sustainable Renovation, published paper, Sweden;

This study surveyed decision-making procedures that helped sustainable renovation process, through inventory existing tools and methodologies based on literature review and results from a workshop with participants from the Swedish building sector, academia, and other stakeholders. In order to understand the current decision-making processes for sustainable renovation to come up the suggestions on how can be improved and handle the significant sustainability aspects. Further, the lacks of sources that describe the decision-making process of renovation were identified to get an image of current processes. In addition, it addressed renovation from a broad perspective, including both residential and commercial buildings, owned and managed by a private sector or municipal.

The study also tried to present the role of decision- making tools and methodologies for sustainable renovation process in the Swedish building sectors including residential and commercial buildings, which can be improved in the future.

1.2.1.6. Hindrichs U. D., et al., 2007, Plusminus 20/40 latitude, Sustainable building design in tropical and Subtropical Regions, Book, London, U.K.;

This book has covered many aspects and various topics which related to the sustainable buildings in detail. It also addressed the global climate change, and the most important criteria and indicators of architectural design, which related to provide thermal comfort and indoor air quality performance in the buildings. In addition, it addressed the traditional and modern design solutions examples of utilizing the natural ventilation in the building and urban environments in different climates. Furthermore, it demonstrated the outer skin of a building, including the glazing and the shading elements in the façade systems, which is considered as a key element in dealing with the environmental requirements. The use of photothermic and photoelectric solar technologies was also examined extensively, along with the use of the energy potential of the soil. Finally, many examples of the building has been illustrated which represented the interplay between the use of natural resources and the building technology that has been added on.

This book is considered a unique and valuable resource that offered the possible architectural standards and solutions to take advantage of natural ventilation and optimize buildings based on thermal comfort and energy efficiency in tropical and subtropical regions.

1.2.1.7. Makrodimitris M., 2010. Energy Efficient Refurbishment of Old Listed Dwellings; The case of Victorian housing stock, published paper, UK;

This study consists of two parts. In the first part tried to study the old existing UK housing stock. It highlighted the principles and advantages of bioclimatic design and energy efficient improvements, to the fabric and services of listed buildings. The second part evaluated the performance of the recently refurbished Victorian house, which is considered as a typical example of low energy refurbishment techniques, it also addressed the impacts of the aforementioned reconstruction on internal conditions during both winter and summer period with more focused on winter performance and annual heating fuel demands. Occupant behavior and its impacting on the low energy Victorian house performance also have been investigated through a questionnaire survey, whereas the cost of refurbishment is evaluated in terms of positive effects of annual savings.

This study can be considered as one of the most valuable examples of energy-saving improvements in the old residential buildings refurbishment, with a greater emphasis on winter performance. This mainly related to the harshness of the winter in Britain. These types of projects can be benefited to renovate traditional residential buildings in cold weather conditions.

1.2.1.8. Hilal A. S., 2012. Strategies of Urban Renovation in Historical Centers, Doctoral dissertation, Iraq;

This study focused on the procedures of preserving cultural heritage in the historical centers in the city during the urban renovation process in Iraq, through analyzing and explaining the problems which faced the historic centers and the possibility for their solutions. It also tried to search for the most important contemporary strategies for urban renovation. Besides, the rehabilitation strategies as the most appropriate strategies have been identified in a sustainable perspective, to ensure the privacy of contexts and urban dimensions associated with the place .

The study also targeted the most important mechanisms and approaches adopted for the renovation of residential, commercial, and industrial buildings within the urban context. It identified the most active and non-active values in the local historical centers, which can be activated through the possibilities strategies for rehabilitation, depending on the specificity of the urban context and local dimensions of the urban environment. Finally, the study determined the number of recommendations that can help in reviving the local historical centers, as a basis of the aims to preserve the heritage built and the possibility to invest it in a sustainable manner.

This study is one of the contemporary studies, which contemplated on finding a comprehensive strategy for urban renovation in the historic centers in the cities, to preserve the cultural heritage, and be able to fulfill the requirements of its users in a sustainable perspective.

1.2.1.9. Jensen P. A., Measles E., 2013, Sustainable Renovation of Residential buildings and the Landlords/ Tenant Dilemma, published paper, Denmark;

This study focused on Danish rented residential buildings renovation and the main obstacles which facing these buildings during the renovation process. It considered one of the main barriers which is the landlord/tenant dilemma. It also explained the reasons for occurring these problems and aimed to give an understandable way to overcome. In addition, it investigated how regulatory changes and contractual solutions can help solve the landlord/tenant dilemma and mentioned on plenty of opportunities to overcome the landlord/tenant dilemma, but principal/agent problems can only be overcome with a package solution. Based on author's perspective, the package solution should consist of legislative changes, financial incentives and better dissemination of information on the sustainable renovation benefits in the community. Therefore, the aforementioned tools must be integrated and used in cooperation to overcome the dilemma.

This study addressed the most important barriers that affect the sustainable renovation of residential buildings and focused on the landlord/tenant dilemma. It considered the combine between the sustainable renovations with the renovation of its energy is a key pillar in this process.

1.2.1.10. Kharufa H.O., 2014, Urban Renovation Policies According to Sustainability Methods, published paper, Iraq;

This study tried to focus on the form of relation between the existing policies of the urban renovation in Iraq and the possibility of their influence on the sustainability methodology, which recently became one of the offered solutions priorities of the most adopted directions in the urban design. Mosul city was chosen as a case study, which has the characteristics of the historical city. In addition, it addressed the most important urban renovation policies at the urban level through presenting a number of vocabularies on this side and their relation to each other.

This study is an example of contemporary studies in which recently conducted how to connect urban renovation policies in the region with the existing sustainability approach in order to renovate the historical center of the city.

1.2.2. Studies on energy and thermal comfort optimization in the buildings

This kind of studies is concerned with the improvement and development energy and thermal comfort efficiency in the buildings based on the using various strategies including passive and active strategy which have an effective role in reducing energy consumption and increasing indoor air quality.

1.2.2.1. Taleb H.M., 2014, Using Passive Cooling Strategies to Improve Thermal Performance and Reduce Energy Consumption of Residential Buildings in U.A.E, published paper, U.A.E.;

The study aimed to test the usefulness of applying selected passive cooling strategies to improve thermal comfort and energy performance in the residential buildings in hot arid climate in U. A. E. One single-family residential building was selected and eight passive cooling strategies were applied. In addition, energy simulation software IES, was used to assess the performance of the building. Energy reduction was achieved, in both the harnessing of natural ventilation and the minimizing of heat gain in line with applying good shading devices alongside the use of double-glazing. Additionally, green roofing proved its potential by acting as effective roof insulation. The study revealed that the total annual energy consumption of a residential building in Dubai might be reduced by up to 23.6% when a building uses passive cooling strategies.

The aim of this study was to utilize appropriate passive cooling strategies to residential buildings in hot arid climatic conditions, to improve thermal comfort performance and reduce energy consumption. Thus, the study was considered a good example for the region that has the similar climatic conditions.

1.2.2.2.Khan N., et al., 2008 ,A Review on Wind Driven Ventilation Techniques, published paper;

The study identified the natural ventilation as a most fundamental principle in the building design. The miscellaneous wind driven ventilation designs have been reviewed with respect to the traditional means such as wind towers and more modern techniques including turbine ventilators. In addition, a distinction between specific types of wind-driven ventilation techniques has been made depending on their operation and mode of engagement with the wind. For example, a static wind catcher classified as passive; a rotating wind cowl as a directed passive technique and a rotating turbine ventilator classified as outright active due to its constant rotation with the wind. Further, the miscellaneous wind driven ventilation techniques have been summarised and presented in a table with their features and typical flow rates.

This study deals with the traditional and modern natural ventilation techniques in the buildings, which is necessary for indoor environment and energy performance in the building. The aim of this study was given a clear vision to constructive researchers, and practitioners to understand how to take advantage of natural ventilation techniques to improve buildings effectively, both in new construction and renovation process.

1.2.2.3. Wang Z., et al., 2009, Night ventilation control strategies in office buildings, published paper, China;

This study presented the effective of night ventilation on the energy efficient approach and improves the indoor thermal environment for office buildings during the summer months in moderate climates. In addition, the typical office buildings, in three cities in northern China with night mechanical ventilation, were chosen. The most important factors influencing night ventilation performance which, including ventilation rates, ventilation duration, building mass and climatic conditions were evaluated. In addition, the whole energy-consumption analysis software Energy Plus was used to simulate the indoor thermal environment and energy consumption. The summer outdoor climate data were analysed, and three typical design days were chosen. The results showed when night ventilation operation time is closer to active cooling time; the efficiency of night ventilation is higher. The longer the duration of operation, the more efficient the night ventilation strategy becomes. It also showed that most energy savings are achieved in the office buildings cooled by a natural ventilation system than ones that do not employ this strategy.

The objective of the current study is to assess the performance of night ventilation and optimize the control strategies in typical conditioned office buildings in moderate climates.

1.2.2.4. Pisello A.L., el at., 2012, A Building Energy Efficiency Optimization Method by Evaluating the Effective Thermal Zones Occupancy;

This study presented an innovative in low-cost methodology to reduce buildings' energy requirements through post-occupancy assessment and optimization of energy operations using effective users' attitudes and requirements as feedback. The proposed method applied to a multipurpose building located in New York City, in USA, where real occupancy conditions assessed. The effectiveness of the method tested through dynamic simulations using a numerical model of the case study, calibrated through real monitoring data collected on the building. The results showed, the method provided optimized building energy operations which allow a reduction of primary energy requirements for HVAC, lighting, room-electricity, and auxiliary supply by about 21%. It also showed that the proposed strategy represented an effective way to reduce buildings' energy waste, in particular in those complex and high-efficiency buildings.

This study addressed a low-cost strategy to reduce energy requirements in the building and applied the proposed strategy on a multipurpose building in New York. The effectiveness of the method was tested through dynamic simulation. The study illustrated building energy efficiency is strongly linked to the operations and control systems, together with the integrated performance of passive and active systems to an optimum building in new high-quality buildings particularly.

1.2.2.5. Jalaei F., el at.,2015, Integration Decision Support System(DSS) and Building Information Modeling (BIM) to Optimize the Selection of Sustainable Building Components, Published Paper;

The main purpose of this study was to propose a methodology that integrates Building Information Modeling (BIM) with decision-making support system (DSS) approaches in order to optimize the selection sustainable building components efficiently at the conceptual design stage of building projects. The multi-criteria procedure embedded in the decision support system relies on numerical models to simulate alternative situations. Thus, the set of models included in the decision support system describes the relationship between sustainability criteria, manufacturer's sustainable materials and the interactions between project team that take place during the design of sustainable building projects. The study aimed to expose the feasibility of using BIM analysing the life cycle costs of sustainable buildings at the conceptual stage. The design alternatives suggested and evaluated in an integrated environment that joins BIM concept and Life Cycle Cost (LCC) method to analyze the operational cost of the whole building. In addition an actual building project was used to validate the workability and capability of the proposed methodology.

One of the challenges in sustainability analysis and its development is the optimum selection of sustainable materials to meet the project's requirements while doing sustainable design. The BIM offers designers the ability to assess different design alternatives at the conceptual stage of a project. It also can be used to assess the impacts of design alternatives on the energy saving of buildings all over their life.

1.2.2.6. Kang J., 2015, Assessment of Passive vs. Active Strategies for a School Building Design, Seoul, Korea, Published Paper;

This study presented a simulation study to reduce heating and cooling energy demand of a school building in Seoul in Korea, based on passive and active strategies comparison. The study has estimated the impact of passive vs. Active approaches to energy savings in buildings using Energy Plus simulation. The study showed by controlling lighting, the energy saving of the original school building design was found most significant, and increased 32% when the design was improved. It is noteworthy that energy saving potential of each room varies significantly depending on the rooms' thermal characteristics and orientation. Thus, the analysis of energy saving should be introduced at the individual space level, not at the whole building level. Finally, it was concluded that priority should be given to passive building design strategies, such as building orientation, as well as control and utilization of solar radiation. These passive energy-saving strategies are related to urban, architectural design, and engineering issues, which more beneficial in terms of energy savings than active strategies.

This study addressed a zero energy school building design project with application and comparison of passive and active design strategies for the reduction energy used in the building. The study proved that passive design strategies are more efficient in terms of energy savings than active strategies. In this study re-design of school building based on passive strategies, and without the application of active design strategies was analysed. The study showed the new design had lower total energy than the original school design that applied with active design strategies.

1.2.2.7. Akande O. K.1 & Adebamowo M. A., 2010, Indoor Thermal Comfort for Residential Buildings in Hot-Dry Climate of Nigeria;

This research is based on a questionnaire surveys and field measurements on indoor thermal comfort and the nature of residential thermal environment during the dry and rainy season conducted in hot dry climate in northern Nigeria. This was carried out to get a variation measurement in terms of indoor and outdoor temperature, relative humidity and air velocity. Thermal comfort index is evaluated and compared with human responses. Indoor thermal comfort has been viewed as being highly dependent on the occupants and the way they see the environment. Finally, the results indicate the need to review the fundamentals of thermal comfort and adaptation requirements by occupants.

The study concluded that the results on thermal comfort should be presented in a form that would be useful and suitable for architects to design the residential buildings in hot-dry climates.

1.2.2.8. Rathi P., 2012, Optimization of Energy Efficient Windows in Office Buildings for Different Climate Zones of the United States, Master thesis, U.S.;

This study proposed the fenestration adjustment guidelines for office buildings by investigating the optimization strategies for thermal and daylight performance of the buildings. Taking into consideration the key factors related to fenestration including glazing type, window to wall ratio (WWR) and aspect ratio for varying office building in seven different climates in the United States. This study provides a method for evaluating the performance of daylight and energy use to achieve the overall efficiency of buildings. To determine the pattern of energy usage with and without daylight utilization, series of computer simulations were conducted using the radiance link in the IES Virtual Environment Simulation software. The optimum ranges of fenestration-related parameters were derived to meet the daylight requirement and to conserve energy. The results revealed 10-15% reductions in the total energy use of office buildings with an increase in overall efficiency. Consequently, this study presents the method to assess the daylight performance and energy usage to achieve the overall efficiency of the buildings.

This study was proposed the fenestration guidelines and considering an integrated approach through optimal strategies for energy conservation to increase the overall efficiency of office buildings, which can help the designers to evaluate the design at the initial design stage to optimize building interface solutions.

1.2.2.9. Wang S., et al., 2016, The Passive Design Strategies and Energy Performance of a Zero-energy Solar House: Sunny Inside in Solar Decathlon China 2013, Published Paper;

This study described the passive design strategies of a zero-energy solar house, named Sunny Inside. It was a single-family wooden house, which combined traditional Chinese building style with innovative energy-efficient technologies. It was designed to participate in the first Solar Decathlon China Competition in 2013. Several passive strategies design for the Sunny Inside were introduced and analysed including ecological atrium, shading, natural ventilation, heat storage system, and thermal insulation design. The discussion of the building's energy performance is based on the measured and simulated data by using several buildings simulation software in the study, including; Ecotect software was used to optimize the house's shading design, Phoenics software is used for simulating the natural ventilation design, and Design-builder software is used in building envelope design to analyse the building's energy consumption. The results showed by using passive design strategies achieved the goal of zero energy consumption in the Sunny Inside.

This study focused on the design of a single-family wooden solar house for zero-energy, in China, through selecting several appropriate passive strategies with the local climate, which provide designers an opportunity to choose the optimal model at the initial design stage with a focus on adapting to the microclimate.

1.2.2.10. Nouanegue H. F., et al., 2007, Numerical Study of Solar-Wind Tower Systems for Ventilation of Dwellings, Published Paper;

The study addressed a numerical study, which is carried out of a simplified or conventional system of solar - wind towers for ventilation of dwellings. In this case, the tower does not function as a wind catcher, but it rather functions as a solar chimney for ventilating air from the dwelling. The opening at the top is oriented against the cardinal wind direction, thus it will be in depression region most of the time. The tower itself can be used as a solar collector and an energy storage system, at the same time providing wind tower function, and the air will be evacuated from the dwelling to the ambience by suction in the tower due to negative wind pressure at the opening and the buoyancy force developed in the chimney. This system only used in the summertime and closed down in the winter.

This study describes how to use the traditional wind tower as a multiuse element. It used as a collector and storage of solar energy, in addition to the original function as a wind tower. This considered a good strategy for the construction of these types of towers and more economic.

Through presenting the literature reviewer, to help for formulating the research problem, it can be noted that several European countries, managed successfully in restoring the old building sustainability, whether residential, commercial or office buildings, and there are many of recent studies approved this aspect. It is noteworthy, that some studies focused on passive strategies and the development of natural ventilation systems such as wind catcher or wind towers to improve energy efficiency in the buildings, without mentioning the integration of ventilation structures with the building's systems. While, some studies confirmed a certain aspect and neglected other, generally, the previous studies dealt with the topics in a fragmented way. Further, in all cases, there is no comprehensive view of the subject or sustainable renovation in the subtropical climates. Hence, the importance of research and the need to study the renovation of residential buildings in subtropical climate is illustrated.

Although several studies have been addressed the issues of sustainable renovation of residential buildings, still residential buildings in the center of the city suffer from structural deterioration and this led to migrate their inhabitants to other residential areas within the city, as a result, buildings remained abandoned. This requires the renovation of the forsaken housings using natural ventilation as a basis for the storage of energy and to reduce the negative impact on the environment. Since Sulaimani city has a hot and dry climate, especially in the summer season, it will be focused on adapting the buildings depending on natural ventilation to improve energy efficiency, in order to be able to meet the requirements of occupants, rather than being abandoned.

1.3. Research Problem

The thesis attempts to find a solution through finding answers to these research questions:

1-What is the systematic methodology for sustainable renovation of residential buildings and what are the major barriers faced during the process?

2- How to find a comprehensive strategy for sustainable renovation of residential buildings in subtropical climates, to preserve cultural heritage, reduce energy consumption, and be able to meet the thermal comfort requirements of its inhabitants?

3- How can define the energy efficiency ratio of passive strategies in comparison with other sustainable building refurbishment measures?

4- What is the possible solution to improve and develop traditional systems for cooling and heating residential buildings in Mediterranean or dry-summer Subtropical climates (Kurdistan climate)?

1.4. Research objectives

The main objectives of the research are:

- Analysing the typical residential buildings in the study area, and investigating the indoor environmental, thermal comfort and energy performance.
- The research focuses on finding a comprehensive strategy for sustainable renovation of residential buildings in order to preserve the cultural heritage and to be able to fulfill the requirements of their occupants, while minimizing the energy consumption.
- Trying to take advantage of natural ventilation to improve indoor air quality, reduce energy consumption, and develop passive ventilation systems for residential buildings during the refurbishment process.
- Trying to propose models of energy and thermal comfort efficient in the renovation of the residential building typologies using appropriate passive and active strategies.

1.5. Research Hypotheses

The thesis configured two hypotheses and tries to approve them consequently:

- Using wind catcher as a traditional passive cooling strategy during the renovation process has a significant impact on reducing energy consumption and increasing indoor air quality in subtropical climates zone.

- Using hybrid strategies for sustainable renovation of residential buildings is considered a comprehensive strategy which can greatly help in achieving thermal comfort with a minimum usage of energy.

1.6. Research Methodology

To achieve the thesis's objectives, the study relies on a descriptive analytical approach, through studying literature review on past and recent studies, which contain the theories and concepts related to the thesis topic. The next step was to identify the typical residential buildings in the study area, through field surveys which including analysing the compositional and morphological properties of the residential building typologies. The last step was optimization for five residential building typologies based on passive and hybrid strategies. In this step, the Indoor Climate and Energy IDA ICE 4.7.1 was used to assess the energy and thermal comfort performance in the residential building typologies. Further, to optimize the selection models, the Excel decision-making support tool was used to compare the results and to make the decision on selecting the optimum models, as shown in *Fig.1.1, Appendix A.*

In summary, the research to achieve its objectives depended on a descriptive and analytical method with the use of a logical conclusion to reach the desired goal and coming up with results taken from the reality by using an experimental actual method of working.

7. Research Structure

The Research consists of seven chapters, which represent a theoretical and practical part of the study.

1.7.1. Chapter 1: Introduction

This chapter dealt with the definition of the research, through a literature review of previous studies which related to the research topic to extract the knowledge gap and defining the research problems, research objectives, and the hypothesis of the research, methodology, and research structuration.

1.7.2. Chapter 2: Climate and Thermal Comfort

This chapter identified the most significant published findings which concerning climate data including global climate change, climate classification criteria, climate classification in Iraq. Further, it also dealt with the thermal comfort indexes, and bioclimatic analysis methods.

1.7.3. Chapter 3: The Concept of Sustainability & Renovation

Based on the literature review this chapter tried to identify the concept of sustainability and to overview the concept of sustainability in the building renovation, and to find an appropriate approach to stimulate the development of sustainable renovation. It also addressed the tools and methods for assessing or classifying buildings in an environmental or sustainability perspective. Furthermore, the sustainable renovation policies in both Europe countries and Iraq were addressed.

1.7.4. Chapter 4: The Sustainable Renovation Strategies

This chapter presented literature review that helps to identify the most appropriate strategies for achieving thermal comfort and energy performance. These strategies included passive, active, and hybrid strategies. The primary focused on the passive cooling, heating, and ventilation as an integral part of architectural elements. Finally, it addressed the energy sources including renewable and non-renewable energy were discussed to take advantage of the renovation process.

1.7.5. Chapter 5: Determination of study area in Sulaimani City

This chapter analysed and investigated the current situation of existing residential buildings in the study, through the field survey and based on the compositional and morphological properties, five types of residential buildings were classified, which are carried out to the renovation process later. Furthermore, to investigate the energy efficiency of the residential building typologies, the computational simulation software IDA ICE 4.7.1 was used.

1.7.6. Chapter 6: Decision -Making Tool for Energy & Thermal Comfort Optimization

This chapter presented the approaches to explore reducing energy consumption and increasing thermal comfort performance in the five typical residential buildings in the study area, through investigating different passive and hybrid optimization strategies. The approaches are supported by IDA ICE 4.7.1 for simulation different scenarios. The Excel decision support tool was used to make a decision on the appropriate strategies and to complete the optimization process.

1.7.7. Chapter 7: Conclusions and Recommendations

The research concluded with presenting a number of conclusions and recommendations that reflect the hypotheses, the goals of the research and the findings, which discussed in the chapters.

2. Climate and Thermal comfort

2.1. Introduction

Climate has a major impact on the energy consumption in the buildings. Studying climate data helps inform and evaluate the design of both passive and active strategies. In order to understand the microclimatic situation in a global context, it is helpful to refer to a climate classification system, in addition, it is important also to study and analyse bioclimatic chart that contributes to the reduction of energy consumption and increase indoor air quality inside the buildings. This chapter identified the most significant published findings that concerning climate data, thermal comfort and bioclimatic chart.

2.2. Climate change

Climate is a critical variable in the building design process; it is also a source of free energy that's available in any climate [1]. As a result of atmospheric pollution caused mainly by human activities, there is a need for readiness for an increase the global temperature that will eclipse everything that has known over the last two million years [6].

According to 1992 data of the Intergovernmental Panel on Climate Change (IPCC), the average global temperature will rise toward the end of the 21st century by approximately 1.8- 4.2 k above the average of 1990. As the basis for this prediction, it is assumed that the CO_2 concentration in the atmosphere of today (360ppm) will increase to (560ppm), as shown in *Fig.2.1* [6].

The latest report from the IPCC in 1996, clarified that, human-induced warming has the particular pattern of temperature increase over the past quarter-century which has finger prints that indicate a substantial contribution from the build-up of greenhouse gases due to human activities [13]. From the perspective of global climate change, which is a product of the excessive human activity on the planet, the discussion on how to reduce these negative anthropogenic impacts on the environment and all the international policies are addressed towards increased environmental awareness, with the aim of more sustainable development [3]. Due to global warming and climate change, the polar and coldest zones are shrinking and there has been an overall expansion of the arid zones in the last 50 years, the greatest18 expansions of arid zones has been in Africa with a 5 % increase in the area followed by Asia [7].

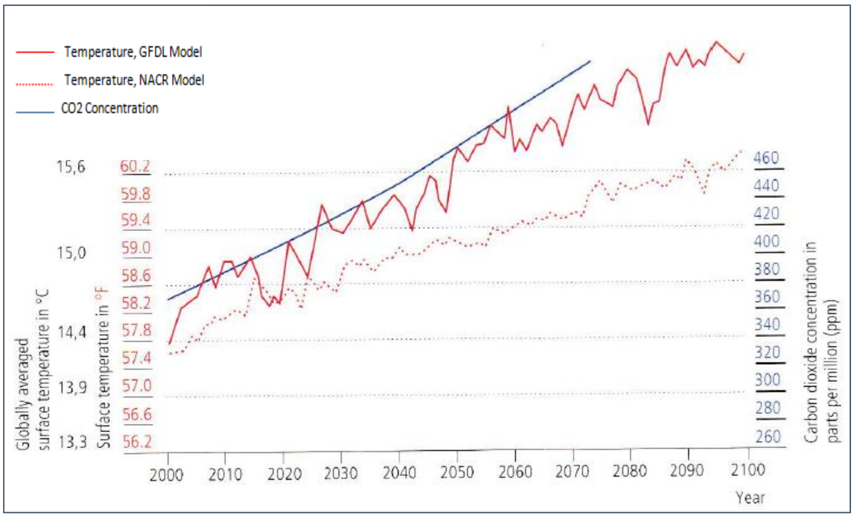

Fig.2.1. Global increases of CO_2 and temperature [6].

Thereupon, the challenges indicated by climate change need to be understood, and those reasons will identify the most significant fact, concerning climate classification and climate data.

2.3. Climate Classification

Mark Twain gets to the heart of the distinction between climate and weather when he said, *"Climate is what we expect; weather is what we get."* Climate is defined as the predominant weather conditions of a place averaged over a long period of time [1]. To understand global context, it is helpful to refer to a climate classification system. There are three fundamental types of classification used in climatology.

2.3.1. Koppen Climate Classification

There are empirical systems of classification that are based on observable features. Koppen system discussed below is an empirical system based on observations of temperature and precipitation [2]. Koppen map is one of the most common climate classification systems. First published in 1918, which has been improved over time and is still used to this day [1]. Wladimir Koppen suggested five main climate zones, A: tropical (humid), B: arid, C: temperate, D: cold and E: polar- with further subdivisions [7]. *According to the Koppen method*, the dominant climate type of land area is cold D (44.4%), followed by arid B (36.3%), temperate C (17.0%) and polar E (2.3%) [3]. The most dominated arid subdivisions are the hot desert arid, BWh, covering 14.2% of the total land area and lying within 35°N, 35°S of the equator, as shown in *Fig.2.2.*

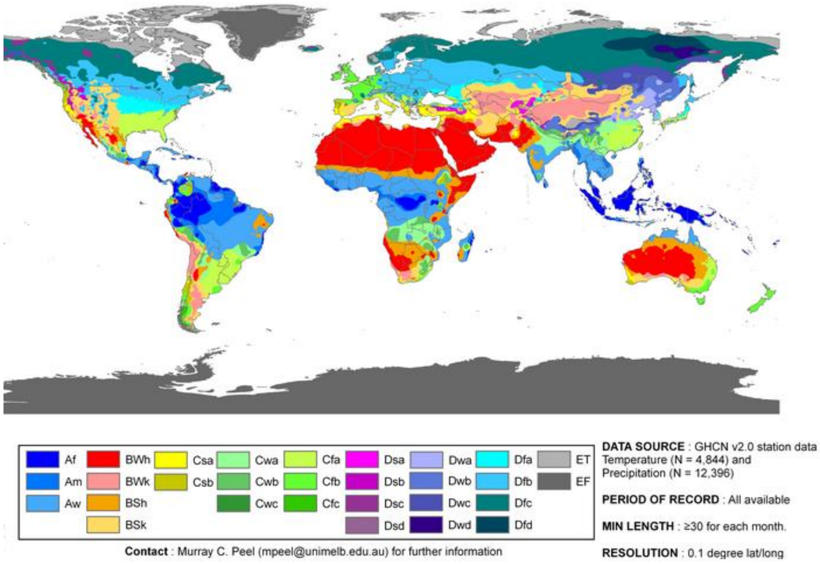

Fig.2.2. Koppen-Geiger Climate Classification Map [3].

Arid zones cover 57.2% of Africa, 23.9% of Asians, 15.3% of North America, 15% of South America, 78% of Australia and 36.3% of the Europe- considering the Arabian Peninsula and the middle- eastern countries as part of Europe [7].

2.3.2. Thornthwait Climate Classification

In 1992, the United Nations Environment programme UNEP developed the precipitation effectiveness method introduced by Thornthwait in 1948 and defined the aridity index as the mean annual precipitation over the potential evapotranspiration [7]. Thornthwait selected effectiveness of precipitation, seasonal precipitation and thermal efficiency as bases for climate classification, regional variation in precipitation and thermal efficiency result in the grouping of humidity provinces and temperature provinces respectively [2]. Thornthwait determined thirteen types in three major groups, based on their latitude (Low latitude- Mid latitude- high latitude), as well as a more general highland climate, as shown in *Fig. 2.3, Appendix A.*

2.3.3. ASHRAE Climate Classification

The ASHRAE Climate Classification based on two parameters: air temperature and precipitation. Relative humidity is not taken into account. Cooling Degree Days (CDD) and Heating Degree Days (HDD) are used for defining various climate zones. The base temperature for CDD is taken as 10°C and the base temperature for HDD is taken as 18°C

[2]. Due to the availability of recent climate data and powerful computational capabilities, Hierarchical Cluster Analysis has been carried out for 16 U.S. climatic regions. The ASHRAE standards 90.1 and 90.2 used eight main clusters of climate type [7], as shown in *Fig.2.4, Appendix A*. These methods have been used for defining climate zones all over the globe [2].

By comparing all the methods, it can be seen that the Koppen and ASHRAE classified the climate based on the annual and monthly averages of temperature and precipitation, while, Thornthwait selected seasonal precipitation and thermal efficiency as bases for climate classification.

2.4. Climate Classification in Iraq

Iraq has a hot, dry climate characterized by long hot dry summers and short cool winters. The climate is influenced by Iraq's location between the subtropical aridity of the Arabian Desert areas and the subtropical humidity of the Persian Gulf [4]. January is the coldest month, with temperatures from 5°C to 10°C, and August is the hottest month with temperatures rising up to 40°C and more [8]. The subtropical high pressure and mid-latitude low pressure are clearly reflected in Iraq’s climate and results in three distinct climate regions when classified using the Köppen climate classification scheme as shown in *Fig.2. 5*[4].

The climate of the western and southwestern areas can be classified as (BWh) climate; a hot, dry desert climate with annual average temperatures above 18°C. A small zone between the Persian Gulf the Turkish Border, in the east of Iraq can be classified as (BSh) climate, a hot, dry climate with the annual average temperature above 18°C.

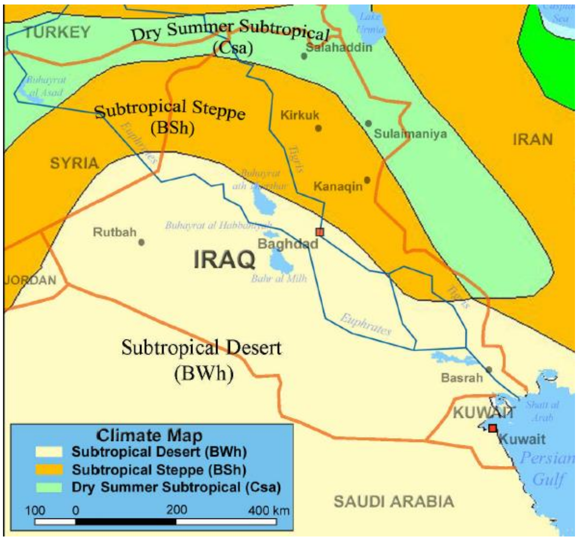

Fig.2.5. The three regional climates in Iraq [4].

Finally, the mountainous regions of the north can be classified as Mediterranean or Dry-Summer Subtropical (Csa) climate, a cold snowy climate with dry summers and wet winters with the warmest month over 22°C and the coldest month below -3°C [4]. International Center for Agricultural Research in the Dry Area (ICARDA), in coordination with the National Agricultural Research Systems (NARS), classified the climate in Iraq into seven subdivisions regional climates, depending on the Koppen climate zones map, as shown in *Table 2.1, Appendix A* [8].

Based on the study of Iraqi climate when classified using the Koppen map, the climatic zone of the Kurdistan region falls within the Mediterranean climate zone (Csa), is known as Mediterranean or Dry-Summer Subtropical.

2.5. Climate in Sulaimani City

The city in terms of the topography is steep from the eastern part, towards the southwestern part, which is characterized by the presence of mountains, hills, plains, valleys. The difference between the mountains and valleys in height, is up to (878 m) causing a significant difference in temperature between areas within the city, could reach up to 7 ° C [14]. The climate of Sulaimani based on Koppen- climate classification system which already has been described, the city has a Dry-summer or Mediterranean climate Csa. It is characterized by hot, dry in the summer and cold, wet in the winter with large temperature differences between day and night and between summer and winter. The annual average temperatures range from 0 °C (32 °F) to 39 °C (102 °F). In addition, it can be predicted that there will be a little amount of snow in winter, although it is not frequent [13]. The prevailing wind direction in the city is northwest, and there are other winds from northeast, locally called (Rashaba) meaning black wind, usually blowing strongly and may last in duration from one to three days [14]. The maximum temperature is in July, and the minimum in December. The *Fig.2.6* shows the mean monthly temperature and relative humidity in Sulaimani in 2014[9].

The Kurdistan region is rich in solar radiation that can play a key role in reducing energy consumption. The average monthly amount of solar radiation and sunshine are shown in *Fig. 2.7, Appendix A.*

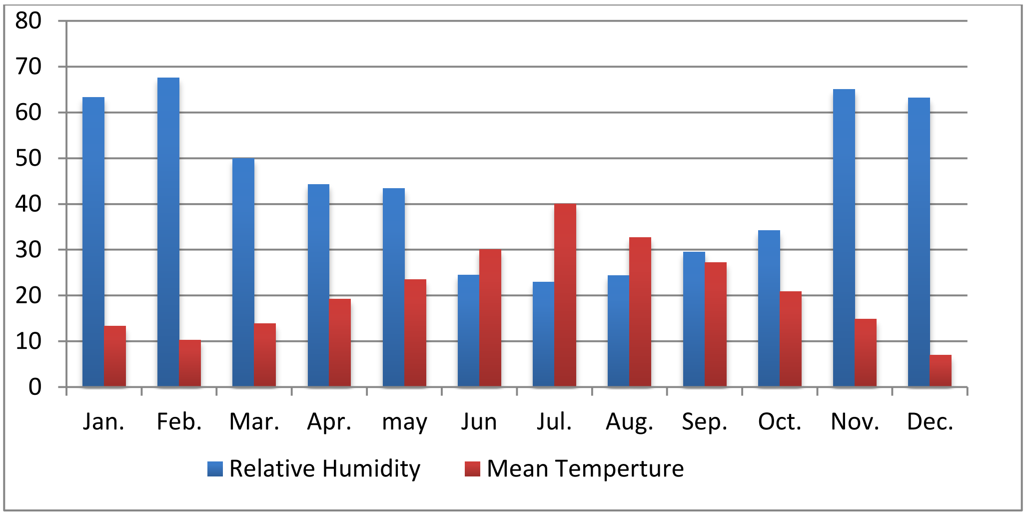

Fig.2.6. The mean outdoor monthly temperature and relative humidity in Sulaimani in 2014 [9].

Studying meteorological data for instance, the average daily or monthly temperature, prevailing wind, with its speed and direction, paired with solar radiation, has a crucial role in making decisions for the preliminary design, the constructional or retrofit process.

2.6. Thermal Comfort

The required energy to heat or cool buildings and the way we define the “comfortable” thermal conditions plays a significant role in this environmental impact [7]. Thermal comfort has been defined by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) as" *the condition which expresses satisfaction with the thermal environment*" There is a connection between this condition on one side and heat gains or losses of the occupant's body due to the metabolic processes and environmental effects on the other side [15]. There are two main factors which determine human thermal comfort; First, “personal factors” such as occupant activity, metabolic rate, clothing, age, gender, and nutrition. Second, “environmental factors” including dry-bulb temperature, mean radiant temperature, which refers to surrounding object’s temperature, humidity, and air velocity” [16]. In addition, the human body produces heat in metabolic processes in which food is converted to energy. The quantity of the generated heat depends on the amount and type of the food consumed and level of the body's activity. The unit which is used to express the metabolic rate per unit in Dubois area is 'met'. Dubois area is the skin area for an average adult which equals to 1.8m^2, as shown in *Fig. 2.8, Appendix A* [15]. Furthermore, when the body is comfortable and at rest, the minimal heat dissipation is approximately 80W [6].

With regard to the clothing, it provides thermal insulation to the human body and determines the amount of body's heat exchange with the surrounding environment. 'Clo' is used as a unit to express the insulation of clothing; one Clo is indicated as the required insulation to keep a person comfortable at 21^{o}C which can be an office worker suit, as shown in *Fig. 2.9, Appendix A.* [15].

The ASHRAE standard 55 on thermal Environmental Conditions for Human Occupancy gives the upper limit of comfortable temperature as 26 °C, and wet bulb temperature lower limit as 20°C. Furthermore, the latest version of ASHRAE Standard 55 starts to adopt the idea of acclimatization and gives a higher upper limit for thermal comfort which could be as high as 27-28°C and 0.012 humidity ratio for the situations where there is a system to control humidity [10].

2.7. Thermal comfort indices

Thermal comfort is one of the most important “comfort index” because people directly feel hot or cold according to the air temperature and the humidity in the home. In order to create more comfortable living spaces, it has to be known how thermal comfort is measured. Predicted Mean Vote (PMV) and Predicts the Percentage of occupants Dissatisfied (PPD) are proposed by Prof. Ole Fanger for measuring the thermal comfort which has become the comfort index in the International Standard Organization (ISO-7730) [17]. The validity of two commonly used thermal comfort models was assessed. The first, Fanger’s Predicted Mean Vote (PMV) Model, combines four physical variables (air temperature, air velocity, mean radiant temperature, and relative humidity), and two personal variables (clothing insulation and activity level) into an index that can be used to predict the average thermal satisfaction of a large group of people. The second, Fanger’s PPD Draught with local draught, from three physical variables (air temperature, mean air velocity, and turbulence intensity). In comparison to Fanger’s PMV model, much less work has focused on the validity of this model [18].

The comfort models in recent standards are based on defining the comfort into categories. For example, ISO -7730-2005 proposes three categories of comfort (A, B, C). Only for the Fanger model, defined by the ranges of PMV, ±0.2, ±0.5, ±0.7, and leaves open the choice about which buildings fit into which category [7]. In addition, when PMV=0, the temperature is neutral, which human body feels most comfortable, that means one can feel neither hot nor cold. Based on the PMV evaluation index established by Fanger, the neutral temperature is 22.4℃ in winter and 25.1℃ in summer [20].

Fanger's PMV model was developed in the 1970's from laboratory and climate chamber studies. In these studies, participants were dressed in standardised clothing and completed standardised activities, while exposed to different thermal environments. In some studies, the researchers chose the thermal conditions, and participants recorded how hot or cold, they felt using the seven-point ASHRAE thermal sensation scale (cold, cool, slightly cool, neutral, slightly warm, warm, and hot) [18]. However, adopting the determining principle of the ASHRAE thermal comfort zone, which would satisfy 80% of the subjects and make sure the unacceptable vote rate of indoor thermal environment is under 20% as the basis of determining thermal neutral temperature's upper and lower limit [20].

The PMV model does not directly address the influence of outdoor climate. Although, it was noted that studies conducted in different parts of the world reported different neutral temperatures, suggesting that outdoor climate could have an influence on thermal sensation [19]. Based on the available evidence, it was found no reason to suggest that predictions based on Fanger's draught model would be seriously biased. More specifically, for occupants wearing normal indoor clothing, performing sedentary activities, at or near thermal neutrality, and without personal control over air velocity, Fanger's draught model can reasonably be applied without concern for serious bias [18].

In order to find an alternative to the PMV-model, in 1995, ASHRAE funded a series of field studies (RP-884) of thermal comfort in office building spread across four different climate zones, (hot and dry, Mediterranean and tropical) and 2 seasons (winter and summer) for natural ventilation and air-condition buildings [19], [20]. The RP- 884 database contains approximately 21,000 sets of raw data from 160 different office buildings located on four continents, and covering a broad spectrum of climate zones [19]. Humphreys and Nicol's analysis of the ASHRAE RP-884 database found that the accuracy of PMV predictions varied, depending on Clo value. PMV best predicted actual neutral temperatures for clothing insulation (including chair) in the range of 0.3 to 1.2 Clo. For heavier and lighter clothing, PMV tended to overestimate actual neutral temperatures [18]. The occupants in naturally ventilated (NV) buildings were found to accept wider temperature variation and higher indoor temperatures than those in air-conditioned (HVAC) buildings [7]. In the HVAC buildings, PMV was remarkably successful at predicting comfort temperatures, demonstrating that behavioural adjustments of clothing insulation and room air velocity fully explained the relationship between indoor comfort temperature and outdoor climatic variation. In contrast, in the NV buildings such behavioural adjustments accounted for only half of the climatic dependence of comfort temperatures [19]. This finding changed the idea that occupants can be considered as passive users, in contrast, occupants either adapt the surrounding environment to suit their expectations –using windows, blinds, fans (ceiling), and doors– or shift their comfort temperature by a number of physiological thermoregulatory mechanisms; changing metabolic rate (activity level and cold drinks), the rate of heat loss (clothing) and thermal environment [7].

The adaptive model has found a proposal for an Adaptive Comfort Standard (ACS) that would serve as an alternative to the PMV-based method in ASHRAE Standard 55 for naturally ventilated buildings [19]. The first step has been to develop a linear correlation between the mean outdoor temperature (To) and the operative temperature (Tc) as Tc =a Tout + 17.8, the second step has been to specify 90% and 80% ranges of acceptance [7]. Arithmetically, averaging those comfort zones widths across all the NV buildings produced a mean comfort zone band of 5^{o}C for 90% acceptability, and 7^{o}C for 80% acceptability, both centered on the optimum comfort temperature. The resulting 90 and 80% acceptability limits are shown in *Fig.2.10* [19].

The new ACS is presented in ASHRAE Standard 55 as ‘‘Section 5.3—optional method for determining acceptable thermal conditions in naturally conditioned spaces’’. Note from the title that the PMV-based prediction method is still accepted as universally applicable for all conditions, while the new ACS is offered only as an option under certain limited circumstances [19].

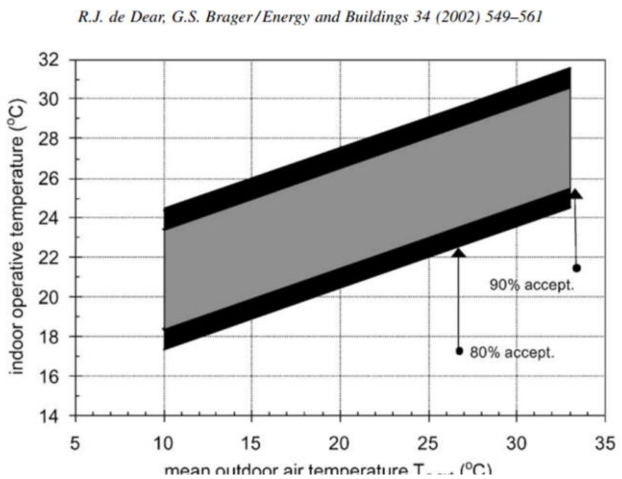

Fig.2.10. The proposed adaptive comfort standard (ACS) for ASHRAE Standard 55, applicable for naturally ventilated buildings. [19].

The ASHRAE adaptive comfort model, defined in ASHRAE standard 55- 2004, is applicable for outdoor temperature ranges 10ºC - 33ºC with constant comfort boundaries above and below these ranges. The external temperature is expressed as the mean monthly outdoor temperature and can be easily determined from meteorological data while Auliciems and Szokolay (1997) chose to mean daily outdoor effective temperature to represent both temperature and humidity. Acceptable ranges of 10% and 20% predicted percentage dissatisfaction (PPD) with ±2.5ºC and ±3.5ºC as ranges of acceptance respectively, used in this model, and are equivalent to ±0.5 and ±0.8 predicted mean vote (PMV) [7]. However, some researchers in SSPC 55 presented strong arguments that the ACS should be applicable to other situations where people have personal control, such as mixed-mode buildings or spaces .The core of these arguments was that the availability of personal control played a primary role in shifting people's thermal expectations. Therefore, the ACS model is likely to be a more accurate representation of people's thermal responses in other realistic situations with personal control, compared to the laboratory studies [19]. Moreover, Fanger and Toftum disagree with the adaptive approach in concept since it only deals with outdoor temperature and neglect the other five primary factors they identified. In hot climates at least air temperature, surface temperature and air velocity were needed. This was also acknowledged by Givoni (1992), who revised his previous notable work on the building bioclimatic chart.

2.8. Bioclimatic Chart Analysis

In general, the selection of building passive thermal design strategies should be based heavily on the local climatic conditions. Identifying suitable strategy for a given location can be made using bioclimatic charts [21]. Bioclimatic analysis methods aim to support climate responsive design decisions and to assess the climate- comfort- building relationship in the early stages of building design [7].

2.8.1. Olgyay's Bioclimatic Chart

The first bioclimatic chart was introduced by Victor Olgyay in 1953, was one of the early attempts to specify different zones at different combinations of relative humidity and dry bulb temperatures, as shown in *Fig. 2.11*, *Appendix A* [21]. There has been lack of solutions provided by this chart when the climate was out of the comfort zone. There are only shading devices available for when the temperature is above 20 ◦C, and wind speed is required when the climate is excessively hot and humid [22]. In addition, Olgyay's chart summarized the relationship between the four environmental parameters of thermal comfort in spite of solar radiation and added moisture content based on clothing insulation 0.8 Clo and an activity level of 1.3 met [7]. Olgyay's chart only considers the outdoor conditions disregarding the indoors physiological considerations. As a result, it can be only applicable for hot, humid climates [21].

2.8.2. Givoni's Bioclimatic Chart

Another more common bioclimatic chart is that of Givoni‒Milne.This chart is based on the linear relationship between the temperature amplitude and vapor pressure of the outdoor air. The Givoni's chart identifies the suitable cooling technique based on the outdoor climatic condition. Five zones are identified on Givoni's chart: thermal comfort, natural ventilation, high mass with night ventilation, and evaporative cooling [21].

It is mainly applied for residential-scale construction, and it provides more alternatives with building design to enable thermal comfort, including natural ventilation, evaporative cooling, thermal mass, passive heating, conventional air conditioning or dehumidification [22].

In the early of 1960s, Baruch Givoni introduced the Building Bioclimatic Chart (BBCC) – developed by Milne and Givoni in 1979 –based on expected indoor temperature rather than the outdoor conditions. The BBCC presents boundaries of the comfort zone and passive strategies –derived from experiments of residential buildings –plotted on the psychrometric chart [7]. Withal, the natural ventilation (NV) zone on Givoni's chart assumes that the indoor mean radiant temperature and the vapour pressure are the same as those at outdoor conditions. On the left of the comfort zone (CZ), heating is needed to restore comfort using solar heating if the shift is slight but mechanical heating is necessary if the temperature is too low [21], as shown in *Fig.2.12, Appendix A.*

2.8.3. Szokolay Bioclimatic chart

The next tool for climatic analysis is the Szokolay Bioclimatic chart. Szokolay developed a new Bioclimatic chart based on the correction of a comfort zone by taking thermal neutrality into consideration, as provided by Humphreys and Auliciems. Therefore, the new comfort zone in this chart is valid only in regions with a relative humidity of no more than 90% [22]. In 1970s Mahoney derived a series of tables first published by the United Nations Centre for Housing, Building and Planning especially for hot regions [7]. The output of this table will determine the design recommendation for the layout, spacing, ventilation for air movement, building envelope (walls and roof), building opening, outdoor space and rain protection [22].

2.9. Conclusion

This chapter has outlined a number of different climate classification methods, and microclimatic condition was identified in the study area that was known as Mediterranean or Dry-Summer Subtropical. The microclimatic data was analysed, including the monthly mean of temperature, prevailing wind direction, and its velocity, solar radiation, and sunshine duration, which altogether have a crucial role in making a decision in the pre-constructional phase. Likewise, the bioclimatic chart systems and thermal comfort models were studied, in order to contribute the reduction of energy consumption and providing indoor air quality in the buildings.

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3-The Concept of Sustainability and Sustainable Renovation

3.1. Introduction.

The environmental issue is an important aspect of sustainability. Even though most "sustainability" issues concentrate on environmental performance, it is important to remember that sustainability is a concept with a tight connection to society. This chapter identifies the concept of sustainability based on the literature review, to overview the concept of sustainability in building renovation, and to find an appropriate approach to stimulate the development of sustainable renovation. In addition, it will address the tools and methods for assessing or classifying buildings from an environmental or sustainability perspective. Furthermore, the policies toward sustainable renovation in EU and Iraq will be critically appraised.

3.2. The Concept of sustainability

The words *sustainable* and *sustainability* are used today in many contexts and many fields. The origin of the English word *sustain* derived from the Latin words *sus* (under, from below), and *tenure* (to hold, to hold up). To sustain, then, means to keep up, to maintain and to prevent from sinking or falling. Considering the sustainability of the natural environment means considering our role in "holding up" the Earth, by keeping its resources from being depleted [10]. In 1972 the concept of sustainable development was introduced for the first time in the report *The Limits Growth*. It is underlined the necessity to reduce the level of resource use for avoiding the world collapse within 100 years and the reach a condition of ecological and economic stability, sustainable far into the future [4].

The Brundtland Report, «Our common future», was a response to a request made by the United Nations in 1987 from the World Commission on Environment and Development (WCED), to analyse the deterioration of man's environment and natural resources, as well as the consequences of the economic and social standpoint. It gave an alarming picture of the state of the environment and a general need in social, economic, cultural and political development on a worldwide scale [2], [8], [10]. In 1987 the United Nation's Brundtland commission defined sustainability as "*meeting the needs of the present without compromising the ability of future generations to meet their own needs*". [1], [2], [4]. It contains within it two key concepts: the concept of 'needs', in particular the essential needs of the world's poor, to which overriding priority should be given; and the idea of limitations imposed by the state of technology and social organization on the environment’s ability to meet present and future needs[2]. The definition is widely used, it still isn’t specific enough. It is not just the protection of the environment that defines sustainability; but it also encompasses culture, economy, community, and family. As a part of the whole, it must be taken into account how human activities affect natural processes and see how nature and natural flows are critically linked to our health and prosperity [10]. The sustainability discussion today focuses more erratically on carbon dioxide and energy, than the resource depletion or air and water quality issues of earlier environmentalists [1]. It is the discussion around the world about the future of Earth, and the consequences of our methods of living on the planet’s climate [9]. Sustainability is simple and complex, local and regional, national and global, and based on actions taken today, past decisions and behavior, and the impacts and results of these choices extending for hundreds of years into the future. Besides, it must be understood not only by planners, designer and professionals but also by policymakers, and ordinary citizens. Many people have a sense that humanity is “bad" for the environment. The problem is the human's ignorance and failure of imagination to understand how could do things better. It can be more comfortable, healthier, and secure by working with nature instead of fighting to subdue and conquer it. Sustainability is a seemingly simple idea, but in practice can be very complex. The first impulse is to believe that a static balance must be achieved between humans and nature, our appetites and impact, and our economy and ecology [10]. Recognizing the strains, it is time to reverse the Brundtland definition and say: Sustainability is the restoration of the ability of future generations to meet their needs without compromising our ability to meet our own [1].

In conclusion, sustainability is the consequence of balanced interconnection between nature and society; however, it can’t be measured or delineated only scientifically. In order to achieve sustainability, our habits, methods of thinking and lifestyles should be changed and respect for cultural and social values. In addition, reduce the environmental resources consumption to protect them for future generations.

3.3. From sustainable development to sustainable building

The existing buildings can have environmental, economic and cultural-social value. It was defined as a combination of three different systems: the environmental system, the economic system, and the social system [4]. The concept of “sustainable building” has been developing since the 1990s, with the commitment signed at the Chicago’s World Congress of Architects in 1993 and the constitution of the Green Building Council in the same year. The sustainable building was first concerned with minimizing the environmental impact of the new construction but soon extended to include efforts toward improving the environmental performances of existing buildings [9]. As emphasized in the 3rd European Minister's Conference on sustainable housing, existing buildings should also be made more sustainable by retrofitting them or ensuring that sustainability is a key consideration in their refurbishment [4]. Green building has now become a forefront of sustainable development in the 21st century that takes the responsibility for balancing long-term economic, environmental and social health. It offers an opportunity to create environmentally efficient buildings by using an integrated approach to design [7]. It also, focuses on increasing the efficiency of resource use, while reducing building impact on human health and the environment during the building's life-cycle.

Sustainable buildings offer many benefits that conventional buildings do not, including; environmental benefits, economic benefits, and social benefits [3], [8].

In recent times, some key events have steered the discussion of sustainability toward specific environmental problems and have demanded increased participation from the building sector on environmental issues [9]:

-To reduce energy consumption.

-To study "healthy building" techniques.

-To comprehend the various aspects of sustainability along with the development of the concept of sustainable development.

-To reduce emissions from greenhouse gases (GHG) in correspondence with the climate .

-To promote equity and democracy and the right to decent dwelling places.

The definition of sustainable development set in 1987, plays an important role, in guiding the building industry in a positive direction. By adapting the sustainable development definition of the buildings, it can be translated that "*the sustainable buildings have to satisfy the needs of the present without compromising the ability of future generations to meet their needs of having a good living condition*" [8]. With respect to sustainability, the construction sector prefers to improve the performance of buildings through using hi-tech things, resulting in less consumption of operation energy and materials, and a good way to treat trash. The construction industry together with the built environment, among many sectors of the economy and human activity, can contribute to the sustainability of the Earth [9]. The core of mainstream sustainability thinking has become the idea of three dimensions, environmental, social and economic sustainability. These have been drawn, as "3-pillars", as shown in *Fig.3.1*[11]. The "pillars" are not isolated from each other; they create a network, and strongly connected to each other. Any change happens in one pillar results in the response of the other two. This kind of definition, which integrates three sustainable fields, is widely used to explain sustainable building project [8].

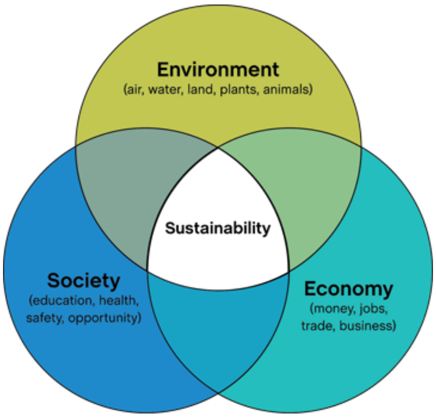

Fig.3.1. Three pillars of sustainability [13].

The resource is a frequently used word in sustainable building. Pearce (2006) presented an understanding of the sustainable building from another perspective. He enlarged the concept of resource, and stated that all the resources can be treated as "capitals", and there exist four main capitals, i.e. Man-made, human, natural and social, as shown in *Fig.3.2.* Each capital is a substitution of others. Reducing one capital is not consistent with sustainability unless another capital is increased [8].

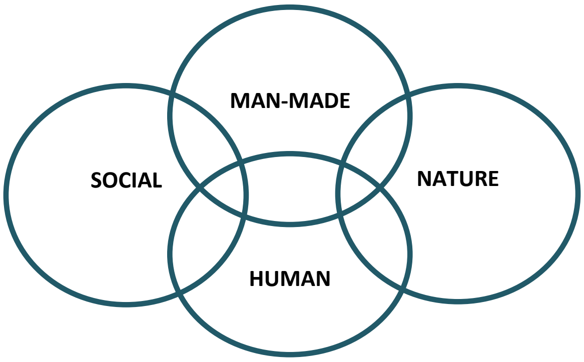

Fig.3.2. The definition of sustainable building based on the concept 'capital' [8].

Based on a study on sustainable construction mentioned earlier, including 3-column and 4-capital ideas, it can be concluded that the creation of eco-efficient buildings is a complex issue, where a number of different factors and fields intertwine and interact, such as natural factors, social worker, man-made and anthropogenic impacts. In addition, the sustainability is a static balance must be achieved between humans and nature, and economy and ecology.

3.4. Sustainability Assessment Method

There is a wide range of international and national tools and methods for evaluating or classifying buildings from an environmental or sustainability perspective. Some are being used globally; others concentrate on local, regional or national specifications [6]. These tools can split into two main categories: multi-criteria assessment tools and Life Cycle Assessment. Both of them are able to evaluate and communicate environmental attributes that related to the buildings [4]. The most established assessment methods are, among others, BREEAM (the Building Research Establishment Environmental Assessment Method, the first commercially available environmental assessment tool for buildings, introduced in 1990 in the UK), the American LEED (Leadership in Energy and Environmental Design), CASBEE (the Comprehensive Assessment System for Built Environment, Efficiency, widely used in Japan), DGNB (the German certification for sustainable buildings, Deutsche Gesellschaft für Nachhaltiges Bauen), EPIQR (Energy Performance Indoor Environment Quality Retrofit), or the Green Building Tool. On the EU level, there are two ongoing projects in the seventh framework program, super-Buildings and OPEN HOUSE [6].

Life Cycle Assessment (LCA) based on the use of these indicators, commonly known as synthetic indicators, that can analyse the real environmental impact of an intervention during the different stages of its life, “from cradle to cradle” or “from cradle to grave”[4].
The assessment tools, either environmental or performance-based, are under a constant evolution in order to overcome their various limitations and to be easily adaptable to different building types and to the constant technological development [12].

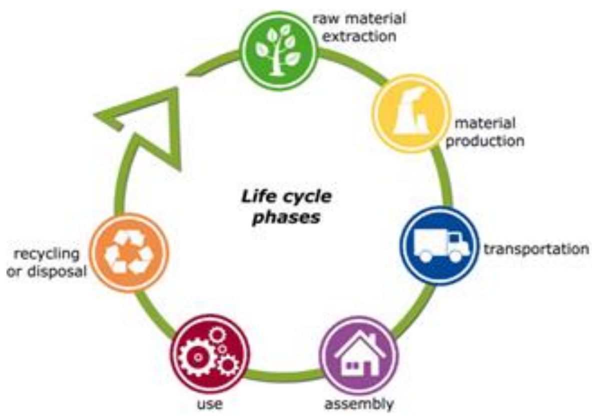

Fig.3.3. Life Cycle Assessment phases (raw material extraction, material production, transportation, assembly, use, recycling or final disposal) [4].

The number of tools is available today to support the building owner in making decisions, but most of them focus on specific aspects such as environmental, economic, or social issues. Few are adapted to handle architectural or cultural-historical issues, and none of the more established methods such as BREEAM, LEED, and DGNB addresses a complexity that balances technical, environmental, economic, architectural, cultural, and social values [6].

The most distinctive method for identifying the sustainable building assessment criteria is studying, surveying and comparing the various researches and finally achieves a set of criteria that can truly assess the performance of such buildings. Based on the comparison between LEED and some other studies, the key building sustainable performance criteria are extracted that can be a base for future studies in order to localize the criteria. These criteria contain 53 key elements grouped into 8 major areas as shown in *Table 3.1, Appendix A* [7].

It can be concluded that, there is a continual conversion from environmental to sustainable building assessment methods and tools and a movement from a purely bottom-up approach to a combined top-down approach.

3.5. Building Renovation

3.5.1. The Concept of Building Renovation

Renovating is the process of replacing or adding parts of the building or restoring the looks and performance of building parts to their original state or better [8]. The Latin word *re-novare* means to make something new again, new a second time [9]. According to Oxford English dictionary, renovation is the process of improving a structure. The word "renovation" is generally used to cover modernization, remodeling, retrofitting, restoration, adaptation, rehabilitation, refurbishment, reconstruction, retro-commissioning, and transformation [6], [8].

Principally, a renovation process has more or less the same phases of a new construction process. However, in renovation, more emphasis should be laid on the preliminary investigation phase in terms of time and resources to achieve optimum results [6]. Cooperation relationship should be set up during the design process between designers and occupiers. Pearce (2006) stated that residents' opinion has sometimes been better than scientific research. After renovation, occupiers should be given enough information to use new installed equipment in a right way to realize sustainability [9].

A renovation may fill the gap between simple housing maintenance and demolition, providing opportunities for establishing closed loops for the usage of buildings. It is an important tool for usage of buildings, shifting from 'cradle-to-grave' to cradle-to-cradle, as shown in *Fig.3.4*, which means 'Renovation' can provide an opportunity for buildings to reborn through reusing some old component that still reliable, and upgrade some elements that should 'retire'[8].

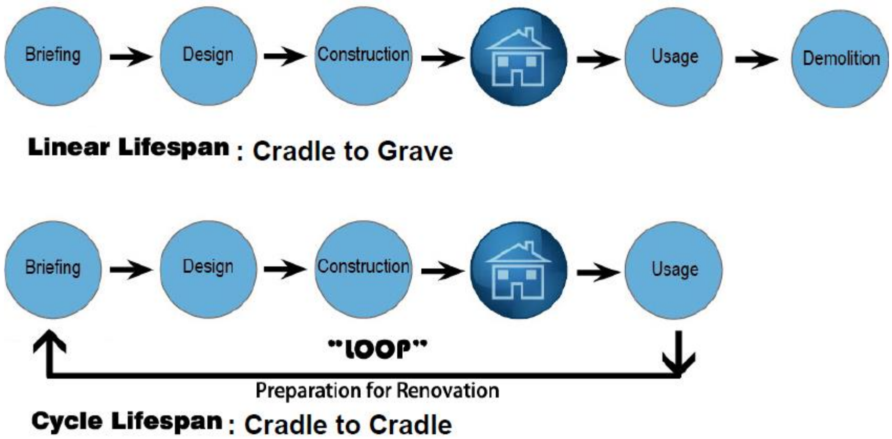

Fig.3.4. Two kinds of life span, Linear and cyclic lifespan [8].

3.5.2. The Building Renovation Strategies

There are two types of renovation strategies:

3.5.2.1. Heavy housing renovation

The idea of heavy renovation consists exclusively of maintaining the existing structure of the building. It therefore implies a new design of the envelope, the layout of the rooms and techniques associated with comfort, but also waste management during demolition and renovation works [2].

The heavy renovation will require:

• Considerable consumption of grey energy, and materials.

• Considerable production of waste.

This type of renovation is largely associated with new constructions and often, despite the significant extent of the works to be carried out and the budget allows for a radical improvement of the energy and environmental performance buildings [2].

3.5.2.2. Light renovation

The concept of light housing renovation consists of working in priority on the interior layout of the building; modifications of the shell being reduced to a minimum. It means maintaining the way the rooms are disposed, the size of the rooms, the relation between them and access to them [2]. Light renovation details are including the following processes:

• Little consumption of grey energy;

• Moderate use of materials;

• Limitation of waste

Production this type of renovation is usually connected to rehabilitation and allows for a significant improvement in energy and environmental performance of the buildings at a lower cost, without achieving the same results as a heavy renovation, nevertheless [2].

3.6. Different Approaches of Renovation

There are three types of building renovation in terms of its approach:

3.6.1. Careful Renovation

In 1983, Ingela Blomberg, Eva Eisenhower and Sonja Vidén defined, careful renovation as "*identifying conditions and qualities and taking care of them as much as possible in meeting new needs and goals*." The careful renovation was introduced as a method of renovating buildings based on the needs of the particular building, in compliance with the local and continental regulations. The aim was to protect the architectural, functional and technical qualities as well as the social values of existing dwellings and housing areas [9].

3.6.2. Environmentally-friendly renovation

Mainly motivated by ecological/ environmental issues, this approach proposes renovation actions that pay special attention to energy efficiency, water conservation and the use of renewable materials. The principal goal is that of preserving natural resources and avoiding environmental pollution [9]. It focuses on the issues of increasing air quality and outdoor space, which means preserve the biodiversity of the existing flora and fauna [8]. Another term has been used by other researchers in similar projects is "ecological retrofitting." In these projects, the existing buildings are considered as a physical resource and the main purpose of the renovation is to improve their environmental performance [9].

3.6.3. Sustainable renovation

The expanding on the ideas of environmentally friendly renovation, this approach includes cultural, social, economic and institutional aspects of the renovation project. The main goal is that of contributing to sustainable development in a wider context, with future generations in mind. Sustainable renovation projects, focused on long-term and wide environmental effects, can be better evaluated by analysing their intentions and the processes they used towards their goals rather than by investigating their immediate results [9].

3. 7. Building Renovation Policies

The control of the construction and building or urban renovation processes is carried out through legislative systems consisting of a set of legislation, regulations, and decisions issued by different parties and on successive periods of time. The existence of law and regulations in any country in the world generates success and a guarantee for the management of that country.

Renovation of buildings is a key to meet the EU's energy efficiency targets [16]. The Energy Performance of Buildings Directive (EPBD) was the first major attempt requiring all Member States to introduce a general framework for setting building energy code requirements based on a whole building approach [14]. In 2002, the EPBD adopted a set of minimum efficiency standards for both new and existing residential and commercial buildings [6]. In 2010, a recast introduced the requirement of implementing energy efficiency measures in case of a major renovation of a building and all EU Member States transposed it into national legislation and local environmental agencies [14]. In addition, it stated that all new and renovated buildings must comply with tough energy-performance standards and supply a significant share of their energy requirements from renewable sources after 2020 [6]. Moreover, the Energy Efficiency Directive (EED) (2012/27/EU) identified the existing building stock as "the single biggest potential sector for energy savings… crucial to achieving the Union objective of reducing greenhouse gas emissions by 80-95% until 2050 compared to 1990 [16].

The EU introduced further legislation in the form of the Energy Efficiency Directive (EED 2012/27/EU). The EED amends and subsequently repeals the Cogeneration Directive (2004/8/EC) and the Energy Services Directive (2006/32/EC). The EED introduces a considerable number of requirements in the Member States, including in the area of energy efficiency in buildings [14].

Despite this great potential, the targets the EU has set for renovations are not clearly defined or easily measurable. The EPBD obliges the Member States to create national plans for promoting the conversion of existing houses to nearly zero-energy buildings (nzeb), but no binding goal has been set yet[15].

In Iraq, there are many, legislation, regulations, and systems concerning to organizing the cities, especially that related to residential land use. While, their existence in different periods of time was inconsistent with the urban development, population and economic growth, on one hand, and has not addressed the building renovation issue in a sustainable perspective on the other.

A quick review of these laws will be made. Which includes the Roads and Buildings System 44 in1935, the Municipal Administration Law 165 in1964, the General Roads Law 1 in 1985 and Regulation Law on the use of External and Highways Road Barriers 55 in 1985, the Exploitation Beaches Law 59 in 1987, the Law 35 in 2001, amended the Municipalities Management Law 65 in 1964. These are available laws that related to pertaining the urban planning and land use for Iraqi cities [17].

* Most of the urban legislations share a number of factors that have limited their efficiency in performing their role.

* One law is exposed to more than one subject; this may cause a problem for users of legislation.

* The Laws are overlapped in a number of its articles or clauses.

*The deficiency of law's articles and the incompatibility of the local systems with the political and economic developments.

* The building controls in the regulated articles include the determination of the residential plot area, rebound to the street, and the percentage of structural coverage of the land area. In addition, the topics that covered by the regulations not exceed of the controls of the regulations, irregularities, and excesses that related to the construction of the new building.

Indeed, none of the existing legislation articles in Iraq in general and in Kurdistan, in particular, addressed the subject of sustainable renovation or even the building renovation.

3.8. Sustainable Renovation

Recently, the concept of “*sustainable renovation*” has started to become a part of architectural terminology, denoting an approach to renovation with the same aims as a sustainable building. The term “sustainable renovation,” as an abbreviation of “renovation for sustainable development,” is indicated in this text as a renovation process that is meant to renovate buildings with care for the architectural, cultural and social qualities, at the same time considering the impact on the natural environment and on people's health and comfort, and aware of the economical and managerial aspects of the renovation project. It takes into account the goals of careful renovation as well as the new concern for the natural environment and the projection towards the future presented in the debate about sustainability [9].

The United States Green Building Council (USGBC) views sustainable renovation as any kind of upgrade at an existing building, that is wholly or partially occupied, to improve energy and environmental performance, reduce water consumption, and improve the comfort and quality of the space in terms of natural light, air quality, in a way that it is financially beneficial to the owner [3]. The sustainable renovation will take into account of today's criteria for good building while maintaining the capacity to satisfy future needs without generating major environmental nuisance for current and future generations [2]. However, the major renovation of the building envelope to reach energy efficiency is scarcer as this is associated with high cost and low return of investment due to a number of factors including the market value of the property, the slow increase of energy prices, and difficulties transfer the costs upon rent [6].

Inspired by the understandings of sustainable building, a network for sustainable renovation of residential buildings was generated by a 7-dimensional model. The model has a pentagonal roof, with each corner representing an aspect of "environmental", "technological", "architectural" "social", and "cultural (emotional)", and all of them are under the heading of "mind" and closely related to "economic", as shown in *Fig.3.5*. All the seven dimensions are closely related, complementing each other and influence renovation efficiency [8].

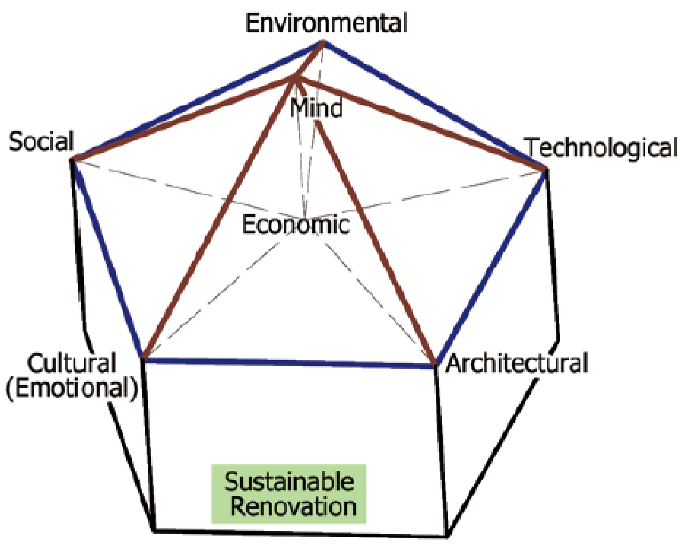

Fig.3.5. Seven dimensional models of sustainable renovation [8].

Many documents and programs refer to *sustainable renovation* to emphasize the intention of combining technical and functional improvements with social and institutional actions aimed at improving the sustainability of the building. Such intentions require the capacity to meet a process of change meant to decrease the environmental impact, but at the same time preserving or improving existing buildings, with respect and care for the existing context, as intended in the *careful renovation*. Incoherence with the aims of sustainability, it has become important to encourage democratic processes, sustainable renovation involving all the actors: owners, builders and material suppliers, technicians, authorities, inhabitants and other users [9]. Furthermore, renovation is more complicated than new construction as different buildings require different solutions, and even more so in protected buildings. Although their energetic and comfort performance may be lower than expected nowadays, these existing buildings can be considered very important from the sustainability perspective and their renovation has several advantages over demolition and reconstruction [4].

The following is a proposal to link common goals of *sustainable renovation* projects to different aspects of sustainability [9].

3.8.1. Health and Comfort aspects

The health and comfort benefits of *sustainable renovation* are shared with sustainable design in general. The Heschong- Mahone study showed that better day-lighting in a classroom in three cities improved student performance up to 20 percent. Herman Miller found that worker productivity, improved 7 percent after a move to a green, day-lit facility. A current *green building* provides or exceeds the comfort to which we are accustomed and more or less automated in adjusting to changes in external weather, climate, and time of day [1].

3.8.2. Economic aspects

It is unwise to pay too much, but it is worse to pay too little. When you pay too much, you lose a little money, - that is all. When you pay too little, you sometimes lose everything [8]. For an owner/occupier, it is easy to show that the premium for *green building* (averaging less than 2 percent of construction costs in new buildings) is easily outweighed by economic benefits. Building green is also correlated with rents up to 10 percent higher than comparable non-green buildings. In the big picture, achieving greater health and productivity the whole economy can benefit by [1]. In addition, the economic goal can be achieved through purchasing products with reasonable price, convenient house management, energy efficiency, low operational cost etc. [9].

3.8.3. Environmental aspects

The renovating of existing buildings should decrease the environmental impact of buildings; constrain the use of energy, natural resources and, building materials [9]. In addition, *sustainable renovation* should use renewable construction materials and the ultimate disposition of waste [8].

3.8.4. Social aspects

Sustainable renovation of existing buildings has also social objectives:

- Provide good and affordable dwellings and facilitate social stability and integration
- Raise awareness about one's own living place and promote sustainable behavior [9].

3.8.5. Architectural aspects

The basic function of a residential building is to provide a place for people to live in. *Sustainable renovation* on residential buildings is a strategy to enhance this function through a comfort and aesthetic form and environment, both inside and outside of the building [8].

3.8.6. Cultural aspects

In the field of common residential buildings, usually, it represents the memory of people and influences people's feeling of happiness and satisfaction. *Sustainable renovation* refers also to cultivating an enhanced humanistic environment. A good community environment and harmonious neighborhood will have a positive influence on people's everyday mood [8], [9].

3.8.7. Institutional aspects

Sustainable regeneration is aimed to:

-promote participation and involvement of the inhabitants.

- provide good management and maintenance [9].

3.9. Conclusion

Sustainability is the consequence of balanced interconnection between nature and society; however, it can't be measured or delineated only scientifically. In order to achieve sustainability, our habits, methods of thinking and lifestyles should be changed and should respect cultural social values, and reduce the environmental resources consumption to protect them for future generations. Based on a study on sustainable construction, it can be concluded that the construction of buildings with environmental efficiency requires the interaction of a number of different factors and fields, such as natural factors and social factors. In addition, There are three approaches to building renovation including; careful renovation, environmentally-friendly renovation, and sustainable renovation. The main goals of these approaches of renovation are protecting the architectural, cultural, social, material resources, and improve the environmental performance.

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4. The Sustainable Renovation Strategies

4.1. Introduction

This chapter presents a literature review that helps to identify the most appropriate strategies for providing thermal comfort, increase indoor air quality, and harness free energy from the ambient environment in residential buildings during the renovation process, these strategies included passive, active, and hybrid strategies. The priority is focused on the passive cooling, heating, and ventilation as an integral part of architectural elements. However, in this chapter, efforts have been made to briefly document the important aspects that focus on traditional cooling and ventilation techniques that were used in the vernacular architecture and influenced mainly by the local climate, including wind catcher, courtyard, and atrium, in order to increase knowledge and as far as possible to be applied to current residential buildings by evaluating and replicating these characteristics. Finally, the energy sources, including renewable and non-renewable energy are being discussed to take advantage of the renovation process.

4.2. Sustainable Renovation Strategies

The implementation of strategies that aimed to promote thermal comfort and limiting energy consumption is clearly a fundamental aspect of sustainable renovation of the residential building today. Thereupon, the most appropriate strategies for the renovation process should be clarified.

4.2.1. Passive Strategies

Passive design is defined as the use of architecture elements and climate to provide heating, cooling, ventilation, lighting, and maximizing the comfort and health of building users while minimizing energy use [1],[18]. Traditional architectures have been an illustrative example of climatic design and represent the techniques to improve their living conditions [22]. It is important to critically reflect on passive strategies as doing both minimizing the negative impacts of the climate while taking advantage of its positive effects [1].

4.2.1. 1. Solar and Thermal Control Strategies

The sun's path directly influences the amount of solar radiation on surfaces, that has the highest angle in the summer, and the lowest in the winter [1], thus the design of the building envelope should seek to control the absorption of solar radiation and its effect indoors. In hot climates areas, thermal and humidity control is essential for the building skin. Solar control can be achieved by the optimal choice of orientation, sun shading, building compactness, window to wall ratio (WWR), and landscape elements. While thermal control can be achieved by the use of wall cavities, thermal mass, and thermal insulation [2].

4.2. 1.1. 1. Building Envelope

The envelope is commonly the element of a building that is most exposed to the ambient and so to the sun [2]. The building envelope is the front line of the building's interface with the exterior environment and climate. It can profoundly control heat gains and losses through it [1]. In most climates, buildings require a tremendous amount of energy to achieve interior comfort, to reduce this energy demand the building envelope (roof, external walls, doors, and windows) must obstruct the transfer of energy [21]. Therefore, the design of the building envelope needs to address and neutralize thermal energy conduction, convection, and radiation loads related to thermal transmission, solar radiation, and infiltration. Neutralizing begins with the optimization of building's orientation and geometry [1]. The renovation of the building's envelope is affected by microclimate and with a well-designed envelope, can provide interior comfort and reduce energy demand.

4.2. 1.1. 2. Infiltration

Infiltration is like having small gaps in the envelope which allow air to pass directly between the interior and exterior environments [1]. In cold climates, much more energy is lost by air infiltration through poorly insulated walls than through the window frame or glass [21], which represent up to 50% of the heat loss in the building [23]. The air barrier is one of the fundamental elements in any building enclosure that addresses air-tightness. Therefore, it must be designed and constructed as complete, continuous system, extending over the entire exterior envelope [1]. For energy efficient buildings the recommended outdoor air flow rate is 0.35 ACH as a minimum value. The average value is around 0.5 ACH, while a "typical" house has an outdoor air flow rate of 0.78 ACH. For a leaky house, the value rises to 1.6 ACH [10].

Furthermore, when considering a renovation of windows, the first priority to prevent air infiltration [21]. In addition, to achieve a high level of airtightness the obligation of design standards for air leakage and a blower door testing is proposed during the building renovation process.

Fig.4.1. Using expansion foam to seal the air gaps [23].

4.2. 1.1. 3. Thermal Insulation

Beyond infiltration, the primary component affecting energy use of a building envelope is the insulation value. The insulation benefits can vary greatly depending on a building's climate zone, solar configuration, humidity controls, and construction method [21],[23]. There is a trend toward higher insulation levels in buildings because they are cost-effective means of reducing thermal energy loads and neutralizing the envelope [1],[7]. Notwithstanding, the building insulation types and their location determine how well the home will perform through the diversity of climate conditions and future challenges [23].

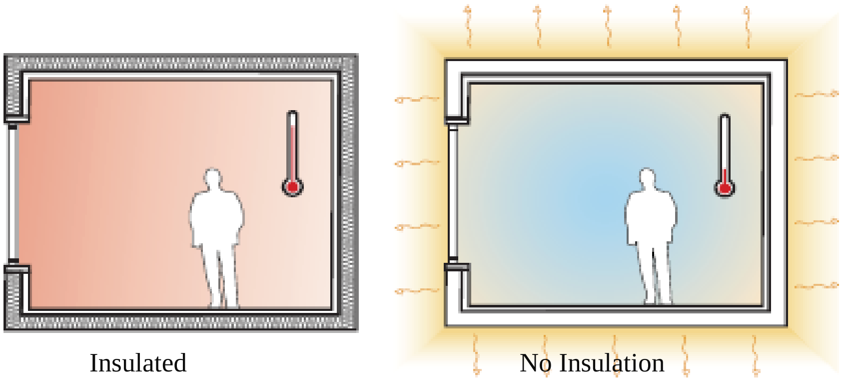

Fig.4.2. The difference in the heat reservation between the room with and without insulation [15].

4.2. 1.1. 4. Building Orientation

One of the earliest design decisions essential in passive heating is the orientation of the building to the sun [1],[20]. The orientation of the building needs to respond to both the sun and wind [1]. It is also important for energy production in passive solar buildings, for heating, cooling, daylight, or electrical production [20]. The orientation affects the angle at which the sun enters windows, causing overheating in the summer. Good building orientation may improve passive gains and thereby reduces the need for mechanical heating or cooling systems [15]. Careful orientation of buildings and windows and solar control strategies can block the unwanted heat from the summer sun, yet still, allow the sun in for winter heating and daylight [20]. Furthermore, the best practice for solar control is maximizing the south and north facades [1].

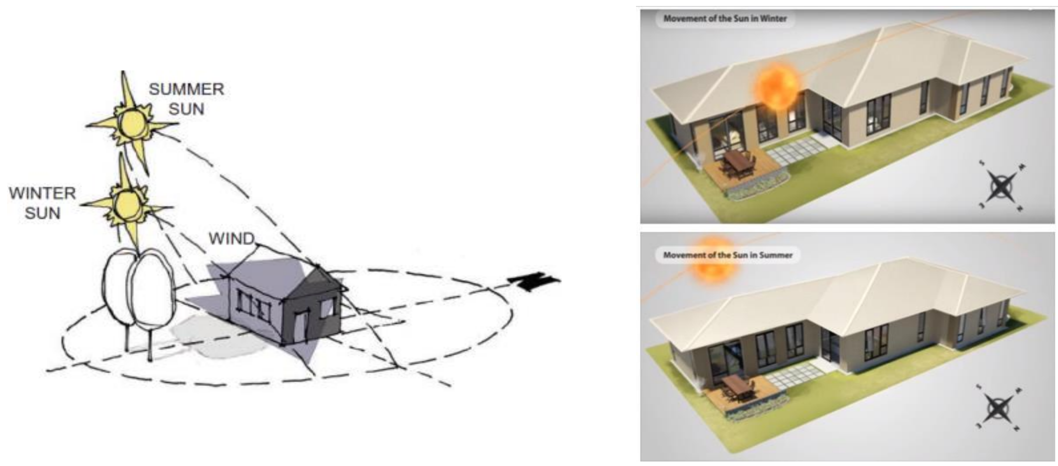

Fig.4.3. The Sun’s path in the summer and winter seasons [15].

4.2.1.1.5. Shading

The usage of shading becomes more important in a warmer climate in the summer season. Using suitable shading building element or device in the summer, it can reduce cooling energy, a device such as overhangs, awnings, and blinds that can be used for this purpose [10].

The role of solar shading device is to reflect (or absorb) solar radiation, particularly during the cooling season [11]. In addition, shading devices are critical for occupant visual and thermal comfort and for minimizing mechanical cooling loads. The shades can be placed primarily on the exterior, secondly in the interior or in the plane of the windows [19]. Shading design should respond to the seasonal cooling needs of a building, the building's orientation, and the sun's path throughout the year [1].

The north side can be provided with large, - but well insulated - windows and shallow overhangs since this orientation will provide diffuse natural daylight mostly without direct solar heat gain. South, east and west orientations for windows should be designed with deeper overhangs for protection against direct sunlight and so more heat gain [19]. Provision of sunshades or light shelves at south facades and shading fins at east and west faces can control excess of direct sunlight and allow the glazing to be tuned more for temperature difference, to prevent heat to escape in cold climates, or prevent entering of heat in hot climates [21]. The width of the overhang is generally determined by the solar angle of the sun on the 21st of June (summer solstice) and the height of the window relative to the width of the soffit. It should totally shade the window in June and allow full solar penetration through the window on the 21st of December (winter solstice) [23].

Fig.4.4. Adjustable louvers are used for shading and solar control [15, 23].

In hot and dry climate it is important to consider the sun's path and the position and axis of shading device during the renovation process, in order to prevent extra solar gain in summer and allow it to enter in winter.

4.2. 1.1.6. Building Shape

The building shape is an important element at an early stage of the design and it has a strong impact on the energy consumption of the building [10]. The building shape is also important for the natural ventilation principle [9]. The exterior surface area to volume (A/V), of the enclosed space, should be decreased to reduce thermal transfer through the envelope that can help to conserve energy [1]. The studies showed that an L-shaped or lengthy house consumes more energy than a compact and cubic one because it causes more heat loss [10]. However, a shape as close to a square (ideally a globe or dome) as possible is optimized to minimize corners and maximize floor area in relation to the outside building envelope area. Row- houses and multilevel town-houses are other forms of design which achieve maximum floor area and minimize opportunities for heat loss [15]. The appropriate shape for the building in terms of energy efficiency is the cubic shape, regardless of the microclimate. Therefore, it should be taken into consideration during the renovation process.

4.2. 1.1.7. Thermal Mass

Thermal mass is any dense of material that absorbs heat during the day and releases it at night after the sun has set [23]. It is also the ability of a material to store heat energy and then releases it gradually [15]. Solar radiation enters through the transparent elements of the building and heats material in the interior [20].Therefore, thermal mass needs to be carefully coordinated with sun-shading in order to avoid building overheating in the summer [21]. Thermal mass can be used on the exterior envelope in hot climates as a means of slowing down temperature swings through the envelope [1].

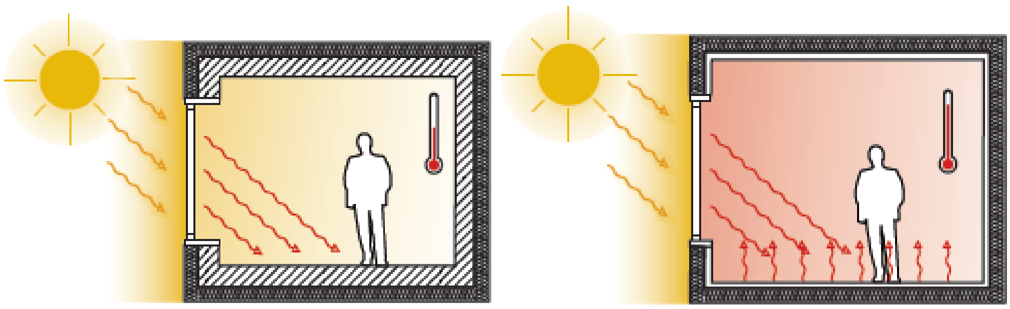

Fig.4.5. The structure with and without thermal massing [15].

High thermal mass is usually used in conjunction with these passive cooling strategies to act as a heat sink that controls and prolongate heat absorption. At the same time, thermal mass reduces the fluctuation of the indoor environment and protects it from the severe dry outdoor climate and the large temperature swings. In addition, the effectiveness of the thermal mass depends on the exposed surface, material properties, and the diurnal dry-bulb temperature variation [2].

4.2.1.1.8. Window Opening

In the buildings, most of the heat gain or loss comes from openings such as windows. It is clear, therefore, that windows are the main element in the transfer of huge amounts of heat between a building and the exterior environment [18], and so the most important objects for effective strategies to make use of solar gain and limit energy loss. When the sun is low in the sky, (close to the horizon) the light hits the window almost perpendicular to the glass. In this case, the heat gain is at a maximum, and when the sun is higher in the sky, the angle is increased, the glass reflects more of the light. In this instance, less heat is transferred to the building. Therefrom, windows on the south elevation can generally exploit most of the sun [15].The main factors affecting the solar gain through the window within the building are orientation, size, type of solar glazing, and of course the shading. Recent research estimates that windows are responsible for 39% of commercial heating energy use and 28% of commercial cooling energy use [19]. Nevertheless, windows have a numerous functional aims, including daylighting, natural ventilation, passive solar heat, views, health, privacy, security, moisture control, and acoustics. One of the key factors in glazing system design is the orientation and the window to wall ratio (WWR) for the building [1]. The WWR of 25% on the south side is an optimum in hot climates while the large south windows are preferable in cold climates from the thermal performance point of view. The north orientation is preferred for a large glass to wall ratio [19].

4.2.1.1.9. Double skin

One of the strategies for neutralizing large glazed area is to use a double skin façade, *(*See *Fig.4.6, Appendix A).* The advantage of this strategy is that the cavity between the inner and outer glazed walls can facilitate solar control and develop high thermal resistance. Double skin facades can be integrated into existing buildings to enhance energy performance and provide new architectural expression [1]. Natural ventilation is possible through extraction of air via the double-skin and as such this constitutes a form of wind tower application [5]. The function of the natural ventilated double skin based on the same principle as for the conventional buildings. The only difference is that windows (in the inside layer) are opened into a controlled climate, thus naturally ventilated system use the cavity control, the air-flow with stack effects and pressure from the wind effects [11].

Moreover, cross flow ventilation is used with the double facade imitating a stack and the dominant driving force is driven by the thermal uplift or wind [5]. For the proper ventilation purpose, it is recommended a minimum distance of 15cm between the sun shading and the external skin of the façade [11]. In hot and dry climate, the high temperature of the glazing would result in an uncomfortable indoor environment. Therefore, double skin facade will be a good strategy for controlling heat gain and natural ventilation in the building that needs careful considerations during the sustainable renovation design process.

4.2.1.1.10. Landscape

Landscape elements can help a great deal with solar control. It is also perfect for providing needed shade for windows or walls that face east or west [20]. Vegetation that block winter sun should be pruned, deciduous trees should be planted as they shed their leaves in winter, allowing the sun [15]. The other important sustainable points of landscaping are producing oxygen for the environment and reducing air temperature [18].

A green roof (See *Fig 4.7, Appendix A)* is another solution for the passive control, which defined as a '*building roof covered by grasses or plants which lie over a waterproof membrane'* [18], [20]. It is regarded as the best method of insulation for a roof [18], and reducing the speed of water runoff, reducing the heat island effect of intense from dark roofs, and reducing heat gain into the building [21]. Literally, in the hot and dry climate landscape elements have a major significant role in providing delightful shading; increasing air humidity that not only cools the house, it also decreases the air dust and increase the environment clean.

4.2. 1.1.11. Daylighting

Day light was an integral consideration in building design until the 1950s.The history is full of wonderful architectural achievements where daylight was a major consideration [20]. Building layout should respond to the path of the sun. When making decisions about lighting it is important to consider that appropriate building layout and orientation can reduce the need for artificial lighting and thus improve occupant comfort [15], when done correctly, it provides cool light, compared to artificial light, so using daylight effectively in place of artificial lighting can reduce both the internal heat gain in a space and the energy to cool it [1]. The basic goal of lighting design is to provide a comfortable, healthful, pleasant, productive, and safe visual environment for people. The reflectance of roofing materials may be used to increase light gain through roof monitors and clerestory windows [20]. Indeed, they are two techniques for bringing daylight into the space; Side-lighting and Top-lighting, which bring daylight into space from apertures in the wall and roof, as shown in *Fig.4.8, Appendix A.* It can also contribute to lower floor levels through the use of atriums, or other devices [1]. As well, light coloured paints can make spaces look and feel brighter while also mitigating heat island effect [15].

4.2. 2. Thermal Zoning Strategies

Thermal zoning within a building refers to the strategic arrangement of spaces to take advantage of the thermal synergies and qualities of spaces, and their relationship to other spaces [1]. The positioning of the building spaces with regard to the path of the sun, prevailing winds, openings locations and landscape design can lead to improved thermal comfort in relation to the functions and climatic requirements [2]. In addition, sunrooms and subspaces can be used in heating-dominated climate to provide a means of passively heating adjacent spaces [1].

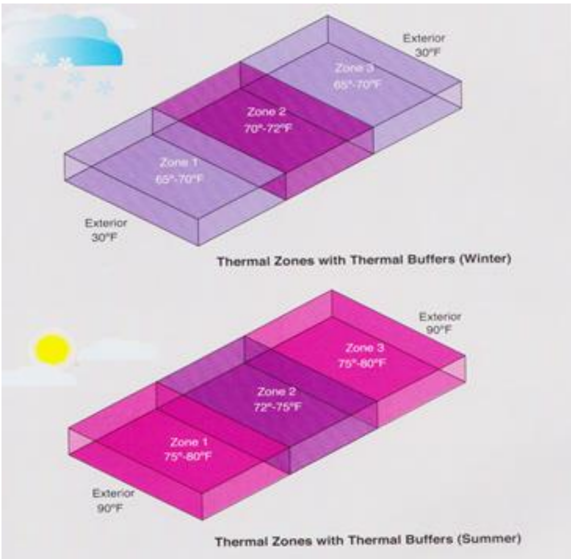

Fig.4.9. Thermal zoning in different seasons [1].

In hot climates, the concept of thermal zoning or heat buffering entails creating intermediate semi-controlled outdoor zones that serve as an active double skin or even triple skin using bioclimatic landscape design strategies. These outdoor zones serve to block the heat in the mass of spaces and include courtyards, deep veranda, porches, and earth-sheltered partitions of buildings [2]. The shade and natural ventilation combination play a significant role in the thermal zoning process that aims to improve the temperatures in the buildings.

4.2. 3. Passive Cooling Strategies

A passive cooling is a bit more complex if compared with the passive heating, but equally achievable in all climates. The sources for passive cooling are the three thermal sinks of cooling night air, night sky radiation, and evaporation wet surfaces [20]. Five main passive cooling strategies are commonly adopted; natural ventilation, nocturnal/night ventilation, direct evaporative cooling, indirect evaporative cooling and ground cooling. Night ventilation and direct evaporative cooling are suggested for hot-dry climates, while natural ventilation and indirect evaporative cooling may be strategies suitable for hot-humid climates [2]. The opportunities for passive cooling are influenced by building type and its size, but efficient design can emerge passive cooling to the small-scale skin-dominated buildings and large building with low skin to volume ratio [20]. The application of passive cooling in the hot climates is a most appropriate strategy to release the heat in buildings; therefore, it should be taken into consideration during the design of sustainable renovation process.

4.2. 3.1. Natural ventilation

Natural ventilation is a ventilation principle that makes use of the natural driving forces to transport the air in a building, without requiring mechanical or electrical driven components [9], [16], [1]. It is dependent on three climatic factors: wind velocity, wind direction, and temperature difference. The speed and direction of the wind over a structure generate a pressure field around the building [16]. Correspondingly, natural ventilation is an effective cooling strategy that saves energy consumption in the buildings [8], [16], [18]. Typically, the energy cost of a naturally ventilated building is 40% less than that of an air-conditioned building [8]. Furthermore, natural ventilation has become a suggestive solution not only for reducing the energy usage and cost but also for providing good indoor air environment while sustaining a comfortable, healthy, and productive internal climate [16],[1],[5].

The location of ventilation openings determines the temperature distribution within a space. If two vents are open, one at the top of the space and the other at the bottom, cool air will flow into the lower opening, and warm air will flow out of the upper opening[8]. Veritably, there are three fundamental approaches to natural ventilation: Wind-Driven Cross Ventilation, Buoyancy-Driven Stack Ventilation, and Single-Sided Ventilation [13], [8], [9]. The single-sided ventilation is more acceptable than cross ventilation in spite of having lower efficiency [8].

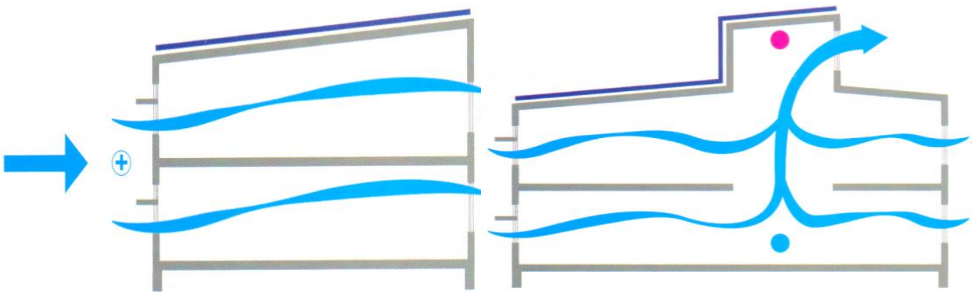

Fig.4.10. Cross ventilation principle (left); Stack ventilation principle (right) [1].

The most common characteristic elements in the building to enhance natural ventilation are windows, wind towers, courtyard, wind scoops, chimneys, double facades, stack, atriums and embedded ducts [9], [4], [16]. The most common natural ventilation cooling techniques that are used for centuries in the Middle East and some European countries are atria and courtyards [16].

4.2. 3.1.1. Wind catcher

Wind catcher or wind tower is a traditional architectural element that has been used in the Middle East for centuries, it used as a natural device for ventilation and cooling of buildings in the hot and arid or humid climates [3],[5],[14]. Wind towers are small towers installed on top of buildings. They have different shapes and structures [3]. They are influenced mainly by local climate, culture and the availability of the building materials [16]. The mechanism of functioning has captured the wind at roof level and direct it down to the rest of the building without using any kind of mechanical system [18],[5]. Accordingly, the air becomes cool and heavy. The major factor of airflow in a wind tower is the gravity force without the use of a fan [14].

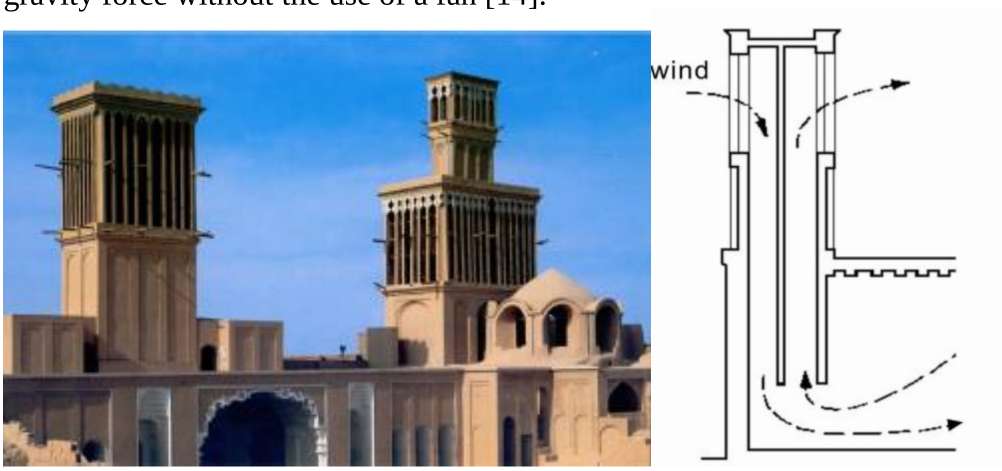

Fig.4.11. The two story wind tower building in Yazd, Iran (left); Section of wind tower (right), [3].

The wind tower must be high enough above the structure to prevent rooftop turbulence. The height of the wind tower (distance from air entrance to discharge point) also affects

the ventilation rate. Similarly, taller wind towers will have stronger wind passing over it, hence a greater negative pressure, generally the wind tower rises up to 5–33 meters [16].
In summary, wind towers can be employed in the hot arid climates and provide a great saving in the electrical energy consumed for the cooling of the buildings in summer.

4.2. 3.1.2. Courtyard and Atria

Common natural ventilation and thus the cooling technique is the use of atria and courtyards. The courtyard can provide a relatively enclosed space to channel and direct the airflow, which is promoted by large openings and results in convective natural ventilation in and around a building, as shown in *Fig.4.12, Appendix. A* [5]. It is exposed to the solar radiation for long hours. Hence, the air in the courtyard becomes warmer and rises up, to replace it, cool make air from the ground level flows through the openings of the living spaces, thus creating the indoor air flow. During the night, the cooling process is reversed. This system can work effectively in hot and dry climates, where daytime ventilation is undesirable [16]. The atrium works in a similar way and is used to provide comfort through a progressively acceptable transmission of the external environment to the inside.

In summary, wind-driven ventilation can be enhanced using courtyards and atria. The airflow pattern will determine the potential for natural ventilation. Stack effects can also help especially in atria where the vertical height is usually greater. Atria and courtyards are confined to particular types of architecture and again depend on changeable driving forces [5].

4.2. 3.2. Night ventilation

Night ventilation or night cooling is an integral part of the ventilation strategy. This ‘free cooling’ occurs during summer months when the control dampers are fully opened to allow the cool night air to invade the building. Thus the building is cleansed of any stale air during the night ready for occupant use in the morning [5]. Hot-dry climates have more night sky radiation cooling that can create cooler night air or can be used directly by a building’s elements and configuration [20]. In addition, the efficiency of night ventilation strategy is higher when the active cooling time is nearly equivalent to the night ventilation operation time [16]. The effect of night ventilation with an exposed thermal mass could reduce the cooling loads, the size of cooling equipment, and the overall energy consumption [2]. However, developing summer night flushing and pre-cooling strategies may result in tremendous cooling energy saving in high-mass buildings [21].

4.2. 3.3. Direct Evaporative Cooling

Passive evaporative cooling is a traditional method used in old buildings in the Middle East, to improve its ventilation and thermal performance, which is used in conjunction with a canal or underground water system, as shown in *Fig. 4.13, Appendix A* [16],[1],[20]. In the direct evaporative cooling process, pads sit at the top of a wind tower with pump re-circulating water over them. Hot air passes through these pads and cooled by the water evaporation. Cool moist air is denser than ambient air and sinks down the tower and into the enclosed space [16]. In this process, sensible heat is converted into latent heat at a constant wet-bulb temperature. This strategy has been suggested for dry -climates with noon relative humidity below 40%, maximum WBT 22ºC – 24ºC and maximum DBT 42ºC – 44ºC [2].

4.2. 3.4. Indirect Evaporative Cooling

In prevailing hot humid climates, the application of indirect evaporative cooling is a useful strategy for providing hygrothermal comfort conditions to the building's occupants. As well, the applied system can be achieved in a building by circulating cooled water within some elements of the building's structure, such as roof, walls and floors [24]. Indirect evaporative cooling uses the same evaporative cooling phenomenon to reduce the zone dry-bulb temperature but without increasing its moisture content. This can be adopted as a passive strategy by integrating roof sprays, moving water film over the surface and roof ponds together with a high conductivity roof slab. In these passive applications, the building structure is cooled by water evaporation from the exterior surface which acts as a heat exchanger to cool the adjacent spaces without raising their moisture content [2]. Thus, these cooled elements provide and transfer radiant and convective cooling to the interior spaces, without raising the indoor humidity. Therefore, this strategy is highly recommended in locations with high air moisture content. [24]. In addition, indirect evaporative cooling can also be adopted as a low energy cooling strategy in either air systems or radiant systems [2].

4.2. 3.5.Ground Cooling

The ground can act as a heat sink for the building to absorb heat by conduction through the ground, and by convection within a circulation fluid. These passive applications deal mainly with the surface ground temperature which follows the ambient conditions at a slower rate [2]. In point of fact, this system is basically a thermal transfer process: It moves heat from the earth to provide heating in the building: and, conversely, it moves heat from the building to the earth to provide cooling in the building [1].

Semi-buried buildings passing fresh outdoor air through earth tubes could exploit the cooling potential of the ground [2]. There are two main types of ground source loops, horizontal and vertical. Vertical loops are very common because they require only a relatively small site footprint on which to install and develop the ground coupling through very deep piped wells[1],[23]. Furthermore, due to the stability of earth temperature, if compared with air temperature, the ground cooling strategy can be used for cooling the building in hot climates. Despite the fact, the ground may require being cooled by shading, planting or irrigation.

4.3. Active Strategies

Overall, passive strategies cannot be counted on to always meet heating, cooling, ventilation and lighting needs. For that reason, the building will need active systems for conditioning when passive strategies are not available [1]. Active strategies are concerned with rejecting excessive heat from the indoor environment to the outdoor using appropriate mechanical heat exchange mechanisms which typically involve some combinations of fans, refrigerant loops, sensors and controls, pipes and ductworks, and other mechanical types of equipment (such as fans, pumps, chillers, cooling towers)[2].

4.3.1. Conventional Air Conditioning Systems

Due to the global climate change and high population density in many developing countries in hot climates, and in order to protect against exposure to this high heat, demand for air-conditioning equipment have increased significantly in the buildings. As a result, cooling becomes an important energy consumer in residential buildings, however its impact on the carbon dioxide emissions and electricity grids are high. This section is going to focus on a number of different air conditioning techniques.

4.3.1.1. Active Ventilation

Active ventilation particularly affects air and moisture flow through the building. For instance, it changes pressure differences across a building and can be achieved with a variety of mechanical methods [1]. Electric fans are one of the oldest ventilation mechanical devices, which are almost a daily use appliance in hot and arid climate, especially in the summer season that helps in maintaining indoor temperature closer to ambient due to a higher rate of air change than what could be achieved through natural ventilation. The most common type is ceiling fans beside pedestal, walls and table fans, as shown in *Fig.4.14, Appendix A,* elevated airspeed is effective at increasing heat loss when the mean radiant temperature is high and the air temperature is low. If the mean radiant temperature is low and humidity is high, elevated airspeed will be less effective [2].

4.3.1.2. Window Air Condition

Window air conditioner is the most commonly used air conditioner for single rooms *(*See *Fig. 4.14, Appendix A).* In this conditioning system, all the components, namely the compressor, condenser, expansion valve or coil, evaporator and cooling coil are enclosed in a single box. This unit is fitted in a slot made in the wall of the room. A window unit works best if just one room is cooled with appropriate efficiency and cooling load rating for the space being cooled [2].

4.3.1.3. Split Units

The split air conditioner comprises of two parts: the outdoor unit and the indoor unit *(*See *Fig. 4.14, Appendix A).* The outdoor unit, fitted outside the room. The split air conditioner can be used to cool one or two rooms. Electrical running costs over several years are high and the average life cycle is very short up to 10 years.

4.3.1.4. Packaged Systems and Units

The Packaged air conditioner is used if more than two rooms or a larger space in a house are cooled. All the components are housed in a single box. The cooled air is thrown by the high capacity blower, and it flows through the ducts laid through various rooms. In contrast, to split system units, all components of a complete cooling system are contained in one location, making package units ideal for situations in which indoor space is at a premium. Similarly, electrical running costs over several years are high and the average life cycle is very short up to 10 years. [2].

4.3.1.5. Variable Refrigerant Flow System (VRF)

The Variable Refrigerant Flow (VRF), or Variable Refrigerant Volume (VRV) is different with conventional types of unitary air-conditioning systems [1],[2]. The VRF system can be regarded as a larger version of the split-type air-conditioning unit, in which a compact air-cooled condensing unit located outdoor and connected to several dozens of indoor fan coil units less than 100 tons, as shown in *Fig.4.15, Appendix A* [2].

The system is able to regulate the refrigerant flow rate to the terminals individually according to the cooling demand of the zone served by each indoor unit. VRF is significantly more expensive than splits and, the system is more complicated, it can cost more to maintain and repair. Electrical running costs should be better with the VRF, which should, in theory, make the total cost over several years tip the balance in its favour. Residential VRF systems contain refrigerant gas so will require annual leak checks and records to maintain the systems for good performance and quickly fix any leaks [2].

However, the VRF is particularly well suited for applications that are likely to have many hours when some spaces are in heating while others are in cooling, the system has a number of limitations and defects for example, and a large number of refrigerants are needed [1].

4.3.1.6. Central Air Conditioning

The central air conditioning system is used for cooling residential apartments over 100 tons. Chilled-water system predominates the residential buildings for cooling [2]. Central air conditioners circulate cool air through a system of supply and return ducts.

Supply ducts and registers (i.e., openings in the walls, floors, or ceilings) carry cooled air from the air conditioner to the home, which becomes warmer as it circulates through the home; then it flows back to the central air conditioner through return ducts and registers [25].

In the unitary AC systems, one compressor is associated with one air-handling unit cooling coil. Hence, the flexibility and redundancy of operation are limited. However, the COP of chillers is high and thus consumes high energy. As system size and sophistication increase, maintenance becomes more difficult. To improve the COP of the AC and avoid condensation, the building has to be very well insulated and sealed for air tightness [2].

4.3.1.7. Heating, Ventilating and Air Conditioning (HVAC) system

Supply Ventilation for Air Conditioned Buildings has long been recognized that the control of air flow is a crucial and intrinsic part of heat and moisture control in sealed or air-tight buildings [2]. From an energy perspective, a heating or cooling load is the amount of heat that needs to be added to or removed from a conditioned space in order to ensure occupant comfort [1],[19]. Heating, Ventilating, and Air Conditioning (HVAC) equipment perform heating and/or cooling for the buildings. It may also be responsible for providing fresh outdoor air to dilute interior airborne contaminants such as odors from occupants, volatile organic compounds emitted from interior furnishings, chemicals used for cleaning [28]. HVAC systems also allow outdoor air introduced into the house to be filtered to remove pollen and dust or dehumidified to provide humidity control. It also needs to be more energy efficient while adhering to an ever-increasing demand for better indoor air quality and performance [19].

4.3.2. Non- Conventional Air Conditioning Systems

4.3.2.1. Radiant Heating and Cooling

A radiant heating and cooling system refer to temperature-controlled surfaces that exchange heat with their surrounding environment through convection and radiation [2]. Radiant heating and cooling rely on surfaces exposed in the space to deliver heat and cooling. Typically, ceilings or floors are used as the heat exchange surfaces. Floors tend to be better suited for heating, and ceilings for cooling. In many cases the not-ideal orientation may prove to be the better approach: for example, providing both heating and cooling from the ceiling because of the economy and easy to maintain [1]. In hot and humid climates, radiant cooling systems are not suitable. Due to the high relative humidity, chilled water temperatures of 6-8^{o}C are required in the warm and hot weather conditions to dehumidify supply air sufficiently to prevent condensation with radiant slab cooling [2].

4.3.2.2. Displacement ventilation With Perimeter Heat

The idea of displacement ventilation is to create a pool of cooler, cleaner air at the bottom of the room. This results in a stratified region high in the room that is warmer and moves contaminants up in this stratified zone which is then removed.

Depending on the balance between ventilation requirements and heat sources in the room, displacement ventilation commonly provides ventilation effectiveness 1.2 to 2.5 times that of an overhead mixing system. This is highly beneficial in the summer and winter when conditioning outside air can be a major energy draw. Because displacement ventilation uses, such a mild supply temperature, it can often be achieved through lower-energy approaches . One of the limitations of the displacement ventilation system is that it uses air to cool working fluid- in fact, slightly more air than a conventional mixed-air system, in most cases. With careful design, the benefits of reduced outside air requirement and lower energy heating/cooling sources will outweigh the slight increase in fan energy [1].

4.3.2.3. Chilled Beams

Chilled beams are a strategy that can provide some of the benefits of a radiant system, but typically at a lower cost. The beam consists of hydronic piping suspended high in the space, with metal fins along its length to increase the surface area for convection. The beam cools the surrounding air, which drops down into the occupied space by natural convention. They are, however, well suited for interior locations that are not expected to need heating [1]. Furthermore, chilled beams classified into two categories, passive and active. Passive chilled beams do not work well for heating. Active chilled beams use ventilation air to enhance the output of the fin tube that is used for both heating and cooling. One drawback of the chilled beam system is that the nozzles in the beam cause a large additional pressure drop in the ventilation system [1].

4.3.2.4. Heat Recovery

Heat recovery is an extremely valuable strategy to reduce the heating and cooling requirements for ventilation. There are a number of types of equipment that achieve heat recovery. Common types, listed in order of increasing performance, are run-around loops, cross-flow heat exchangers, heat pipes, and heat wheels. Depending on the type of heat exchanger used and the airspeeds through the heat recovery device, 50% to 80% of the energy can be transferred from one airstream to the other. The energy recovery strategies just described transfer “sensible heat”– that is, no moisture. This approach can be beneficial in cold, dry and hot humid climates [1].

4.3.2.5. Evaporative Cooling

Evaporative cooling systems are based on the conversion of sensible heat to the latent heat of evaporated water, where water is supplied mechanically, thus the temperature of air reduced. Currently, evaporative cooling methods include fan pad, fogging system and roof evaporative cooling [2]. The simplest form of evaporative cooling is called direct evaporative cooling. With this approach, air being supplied to a building, cooler and more humid [1]. Indirect evaporative cooling, a modification of evaporative cooling adds moisture to a “scavenger” airstream separate from the air entering the building. Because of the limited effectiveness of the heat exchanger, and its associated pressure drop indirect cooling has a more limited capacity to lower the outdoor air temperature, and comes with a higher fan energy penalty than direct evaporative cooling [24]. Therefore, direct evaporative-cooling is a promising strategy for hot and dry climate, while indirect evaporative cooling is a promising strategy for the humid climate.

4.3.2.6. Heat Pumps

Heat pumps operate on the same principles as standard cooling equipment, but they can operate in reverse as well, to produce heating. The cooling capacity of the cycle is equal to the amount of heat drawing into the evaporator, and the heating capacity of the cycle is the heat rejected from the condenser, which is equal to the evaporator heat plus the compressor energy. It works on the principle of vapour compression; it's simply a refrigerator running in reverse [1], [23]. One of the advantages of heat pumps is their flexibility. They can draw heat from a variety of sources, such as outside air, and air from an indoor space that need cooling. The smaller the temperature difference between the condenser and the evaporator the more efficiently heat pumps work [1]. In summary, heat pumps can draw heat from inside the house and dump it, either into the air or into the ground via the same underground loop used in winter for heating. Both of them are very energy efficiency [23].

4.4. Hybrid Strategies

Generally, passive strategies cannot be counted that always meet heating, cooling, ventilation, and/or lighting needs. Hence, the building will still likely need active systems to supplement passive systems or to condition the building when passive strategies are not insufficient [1]. The hybrid or mixed-mode is a term that used to describe service strategies that combine natural ventilation with mechanical ventilation [2],[9]. The mixed-mode cooling concept dates back to the late 1980s when research began to address issues such as carbon emissions, building-related health problems, productivity and occupy satisfaction [2]. Hybrid ventilation systems attempt to combine the benefits of both natural and mechanical ventilation in an optimal way to provide a better indoor climate, lower energy use by limiting the number of pulse ventilations needed on cold days, increase the thermal comfort [1],[9],[13]. Furthermore, the application of mixed-mode ventilation in severe hot climates and its integration with other passive and low energy has not been systematically studied [2].

4.5. Energy Sources

The term of energy source is a broader and more meaningful way to refer to energy production; it is inclusive of fuel, nonfuel energy sources, and secondary energy sources such as electricity or hydrogen. Energy sources are either non-renewable energy such as fuels or renewable energy such as water power, wind, and the sun [1].

4.5.1. Non-Renewable Energy Sources

Nonrenewable energy sources come out of the ground as liquids, gases, and solids. They are finite; they cannot be replenished such as fossil fuel. Fuels are materials that can be consumed to produce energy, such as coal, natural gas, and oil are nonrenewable. Uranium is a metallic element that used to generate energy through nuclear fission; it is also the nonrenewable energy source. It does not directly result in greenhouse gas emissions. The disadvantages of nuclear power include the production of radioactive waste and the potential for an uncontrolled reaction at the plant [1].

4.5.2. Renewable Energy Sources

Renewable energy sources are those that are continually replenished. These sources are considered “clean’’ because they emit no greenhouse gases or are carbon-neutral [1]. Nowadays, several types of renewable energies are used for different applications, for example in power plants or in buildings, include solar energy, geothermal energy, wind energy, tidal and wave power, photovoltaic cells, urban and agricultural trash, and biomass[25].

4.5.2.1. Solar Power Systems

Solar power derived through the use of photovoltaic (PV) technologies is the workhorse of the distributed, on-site renewable energy sector. It is the most common renewable energy resource. PV systems perform based on sunlight striking the surface of the module, the photovoltaic process is highly reliable. Moreover, they are free of moving parts and have low maintenance requirement, and their operation is quiet and pollution-free they work based on a physical property called the photovoltaic effect [1]. In addition, solar modules come in two distinct categories – crystalline silicon and amorphous silicon [2].

4.5.2.1. 1.Crystalline PV Modules

Crystalline solar modules are covered with tempered glass on top and a tough ethylene vinyl acetate material at the back. The glass and backing material protect the solar cells from moisture [2]. In the same way, there are two types of crystalline solar cells, mono-crystalline and poly-crystalline as shown in *Fig.4.17, Appendix B.* Poly-crystalline cells are less efficient and less expensive than mono-crystalline [1].

4.5.2.1. 2. Amorphous PV Modules

Amorphous silicon is one of the methods of thin film technologies, as shown in *Fig.4.18, Appendix A.* This type of solar cell can be applied as a film to low-cost substrates, such as glass or plastic in a variety of module sizes. Advantages of thin film cells include easier deposition and assembly, low cost of substrates or building materials, ease of production and suitability to large applications. The efficiency of thin film modules is lower than the crystalline modules. All PV modules need to be purified periodically to sustain their efficiency [2].

4.5.2.2. Solar Thermal Systems

Because of having difference in temperature, the choice of the most suitable solar collector type alters. In this section, a brief technical description of the available solar collector technologies and solar system concepts is outlined.

4.5.2.2.1. Solar Thermo syphon

The solar thermo syphon is one of the first straightforward technologies to reduce traditional energy for domestic hot water [1]. The principle of the thermo syphon system is that cold water has a higher specific density than warm water, and so being heavier will sink down. From this perspective, the collector is permanently mounted below the water storage tank, so that cold water from the tank can reach the collector via a descending water pipe. If the collector heats up the water, the water rises again and reaches the tank through an ascending water pipe at the upper end of the collector, as shown in *Fig.4.19, Appendix A*. The efficiency of solar thermo syphon is normally 70% [2].

4.5.2.2. 2. Solar Flat Plate Collector

Flat plate collectors are shallow framed panels with a glazed face that backed with rigid insulation to reduce the heat loss. Flat plate collectors consist of a black surface with some fluid circulating in or around it, as shown in *Fig.4.20, Appendix A* [1]. The fluid serves to extract the heat produced by the radiation absorbed from the sun thus it can be used for some practical application. Solar collector efficiency decreases as the fluid temperature increases or the available solar radiation declines. Solar flat collectors are used for solar assisted air conditioning systems. The efficiency of standard flat-plate collectors is approximately 70% [2].

4.5.2.2. 3. Solar Air Collector

Solar air collectors are similar to flat-plate liquid collectors but the heat transfer fluid is air instead of a liquid and a fan provokes the circulation instead of a pump, as shown in *Fig.4.20, Appendix A*. Solar air collectors are used for solar assisted air conditioning systems. The main positive aspects of flat plate liquid collectors are: They have no overheating problems (summer), and there is no risk of liquid leakage. While, the main negative points of solar air collectors are: The efficiency of the collectors is lower than flat-plate collectors, and no standard heat storage units are available on the market [2].

4.5.2.2.4. Solar Evacuated Tube Collector

Evacuated tube collectors are newer than flat plate collectors, which consisted of rows of parallel glass tubes connected to a header pipe, as shown in *Fig.4.21, Appendix A.* Every single tube is evacuated to reduce heat losses. Evacuated tube collectors can be classified into two types, heat pipe tubes and direct flow tubes [1]. They are very efficient at low working temperatures (heating or domestic hot water applications) but can suffer problems relating to loss of vacuum. This is primarily due to their seal (glass to metal). The heat expansion rates of these two materials are different, after a few years of daily contraction and expansion, the seal can fail to result in a loss of vacuum. Glass-glass tubes, although generally not quite as efficient as glass-metal tubes, which are generally more reliable and much cheaper [2].

4.5.2.3. Wind Power Systems

The kinetic energy of the wind that is available throughout the world – day or night, as long as the wind is blowing and convert into a useful form of energy through a wind turbine [1],[26]. The generated energy is affected by the size of wind turbine blades and high of the wind speed [1]. Basically, there are two types of wind turbines; horizontal axis and vertical axis, the horizontal turbine is the most common and proven technology, it has three blades radiating from the hub, usually designed to face the wind and can track with the wind direction[26]. However, both of them are required ongoing maintenance and mounted high off the ground [1].Today over 70 countries around the world take advantage of wind energy to generate electricity [26]. In Kurdistan Region of Iraq, wind energy has not been used as the source of energy yet.

4.5.2.4. Hydropower Energy

Hydropower is the oldest and most established form of renewable energy technologies that is movement via gravity or waves. It is a source of kinetic energy that transforms into a useful energy through turbines [1]. Hydropower is a vital source of thermal energy stored from the sun. There are three different forms of hydroelectric schemes [26]:

1. ***Run-of-river*** is suitable for stream or river which does not experience massive differences in flow rate during different seasons of the year. The turbine and generator are located either in the dam or found alongside it.
2. ***Diversion scheme***: It is where the supply of water is taken from a dammed river or lake to a remote powerhouse containing the turbine and generator .
3. ***Catchment schemes***: a man-made or natural reservoir will be used to collect water and rainfall, also to produce a sensible hydrostatic head. The turbines are installed at a lower level and fed by pipes or tunnels.

There are two hydropower stations in Kurdistan, which produce electricity namely Dukan and Derbendikhan.

4.5.2.5. Geothermal Energy

Geothermal energy comes from the heat or thermal energy stored in the earth. The earth's core temperature is extremely hot, about the same temperature as the surface of the sun [1]. The first electrical power station using geothermal resources was established in 1913 at Larderello in Italy[26].There are several geothermal power technologies used worldwide to generate renewable electricity from the steam or hot water gathered from below the earth's surface[1],[26]:

***Dry steam power plant*:** this type of plant, the oldest established technology; it can be constructed on wells which produce superheated steam.

Flash steam power plant: this is the most common type of geothermal power generation plants in operation today. It uses pressurized water at temperatures greater than180°C.This process produces both steam and water.

***Binary cycle power plant*:** this type of power plant can operate with lower temperature water at around 100°C by using heat exchangers to transfer the heat of the water to another working fluid that vaporizes at lower temperatures.

4.5.2.6. Biomass

Biomass is a diverse source of renewable energy derived from a biological or organic material. It is considered as a renewable source of energy because it can be readily replenished [26].Typically, plants absorb the sun's energy in a process called photosynthesis. When biomass is burned, the chemical energy in biomass is released as heat. Biomass can be burned directly or converted to liquid biofuels or biogas that can be burned as fuels. When biomass is combusted to generate heat or electricity, the carbon dioxide is reemitted into the atmosphere. In addition, Biomass can be converted to other usable forms of energy such as methane gas or transportation fuels such as ethanol and biodiesel [1].

4.5.2.7. Fuel cell and Hydrogen

A fuel cell is a device that generates electricity, without combustion, through an electrochemical process involving a fuel (hydrogen and oxygen) [23],[25]. The process is a more efficient than conventional engines and turbine. The by-products of fuel cell electricity generation are heat and water. Hydrogen can be used to generate electricity through a fuel cell in a number of applications. There are a number of methods to produce hydrogen, currently, the most common and cost-effective is called steam methane reforming, which used high-temperature steam to separate hydrogen from the methane molecules in the natural gas. This method results in greenhouse gas emission, other emerging methods are being developed to generate hydrogen without emitting greenhouse gases [1].

In Kurdistan, renewable energy sources include hydropower and solar energy. The history of hydropower renewable energy use dates back to 1980s, through both power stations of Dukan and Derbendikhan dams. However, the generation capacity of these dams is insufficient to meet the energy demand. The solar power energy began to use it in recent years, generally, it has not exploited in Kurdistan building sector yet.

4.6. Conclusion

This chapter covered the most important passive and active strategies that help to identify the appropriate strategies for providing thermal comfort, increasing indoor air quality and harness free energy from the ambient environment in the residential buildings. The study focused on passive cooling, heating and ventilation as an integral part of architectural elements which mainly influenced by the local climates. These strategies could provide part of the cooling requirements in hot dry climates, reduce the continuous reliance on common active cooling systems and promote for energy and carbon emission savings since they depend on natural energy sources in the surrounding environment. However, in hot and dry climate it is important to consider the sun's path and the position and axis of shading device during the renovation process, in order to prevent extra solar gain in summer and allow it to enter in winter. Landscape elements also play an important role in providing pleasant shading; increasing air humidity, cooling the house, and reducing air dust and increasing clean environment. Finally, the energy sources, including renewable and non-renewable energy are being discussed to take advantage of the renovation process.

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5. Determination of study area in Sulaimani City

5.1. Introduction

In this chapter, analysis of the current situation of the existing buildings in the area of Sabunkaran is presented to investigate which kind of building is appropriate for going under renovation. In addition, through the field survey in the study area and based on their compositional and morphological characteristics, five types of residential buildings are classified, which are carried out to the renovation process later. Furthermore, to investigate the energy efficiency of the residential building typologies, the computational simulation IDA ICE software was used. As the buildings are in different orientations, the south orientation is assumed for all of the types as the best direction for energy efficiency.

5.2. The Brief History of Sulaimani

The city of Sulaimani is located in Northern Iraq, as shown in *Fig.5.1, Appendix B.* The geographical coordinates of the predestined governorate are 35°33′40″ N and 45°26′14″ E, the elevation of the city is about 830 m above sea level [2]. The founding of the Sulaimani city started in a village called Malkandi (today a quarter of the same name) and extended along the Magra in the south-west of the city because of favorable topographical conditions. In addition, the city has expanded due to the geographical locations of the region and the availability of water and agricultural land [4]. The first census of the city was, specifically in 1831, during the Ottoman Empire which was conducted in a discretionary and was only for the purpose of military service and taxes collection. Some British tourists and politicians wrote about the population of the city. Claudius Jim claimed that "*the information that I obtained confirms that there are (2000) houses for Muslims, (130) houses for the Jews, 9 houses for Christians and (5) houses for Armenians*". This reveals that the city of Sulaimani since antiquity a place to live and homogeneity of different religions and sects [3].

Major Saone stated in his annual report in 1919, "*The number of residents of the city reached at ten thousand people in 1830 and at twenty thousand people in1914*". Major Saone’s annual report is closer to the truth because in the annual report of the Ottoman State between 1911 and 1912 limits the number of residents of the city by 15 thousand people” [3].

According to Sulaimani map 2003, the historic town is divided into 8 urban quarters; Bazrgani, Dargazen, Jwlakan, Kani Askan, Malkandi, Sabunkaran, Sarshaqam, and Shekhan [4].

5.3. Urban Context of Sulaimani City

Based on the studies and analysis of the existing situation of the Sulaimani city for developing its master plan in 2008, six periods for urban expansion were identified, which is more or less related to the successive wars and political situations that took place in the region. In 1925 the city corpus of Sulaimani was situated in the south-east of today's city. The corpus was of longitudinal shape, pointing towards the north from a south-west to a north-east direction, located on a fairly plain plateau. The urban form looks compact and dense.

In 1973, nearly 50 years ago, the city corpus has grown more or less in the ring form to the west, north and east, while the extensions to the south are less in size. In addition, the borders of the developed areas don't show a homogeneous form, they start looking irregular in shape [5]. In 1980, another large increase in the corpus of the city could record. The urban extensions are predominantly towards the north and the east and to a lesser extent towards the south. The shape of the city's borders is quite irregular showing bulges that penetrate outwards. Furthermore, through the modification of the master plan of 1957 in 1980s due to the unexpected speed of growth, urban development occurred in the structured pattern.

Over the last decade of twentieth century, a considerable increase in the size of the urban area has been identified. The urban extension occurs predominantly in the north-western direction, but not in a consistent form, more or less disconnected to the actual city corpus. For the first time, urban development occurs in the western direction; outside the official demarcation of the city.

The growth pattern in 2003 is in character and form very different from the development in previous decades. The urban development spreads predominantly in the western direction. The ring road around the city has lost its function as a boundary altogether. The overall developed urban area is located outside the official demarcation of the city. However, the city grew rapidly like an amoeba, but there was no conclusive development planning.

The satellite map of 2007 enhances the development trend that had occurred in the previous map. It can be seen from the *Fig.5.2* that a large number of scattered developments have been recorded in the western direction, and also in the north, the south-west and south-east. The extensions in the north and in the south-east start reaching into the feet of the mountains, which creating considerable ecological problems.

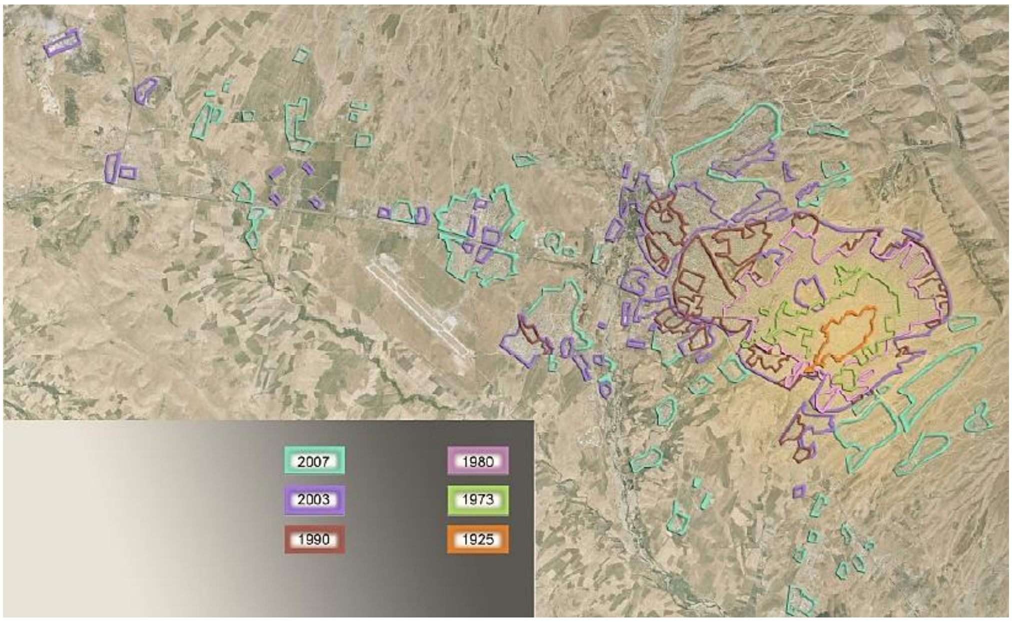

Fig.5.2. The Spatial Development of Sulaimani [3].

The residential buildings in Sulaimani are constructed in single-family detached houses, single-family terraced houses and apartment blocks form, as shown in *Fig.5.3, Appendix B.*

5.4. Energy Consumption in Kurdistan

In recent years, with the rapid development of urbanization, faster population growth, people's incomes and living standards, building energy consumption have increased dramatically, in particular in the residential buildings. Internationally, energy consumption of the residential sector accounts for 16-50% of the energy consumed by all sectors, and it averages approximately 30% worldwide [1]. Meanwhile, the residential building sector in Kurdistan, accounts for 70% of the total energy consumption, as shown in *Fig.5.4, Appendix B.* Therefore, energy consumption management is a very significant task, not only to prevent the consequences resulting from increasing consumption patterns but also to improve the performance of building energy systems.

Additionally, based on the annual report released by the Ministry of Electricity and Energy in Kurdistan (MEEK), the residential sector is the first electricity energy consumer during the past four years.

5.4.1. Energy consumption in Sulaimani

According to the annual report of MEEK, in 2014 the electricity consumption for acclimatization and lighting residential buildings in Sulaimani was 71% of the total national generated electricity, as shown in *Fig.5.5* [10]. This is an important indicator of the importance of studying energy in the residential buildings.

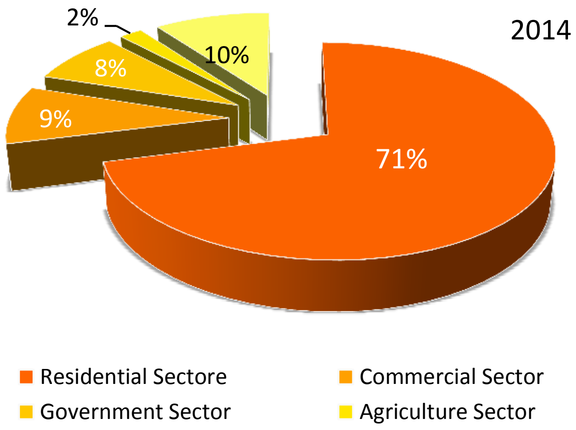

Fig.5.5. Energy consumption by end use of Sulaimani in 2014[10]

5.4.2. Residential household energy consumption

It is important to present an anatomy of energy end-uses in the residential buildings, to assess the energy performance analysis, while this information is not available in Kurdistan. Therefore, this study evaluated a middle-income urban residential community in Kurdistan. *Fig.5.6* shows the greatest user of energy in residential buildings which is for cooling (electricity). The second largest use is for heating (electricity) followed by domestic hot water (electricity), plug loads, and other uses. Indeed, 68% of the consumed energy stands for indoor air conditioning (heating and cooling).

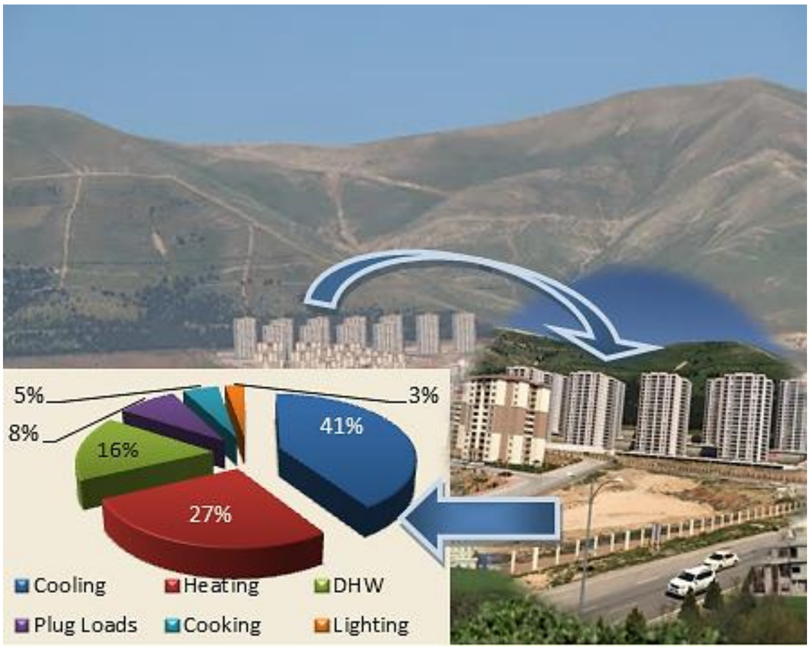

Fig.5.6 Energy Consumption per Household in Goizha city, Sulaimani [Researcher].

5.5. The Reasons for Determination of Sabunkaran District

Sabunkaran represents the southern part of the city center of Sulaimani. It is also one of the most important urban districts with regard to preservation of cultural heritage building within the city. Indeed the district consists of two parts; the first part represents the actual historic of the district and the second is the new terraced housing area [5]. In addition, Sabunkaran's name is related to the profession of its indigenous people, Sabunkaran means industry of soap in Kurdish language. The last census was carried out by the Statistics Department of Sulaimani in 2009, where the number of its population was 3374 capita [6].

Furthermore, the historical features in Sabunkaran suffer from deteriorating and have begun to disappear gradually for the following reasons:

- The absence of the clear architectural criteria that should be used by the municipality of the city, to keep the nature of the region. However, the development and renovation of a specific direction are making the general output a disproportionate mixture of buildings; in style, height, materials used colors, spaces, and processors. This leads to the deprivation of architectural and urban identity in the modern and the traditional buildings.
- Constructing new buildings without or far from commitment controls.
- There are many destroyed or abandoned buildings that become a place for pollution.
- The absence of a program for maintenance or restoration of the buildings that have heritage value.
- Extension of the industrial and commercial activities to the old residential neighborhoods.

Moreover, the modern incision streets that tore the historic urban fabric, these reasons might together lead to deteriorating stages that need many efforts to get repaired and cause loss of cultural heritage that can't be compensated.

5.5.1. Urban Fabric of Sbunkaran District

The urban fabric of Sabunkaran resulted spontaneously; it is characterized by the narrow alleys that haven't taken an identical pattern in the direction and widening, each alley is branching of a secondary road which connected with others that may be closed at the end in some cases. Undoubtedly, the narrow winding alleys have many climate benefits including; treatment of harsh weather conditions by preventing the sun from directly hitting pedestrians. Similarly, the ratio of the building to the street is high, which creates a good shading and pleasant pedestrian environment, especially in the summer, as shown in *Fig.5.7*. Furthermore, they are characterized by continuous movement and change the scene of the facades of monolithic buildings on a curved line, which provides a high degree of enclosure, and privacy, especially in the closed ends of the alleys, as shown in *Fig.5.8, Appendix B.*

The entrance is an important element of communication between inside and outside. Here, in the old urban fabric, there is a preservation of individual privacy, that the main entrances of the houses have not corresponded with each other, and mostly in a form which eclipses inside the main wall of the house, as a kind of definitions of the entrance, as shown in *Fig.5.9*, *Appendix B.* Likewise, the patterns and the style of houses have been built in a way that the private spaces were starting with the external wall of the house and this leads the house not exceeding on each other and prevent visual penetration as in the modern urban fabric.

Fig.5.7. The narrow and winding alleys in Sabunkaran district.

In reality, nowadays the urban fabric of Sabunkaran suffers from deteriorating due to the lack of maintenance and repair of the old buildings. This has several reasons, such as the migration of its original inhabitants to other more sophisticated places, economic conditions of the householders and their inability to maintain and repair it, or urban renovation policies. In spite of some excesses, new constructions, or demolition of some of the historic buildings, the area still has its historic fabric that identifies the local architecture.

5.5. 2. Land Uses of Sabunkaran District

Based on the latest survey, carried out by the Presidency of Sulaimani Municipality in 2009, in order to determine the land uses, the buildings of Sabunkran are classified as follows (*Fig.5.10*):

1- Residential buildings currently used and it's 539

2- Forsaken residential buildings and its 36 buildings.

3- Commercial buildings, its 165 buildings.

4- Religious buildings, 4 buildings.

5- Education buildings, 3 buildings

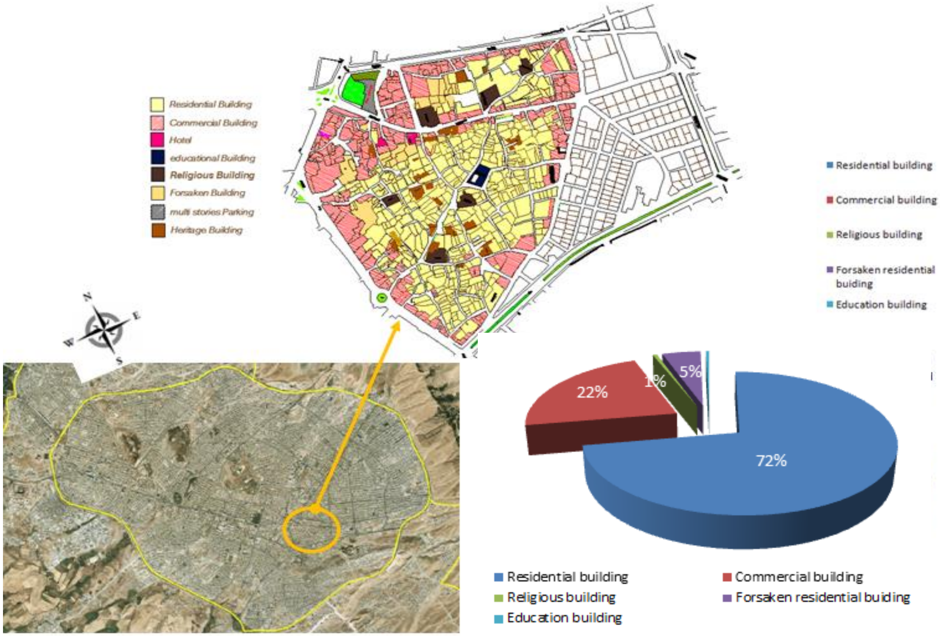

Fig.5.10. The location of Sabunkaran district in Sulaimani Governorate and its land use [4].

It can be revealed from the land uses of Sabunkaran district, 72% of the buildings are residential buildings, while 22% are the commercial buildings, and forsaken buildings account 5% as compared to the religious and cultural buildings in the region share the smallest proportion of the total buildings. Consequently, it will be feasible to choose from residential buildings for the purpose of study and research.

5.6. Residential Building Types in Sabunkaran

On average, 98% of the world’s building stock consists of existing buildings [9]. The residential area in form and content is the product of cultural accumulations which was carried out through the efforts of previous generations. In like manner, the study of the existing building types of a certain period reflects the life of this community and gives its urban image. This image is determined by civilization factors in terms of cultural, geographical, social, technical, political and economic indicators. All these indicators contribute to the qualities and properties and relations of housing patterns within a particular community [8]. Based on a field survey that was done by the researcher on the existing residential building in Sabunkaran, the study classified the residential building types according to their compositional and morphological properties.

5.6.1. Residential Building Types, Based on Composition Properties

Through the field survey of the Sabunkran districts, the compositional properties of the residential building were analyzed, the most important composition properties which include*:*

- *The relation between mass and space*; Space is dominant over mass, mass is dominant over space or there is a balance between them *.*
- *Courtyard location*; central courtyard , side courtyard, front courtyard, and or back courtyard
- *Spaces Organization*; overlapping spaces with functions, Separate service functions of the other functions or separate spaces based on their functions.

Based on these composition properties that mentioned above, there are five types of houses in sabunkaran, including; central courtyard, side courtyard, front big courtyard, back courtyard, front small courtyard.

5.6.1.1. Central Courtyard Houses

This type of house is characterized by a central courtyard. Mostly consists of one floor with two rooms, a small kitchen, and service spaces. Due to the small size of some houses, many functions take place in one multi-functional space; this means there is overlapping between spaces and functions, as shown in *Fig.5.11, Appendix B.* There is another common type similar to this type in its layout, but different in the number of rooms and floors. This type includes a central courtyard, a multifunctional space, bedrooms, a kitchen, and services spaces. In addition, the external staircase leads to the up floor, which mostly is used for an extended family where the oldest child who is recently married is likely to live with his family in the second floor and share other spaces in the house like kitchen, reception, and family living.

5.6.1.2. Side Courtyard Houses

This type has a side courtyard, mostly consists of two floors and leads to the upper floor within an external stair, is shown in *Fig.5.12*, Appendix B. The ground floor contains the entrance, the side courtyard, service space, kitchen, a multi-function room and private space for the use of family at the far end of the plan. It is also more likely to accommodate for more than one family or an extended family due to the possibility of having a separated room that can act as a private living and sleeping for the married while other common rooms and services can still be shared with his family. Furthermore, there is an overlap between space and its function. In addition, the proportion of the mass to space more or less it is equal which creates a type of balance between them.

5.6.1.3. Front big yard houses

This type is representing the traditional type that has a heritage value in the district. Typically, it consists of two floors. The ground floor is mainly reserved for services and public reception, including bakery, kitchen, bathroom and public reception or guest reception, where the upper floor is purely private, and contains two or three rooms that overlooking on inner Iwan which is often supported by two or three wooden columns, as shown in *Fig. 5.13, Appendix B.* [7].

Therefore, the division between the public and the private domain has been achieved vertically. In addition, this type is a more elaborate type in comparison with central and side courtyard and begins to separate service function with the other functions, by looking at the layout, can be noted that space is dominated over mass. This type is also more likely to accommodate more than one family or an extended family, as shown in *5.14.*

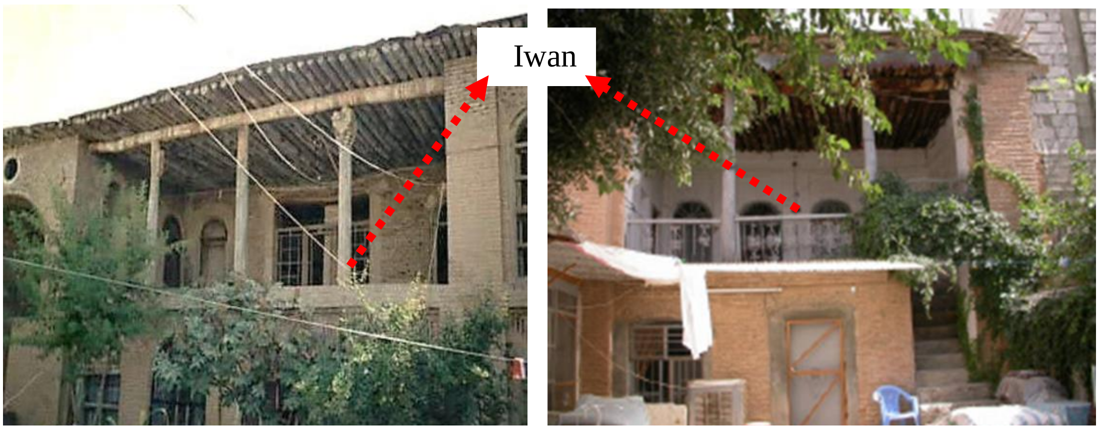

*Fig.5.14.*The view from inside in the front courtyard type in Sabunkaran district [Researcher].

5.6.1.4. Back Courtyard Houses

This type tends to transfer from traditional to modern housing, it is characterized by a back courtyard, and more elaborate space organization than the three aforementioned kinds, this type began to separate spaces based on its function. Typically, it consists of either one floor or two floors, which contain living room, bedrooms, kitchen and health facilities that located in a separate zone from the other spaces that access through the backyard. Simultaneously, in this type, it can be noted that mass is dominated on space, as shown in *Fig.5.15, Appendix B.*

5.6.1.5. Front Small Courtyard Houses

This type is tending to modern housing, where the householders demolished their buildings due to the bad condition of the buildings and rebuilt it in a modern form. Characteristically, it consists of two floors, ground floor contain the living rooms, bedrooms, kitchen and health facilities which located in a zone far from the living room. In addition, this type has more elaborate layout than others, and its spaces are separated based on their functions. Furthermore, it has external and internal staircase both of which lead to the upper floor. Similarly, in the upper floor it has nearly the same spaces that exist in the ground floor. Hence, it is more likely to accommodate for more than one family. Equivalently, in this type, it can be noted that mass is dominated on space, as shown in *Fig.5.16, Appendix B.*

5.6.2. Residential Building Types Based on Morphological Properties

The study classifies the residential building types in Sabunkaran district based on their morphologies properties into five types, which include; analysing building materials, wall thickness, building orientation, window and opening size, entrance and access to the house, and land plot size.

5.6.2.1 Residential Building Types -1-

It represents the traditional residential buildings type in Sabunkaran. It consists of two floors. Customarily, mud brick is used as a wall construction with a thickness ranged between 40-80 cm, and mud mortar is used for the interior and external wall finishing. The windows are wooden framed, single-glazed. Mostly, there are three windows side by side on the walls of the rooms. Frequently, the spaced narrow windows provide the sunlight to penetrate the deepest point of the spaces. In addition, the house roof was made of bole of trees, with diameters not exceeding than 15 cm, which was used as a crossbeam form. It was covered by a layer of mat, and then layered with compacted soil that was mixed with straw. These practices assist energy conservation in buildings by reducing heat loss through the roof. Furthermore, the house oriented toward the inside, and the size of the land plot ranged from a medium to large, as shown in *Fig.5.18, Appendix B.*

5.6.2.2. Residential Building Types -2-

This type is semi-traditional building, mostly resembling type one in terms of walls and roof construction materials, the size of the opening and the windows. In contrast to the first type, in terms of the size of the land plot, this type ranges from medium to small, and is characterized by the central courtyard, as shown in *Fig.5.19, Appendix B.*

5.6.2.3. Residential Building Types -3-

This type usually consists of two floors; the main character is the use of local stone beside the mud-brick and sometimes used together, especially at the entrance. It also characterized by demonstrating the construction materials without using any finishing mortar for external walls, while it resembles the two previous types in terms of roof construction materials and details. What's more, the size of the openings was increased, in comparison with the first and second types. However, the spaces are oriented toward inside around the central courtyard, and the size of the land plot ranged from medium to small, as shown in *Fig.5.20, Appendix B.*

5.6.2.4. Residential Building Types -4-

The main feature that distinguishes this type from other previous types is the use of reinforced concrete (RCC) for roofing the houses. In addition, stone and bricks were used together without external finishing, mostly the building oriented towards inside through the back courtyard and toward outside through small windows across the facade at the height 1.5 m, as it is shown in *Fig. 5.21, Appendix B.*

5.6.2.5. Residential Building Types -5-

This type is representing the modern houses in the district, as shown in *Fig. 5.22, Appendix B.* Instinctively, it has a front small courtyard, it consists of two floors, with regard to construction materials, the hollow cement blocks are used for constructing external and internal walls with a thickness 20 cm and roofing the house by reinforced concrete with a thickness 15 cm. Moreover, various materials were used for external walls finishing, including cement plaster, decorative stone and ceramic tile, whereas gypsum is used for internal wall finishing [7]. In addition, the size of the window is increased significantly, in comparison with the previous types. Furthermore, the spaces oriented toward the outside, and the size of the land plot ranged from medium to small. However, it has two entrances: a small one leads to the house's space while the big entrance leads to the garage.

To sum up the information, it can be observed that the morphological and compositional characteristics change progressively. This is the nature of change in the characteristics of residential constructions in many societies despite their different cultures.

Based on the aforementioned, five types of residential buildings are selected to investigate energy and thermal comfort performance, which are the most important objectives for sustainable renovation strategies, as shown in *Fig.5.23.*

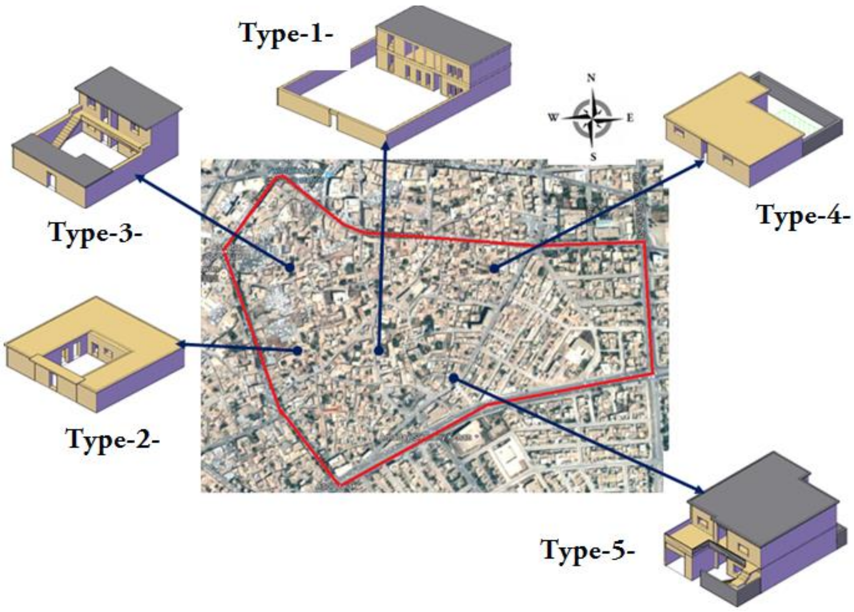

*Fig.5.23.*The residential building typologies in Sabunkaran district.

In order to identify the rate of the residential building types in Sabunkaran that were chosen for renovation process, the field survey was implemented by the researcher in the study area and the result was found, that the type -1- is more common type that accounts for 32% of residential building, followed by type 3, type 5, type 2, and type 4, respectively, as shown in *Fig.5.24, Appendix B.*

5.7. Energy performance analysis in the Residential building typologies

Creating typology is a comparative method to investigate the physical or other characteristics of the built environment. It can also be a useful instrument in the existing residential buildings to reduce energy consumption during the renovation process [1]. To investigate the energy performance of the residential building typologies, there is a need for an accurate numeric analysis and modeling tools, the dynamic simulation software IDA ICE 4.7.1 has been applied for feasibility purposes. Firstly, in order to get results in a reasonable time, simplification of the architectural layout is needed before importing into IDA ICE. Then, information on the materials used for constructing walls, roofs, floors, and their thickness, as well as window panes and building services system, were taken from the construction plans. In addition, PRN weather file which created by Meteonorm software7.2 was used which consisted of 6 parameters: dry -bulb temperature, relative humidity, direct normal radiation, diffuse radiation, wind speed, and wind direction, the air temperature was measured at a height of 10m. Based on the field survey information, fuel was used for heating the houses typologies, while the Electricity was used for cooling and Domestic Hot Water (DHW). The basic parameters used for energy simulations are highlighted in *Table 5.1, Appendix B.*

Furthermore, the software faces difficulties during handling non-perpendicular wall. To avoid this, it is necessary to transform the layout into an approximate state, while keeping the original building physics related dimensions.

The IDA ICE, models can be created after setting up all the parameters, as shown in *Fig.5.25*. Running one-year simulations will provide results for energy analysing. However, the analysed and compared objects are five types of residential buildings in Sabunkaran district, by assuming south direction as the same orientation overall.

After simulation the models, the results from IDA ICE were analysed, and the total energy for each model was compared;

- The best residential building type in terms of energy efficiency is type two;
- The type one performed as the second best model;
- There is a similarity between type three and type four in terms of energy efficiency;
- Type five is the largest energy consumer, and it was considered the worst type.

By analysing the supplied energy results, as shown in *Fig.5.26, Appendix B, and Table 5.2,* it is evident that Type 1 of the residential building requires around 225.5 kWh/m^2 while Type 2 needs 295.4 kWh/m^2. Furthermore, Type 5, which is the largest energy consumer, and the most deteriorating type in terms of its energy performance required 311.2kWh/m^2. Both Type 3 and Type 4 required 554.7kWh/m^2 and 515.1kWh/m^2 respectively.

It is worth to mention, the IDA ICE software, for calculating supplied energy has been used up the whole area into account during the calculating procedure. Actually, there are some spaces did not require heating, and cooling system included (bathrooms, storages, and garage), thus, it gives inaccurate results. In order to find out the actual delivered energy for each type, the deduction of space's area that does not require air-conditioning to the total area, when calculated in this manner, it runs out. Therefore, for accurately calculating the energy efficiency in any type, it will better to count on the energy that required per square meters instead of the total energy for the whole building, in this way, the first type is actually the best among others in terms of energy efficiency requiring only 225.5 kWh/ m^2. While worst type is Type 3, which required 554.7kWh/m^2.

Fig.5.27 clearly illustrates the total supplied energy for the whole area (left) and the required delivered energy per m^2 (right), for residential building typologies.

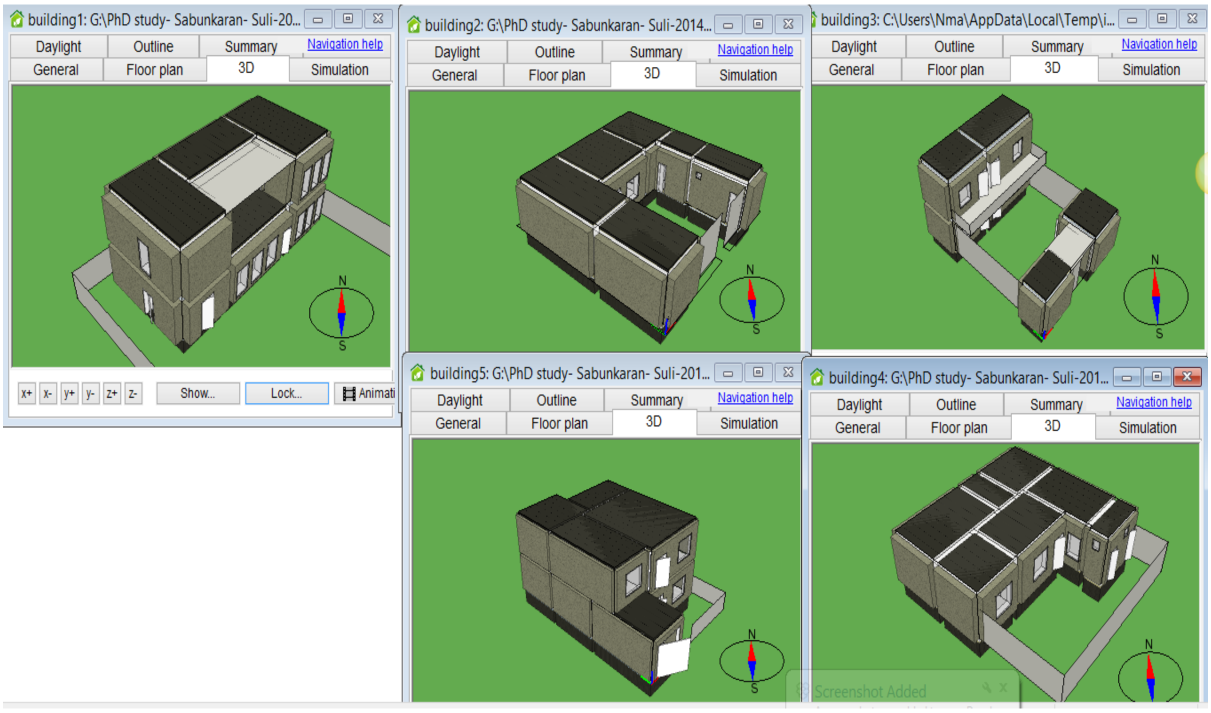

Fig.5.25. IDA ICE Simulation models for housing types in Sabunkaran district.

Table 5.2. Total supplied energy report of the models from IDA ICE

	Building1-		Building2		Building3.		Building4-		Building5-	
	Kwh	Kwh/ m^2	Kwh	Kwh/ m^2	Kwh	Kwh/ m^2	Kwh	Kwh/ m^2	Kwh	Kwh/ m^2
Lighting, facility	1839	11.6	920	11.5	1051	15.5	1051	13.4	2234	11.2
Electric cooling	5949	37.6	2074	25.9	3729	55.0	4525	57.8	7968	39.8
HVAC aux	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Electric heating	8421	53.2	6516	81.3	6283	92.6	6597	84.2	8883	44.4
Total, Facility electric	16209	102.3	9510	118.6	11063	163.1	12173	155.4	19085	95.4
Fuel heating	19508	123.2	14179	176.8	26568	391.6	28163	359.6	43182	215.8
Total, Facility fuel*	19508	123.2	14179	176.8	26568	391.6	28163	359.6	43182	215.8
Total	35717	225.5	23689	295.4	37631	554.7	40336	515.1	62267	311.2

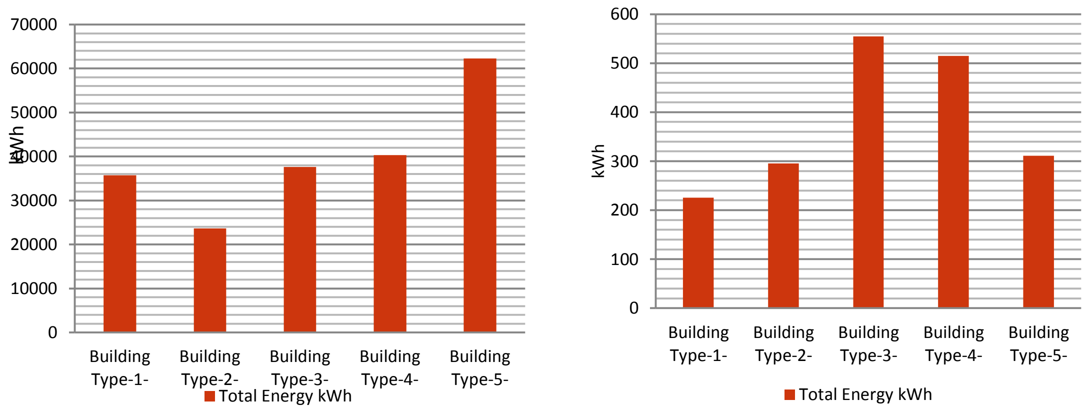

*Fig.5.27.*The total supplied energy (left), the energy required per meter square (right), in the building types.

5.8.Conclusion

The current situation of the existing residential buildings in the study area was analysed, through the field survey and based on their compositional and morphological characteristics analysing, five types of residential buildings were classified in the study area. The residential buildings typologies were simulated to investigate energy efficiency. The results revealed that the compositional and morphological characteristics of the buildings have a significant influence on the energy performance. In addition, the building materials and construction techniques have also a substantial part of the energy performance. Consequently, the houses that have better thermal mass, they deliver lower energy requirement.

5.9.References

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6. Decision-making Tool for Energy and Thermal Comfort Optimization

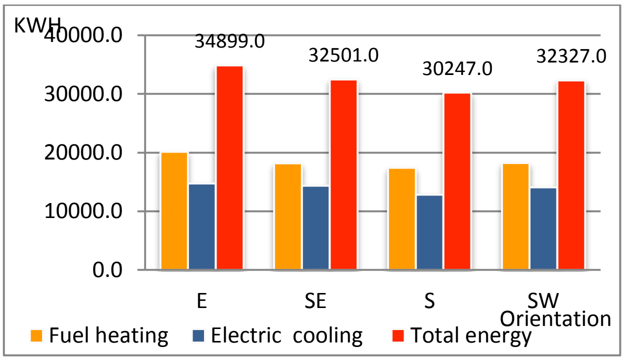
6.1. Introduction

This chapter will present the approaches to explore reducing energy consumption and increasing thermal comfort performance in the five typical residential buildings in Sabunkaran, through investigating different passive and active strategies with more focus on passive strategies, this is mainly due to the passive strategies could be achieved by using architectural elements which should take into consideration during renovation process. The approaches are supported by computational IDA ICE 4.7.1 for simulation different scenarios. In addition, the Excel decision support tool was used to complete the optimization process. In order to formulate the optimum solution, the total convenient passive and hybrid strategies for optimization were summarized and the optimum models for the residential building typologies in Sabunkaran were proposed.

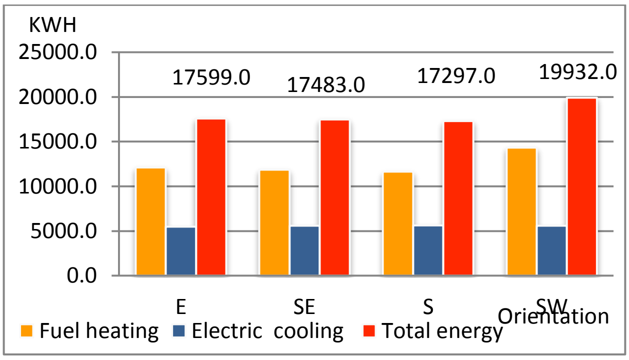
6.2. Best Orientation for Energy Optimization

Optimization is a technique which used to obtain the best results from a system or process. In essence, the importance of optimization lies not in trying to find out all about a system, but to find out, with the least possible effort, the best way to adjust the system [9]. Furthermore, international studies confirm this conjecture, according to which 30% more energy savings can be achieved by optimization of the building [10]. Indeed, the orientation of the building to the sun is considered one of the earliest design decisions essential for passive heating and cooling [8], the certainty of the summer and winter sun's path, take the guess-work out of solar-appropriate design [3].

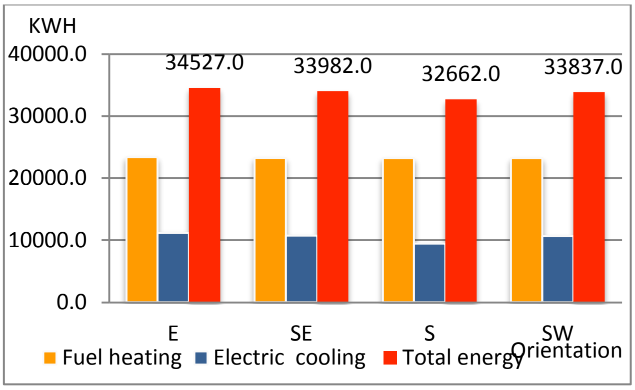
Typically, the residential buildings typologies in Sabunkaran district are in different orientation and due to they represent the traditions houses (except type 5 which mentioned before), the houses have been oriented based on the sun's path to take advantage of the microclimate for getting passive heating and cooling in the seasons, which including; East, South-east, South-west, and South. As a result, the first factor that took into consideration for optimization was building orientation, which plays a significant role in reducing energy consumption. In order to find the best orientation for energy efficiency in the existing building, fourth alternative orientations were selected for each type including East, South-east, South-west, and South. Moreover, the IDA ICE was used for simulation. Based on the alternative orientation, the residential building typologies have been simulated, and the results have been analysed and compared. *Fig.6.1* illustrated the best orientation for all the models which was the south orientation.



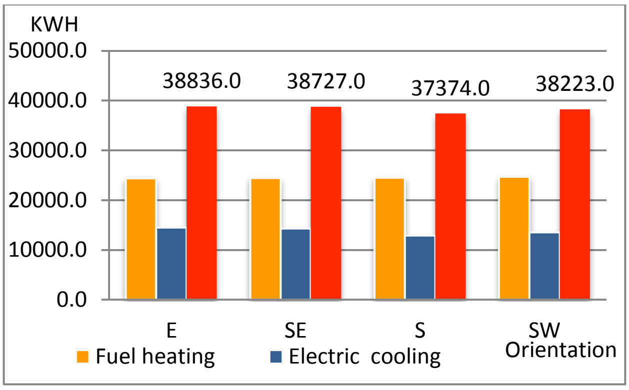
Model-1-



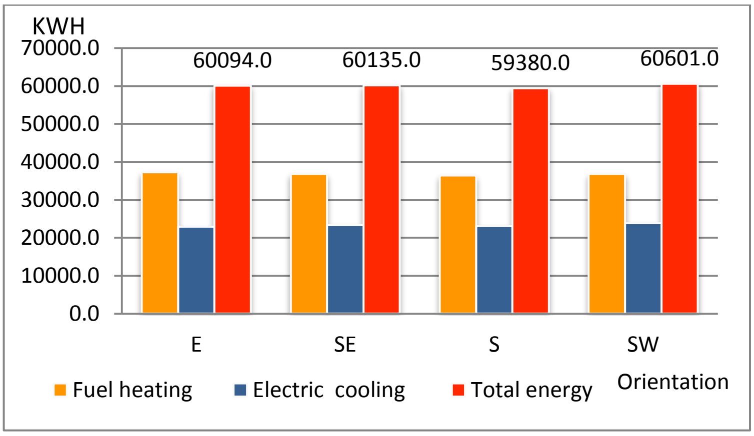
Model-2-



Model-3-



Model-4-



Model-5-

Fig.6.1. The annual delivered energy comparison in four different orientations from IDA ICE Simulation [Researcher].

6.3. Energy and Thermal Comfort Optimization

In order to investigate the most appropriate strategies for improving thermal comfort, indoor air quality, and energy consumption during the renovation process in the residential building typologies in the Sabunkaran district, that will be benefited for the building renovation such climate in Kurdistan. These should be achieved due to harnesses of both passive and active strategies.

6.3.1. Passive Strategies Optimization

The Passive design responds to the local climate and site conditions. It is also one of the most effective strategies for reducing energy consumption and improving indoor air quality in the building. Therefore, the key for designing passive building is to take the best advantage of the local climate [1], [2]. The most important factors must be addressed when designing and optimizing passive buildings, including; building shape, building orientation, thermal insulation, air infiltration, shading device control, and window's frame and glazing [5]. One of the key factors in the glazing system design is the window to wall ratio (WWR) for the building and its different orientations. Many high-performing buildings have WWR's equals to (25 to 35 %) [3]. In addition, the natural ventilation can take away the indoor heat and humidity and provide fresh air to improve indoor thermal comfort conditions when the outdoor climate is uncomfortable [6]. Furthermore, for centuries, wind tower as a passive cooling strategy had been used for ventilation and cooling the buildings in the hot- arid or hot- humid areas, and still used in some areas of the Middle East and Egypt [7].

Based on the passive strategies optimization for the five residential building typologies in Sabunkaran, several scenarios were selected, including thermal insulation, glazing pane, wall to window ratio (WWR), infiltration, form compact, fixed shading, and wind catcher, the last scenario was applied for getting the optimum model, as shown in *Table.6.1, Appendix C.*

Additionally, the applicability of any selected strategy for the residential building types depend on the possibility of applying this strategy to the models or not, for example, the possibility of utilizing the wind catcher for the first and fifth types, and not being utilized for the second, third, and fourth models, this is mainly due to their content the courtyard which helps for natural ventilation. In consequence, within the chosen strategies, the most effective strategies were used for each model.

Specifically, the information have been inserted into IDA ICE which including the construction materials, utilized heating and cooling system, building orientation, and window glazing pane type. In addition, the schedules for occupants, lightings, windows and doors hourly opening for the building have been inserted for the year seasons, thus a computational model has been created for each type.

It is worth to mention, during the simulations process all inserted information into IDA ICE software was considered the constants, the only variable was the strategy that used. For instance, when the model was simulated based on replacing pane glazing strategy, the only variable was the pane glass. In addition, after simulation, all scenarios for each model, based on the Excel decision- making support tool the simulated results were analysed, and compared with the base model. Accordingly, the most efficient scenarios in terms of energy and thermal comfort performance were selected for getting the optimum solution model. The optimum models were also simulated and compared their results with the base model. However, seven parameters were recorded for comparison including maximum heating and cooling load, heating and cooling demand, CO_2 level, daylight level, and acceptable thermal comfort hours to investigate the impact of each strategy on the energy consumption and indoor air quality inside the building typologies.

6.3.1.1. Passive Strategies Application for Model type -1-

After creating the base model for this type, as shown in *Fig.6.2, Appendixes C*. the first step in the optimization process was choosing the applicable passive strategies scenarios from the *Table 6.1,* which including thermal insulation, glazing pane, WWR, infiltration, form compacted, fixed shading, and wind catcher. Then, all selected scenarios have been simulated, and the simulation results have been compared with the base model, the Excel tool was used for comparing the results with the base model, as shown in *Fig.6.3, Appendixes C*.

The results of simulations have been shown in *Table 6.2*, when adding 20 cm insulation in the building envelopes, and replacing the single pane glazing to triple pane glazing, in the first and second scenario, the energy consumption was reduced significantly for both, while the acceptable thermal comfort hours was decreased slightly in the first scenario, and reversed in the second.

It is worth to mention by reducing the WWR from 45% to 25% in the southern facade, the energy consumption was reduced significantly, while the CO_2 level was increased to more than 50% when compared to the base model. Based on results analysis, the most effective strategies for reducing annual energy consumption were WWR, wind catcher followed by pane glass, thermal insulation, and form compacting, that should take into consideration for creating the optimum model. While the most effective strategies for thermal comfort was WWR, pane glass, and fixed shading. In addition, the infiltration strategy had the least effect on the energy and thermal comfort performance.

Table 6.2. The percentage of reduction and increased energy consumption and thermal comfort in all scenarios in model-1 [Researcher].

Residential building Type-1-			**Passive strategies**							
Zone: Guest room Orientation: South			1	2	3	4	5	7	8
		Basis	Insulation 20	3 pane glass	WWR 25%	Infiltra-Tion	Form compact	Fixed shading	Wind catcher
Max. Heating load	W	0.0%	-21.3%	-22.9%	-29.7%	-1.9%	-9.8%	-2.8%	- 12.7%
Max. Cooling load	W	0.0%	-15.2%	-20.2%	-31.2%	-0.4%	-6.1%	-8.6%	- 17.9%
Heating demand	Kwh	0.0%	-36.9%	-22.1%	-9.0%	-3.5%	-18.3%	23.1%	- 15.5%
Cooling demand	Kwh	0.0%	15.1%	-15.8%	-57.2%	0.4%	5.2%	-44.1%	-31.7%
CO_2	Ppm	0.0%	-0.8%	0.0%	51.9%	41.5%	-2.8%	1%	2.8%
Daylight	Lux	0.0%	0.0%	-17.4%	-59.0%	0.1%	1%	-35.4%	- 28.1%
Acceptable Thermal comfort	Hour	0.0%	-1.2%	1.3%	3.5%	1.1%	0.1%	1.2%	1%

6.3.1.1.1. Evaluation for Passive Strategies Optimization (EPSO)

In order to determine the most effective passive strategies for creating an optimum model for this type, the virtual digital value from one to ten was estimated. The (+) value represented positive point, and the (–) value represented negative point. Thus, the percentage of energy and CO_2 level reduction from one to ten, (+1) value was given, while the percentage of energy and CO_2 level increase from one to ten, (–1) value was given, and so on, this is reversed in the thermal comfort and daylight level, this implies, for the reduction the (–) value was given, and for the increase, the (+) value was given, as shown in *Table.6.3.Appendix C.*

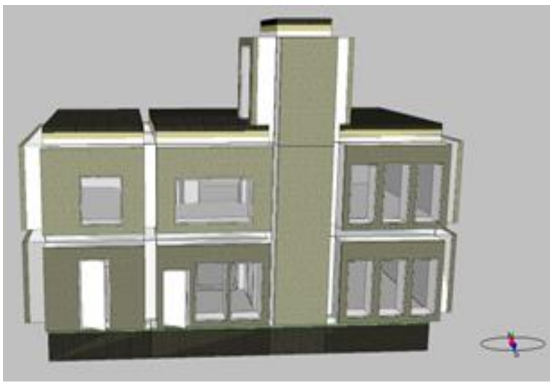
Methodologically, all parameters have taken the numerical value at the same level. Undeniablly, this might lead to inaccurate results due to being contrast in the parameters in terms of significance, some parameters are more important than others, that should take priority during the optimization process. Correctly, the thermal comfort and indoor air quality have been considered the most important parameters. As a matter of fact, they should take into priority. In order to get reasonable results, the obtained numerical value of each parameter was multiplied by other numerical value that represents its importance.

Hence, the obtained value for thermal comfort is multiplied by 5 to present its importance, and the maximum heating and cooling load which considered less important than others, Therefore, their obtained values is multiplied by one and so on, as shown in *Table 6.4.*

Table 6.4. The numerical value assessment for the passive strategies in model-1-[Researcher].

Passive strategies								
		Insulation 20cm	3Pane glass	WWR 25%	Infiltration 0.5ACH	Form compact	Fixed Shading	Wind catcher
Max. Heating load	W	3*1= 3	3*1= 3	3*1= 3	1*1=1	1*1=2	1*1=1	2*1=2
Max. Cooling load	W	2*1= 2	3*1= 3	4*1= 4	0*1=0	1*1=2	1*1=1	2*1= 2
Heating demand	Kwh	4*3= 12	3*3= 9	1*3= 3	1*3=3	2*3=6	- 3*3= -9	2 *3= 6
Cooling demand	Kwh	-2*3= - 6	2*3= 6	6*3= 18	0*3=0	-1*3 = -3	5*3= 15	4*3= 12
CO2	Ppm	1*4= 4	0*4= 0	- 6*4= -24	-5*4= -20	1*4= 4	-1*4 = - 4	-1*4= - 4
Daylight	Lux	0*2= 0	-2*2= - 4	-6*2= -12	0*2= 0	1*2=2	-4*2= - 8	-3*2= -6
Acceptable Thermal Comfort	Hour	-1*5= -5	1*5= 5	1*5= 5	1*5= 5	0*5 = 0	1*5= 5	1*5= 5
		10	22	-3	- 11	13	1	17

Based on this method, the appropriate strategies for creating the optimum model were chosen including **pane glass**, **wind catcher**, **form compact** and **thermal insulation**, which integrated to get the proposed optimum model. Subsequently, the proposed model has been simulated, and the simulation results have been compared with the base model. The results showed that the largest reduction in the heating demand was 54.9%, followed by the maximum heating load and maximum cooling load, were 40.4%, 36.2% respectively, while the CO_2 level was reduced to 28.9%, this means a good indicator for increasing the indoor air quality by equipping the wind catcher, as shown in *Fig.6.4.*



Optimum model -1- (Passive strategies)			
Zone: Guest room		Basis	Optimum model
Max. Heating load	W	0.0%	- 40.4%
Max. Cooling load	W	0.0%	- 36.2%
Heating demand	kWh	0.0%	- 54.9%
Cooling demand	kWh	0.0%	-5.2%
CO2	ppm	0.0%	- 28.9%
Daylight	Lux	0.0%	-6.5%
Thermal comfort (Acceptable hours)	Hour	0.00%	- 1.3%

Fig.6.4. The proposed optimum model from IDA ICE (left), The percentage of energy and thermal comfort reduction in the optimum model (right).

6.3.1.2. Passive Strategies Application for Model type -2-

The base model from IDA ICE was created for model type -2-, as shown *in Fig. 6.5, Appendixes C*. the applicable passive strategies scenarios have been chosen, including thermal insulation, pane glass, WWR, infiltration, form compact, and fixed shading. Furthermore, all models for different scenarios were simulated, the Excel tool was used for comparing the results with the base model, as shown in *Fig.6.6, Appendixes C.*

The simulations results have been analysed, as shown in *Table 6.5*, by adding 20 cm thermal insulation for the building envelopes, in the first scenario, the heating demand and maximum heating load were reduced significantly, while the acceptable thermal comfort hours was also increased slightly. Moreover, by expanding the WWR from 20% to 25% in the windows that overlooking the central courtyard, the daylight level were increased slightly, and the CO_2 level decreased in small amount. Besides, by making the form more compact,the energy and CO_2 level were decreased gradually. Indeed, the two strategies that have a negative effect on both energy consumption and indoor air quality were the air infiltration and fixed shading.

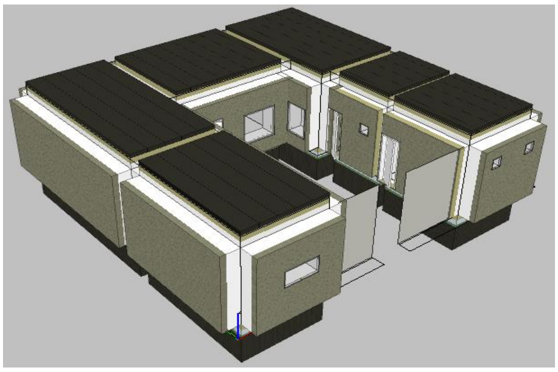
Based on the results analysis in *Table 6.5*, and virtual digital value estimation for all scenarios then, multiplying the gotten results by another numeric value to represents their importance, which was illustrated in the model type-1 (EPSO method).

Table 6.5. The percentage of reduction and increased energy consumption and thermal comfort in all scenarios in model-2 [Researcher].

Residential building Type -2-			Passive strategies					
Zone: Living room Orientation: South			1	2	3	4	5	6
		Basis	Insulation 20cm	3 pane glass	WWR 25%	Infiltration	Form compact	Fixed shading
Max. Heating load	W	0.0%	-35.1%	-11.4%	6.7%	-1.2%	-9.4%	-1.2%
Max. Cooling load	W	0.0%	-27.7%	-10.6%	7.6%	-0.2%	-9.0%	-3.6%
Heating demand	Kwh	0.0%	-45.2%	-2.3%	1.5%	-1.5%	-2.6%	9.9%
Cooling demand	Kwh	0.0%	-8.7%	-8.3%	12.3%	-0.6%	-18.5%	-12.8%
CO2	Ppm	0.0%	-0.6%	0.1%	-6.5%	57.5%	-9.9%	0.4%
Daylight	Lux	0.0%	-0.1%	-17.2%	13.6%	0.2%	6.4%	-33.5%
Acceptable Thermal comfort	Hour	0.0%	3.2%	0.5%	-0.2%	0.1%	- 0.3%	-1.6%

The appropriate strategies for creating the optimum model have been chosen, including **thermal insulation**, **form compact**, and **pane glasses**. In addition, the infiltration and fixed shading strategies had the least effective energy and thermal comfort performance, as shown in *Table.6.6, Appendix C*. Generally, the proposed model has been simulated, and the simulation results have been compared with the base model.

Overall, the results were satisfying for all the parameters. In *Fig.6.7* clearly illustrated that the largest reduction was in the maximum heating load was 51.3%, followed by heating demand, maximum cooling load, and cooling demand, 50.5%, 44.5%, 38.2% respectively. While the daylight increased 12.2%, and the CO_2 level was reduced to 9.1%, lastly, the acceptable thermal comfort hours was increased by 2.5%.



Optimum model -2- (Passive strategies)			
Zone: Guest room		Basis	Optimum model
Max. Heating load	W	0.0%	- 51.3%
Max. Cooling load	W	0.0%	- 44.5%
Heating demand	kWh	0.0%	- 50.5%
Cooling demand	kWh	0.0%	- 38.2%
CO2	ppm	0.0%	-9.1%
Daylight	Lux	0.0%	12.2%
Thermal comfort (Acceptable hours)	Hour	0.0%	2.5%

*Fig.6.7.*The proposed optimum model from IDA ICE (left), The percentage of energy and thermal comfort reduction in the optimum model (right).

6.3.1.3. Passive Strategies Application for Model type -3-

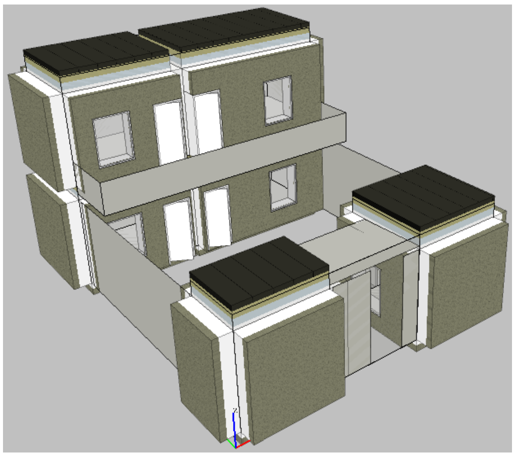
The base model from IDA ICE was created for model -3-, as shown in *Fig.6.8, Appendixes C*. the applicable passive strategies scenarios have been chosen for this type, including thermal insulation, pane glass, WWR, infiltration, form compact, and fixed shading. In addition, all scenarios have been simulated; the analysis results have been compared with the base model. It can be seen from *Fig.6.9, Appendixes C*, and *Table 6.7* that clearly illustrated the largest reduction for both energy and indoor environment performance when adding 20cm insulation to the building envelopes. Further, the two strategies that have a negative effect were infiltration and fixed shading.

Based on the results analysis in *Table 6.7*, and EPSO method utilized as shown in *Table 6.8, Appendixes C*, the appropriate strategies for creating the optimum model have been chosen, including **thermal insulation**, **WWR** , and **pane glass**.

The proposed optimum model for type-3 has been simulated and the results were compared with the base model. The results revealed that the optimal model has the best performance in both energy and thermal comfort. *Fig.6.10* illustrated the maximum reduction was achieved in the heating demand that was 91%, followed by maximum heating load 70.3%, maximum cooling load 61.7%, Indeed, the thermal comfort also increased significantly was 24.8%. Moreover, the daylight and CO_2 levels were significantly improved by 86.8% and 43.4%, respectively.

Table 6.7. The percentage of reduction and increased energy consumption, thermal comfort in all scenarios in type-3 [Researcher].

Residential building Type -3-			**Passive strategies**					
Zone: Living room Orientation: South			1	2	3	4	5	6
		Basis	Insulation 20cm	3 pane glass	WWR 25%	Infiltration	Form Improved	Fixed shading
Max. Heating load	W	0.0%	- 65.2%	-1.8%	5.7%	0.0%	0.7%	- 2.0%
Max. Cooling load	W	0.0%	- 52.9%	-2.0%	8.2%	0.1%	0.6%	-1.8%
Heating demand	Kwh	0.0%	-72.5%	-2.4%	-0.1%	- 0.7%	-1.0%	1.5%
Cooling demand	Kwh	0.0%	- 45.7%	-1.2%	7.4%	- 0.3%	- 0.2%	- 0.9%
CO2	Ppm	0.0%	- 3.1%	-0.5%	-14.9%	43.8%	6.4%	0.1%
Daylight	Lux	0.0%	8.9%	-17.5%	112.9%	0.2%	- 3.9%	-35.9%
Acceptable Thermal comfort hours	Hour	0.00%	26.6%	2.7%	-0.2%	0.4%	0.2%	- 3.5%



Optimum model-3-(Passive strategies)			
Zone: Guest room		Basis	Optimum model
Max. Heating load	W	0.0%	-70.3%
Max. Cooling load	W	0.0%	- 61.7%
Heating demand	Kwh	0.0%	- 91%
Cooling demand	Kwh	0.0%	- 40%
CO2	Ppm	0.0%	- 43.4%
Daylight	Lux	0.0%	86.8%
Thermal comfort (Acceptable hours)	Hour	0.0%	24.8%

*Fig.6.10.*The proposed optimum model from IDA ICE (left), The percentage of energy and thermal comfort reduction in the optimum model (right).

The three types that aforementioned represent the traditional and semi-traditional types in the study area, there are more or less have the same construction materials and the same roofing techniques as mentioned in chapter 5. Despite selecting the same climate condition and same building orientation, there is a significant difference for responding to the optimization process for each model. Furthermore, the first two types that represent the traditional types have less responding to the optimization than the third type, this is mainly due to having more harmonisation with the local climate and having a high thermal mass of mud bricks for the external walls. In addition, the difference due to the layout design and building construction techniques, this implies, the design has an effective role in reducing the energy and thermal comfort performance in both new construction and renovation process.

6.3.1.4. Passive Strategies Application for Model type -4-

Type-4 is considered a transition point from traditional to modern type, the most important difference with the previous types is the materials and techniques in roof construction, where reinforced concrete was used for roofing as mentioned in chapter 5. In addition, it has more compact form when compared with the other previous models. In order to optimize this type, all the steps that were used for the three mentioned types have been applied, including creating a base model, as shown in *Fig.6.11, Appendixes C,* selecting applicable passive strategies scenarios, including thermal insulation, pane glass, WWR, infiltration, and fixed shading. The five different scenarios were simulated, and the Excel tool was used for comparing the results with the base model, as shown in *Fig.6.12, Appendixes C.*

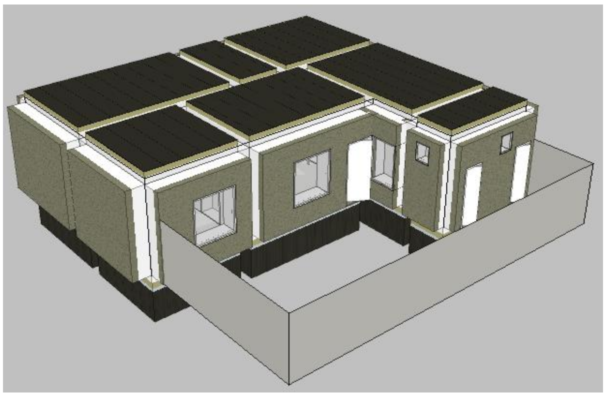
The simulations results have been analysed, as shown in *Table 6.9*, by adding 20 cm thermal insulation for the building envelopes, in the first scenario, the heating demand and maximum heating load were reduced considerably, while the acceptable thermal comfort hours was also increased slightly. In addition, the least effective passive strategy for this type was infiltration and fixed shading strategies.

Table 6.9. The percentage of reduction and increased energy consumption, thermal comfort in all scenarios in model-4 [Researcher].

Residential building Type - 4 -			**Passive strategies**				
Zone: Guest room Orientation: South			1	2	3	4	5
		Basis	Insulation 20cm	3 pane glass	WWR 25%	Infiltration	Fixed shading
Max. Heating load	W	0.0%	-66.3%	-4.0%	4.0%	-0.3%	- 2.7%
Max. Cooling load	W	0.0%	-54.7%	-4.6%	6.4%	-0.1%	-3.5%
Heating demand	Kwh	0.0%	-72.5%	-2.4%	-0.6%	0.0%	6.9%
Cooling demand	Kwh	0.0%	-55.8%	-2.9%	8.7%	- 0.7%	-9.2%
CO2	Ppm	0.0%	-2.7%	- 0.2%	-15.7%	44.6%	0.4%
Daylight	Lux	0.0%	0.1%	-17.7%	20.4%	0.0%	-45.8%
Thermal comfort (Acceptable hours)	Hour	0.0%	10.6%	3.2%	- 1.1%	0.9%	-1.7%

Based on the results analysis in *Table 6.9*, and EPSO method has been used, as shown in *Table 6.10*, *Appendix C*, the appropriate strategies for creating optimum model have been chosen, including **thermal insulation** and **pane glass**. After identifying the most effective strategies, the proposed model was simulated and compared the results with the base model. It can be seen from *Fig.6.13*, that clearly illustrated the largest reduction in the energy which was 85.3% for the heating demand, followed by the maximum heating load, cooling demand, and maximum cooling load which were 72.7%, 69.3% and 67.6% respectively. While the thermal comfort was increased to 9.9% and the CO_2 level was reduced to 8.8%. Notably, although the daylight reduced 50 %, the optimum model still gets a high level of daylight.

Actually, the comparison results were revealed the type 4, was possible to get optimum solutions in terms of energy and thermal comfort performance only by utilizing two strategies including thermal insulation and pane glass, this mainly due to having more space organization, and more form compact, this is an indicator of design role in the indoor environment and energy performance.



Residential building Type-4- (Passive strategies)			
Zone: Guest room		Basis	Optimum model
Max. Heating load	W	0.0%	-72.7%
Max. Cooling load	W	0.0%	-67.6%
Heating demand	kWh	0.0%	- 85.3%
Cooling demand	kWh	0.0%	-69.3%
CO2	ppm	0.0%	-8.8%
Daylight	Lux	0.0%	- 59.5%
Thermal comfort (Acceptable hours)	Hour	0.0%	9.9%

*Fig.6.13.*The proposed optimum model from IDA ICE (left), The percentage of energy and thermal comfort reduction in the optimum model (right).

6.3.1.5. Passive Strategies Application for Model type -5-

This type represented one of the modern types of the residential buildings, not only in the study area but also in the other districts in Sulaimani city. It varies from the previous models, in terms of outline design, construction materials, and spaces organization, where separated based on their functions, it also has a more compact form. Therefore, the optimization of this type should take into consideration for the building renovation process not only in the study area but also in the whole city. Thus, this type was optimized, based on applying the same methods that was used for the previous types, including creating a base model, as shown in *Fig,6.14, Appendix C,* and choose the most appropriate passive strategies for optimization, which including thermal insulation, 3pane glass, WWR, infiltration, wind catcher, and fixed shading. The six selected strategies have been simulated and the results have been compared with the base model, the Excel tool has been used for comparing the results, as shown in *Fig.6.15, Appendix C.*

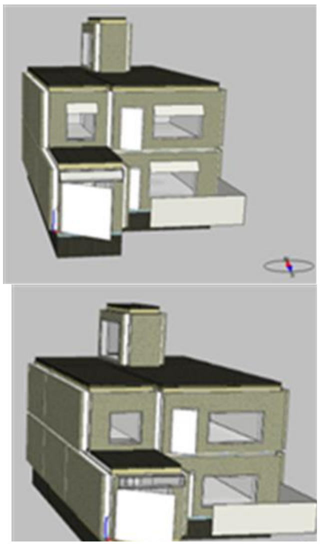
Based on the results analysis in *Table 6.11*, and EPSO method utilized as shown in *Table 6.12, Appendix C,* the results illustrated that the most effective strategies for the proposed optimum model, including **thermal insulation**, **wind catcher**, followed by **pane glass**, **WWR**, and **fixed shading**, it's worth to mention, the fixed shading was less efficient among other effective strategies. In order to find the best solutions, in term of energy and thermal comfort performance, a decision was made to create two optimum models; **with** and **without shading**, and both have been simulated and compared with the base model.

Table 6.11. The percentage of reduction and increased energy consumption and thermal comfort in all scenarios in model-5 [Researcher].

Residential building Type - 5 -			**Passive strategies**						
Zone: kitchen Orientation: South			1	2	3	4	5	6
		Basis	Insulation 20cm	3 pane glass	WWR 25%	Infiltration	Wind Catcher	Fixed shading
Max. Heating load	W	0.0%	-67.6%	-3.7%	4.4%	- 0.2%	- 3.4%	0.6%
Max. Cooling load	W	0.0%	35.4%	-10.5%	-1.2%	- 6.3%	-12.7%	-7.5%
Heating demand	Kwh	0.0%	-72.3%	-1.6%	0.0%	- 0.9%	- 0.9%	7.4%
Cooling demand	Kwh	0.0%	-52.3%	-11.6%	- 3.8%	- 9.7%	-19.1%	-14.1%
CO2	Ppm	0.0%	-36.6%	- 35.1%	-37.8%	2.3%	- 47.9%	-35.1%
Daylight	Lux	0.0%	-0.2%	-17.5%	26.8%	0.0%	-6.4%	-35.1%
Thermal comfort (Acceptable hours)	Hour	0.0%	1.1%	-1.1%	-1.4%	-1.4%	- 1.4%	- 2.8%

In *Fig.6.16.* the comparison results analysis showed, in both optimum models the energy consumption was reduced significantly, the largest reduction in the heating demand was more than 70%, the difference was in the daylight level, in the shading optimum model, the daylight level was reduced 6.6%, while in the optimum model without shading, the daylight level was increased 7.7%.

Thus, the comparison revealed that the optimum model **without shading** is more efficient, this is mainly due to the shading might reduce the daylight level which penetrates within inside, and this lead to consuming more energy in the winter season.



Residential building Type-5-			(Passive strategies)	
Zone: Guest room		Basis	Optimum model	
			with shading	Without shading
Max. Heating load	W	0.0%	- 70.9%	- 68.4%
Max. Cooling load	W	0.0%	- 66.1%	- 63.1%
Heating demand	kWh	0.0%	- 72.1%	- 71.4%
Cooling demand	kWh	0.0%	- 58.9%	- 51.6%
CO2	ppm	0.0%	-51.1%	- 51.3%
Daylight	Lux	0.0%	-6.6%	7.7%
Thermal comfort	Hour	0.0%	1.57%	1.8%

Fig.6.16. The proposed optimum model from IDA ICE (left), the percentage of energy and thermal comfort reduction in the optimum model (right).

6.3.2. Hybrid Strategies Optimization

Generally, passive strategies alone are insufficient to meet heating, cooling, ventilation, and lighting that need in the buildings when the ambient temperature is too high or too low, in the winter and summer seasons. Therefore, the conditioning buildings need active systems to supplement passive systems. The hybrid strategies system attempts to combine the benefits of both passive and active strategies in an optimal way to provide better indoor climate and lower energy use.

In order to apply hybrid strategies, the optimum models, that are most responsive to the passive strategies optimization, have been selected. Actually, they are two models that were most responsive: models 3 and 5. The model-3 consisted 29% and model-5 was 23% of the residential buildings in the study area, model 5 was chosen to apply the active strategies. This is mainly due to model-5 represented the modern style of residential buildings in the study area. The appropriate selected active strategies are: **External shading**, **heating/cooling floor system**, **heating/cooling floor system with heat pump (HP), heating/cooling floor system with HP and solar thermal, water radiator and active beam system**, **water radiator with Air Handling Unit (AHU).** The last scenario was applied the most effective scenarios together for getting the optimum model, as shown in *Table.6.13, Appendix C.*

After selecting the scenarios, IDA ICE 4.7.1 was used for simulation all the scenarios. The simulation results have been analysed, and the Excel tool has been used to compare the results with the base model, as shown in *Fig.6.18*, *Appendix C*, It is worth mentioning that the base model is an enhanced version of model-5 based on passive strategies.

The results showed that the acceptable thermal comfort hours in all scenarios reached satisfactory results and culminated. The unacceptable thermal comfort hours ranged (4-9) hours throughout the whole year. This is an important indicator of achieving one of the research goals which is increasing thermal comfort efficiency inside the building during renovation. Furthermore, the results also showed that CO_2 and daylight levels were stable when compared to the base model.

It can be concluded from *Table 6.14*, that the **acceptable thermal comfort hours**, **CO_2**, and **daylight level** in all scenarios are similar and have satisfactory results. Consequently, the results comparison is focusing on the energy efficiency. Thus, it should be dealt with the delivered energy in the system energy that was used in the whole building, rather than the zone level, as done in the passive strategies. This is because, when passive strategies were applied, one system was used for heating and cooling the buildings for all the models while the heating and cooling system varied with applying each hybrid strategy scenario.

Table 6.14. Comparison the hybrid strategies results with the base model [Researcher].

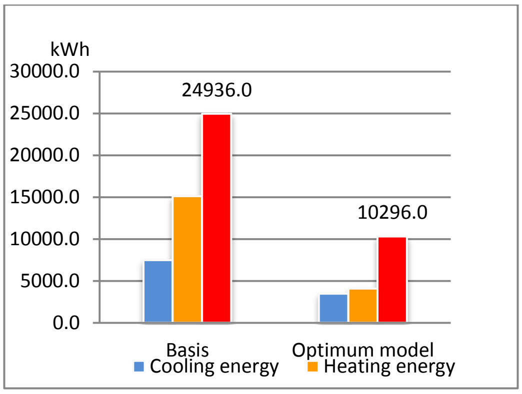
Residential building Type - 5 -			Hybrid strategies					
Zone: kitchen Orientation: South			1	2	3	4	5	6
		Basis	External Shading	Heating/ Cooling Floor	Heating/ Cooling Floor +HP	Heating/ Cooling Floor +HP+ Solar Th.	Water Rad.	Water Rad.+ AHU
Max. Heating load	W	0.0%	-0.2%	-38.8%	-37.9%	-38.1%	-0.5%	5.5%
Max. Cooling load	W	0.0%	-11.2%	-21.7%	-21.9%	-21.9%	-1%	1.8%
Heating demand	Kwh	0.0%	0.1%	5.9%	5.9%	5.8%	-8.4%	12.3%
Cooling demand	Kwh	0.0%	-39.5%	26.8%	25.9%	25.8%	1.4%	3.9%
CO2	Ppm	0.0%	0.4%	0.0%	0.0%	-0.1%	-0.4%	-53.6%
Daylight	Lux	0.0%	-14.2%	2.3%	2.3%	2.3%	0.0%	0.0%
Thermal comfort (Acceptable hours)	Hour	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

In *Fig.6.19*, *Appendix C*, and *Table 6.15*, the comparison results analysis showed that the total energy consumption for the whole building was reduced significantly, in all the hybrid strategies used. Based on the results, the most efficient and economic system was heating and cooling with HP and solar thermal in the fourth scenario, the total energy was reduced by 54.6%. In addition, the cooling demand was reduced significantly when external shading strategies had been used.

Table 6.15. The comparison delivered energy in different hybrid strategies' scenarios [Researcher].

Residential building Type - 5 -		Hybrid strategies						
Orientation: South			1	2	3	4	5	6
		Basis	External Shading	Heating/ Cooling Floor	Heating/ Cooling Floor +HP	Heating/ Cooling Floor +HP+ Solar Th.	Water Rad.	Water Rad.+ AHU
Cooling energy	W	0.0%	-16.2%	-70.9%	-40.7%	-41.3%	-74.4%	-73.2%
Heating energy	W	0.0%	0.0%	2.4%	-71.4%	-73.2%	-1.8%	4.1%
Total energy	Kwh	0.0%	-4.9%	-19.6%	-53.8%	-54.65	-23.3%	-12.9%

Based on the aforementioned, to propose an optimal model, two strategies have been integrated: **External shading** and **heat/cool floor system with HP and solar thermal**. The optimum model has been simulated and the results were compared with the base model. In *Fig.6.20*, the comparison results analysis showed that the largest reduction in the energy was in the heating system 73.1%, while the total energy for the whole year was reduced by 58.7%.



Optimum model-5- Hybrid strategies			
		Basis	Optimum model
Cooling energy	Kwh	0.0%	-53.8%
Heating energy	Kwh	0.0%	- 73.1%
Total energy	Kwh	0.0%	- 58.7%

Fig.6.20. The delivered energy for the optimal model and its comparison with the base model in the hybrid strategies.

In summary, based on the supplied energy analysis for all the models in chapter 5, largest energy consumer was type 5, which required 62267 kwh for the whole year. Indeed, after the optimization process ,based on the appropriate passive and hybrid strategies, the supplied energy for model 5 was 10296 kwh (83 % reduction).

In addition, the improved model is more efficient in terms of acceptable thermal comfort hours and indoor air quality performance.

6.4. Results and discussion

- The most effective passive strategies for all the models were thermal insulation and pane glazing. In contrast, the least effective passive strategy for all the models was infiltration which, therefore, is not recommended for building optimization in hot and arid climate.

- The models 5 and 4 were more responsive models respectively. This was mainly due to both models lacking high thermal mass.
- Providing wind catcher for models 1 and 5 was effective in increasing indoor air quality and lead to energy consumption reduction for cooling demand in the summer season. This is an important indicator of the validity of one research hypothesis is; *Using wind catcher as a traditional passive cooling strategy during the renovation process has a significant impact on reducing energy consumption and increasing indoor air quality in subtropical climates zone.*
- Building materials, construction techniques, and design style have an effective role in selecting the appropriate passive strategies for optimization.
- Based on the feasible passive strategies, an optimal model for each type was proposed. The optimum models performed better in both energy and thermal comfort, and efficiency, by comparison with the base model.
- Despite varied the heating and cooling system with applying each active strategy scenario, the acceptable thermal comfort hours, CO2, and daylight level in all hybrid scenarios are similar results.
- Based on the result analysis the most effective hybrid strategies, were external shading and heat/cool floor system with Heat Pump and solar thermal.
- In summary, based on the passive and hybrid optimization process, the largest energy consumer was type 5, which reduced from 62267 kWh for the whole year to10296 kWh.

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7. Conclusion & Recommendation

7.1. Conclusion

- The best opportunities for improving energy efficiency, indoor air quality and thermal comfort performance in the existing buildings are sustainable renovations. Therefore, **the first step of my study was identifying five types of existing residential buildings in the study area, through field surveys based on their compositional and morphological characteristics analysing.**
- To investigate the energy efficiency in the existing residential buildings, the models have been simulated. During the simulation results analysing **I have found that the building materials and construction techniques have a significant impact on the energy performance. Consequently, I investigated that the houses that have better thermal mass, have lower energy requirements.**
- To improve the indoor environment, **I have studied the appropriate passive, active and hybrid strategies, and tried to apply them, as traditional and contemporary techniques on the existing residential buildings typologies during the optimization process.** Through my studies, **I came to the result that both passive and hybrid strategies are promising strategies to optimise the building more sustainable with low energy use and good indoor air quality.**
- Through the cases study, one thing **I can be stated here is despite differences of the residential building types, there are some common passive strategies have a significant effect which includes thermal insulation, glass pane, window to wall ratio, that play a big role in the increasing thermal comfort and energy performance.**
- Based on my results, **I have established that the hybrid strategy usage more efficient in the indoor air quality and thermal comfort, compared to the passive strategy. While passive strategies are more efficient in terms of energy savings.**
- During my study on the microclimate in Kurdistan, **I have proved that potentially it is very well-suited to natural ventilation especially in the several months including May, June, and September in Sulaimani, and Duhok governorate. Whereas, other hotter locations like Erbil city and its surroundings less suited to a simple natural ventilation strategy but may be able to benefit from hybrid ventilation system strategies.**

- July and August are the hottest and driest months in the year where mechanical cooling is required for maintaining thermal comfort, whereas high thermal mass can be effective during the months of March, April, October and November.
- **I have established that in the optimization phase, when simulations serve as a means to compare different scenarios of passive and hybrid strategies, this simulation can predict that the optimal model reduces 85% of total energy consumption during the year compared to the base model. While the improved model is more efficient in terms of acceptable thermal comfort hours and indoor air quality performance.**

Recommendations

- The architect should contribute to climate change mitigation not only in the new design process, but also in the renovation process in a way that respects microclimatic, cultural, and economic conditions of the local area and should take advantage of renewable energy resources to make buildings more sustainable over time.
- The energy saving potential of the strategies used is influenced significantly by the thermal properties of the room such as orientation, WWR and thermal mass. Therefore, when assessing the energy and thermal comfort based on IDA ICE simulation results, should be investigated at the level of room or zone.
- Using computational techniques are seen as important tools that can aid to evaluate the energy and thermal comfort performance in the building. However, because of the time-consuming nature of the process involved and expertise needed for data input; these tools are not widely used, as a result leading to non-integrated methods in the building optimization procedure.
- The results analysis in considerable iterations undertaken during the scenarios' simulation is very important because time is one of the most reported barriers during design or renovation stages. Therefore, it is essential that architects receive a sufficient knowledge in sustainable environmental building to use the tools for quick evaluation of design or optimization concepts. Thus, evolution has to take place in the academic field and consulting engineering offices by introducing new classes of building simulation tools.
- The workshop as a field activity is a good attitude for discussions and establishing a common understanding, which is fundamental in all interdisciplinary work, especially work aimed at generating actionable knowledge.

- The government's incentive measures and improvement of public culture and awareness toward renovation building in a sustainable way can be effective for energy and thermal comfort efficiency in the residential buildings.
- The process of optimization thermal comfort and energy efficiency in residential buildings are not only architects' responsibilities in academia and practice fields, but also, developers and householders also play a major part in this process.
- It is possible to use advanced technical facilities through the use of architectural solutions and the integration of heating and ventilation strategies in the construction of buildings. Focusing on high-quality solutions and flexibility is important to achieve sustainable buildings with a long lifespan.
- Today, the building sector in Kurdistan suffers from lack of electricity in daily life. Since the residential buildings are the first electric energy consumer during the past four years. Therefore, sustainable renovation for the residential building may be directly involved in reducing energy consumption. Hopefully, this study can contribute a bit to research in this area focusing on sustainable renovation and providing knowledge and experience for similar projects in the future.

List of papers

The following relevant papers to the thesis topics:

- **Paper I** Traditional Houses Energy Optimization Using Passive Strategies, Pollack Periodica Journal, University of Pecs, Hungary. Approved for publishing in August 2018.
- **Paper II** Energy Efficient optimization in a typical school building, Eurasian Journal, Ishik University, Erbil, Iraqi Kurdistan, Approved for publishing in June 2018.
- **Paper III** Thermal Performance Analysis of Sabunkaran Residential Building Typology, Pollack Periodica Journal, University of Pecs, Hungary, published in August 2017.
- **Paper IV** Efficient Natural Ventilation in Traditional and Contemporary Houses in Hot and Dry Climate, proceeding of the Conference (ICASCE'16), London, UK, published in March 2016.

Appendix A (A.A)

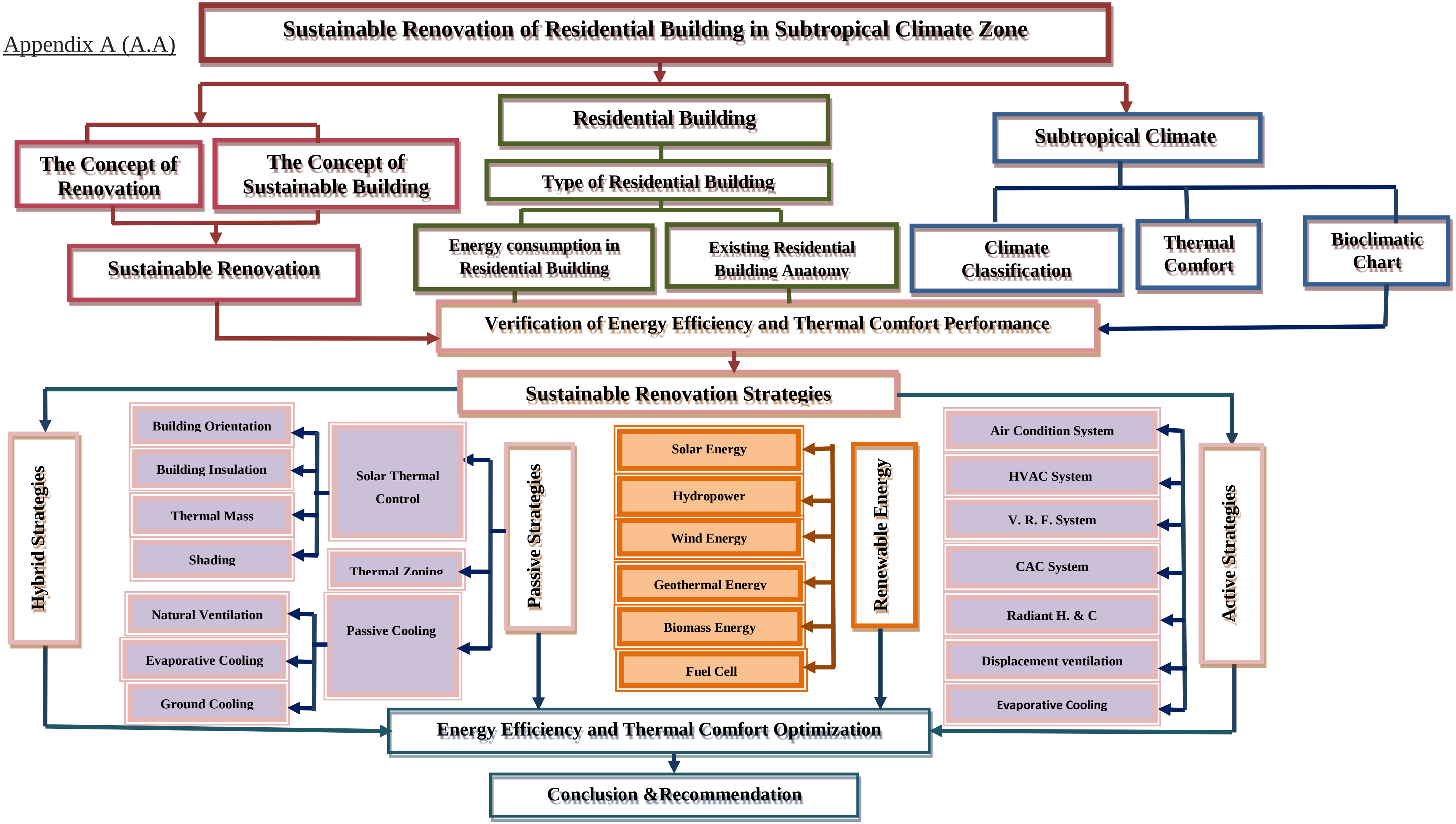


Fig.1.1. The methodology of the research [Researcher].

Appendix A (A.A)

Group I Low Latitudes Climates	Group II Mid- Latitudes Climates	Group III High-Latitudes Climates
Equatorial rain forest	Humid subtropical	Subtropical
Trade wind littoral	Mediterranean	Tundra
Tropical monsoon	Marine west-coast	Ice cap
Tropical savanna	Dry mid-latitude	
Dry tropical	Humid continental	

Fig. 2.3. Climate groups based on the Thornthwait climate classification.

International Climate Zone Definitions

Zone Number	Zone Name	Thermal Criteria (I-P Units)	Thermal Criteria (SI Units)
1A and 1B	Very Hot –Humid (1A) Dry (1B)	9000 < CDD50°F	5000 < CDD10°C
2A and 2B	Hot-Humid (2A) Dry (2B)	6300 < CDD50°F ≤ 9000	3500 < CDD10°C ≤ 5000
3A and 3B	Warm – Humid (3A) Dry (3B)	4500 < CDD50°F ≤ 6300	2500 < CDD10°C < 3500
3C	Warm – Marine (3C)	CDD50°F ≤ 4500 AND HDD65°F ≤ 3600	CDD10°C ≤ 2500 AND HDD18°C ≤ 2000
4A and 4B	Mixed-Humid (4A) Dry (4B)	CDD50°F ≤ 4500 AND 3600 < HDD65°F ≤ 5400	CDD10°C ≤ 2500 AND HDD18°C ≤ 3000
4C	Mixed – Marine (4C)	3600 < HDD65°F ≤ 5400	2000 < HDD18°C ≤ 3000
5A, 5B, and 5C	Cool-Humid (5A) Dry (5B) Marine (5C)	5400 < HDD65°F ≤ 7200	3000 < HDD18°C ≤ 4000
6A and 6B	Cold – Humid (6A) Dry (6B)	7200 < HDD65°F ≤ 9000	4000 < HDD18°C ≤ 5000
7	Very Cold	9000 < HDD65°F ≤ 12600	5000 < HDD18°C ≤ 7000
8	Subarctic	12600 < HDD65°F	7000 < HDD18°C

Fig. 2.4. The International climate zone definition.

Table 2.1. The seven different climatic zones in Iraq [9].

Zone	Map code	Description	Iraq
Bswh	11	Hot semi-arid (steppe) climate, winter precipitation	9.0
Bswk	12	Cool semi-arid (steppe) climate, winter precipitation	0.3
Bwwh	24	Hot arid (desert) climate, winter precipitation	83.0
Bwwk	25	Cool arid(desert), winter precipitation	0.7
Csa	36	Warm temperate rainy climate with dry and hot summer	6.4
Dsa	53	Subarctic climate with humid winter and hot summer	0.3
Dsb	54	Subarctic climate with humid winter and warm summer	0.3

<u>Appendix A (A.A)</u>

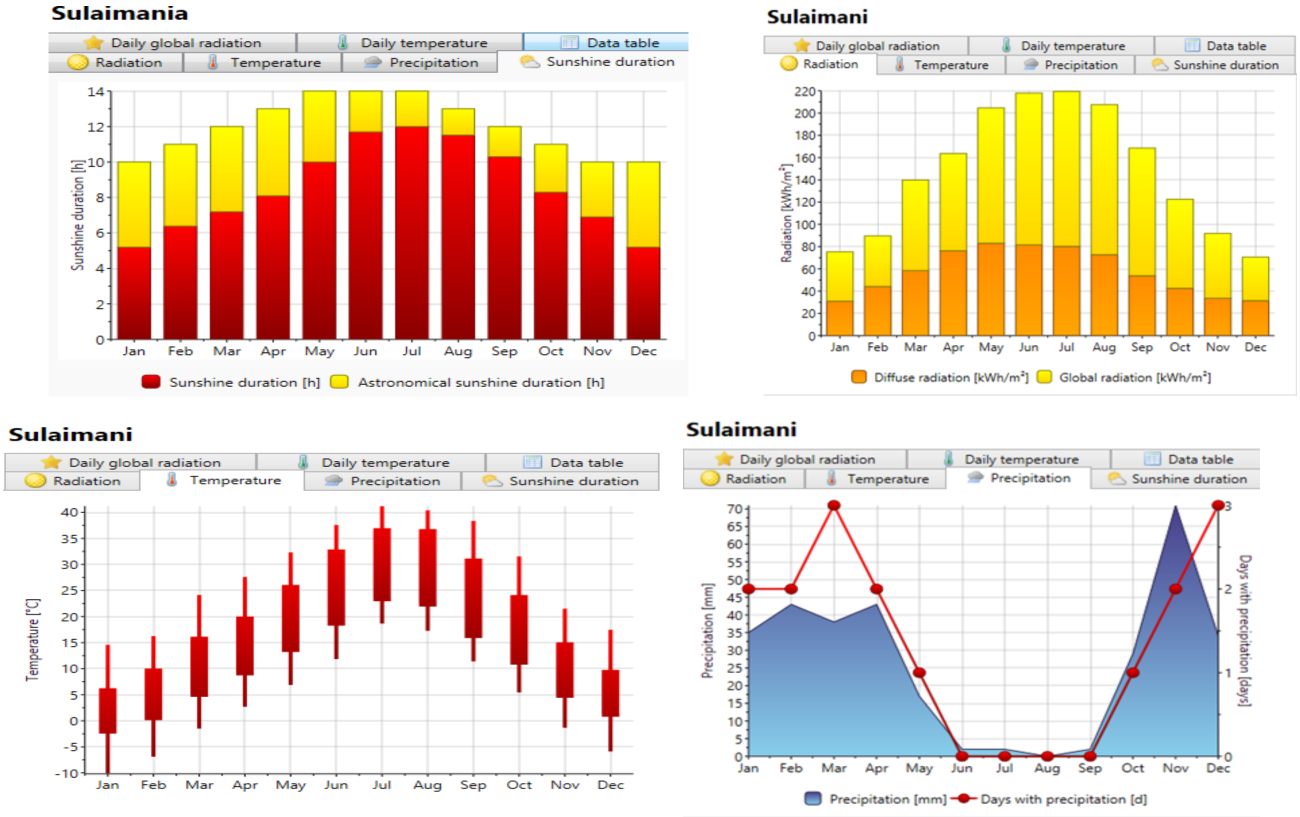


Fig.2.7. The weather Data in Sulaimani [Meteonorm Version 7.2]

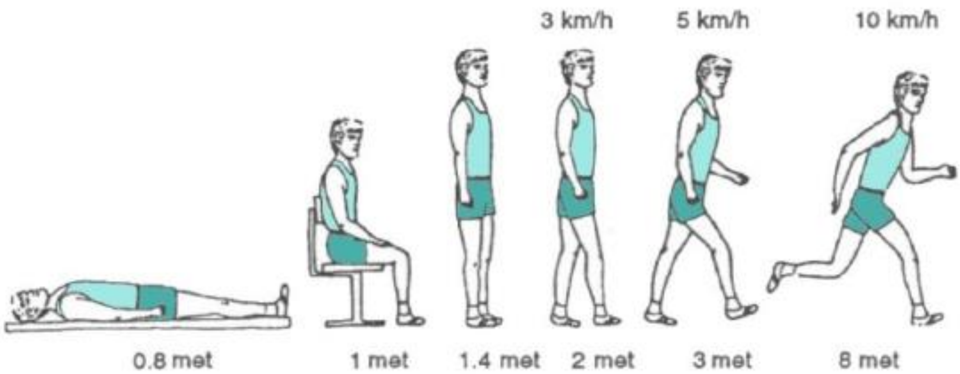


Fig.2.8. The metabolic rate (met) of different activities.

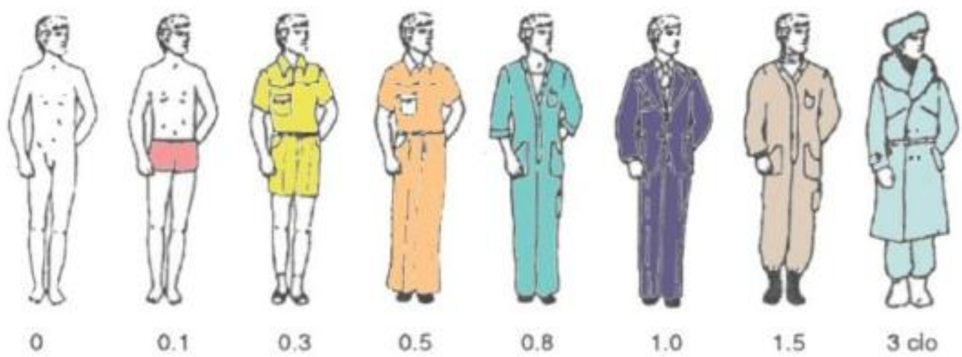


Fig.2.9. The insulation values (Clo) of typical combinations of clothing.

<u>Appendix A (A.A)</u>

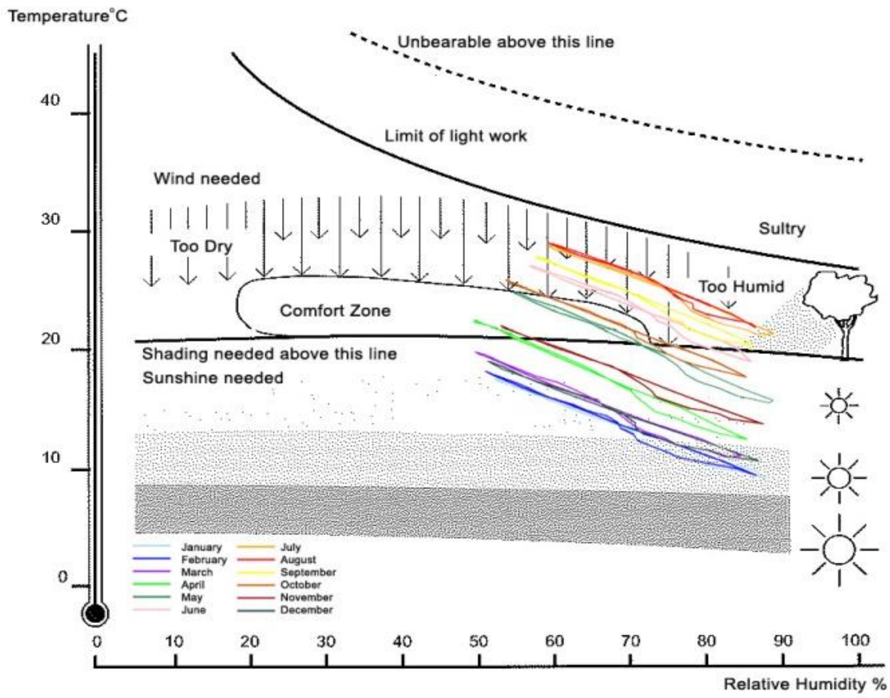


Fig.2.11. The Olgyay's bioclimatic chart.

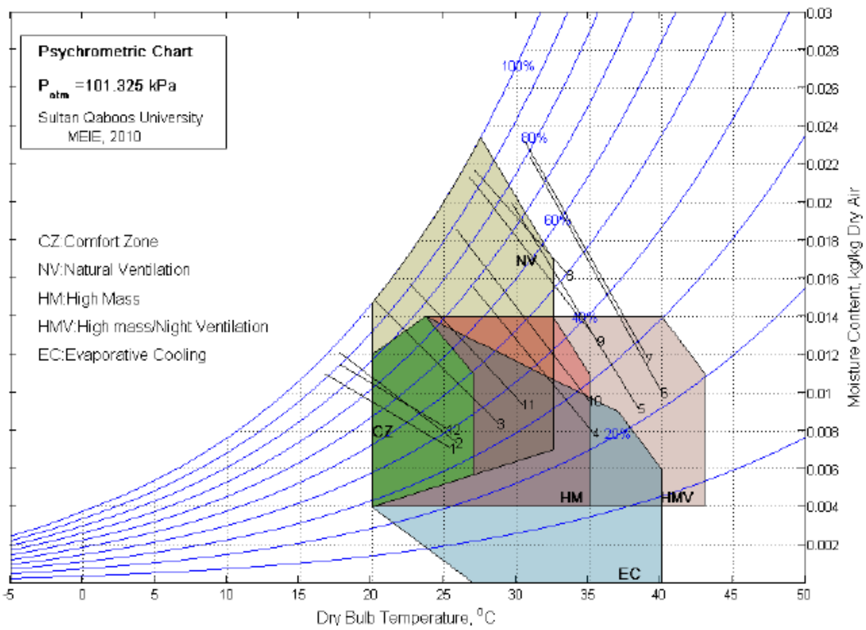


Fig.2.12. The Givoni bioclimatic chart.

Appendix A (A.A)

Table.3.1. The key building sustainable performance criteria.

	Criteria
Sustainable site	*Site selection
	*Reduce pollution generation
	*Transport and accessibility
	*Construction activity pollution prevention
	*Reduce heat island effect
	*Development of density and community connectivity
	*Site development
	*Surface water runoff control
	*Light pollution reduction
Energy efficiency	*Renewable energy
	*Minimum energy performance
	*Reducing greenhouse gas emission
	*Fundamental commissioning of the building energy systems.
	*Building envelope performance control
	*Energy savings
	*Green power
	*Fundamental refrigerant management
	*Enhanced commissioning
	*Measurement and verification
	*Optimize energy performance
Economical	*Life-cycle cost
	*Life-cycle profit
	*Project budget
	*Effect on local development
	*Protection to cultural heritage
Social	Aesthetic options
	Effect on local development
	Protection to culture heritage

	Criteria
Water efficiency	*Water use reduction
	*Water efficient landscaping
	*Wastewater technology
	*Water conservation
	*Water treatment
	*Pollution effect on water quality
Material and resources	*Reduce waste generation
	*Renewable material use
	*Material reuse
	*Local material use
	*Storage and collection of recyclables
	*Material durability
	*Recycled material use
	*Building reuse
Indoor environment quality	*Indoor air quality management
	*Outdoor air delivery monitoring & increased ventilation
	*Day lighting and views
	*Indoor chemical & pollution sources control
	*Tobacco smoke control
	*Controllability of systems
	*Minimum indoor air quality
	*Thermal comfort
	*Low-emitting material
	*Acoustic & noise control
Innovation	*Innovation in design

Appendix A (A.A)

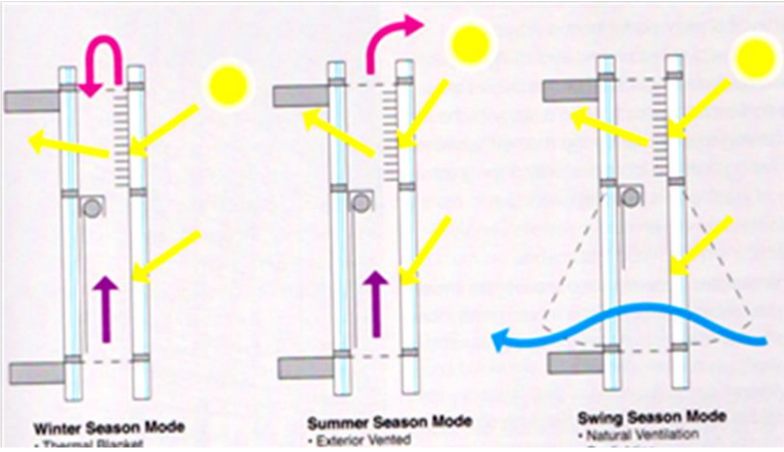


Fig.4.6. Double skin façade concept in seasonal operation (left); Double skin façade integrated into existing buildings (right).

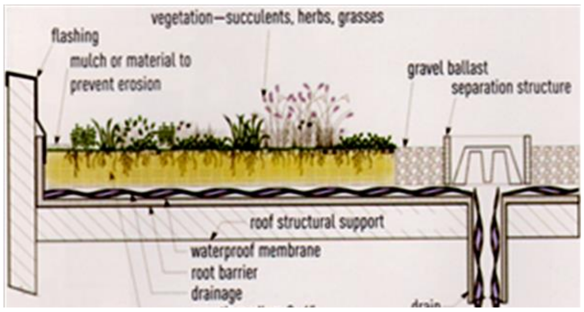


Fig.4.7. The *g*reen wall provides effective cooling (left); Green roof cross section, (right).

Fig.4.8. Side-lighting in a North Zone (left); Top-lighting in the gymnasium hall (right).

Appendix A (A.A)

Fig.4.12. Courtyard in hot and arid climate.

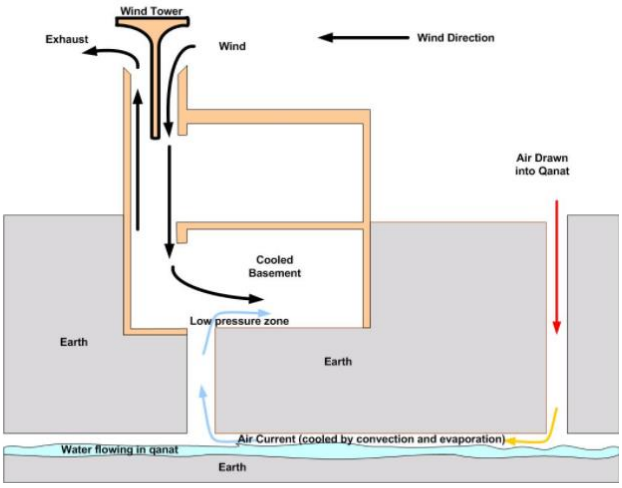


Fig.4.13. Evaporative cooling through the underground canal and wind catcher.

Fig.4.14. Fan, Window AC, Split AC, Packaged AC, and Central AC chiller.

Appendix A (A.A)

Fig.4.15. Variable Refrigerant Flow (VRF) System.

Appendix A (A.A)

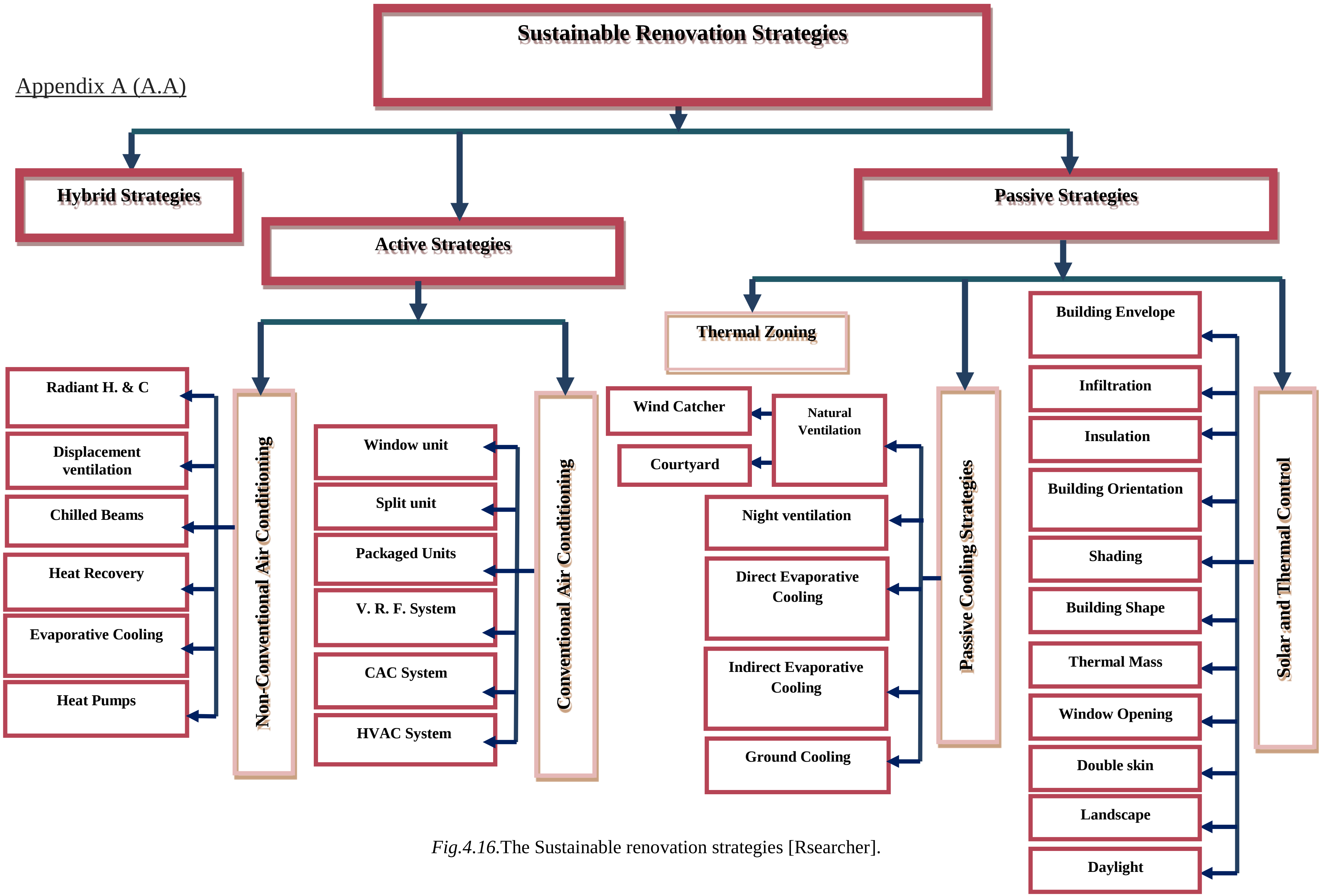


*Fig.4.16.*The Sustainable renovation strategies [Rsearcher].

Appendix A(A.A)

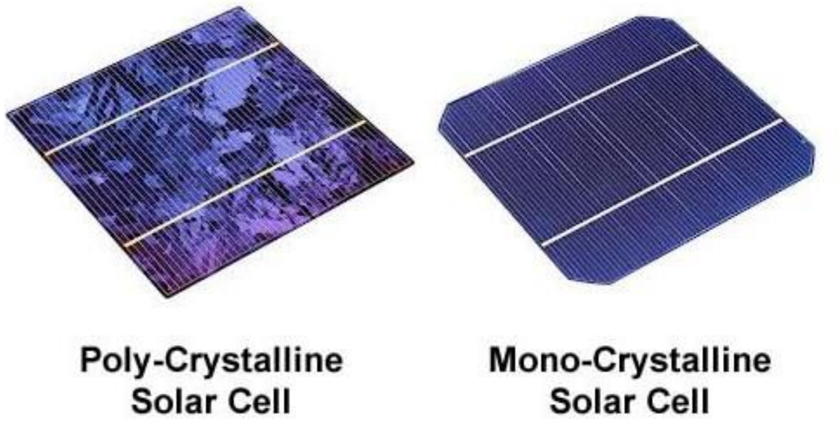


Fig.4.17. Crystalline PV Modules types.

Fig.4.18. Amorphous PV Modules.

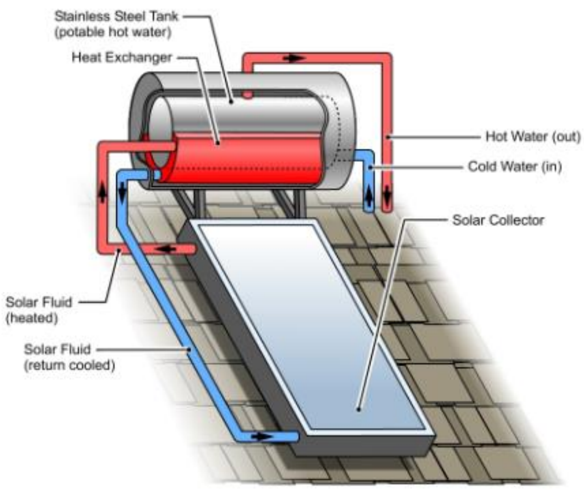


Fig.4.19. Solar thermo syphon system.

Appendix A (A.A)

Fig.4.20. Flat plate collectors (lift), solar air collectors, (right).

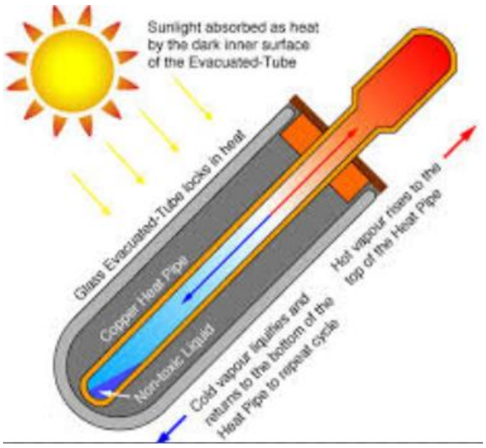


Fig.4.21. Evacuated tube collectors system.

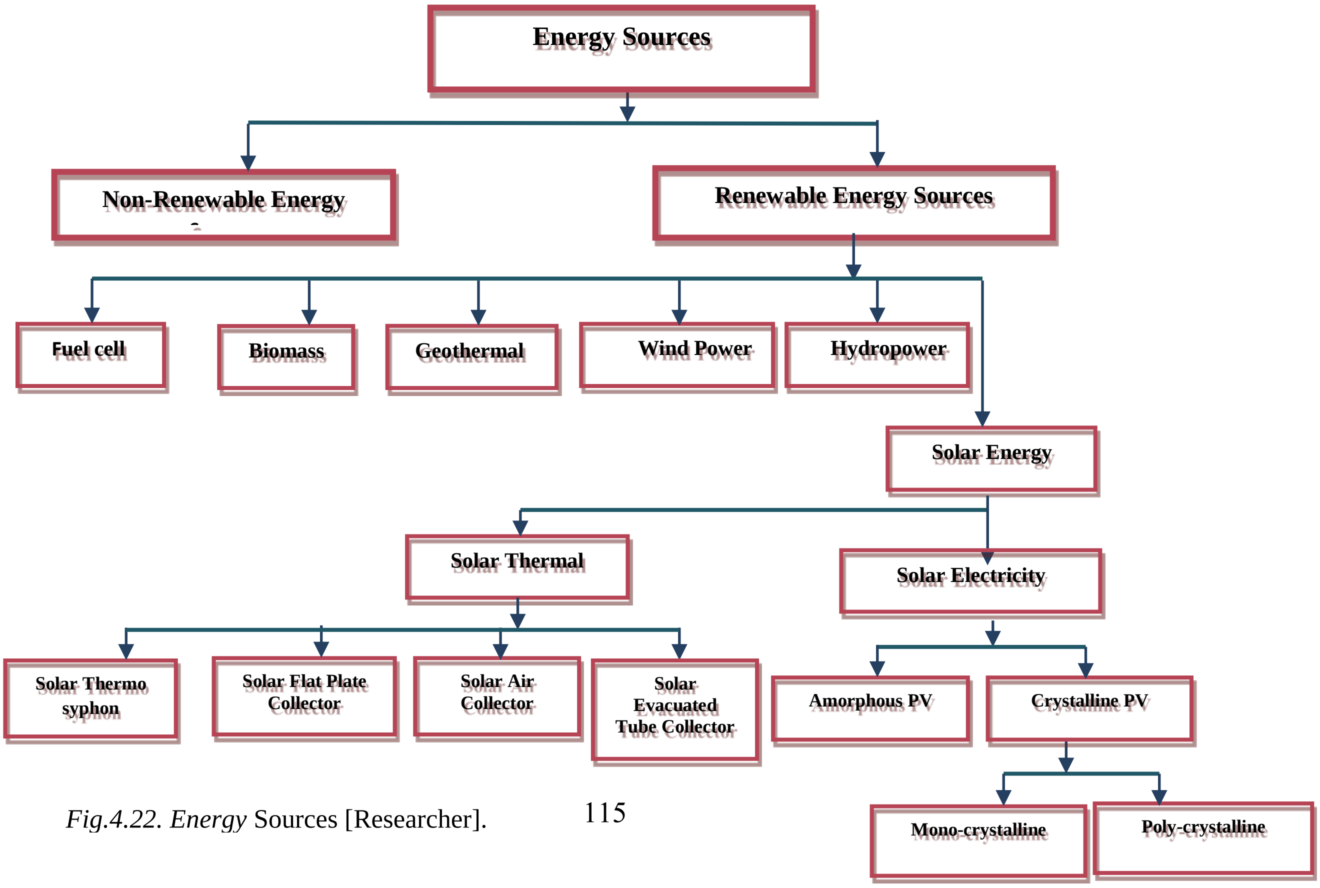


Fig.4.22. Energy Sources [Researcher].

Appendix B (A.B)

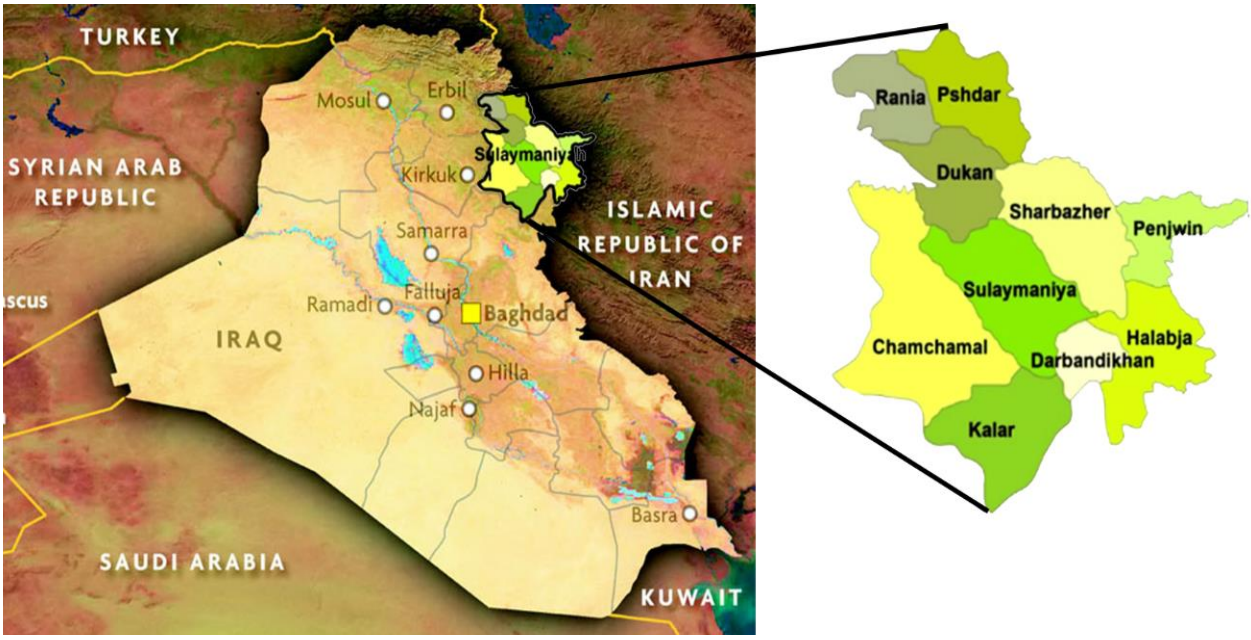


Fig.5.1. The location of Sulaimani in Iraq.

Fig.5.3. Examples of Residential Building types in Sulaimani [Researcher].

Appendix B (A.B)

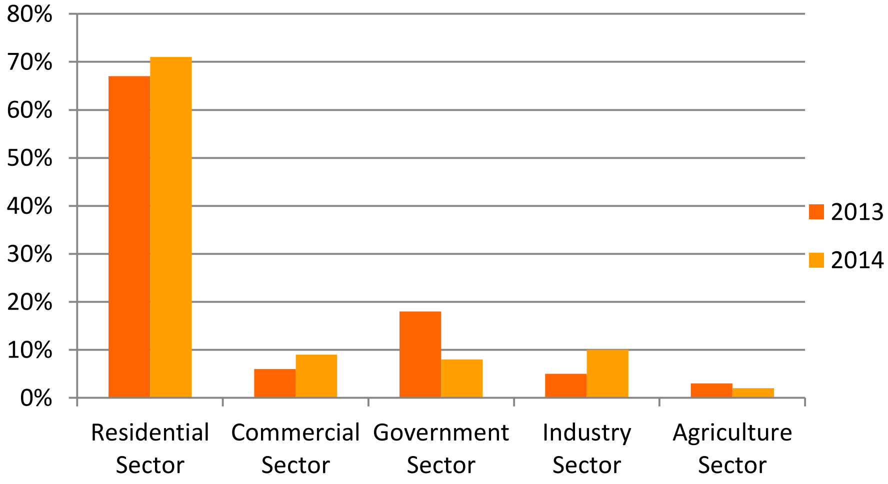


Fig.54. Energy Consumption in Kurdistan.

Fig.5.8. The closed ends of the alleys in Sabunkaran district [Researcher].

Fig.5.9. The definitions of the entrances in Sabunkaran district [Researcher].

Appendix B (A.B)

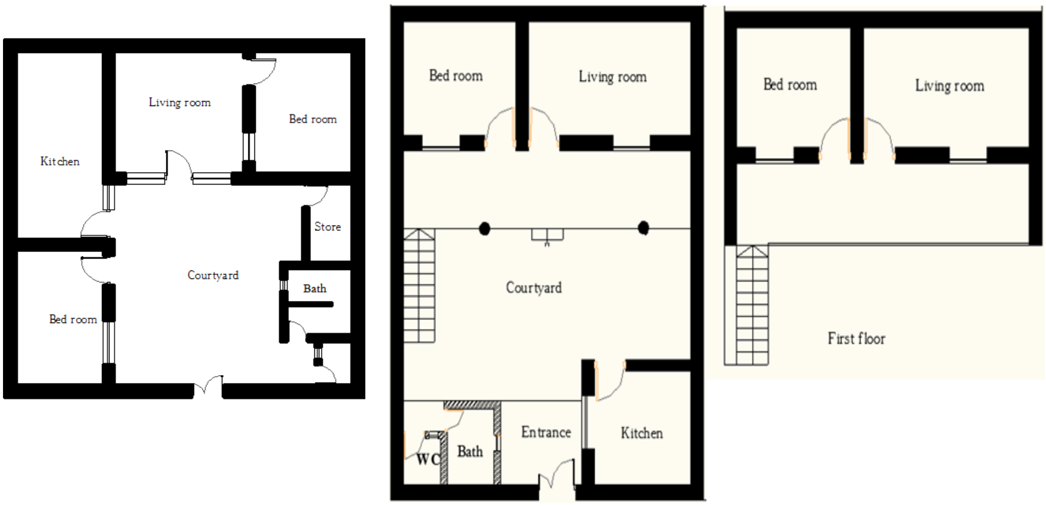


Fig.5.11. The central courtyard houses type in Sabunkaran district [Researcher].

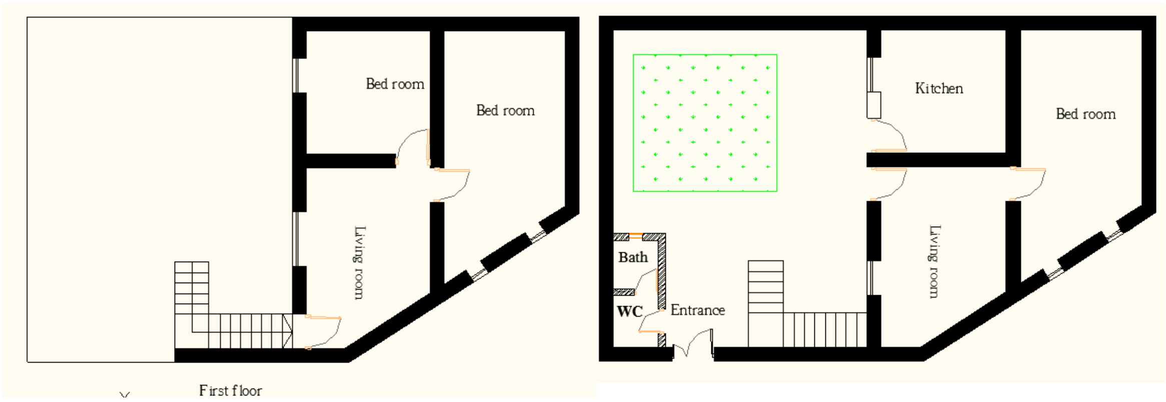


Fig.5.12. The sidecouryard houses type in Sabunkaran [Researcher].

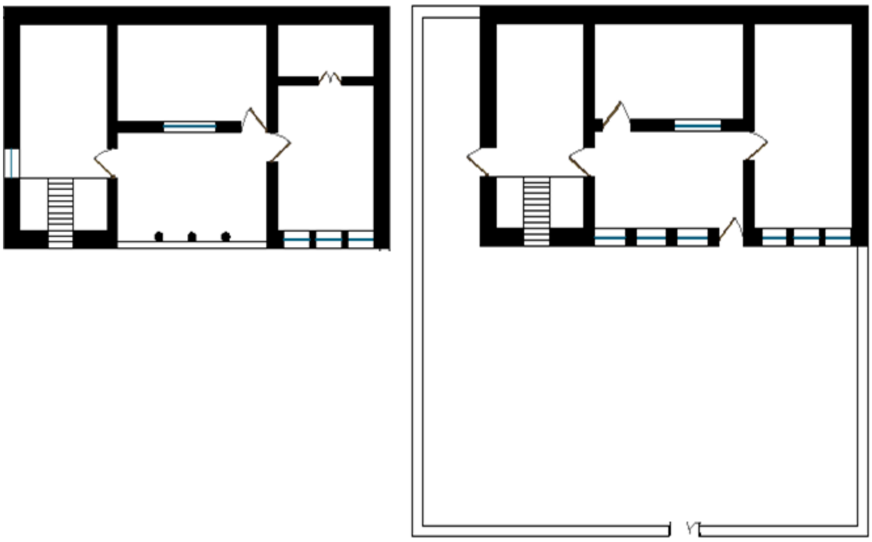


Fig.5.13. The big front courtyard houses type in Sabunkaran district [Researcher].

<u>Appendix B (A.B)</u>

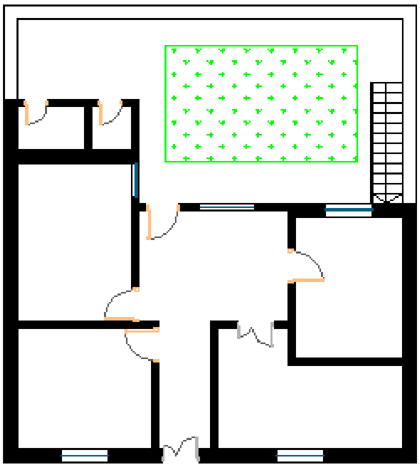


Fig.5.15. The back courdyard houses type in Sabunkaran district [Researcher].

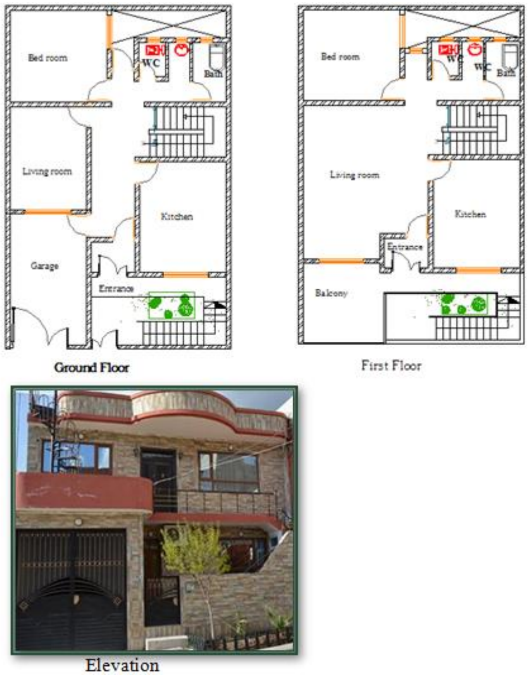


Fig.5.16. The front small courtyard houses type in Sabunkaran district [Researcher].

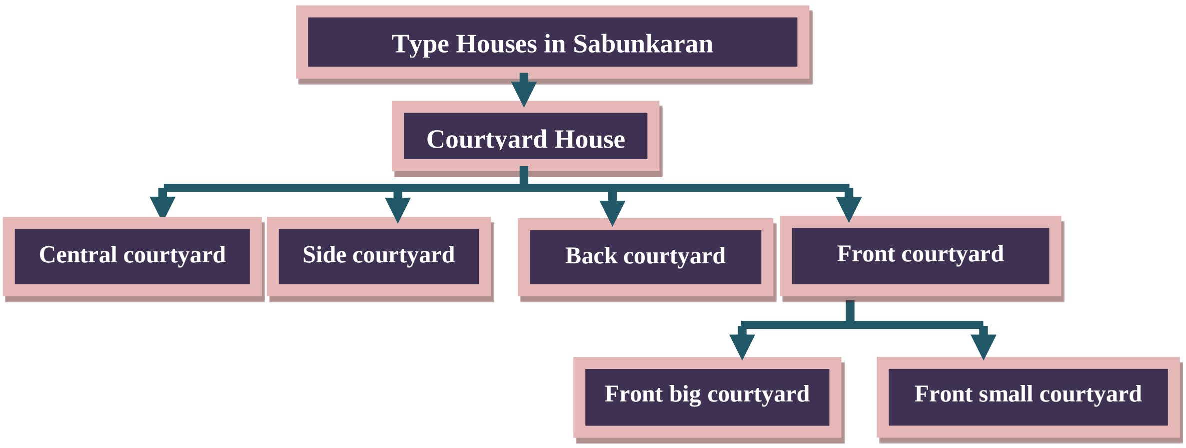


Fig.5.17. The residential Building types based on their composition properties in Sabunkaran district [Researcher].

Appendix B (A.B)

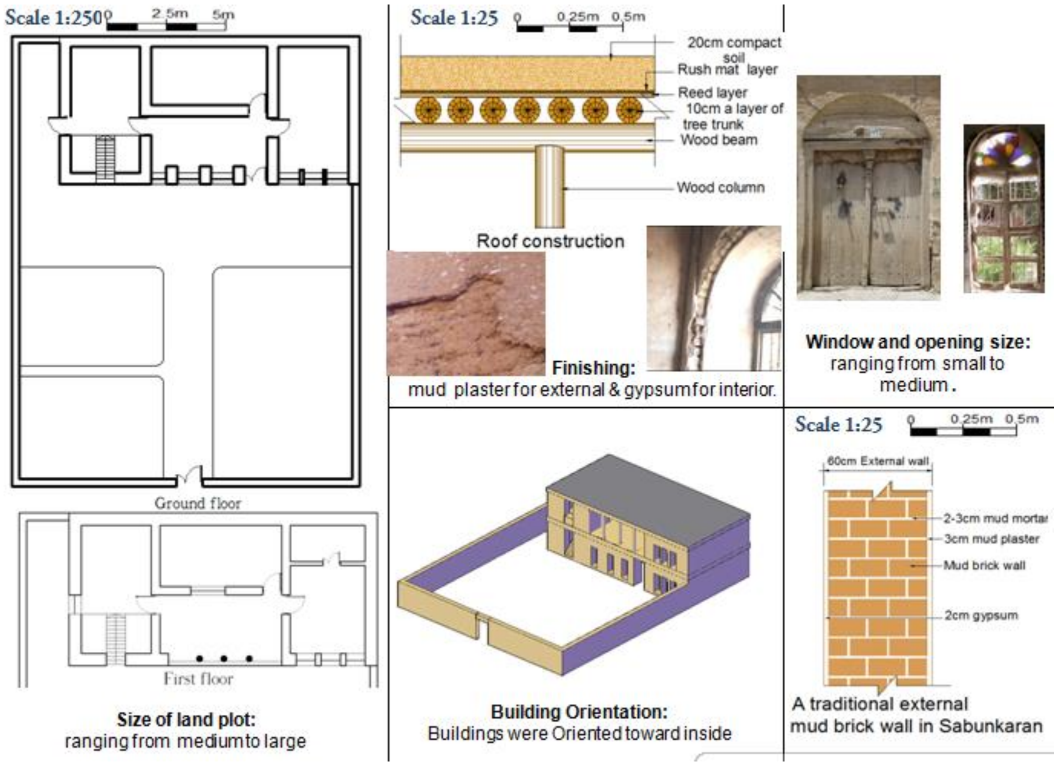


Fig.5.18. The Morphology properties of Type-1[Researcher].

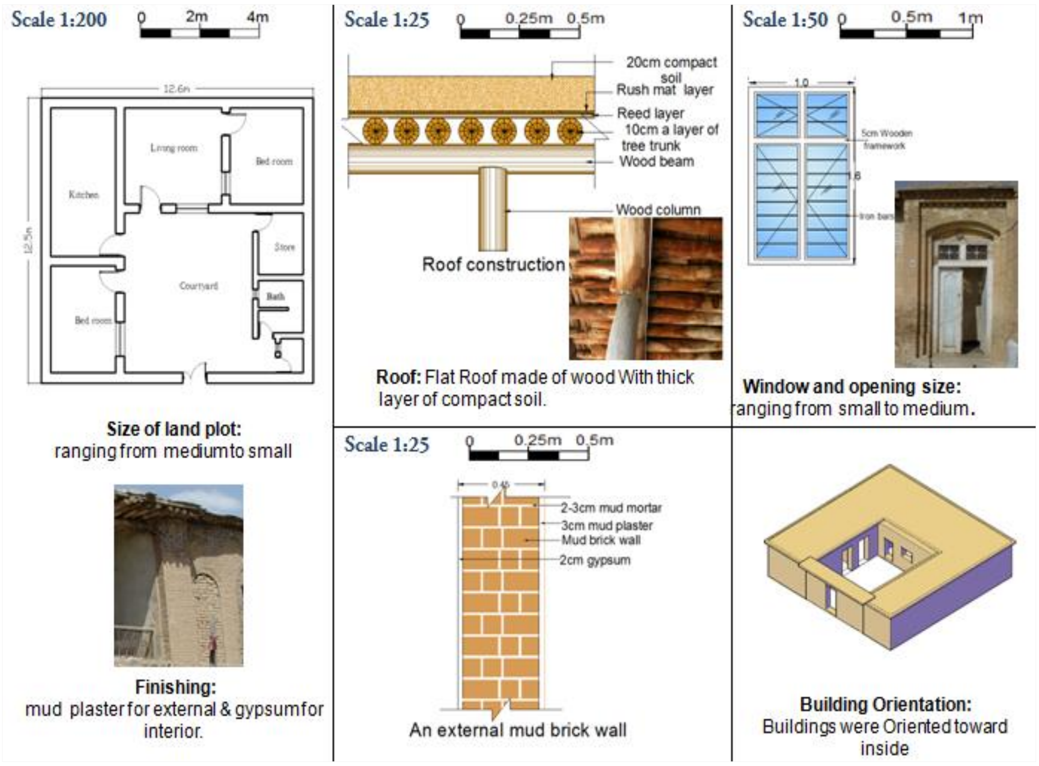


*Fig.5.19.*The Morphology properties of Type-2[Researcher].

Appendix B (A.B)

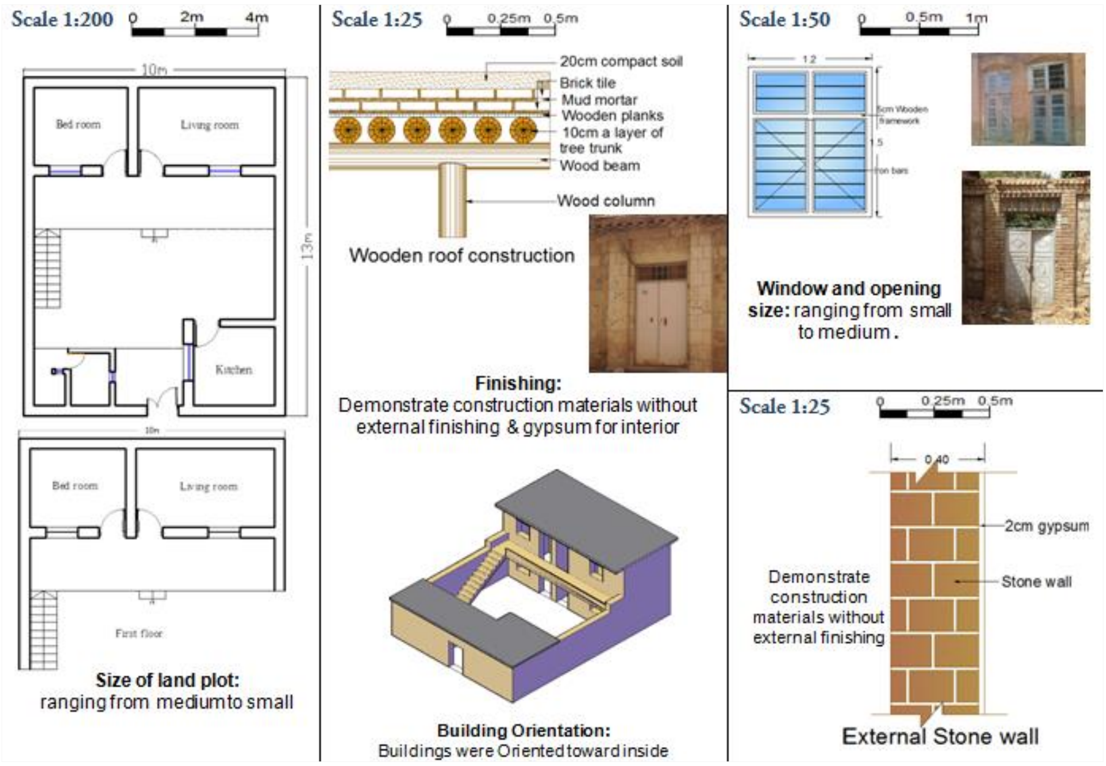


*Fig.5.20.*The Morphology properties of Type-3[Researcher].

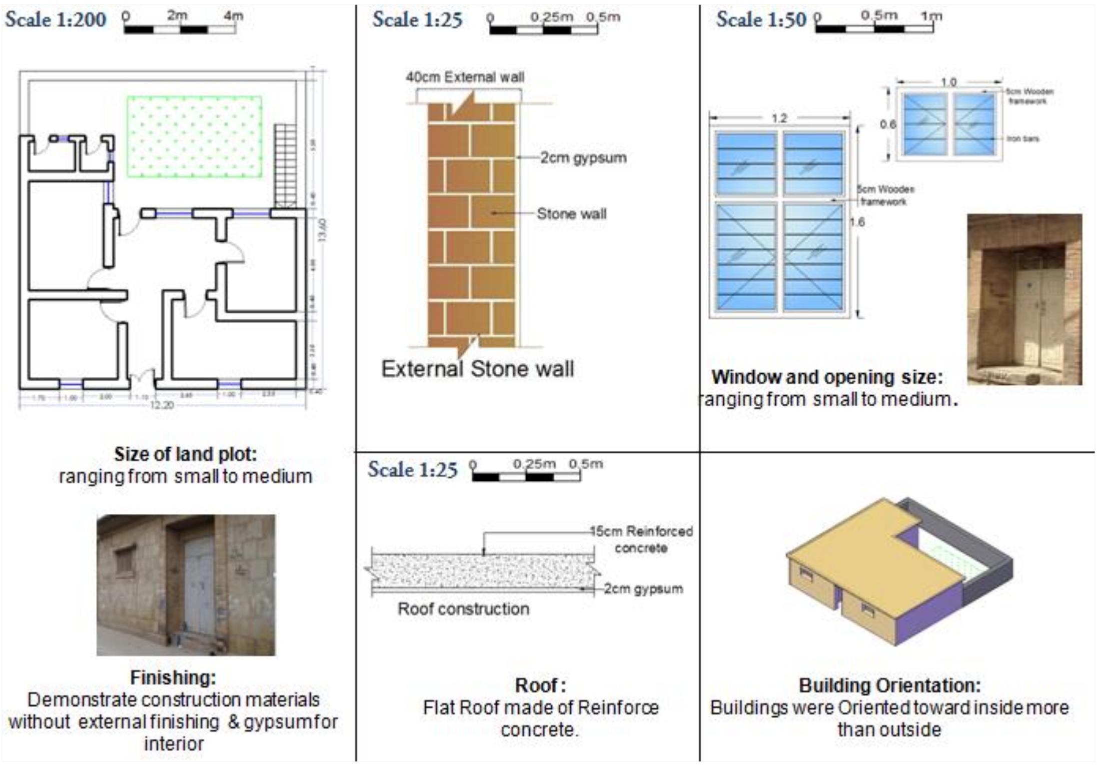


*Fig.5.21.*The Morphology properties of Type-4 [Researcher].

Appendix B (A.B)

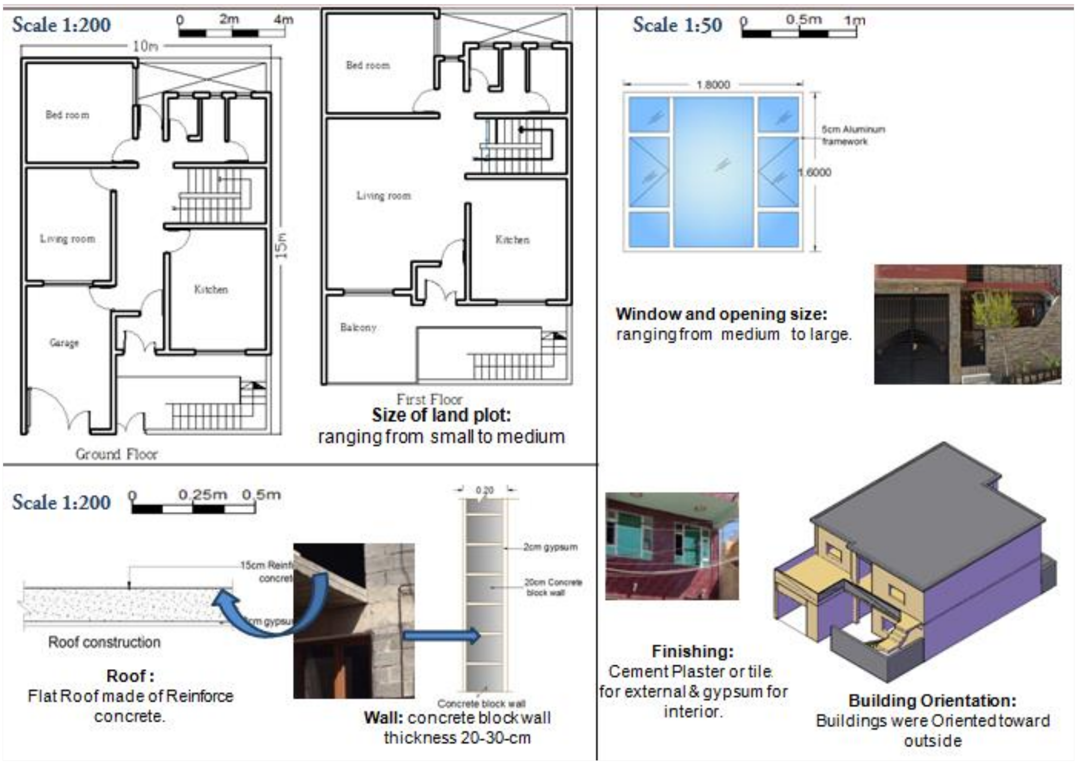


*Fig.5.22.*The Morphology properties of Type-5[Researcher].

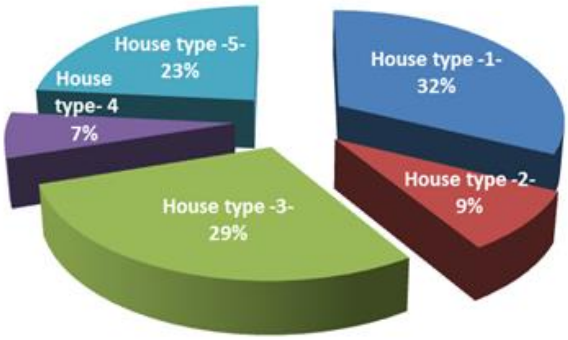


Fig.5.24. The proportion of residential building types in Sabunkaran district based on the field survey [Researcher].

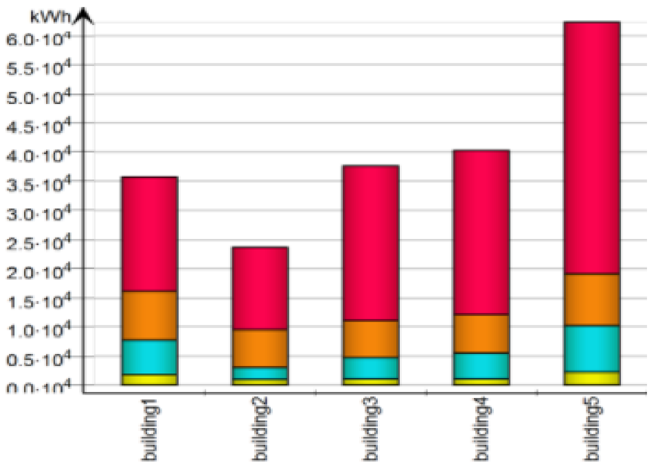
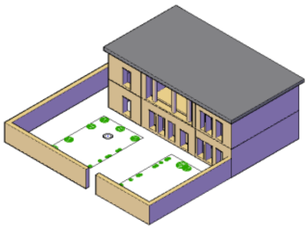
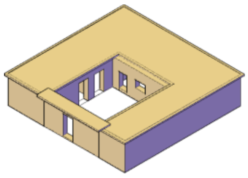
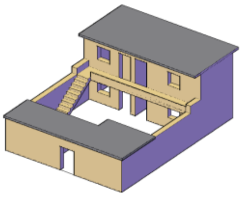
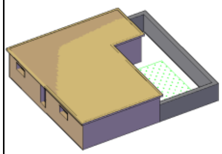
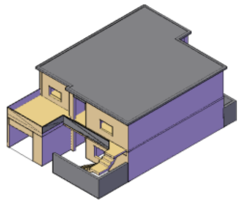


*Fig.5.26.*The comparative results for residential building types from IDA ICE

Appendix B (A.B)

Table 5.1. Description of the residential building [Researcher].

						
Construction materials	External Wall	60cm mud brick wall	40cm brick wall	40cm brick wall	40cm stone wall	20cm hollow concrete block
		5cm double mud plaster	5cm double mud plaster	2cm gypsum	2cm gypsum	2.5cm cement plaster
						2.5 cm gypsum plastering
	Internal wall	40cm mud brick	40cm mud brick	40cm stone wall	40cm stone wall	20cm hollow concrete block
		5cm double gypsum	5cm double gypsum	5cm double gypsum	5cm double gypsum	5cm double gypsum
	Internal floor	15cm wood	15cm wood	15cm wood	15cm reinforced concrete	15cm reinforced concrete
		2cm light isolation	2cm light isolation	2cm light isolation		
		20cm compact soil	20cm compact soil	20cm compact soil	5 cm fine sand	5 cm fine sand
		3cm brick tile	3cm brick tile	3cm brick tile	2 cm tile	1 cm tile
	Roof	15cm wood	15cm wood	15cm wood	15cm reinforced concrete	15 reinforced concrete
		2cm light isolation	2cm light isolation	2cm light isolation		20cm air gap
		20cm compact soil	20cm compact soil	20cm compact soil	2cm gypsum	1cm gypsum board
	External	5cm compact soil	20cm concrete	20cm concrete	20cm concrete	15cm concrete
		5cm brick tile				5cm fine sand
						2m tile
Generator Efficiencies	Glazing	1 panes glazing	1 panes glazing	1 panes glazing	1 panes glazing	1 panes glazing
	Heating	Fuel Heating Max. Power/ 13.3kw	Fuel Heating Max. Power/ 6.6kw	Fuel Heating Max. Power/ 6.1kw	Fuel Heating Max. Power/ 7.4kw	Fuel Heating Max. Power/ 11.5kw
	Cooling	Electric Cooling Max. Power/ 31.6kw	Electric Cooling Max. Power/ 13.1kw	Electric Cooling Max. Power/ 12.2kw	Electric Cooling Max. Power/ 14.7kw	Electric Cooling Max. Power/ 27.6kw
	DHW	Electric Heating	Electric Heating	Electric Heating	Electric Heating	Electric Heating

Appendix C (A.C)

Table 6.1. Scenarios detailed descriptions [Researcher].

Scenarios	Description
Scenario (1)	Adding 20 cm thermal insulation to the building envelopes.
Scenario (2)	Replacing single pane glazing to triple pane glazing.
Scenario (3)	Setting 25% WWR for all the models from the southern facade.
Scenario (4)	Reducing air infiltration from 10 ACH to 0.5 ACH, for all the models.
Scenario (5)	Improving house form to more compact form.
Scenario (6)	Providing fixed shading for the windows on the south façade.
Scenario (7)	Equipping wind catcher in the house as a natural ventilation technics.
Scenario (8)	Applying the most effective scenarios together.

Fig.6.2. IDA ICE model for residential building type-1-.

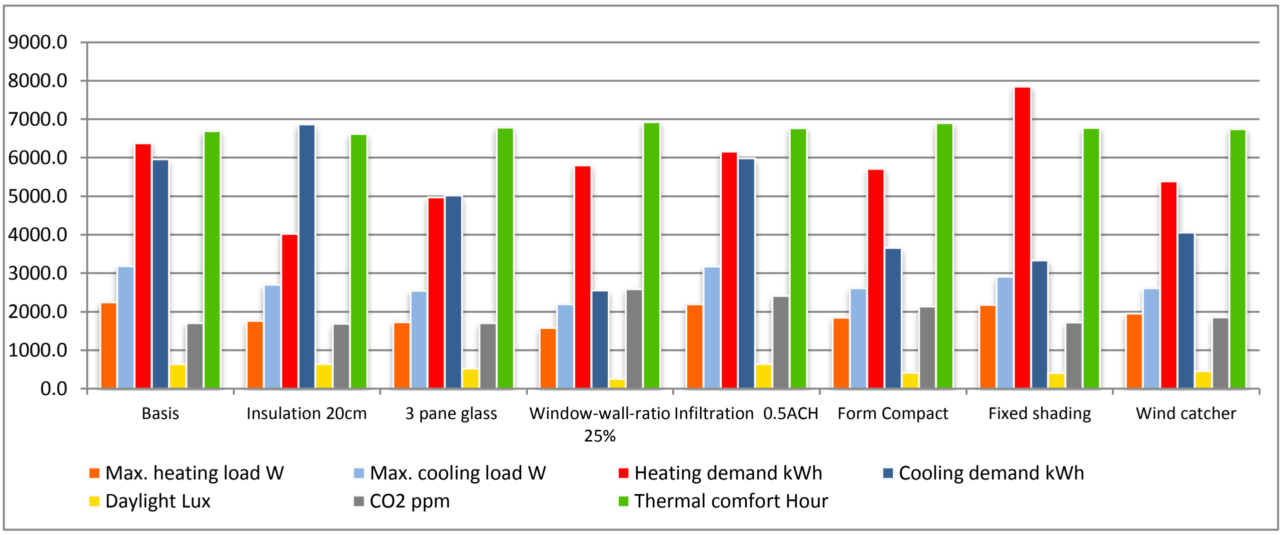


Fig.6.3. The comparison results analysis for different passive strategies in model-1-[Researcher].

Appendix C (A.C)

Table 6.3. The estimated value of the percentage of reduction and increase passive strategies [Researcher].

Positive point	Negative point
(1% -10%) → 1	(1% -10%) → -1
(10% -20%) → 2	(10% -20%) → - 2
(20% -30%) → 3	(20% -30%) → - 3
(30% -40%) → 4	(30% -40%) → - 4
(40% -50%) → 5	(40% -50%) → - 5
(50% -60%) → 6	(50% -60%) → - 6
(60% -70%) → 7	(60% -70%) → - 7
(70% -80%) → 8	(70% -80%) → - 8
(80% -90%) → 9	(80% -90%) → - 9
(90% -100%) → 10	(90% -100%) → - 10

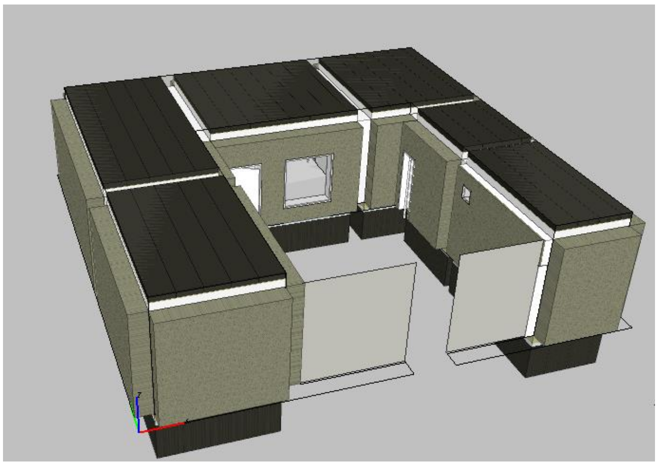


Fig.6.5. IDA ICE model for residential building type-2-

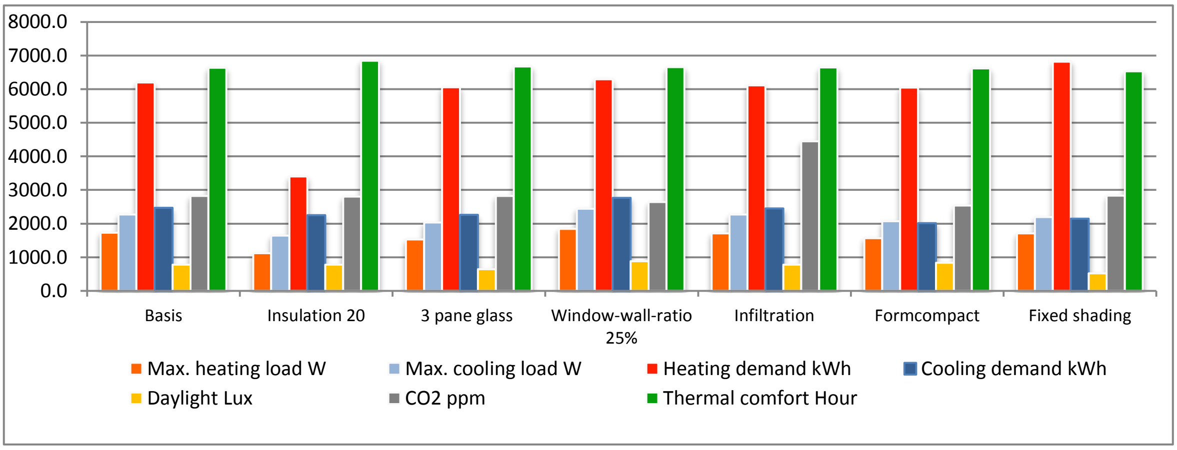


Fig.6.6. Comparison results analysis for different passive strategies in model-2-[Researcher].

Appendix C (A.C)

Table 6.6. The numerical value assessment for the passive strategies in model-2-[Researcher].

Passive strategies							
		Insulation 20cm	3Pane glass	WWR 25%	Infiltration 0.5ACH	Form compact	Fixed Shading
Max. Heating load	W	4*1= 4	2*1= 2	-1*1= -1	1*1=1	1*1=1	1*1=1
Max. Cooling load	W	3*1=3	2*1= 2	-1*1= -1	0*1=0	1*1=1	1*1=1
Heating demand	Kwh	5*3=15	1*3= 3	-1*3= - 3	1*3=3	1*3=3	-1*3= -3
Cooling demand	Kwh	1*3=3	1*3= 3	-2*3= - 6	0*3=0	2*3 =6	2*3= 6
CO2	Ppm	1*4= 4	0*4= 0	1*4= 4	-6*4= -24	1*4= 4	0*4= 0
Daylight	Lux	0*2=0	--2*2= - 4	2*2= 4	0*2=0	1*2= 2	- 4*2= -8
Acceptable Thermal comfort	Hour	1*5= 5	1*5= 5	0*5= 0	0*5=0	0*5= 0	-1*5= - 5
		34	11	- 3	- 20	17	- 8

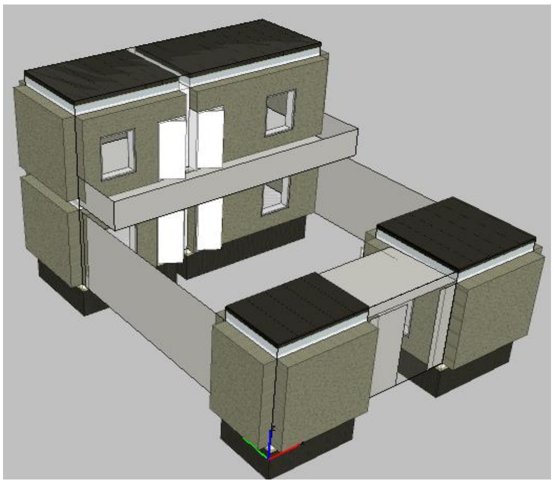


Fig.6.8. IDA ICE model for residential building type-3-

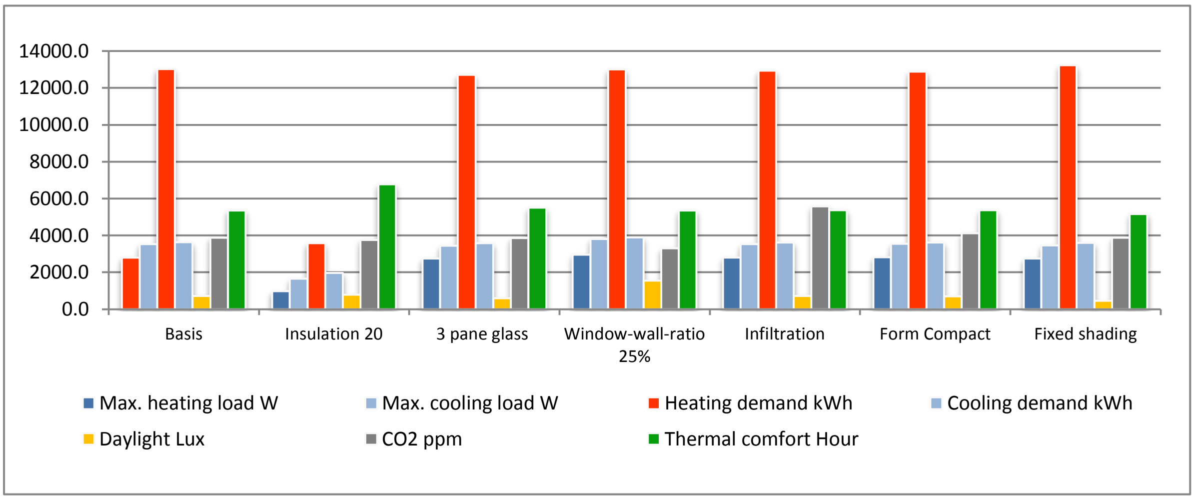


Fig.6.9. Comparison Results Analysis for different passive strategies in model -3 [Researcher].

Appendix C (A.C)

Table 6.8. The numerical value assessment for the passive strategies in model-3-[Researcher].

Passive strategies							
		20cm Insulation	3Pane glass	WWR 25%	Infiltration 0.5ACH	Form Improved	Fixed Shading
Max. Heating load	W	7*1= 7	1*1= 1	-1*1=-1	0*1=0	-1*1= -1	1*1=1
Max. Cooling load	W	6*1= 6	1*1= 1	-1*1= -1	0*1=0	-1*1= -1	1*1=1
Heating demand	Kwh	8*3=18	1*3=3	0*3=0	1*3=3	1*3=3	-1*3= -3
Cooling demand	Kwh	5*3=15	1*3= 3	-1*3= -3	0*3=0	0*3 =0	1*3= 3
CO2	Ppm	1*4= 4	1*4= 4	2*4=8	-5*4= - 20	-1*4= - 4	0*4= 0
Daylight	Lux	1*2=2	-2*2= - 4	10*2= 20	0*2=0	-1*2= - 2	- 4*2= - 8
Acceptable thermal comfort	Hour	3*5= 15	1*5= 5	0*5= 0	0*5= 0	0*5=0	-1*5= - 5
		67	13	23	- 17	-5	- 11

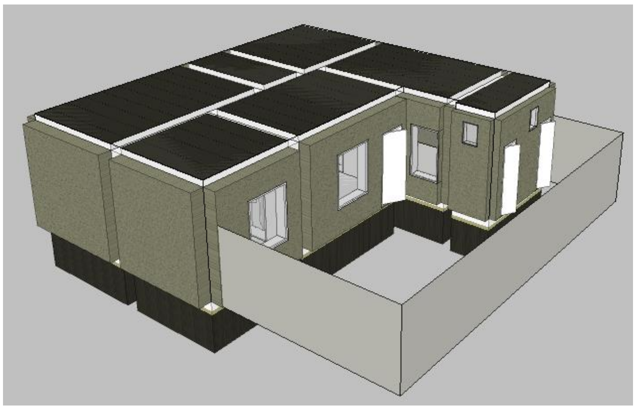


Fig.6.11. *IDA ICE model for residential building type-4-*

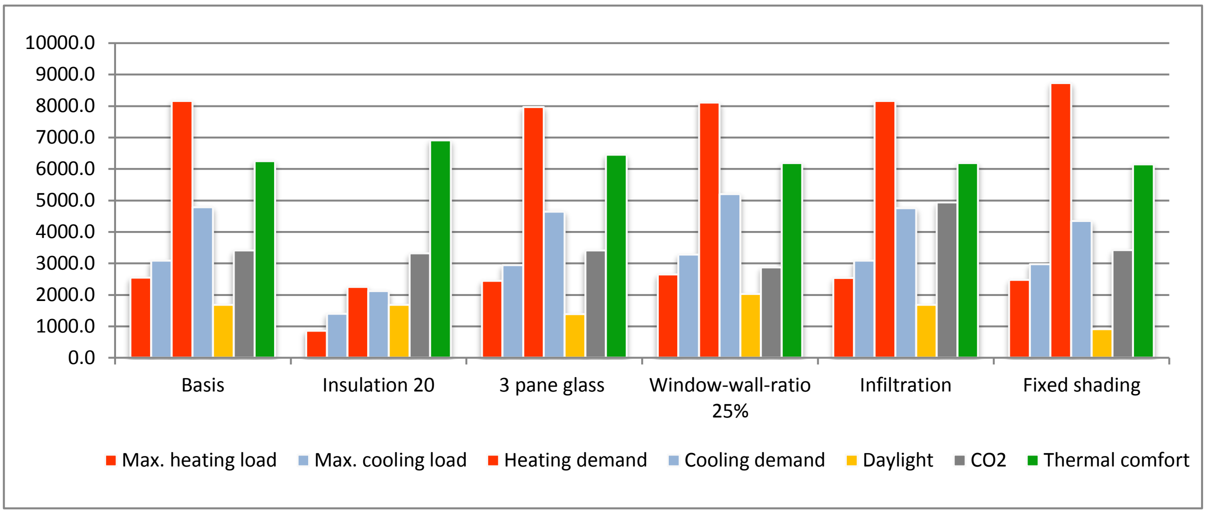


Fig.6.12. Comparison Results Analysis for different passive strategies in model -4. [Researcher].

Appendix C (A.C)

Table 6.10. The numerical value assessment for the passive strategies in model-4-[Researcher].

Passive strategies						
		20cm Insulation	3Pane glass	WWR 25%	Infiltration 0.5ACH	Fixed Shading
Max. Heating load	W	7*1= 7	1*1= 1	-1*1= - 1	0*1=0	1*1=1
Max. Cooling load	W	6*1= 6	1*1= 1	-1*1= -1	0*1=0	1*1=1
Heating demand	Kwh	8*3=24	1*3= 3	0*3=0	0*3=0	-1*3= - 3
Cooling demand	Kwh	6*3=18	1*3= 3	-1*3= -3	1*3=3	1*3= 3
CO2	Ppm	1*4= 4	0*4= 0	2*4= 8	-5*4= -20	0*4= 0
Daylight	Lux	0*2=0	-2*2= -4	3*2= 6	0*2=0	-5*2= - 10
Acceptable Thermal comfort	Hour	2*5=10	1*5= 5	-1*5= -5	-1*5= -5	-1*5=- 5
		69	9	4	- 22	-13

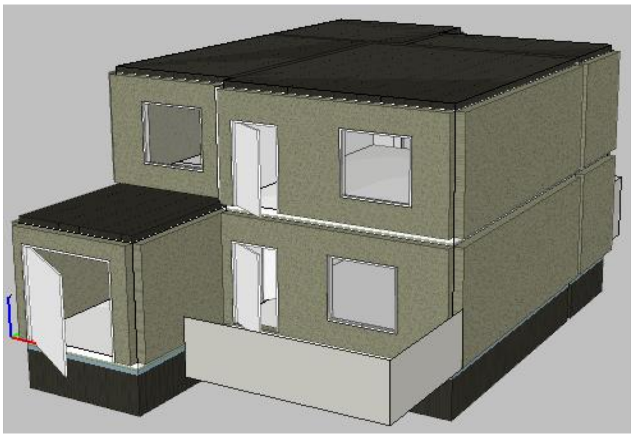


Fig.6.14. *IDA ICE model for residential building type-5-*

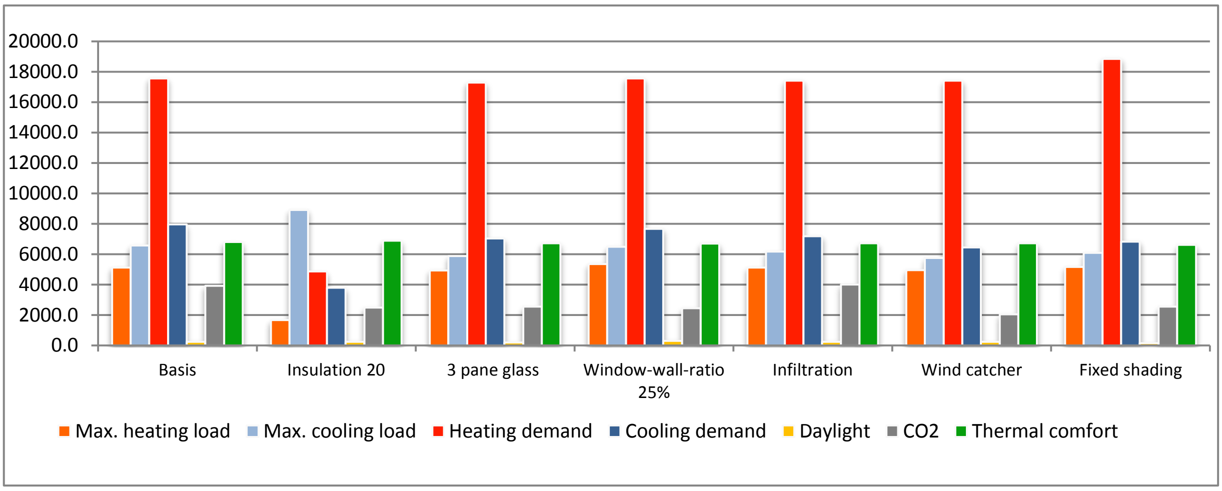


Fig.6.15. Comparison Results Analysis for different passive strategies in model -5[Researcher].

Appendix C (A.C)

Table 6.12. *The numerical value assessment for the passive strategies in model-5*-[Researcher].

Passive strategies							
		20cm Insulation	3Pane glass	WWR 25%	Infiltration 0.5ACH	Fixed Shading	Wind catcher
Max. Heating load	W	7*1= 7	1*1= 1	-1*1= -1	0*1=0	-1*1=-1	1*1=1
Max. Cooling load	W	- 4*1= - 4	2*1=2	1*1= 1	1*1=1	1*1=1	2*1=2
Heating demand	Kwh	8*3= 24	2*3= 6	0*3=0	1*3=3	-1*3= - 3	1*3= 3
Cooling demand	Kwh	6*3= 18	2*3= 6	1*3= 3	1*3=3	2*3= 6	2*3 =6
CO2	Ppm	4*4= 16	4*4= 16	4*4= 16	-1*4= - 4	4*4= 16	5*4= 20
Daylight	Lux	0*2=0	-2*2= - 4	3*2= 6	0*2=0	-4*2= - 8	-1*2= - 2
Thermal Comfort (Acceptable hours)	Hour	1*5= 5	-1*5= - 5	-1*5= - 5	-1*5= - 5	-1*5= - 5	-1*5= - 5
		77	22	20	- 2	8	25

Appendix C (A.C)

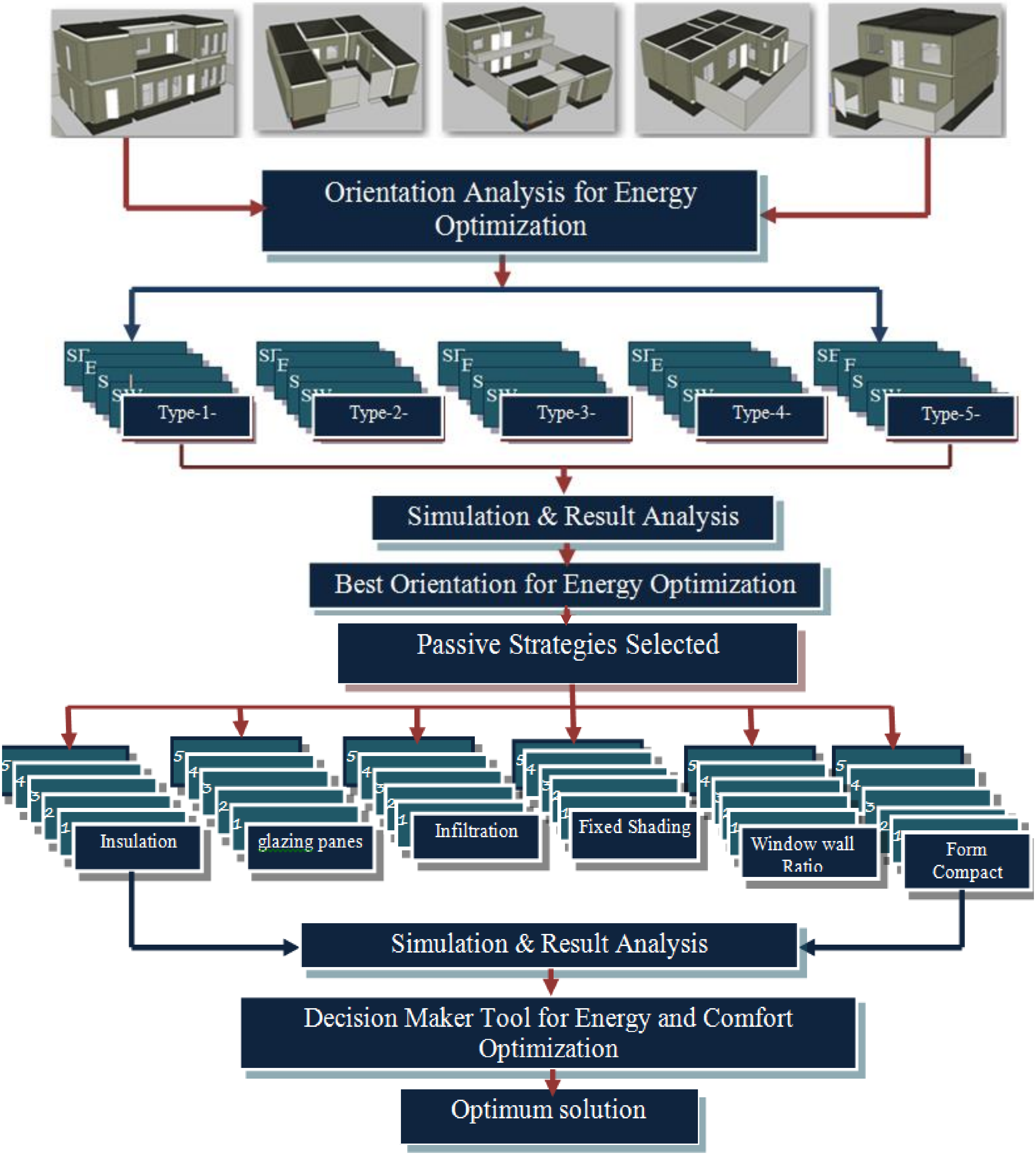


Fig.6.17. The optimization process for getting optimum models based on the passive strategies[Researcher].

Appendix C (A.C)

Table 6.13. Scenarios detailed descriptions [Researcher].

Scenarios	Description
Scenario (1)	Providing external shading for the windows on the south façade.
Scenario (2)	Heating and cooling floor system
Scenario (3)	Heating and cooling floor system with HP
Scenario (4)	Heating and cooling floor system with HP and Solar thermal collector
Scenario (5)	Water Radiator for heating and cooling device
Scenario (6)	Water Radiator with AHU
Scenario (7)	Applying the most effective scenarios together.

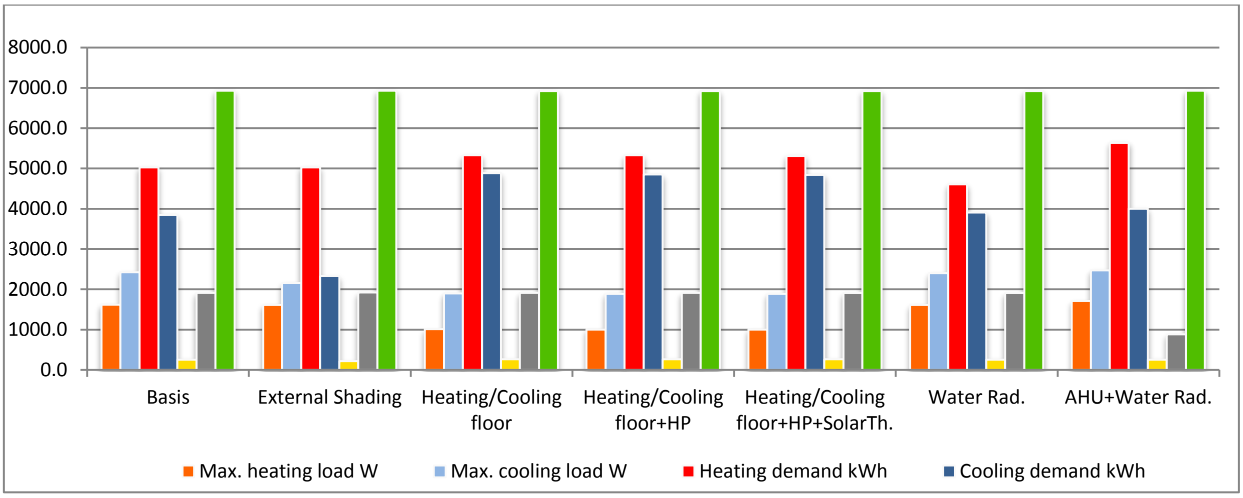


Fig.6.18. The optimization process for getting optimum models based on hybrid strategies [Researcher].

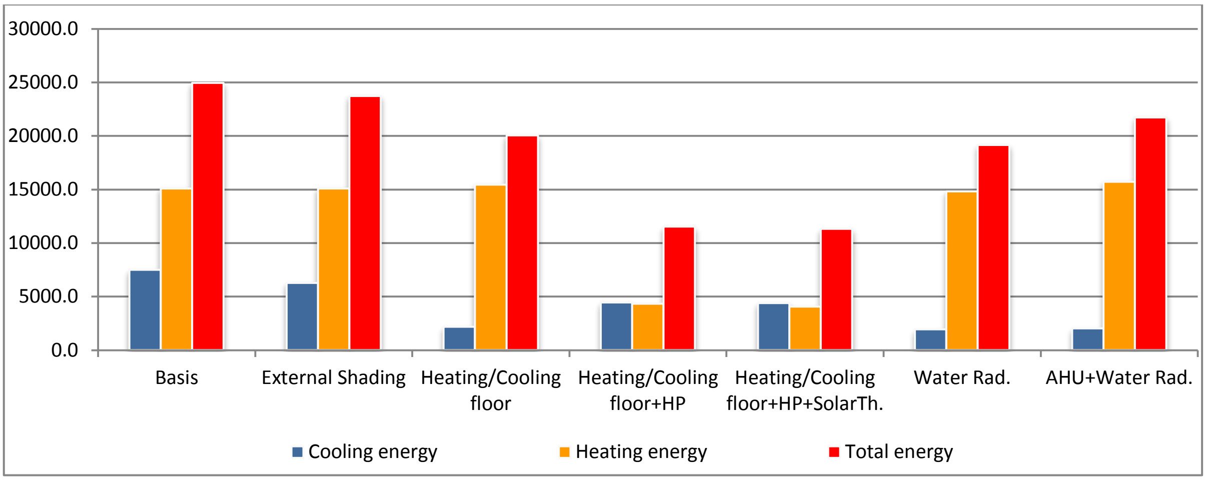


Fig.6.19. The comparison delivered energy in different hybrid strategies' scenarios [Researcher].

Appendix D (A.D)

Table D.1. The Schedule for opening windows and doors during the year [Researcher].

(1 January -14 January)			(15 January -23 January)			(24 January -25 January)			(26 January -31 January)		
Hour	Minute	Window open.	Hour	Minute	Window open.	Hour	Minute	Window open.	Hour	Minute	Window open.
00:00	0.3	0.5	01:00	0.4	0.1	00:00	1	0.1	00:00	1	0.1
01:00	0.3	0.5	02:00	0.5	0.1	01:00	1	0.2	01:00	1	0.1
03:00	1	0.1	04:00	0.5	0.1	02:00	1	0.2	03:00	1	0.1
04:00	0.5	0.1	05:00	0.6	0.2	04:00	1	0.2	06:00	1	0.1
07:00	0.7	0.1	06:00	0.8	0.3	06:00	0.7	0.2	08:00	1	0.2
09:00	0.5	0.1	07:00	0.3	0.3	07:00	0.7	0.2	09:00	1	0.2
12:00	1	0.3	08:00	0.7	0.3	08:00	0.7	0.2	12:00	1	0.2
16:00	0.7	0.3	11:00	0.5	0.1	12:00	1	0.2	16:00	0.7	0.2
18:00	0.2	0.2	12:00	0.5	0.2	13:00	0.5	0.2	18:00	0.5	0.1
20:00	0.5	0.2	14:00	0.4	0.1	16:00	1	0.1	20:00	1	0.1
21:00	0.6	0.2	16:00	1	0.1	18:00	1	0.2	23:00	1	0.1
23:00	1	0.3	18:00	0.5	0.1	20:00	1	0.2			
			20:00	0.5	0.2	23:00	1	0.2			
			23:00	0.4	0.1						
(1 February -7 February)			(8 February -13 February)			(14 February -15 February)			(16February -10March)		
Hour	Minute	Window open.	Hour	Minute	Window open.	Hour	Minute	Window open.	Hour	Minute	Window open.
00:00	2	0.3	00:00	0.3	0.1	00:00	0.5	0.2	01:00	0.8	0.8
01:00	2	0.3	01:00	0.3	0.1	02:00	0.8	0.2	03:00	0.7	0.8
02:00	2	0.2	02:00	0.5	0.1	03:00	0.8	0.2	04:00	1	0.1
03:00	0.7	0.1	03:00	0.4	0.1	05:00	0.8	0.2	06:00	1	0.1
04:00	1	0.2	04:00	0.5	0.2	07:00	0.7	0.3	07:00	0.6	0.1
06:00	0.7	0.3	06:00	0.4	0.3	08:00	1	0.3	08:00	0.6	0.1
08:00	1.5	0.3	08:00	1	0.3	11:00	1	0.1	10:00	1.5	0.3
10:00	0.7	0.3	12:00	1	0.3	12:00	1	0.3	13:00	1	0.3
12:00	1	0.4	15:00	1	0.3	13:00	0.5	0.2	16:00	1	0.3
15:00	1	0.4	19:00	0.5	0.1	14:00	0.5	0.1	19:00	0.5	0.1
19:00	0.7	0.1	21:00	0.4	0.1	18:00	0.4	0.8	21:00	1.5	0.1
21:00	0.4	0.1	23:00	0.4	0.1	23:00	0.3	0.5	23:00	0.5	0.1
23:00	0.4	0.08									
(11 March -31 March)			(1 April-10 April)			(11 April – 12 April)			(13 April-30 April)		
Hour	Minute	Window open.	Hour	Minute	Window open.	Hour	Minute	Window open.	Hour	Minute	Window open.
00:00	0.5	0.2	02:00	1	0.3	00:00	2	0.4	02:00	1	0.3
01:00	1	0.2	04:00	1	0.3	02:00	1.5	0.3	04:00	1	0.3
03:00	1	0.5	06:00	0.8	0.2	04:00	1.5	0.3	06:00	0.8	0.2
06:00	0.8	0.2	07:00	0.7	0.1	06:00	1.5	0.3	07:00	0.7	0.1
08:00	0.5	1	08:00	1	0.3	07:00	0.7	0.1	08:00	0.7	0.2
12:00	1	0.4	10:00	0.7	0.2	08:00	0.7	0.2	10:00	0.7	0.2
16:00	1	0.4	12:00	2	0.4	10:00	0.7	0.2	12:00	2	0.4
19:00	0.5	0.2	1600	2	0.6	12:00	2	0.4	16:00	2	0.6
20:00	0.5	0.2	18:00	0.7	0.2	16:00	2	0.4	19:00	0.5	0.4
22:00	0.5	0.2	19:00	0.7	0.5	19:00	0.5	0.4	21:00	0.8	0.2
			21:00	1	0.3	21:00	0.8	0.2	23:00	0.8	0.1
			23:00	1	0.2	23:00	1	0.1			

(1 May -11 May)

Hour	Minute	Window open.
02:00	0.3	0.1
04:00	0.8	0.2
06:00	1	0.2
07:00	0.4	0.1
08:00	1.5	0.3
10:00	2	0.3
12:00	7	1
14:00	10	1
15:00	10	1
16:00	20	1
18:00	8	1
20:00	10	1
22:00	15	1

(12 May -14 May)

Hour	Minute	Window open.
04:00	0.4	0.1
06:00	0.5	0.1
07:00	0.3	0.1
08:00	1.4	0.1
10:00	1	0.1
12:00	3	0.6
14:00	2	0.5
15:00	2	0.5
16:00	2	0.3
18:00	3	0.5
20:00	1	0.3

(15 May -24 May)

Hour	Minute	Window open.
02:00	0.3	0.1
04:00	0.8	0.2
06:00	1	0.2
07:00	0.4	0.1
08:00	1.4	0.3
10:00	2	0.3
12:00	7	1
14:00	10	1
15:00	10	1
16:00	20	1
18:00	8	1
20:00	10	1
22:00	15	1

(25 May -31 May)

Hour	Minute	Window open.
06:00	60	0.1
08:00	40	0.5
10:00	8	1
10:00	8	1
12:00	15	1
15:00	10	1
16:00	10	1
20:00	15	1
21:00	15	0.3
22:00	40	0.3
23:00	60	0.1

(1 Jun -16 Jun)

Hour	Minute	Window open.
00:00	60	0.2
04:00	60	0.2
06:00	10	1
08:00	12	1
10:00	10	1
12:00	8	1
15:00	1	0.2
18:00	1	0.2
20:00	3	0.3
22:00	5	0.5
23:00	5	0.4

(17Jun- 17 July)

Hour	Minute	Window open.
00:00	60	0.5
04:00	60	0.5
06:00	10	1
07:00	10	1
10:00	8	1
12:00	2	0.4
13:00	2	0.4
14:00	1	0.4
15:00	1	0.4
18:00	1	0.4
22:00	1	0.3
23:00	60	0.3

(18 July 31 July)

Hour	Minute	Window open.
00:00	10	0.6
02:00	60	0.6
04:00	0.5	1
06:00	8	1
07:00	10	1
08:00	20	1
09:00	15	1
10:00	10	0.7
11:00	10	1
12:00	10	1
14:00	7	1
16:00	7	0.6
20:00	7	0.6
22:00	420	0.6
23:00	300	0.6

(1 Aug. - 9 Aug.)

Hour	Minute	Window open.
00:00	1hour	0.4
02:00	15	1
04:00	20	1
06:00	10	1
07:00	20	1
08:00	20	1
10:00	20	1
11:00	5	1
12:00	3	1
13:00	10	0.5
14:00	1	0.5
15:00	1	0.5
18:00	1	1
22:00	10	1
23:00	1hour	0.5

(10 Aug.- 16 Aug.)

Hour	Minute	Window open.
00:00	60	0.5
04:00	20	0.3
06:00	10	1
07:00	10	1
10:00	1	1
12:00	0.8	0.4
13:00	1	0.2
14:00	0.8	0.3
15:00	1	0.2
18:00	1	0.4
22:00	1	0.4
23:00	3	0.4

(17 Aug. – 21 Aug.)

Hour	Minute	Window open.
00:00	60	1
04:00	60	1
06:00	10	1
07:00	10	1
10:00	4	0.6
12:00	3	0.3
13:00	10	0.3
14:00	3	0.5
15:00	3	0.5
18:00	3	0.6
22:00	1	0.6

(22 Aug. – 24 Aug.)

Hour	Minute	Window open.
00:00	60	0.3
02:00	15	1
04:00	20	1
06:00	20	1
07:00	20	1
10:00	20	1
11:00	5	1
12:00	5	1
14:00	1	0.5
15:00	1	0.5
18:00	1	0.5
20:00	1	0.5
22:00	1	0.5

(25 Aug. – 31 Aug.)

Hour	Minute	Window open.
00:00	60	0.6
02:00	60	0.6
04:00	20	1
06:00	10	1
08:00	20	1
10:00	10	1
11:00	10	1
12:00	10	1
14:00	2	1
16:00	2	0.6
20:00	2	0.6
22:00	7	0.6
23:00	5	0.6

(1 Sep. - 3 Sep.)

Hour	Minute	Window open.
00:00	60	0.3
04:00	5	1
6:00	5	1
07:00	6	0.7
09:00	7	0.7
10:00	4	0.6
11:00	5	0.5
12:00	3	0.4
14:00	2	0.4
15:00	2	0.4
18:00	2	0.4
21:00	1	0.2
22:00	60	0.1

(4 Sep. -9 Sep.)

Hour	Minute	Window open.
00:00	60	0.2
04:00	10	1
06:00	10	1
07:00	6	1
09:00	7	1
10:00	2	0.5
11:00	3	0.4
12:00	1	0.4
14:00	1	0.3
15:00	1	0.3
18:00	3	0.4
21:00	1	0.2
22:00	60	0.1

(10 Sep. -24 Sep.)

Hour	Minute	Window open.
00:00	1Hour	0.1
04:00	5	1
06:00	5	1
07:00	5	0.7
09:00	7	0.7
10:00	15	1
11:00	15	1
14:00	2	0.4
15:00	2	0.4
18:00	3	0.4
21:00	15	1
22:00	15	1

(25 Sep. – 30 Sep.)

Hour	Minute	Window open.
00:00	1	0.2
02:00	5	1
04:00	5	1
06:00	5	1
08:00	5	1
09:00	5	1
12:00	15	1
16:00	15	1
18:00	15	1
20:00	5	0.8
23:00	2	0.3

(1 Oct. – 10 Oct.)

Hour	Minute	Window open.
02:00	1	0.1
04:00	3	0.1
06:00	2	0.1
08:00	1	0.1
09:00	3	0.3
12:00	20	1
16:00	15	1
18:00	3	1
20:00	5	0.5
23:00	5	0.3

(11 Oct. – 31 Oct.)

Hour	Minute	Window open.
00:00	1	0.4
02:00	0.5	0.1
04:00	0.4	0.1
08:00	0.7	0.1
09:00	2	0.3
12:00	6	0.6
16:00	5	0.6
18:00	5	0.5
21:00	2	0.1
23:00	1	0.1

(1 Nov. -6 Nov.)

Hour	Minute	Window open.
01:00	1	0.1
02:00	1	0.2
04:00	1	0.1
05:00	0.7	0.1
06:00	1	0.2
08:00	1	0.2
11:00	0.8	0.2
14:00	0.8	0.2
17:00	0.8	0.2
21:00	1	0.1
22:00	0.5	0.1

(7 Nov. -8 Nov.)

Hour	Minute	Window open.
00:00	1	0.1
01:00	1.5	0.2
03:00	0.6	0.2
04:00	1	0.2
06:00	0.5	0.2
08:00	0.7	0.2
10:00	0.7	0.4
12:00	0.7	0.3
13:00	0.5	0.3
16:00	1	0.3
19:00	1	0.1
20:00	0.5	0.2
21:00	0.5	0.1
22:00	0.5	0.1

(9 Nov. – 14 Nov.)

Hour	Minute	Window open.
00:00	1	0.2
01:00	1	0.1
03:00	1	0.2
04:00	1	0.2
06:00	1	0.3
08:00	0.8	0.2
10:00	0.7	0.4
12:00	0.7	0.3
16:00	1	0.3
19:00	0.5	0.1
21:00	0.8	0.2
22:00	0.5	0.1
23:00	0.8	0.2

(15 Nov. – 17 Nov.)

Hour	Minute	Window open.
01:00	1.5	0.2
03:00	0.6	0.2
04:00	60	0.3
06:00	0.7	0.3
08:00	0.8	0.3
10:00	0.6	0.2
12:00	0.7	0.3
14:00	42	0.3
16:00	1	0.3
19:00	1	0.2
20:00	0.5	0.2
21:00	0.5	0.1
23:00	0.8	0.2

(18 Nov. – 29 Nov.)

Hour	Minute	Window open.
00:00	0.5	0.1
01:00	0.5	0.1
03:00	0.5	0.2
04:00	0.5	0.2
06:00	0.5	0.3
08:00	0.7	0.2
10:00	0.7	0.4
12:00	0.7	0.3
16:00	1	0.3
19:00	0.5	0.1
21:00	0.8	0.1
23:00	0.7	0.2

(30 Nov. – 15 Dec.)

Hour	Minute	Window open.
00:00	1	0.3
01:00	0.8	0.2
03:00	0.5	0.1
04:00	1	0.2
06:00	1.5	0.2
07:00	0.5	0.2
08:00	0.5	0.2
09:00	0.5	0.2
12:00	0.7	0.3
18:00	0.5	0.1
19:00	0.5	0.1
20:00	0.7	0.2
21:00	1	0.2
23:00	1	0.3

Appendix D (A.D)

(16 Dec. -17 Dec.)			(18Dec. -20Dec.)			(21 Dec. -22Dec.)			(23Dec. -31 Dec.)		
00:00	0.5	0.3	00:00	0.3	0.1	00:00	1	0.3	00:00	0.3	0.05
01:00	1.5	0.2	01:00	0.5	0.1	02:00	1	0.3	01:00	0.3	0.05
03:00	1	0.2	03:00	0.6	0.2	04:00	1	0.3	03:00	1	0.1
04:00	1	0.3	04:00	1	0.3	06:00	2	0.4	04:00	0.5	0.1
06:00	0.5	0.3	06:00	0.7	0.3	07:00	0.5	0.2	07:00	0.7	0.1
08:00	0.7	0.3	07:00	0.5	0.3	08:00	0.5	0.2	09:00	0.5	0.1
12:00	0.8	0.4	08:00	0.5	0.3	09:00	1	0.2	12:00	1	0.3
16:00	0.8	0.3	09:00	1	0.2	12:00	0.7	0.3	16:00	0.7	0.3
18:00	0.5	0.1	12:00	1	0.4	16:00	0.7	0.2	18:00	0.2	0.2
20:00	0.5	0.1	16:00	0.7	0.4	18:00	0.5	0.2	20:00	0.5	0.2
21:00	0.5	0.2	18:00	1	0.1	20:00	0.7	0.2	21:00	0.6	0.2
23:00	0.5	0.2	20:00	1	0.1	21:00	0.5	0.2	23:00	1	0.3
			21:00	1	0.2	23:00	0.5	0.2			
			23:00	0.6	0.2						

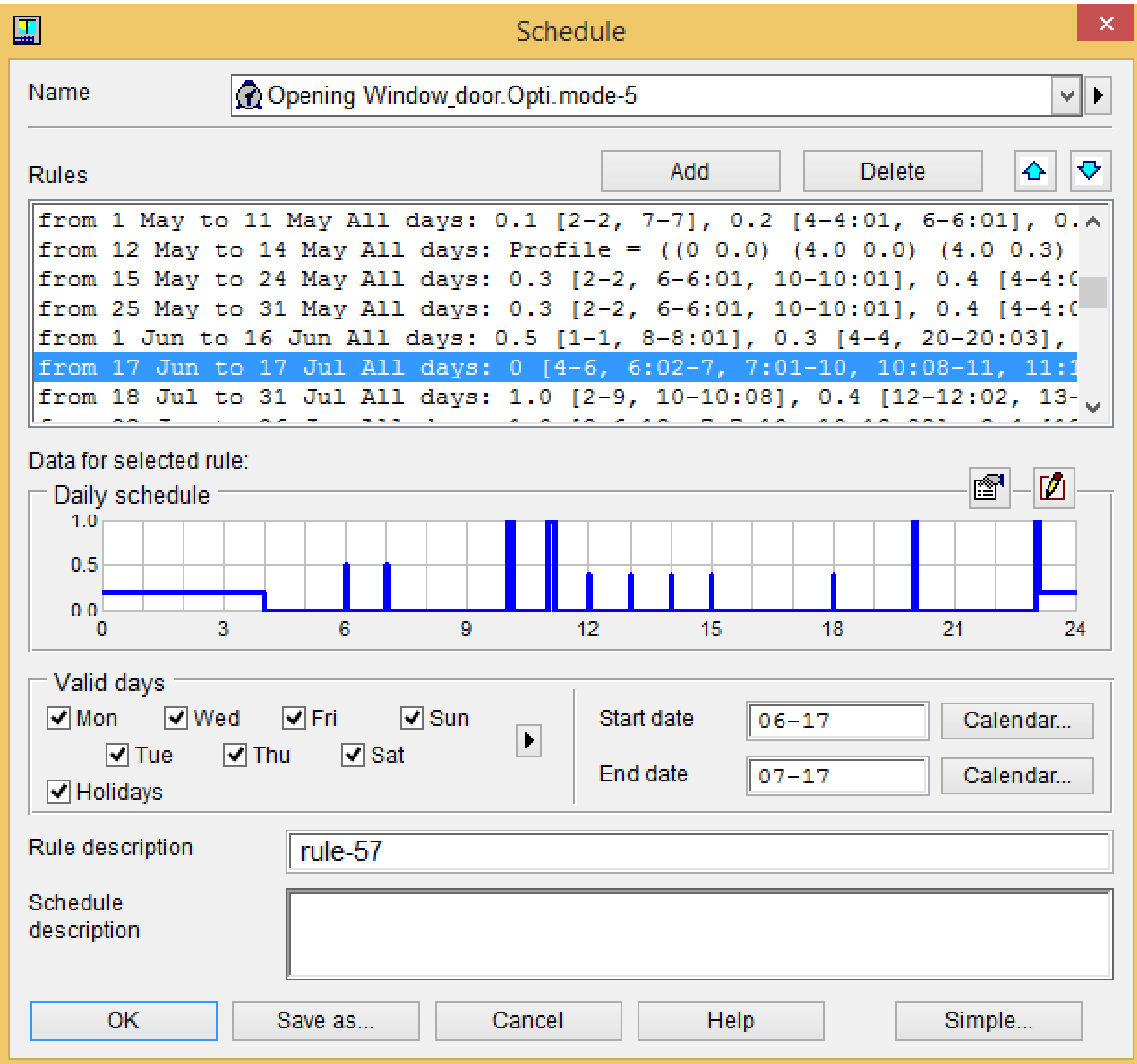


Fig. D.1. The schedule for opening windows and doors from IDA CE (optimum model-5)

Appendix D (A.D)

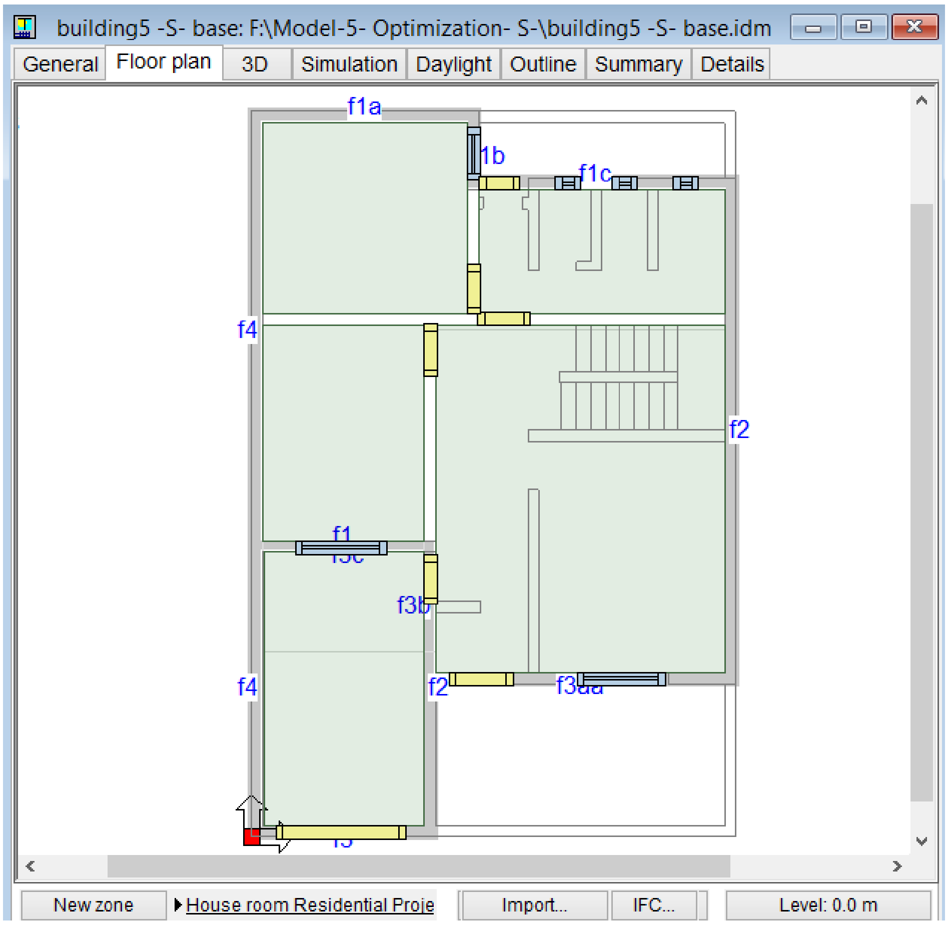


Fig. D.2. Inserting the plan of model-5 into IDA ICE.

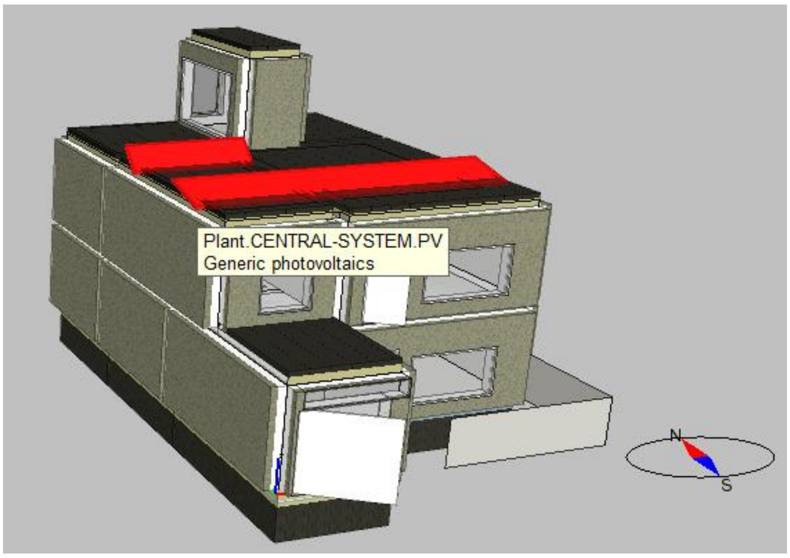


Fig. D.3. Creating the optimum model-5, from IDA CE.

Appendix D (A.D)

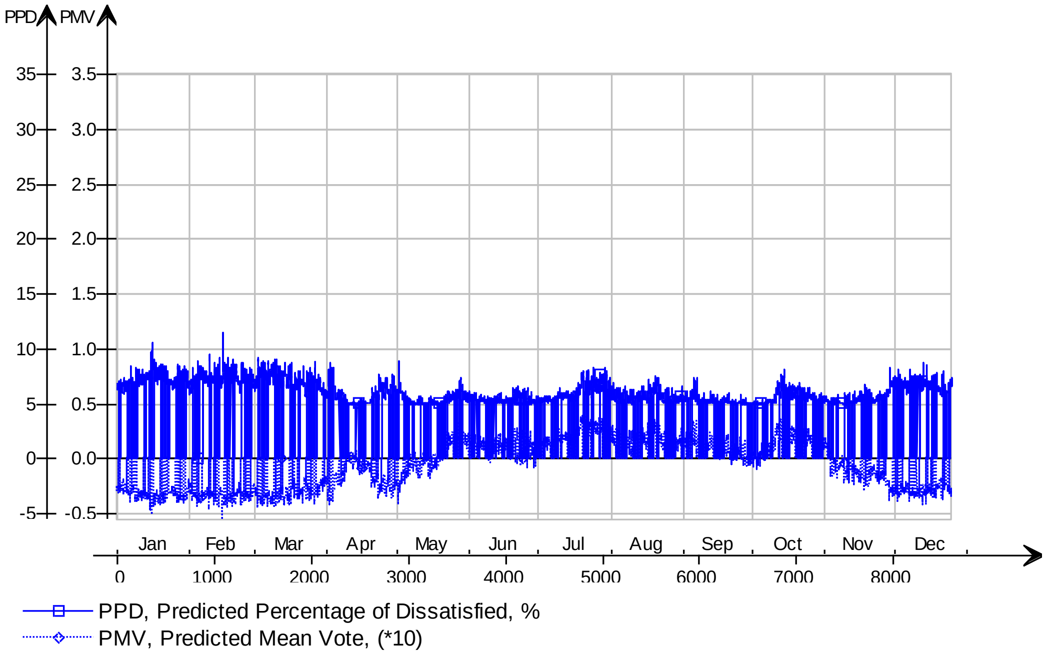


Fig. D.4: Fanger's comfort indices in the optimum model-5.

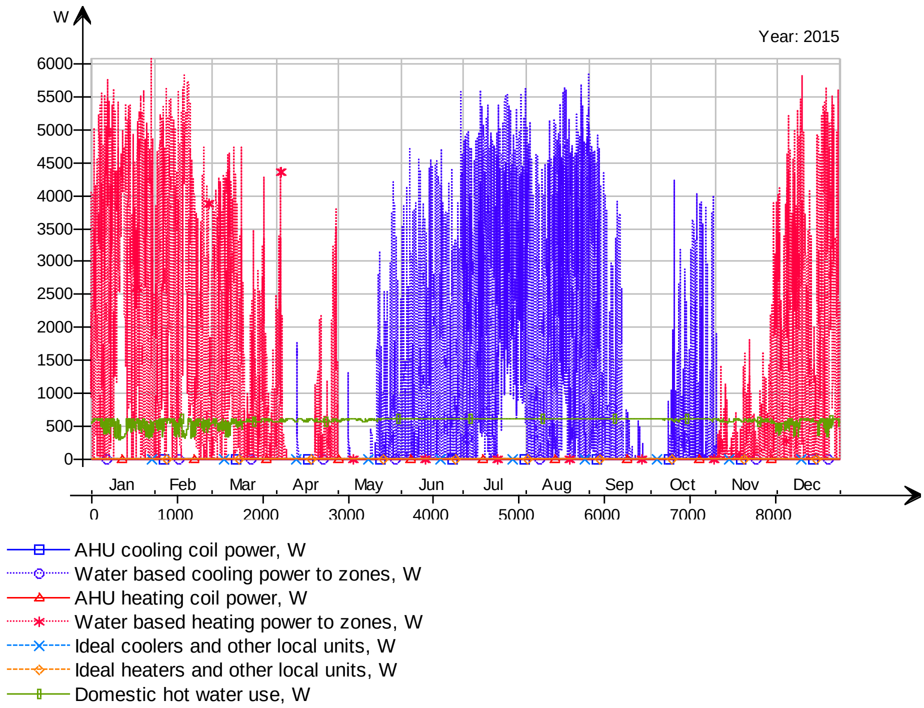


Fig. D.5. The Total heating and cooling supplied by plant in the optimum model-5

Appendix D (A.D)

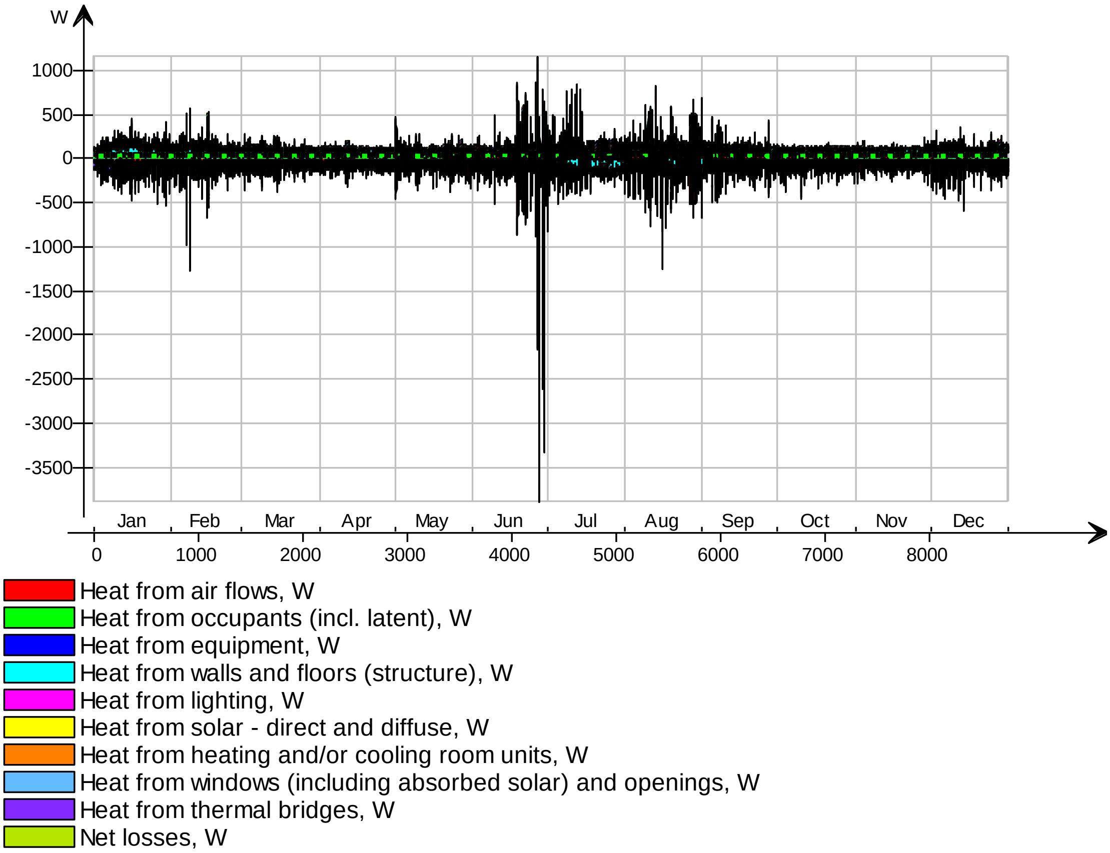


Fig. D.6. The heat balance in the optimum model-5

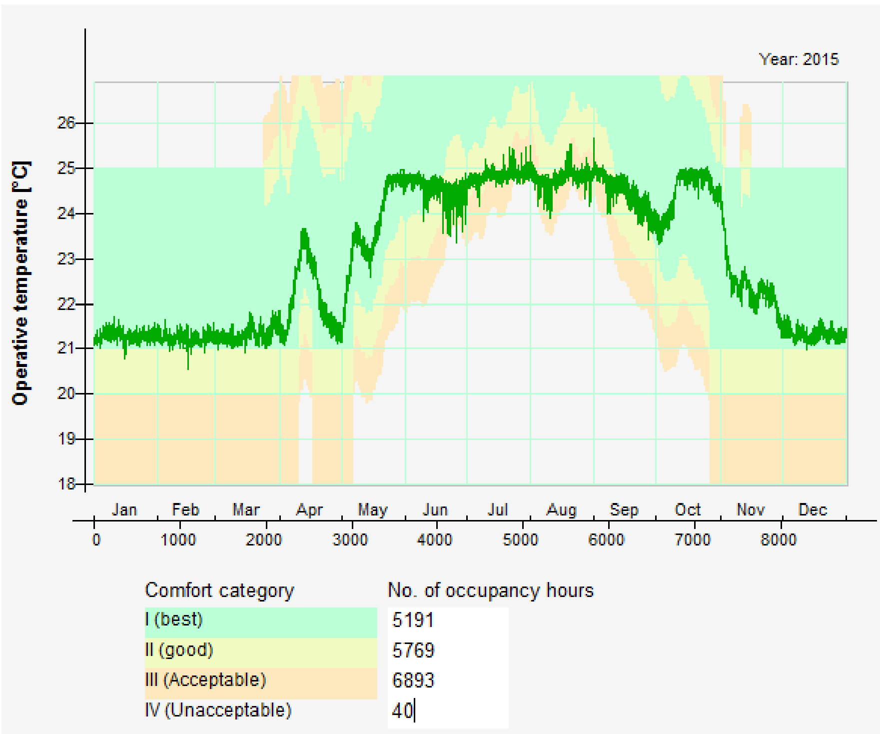


Fig. D.7. The acceptable and unacceptable thermal comfort hours in the optimum model -5.

Appendix D (A.D)

Month	Envelope & Thermal bridges	Internal Walls and Masses	Window & Solar	Mech. supply air	Infiltra-tion & Openings	Occu-pants	Equip-ment	Lighting	Local heating units	Local cooling units	Net losses
1	-303.3	147.5	105.3	0.0	-51.6	59.5	0.0	22.4	0.0	0.0	21.7
2	-242.5	116.6	92.6	0.0	-57.0	53.3	0.0	20.2	0.0	0.0	18.5
3	-207.8	71.9	83.1	0.0	-44.7	59.6	0.0	22.4	0.0	0.0	17.2
4	-149.5	30.1	60.9	0.0	-35.1	58.2	0.0	21.6	0.0	0.0	14.0
5	-115.9	-1.8	73.4	0.0	-50.9	60.4	0.0	22.3	0.0	0.0	12.1
6	16.0	-18.4	41.4	0.0	-125.0	56.7	0.0	21.6	0.0	0.0	8.0
7	22.6	-83.0	30.1	0.0	-51.7	55.6	0.0	22.4	0.0	0.0	4.5
8	72.7	-56.4	66.1	0.0	-169.1	59.7	0.0	22.4	0.0	0.0	5.7
9	7.0	-14.1	109.4	0.0	-190.0	56.4	0.0	21.6	0.0	0.0	10.3
10	-138.7	-5.3	116.4	0.0	-65.7	60.0	0.0	22.4	0.0	0.0	11.7
11	-202.7	47.7	107.0	0.0	-46.9	59.0	0.0	21.6	0.0	0.0	14.1
12	-257.1	103.8	101.8	0.0	-47.3	59.3	0.0	22.4	0.0	0.0	18.9
Total	-1499.2	338.5	987.6	0.0	-934.9	697.7	0.0	263.3	0.0	0.0	156.4
During heating (4297.2 h)	-1277.8	535.8	520.6	0.0	-343.9	343.6	0.0	123.4	0.0	0.0	103.6
During cooling (3161.0 h)	-217.3	-264.1	316.9	0.0	-213.6	248.6	0.0	105.2	0.0	0.0	28.9
Rest of time	-4.1	66.8	150.1	0.0	-377.4	105.5	0.0	34.7	0.0	0.0	23.9

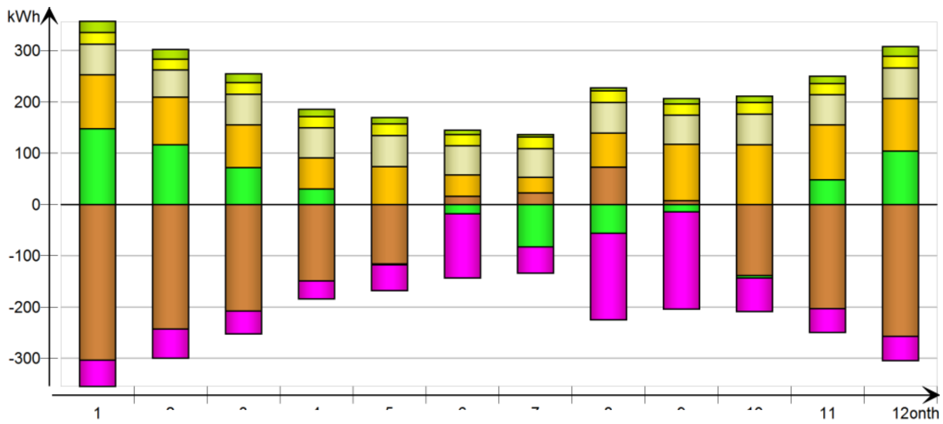


Fig. D.8. The sensible energy for the optimum model-5.

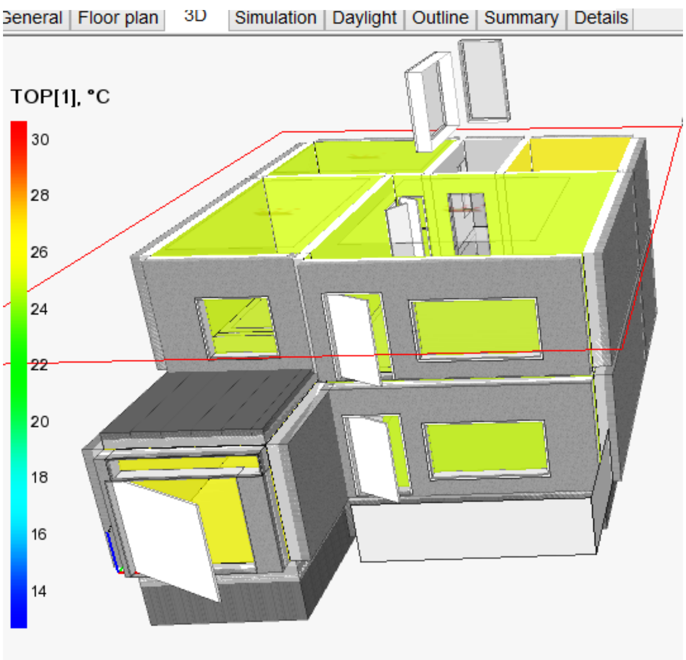


Fig. D.9. The operative temperature in the 15th August at 12:00 in the optimum model-5.