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Review on Solar Space Heating - Cooling in Libyan Residential Buildings

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Abstract: This review paper focuses on documenting and studying published papers and works in the field of solar heating and cooling air space in residential buildings. The goal of this survey and documentation is to find out the most important flashing results and conclusions specifically in fields of using solar energy for space heating, cooling and ventilation of local residential buildings in Libya. This covers using active and passive solar systems in, achieving thermal human comfort in such buildings leading to reduce electrical energy consumption. This paper also concentrates on applying energy efficiency measures in buildings; planning, design, and construction stages with the use of the principles of energy conservation in buildings. There are several studies comparing traditional with modern house designs in several local cities including both famous old cities of "Ghadames" and "Gharyan". Several conclusions and recommendations are summarized within the text of this paper.

ورقة مراجعة عن التدفئة و التبريد بالطاقة الشمسية في المباني السكنية الليبية

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ملخص: هذه الورقة تعرض وتوثق الدراسات والورقات المنشورة في مجال تدفئة وتبريد المباني السكنية بالطاقة الشمسية. والهدف من هذا المسح والتوثيق معرفة أهم النتائج والاستنتاجات على وجه التحديد في مجالات استخدام الطاقة الشمسية للتدفئة والتبريد

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والتهوية للمباني السكنية المحلية في ليبيا. ويغطي هذا استخدام أنظمة الطاقة الشمسية النشطة والسلبية في تحقيق الراحة البشرية في هذه المباني ويؤدي كذلك إلى خفض استهلاك الطاقة الكهربائية. وتركز هذه الورقة أيضا على تطبيق تدابير كفاءة الطاقة في المباني وذلك بالتخطيط والتصميم والبناء باستخدام مبادئ حفظ الطاقة في المباني. وهناك عدة دراسات مقارنة للمنازل التقليدية القديمة مع تصاميم البيت الحديث في العديد من المدن المحلية بما في ذلك كل المدن القديمة الشهيرة مثل «غدامس» و «غريان». وفي هذه الورقة العديد من الاستنتاجات والتوصيات ضمن نص الورقة.

Keywords: ***Solar applications, residential buildings, space heating and cooling, passive and active systems, energy efficiency practices.***

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1. INTRODUCTION

Nowadays, most of the buildings in Libya are built without insulation that reduces heat transfer through building walls. The heating and cooling loads inside this style of buildings are large which has negative effect on electrical energy consumption in buildings. A number of local researchers have published several studies in the field of solar heating and cooling air space in residential buildings in Libya These studies consider the employing of natural ventilation and solar space heating, insulation for building envelope, proper lighting and equipment, solar water heating, optimum window to wall ratio.

There are many case studies regarding old buildings, including the old city "Ghadames" that have been passively designed, where natural ventilation and sunlight used to light and ventilate all homes. The local building materials were used to build the city with a suitable wall thickness that reduces energy exchange. Regarding this valuable subject, many local researchers have been interested in studying the design of buildings in this city and thermal comfort achieved in such buildings. A number of research papers and M. Sc. theses were published. The available theses will be considered in the list of the references while they will be touched briefly within the text of this paper. There are many case studies concerning houses and buildings in other local cities, such as Sabha, Hun, Rajban and several other cities.

2. ELECTRICAL ENERGY DEMAND IN LIBYA

The electric energy sector has been developed during the last decades, where many power plants were built including steam and gas units. It has mostly a long bright development history. The peak load has increased from 1,595 MW in 1990 to 5,981 MW in 2012 while the total installed capacity has increased from 3352 MW in 1990 to 8,553 MW in 2010. The energy consumption per capita has increased from 1,493 kWh/c in 1990 to 4,850 kWh/c in 2012 [1,2]. The electrical energy demand grows very rapidly with an annual growth of produced electricity of 8%. The total number of local electricity customers is of about 1,223,727 distributed among seven categories. Residential sector represents the highest share in the local electrical energy demand with a share of about 36 % of the total consumption, followed by the commercial sector with 14% as shown in Figure 1 [2].

The lifestyle has evolved, and people have become used to many electrical devices in their daily life activities, such as air conditioners, water heaters, lights, space heaters, refrigerators, washing machines, etc., which are reflected in a significant increase of electricity consumption per capita. Here, the domestic air conditioning load represents 18.35% of the total residential electricity consumption, as shown in Figure 2 [4].

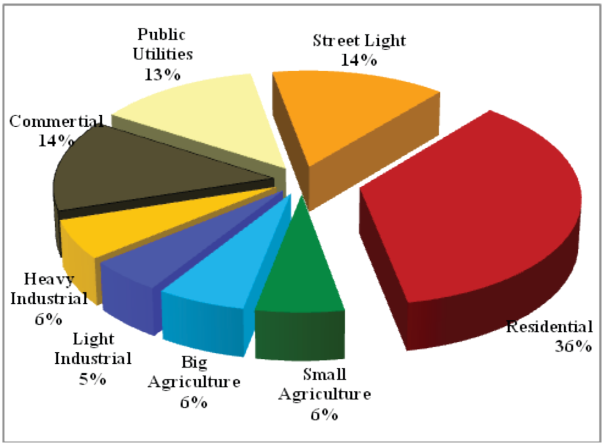

Figure (1). Electricity consumption (2012) [3].

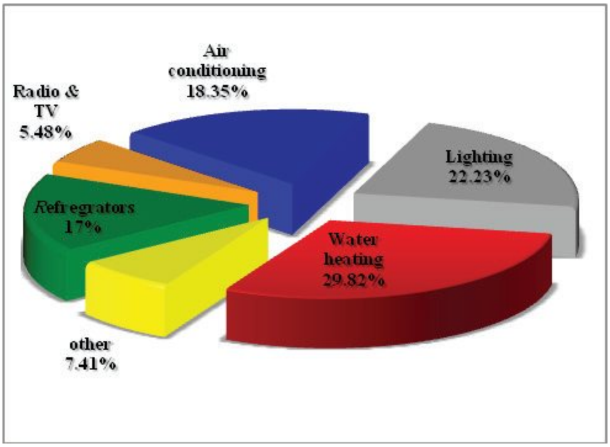

Figure (2). Residential energy use [4].

3. ENERGY EFFICIENCY

Several steps should be taken to save energy. Those steps are: assessment, energy conservation, energy efficiency measures, and use of alternative or renewable energy as shown the pyramid in Figure 3; usually called the energy pyramid, however, in this work, it has been decided to call that sketch energy saving pyramid.

The term, "Energy Efficiency" is used when trying to save energy; using less energy and grants the same needs of energy.

3.1. Energy Efficiency in Buildings

Energy efficiency measures are intended to reduce the amount of energy consumed while maintaining or improving the quality of services provided in buildings. Benefits likely to arise from energy efficiency investments in buildings include: providing better comfort conditions, reducing electrical energy is used for water heating, space cooling, space heating, lighting, equipment, and enhancing property value.

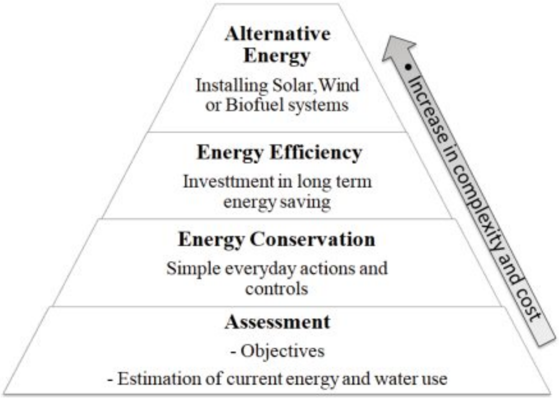

Figure (3). Energy saving pyramid [5].

3.2. Energy Efficiency in developing countries

People in developing countries suffer from the shortage of electricity. Reducing power and energy requirements in buildings might reduce the cost required for energy production and also reduce the electricity shortage.

4. SOLAR SPACE HEATING AND COOLING SYSTEMS

In most parts of the world, space heating and cooling systems are necessary during the winter and summer time. Unfortunately, the vast majority of these systems rely on grid-tied, non-renewable power sources to provide the required demand [6].

The two principal categories of building solar heating and cooling systems are passive and active. The term passive system is applied to buildings that include, as integral parts of buildings, elements that admit, absorb, store, and release solar energy and thus reduce the needs for auxiliary energy for comfort heating. Active systems are those that employ solar collectors, storage tanks, pumps, heat exchangers, and controls to heat and cool buildings [7,8].

4.1 Active solar space heating systems

Active solar space heating systems consist of collectors that collect and absorb solar radiation combined with electric fans or pumps to handle the working fluid. Active systems usually have an energy storage system to provide heat when the sun is not shining. The two basic types of active solar space-heating systems use either liquid or air as the heat-transfer medium in their solar energy collectors [7,8,9].

4.1.1 Liquid-Based (Hydronic) Systems

Liquid-based solar water heating systems, heat water in a flat plate collector and then pump the heated water to a heat exchanger (like a radiator) where the heat is "radiated" to the interior space as shown in Figure 4. These systems would need to use an antifreeze solution where ambient temperatures could reach below freezing [10,11].

4.1.2 Air-based systems

Air-based solar air heating systems heat air in a flat plate collector and then pass the air using fans and ducting to the interior space as shown in Figure 5. These systems can be integrated in the existing home heating duct system so that all rooms receive heat or individual heating units can be installed for separate rooms, the hot air developed in such collectors can be used directly in the home during the daytime or stored in massive materials (rock or water) [12].

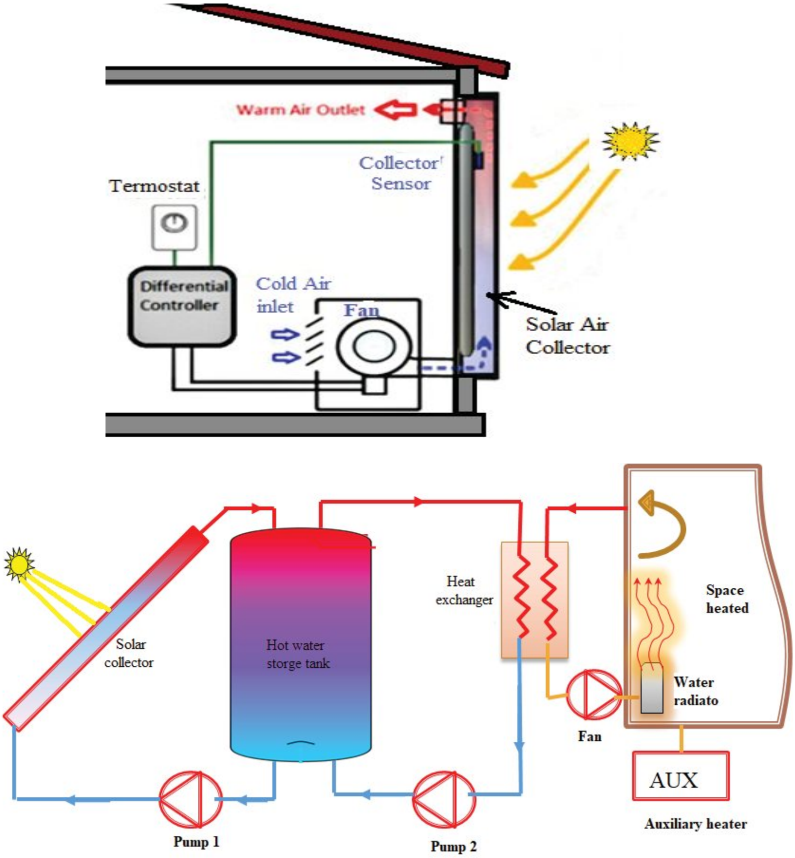

Figure (5). An example for an active air solar space heating system [6].

4.2 Active solar thermal cooling systems

Solar cooling of buildings is an attractive idea because the cooling loads and availability of solar radiation are both in phase. Additionally, the combination of solar cooling and heating greatly improves the use factors of collectors compared to heating alone. In principle, solar assisted cooling systems may be operated thermally by solar to mechanic energy converters (e.g., solar collector driven Rankine machines) combined with compression chillers by solar thermal collectors connected to thermal driven cooling devices, or driven electrically solar-to-electric converters (photovoltaic) combined with compression chillers which is not considered in this paper [8,13].

4.2.1 Solar powered Rankine refrigeration system

Solar mechanical refrigeration uses a conventional vapor compression system driven by mechanical power that is produced with a solar-driven heat power cycle. The heat power cycle usually considered for this application is a Rankine cycle in which a fluid is vaporized at an elevated pressure by heat exchange with a fluid heated by solar collectors. A storage tank can be included to provide some high temperature thermal storage.

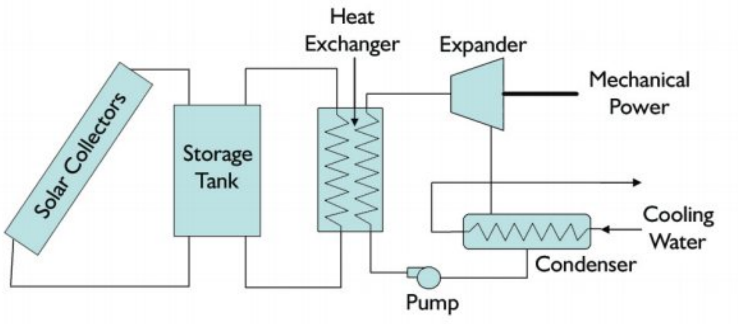

Figure (6). Solar driven Rankine refrigeration cycle [14].

The vapor flows through a turbine or piston expander to produce mechanical power, as shown in Figure 6. The fluid exiting the expander is condensed and pumped back to the boiler pressure where it is again vaporized [13].

4.2.2 Solar powered absorption refrigeration systems

Figure 7. shows a schematic diagram of a solar absorption refrigeration system. This system is different from a conventional vapor compression refrigeration system. Basic components of such refrigeration system are absorber, generator, solar panel, condenser, expansion valve, evaporator, DC battery and fan. The compressor in the vapor compression system is replaced by a generator, absorber and a pump. Refrigerant (NH3) in the evaporator absorbs the heat from the refrigerated space and gets evaporated. It is then passed to absorber where it is dissolved with absorbent (H_2O) and pumped to generator [14].

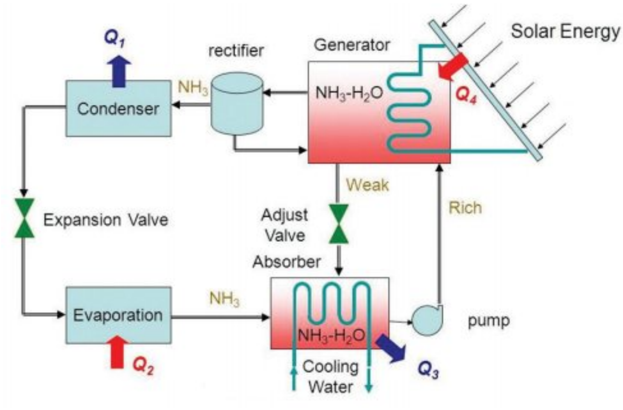

Figure (7).Solar absorption refrigeration system.

4.2.3 Solar powered adsorption refrigeration systems

Adsorption cycle is shown in Figure 8 works with the interaction of gases and solids. With adsorption chilling, molecular interaction between solids and gases allows gases to be adsorbed into the solids. The adsorption chamber of the chiller is filled with solid material, silica gel, eliminating the need for moving parts and eliminating noises associated with those moving parts. The silica gel creates an extremely low humidity condition that causes water refrigerant to evaporate at low temperatures. As water evaporates in the evaporator, it cools chilled water. The adsorption chiller has four chambers; an evaporator, a condenser and two adsorption chambers. All four chambers are operated at nearly a full vacuum. These systems can use a variety of energy sources, typically process waste heat, biomass heat, solar collectors, tri-generation (CHP) generators, or traditional power plants [15,16].

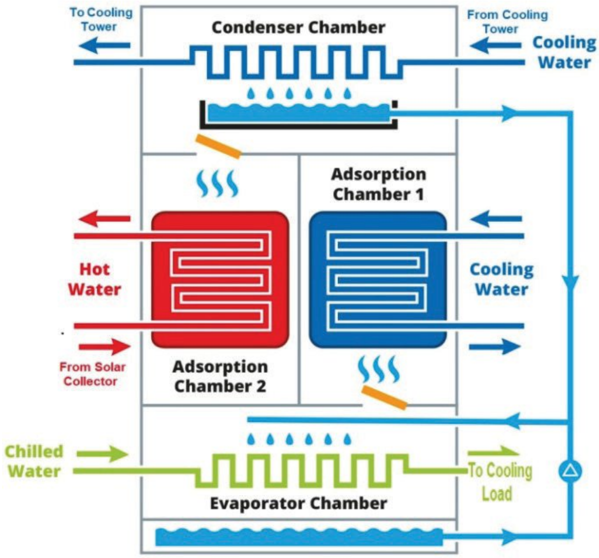

Figure (8). Adsorption cycle (SolarNext AG) [17].

4.2.4 Desiccant-Evaporative Cooling DEC

In this method, atmospheric air is being dried by a desiccant material. Then it is cooled by cold water generated by cooling towers as shown in Figure 9 [18]. The solar heat is utilized to remove moisture from the desiccant material in order to continue the cycle. However, this cycle is not a close cycle where the atmospheric air is employed and rejected. Otherwise, DEC technology has a high COP where the required temperature is low (approximately 60-70 ^{o}C) [18].

5. SOLAR PASSIVE DESIGN

Solar energy is a radiant heat source that causes natural processes upon which all life depends. Some of the natural processes can be managed through building design in a manner that helps heat and/or cool the building when required. The basic natural processes are the thermal energy flows associated with conduction, natural convection, and radiation. When sunlight strikes envelopes of a building, envelopes can reflect, transmit, and/or absorb solar radiation. Additionally, the heat generated by sun causes air movement that can be predictable in designed spaces. These basic responses to solar heat lead to design elements, material choices and placements that can provide heating and/or cooling effects naturally in homes [19].

In passive solar building design, windows, walls, and floors are made to collect, store, reflect, and distribute solar energy in the form of heat in winters and reject solar heat in summers. A large number of recently-built residential buildings in Libya provide a poor quality indoor environment or require huge amounts of energy to run air conditioning systems, therefore influencing the thermal comfort, energy consumption and carbon emissions. Where the use of electrical energy in buildings is the major contributor to air pollution and global climate change [20].

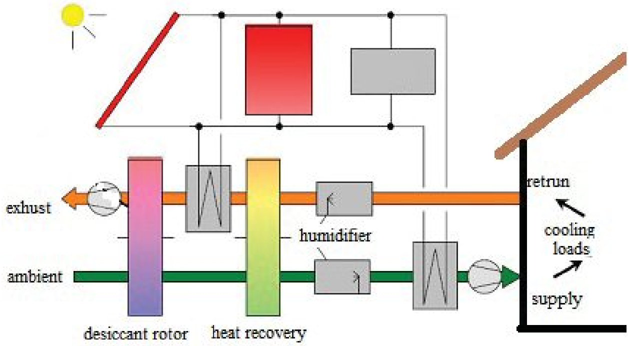

Figure (9). Desiccant-Evaporative Cooling [18].

5.1 Key features of passive solar design

There are many features that should be considered in passive building design. These are as follows [21]:-

- **Increased south-facing glass area.** The windows facing the sunlight help warming of homes in the winter months. In the winter, the south-facing windows receive sunlight about three times as those facing east and west; however the south-facing windows receive less sunlight in summer than that in winter.
- **Lower east and west glass areas.** This reduces summer cooling loads; because this prevents unwanted sun radiation from entering homes in morning and afternoon. Eliminating windows also lowers construction costs.
- **Orientation and site selection.** In planning buildings, it is just as important to design for protection from summer sun as for access to winter sun. Overhangs and shading devices are important to keep direct sunlight out of buildings during warm weather. Care should be taken when designing windows on east and west exposures of buildings, since sun will shine directly into these windows while it is low in the sky on summer mornings and late afternoons. In addition, the direction of the prevailing breezes at building site should be taken into account so that adequate natural ventilation can be incorporated in buildings in order to cut expenses of running air-conditioning units.
- **Energy efficient design.** The first step in a successful passive solar home includes proper installation of recommended levels of insulation, airtight design, and efficient heating and cooling systems.
- **Thermal storage mass.** materials such as concrete floors, interior brick walls, brick pavers, and tile store heat and regulate interior temperatures both in winter and summer. A number of new products use phase change materials (PCMs) to capture and store more heat per unit volume [22].
- **Effective window shading.** This reduces summer cooling needs and glare. Window shades lowered at night can also be used to help trap the heat absorbed by the thermal mass.
- **Moisture control systems.** This increases buildings durability, improve indoor air quality, and provide comfort conditions in both summer and winter seasons.
- **Plan rooms layout.** This is to take advantage of sun's path. Rooms should match or avoid solar gain at day periods during different seasons.

5.2 Passive elements

There are five elements that constitute complete passive solar heating systems as shown in Figure 10. Each performs a separate function, but all five must work together for the system to be successful [23,24].

- Windows/Apertures. They are mostly large areas of glazing used to allow as much sunlight as possible into buildings.
- Absorber. It absorbs solar radiation well (usually darker colors).An absorber is a wall designed to absorb heat during the day and release it slowly into the house at night.
- Thermal Mass. This is to store heat and prevent overheating, e.g. masonry wall, floor, phase-change materials, or a body of water.
- Distribution. This represents an extraction of stored heat from the thermal mass and circulates it throughout the building.
- Control. This is an important item used to prevent under and overheating. Roof overhangs can block direct sunlight during summer months when sun is high in the sky but allow it to penetrate the building during winter months when the sun is lower. Other systems used include differential thermostats, vents and dampers, low-emission blinds and awnings.

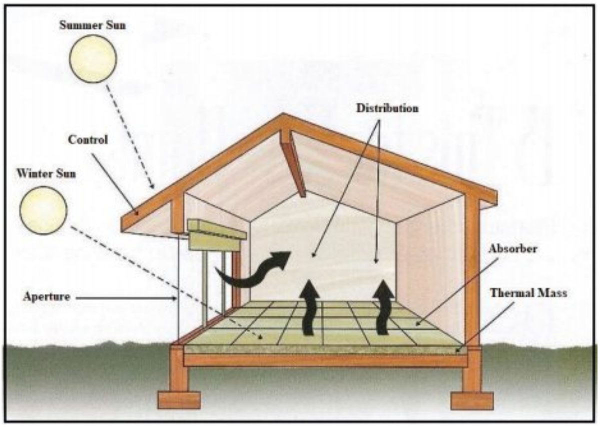

Figure (10) . Five passive elements.

5.3 Passive Solar Heating Techniques

There are three approaches to passive systems- direct gain, indirect gain, and isolated gain. The goal of all systems is to capture the heating radiation within buildings and release the stored heat at nights. Solar heat should be implemented for keeping the space comfortable and not overheated [8].

5.3.1 Direct gain

The simplest passive heating technique is called direct gain. As shown in Figure 11. sunlight enters houses through windows that are larger than normal windows facing south and strikes walls and/or floors. The surfaces of walls and floors have dark colors that absorb sun's heat, which stored in the masonry. At night, as rooms cool, the heat stored in the masonry radiates into the rooms [8,18].

5.3.2 Indirect gain

The solar radiation is intercepted by an absorber and storage wall that separates the south facing glass from the room. This gain uses materials that hold, store, and release heat; the material is located between the sun and living space [22].

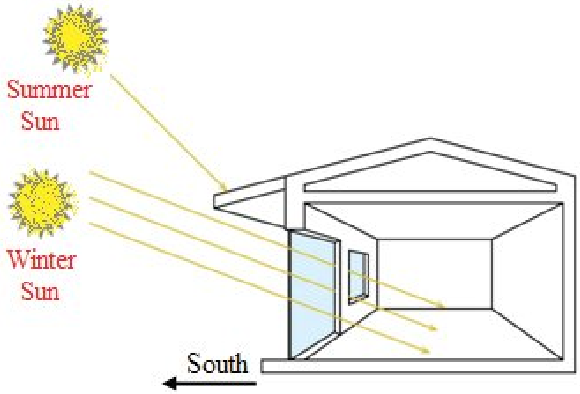

Figure (11). Direct gain.

There are many architectural ways to achieve this gain as the following details:

a. Trombe Wall: It is the primary example of an indirect gain approach. As shown in Figure 12. it consists of a thick masonry wall on the south side of a house. Trombe wall system consists of a massive wall installed at a small distance from a glazing. The wall absorbs solar radiation and transmits part of it into the dwelling by natural convection through the solar chimney formed by the glazing on one side and the wall on the other. The air circulates through the vents at the bottom and the top of the wall into the adjacent room. The natural convection is then controlled by these vents [25].

b. Water wall: It is a variation of the Trombe wall. In place of a masonry wall, water containers are positioned between the living space and the glazing as shown in Figure 13. A water wall absorbs and stores solar heat in much the same way as a Trombe wall, with the exception that water holds more heat than an equal volume of masonry [8,25].

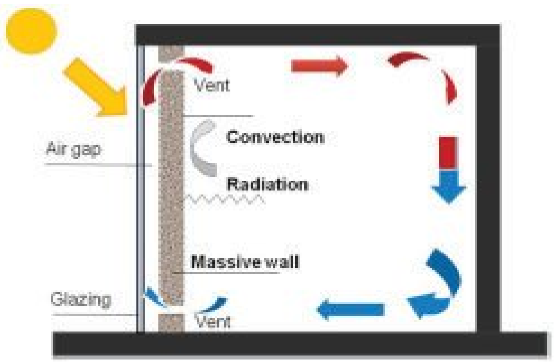

Figure (12). Trombe Wall (Indirect gain).

c. Roof Pond: A variation of water wall is a roof pond shown in Figure 14. Roof ponds are essentially waterbeds of sturdy plastic. They rest on special ceiling structure and are covered and insulated on winter nights by movable roof. During the day the mechanically operated roof is opened. Exposing the roof pond to the sun so it can absorb heat to radiate to living area later [8,27].

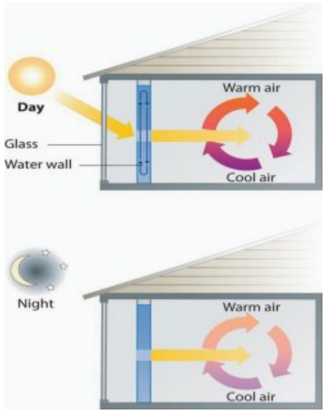

Figure (13). Water Wall (Indirect gain).

5.3.3 Isolated gain

The solar radiation is captured by a separate space such as a greenhouse as the following:

i. Solar greenhouse: A greenhouse added to the south side of a building enables it to collect heat due to its solar exposures shown in Figure 15. The heat can be conducted through a thermal storage wall separating the house and greenhouse or can be convected to the interior space of the building. For the greenhouse it is better to be recessed into the south facade of the building, thereby minimizing east and west exposures, which have little heat collection but can be a great source of heat loss. Furthermore, this configuration will increase heat transfer through the common wall between the greenhouse and the living space [19].

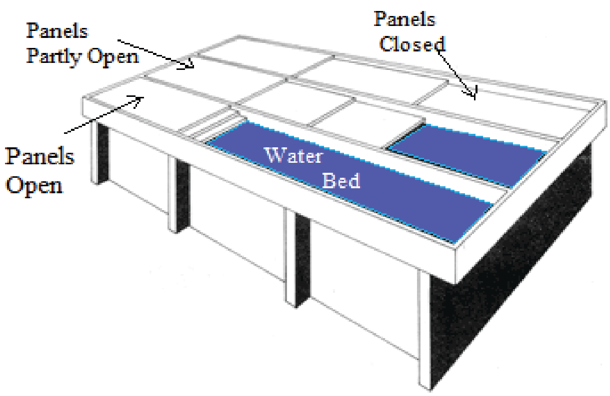

Figure (14). Roof Pond

ii.Thermosyphon collector: Thermosyphon air collectors use a black painted absorber with glass or plastic glazing. A thermosyphon collector can be built into the south wall of a house at a level lower than the house. As shown in Figure 16. It can be hooked up with a rock storage bin. The heat circulates naturally, but much of it is absorbed and stored as it passes through the bin [28].

iii. Sun Tempering: Sun-tempering occurs when a house or other building collects solar radiation through large south-facing windows (or thermosyphon collector) but does not have a storage element as in Figure 17.

This is not a complete passive system, and its use is limited to daylight hours. The window collection area must be sized carefully, because without storage mass there is the possibility that the living space will become overheated quickly during the day [8,26].

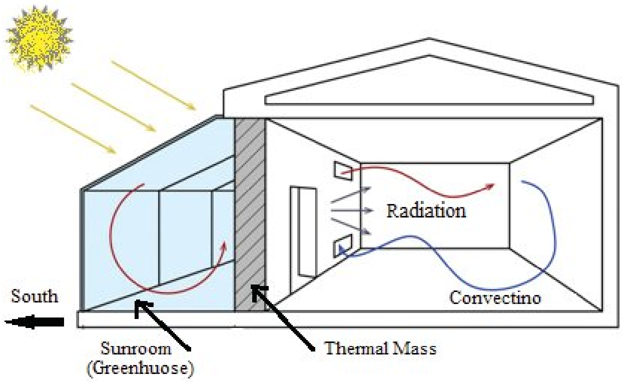

Figure (15). Solar Greenhouse

5.4 Passive solar cooling techniques

Active solar cooling is still in the experimental stages. In active solar cooling, heat is used to run some kind of an absorption refrigeration machine. High temperatures are required in this application and so far have not proven to be cost effective. The passive technology has produced few techniques where by the sun's rays have directly or indirectly resulted in cooling. There are five types of passive cooling techniques: Load avoidance and reduction, Natural ventilation, Earth contact cooling, evaporative cooling, night sky radiation cooling [22].

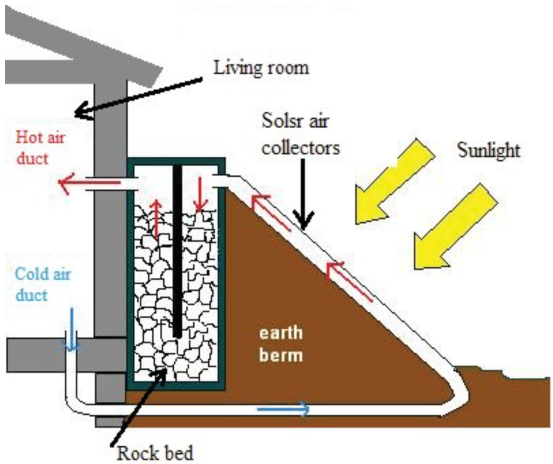

Figure (16). Thermosyphon air collectors with Rock-bed

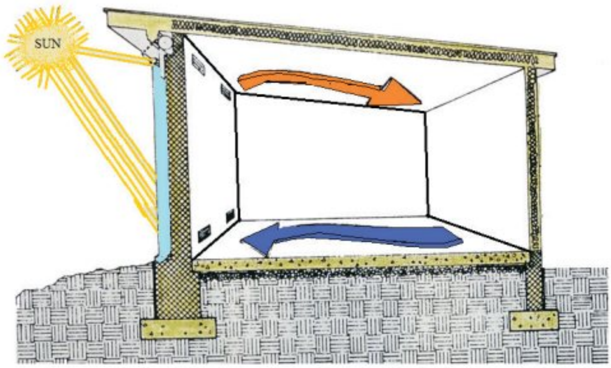

Figure (17). Sun tempering [8].

5.4.1 Load avoidance and reduction

The basic goal is to prevent passive-solar heating in summer. This goal is achieved largely by appropriate placement of windows. It is important to shade windows from summer sun by correctly designed overhangs on the south windows and by placement of vertical louvers, shading walls, or appropriately placed trees on the east and west sides of the building as shown in Figure 18 and light color on outside walls and roof to reflect sun light from the building.

5.4.2 Natural ventilation

Natural ventilation cooling is probably the most important type in most climates. Design for natural ventilation consists of careful sitting of the house so that it has good access to the prevailing summer breezes, location of windows so that breezes can blow through the house, and adequate heat-storing mass within the house so that daytime heat can be absorbed by the walls for release to cool night breezes, Figure 19.

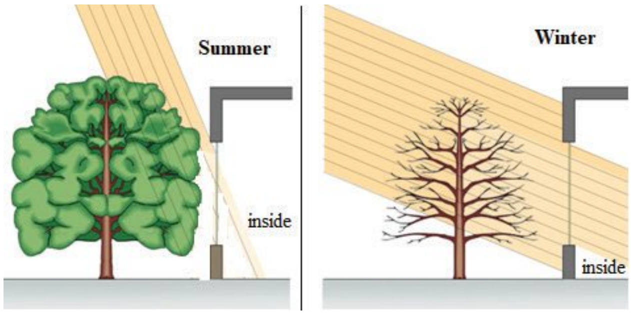

Figure (18). Load Reduction [29].

Thermal chimney also shows promise in aiding hot-weather ventilation. Air within the Chimney is heated causing it to rise, thereby effecting air movement for ventilation or to provide air exchanges. The updraft induced by this device can be coupled with earth tubes or some kind of earth contact or night-cooled storage mass [30].

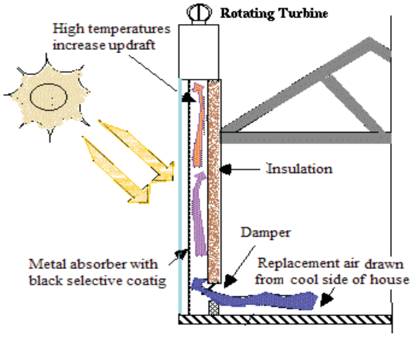

Figure (19). Solar Chimney [30].

5.4.3 Earth contact cooling

Another techniques for modifying both summertime and winter time temperatures is earth contact or earth sheltering. By digging a building into the ground, or pilling earth up around it, the constant temperature of earth and the associated heat sink can be used to make the building cooler in the summer and warmer during the winter, Figure 20 [8].

At one extreme, earth contact cooling takes the form of underground construction. At the opposite extreme is slab-on-grade construction. In between lies pilling earth against certain outside walls. This requires special attention to structural design for protection from the increased loads and pressure from the ground and also special care in waterproofing of the walls. Because of structural and waterproofing problems, underground construction is a very specialized topic requiring considerable research and engineering [8].

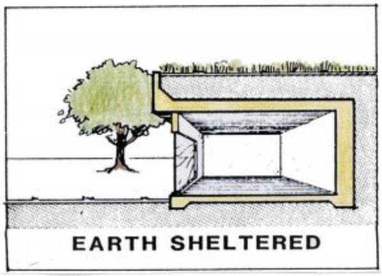

Figure (20). Earth Sheltered [8].

Another earth contact cooling technique is the earth tubes, which are, buried underground, and they bring in fresh air that has been cooled as a result of its journey underground, as indicated in Figure 21 [30].

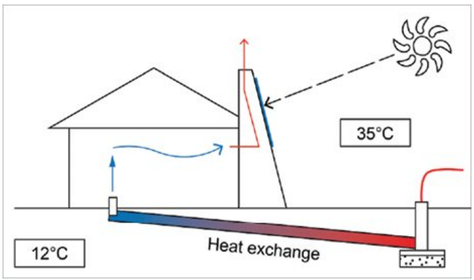

Figure (21). Earth Tubes

5.4.4 Evaporative cooling

In hot dry climates, evaporative cooling may be very effective. There are several types of apparatus that cool by evaporating water directly in the living space (direct evaporative cooling). Interest has increased in equipment that combine the evaporative cooling effect in a secondary air stream with heat exchange to produce cooling without adding moisture to the living space air (indirect evaporative cooling).

5.4.5 Night sky radiation cooling

The use of roof ponds also shows promise as a cooling technique. During hot weather, the shutter (cover) is kept closed during the day. At night it is opened, and the pond radiates heat out into the night sky, becoming substantially cooler than ambient temperature. The pond then becomes an effective heat sink during the day. In cold weather, the process is reversed. The shutter is opened during the day and closed at night [31,32].

6. RESEARCH ACTIVITIES

Many studies were conducted and published as research papers in local, international journals, conferences, and seminars. This review paper focuses on documenting and studying such published papers, in order to find out the most important flashing results and conclusions specifically in fields of using solar energy for space heating, cooling and ventilation of local residential buildings. This covers using active and passive solar systems in achieving thermal human comfort in such buildings leading to reduce electrical energy consumption. This paper also concentrates on applying energy efficiency measures in buildings; planning, design, and construction stages with the use of the principles of energy conservation in buildings. There are several case studies that comparing traditional with modern house designs in several local cities including both famous old cities of “Ghadames” and “Gharyan”.

6.1 Energy Efficiency

Although energy efficiency in buildings is a vital issue when trying to save energy, reduce emission, saving the environment, working toward sustainability, yet it has not got enough attention in Libya. That is because there are no national supported programs or projects to work on this subject. However, there are some individual attempts by researchers to explore the dimensions of energy efficiency in residential buildings in Libya.

El Bakkush et al [33], investigated a domestic building in Libya with a general target to reduce its energy consumption. The study included a detailed monitoring of the building and then a simulation was conducted in order to apply energy consumption saving strategies. Their findings were primitive as they concluded that there is a strong correlation between energy consumption in that building and the outside temperature. They also concluded that the real situation is difficult to simulate due to some reasons summarized in their paper.

Badi et al [34], focused in their research on residential building energy consumption in Libya. The study showed that the residential sector is one of the most sectors consuming electricity with a percentage of 34.6% with lighting have the most share of 32.0% followed by water heaters which consumes about 29.9% from total residential consumption. The study showed that it is possible to achieve an important energy saving by applying saving measures to both lighting and water heating. They claimed that this will eventually result in reducing carbon emission by 4.7%.

Etaib and Elgnain [35], addressed the issue of the importance of applying energy labeling for different appliances. They also addressed the expected difficulties and problems and possible solutions to those issues. They claimed that the success of energy efficiency cards programs depends heavily on market interactions and the extent of coordination between the relevant parties through which the programs will be implemented.

Amongst their recommendations, they listed several mechanisms to reach the goals.

The optimization of the insulation thickness and material of buildings' external walls has received a good deal of attention. Alghoul and Hatab [36,37], studied the main parameter that affects the thermal performance of building walls using Taguchi and Grey-Based Taguchi optimization methods. They found that the conductivity is the most influential factor on energy transmitted through building walls followed by wall thickness, block density and block specific heat, respectively.

Bodalal et al [38], calculated the heating and cooling loads for residential buildings by using degree days method for some Libyan cities. They finished their paper with a list of recommendations with emphasis on the need for establishing a design code for Libya and on the adoption of using designs that consume a minimum amount of energy.

Alghoul and Alrijabo [39] conducted a research on the importance of windows type and shading on building energy efficiency in Tripoli. They examined both window size and orientation and their effect on energy consumption. A number of findings were listed in their papers that specify optimum window sizes and energy consumption related to each orientation. Alghoul et al [40], developed a correlation for the estimation of energy consumption for building facades. The aim of the correlation was to provide architects with a simple tool that can be used to estimate the energy losses due to certain designs. The correlation is mainly dependent on the window to wall ratio and wall orientation. They found that adding windows to facade results in an increase in annual total energy consumption by 6–181% for the cases explored in their study.

Aljannan et al [41], have conducted a comparative study for a residential building energy consumption in Tripoli-Libya employing simplified and simulation methods. The results were compared to the electricity bills and illustrated deviations of 4.3%, 55.9% and 74.2% for Beopt, hand calculations and Degree-Day methods, respectively. However, it is found that heating and cooling loads are higher than B10 benchmark due to the lack of building codes and standards in the country. It is deeply recommended to develop building codes to reduce thermal loads and save more energy.

Many conducted projects have indicated that the country's energy demand generation could be significantly reduced if improved energy utilization efficiency by the major energy sectors is achieved. Building standards have been based on fixed comfort temperatures found from tests held in climatic chambers. Those standards assume that the indoor temperature is fixed to a set value and controlled by heating and air conditioning systems. In Libya the heating and air conditioning systems are not used continuously. Thus, the indoor temperature is fluctuating. The thermal sensation of the building occupants is the only controller of the ventilation, the heating or the cooling of the building. Unlike the conventional thermal regulations, which are based on energy consumption, the special feature of the future Libyan thermal regulation is related to the fact that it must ensure a minimum level of thermal comfort when the building is free running without any heating or cooling system [42].

6.2 Active Solar Space Heating.

Misellati and El-Twaty [43], have discussed many passive and active methods for solar space heating in Libya and compared the need for space heating between several locations in the country utilizing Degree-Days method. They found that the mountain cities require heating more than cooling even that Libya is a Saharan region. However, the cooling load of the flat cities, such as Tripoli and Hon, is more important. Furthermore, the authors have concluded that the most suitable system of the solar space heating is the sky-therm concept due to several advantages, such as that it is suitable for flat roofs and it doesn't need any major equipment.

Azzain [44], presented a theoretical computer simulation using TRNSYS to analyze the incensement of solar contribution in space heating for Sebha Solar House (Sebha-SH), which is done by the replacement of the old PV panels by equivalent PV-thermal collectors to achieve electricity-heat cogeneration. Where technology of PV-thermal collectors has the potential of satisfying the whole heating load on Sebha-SH and simultaneously, it produces considerable amount of electrical energy. The extended photovoltaic array maybe used during summer to generate more electricity for space cooling. The use of Rock-bed technology has proved higher degree of reliability with typical performance records. The integration of thermal energy storage using Rock-bed technology with the use of various passive and active solar energy utilization technologies has the potential to upgrade all these technologies and raises system energy efficiency, additional to the increase of solar contribution.

The typical solar house in Sebha was constructed in 1993, where the total cost of this house was one million dinars. It was used as a research station for solar energy field. Through the computer follow-up system, the information was collected continuously throughout the day to evaluate the system later, and study the rate of performance. The house has an architectural area of 300 m^2, which has been supplied with thermal and electric systems for various purposes. It is equipped with different measuring devices. The amount of thermal energy needed by the house was evaluated by the calculation of cooling and heating loads. The thermal system was designed for the air conditioning of the house and to heat the required water, where the vacuum tubes solar collectors were used in this thermal system. In this house, some factors have been studied to evaluate the systems, such as the monthly average of solar radiation on a horizontal surface, the power generated by the solar cells, the angle of the solar collectors, the level of charge in the storage batteries and the efficiency of the devices and elements used in the solar systems [45].

Agll et al [46], have estimated the annual heating energy and fuel consumption for many buildings in several cities in Libya representing the regions of cost, desert and mountains. In the same time, the buildings are classified to residential, hospital, schools, and administrative office buildings at cold season from October until March. Employing BET method to estimate the heating degree-days.

Because the solar air collectors are used as one of the solar heating technologies in buildings, Alghoul & Alhrari [47], conducted a numerical analysis for the flow and the temperature inside a flat plate solar air collector, using the explicit finite difference method in order to solve dimensionless governing equations for air solar collector without and with a storage bed. That is to study the possibility of storing solar energy obtained during the day in a period of solar radiation during the night. Amongst the results they found that the air velocity at the outlet of the collector has increased by 38% of the air velocity at the entrance. The effect of using the storage bed is to reduce the maximum outlet air temperature to about 26% of the temperature reached without using the storage bed.

6.3 Active Solar Thermal Cooling Systems

Abdel-Dayem and Fatima Alghoul [48], have conducted a theoretical study for a single-stage Lithium-Bromide absorption cycle that contains a simulation and evaluation for the system at different parameters. The results showed that the increase in the generator temperature increases the COP of the system. Furthermore, the COP and the cooling capacity could be promoted by utilizing a low temperature absorber and a subcooled condenser; however, that increases the rejected heat. Otherwise, it is found that the increase of the cycle high pressure will not increase the COP of the system.

Abdullah and Ahmed [49], have experimentally studied the performance of an internally cooled dehumidifier that being utilized in the liquid desiccant air conditioning system. Whereas a parametric study is performed by the variation of the inlet values to the dehumidifier such as: air temperature, humidity and desiccant flowrate, the effectiveness of the dehumidifier was investigated. Finally, it is found that the dehumidifier effectiveness is increasing with the increase of the desiccant flow rate and concentration and decreases by the increase of inlet air flow rate and humidity.

Mosbah et al [50], have constructed a solar powered air conditioning mathematical model based on LiBr-Water chiller and fed by flat plat solar collectors. The results demonstrated that the maximum solar factor for the model is 48% where the solar collection area is 1400 m^2. Furthermore, the local weather is found to be the main effective parameter.

Abdullatif Zgalei [51], has studied a double stage LiBr-Water absorption system that powered by solar energy. A computer simulation code is produced. However, a modification of the system is studied in order to recover the absorption heat, where it is found that COP of 1.66 is reached with a generating temperature of 95 °C. Moreover, the author has recommended the addition of refrigerant and solution tanks in order to accumulate the condensed refrigerant during the high insulation time and leave it to be expanded at load time.

Another study by Zgalei and Aburwin [52], has investigated the technical feasibility of the solar cooling systems for several locations in Libya by studying their metrological data. Therefore, it is concluded that the solar cooling in Libya is feasible and could fulfil about 25% of the total installed capacity of the air conditioning devices in the country.

Solid absorption cycle is studied by Farwati [53] for Benghazi, Libya. The author has focussed on the sizing of the zeolite optimum thickness in the adsorption core by modelling 3.4 MJ/day system in a computer programme.

Bagdady and Keshrewo [54], have performed a review work for some solar technical projects that constructed in Yefren technical institute, where two solar cooling technologies mentioned utilizing PV system to operate a water cooling system or an evaporative air conditioning system. It is found that the utilization of such technology is available in Libya. However, few problems are observed such as the high capital cost and the need for a wide collection area. The continues update of the concerning research and the cooperation with the other interested countries are recommended by the authors.

Attractively, Abughris [55], has mentioned the solar absorption systems from the technical and economic sides, where cooling and heating systems' problems are demonstrated and discussed, such as thermal storage location, qualified maintenance labour and the total cost of the systems.

Alghoul [56], conducted a study to compare HVAC systems from an energy consumption point of view, where the Energy Plus building simulation software along with Open-Studio software were used to model a medium size residential building in Tripoli city of Libya, and also to model different HVAC systems.

The results show the annual energy consumption of different HVAC systems that could be used in residential buildings. It was also concluded that when the variations in energy consumption of the considered HVAC system decrease, the coefficient of performance (COP) increases and vice versa.

Ahmed, Abdalla [57], investigate experimentally the performance of an internally cooled Triethylene Glycol (TEG) liquid desiccant regenerator. The performance of the system is evaluated using the water evaporation rate, regenerator effectiveness, and enthalpy effectiveness. The results showed that the moisture evaporation rate increases as inlet air and desiccant flow rate increased. But it decreases as inlet air humidity ratio and desiccant concentration increase. The results also showed that the regenerator and enthalpy Effectiveness increase as inlet humidity ratio and inlet desiccant flow rate increased. But the regenerator and enthalpy effectiveness decrease as the inlet air flow rate and desiccant solution concentration increased.

A feasibility study was conducted based on the life cycle cost of a solar powered absorption chiller as cooling system for a store house building in Misurata city. The simulation of the solar system program showed that the solar cooling has the potential to curb the ever-increasing demand for conventional energies used for cooling purposes, which contribute to decrease the dependency on fossil fuels and to avoid CO_2 emissions. By lowering electricity demand at times of peak loads, it increases the stability of costs of the electricity grids [58].

Solar operated absorption air-conditioning systems, in different situations, have been found to be feasible. Such systems can make use of the expensive collectors which are, in any case, installed for water and space heating. It is used for the cooling of a prototype house in Kufra. The measured radiation and ambient data calculations are performed on an hourly basis to determine the cooling load, radiation in the collector plane, heat delivered by the collectors and the heat stored in or discharged from the storage tank. Three different types of collectors with varying efficiencies are considered. These collectors are of the evacuated tube, selective coated and black painted types. The study confirms that the water-lithium bromide absorption system can provide summer air conditioning in arid zones of Libya where there are difficulties with the supply of electricity and fossil fuels. The thermal analysis of the absorption system showed that a cooling tower of 38 kW capacity will be needed to offset absorber and condenser loads [59].

Amer et al [27], have reviewed the technologies developed in evaporative cooling, which is one of the successful thermal cooling methods due to its high COP and low energy consumption. The study has covered direct, indirect and combined direct-indirect evaporative cooling systems. It is concluded that the dew point indirect method is the most attractive evaporative cooling method for research due to its low energy demand and higher efficiency.

6.4 Solar passive design

6.4.1 Thermal mass

Bodalal and Haghighat [60], present a new experimental method for measuring thermal conductivity and thermal partition coefficient for building materials. The methodology in this research is based on solving the transient one-dimensional conduction equation by using Laplace-Carson Transformation Technique.

Awad and Bodalal [61], investigated the impact of building envelope construction materials on the thermal behavior of two different designs for residential buildings in Benghazi - Libya. A commercial software (Cymap) was employed to simulate building thermal behavior where two methods were used namely; Budget Cost Method (BCM) and Residential Envelope Transmittance Value (RETV) Method. The BCM standard is used to set a maximum value of required power per unit floor area, which is set at 0.11 kW/m^2. Based on RETV method, the west wall has the highest value of power per unit area, this is largely due to the considered west walls that mostly have a relatively considered high window to wall ratio.

El Bakkush et al [62], worked on a detailed monitoring and analysis of measured data with recommendations leading to reduce energy consumption and carbon emissions. Their results confirm that flats on the upper floor suffer the highest heat gains due to the most significant roof surface heat gain. They concluded that roof insulation is recommended as a cost-effective measure to reduce energy consumption. Flats located on the ground floors have to use air conditioners during the day while flats on first floor at night due to the time lag in heat transfer profile.

Alghoul and Hassan Alrijabo [39], Used the EnergyPlus simulation engine with Sketch-Up and Open-Studio software to calculate the required cooling and heating capacity and the energy consumption for an office space in Tripoli, Libya. Using glazing with solar control for all orientations provide high energy saving when compared to other types without solar control. Reflective, absorptive, and spectrally selective window types provide high energy saving for cooling, while other types provide more energy saving for heating due to the allowance of more passive solar heating to the office space. The amount and percentage of energy savings vary significantly for different orientations. Reflective window glazing provides a maximum energy saving for southwest orientation.

Alghoul et al [63], studied the effect of the electricity prices on the optimum insulation thickness for the city of Tripoli. In order to highlight the amount of energy losses due to space cooling and heating from the external walls, Degree-days values were used to estimate the amount of annual heating and cooling required per meter square of wall area. The life-cycle cost analysis was used to estimate the optimum insulation thickness. They concluded that the current subsidized price of electricity does not encourage consumers to use thermal insulations in building walls for energy saving. Increasing in electricity price leads to increase in the thermal insulation thickness.

El Bakkush et al [64], explained that the use of suitable thermal mass and thermal insulation devices such as external and internal solar film devices as an argue is important for heat absorption, reduction and efficiency. There are a lot of heat gains during summer periods in Tripoli and the heat absorption pattern increases during such periods through the walls and other openings. The adoption of bioclimatic architecture is one of the best energy saving measures that can reduce the energy factor of buildings in Tripoli. Also, passive solar design adoption is another surest way of minimizing the thermal effect of the outdoor air temperature on buildings.

Faggal and Eshawakh [65], recommended many ways to reduce the heat transfer into the space, where the walls must have high degree of delaying thermal energy into internal spaces and made of local material suitable with surrounding conditions like using sandstone bricks and using double walls with moving air space and selecting right color of the external surface. In additional, using insulated roofs with suitable insulations or roofs with two separate blocks with moving air separation and also using curved and shell roofs which help effectively in reducing heat transfer through space. The right selection of openings positions and reducing their sizes in a way not affecting their functions and selecting type of thermally processed glass with special photo and thermal qualities to help greatly in reducing heat transfer.

Suleiman [66], used the Hot Disk technique to obtain measured thermal conductivity values that might provide the basis for insulation materials manufactures to produce suitable and reliable insulation materials that can be used to improve the thermal loading performance that will lead to a reasonable human comfort and reduce energy consumption of houses.

Alghoul and Hatab [37], studied the effect of lightweight concrete blocks factors on heating and cooling consumption by using Taguchi design of experiment and using Energy plus simulation software to calculate the heating and cooling energy consumption. They found that the lightweight concrete blocks reduce energy consumptions when compared to normal weight concrete blocks.

El Bakkush and Harris [20] used the IES software to model the residential building without any improvement and changes, and compare it with improving energy efficiency through the application of bioclimatic design principles in residential buildings in Libya, which is a critical factor in reducing energy consumption, securing thermal comfort, and hence is an effective policy for reducing the environmental impacts such as a global warming and ozone layer depletion. Adding the shading devices can cut 15.78% from the total chillier load, and for the most impressive saving is to add outside solar film on the glazing which can save 45.18%. Furthermore, adding to the roof lower emissivity paint and slab absorber will not add extra saving (not more than 1%), while 2% more can be saved by adding internal solar film on glazing. However this is not worthwhile for the impact as it will reduce the natural light to the building. The summer time is the peak CO_2 producer because the building uses air conditioning more than the rest of the year, the higher outdoor temperature increases, the more CO_2 is produced.

Farhat and Farhat [67], investigated the thermal performance of modern materials which are used in slabs, walls and floors, and compared the thermal performance of these with traditional materials which have long been used. The traditional house offers better responses to the demand for thermal comfort, however, traditional houses need to be improved in order for building materials could play an important role in the thermal design of buildings. Appropriate building materials can minimize thermal discomfort, and should be chosen according to their thermal properties which represent the corner stone of thermal design of the building.

In addition, the wall thickness is one of the most important factors involved in the process of thermal transmittance from outdoor to indoor climate; where the traditional wall shows that a satisfactory delay in heat transfer; it has a longer time-lag than modern ones. However, brick concrete walls, when provided with proper insulation, properly installed, will reduce thermal transmittance and consequently give optimum thermal transference. Concrete roofs also demonstrate their efficiency when provided with thermal insulation. They also give an optimum time-lag. Like comfort, cost is also important where the most traditional building materials are low in cost.

A simulation program (ECOTECT) is used to analyze the residential buildings in Sebha. That is to reach a thermal comfort point in the interior space without the need of mechanical utilities. This could be done through improving the temperature in the architectural space, with climatic treatments for every element of the external shell to protect the building from the exposure of the solar radiation. This is considered one of the most important things that can be done in order to decrease the thermal gain of buildings. Using building materials such as Adobe Bricks are considered the best natural material that can provide good thermal insulation for the internal spaces of buildings. In addition, wood can be used to make flat roofs and domes, and its usage is increased due to its good insulation qualities especially in hot regions. It's also used as an assisting material in building walls so if there is any cracks shadowing it doesn't affect the other walls [68].

The energy consumption can be reduced with some recommendations of the building materials such as the classification of locally available building materials with studying their various properties. Some special specifications and conditions should be considered when using new local or non-local building materials. Large thermal masses are recommended for heating seasons. In additional, using the thermal insulation should be enhanced for government buildings and facilities [69].

The Ghadames city is one of the best examples of desert cities where the planning in advance for it, was conducted to provide suitable air for the entire city, to reduce heat load on buildings and to achieve thermal comfort. The design and study of architectural elements and structural components of the building lead to thermal balance of buildings, with selection of suitable building materials and methods of construction. For design phase, there are many passive criteria that should be considered, such as using the central courtyard in residential buildings, using the large resistance building materials and thermal mass, and using the light colors for external surfaces [70].

The economic feasibility can be achieved by encouraging citizens and government agencies to use the best building methods to improve the buildings envelop by using thermal insulation in construction phase, which leads to increase the performance of the cooling and air-conditioning systems, and to save energy with providing the comfort of the citizens in their homes [71].

As stated previously, building materials for walls and roofs have an effect on the thermal buiding loads, M. I. Alowa and G. Azzain. [72], conducted study about the effect of building's materials on the thermal load for 170 m2 residential house in Sebha city area, where the house constructed from local materials including walls that are constructed by sand and gravel aggregate, two core block, brick block, sand stone, or clay block, roofs and windows. ASHRAE method was applied, and the obtained results show that the maximum energy loads were caused due to roof heat exchange.

Alghoul et al [73], determined that the optimal thicknesses of the thermal insulation of external walls in order to reduce energy consumption in residential buildings located in three cities from different climate zones in Libya (Tripoli, Sabha and Yefren). Rockwool and Polystyrene were used as insulation materials of external building walls. The optimization is based on the analysis of life cycle cost. Depending on the type of insulation, the kWh cost of electricity and the climate zones, the optimum thickness of insulation ranges from 7.2 cm to 14.7 cm with an amount of energy savings between 6.6 – 16.2 LD/m^2. The payback periods were calculated to be 1.5 to 2.3 years. The highest value in energy saving is found in the city of Yefren where polystyrene was used. In addition, the polystyrene insulation was the favorite in all locations. The optimization also showed that the current subsidized price of electricity does not encourage consumers to seek means to save energy by using thermal insulations.

6.5 Passive Space Heating and Cooling

Wahhad et al [74]. have used ANSYS CFD V.13.0, FLUENT, and k-ε for analysis and validation of an experimental work in order to evaluate temperature difference between outdoor and indoor environments, and to determine air temperature field. The results showed that well-designed double glazing can reduce the emission of sunshine and heat gain into desert buildings, even though with using a northeastern facade in sunny climates.

Almansuri et al [75] and Belhaj et al [76], gave an overview of the general architecture principles and made a study of the components of the environmental design and the architectural treatments for Libyan climatic zone. A model of a house for Libyan family life style used to give an idea of the application of some architectural treatments for sustainable buildings taking into consideration the physical, cultural and social differences. The architectural designer should play role in reducing the impact of buildings on the environment. They must consider energy efficient design strategies in the early design stages and should not rely on using simplified analysis, synthesis techniques, and historical examples. Building energy simulations are becoming more common in the design of buildings, where architects should use it in the early design stages.

Shateh et al [77], stated that in "Gadames", materials used for buildings construction are of a composition of local materials such as clay, limestone, and gypsum, and palm wood. These are cheap and have low thermal conductivity. In such houses, no windows used and light enters in through small aperture (louver), which does not exceed 1m^2 in area, opened in the roof of the central living space and through the two floors. Their internal wall surfaces are made with reflective elements to provide good lighting without risking for more heat gaining.

Krem et al [78], examined four different buildings footprint aspect ratios and two different orientations in order to investigate the sensitivity of site layout planning characteristics on the energy consumption of high-rise office buildings in four different climate regions.

Almansuri et al [79], explained that "Ghadames" traditional houses can provide a desirable microclimate for the whole year round without employing air conditioning devices. These houses were confirmed to be most successful and appropriate for such atmospheric conditions regarding ventilation and insulation systems. The local architecture in "Ghadames" respected the nature, where vernacular, urban and architectural patterns provide useful hints for designing more sustainable environments.

Traditional houses in "Ghadames" were designed mainly to provide maximum protection from solar radiation and direct sunlight. However, modern houses are designed with little consideration to the climatic condition and they have large unprotected glass windows on all four sides of the buildings. Shawesh [80] described and investigated the traditional and modern spaces within desert settlement of "Ghadames", in order to determine the impact of the external climate on the performance of buildings and on comfort of its occupants. Using of modern materials with thin light weight walls and roofs with quick time-lag leading to poor behavior for modern housings in the town.

El Bakkush et al [81,82], explained that the best way to control and reduce the energy gains pattern in a building is to introduce energy modification devices such as shading device, solar film emissivity paints and roof slab absorbers among others. In specific terms, the best device would be the application of external solar film, followed by shading device and internal solar film. An application of emissivity paints and roof slab absorbers does not contribute significantly to the energy reduction in buildings. The external solar film devices are again suitable mechanism for the reduction of CO_2 in buildings.

Bodalal et al [38], investigated the potential of energy consumption reduction, cost savings and pollutant emission prevention achieved by installing different insulation materials of optimum thicknesses in residential building walls in Libya. That can reduce the energy consumption and emissions by 70-80% in comparison to walls without insulation, where the values of optimum insulation thickness varies in the range of $0.0061 \leq X_{opt} \leq 0.1187$ (m) depending on the values of CDD/HDD used in the calculation for a typical residential house in the city in Benghazi.

Sharif et al [83] and Almansuri et al [84], explained that the courtyards are usually the heart of the dwelling spatially, socially, and environmentally; where the courtyards in Arab houses are developed taking thermal comfort factors into consideration such as the building orientation, ventilation, and shadowing. A courtyard can provide security, privacy, and a comfortable place within the house. Even without modern, mechanical heating or cooling systems the courtyard house provides a comfortable living environment through seasonal usage of sections of the structure. The mass of walls and floor of the courtyard is cooled by outgoing long wave radiation, and therefore, the surface of the courtyard floor and walls will remain cool by the following morning. In this way, the mass of the walls and floor of the courtyard (and not the air deposited in the courtyard) serves as a reservoir of coolness if it is not too large and well shaded.

Gabril, et al [85], presented a field study results of thermal comfort in three cities in Libya. A thermal comfort survey has been held out in 39 domestic building across three cities Tripoli, Ghadames and Gheryan. A thermal comfort investigation in the three cities is conducted to calculate comfort temperature in Libya. Occupants' adaptive adjustments have a great influence in setting the thermal comfort temperature in the three cities.

The comparison between the comfort temperature and the maximum and minimum outdoors temperatures can help designer to judge whether passive heating and cooling techniques are appropriate for the climate under consideration [86].

Investigated that the majority readings of indoor temperature for the traditional single family houses in mountain (city of Gharyan) are approximately constant during the day in summer and in winter, and were within the range for human comfort in this zone. That is because of many reasons such as old houses adopted in such a technique using local masonry materials with thick walls and roofs up to 70 cm. The underground dwelling in Gharyan is known for the suitability to environmental conditions, where the temperature is similar to the temperature of the ground. The field measurements indicated that the troglodyte dwellings provide more comfortable environment in this region throughout the year. On the other hand the traditional Libyan house in the old city of Ghadames desert region is relied on the local building materials that have a function to make the house more suitable to the climate. That high temperature leads to the consideration of the "closed design", where the construction is shadowed by walls and ceilings in order to be cool and comfortable, even during the hottest part of the day [87,88].

A passive technique for Hun city obtained from Mahoney tables is recommended. Mahoney tables are an appropriate measure for avoiding negative designs of residential buildings, and it's used to analyze the climatic data record (air temperature, relative humidity, rainfall, and wind) for the years (2012-2014) in order to maintain thermal comfort where the climate plays an important role in human life, it has a direct impact on nature and human conditions. Architectural designs have an objective of harmonizing the outer shell of the buildings with the climate in their environment to create a comfortable heat that contributes to reduce using the mechanical solutions which significantly contribute to the consumption of electricity in the home; and will prevent the required production of a considerable quantity of electrical power that will contaminate the environment and drain the natural resources while also contributing to a high monthly bill [89].

Ealiwa et al [90], reviewed the results from a field survey of thermal comfort within two types of buildings; old (traditional) and new (contemporary), in Ghadames oasis in Libya. The full-scale measurements have been carried out involving environmental parameters and human thermal comfort responses from 51 buildings in Ghadames. These buildings are either natura1ly ventilated with courtyards or mechanically ventilated with air conditioning systems. The survey has shown that the measurements of predicted mean vote (PMV) in new air-conditioned buildings provide satisfactory comfort conditions according to ISO 7730 and the occupants agree by indicating a satisfactory actual mean vote (AMY). The equivalent measurements and survey results in old traditional buildings indicated that although the PMV based on measurements and ISO 7730, implied discomfort (hot), the occupants expressed their thermal satisfaction with the indoor comfort conditions. The field study also investigated occupants' overall impression of the indoor thermal environments. The results suggest that people have an overall impression of higher standard of thermal comfort in old buildings than in new buildings.

Bukamur [91], stated that the most efficient building design criteria for the hot dry climate in "Sabha" is based on three critical points. First, minimizing solar heat penetration and maximize reflective outside vertical surfaces, secondly, using low thermal conductivity materials, thirdly, choosing best energy-related orientation for the building.

Ahmad and Sheridan [92], conducted a computer simulation for a mathematical model based on the thermal response factor concept that used to simulate the thermal behavior of a building with roof pond. The results show that the roof pool can maintain 21°C average indoor temperature in a typical Brisbane winter, while the same building without a roof pond system would have 17°C average inside air temperature under similar weather conditions. A roof pond system can provide 23°C average inside air temperature under typical summer weather conditions in Brisbane.

Ahmed and Abughres [93], explained that most of Libya has heating degree days between 600-800°C –days except the mountainous region that have maximum number of heating degree days between 800-1000°C-days, and for the northern region near the Mediterranean coast it varies from 1000-1200°C-days. The potential for convective cooling was estimated using average hourly temperature for August as it is considered to be the hottest month of the year. Libya is a summer dominated country where it requires more space cooling than heating processes. The study also estimates the potential for convective cooling which varies from 3.5-7 MJ/m^2/day and roughly equals the cooling loads in some local regions. The estimates for the thermal mass of building required to store this cooling for daytime-use vary from 1000 kg/m^2 to 3000 kg/m^2 of the floor area in the north and south of the country, respectively. They concluded that only a narrow strip along the Mediterranean coast which includes Tripoli and Benghazi cities has a convective cooling potential between 3.5-5 MJ/m^2/day. All local parts south of this strip have convective cooling potential between 5 -7 MJ/m^2-day. This cooling potential is roughly equal to that required to maintain indoor thermal comfort in different climatic regions of Libya. The efficient use of convective cooling needs operable windows of suitable orientation in order to provide sufficient wind speed to the air flowing inside the building to remove indoor heat, while interior spaces should be accessible to the flowing breeze.

Ahmed et al [94], have recommended passive-based strategies for Libya that are based on the monthly averages of the maximum and minimum temperatures for 24 local locations. They confirm that energy conservation and improvement of indoor conditions can be affected economically through passive-based design of buildings. The northern region along the Mediterranean coast is characterized by the availability of big chances to employ passive solar heating. The buildings in this region should restrict conductive heat flow, prevent infiltration and promote solar heat gains. On the other hand, in the southern region which is a part of the Saharan desert, there is a need for buildings of high thermal mass to moderate local weather extremes. The buildings of this region should promote natural ventilation, restrict solar heat gain and encourage evaporative and radiant cooling.

Omar et al [95], recommend some natural shading and shadow methods to enhance the thermal comfort in houses and reduce the electricity consumption. The current situation of energy consumption and thermal comfort in Hun city in Libya are achieved using electricity consumed by mechanical devices such as air conditions and fans or electrical heaters to reach thermal comfort in summer and winter. This leads to an increase in electric power consumption rate especially for cooling and heating. In addition, the evaporative cooling is found to be the best technique to reduce heat from roofs, which leads to reaching thermal comfort inside the buildings. However, it needs a huge amount of water so it is suggested that using white glazed tiles stuck over the roof that can be used to reduce evaporation and reduced water consumption.

Aida Ejarushi et al [96], and Aida Ejarushi [97], explained that the shading devices are important construction elements. They have an impact on protecting buildings from the direct heat gain. They can allow the low sun to inter the space during the cold periods. These advantages are considered so important especially in the temperate regions such as Libya.

Alabid and Taki [98], worked on the optimization of residential courtyard performance to enhance the indoor conditions for housing, and to meet the social and environmental requirements of today's housing conditions taking the advantage of traditional architecture of Ghadames. Where the indoor comfort temperature in a traditional courtyard was found to be at 34°C. An optimization design process was conducted to a courtyard building resulted in reducing the indoor comfort temperature to about 28°C.

Eltrapolsi and Altan [99], investigated different passive cooling strategies on scenarios to enhance adaptive thermal comfort during summer within a chosen month; June 2014, in the new urban area of Ghadames by using Design Builder simulation software package was considered with actual monitored weather data. Where the natural ventilation cooling without the use of air conditioning inside the house during summer whereas natural ventilation has the most profound effect on building's indoor environment to improve thermal performance of building envelope in domestic buildings toward reducing energy loads in hot arid zone of Libya.

Alabid et al [100], investigated the environmental performance of naturally ventilated dwellings and air conditioned dwellings in Ghadames and the impact of bioclimatic concepts on energy use for future housing development. A range of EnergyPlus simulations were carried out to predict the indoor climate conditions and energy consumption of typical dwellings considering different scenarios including the case of electrical power cuts. The traditional dwellings consume 66.1% less energy than contemporary dwellings. The simulation showed that building fabric and form of traditional dwellings perform far better than contemporary dwellings in terms of solar heat gains, thermal performance of materials, land use and natural ventilation. In additional, the passive design features found in traditional dwellings of Ghadames and use of appropriate architectural design and elements can help achieve zero energy housing, taking into account local community needs and future developments.

Referring to the safety of our and global environment, green buildings should be applied on a large scale covering whole country going in parallel with the local progress in construction of buildings [101].

In order to evaluate the thermal human comfort in traditional and modern residential buildings at "Aljabal Algharbi" region of Libya, measured values of inside and outside temperatures and relative humidity measurements during coldest winter days and hottest summer days are used as input data for Psychometric chart. This shows that summer climatic conditions are comfort. Consideration should be given to winter climatic conditions, because most of residential buildings styles do not meet the thermal comfort requirements in winter except the earth-sheltered houses [102]. The study concerns two traditional buildings consisting of earth-sheltered style, stone and gypsum plaster style, other private separated styles, and public residential buildings considered as modern ones.

To improve design of modern energy efficiency homes, a study was conducted on two adjacent houses in "Rajaban", Libya. One of which is a traditional semi-underground house and the other is a modern house. Through the study, the under-grounded houses gave good results for energy loads and humidity throughout the year. However, the main problem is inadequate lighting, poor ventilation, and so for partially undergrounded houses. A comparison study of the thermal behavior of semi-underground and modern homes shows that the average temperatures in summer were 24°C and 31°C, respectively. The average temperatures in winter were 5°C for modern houses and 10°C for semi-underground houses. This summarizes human compatibility with nature and optimal utilization of its resources. The heat loss and gain in modern homes is largely through their roofs, which is the cause of thermal discomfort in such homes. In addition, the house style does not have southern windows that provide light and heat during winter, so modern homes can provide greater thermal comfort if their roofs are isolated while they have southern windows [103].

Alwerfaly [104], conducted a study of design and construction of buildings that leads to insure comfort to the residents. This is done by applying natural ventilation, natural lighting and thermal comfort. There are several ways to achieve compatibility between the architectural design of a building, its location, its construction materials, and its environmental conditions in order to achieve the lowest consumption of energy inside buildings. It is possible to take advantage of the environmental conditioning elements and architectural design elements to reduce the temperature inside the building, thus providing thermal comfort for residents at low costs, and possibly for long periods without relying on traditional energy sources. Applying passive solar energy use systems usually leads to; economically achieve natural comfort zones, reduction in energy consumption, less pollution, less electrical energy shortage, and thus a number of positive returns for the country.

Grein et al [105] conducted a study about the underground thermal energy storage (UTES) systems, which is used as heating or cooling source and/or as a medium for thermal energy storage. The overall objective of this project was to adapt Swedish UTES practices for North African conditions in particular for Libya. Natural cooling and heating systems with very low operating cost and also active seasonal storage of thermal energy would release economic resources to other important areas. This work was aimed to explain many procedures and requirements to apply this project in Libya.

Utilizing thermal capacity of the ground in Libya is studied in details by Ahmed et al [106], where traditional techniques is evaluated such as; underground houses, thick walls and slab on ground. It is concluded that the cooling potential of slab on ground method alone is not significant without any convective cooling. In addition, it is found that the cooling potential of the floor varies from 0.2 $MJ/m^2/day$ in the northern coastal region to 0.6 $MJ/m^2/day$ in the southern desert region.

A mathematical equation is developed by Ahmed et al [107], as a design tool for passively conditioned buildings. The equation is applicable for the traditional style buildings, the equation has been developed for the design of a large thermal mass building on the earth surface and underground building less than 10 m deep.

The design and selection of building materials of historic city of Ghadames are made with special stress on thermal efficiency. The adobe-gypsum walls have a thermal resistance that is comfortably higher than required for arid zones while the adobe or whitewash surfaces have good light reflecting properties reflecting most of the incoming radiation energies. Wall thicknesses are such that a time lag of 12-15 hours is realized ensuring perfect dampening of high day temperatures [108].

Ahmed and Abughres [109], conducted an experimental study to suggest improvements in the new houses at Ghadames to conserve energy and enhance indoor thermal comfort. The experimental observation showed that the old house can provide a year round comfortable environment. The thermal mass of the new house is large enough. As a suggest improvement the outside walls of the buildings should be constructed to minimize the exposed surface area. However the detached surface of the houses should be white washed to reflect the sun light, and should be insulated to reduce heat flow. Where the improvement of window (except southern) should de avoided to minimize direct solar gain during summer and maximize it in winter. Also the overall heat transfer coefficient of the new buildings should be further reduced without reducing the thermal mass of the structure. The gypsum plastering for interior surfaces should be used which reduces heat flow and balances indoor humidity.

7. CONCLUSIONS AND RECOMMENDATIONS

Referring to the survey of the solar-related space heating and cooling for residential buildings presented above, the main conclusions and recommendations can be summarized in the following points;

- Site; Libyan country may classified into three metallurgical regions; northern region near Mediterranean coast, southern region, and mountain region. Buildings in southern region should promote natural ventilation, restrict solar heat gain, and encourage evaporative and radiant cooling. Most of Libyan areas have heating degree days between 600-800°C-days except for mountainous region which has maximum number of heating degree days between 800-1000°C-days. However, for Mediterranean coast region they vary from 1000-1200°C-days.
- Orientation and layout; Heating and cooling loads vary significantly with building orientation. Cooling air streams and natural ventilation depend greatly on relative wall directions. For rectangular plan buildings, the longest side is recommended to be in an east - west direction. This is due to the cooling load reduction. Undergrounded houses gave acceptable comfort results for heat and humidity throughout the year, however, inadequate lighting and poor ventilation are mostly present.
- Design; Passive solar design adoption is the shortest way of minimizing the thermal heating and cooling loads due to outdoor air conditions. Adding the shading devices can cut about 15% from the total chillier required load. Where adding outside solar film on the glazing can save up to about 45%. The design and construction buildings are so important in providing comfort to the residents. This could be done by applying natural ventilation, natural lighting and thermal comfort. The adoption of bioclimatic architecture is one of the best energy saving measures that can reduce the energy factor for residential buildings.
- Envelope; Walls must have high degree of delaying thermal energy into internal spaces and made of local material suitable with surrounding conditions like using sandstone bricks.
- Window to wall area ratio; the right selection of openings, positions, and reducing their sizes in a way not affecting their functions, help greatly in reducing window heat gain. While, it is recommended to select type of glass with special thermal qualities. South facing windows greatly reduce heating loads while eastern and western windows increase cooling loads. Window to wall area ratio becomes a measure for building description where energy loads vary according to this ratio. Efficient use of convective cooling needs operable windows of suitable orientation so as to provide sufficient wind speed to the air flowing inside the building to remove indoor heat.

- Roofs; Roof surfaces are the most significant heat absorber in buildings, thus thermal insulation of such roofs should be considered as a cost effective measure to reduce energy consumption. As a matter for priority based on yearly energy wise, for documented cases, insulation of such roofs could minimize required loads better than that of insulation of the walls. For other cases, roof pools can maintain 21°C average indoor temperature in a typical Brisbane winter, while the same building without roof ponds would have 17°C an average inside air temperature under similar weather conditions. The evaporative cooling is found to be one of the best techniques in order to reduce heat transfer from roofs, which leads to reaching thermal comfort inside buildings.
- Walls and Insulation; The optimum wall thickness of insulation ranges from 7 cm to 14.5 cm with an amount of energy savings between 6.6 - 16.0 LD/m^2. Polystyrene insulation type was recommended for Tripoli, Sabha, and Yefren, where the highest value in energy savings is found in Yefren.
- Materials; Appropriate building materials can minimize thermal discomfort and should be chosen according to their thermal properties. The adobe bricks thermal walls are considered the best natural material that can provide high thermal performance walls.
- Shading; Shading devices are important construction elements. They have an impact on protection of buildings from direct heat gain that reducing cooling loads.
- Ventilation; Residential courtyard performance leads to enhance indoor house conditions, and to meet social and environmental requirements of today's housing conditions taking the advantage of traditional architecture of Ghadames. Natural ventilation cooling without use of air conditioning inside the house during summer is recommended whereas natural ventilation has the most profound effect in the new urban area of Ghadames.
- Colors and glazing; Reflective window glazing provides a maximum energy saving for southwest orientation.
- Electricity; It is recommended to increase electricity bills encouraging people to consider thermal envelope insulation in their residential buildings.
- Case studies; "Ghadames" is one of the best examples of desert cities. There are many passive criteria that were considered in the design of its traditional buildings, such as selecting the right position and orientation, using central courtyard, large resistance walls, huge thermal masses, limited windows, and light colors for external surfaces. The traditional houses offer a better response to the demand for thermal comfort. The most traditional building materials are low in cost. They used an appropriate architectural design that could help achieve zero energy loads, where traditional dwellings consume about 66 % less energy than contemporary dwellings. In "Gharyan", the majority of readings for indoor temperature for the traditional single family houses are approximately constant during the day in summer and in winter. They are within the range for human comfort in this local zone.
- Computer software packages; Research techniques have adapted a number of computer commercial software packages. These are used to simulate, study, and analyze thermal behavior of buildings with different styles for various scenarios leading to determine heating and cooling loads even at early stages prior building implementation. Dealing with such packages gives the flexibility to deal with a wide range of sites, orientations, styles, materials, windows, shadings …etc. Results can be well presented. This leads to determine the appropriate description for the desired energy efficiency building. There are different available packages including TRNSYS, Energy Plus, and ANSYS.

8. REFERENCES

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