Passive Solar Design in Ecological Houses

Mohammad Borzooeian
Department of Architecture,
Eastern Mediterranean University,
Northern Cyprus

Abstract- **Passive solar architecture has been a significant criterion of achieving zero energy since 1979. Obviously there will be vast long-period benefits in the growth and development of inexhaustible, economical, and clean solar energy technologies, as the International Energy Agency said in 2011. The significance of the subject is related to global advantages and goals such as reducing pollution, developing sustainability, keeping fossil fuel prices low, increasing energy security, and increasing reliance on an in exhaustible and indigenous resource. Passive solar design generally means using sunlight and convert it into usable energy for heating (air, water, thermal mass), which leads to air-movement for ventilation or future use with only a little use of other energy sources. And on the other hand we have passive cooling which reduces summer cooling requirements using the same solar design principles. Some passive systems also use a small amount of energy for controlling devices such as dampers, fans, shutters, etc. in order to increase solar energy collection, storage, distribution, and use, and decline heat loss. This article reviews the basics and principles of ecological housing, passive solar concepts and three cases through doing document review. The purpose of the research is to find out how the solar concepts and principles are become feasible and practical.**

Index Terms **— Solar architecture; Ecological house; Energy efficiency**

I. Introduction

Considering *home* as a set of design characteristics and features is the solution to successful design. In this regard, it is necessary to consider a home as a set of components which work together efficiently in order to provide comfort and easement in all seasons and any time of the year. The required factors to have a comfortable and pleasant indoor environment are heat, coolness, fresh air, and sufficient light [1]. Overly, passive solar design means using sunlight to light the indoors and heat them without other electrical and mechanical systems [2]. In fact, buildings have a significant role in creating environmental problems because of exceeding consumption of natural resources and energy. However, it is possible to design a residential building to meet the residents' needs for thermal and visual comfort at low levels of energy consumption considering solar passive techniques for ventilation, heating, cooling and lighting. The solution is to use proper construction methods, low-energy materials, renewable energy systems and energy-efficient lighting. In brief, different factors of energy use can be balanced through designing energy-efficient buildings. It is possible to achieve energy efficiency in residential buildings by benefiting from favorable conditions, studying and analyzing the site and its macro and micro climate, and using bioclimatic architectural fundamentals to defeat the adverse conditions. The passive solar concepts which are focused in this article are; *passive heating*, *passive cooling*, and *daylighting*. To see how these concepts are applicable, one case is finally reviewed. But at the first step, it is significant to define the *ecological house* and some other criteria.

II. Ecological housing

One of the most significant features of an ecological house is compatibility with ecological limits and demographic patterns and lifestyles. It can be necessary for a positive development and sustainable future. On the other hand, as Moore et al [3] mentioned, energy issues are truly significant in many of countries. Considering the passing time, we see that many of the buildings we build today may be still in use in the distant future, while outstanding changes will have created a quite different environment. These changes may include climatic changes, population and natural resources. Thus, this kind of housing should be flexible and also adaptable to make us ready for such predictable and unpredictable changes. When we will face lack of resources, housing should be energy-efficient and able to meet its water needs, recovering materials from waste and even producing food. In the future, housing will probably be located near the public transportation facilities in order to reduce transportation costs and energy demands [4]. But the 'ecological house' should have four features; *adaptation to climate changes, affordability, carbon neutrality*, and *livability*.

Adaptation to climate changes

Basically a home is expected to provide the residents a refuge or shelter from the climate. This is the main reason we need this feature in our homes. When the climate changes concurrent with the passage of time, the home may not be able to resist such climatic changes and accordingly meet this need [5]. Thus, adaptation means being ready for facing adverse aspects of climate change to minimize the damage they may cause through anticipating solutions and taking appropriate actions [6]. For instance, in Australia the life of a timber home is estimated about 58 years. It is about 88 years for a brick home [7]. Many of buildings last even much longer than this. Therefore, today's decisions will obviously have consequences in the future [5].

Affordability

Affordability has always been a significant issue in housing. It generally refers to any kind of housing that has an affordable rent or sale price for household. These costs contain tax, insurance, repair, maintenance and etc. When we intend to achieve a sustainable design, it may increase the capital cost of the building while the saved amounts of money from decreased energy bills balance extra mortgage payments [8].

ISSN 2201-2796

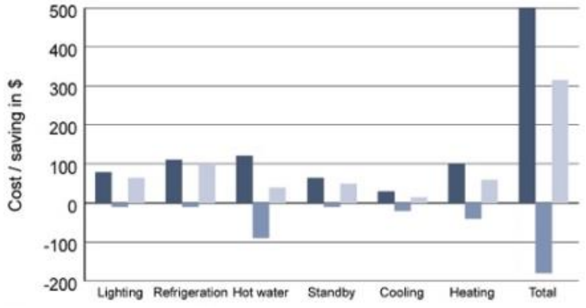

Chart 1. Annual saving in energy bills Annualized increase in capital costs Net annualized savings
Remarkable cost effective savings is indicated in the net annualized savings [9]

For instance, affordability over the life span of the residential building can be increased through water saving and energy improvements. The capital costs and resultant savings of energy saving improvements of an existing home are presented in Chart 1. It is indicated that annual net savings has exceeded $300 in this case, although the primary cost of improvements had been significant [9].

Carbon neutrality

There are many daily activities that emit different amounts of carbon into the atmosphere. If we look for long-term effective sustainable solutions to climatic changes and increasing global warming, then it is necessary to decrease or eliminate this amount of carbon emitted from these activities. It is possible through building carbon positive or carbon zero homes. As defined by the Australian Sustainable Built Environment Council (ASBEC), a carbon-zero building has no emissions from direct fuel combustion and also electricity use from operation of building integrated systems In other words, in a carbon neutral home overall CO^2 emissions are equal to overall CO^2 reductions [10]. While a carbon positive home goes beyond this. In a carbon positive home the produced energy is even more than the building's requirements. These buildings have additional positive contributions environmentally on the site. These buildings also have a significant role in positively affecting global warming in the future, while carbon zero homes can be best practices of today [11].

Livability

People usually expect a new home to be a place to live in for many years or decades. In addition to residents, home hosts many changing needs during its lifetime. Thus, we can describe 'livability' as the ability of home in responding to changing needs and lifestyles without the need to change or modify the existing structure or services, in other words, without costing a lot. A livable and adaptable home has the possibility to be divided into two smaller housing units [12]. The Fig. 1 shows an example of the adaptability of floor plans.

There are four features considered in designing livable homes; *easy entrance, ease of access inside and around, cost-effective adaptation,* and *being responsive to the changing needs of residents*. The livable design brings ease of access, safety and comfort [13].

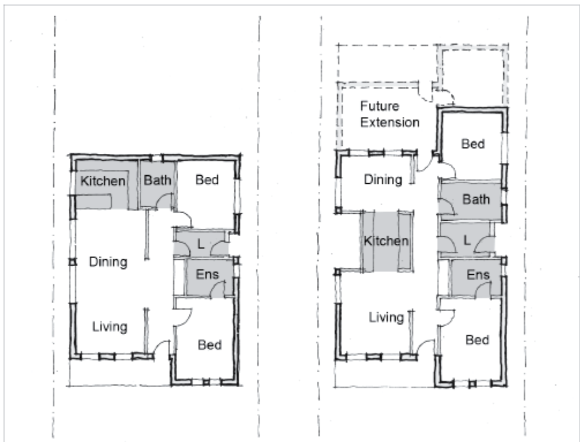

Fig. 1. Adaptable floor plans [12]

III. PASSIVE SOLAR ARCHITECTURE CONCEPTS

Passive solar design includes designing walls, windows, and floors to collect and store heat in winter and reject it in summer. Unlike active solar systems, this system does not involve other mechanical and electrical systems [14]. The passive solar systems as mentioned before use the sun's energy for heating and cooling. All passive solar homes have three components; *Collection*, *storage*, and *distribution* [15].

.*Collection* – It means collecting solar energy using south-facing double-glazed windows.

Storage – After absorption and collection of the sun's energy, some heat is stored and some is immediately used in interior living spaces. Therefore, this storage which helps to save this energy is called *thermal mass*. The thermal mass is explained in the section 3.1.3.

Distribution – The release of the heat stored in thermal mass is called distribution.

According to Architectural Energy Corporation (AEC), passive solar concepts for heating (H) include; *direct solar gain, indirect solar gain,* and *isolated solar gain,* for cooling (C) include; *natural ventilation* and *night mechanical ventilation*, and for lighting (L) include; *sidelighting, toplighting* and *core daylighting.* The letters (H), (C), and (L) here stand for each passive solar system concept; heating, cooling, and lighting [16].

Direct solar gain (H)

The simplest passive design technique is direct gain. Sunlight enters the home from the windows. The masonry walls and floors then absorb and store the heat and yield it into the room at night as indicated in Fig. 2.

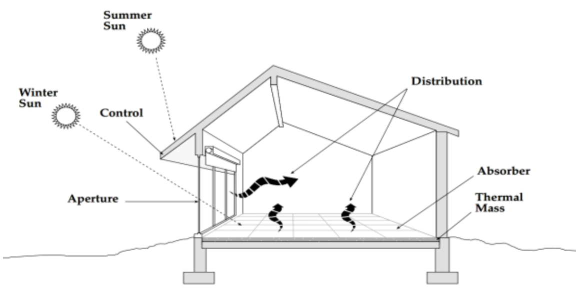

Fig. 2. Direct gain [14]

There are two kinds of direct gain; *direct gain without storage (DG)*, and *direct gain plus storage (D+S)*. In *a direct gain without storage* no extra interior mass is included in the building, as shown in Fig. 3.

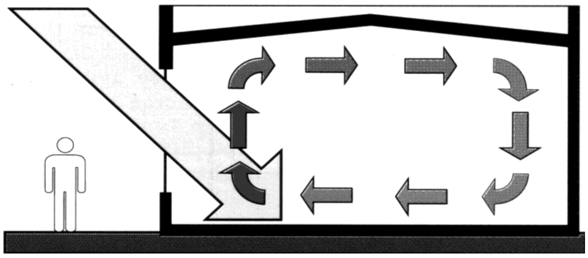

Fig. 3. Direct gain without storage (DG) [16]

But in *a direct gain plus storage* we can see additional internal mass which is used to extend the storage capacity to about eight hours as shown in the following figure.

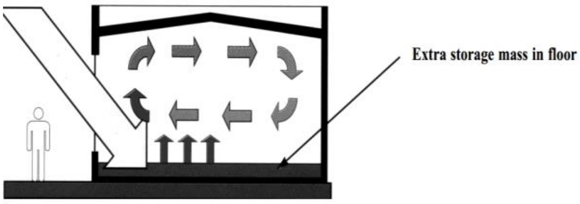

Fig. 4. Direct gain plus storage (D+S) [16]

There are five elements which should work together to complete the passive solar system, although each of these elements performs separately. These elements are; *aperture (collector), absorber, thermal mass, distribution, control* as described by National Renewable Energy Laboratory [14].

Aperture (Collector) – It includes windows and skylights which let the sunlight in. The aperture should take sunlight between 9 a.m. and 3 p.m. and not be shaded by barriers such as trees or other buildings.

Absorber – The absorber is the dark (usually black) color surface of the storage element. It should directly receive sunlight in order to absorb its heat.

Thermal mass – Thermal mass is the material which stores the heat from sunlight. This part refers to the material behind the absorber surface.

Distribution – Distribution is the method of heat circulation from storage parts to indoor spaces and all areas of the house. The heat can be distributed through conduction, convection, and radiation. In some cases, fans or ducts may also be used for distribution.

Control – It includes controller systems such as shaders or roof overhangs, electronic sensing devices such as thermostats or operable vents and etc.

Indirect solar gain (H)

This system uses a space between the living spaces and (south-facing) windows as thermal storage. In this system, the heat stored in the thermal mass is slowly distributed and indirectly transmitted to the spaces through conduction and convection. The Building Science Department of the University of Southern California introduces three indirect gain systems which are described here; *roof pond*, *water wall*, and *trombe wall* [15].

Roof pond

In this system the storage mass is located into the roof to radiant heat to the indoor spaces. There is a body of water located in the roof. This part is protected by exterior movable insulation and absorbs and stores the heat directly gained from sunlight. The thermal storage which is the ceiling of the building radiates same low-temperature heat to the spaces in both cloudy and sunny conditions. This kind of distribution of heat is by radiation only. Since radiation density declines with distance, the distance between the ceiling and the individuals being warmth is also important as shown in Figs. 5 and 6.

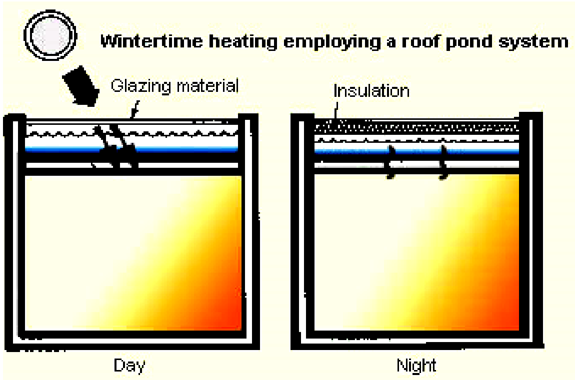

Fig. 5. This system can also be used where there are day-light temperature swings [15]

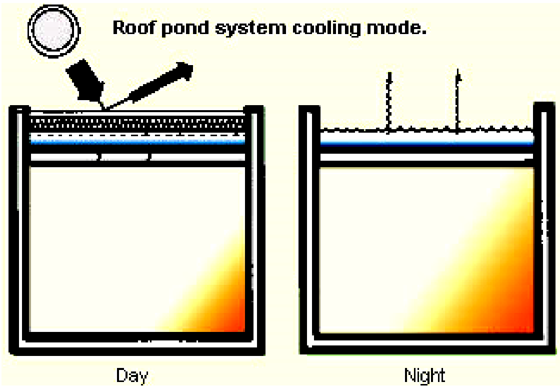

Fig. 6. It is possible to make man-made or natural ponds in this system through creating a salt-concentration gradient [15]

Water wall

Water wall is the second important indirect gain system in this group. In this system the collector glazing intercepts the sun's rays by a water storage mass. The heat then will be distributed to the indoors by radiation and convection (Fig. 7).

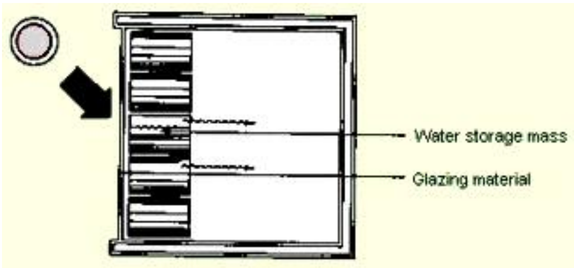

Fig. 7. This system also needs a glazed area and adjoining heat storage. The storage here can be water or another liquid. Faster heat distribution can be achieved through designing smaller container volumes, while longer-term and greater heat storage capacity can be provided by larger storage volumes [15]

Trombe wall

The third indirect gain solar system is Trombe wall (Fig. 8). In this system there is a masonry or concrete wall which serves as heat storage. the sun`s rays are intercepted in the air space of 4-8 inches between the collector glazing and this wall. The mass absorbs heat during the day and releases the warmth to the indoors during the night hours. In order not to lose the heat during the evening and night hours, it is necessary for the glazing to have exterior shutters for nighttime use.

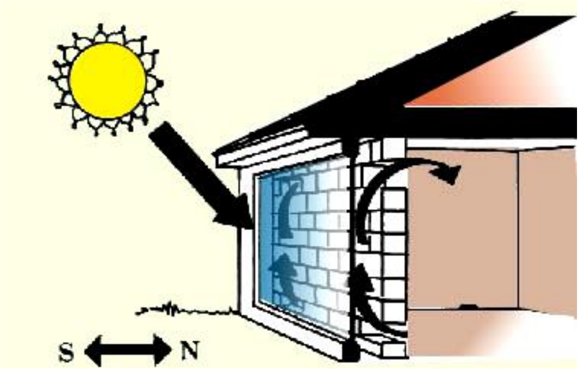

Fig. 8. Trombe wall system [15]

Isolated solar gain (H)

In the isolated-gain systems the living areas of the building are thermally separated and isolated from solar collection and storage and this is contrasted with the direct gain systems where the living spaces are inseparable and integral with collection and storage. It is also contrasted with the indirect gain concept where the living areas are separate from collection and storage but directly linked thermally. Thus, in this system the collector and storage can function independently and apart from the building. Therefore, the distinct point of this type of system is the possibility of isolating the system from the main living areas as shown in Fig. 9.

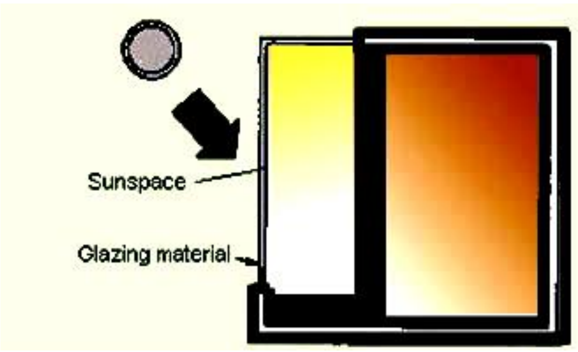

Fig. 9. Isolated-gain system [15]

Natural ventilation (C)

To decrease the use of mechanical cooling, it is possible to rely on the natural breezes and airflow. It simply occurs by opening the windows when the outside air temperature is lower than inside. This is an effective and useful strategy in spring and autumn, and also a no-cost change or conversion in building design. See Fig. 10.

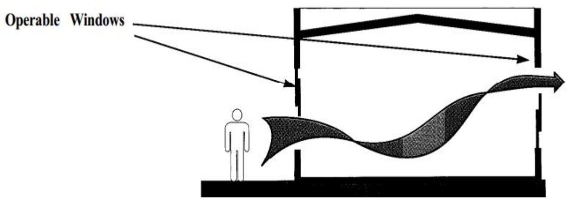

Fig. 10. Natural ventilation [16]

Night mechanical ventilation (C)

This system uses the low-temperature night air to cool the building's internal mass. The cool night air is distributed throughout the building using fans and ducts as shown in Fig. 11.

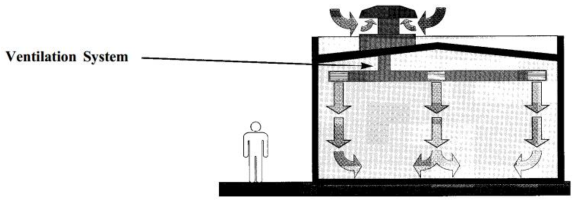

Fig. 11. Night mechanical ventilation [16]

Daylighting (L)

It is significant to use natural in lighting design as a supplement for electric lighting. The main different between traditional daylighting systems and passive heating systems is the source of light. In daylighting systems the source of light is sky, while in passive heating systems direct sunlight is needed. Thus, daylighting systems do not let the sunlight into the building. But according to the kind of collection system, daylighting systems are categorized in three main types; *sidelighting, toplighting* and *core daylighting.*

The better use of daylight can lead to more reduction in electricity consumption for lighting.

Sidelighting

In housing design, windows are the main elements to illuminate the interior spaces as a sidelighting system (Fig. 12). But the layout and combination of interior furnishings, walls and other elements may decrease the depth of daylight penetration. The daylight penetration into the building is somehow limited to 30 feet. Thus, there might be need other types of daylighting. It is also possible to control the glare by using operable blinds.

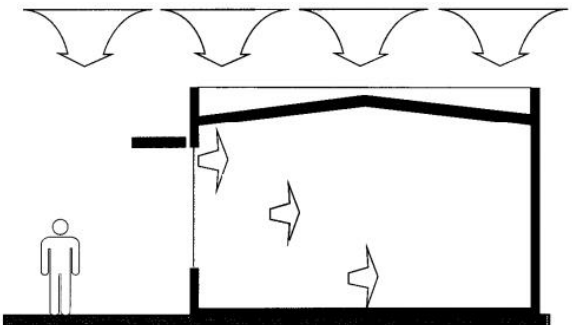

Fig. 12. Sidelighting [16]

Toplighting

These systems let the light into the spaces through the roofs. Toplighting is mostly proper for one-story buildings.

There are three types of this system; *skylights*, *monitor apertures*, and *sawtooth apertures*. But among these three types of toplighting system, skylights are more functional for residential buildings. Fig. 13 illustrates a skylight.

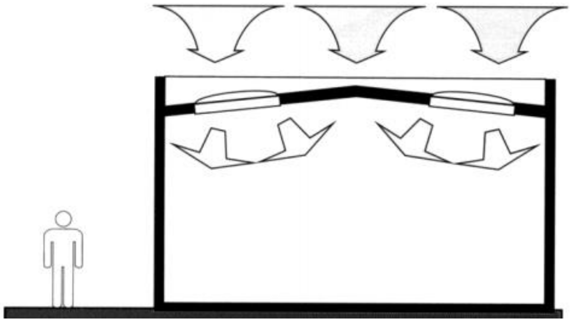

Fig. 13. Skylight [16]

Core daylighting

In this system, atriums are the main elements. This system is also appropriate for multistory residential buildings and since the center of the building is always the most difficult point to daylight, its best location can be above the building core. The core daylighting can work as a supplement to the sidelighting system. See Fig. 14.

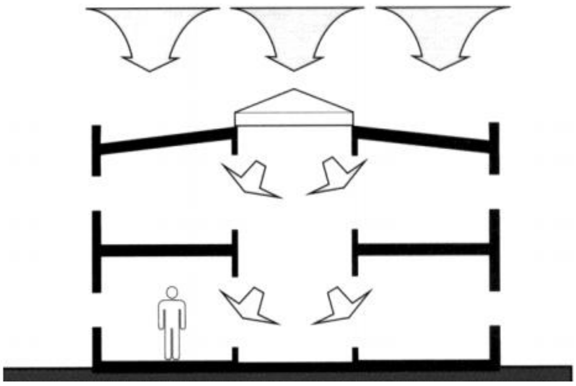

Fig. 14. Skylight [16]

IV. CASE STUDIES

In this section I tried to provide a few cases which demonstrate the best-practice eco design for homes across different climate zones.

Case #1

This case is designed and built by Jigsaw Housing in Curtin, Australian Capital Territory. See Fig. 15. The area has a cool temperate weather. The weather in this area can fall below zero in winter, while it is usually warm and dry in summer. The size of land is 825m² and the area of the house is 228m². It costs $296,000 plus an additional $15,000 professional fee. This house is the outcome of a renovation project and transformed into a family-friendly, comfortable and livable place which is now more responsive to the environment. This house can be a good example of ecological house. It has a proper access to public transport and bike paths. The house is designed to be warm in winter, use passive heating and take good advantage of natural light. The owners have also wanted the upper story able to become a separate rental unit for the future.

The owner has replaced the old electric hot water service with a solar hot water system. The main focus in this case has been to reduce heating and cooling costs in order to improve its energy efficiency.

It has been possible to maximize natural lighting by using sidelighting system and because of good window design and location of the case. It can cause reduction in electricity consumption.

Fig. 15. Case study, (Photo by Jeremy Rozdarz, Jigsaw Housing)

For maximizing the energy efficiency and assisting natural cross-ventilation, double-glazed windows and doors with flexible opening mechanisms are installed in the northern side. The doors and windows are made of a material with proper insulation similar to timber, lead-free uPVC. But the Canberra’s cold winters do not make it possible to just rely on passive systems. Therefore, it is required to use a form of active heating which is an energy efficient hydronic heating system in this case. The system utilizes radiator panels and a gas-fired boiler [17].

In some parts of the building, bricks are removed and replaced with reconstituted timber weatherboards as cladding. Insulation is a necessity to keep the indoors warm in winter and cool in summer. In an area with such a cool temperature, reducing heat loss is the main priority of insulation. The walls have been insulated with recycled polystyrene. Polyester batts have been used for insulating timber floors and wool cell insulation for ceilings.

As for lighting, energy-efficient LED lights are used with a creative design as shown in Fig. 16.

With the annual rainfall of over 600mm, capturing and using rainfall in the home and garden is one beneficial and significant consideration.

Fig. 16. Energy-efficient LED lights, (Photo by Jeremy Rozdarz, Jigsaw Housing)

As mentioned before, the owners had wanted to upper story separable. In this renovation project they have reached this. Situating the staircase in one side provides this possibility to separate the upper story as a rental unit in the future.

As a final assessment, this house is now much brighter and environmental-friendly. The Alternative Technology Association has reported a great reduction in electricity consumption. It is now more livable and adaptable. The house also has a balanced thermal efficiency [17].

Case #2

This case is located in Tlemcen (Western Algeria). The architectural zoning of the plans and their good direction help the house to collect more solar radiation. This case has been an effort to consider the principles of bioclimatic architecture, which are necessary for the ecological design (Fig. 17).

The external walls include 30cm framework wood and also a layer of cellulose wadding. Double glazing and good air tightness is also considered for external doors and windows. The criteria and principles of energy saving are mainly considered in the current design, such as insulation and use of solar energy. It can be said that the energy consumption depends on the interior temperatures and heat loss occurs because of the temperature differences of indoor and outdoor. The way of controlling the indoor environment and temperature is also influential. Generally, when there is comfort in the interior environment, the construction can be considered successful. In fact, thermal comfort is one of the most significant needs in residential environments [18]. However, it is proven that the residents' perceptions of the quality of the indoors can affect their thermal comfort [19, 20]. Consequently, discomfort may cause increase in energy loss or consumption. A comparative study has been done between this case and a conventional house for heating and electricity during one year. See Chart 2.

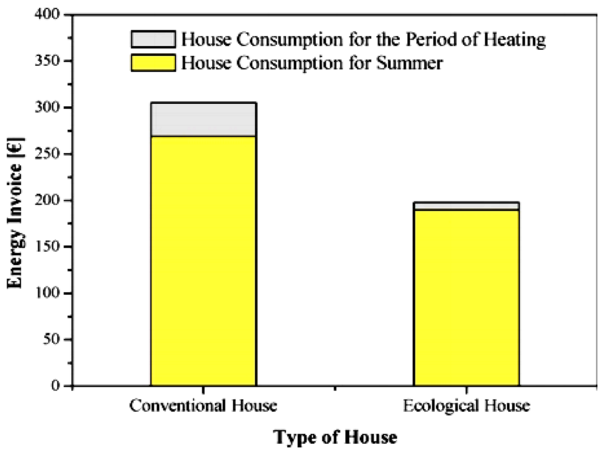

Chart 2. Consumption comparison for electricity and heating during one year [18]

Chart 2 shows that the energy bill for the ecological house is about 200€ annually, while that of a conventional house is about 300€. This economic assessment between these two cases demonstrates a clear distinguish.

Fig. 17. Case #2 [18]

The assessment shows a deep difference in CO_2 emission of a conventional house and this case study. CO_2 emission is distinctly greater in a conventional house. The material of insulation has an important role at this point. It can lead to reduction in consumption of heating and air-conditioning. Applying a good thermal protection declines the need to heating which can make a separate heating system unnecessary. Finally, we see an overall reduction of economic cost, consumption, environmental impacts, and the potential of total warming and exhaustion. Therefore, this ecological house can be a reliable and effective solution in Mediterranean climate to improve the environmental performances and energy of the residential environments compared to the Algerian lawful context. According to this study, it is deduced that building an ecological house costs 15% more than a conventional house, although it will lead to profitability at the end of 10 years [18].

Case #3

This case is located in Summerfield, a residential suburb near Birmingham. A lot of social and environmental improvements have occurred during the last few years in this area. The eco-neighborhood project which is a large renewable energy project in UK is initiated in the area. There are 329 homes in the area which are improved by installing solar panels. This can cause a great reduction in the fuel bills by more than £150 annually. The system is estimated to provide 60 per cent of each houses' hot water per year. It has also been an effort to use other innovative technologies to make the building as green as possible, such as installation of grey water recycling and air source heat pumps, solar photovoltaic panels, powerful insulation made from recycled paper, and use of recycled materials for the kitchen, water saving devices, and low energy lighting. This project is used as a learning tool to inform future regeneration programs and investment strategies for further development. This is one important aspect regarding this case is that the scheme has grown and developed from a single house remodeling, to a neighborhood wide program (Fig. 18).

Fig. 18. Birmingham's First Eco-Neighborhood, (Photo by Urban Archive)

This case is equipped with cutting edge green technologies to demonstrate the developers' determination in developing Birmingham's first Eco Neighborhood and testing new technologies in order to push the boundaries. The house has met the residents' needs and made them satisfied through demonstrating minimum pollution, high energy preservation, using sustainable materials, water conservation, transport and land-use. Fitted with such environmentally friendly specifications, this house caused the Department of Communities and Local Government (DCLG) lots of successes and achievements. The Sheffield Hallam University also confirmed the success of this project through an independent evaluation in 2008. The energy and fuel bill savings for five eco-houses are estimated about £1,084 annually which means a 35% saving [21].

V. Conclusion

Significant elements in energy-efficient housing design begin from appropriate placement of room-types, internal walls and equipment. The orientation of the building and extending its dimensions along the east/west axis, and considering appropriate size for windows to take advantage from sunlight in winter and be shaded during summer are other significant aspects of design. Minimizing windows size on eastern and western sides of the building is also significantly effective. Use of roof overhangs or other shading elements such as trees, fences, shutters, etc. can also be effective and useful. From other elements can mention to proper types and amounts of insulation for minimizing seasonal heat gain or loss, and also using thermal mass to store solar energy during winter days. These were significant elements which should be considered in housing design to gain a good solar architecture and energy-efficiency as an important issue today.

To build and construct ecologically is therefore a beneficial operation which is more, one question of choice that means, and who returns within the framework of sustainable development [18].

Acknowledgements

The author would like to thank Dr. Harun Sevinç for his taught course, *Solar Architecture*, at the Eastern Mediterranean University.

References

[1] Chiras, DD. (2002). The solar house: passive heating and cooling. Retrieved from http://www.chelseagreen.com/bookstore/item/the_solar_house:paperback (accessed 15,05,2014)

[2] Chalom, M. (1993). Passive solar design. Retrieved from http://www.nmsea.org/Passive_Solar/Passive_Solar_Design.htm (accessed 05,05,2014)

[3] Moore, T, Morrissey, J and Horne, R. 2010. Cost benefit pathways to zero emission housing: implications for household cash-flows in Melbourne. Centre for Design RMIT, Melbourne.

[4] McGee, C. (2013). Housing of the future. Retrieved from http://www.yourhome.gov.au/housing-future (accessed 15,05,2014)

[5] Department of Climate Change and Energy Efficiency (DCCEE). (2013). Adapting to climate change. Retrieved from http://www.yourhome.gov.au/housing/adapting-climate-change (accessed 01, 05, 2014)

[6] European Commission. (2014). Adaptation to climate change. Retrieved from http://ec.europa.eu/clima/policies/adaptation/index_en.htm#top-page (accessed 15, 04, 2014)

[7] Snow, M and Prasad, D. (2011). Climate change adaptation for building designers: an introduction. Environment design guide, EDG 66 MSa. Retrieved from http://www.environmentdesignguide.com.au(accessed 05,05,2014)

[8] Gabriel, M, Jacobs, K, Arthurson, K, Burke, T and Yates, J. (2005). Conceptualising and measuring the housing affordability problem. Australian Housing and Urban Research Institute National Research Venture 3: Housing Affordability for Lower Income Australians, Research Paper 1. Melbourne.

[9] Australian Conservation Foundation (ACF), Australian Council of Social Service (ACOSS) and Choice. (2008). Energy and equity preparing households for climate change: efficiency, equity, immediacy. Retrieved from http://www.acoss.org.au (accessed 15,04,2014)

[10] Riedy, C., Lederwasch, A., and Ison, N. (2011). Defining zero emission buildings — review and recommendations: final report. Australian Sustainable Built Environment Council. Retrieved from http://www.asbec.asn.au (accessed 01,05,2014)

[11] Reardon, C. (2013). Carbon zero, carbon positive. Retrieved from http://www.yourhome.gov.au/housing/carbon-zero-carbon-positive (accessed 01,05,2014)

[12] Palmer, J. (2013). The livable and adaptable house. Retrieved from http://www.yourhome.gov.au/housing/livable-and-adaptable-house (accessed 15,04,2014)

[13] Livable Housing Australia. (2012). Design guidelines, 2nd edn. LHA, Sydney. Retrieved from http://livablehousingaustralia.org.au./ (accessed 01,05,2014)

[14] National Renewable Energy Laboratory (NREL). (2001). Passive solar design for the home. Retrieved from http://www.nrel.gov/docs/fy01osti/28751.pdf (accessed 15,04,2014)

[15] Schiler, M., Tripathi, A. and Brahmbhatt, S. (2014). Indirect gain systems. Retrieved from http://www.usc.edu/dept-00/dept/architecture/mbs/tools/thermal/controls_passolar_ind.html (accessed 01,05,2014)

[16] Architectural Energy Corporation (AEC). (2007). Passive Solar Handbook: Introduction to Passive Solar Concepts. Retrieved from http://wbdg.org/ccb/AF/AFH/pshbk_v1.pdf (accessed 15,04,2014)

[17] Alternative Technology Association (ATA), (2013). Curtin, Australian Capital Territory. Retrieved from

http://www.yourhome.gov.au/case-studies/curtin-australian-capital-territory (accessed 01,05,2014)

[18] Boukli Hacene, M. A. and Chabane Sari, N. E. (2011). The various aspects of an ecological house, Environmental Progress & Sustainable Energy, 32(1), 109-114

[19] Humphreys, M.A., and Nicol, J.F. (2002). The validity of ISO-PMV for predicting comfort votes in every day thermal environments, Energy and Buildings, 34, 667–684

[20] McCartney, K.J., & Humphreys, M.A. (2002). Thermal comfort and productivity. In H.Levin (Ed.), Proceedings of the 9th

[21] International Conference on Indoor Air, 1, 822–827, Indoor Air: Santa Cruz

[22] Family Housing Association (FHA). (2012). Summerfield eco-housing. Retrieved from http://www.family-housing.co.uk/Eco+Projects/ (accessed 06,06,2014)