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A Holistic Approach of Energy Efficient Building Design. Case Study: A Housing Design Proposal in Seferihisar, İzmir, Turkey

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A B S T R A C T

As one of the developing countries in the world, Turkey has significant potential of solar, wind and geothermal energies. Besides, residential areas have primary importance in terms of energy requirements in Turkey since 29.6% of end-use energy is used by the residential sector. The aim of this paper was to set a link between theory and practice in terms of energy efficient building design. First, energy efficient environmental and building design principles were reviewed in the current literature. Afterwards, a holistic design approach beginning with site selection and extending to building design principles, which combines energy efficiency and sustainable principles of *"conservation of resources", "life cycle design" and "design for human"* were proposed. In the second stage, a practical housing design model for Seferihisar was developed following predetermined passive and active energy efficient design principles. Energy efficient design principles, integration of active energy resources into design model were considered and these technical instruments that regenerate energy have been interpreted as architectural artefacts during the design process.

1. INTRODUCTION

Air pollution and increase in greenhouse gases are the major environmental problems that threaten the sustainability of the ecosystems in the world. Meeting energy need with fossil fuel is the main issue that causes environmental problems. While fossil resources have been consumed quickly, the energy needs have increased beginning with the industrial revolution [1], [2]. A considerable amount of energy needs derive from building design facilities since about half of the consumed energy in the world is devoted to buildings. Therefore, the major concern of ecological and sustainable architecture, the *"energy efficient building design"* constitutes an important issue at the global level.

Turkey is one of the countries that have most significant renewable energy sources, such as solar energy, wind energy, bio energy, geothermal and hydro power energies in the world. Although Turkey has rich renewable energy sources, it is heavily dependent on the imported energy resources that place a big burden on the economy. Roughly, in 2005, three-quarters of energy need was met through imports. The building sector requires an important part of the total energy needs and constitutes approximately 25% of the total energy consumption, which includes transportation, building, industry and agriculture sectors. Residential sector has primary importance in the energy consumption of Turkey, because 29.6% of end-use energy was used by residential sector in 2007 [3]. Building design has a direct impact especially on the conservation of energy. Sustainable and ecological building design, which is the base of energy efficient design, is a new approach and begins to find a place in the agenda of modern Turkish architecture especially in the last two decades. There are limited researches that focused on the issue of sustainability in modern Turkish architecture. While some current researches investigated urban sustainability [4], others evaluated traditional Turkish architecture in terms of sustainable and ecological design issues [5].

In the international arena, a growing body of literature on energy efficient housing design has been conducted in recent years. The interactions among vegetation, microclimate, urban environment, building and energy efficient design have previously been researched by many authors [6], [7], [8], [9]. One of the research evaluated the relationships between urban built form and two conventional forms and the one proposed energy efficient form under selected climatic conditions [10] and another discussed the effects of urban design parameters of street width and orientation and building design parameters of roof shape and building envelope design on solar access and solar heating strategies in residential buildings [11]. Some researchers have concentrated on both specific passive urban and architectural design strategies in relation to energy efficiency [12], [13], [14], while others developed design models and design optimization studies with simulation programs in specific regions especially regarding passive design strategies and active solar systems [15], [16], [17].

In accordance with the above stated issues, a holistic and integrated energy efficient design approach including both urban and architectural parameters along with passive and active energy efficient principles as a design guideline was determined as an important requirement especially for housing sector that constitutes a highly important portion of the current building stock and of energy consumption. Moreover, there is no case study that developed an energy efficient housing design model in case of Turkey and Izmir. The aim of this paper is to propose both a holistic and integrated design approach addressing energy efficiency and a housing design model as a pilot study for Izmir following the proposed design approach and its related guidelines. Therefore, the first energy efficient design principles were researched by literature review and then a housing design model was developed for Izmir, which is the third largest and one of the richest cities in terms of renewable energy sources in Turkey.

2. ENERGY EFFICIENT BUILDING DESIGN PRINCIPLES

The Brundtland report defined sustainable development as *"...meeting the needs of the present without compromising the ability of future generations to meet their needs"* [18]. Based on the main argument of sustainable development, sustainable architecture means to create qualified and liveable environment for humans aiming for the sustainability of economy, socio-cultural values and physical environment. Ecological architecture is mostly defined as the approach of sustainable architecture with special consideration to the impact of design and buildings on the environment. Ecological architecture aims to create and sustain beneficial relationships with all the local ecological system components, including conservation of resources in relation to energy efficient design [19]. Therefore, energy efficient design strategies should be evaluated within the context of this holistic perspective that does not contradict with sustainable and ecological concerns.

Many researchers tried to explain the fundamental principles of sustainable architecture. Kim and Rigdon (1998) have stated three basic principles: economy of resources, life cycle design and design for human. Economy of resources is concerned with the reduction, reuse and recycling of the natural resources. Life Cycle design, which is a widely accepted method to assess environmental impact, provides a methodology for analyzing the building process and its impact on the environment. Human design focuses on the interactions between humans and surrounding natural and built environment [20].

Miyatake (1996) has stated six principles for sustainable design. These are to minimise resource consumption, to maximise resource reuse, use of renewable and recyclable energy sources, protect the natural environment, create a healthy and nontoxic environment, and pursue quality in creating the built environment [21]. Following the above statements, the general principles of our energy efficient design have been classified under the headings of resource economy, life cycle assessment through design process and design for human addressing sustainability issues. The energy efficient principles were discussed within this framework that structures the theoretical base of energy efficient building design.

2.1. Resource economy

The principle of *"Resource Economy"* aims to sustain efficient use of all resources of the ecosystem including energy and natural sources. The efficient use of energy aims to minimize the energy consumption along the entire building life cycle, and to use energy sources efficiently. For an efficient use of energy, energy conservation and energy production are the main concerns that should be taken into consideration during the design process. The important factors stated in the literature in relation to energy efficiency can be summarized in three categories, namely environmental factors, building design factors and integration of energy producing systems. Whilst the first and second factors are related to energy conservation, the third one is related to energy production.

Environmental factors that should be taken into consideration for energy efficiency can be defined as efficient site planning and efficient use of environmental resources such as topographical structure of land, climatic conditions, vegetation and landscape design, etc. [22].

Building design factors are related to design of the building such as orientation, space organization, form, massing, window ratio, building envelope, structure, materials and equipments [23]. Integration of energy generating systems is related to both active and passive systems including the use of renewable energy sources such as sun, wind, geothermal, water and biomass, as it is described in various researches [24].

The efficient use of natural resources means conservation of water, soil and living habitat in the ecosystem. Water has been used for different purposes in buildings, such as for drinking, daily use, cleaning and watering the plants. The efficient use of water provides energy and resource conservation by decreasing consumed and waste water. The main principles that should be taken into consideration during design process for water conservation extend from selecting water saving equipments to the reuse of rain water, from waste water recycling to landscape design that helps water conservation. While supporting energy efficiency, protection of soil, air and the living habitat, and the optimization of relationships among buildings, humans and nature should be a stronger presence in the agenda of energy efficient architecture, in support of a sustainable, healthier society and environment.

2.2. Life cycle assessment through design process

Life cycle assessment (LCA) is a tool that is broadly used in practice to assess the environmental impacts and resources throughout a product's life cycle from raw material acquisition to waste management [25]. In traditional approach, building life is defined by a linear process including four phases, namely design, construction, using-maintenance and destruction. Conservation of the resources and the environmental impact of buildings are ignored in this approach. Life cycle assessment has three phases, as follows: preconstruction, construction, and post construction, and has no beginning and ending points. LCA has a cycling process starting from raw material equation to its processing, marketing, transportation, construction, maintenance, recycle and raw material state [26]. LCA has widely been used as a tool to assess energy consumption of buildings [27] and the role of construction materials on global warming [28]. LCA should be used as a tool for energy efficient design process including the selection of the project appropriate site, related urban and spatial planning process, building design decisions related to the form, materials and building systems etc. LCA shall support the process of energy efficient design by highlighting solutions to conserve resources, and by evaluating the environmental impact of energy friendly buildings. Regarding resource conservation, the efficient use of energy through life process of buildings is mainly related to the pre-construction, construction and post construction stages. LCA in preconstruction stage requires the selection of appropriate construction site and following rules of energy efficient design and choosing low embodied building materials and structural systems. In the construction stage, the energy used for construction, operational expenses, use and maintenance costs should be important concerns for energy efficient design. Besides, the design provisions regarding energy reusing, recycling and the cost of destruction should be regarded in post construction stage. Generally, to achieve energy efficiency in building design, consideration should be given to life cycle assessment through design process including low embodied energy of the selected systems, equipments and materials, waste management, disassembling and recycling operations.

2.3. Design for human

Human comfort can be broadly defined as the building occupants' satisfaction with the physical environment of designed buildings. It is essential for a designer to understand which design parameters can enhance human health and wellbeing. There is a connection between physical and psychological health of human. Both physical and psychological satisfaction of building occupants and improved indoor environmental quality, occupant comfort, satisfaction, health, living quality and working performance should be considered in energy efficient building design [29].

The primary function of building is to provide a suitable inner environment according to the building functions. Energy efficient buildings that regard only installation of renewable energy sources and conservation of energy and neglect requirements of building occupants would affect both physical and psychological health of building occupants [30]. Construction technology, spatial planning, orientation of buildings, thermal insulation, moisture control, window proportion, natural ventilation and sun shading precautions etc. are all important parameters for the thermal comfort of building users, that should be considered in the energy efficient design process. Additionally, ergonomic design that meet users' requirements, for instance the access to natural environment and view, accessibility for handicapped people, safety and security precautions, using nontoxic materials, aesthetic pleasantness and sense of beauty in the designed environment are all important concerns of the principle of design for human use facilities.

3. THEORY AND METHODOLOGY

3.1. Towards a holistic design approach by addressing energy efficiency

There are two major approaches in sustainability, majorly covering energy efficiency; one of them is Top-Down approach that aims at developing policies, strategies and standards while the other is Bottom-Up approach that aims at building public and professional awareness about sustainability. The main inefficiency in these efforts is that they are not really articulated. Furthermore, design guidelines are generally rough, quantitative, and generic and do not address specific building type and application process [31]. Besides, since good design can decrease a considerable amount of energy consumptions and CO_2 emissions of dwellings, it is very important to develop a comprehensive holistic energy efficient approach for housing to develop green, clean, safe and sustainable settlements [32]. Based on the above statements, a holistic energy efficient design approach was proposed, which develops a multi-dimensional structure of sustainable design with energy efficiency and use of renewable energy sources. Thus, the integration of passive design strategies with hybrid active energy generating systems was provided along with the conservation of natural and ecological resources in our design approach. Since the multi-use of renewable energy systems meets the energy needs regardless of seasonal differences, the installation of various kinds of renewable resources that corresponds to seasonal differences achieves more energy efficient solutions especially in countries that have rich renewable energy sources like Turkey. Design principles were grouped under three main headings of resource economy, life cycle design and design for human, considering the multi-dimensional structure of sustainable design, which means environmental, economic and social aspects. Specific design principles were described under the sub-headings in which they were mostly related (Fig. 1). Strategies for designing a sustainable and energy efficient building vary according to the regions' cultural, geographical, climatic and economic characteristics. There is no standardised approach to the energy efficient design, however, this framework providing general design strategies for the building designers to follow in the process of energy efficient building design, and can be adapted to the climatic and regional specific features.

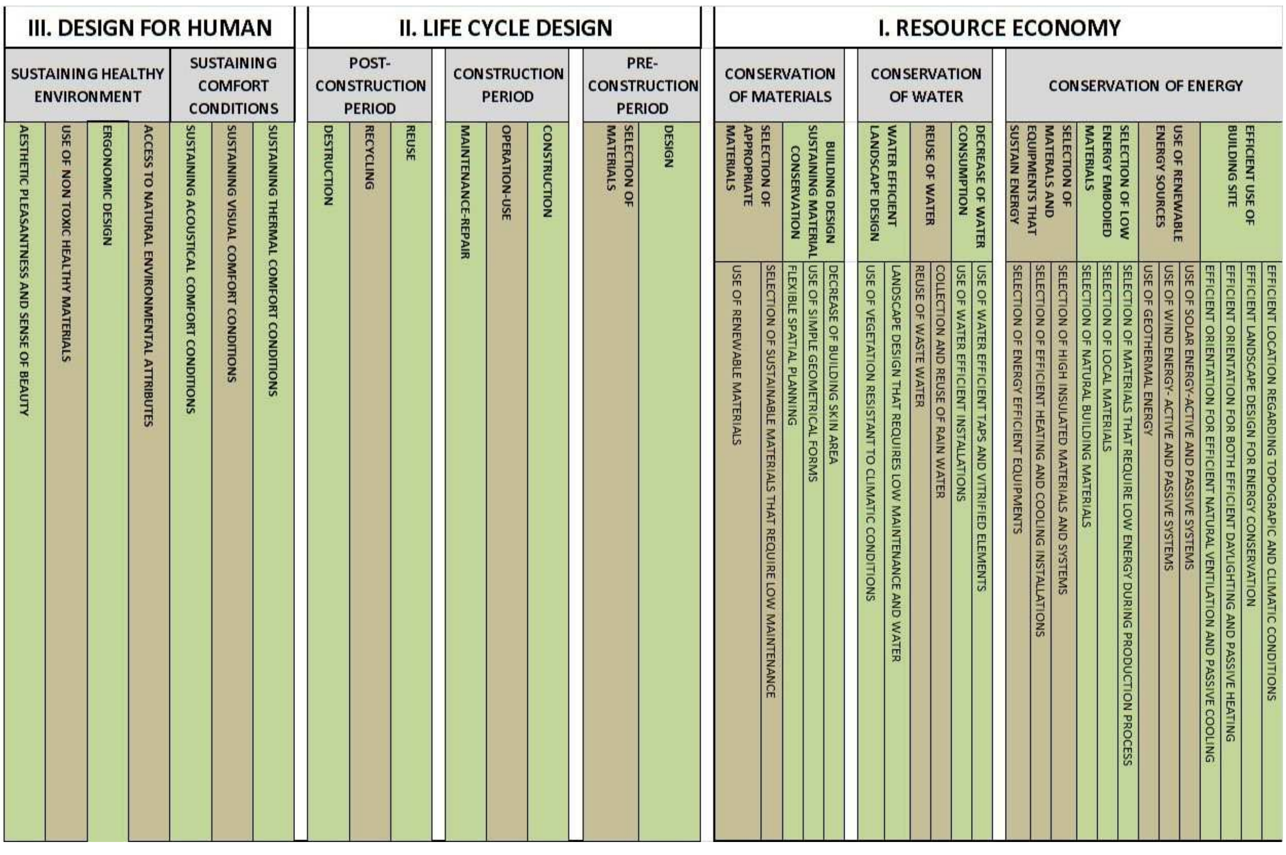

Fig. 1. Energy efficient design principles.

3.2. Case study

3.2.1. Selection of the project area

The method for the selection of project area was developed based on the principle of life cycle assessment through design process for efficient installation of renewable energy sources. Design approach of our case study integrates the multiple use of energy generating systems along with passive energy conservation strategies into the building design. Therefore, choosing a region where various types of renewable energy sources are available was important for developing the energy efficient housing model.

The method used for the project area's selection was developed in our preliminary research which offered a systematic evaluation of renewable energy sources in the Izmir city's neighbourhood area [33]. A pointing method based on the main principles of Analytical Hierarchy Process (AHP) was used to evaluate the potential renewable energy sources in the City of Izmir area. The AHP method has been used to evaluate the options within the decision making process in many fields, including architecture. The method relies on the identification of the factors that affect decision process, the factors' scoring, and an options list [34]. As important renewable energy sources of Izmir, sun, wind and thermal energies were evaluated and scored as relevant factors, based on AHP model, in order to decide the most efficient area in Izmir where to locate the energy efficient building design pilot project. Based on the measurements provided by the Solar Energy Potential Atlas (GEPA), Wind Energy Potential Atlas (REPA) and Izmir Geothermal Institute, 1 point was given for the lowest and 10 point for the highest average measurements. In order to compare all neighbourhoods' total renewable energy, the scores of neighbourhood's different renewable energy resources were summed and their average values were calculated. Potential of the three renewable energy sources was calculated using scoring units related to all neighbourhoods in Izmir city, and arranged in order [33].

According to the results of the calculation, the neighbourhood of Seferihisar was identified as the richest in terms of solar, wind and geothermal energy sources for multi applications of renewable energy sources. Additionally, Seferihisar is an important settlement in Izmir that contributes in the sustainable urban development process, and in 2010 it joined the international network of Cittaslow, which is a sustainable and a volunteered movement facilitating the use of renewable energy sources and the sustainable building technologies development [35].

3.2.2. Characteristics of the project area

Seferihisar is located in the south-eastern part of city of Izmir, which is the third most populous city in Turkey. The settlement is 45 km away from Izmir city centre adjacent to Urla and Güzelbahçe in North, and to Menderes in East. The settlement of Seferihisar covers a surface of 386 square kilometres and runs along a 60 km coast line [36]. The city centre has lost its distinctive architectural character, developed along the Seljuk and Ottoman periods. During the modern and contemporary periods, especially after 1980's, a considerable amount of historical heritage has been lost except a few conserved buildings in the city centre (Fig. 2).

Fig. 2. Location and overview of Seferihisar *(source: www.mapsof.net, 2013; Author's archive, 2010).*

Seferihisar is located in a first degree earthquake region. In 2003, a considerably strong earth quake has damaged 800 buildings in town. There are active fault lines in the area, and one of them, located in south-east direction of Cumali-Doğanbey region, caused thermal spring water outcome. Climate of Seferihisar, including temperature, rainfall and moisture values has considerably been affected by the sea since the settlement is rather a flat land that has not been surrounded with high mountains. Generally, Seferihisar's climate is Mediterranean, where summers are hot and dry and winters are warm and rainy. While the yearly average temperature of Seferihisar is of 16.6°C, the monthly high temperature average is 35.2°C in July and the low temperature average is 4.2°C in January. The yearly average wind speed in Seferihisar is about 3.5 m/s. The highest wind speed in the region is 7.5 m/s in north and 6 m/s in south. Prevailing cold winds in Seferihisar are from North and North-West directions. The yearly total rainfall is 593.5 l/m^2 and the winter is the highest average rainfall season. The sunny days are up to a half of the year (165 days), and they concentrate especially during summer. In winter time, the average number of sunny days has the lowest value [36]. Connected with the principles of life cycle design and conservation of resources, the criteria of project site selection for housing design model purpose in the Seferihisar area, have been identified as below:

- neither natural nor constructed environmental components should be in the project area as possible, so the future building would benefit of natural environment components such as sun, wind, view etc. (which are especially blocked by the current existing built structures);

- the project area should not require energy for destruction and damage current ecosystem or resources;

- the project area should be in urban development process that is open to sustainable improvements;

- the project location should be in close vicinity with city centre in order to ensure easy pedestrian and transportation accessibility.

According to above listed criteria, Necip Hepkon Street located in the South-East of Seferihisar, close to city centre, has been selected as the project site. The street, which is in urban development process, is located in the East-West direction enclosed with plants and gets green view from South, and open to prevailing winds in North. Project area was selected as a part of the street area renewal. A sample project site surrounded with visually unqualified five-storey adjacent buildings was selected as a convenient urban site, which allows housing design model to be implemented in various locations along the street. Around the selected area three apartment blocks and one storage building are located. The 5 storey apartment buildings are located on the Western side of the selected site, the 4 storey apartment buildings are in North of the site, the three storey apartment buildings are in North-West, and one storey storage building is located in North (Fig. 3)

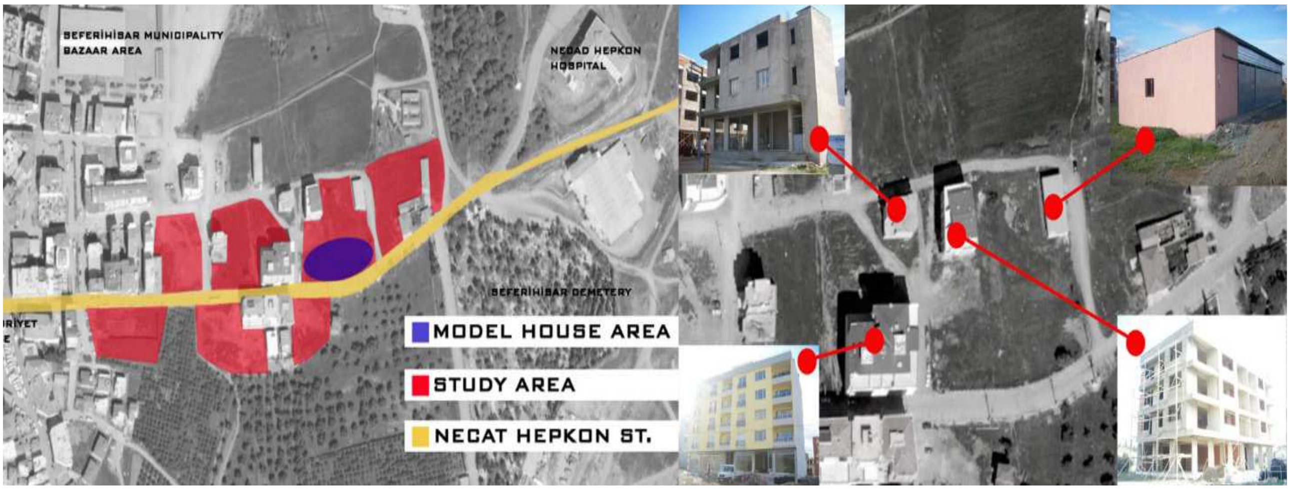

Fig. 3. Location of project area and surrounding buildings *(source: www.maps.google.com; Authors' archive, 2010).*

4. RESULTS AND DISCUSSION

4.1. Energy efficient (integrated) building design model

Following the main principles of our design approach, which are resource economy, life cycle design and design for human, an ecological single family housing design model is proposed. While designing, main principles of building and urban design approach were used as a guide and interpreted according to the spatial and urban characteristics of Seferihisar. Urban design principles of the design model are limited to the ones in close relation with architectural design such as site selection, site and landscape planning and orientation. The urban equipments such as public lightening, urban furniture and services such as waste management are not included in the model.

Since design is a holistic and a creative process, design decisions were explained in specific sections in relation to proposed ecological design principles, beginning with the site planning process, up to the details of materials, equipment and structural system selections. Eco-design considerations of housing design model were detailed in a series of sections concerning the site planning and landscape, building envelope and sun shading, spatial organization, passive heating and cooling systems, active energy generating systems, and selection of materials and equipments.

4.1.1. Site and landscape planning

The proposed site planning has been designed to provide South orientation for all the houses, and get maximum amount of sunlight in support of both efficient daylight and passive heating. Houses were organized on the site considering shadow lengths to get efficient daylight from South. Since topography of project area is flat, the air flows were not considered as influencing factors of the site. But the prevailing winds from North and North-West were taken into consideration as an important climatic factor.

The urban design solution organized the familial houses into groups of individual houses and coupled houses, in order to enable natural ventilation and passive cooling of the outdoor space, especially because of the Seferihisar summer which is usually hot and dries (Fig. 4 and Fig. 5).

In order to reduce heating and cooling costs, the landscape planning process made use of the energy efficient design principles. Initially, the project site did not have any green area to be considered. Therefore, a considerable amount of green was proposed by the landscape design, in support of energy conserving improving the energy efficiency, and providing green environment for the housing area.

In the process of site planning, breadfruit tree *(Arto carpusaltilis)* and umbrella thorn acacia trees *(Acacia tortillis)* were proposed in the North and North-West of the project site. Since these types of trees stay green during winter and drop their leaves during summer, it was possible to contribute to the heating and cooling energy savings of the houses by preventing cold winds during winter and by allowing cooling winds during summer.

Additionally, oak tree *(Quercus robur)* and maple tree *(Acer)*, which are green in summer and drop their leaves in winter, were proposed in the South and West of the project site, in order to provide natural sun control and to prevent excessive heat during summer.

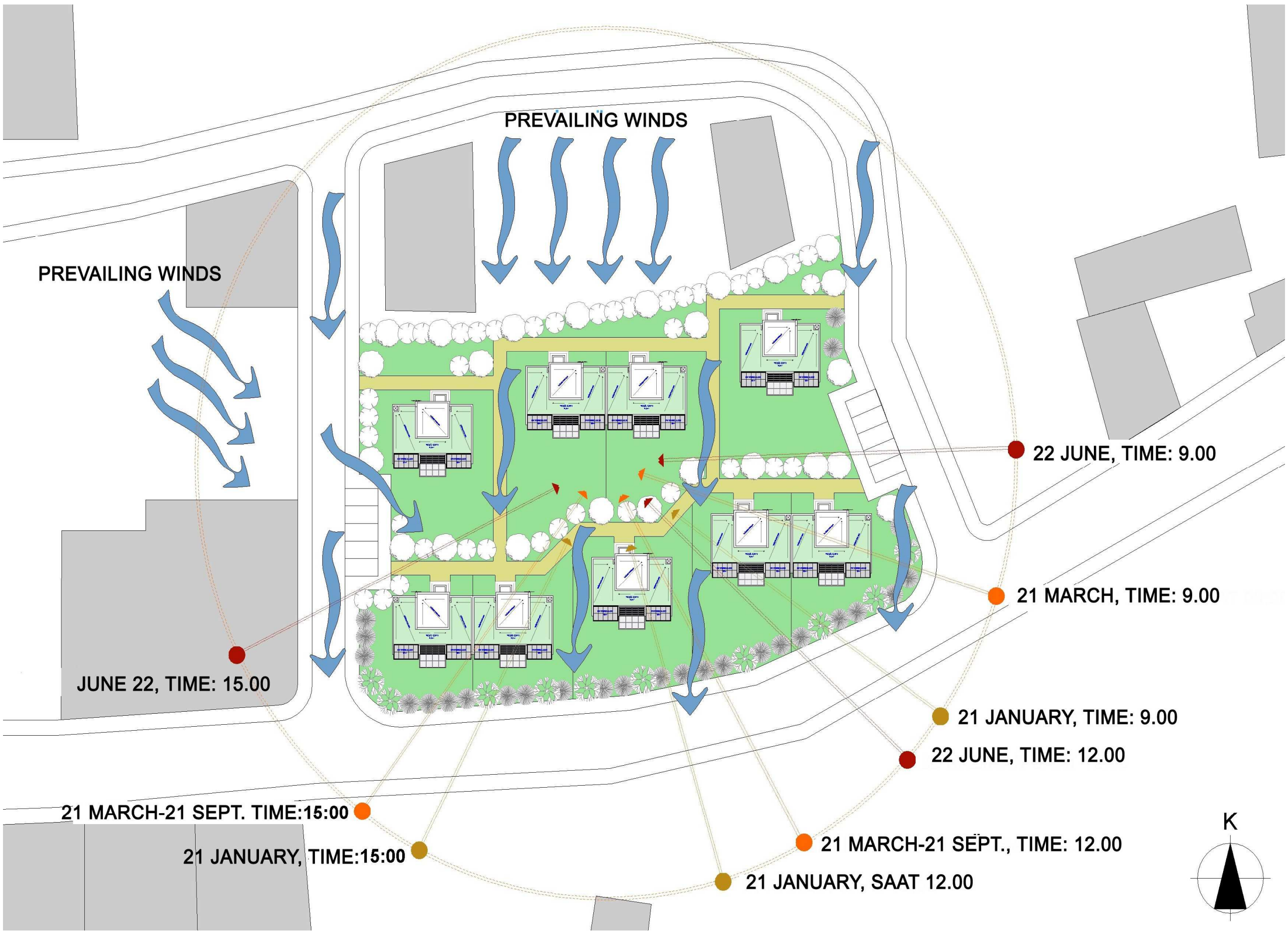

Fig. 4. Site plan.

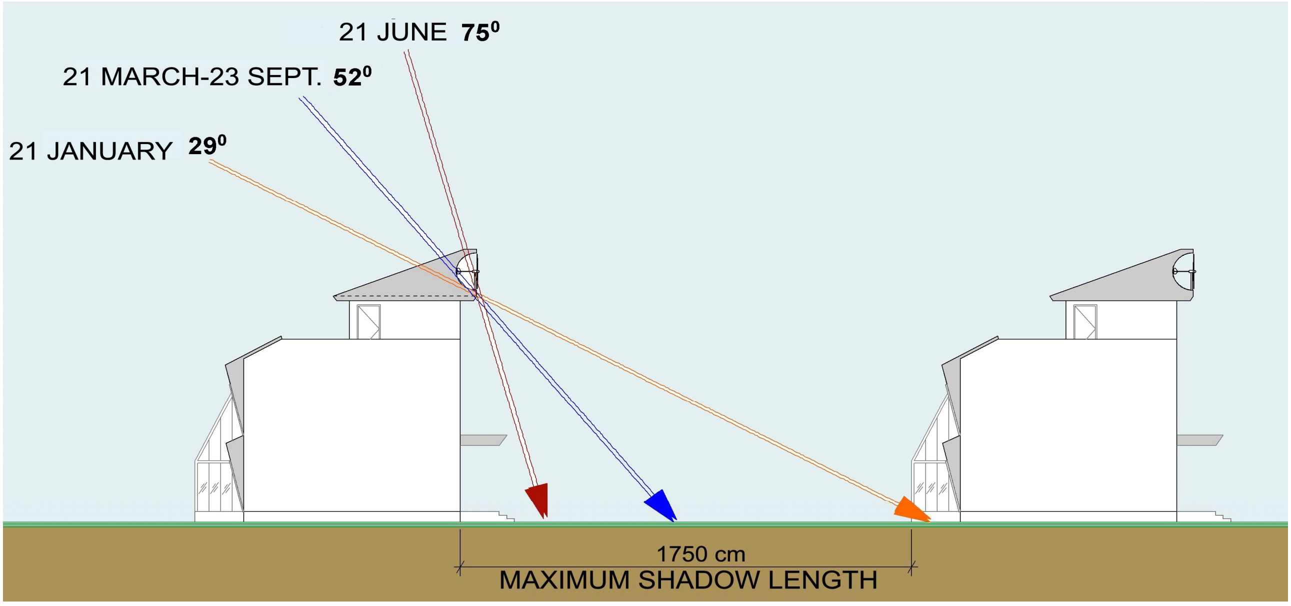

Fig. 5. Shadow lengths variation during seasons.

In order to reduce the impact of temperature variation along seasons, the project provided green roofs solutions for the houses. An amount of 70% of the land occupied by the houses was recycled using energy efficient landscape design solutions. Additionally, green roofs enabled the rain water recycling and to use it within the execution process of the proposed green landscape. All open green spaces are comfortable and designed for the relaxation and social interaction of users.

4.1.2. Spatial organization, building shape and envelope

The proposed design of the house took in consideration the spatial needs of a nuclear family consisting of a pair of adults and their children which is most common in the modern Turkish society. Houses design flexibility was an important parameter in order to both open the proposed design for future development if needed, and provide design alternatives for various spatial needs according to the users' profile and related family needs, and also meet the principle of *"Design for human use"*. The houses structure made use of a solution based on a modular and flexible system of steel, able to provide flexibility of spatial organization and functions. Spatial organization of the building relied on a modular structural system of 4 meters opening between the East-West structural axis, in order to get maximum benefit of the natural lighting and in support of a passive heating (Fig. 6).

The 3 bedrooms and the living room were designed in a flexible and modular two storey house. At the ground floor the proposed winter garden serves as both a thermal regulator and a buffer space between indoor and outdoor spaces.

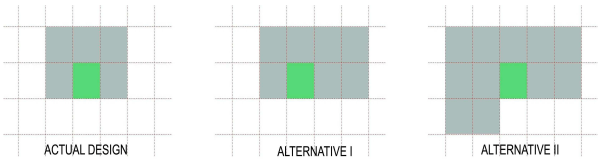

Fig. 6. Modular and flexible spatial planning of houses alternatives.

While all living areas have South orientation, the wet spaces, service spaces and circulation are located in the Northern part of the house, with limited openings, in order to conserve the energy (Fig. 7).

4.1.3. Passive heating and cooling systems

The winter garden, which is a useful solution for passive heating during winter in hot regions like Seferihisar, is south oriented, to help passive heating, and is an important component in the house design proposal that helps conserve the energy. The winter garden enables the heat distribution through the galleries, to the upstairs living spaces. The winter garden is provided with light mobile and sliding enclosure elements in order to be easily connected to the rest of the ground floor spaces and functions, and facilitates the flexibility of its utilization. Furthermore, the winter garden's sliding windows enable the ground floor living areas to be used as terrace that connects the indoor and outdoor spaces especially during summer.

Passive cooling in design can be supplied firstly by means of previously explained site planning decisions which allowed prevailing winds to blow both through housing settlement and through houses by means of openings.

Accumulated passive heat was removed by natural ventilation in case of cooling. Heat accumulation of winter garden was supposed to be removed up both by its operable windows located up and down and by stairwell which worked as a kind of ventilating tower (Fig. 9).

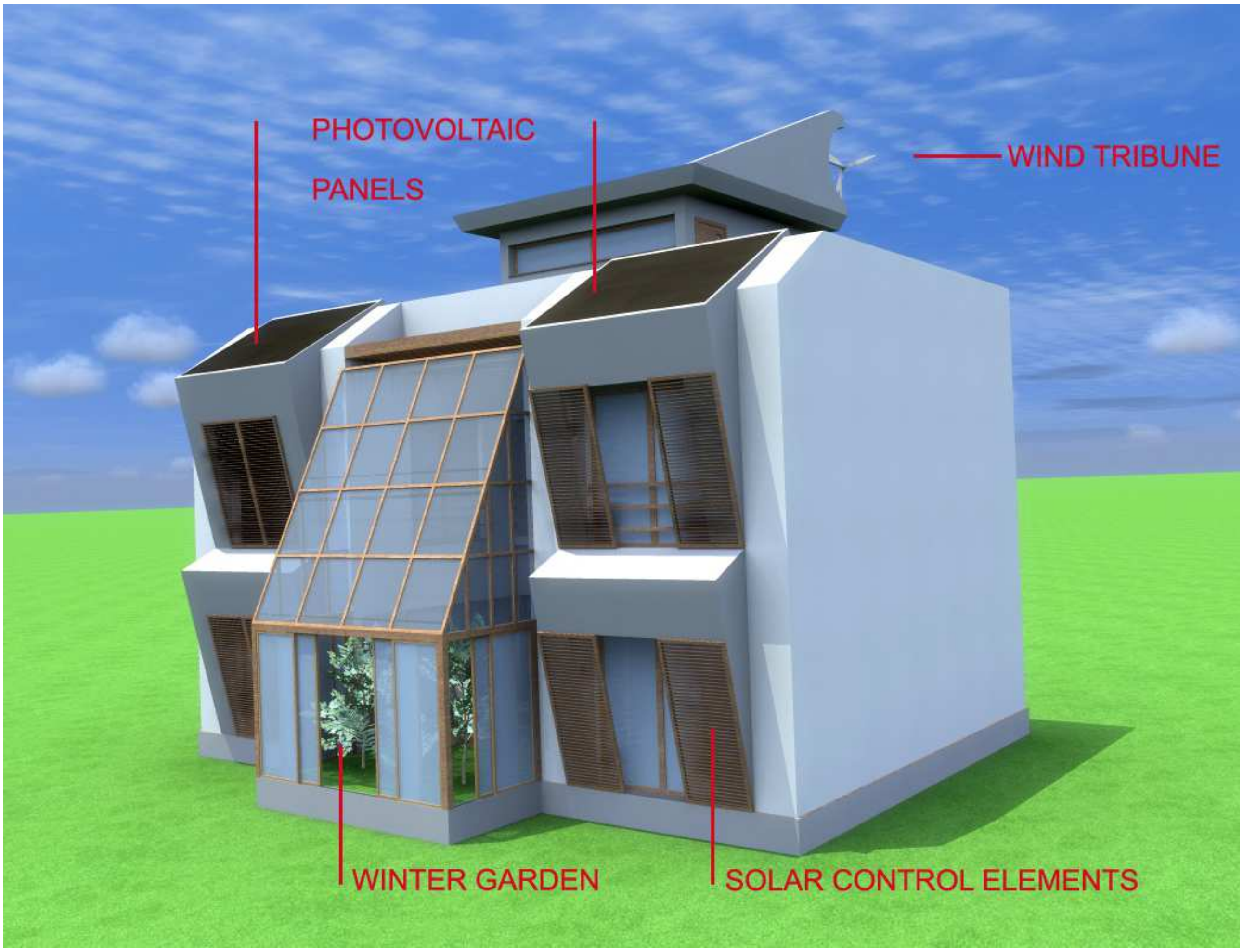

Fig. 7. The spatial simulation of the energy efficient housing model.

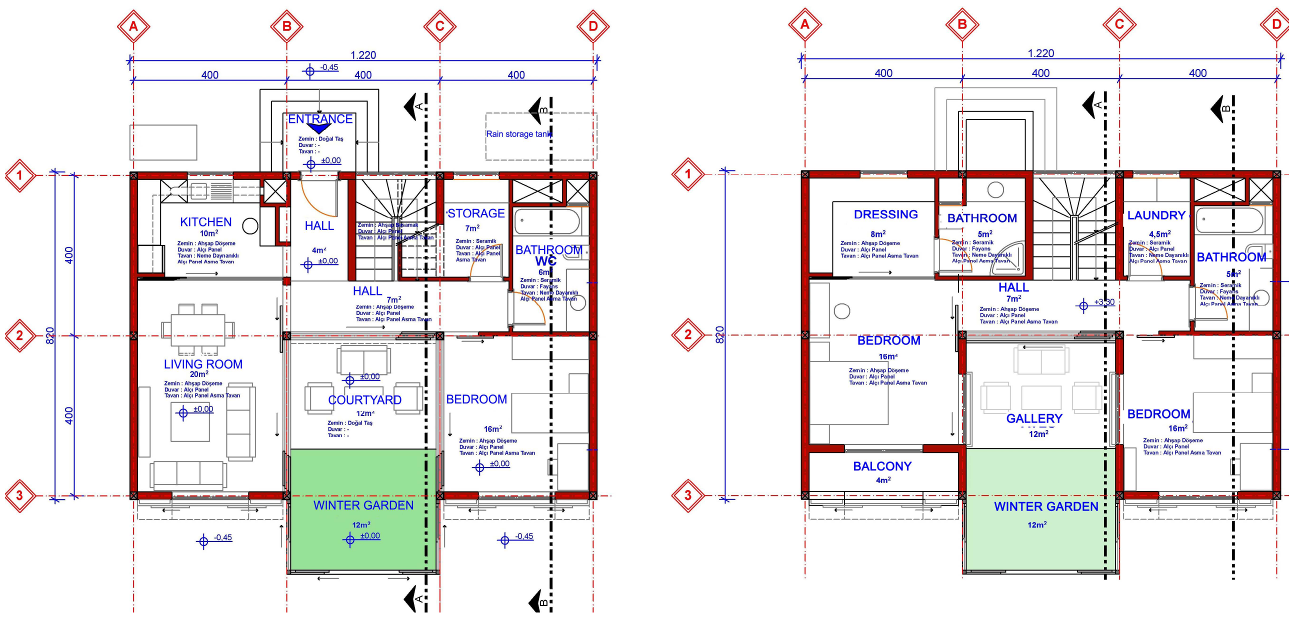

Fig. 8. Ground and upper floor plans.

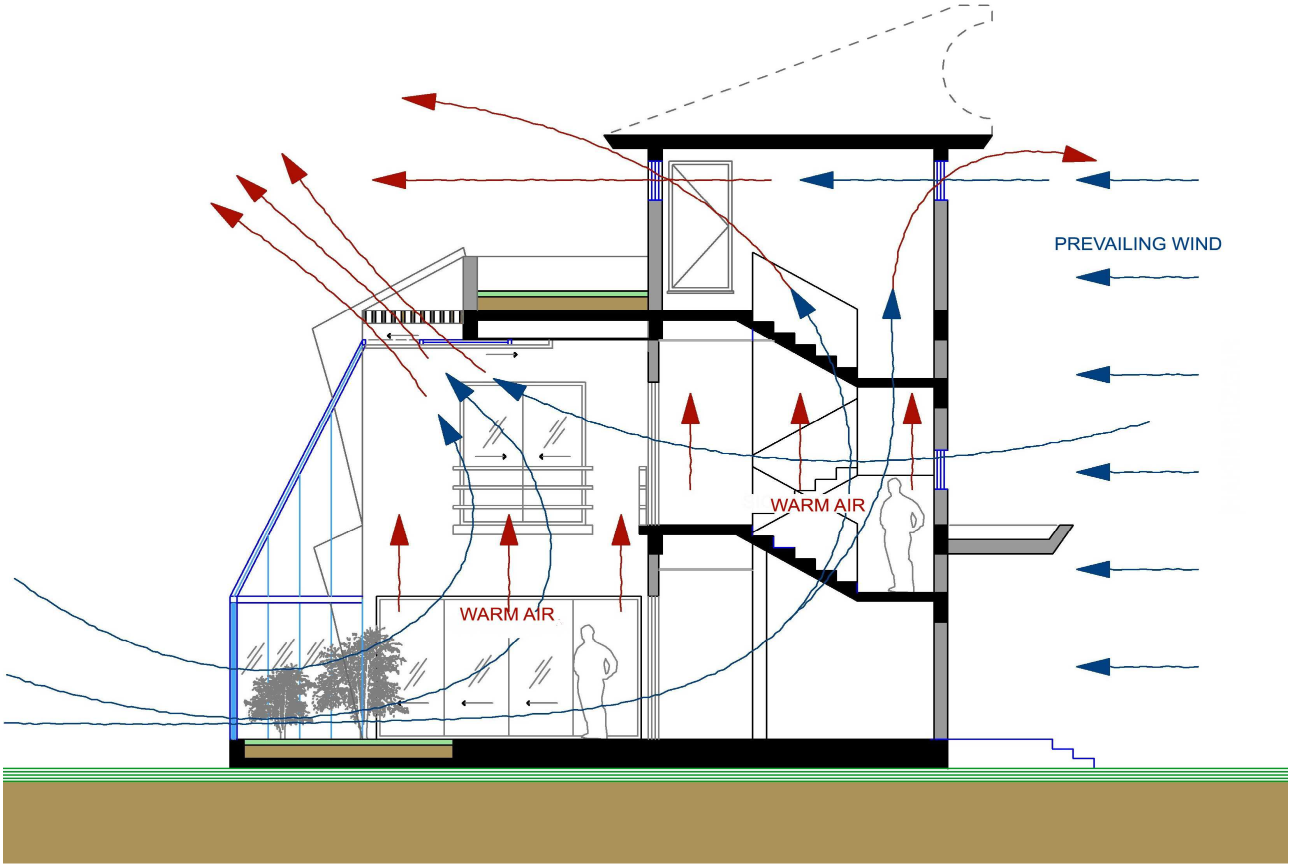

Fig. 9. Passive heating and cooling system of the model house.

Since project area was located in hot region, conservation of energy for cooling was considered to be important and a natural cooling system was additionally proposed. The system works with heat pumps and gets benefit from cooler soil and underground water temperatures.

Natural cooling system distributes cool air to interior spaces with fan coils and controls it like an air condition. Natural cooling system is known as the most energy efficient and economical method to cool spaces more effectively. With this system, it was estimated that 70% less energy could be consumed when compared to air condition. Additionally, another advantage of this system is that fan coils can filter the natural air coming from outside and supply fresh air all the time when the system did not work for cooling.

4.1.4. Integration of active energy generating systems

Energy efficient design approach of the study offers multiple uses of renewable energy systems that enable efficient use of renewable energy regarding seasonal differences. Integration of renewable energy systems of sun, wind and thermal resources were considered in our energy efficient housing design model as these systems are the most familiar ones for housing applications. Amount of daily energy consumption of a single house was regarded while calculating the equipments of renewable energy systems. Since daily energy requirement of a house depended on types, quantities and using frequencies of the used mechanical equipments during a day, presumed amount of energy have been accepted as a reference for daily energy consumption.

In this study, energy consumption of a model house has been presumed as 10 kWh except cooling loads. Fan coil system used for both cooling and natural ventilation was estimated to work 5 hours per day during summer and to consume energy 2 kWh per hour. Therefore, daily energy consumption of a single model house for cooling was supposed to be 10 kW (2×5 kWh=10 kW).

Location of photovoltaic panels was handled with design of building form as an integrated part of elevation design not as a machine like instrument. The panels were located on top of the angled openings orientated to south (see Fig. 7). Regarding energy need, 18 m² photovoltaic panels were offered to be applied. Energy of 1.5 kWh was predicted to be produced from photovoltaic panels per hour. For an application in Seferihisar, which has 8.42 hours of yearly sunshine duration, it was estimated that photovoltaic panels would efficiently work 8 hours per day. Therefore, daily energy production from photovoltaic panels were calculated as 12 kW (1.5 kWh × 8=12 kW).

In housing design proposal, wind energy, which has considerably higher mean values in Seferihisar, was considered as the second important renewable energy system to be integrated in building design. 1 kWh wind tribune was proposed on top of stairwells of houses located in north to get prevailing winds in the project area (see Fig. 7).

Wind tribune was interpreted as an integral part of building form that sustains energy efficient house image. Since wind energy was rather variable resource when compared to solar energy, predictions related to daily performance of wind energy cannot be made. Therefore, it was estimated that wind tribune would work efficiently 8 hours per day in Seferihisar since yearly mean value of wind speed is rather high (3.5 m/s). 8 kW (8 h × 1 kWh =8 kWh) energy was estimated to be produced by wind tribune per day. Daily energy produced by solar and wind energy systems are totally 20 kWh and the presumed energy requirement of a single house was met by the two renewable energy systems.

Thermal energy as the third renewable energy resource was regarded and integrated into housing design model considering future developments. It was estimated that valuable geothermal resources of Doganbey, which is 10 kilometres away from city centre, would be transferred to Seferihisar city centre in near future. In this meaning, the proposed housing model was designed as if houses would get their energy requirements for heating and cooling from geothermal energy. Since available temperature of geothermal fluid used for residential purposes is generally around 50°C - 70°C, ground heating system was proposed in design.

4.1.5. Selection of structural system, materials and equipments

For selection of structural system, materials and equipments for model house design, principles of *"conservation of water"* and conservation of materials related to main principles of resource economy, life cycle design, and design for human have been taken into consideration. Structural system of design was proposed as steel construction since project area has been located in the first earthquake region. Furthermore, steel is an efficient sustainable material with its durable, long lasting properties and load bearing capacities although its embodied energy is rather high. Additionally, it offers an efficient and flexible structural system for modular spatial design. Flexible and recyclable properties of steel were also important for principle of life cycle design.

Related to principle of conservation of resources, other materials and equipments have been selected by taking care of their sustainable and recyclable properties. Related to the principle of life cycle assessment, they were selected as to require low maintenance and to be locally produced material. Related to principle of design for human, they were selected as regarding to be healthy and nontoxic materials, and equipments. For example, high performance insulated double glazing system was proposed with woodwork, which is a sustainable material. Plaster, as healthy, moisture regulating and fire resistant material was offered for interior partitions. Massive wood was offered for ground coverage of interior spaces except bathroom and storage spaces. Both ground floors and walls of wet spaces were offered to be covered with ceramic tiles, which are local, healthy, easy cleaning and long lasting building materials, which do not require high maintenance costs. Entrance stairs and terraces were proposed to be covered with natural stone which is natural and sustainable building material that can be found easily around Izmir.

Related to principle of conservation of water, water efficient vitrified elements and armatures were offered in design model. Especially, photocell armatures were supposed to conserve a considerable amount of water during using process considering life cycle principle. For water conservation principle, rainwater collecting systems were proposed to be applied on green roof which can be used for closets, washing and etc. The proposed green roof approximately in 100 square metre for each single house sustains water conservation of 59 tones when yearly average rainfall of Seferihisar was considered (593.5 kg/m^2).

5. CONCLUSION

In the end of this study that aims to propose holistic energy efficient design approach and a housing design model following the predetermined design principles, some valuable results were obtained.

Energy efficient design principles of this study were classified under three main headings of *"Resource economy"*, *"Life cycle design"* and *"Design for human"* which addressed to environmental, economical and social aspects of sustainable design. These principles were offered to be balanced regarding priorities of the context during design process. We tried to combine both theory and practice. Energy efficient design principles of the study were supposed to constitute a flexible framework for both building practitioners and researchers. Regarding properties of different regions and climates, it is possible to interpret these principles in a different way.

Both passive and active energy efficient design considerations related to environmental dimension of sustainability was proposed to be handled holistically in both urban and building scales. Beginning from site planning and extending to building design considerations, materials and equipments selections, a modular and flexible housing model was proposed for Seferihisar.

In design stage that aims to develop an energy efficient housing model in city of Izmir, the renewable energy potentials of Turkey and its problems for energy shortages were considered by following the proposed design approach. Based on the principle of *"conservation of energy"* and life cycle assessment, the site selection method developed in our preliminary study was used in this study. Seferihisar, which was found as the most renewable energy efficient neighbourhood was used as a case to develop housing design model. The method can be improved in further studies by considering not only potentials of renewable energy sources but also considering other environmental and economical properties of sites.

Housing design proposal was tried to be developed as a modular urban catalyser that does not disturb ecological balance and improve sustainable urban development. Additionally, flexible and modular space planning of the housing model enabled to make variable space solutions for future requirements of users. During design process, energy efficient considerations were tried to be combined with economical concerns and artistic sensibilities addressing design for human principle.

Generally, architectural expressions of energy efficient or ecological houses are machine or instrument like buildings. Integration of active energy generating instruments, such as photovoltaic panels and wind tribunes with the form of design is the responsibility of architects. Therefore, this issue has been taken into consideration in development process of design model. Photovoltaic panels and wind tribunes have not only been considered as energy generating instruments but also been interpreted as the integral parts of design that create an image of energy efficient house. While wind tribune has been evaluated as a vertical element plugged in the stairwell, photovoltaic panels have been applied as integral part of south elevation with necessary angles.

This study has both calculated and modelled the applications of energy generating systems of solar, wind and thermal energies in a housing design model. In terms of energy production, multiple uses of renewable energy systems in houses and other kinds of buildings seem to have more advantages, since single systems have some deficiencies for achieving net zero energy houses regarding seasonal differences. Therefore, for further studies, it is very important to research comparative cost and benefit analyses of multiple and single applications of these renewable energy systems. Furthermore, method of site selection should be integrated with city development constraints of the land development and investment decisions since selection of project sites for energy efficient building applications are not always possible in practice.

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