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Low Carbon Architectural Design

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Abstract

Tendency towards sustainable energy resources is increasing and leading engineers and architects make joint efforts. Renewable energy potential present in nature can be used more efficiently so that while energy consumption is reducing, rate of energy gain, on the other hand, increases by architectural design methods. A sailing club in Gölbaşı, Ankara is designed as a low carbon building for optimum usage of solar and wind energy. It can be concluded using an energy efficient architectural design for a building before its construction makes it possible to meet the electrical and heat energy requirements at minimum cost and environmental friendly.

1. INTRODUCTION

Approximately 87 % of energy used worldwide is produced by fossil resources. During energy production, these resources are combusted and some gases are emitted into the atmosphere, which cause the greenhouse effect. Consequently, the energy production from such sources is considered as the major cause of the climate change. Building sector accounts for 40% of total energy consumption in European Union (EU) and is responsible for significant environmental impacts. In order to take some measures, the countries arrange regulations in this context. For example, to apply the European Energy Performance Building Directive 2002/91/EC in the Portuguese context, a new regulation with two codes have been implemented in 2006 [1]. One way to reduce building energy consumption is to adopt energy efficient technologies and strategies. Due to environmental concerns and high cost of energy in recent years there has been a renewed interest in building energy efficiency and integration of renewable energy technologies. Studies have been made on active building envelope technology which provides a cost-efficient way of minimizing energy demand of buildings in accordance with the global principle of sustainability [2]. Measuring and accounting for solar gains in steady state [3], the heat transfer of phase change building materials [4], determination of external convective and radiative coefficients for building applications [5], performance comparison of building-integrated combined photovoltaic thermal solar collectors (BiPVT) with other building-integrated solar technologies [6], and energy and exergy optimization for a new solar heater [7] are the new and valuable studies published on this context.

Turkey is one of the largest markets for energy in the world from the viewpoint of its rapidly growing young population, strong economic growth and urbanization. Turkey's dependency on natural gas is getting increasing every year in spite of the lack of natural gas reserves. Total energy demand is estimated between 134.32 and 150.86 MTOE (million tons of oil equivalent) for the year 2025 in one of the latest

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studies by Bulut and Yıldız [8]. In order to lower the dependency on fossil fuels, the usage of renewable energy sources are gaining importance in Turkey. In 2014, a conference has been held in order to bring academics and industrialist together from across the world to discuss and address the needs of the youth in terms sustainable buildings and infrastructure, focusing on low-cost, low energy housing units, industrial buildings and incubators to serve the needs of the ever growing younger population [9]. The interest for renewable energy sources are being aroused due to reasons such as serious environmental issues caused by fossil energy sources, potentially decreasing reserves, various political and economic problems caused by dependency on source providing countries and price instability. In case of inadequacy of existing natural energy sources, the importance of architectural design which aims enhancing the natural energy facilities and the methods designing a building that does not take energy from the outside, are increasing gradually. Zero-energy buildings (ZEB) are not realistic, but zero-CO_2 buildings are. The definition of zero-CO_2 building does require some qualification. Building materials and elements, including energy-generating installations such as solar panels and wind turbines, have an embodied energy. This embodied energy is generally associated with CO_2 emissions. The concept of a zero-CO_2 building can therefore currently only be applied to the building's operation. Moreover, a further distinction is required between zero-CO_2 energy supply technologies and renewable energy: not all renewable energy is necessarily zero-CO_2 [10].

In the literature, over the decades, different ZEB's were described and evaluated. Very often, the ways the zero energy goals were achieved have significantly affected the ZEB definition. Recently, the lack of common understanding and common definition for ZEB became noticeable, since this building concept is thought to be an effective solution for decreasing the energy use and greenhouse gas emissions from the building sector [11]. Energy use in buildings accounts for a significant proportion of the total energy use in many countries. While past and current buildings have solely been energy consumers, future buildings will, besides using less energy, also need to produce (part of) the required energy on site with renewables. Solar energy is generally very suitable for producing this on-site renewable energy [12]. Even, the solar energy can be stored as potential energy of compressed air. This can be simply accomplished by a heat engine. Here, air enclosed in a solar collector heats up and so its pressure will be higher. Then the high pressure air drives a double actuated piston cylinder mechanism [13].

The European and International Standard UNE-EN ISO 13790 and TS EN ISO 13790 "Energy performance of buildings - Calculation of energy use for space heating and cooling" represent a set of calculation methods for the evaluation and design of energy and thermal performance of buildings [14]. These methods have diverse range of details for calculating the energy use of heating and cooling in different building zones, as well as for calculating the heat transfer and solar heat gains of special elements, such as ventilated solar walls (trombe walls). The corrected equations and new correlations are proposed for Mediterranean climates by Ruiz-Pardo *et.al*. [15]. Turkey has a great potential of solar energy, and the application of the trombe wall which is one of the efficient ways of using solar energy is studied in an existing building in Istanbul, Turkey [16]. A theoretical comparison study has been made for the south facade of a flat in an existing building with renovated facade according to the thermal performances and hourly variations of wall interior temperatures. Another study for Turkey has been done on predicting energy requirement of existing and new built apartment blocks in Ankara, Istanbul and İzmir based on climate change scenarios. It is concluded that the climate of Turkey is expected to warm up, but still the heating requirement in buildings is higher than the cooling demand. Buildings constructed according to TS 825 provide better energy performance in winter seasons but not are in summers. This indicates necessity of passive cooling strategies such as natural ventilation and shading as well as thermal insulation in such buildings [17]. The recent studies have been performed on hybrid systems. In one study, the performance of photovoltaic-trombe wall is considered and the influence of PV coverage ratio is investigated. The simulation results show that as the coverage ratio increases the total efficiency increases [18]. In another study, solar-hydrogen hybrid system is integrated to a sustainable house and an analytical model to size, analyze assess the feasibility of a hybrid photovoltaic/hydrogen energy conversion system using a real weather data is presented. Yunez-Cano et al [19] conclude that the analytical model proposed can make it possible to choose strategies for the decision makers.

The aim of this study is to research for maximum energy efficiency of a building by architectural design method in order to increase the usage of the solar and the wind capacity in cooperation with the architectural and engineering sciences before it is built. Ankara sailing club in Gölbaşı location is considered as a case study. In the design, nearby the comfort of the sailors and keeping the boats safely, the energy need of the building and how to meet this energy by renewable sources and by architectural design are considered. The energy need of the club is met by both wind and solar energy. The solar energy is used by PV panels in order to generate electricity and as a heat source in maximum amount by the architectural design. PV panels in the market are generally based on the crystalline silicon and they represent the majority of solar cells produced currently. However, there are many new and promising technologies that have the potential to be scaled up to meet future energy needs. One of them is thin film cadmium telluride (CdTe) technology in the development of sustainable and affordable electricity generation. Munchi and Sampath [20] suggest that CdTe photovoltaics can be seen as the energy solution in the long term with the lower cost and the smallest life cycle impacts saying they have the smallest carbon print, the fast payback time and the lowest water input amongst all the energy sources.

2. METHOD

In the present study, the first step is to choose the case study which is a sailing club in Gölbaşı area. The aim is to construct a new and energy efficient club instead of old and small one. A project team is formed by the academics and the students from the departments of architecture and energy systems engineering and the other steps are as follows:
Climate and renewable energy resources analysis: Ankara and Gölbaşı region are analyzed from the viewpoints of climate and renewable energy resources
Architectural design for a sailing club
Form and direction selection for wind and solar energy
Electrical energy need calculations
Electrical energy supply calculations from renewable energy resources
Trombe wall selection for the south wall.
Unsteady state heat transfer calculations for a water-layer-trombe wall.

2.1. Climate and Solar Radiation

The sustainable natural energy sources in Ankara region are researched at the beginning of the study [21]. Ankara has a hot Mediterranean/ dry-summer subtropical climate (Köppen-Geiger classification: Csa) that is mild with moderate seasonality. Summers are dry and hot due to the domination of subtropical high pressure systems while winters are cold and snowy due to the polar front.

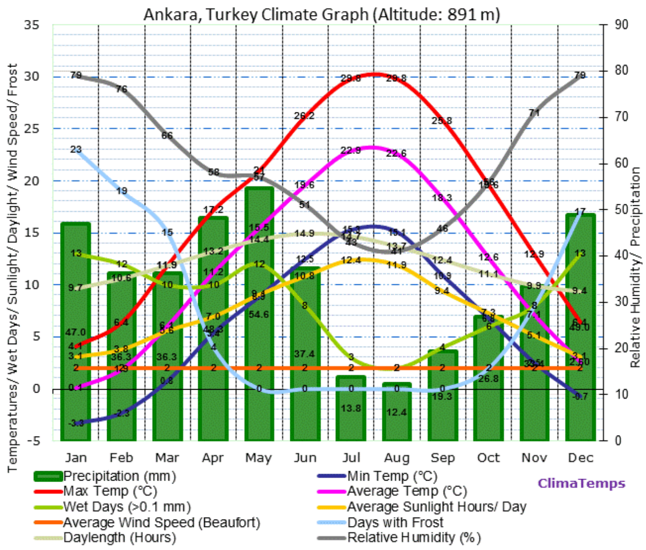


Figure 1. *Ankara zone climatic graphic*

The average wind speed for Ankara is shown as 2 m/s. Monthly mean temperatures range from 0.3 °C in January to 23.5 °C in July, with an annual mean of 12.02 °C. There are considerable temperature differences between middays and midnights as shown in Fig.1.The global yearly radiation for Ankara and Gölbaşı is shown on Fig. 2. The monthly sunshine duration and global radiation values are indicated for Gölbaşı in Fig.3 [22].

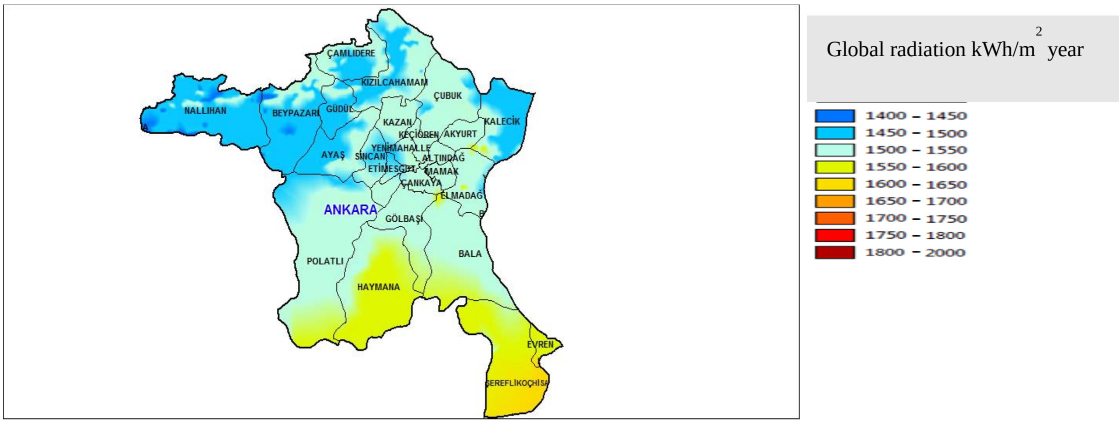


Figure 2. *Global Radiation for Ankara and Gölbaşı*

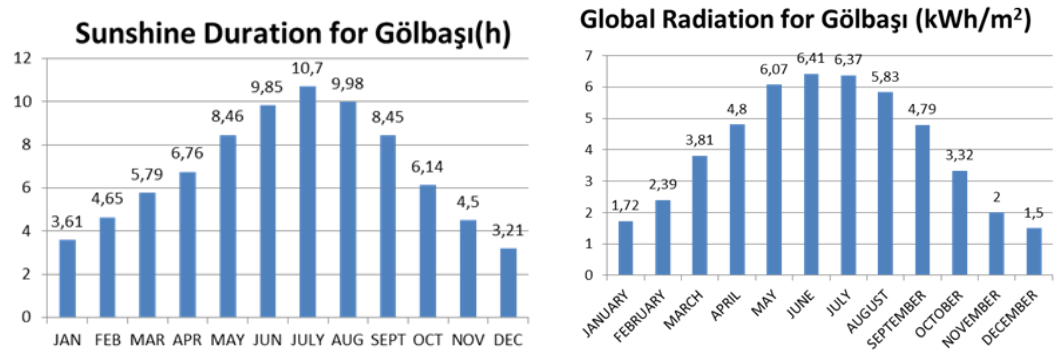


Figure 3. *Sunshine duration and Global Radiation for Gölbaşı*

2.2. Building Selection

There are two important reasons for the selection of a sailing club building project as a zero energy building. Firstly; the peak time used by athletes, guests and coaches is the sunshine and windy days. So, the energy consumption and the maximum energy gain days and times are coincide. Therefore, the energy storage requirements are minimized. It is important to improve some new architectural design methods, in order to use such advantages. Secondly, the sailing clubs are generally located outside of the municipality areas and they cannot utilize the ordinary electricity facilities.

The project has been prepared for Turkish Sailing Federation’s State Ankara Sailing Club. Architectural design includes a resting area for the athletes, coaches, officials, and parents, a daily shelter area for guests, and a hangar area which has been designed as a storage, maintenance, and control of boats. Club's area is determined to be totally 250 m^2, which has a 50 m^2 resting area and a 200 m^2 for hangar area. The height of the building at the hangar side has to be more than 5 meter, and can be 3 meter at the resting and preparing area. Therefore, it has an inclined roof. In this research, the design of the building is prepared as a Zero-energy building (ZEB) or “Zero-emission building which does not need any extra energy from Municipality.

In order to reach its aim of minimum energy consumption of the building, first of all the alternatives of increasing energy production and decreasing energy consumption for a zero- CO_2 building are considered. Research begins from the analysis of natural sustainable energy sources in that area. These data is used for architectural design form to increase the rate of energy gain from sustainable natural energy sources. Here, the architectural design form is also used for the minimum energy consumption of the user. The problem is that "energy is not needed by the buildings, it is for the users. Because, the buildings do not use energy, people use. This is the reason why the solution for the minimum heat, light and the other vital needs for energy is firstly researched. After all, the research and analysis have been done for local sustainable natural energies of solar, wind, water and soil. Amongst the others, two alternatives; solar energy and wind energy are found to be worthy.

2.3. Architectural Design

Various architectural design forms have been investigated in the efficient use of the natural sustainable energy sources. Direct solar gains are significantly influenced by the glazing ratio. The simplest and the most effective way for more solar gains is to have bigger glazing areas, which also cause heat loss depending on the glazing type and U value on the other hand. At this research, because of the transparency, trombe wall has been designed with glazing and an aquarium type of trombe wall is decided instead of brick wall for increasing the glazing ratio. The heating of the building will be achieved by the heat transfer from the trombe wall. In order to increase the availability of using solar energy, an inclined wall is used not only at the elevation but also in the roof design. Here stenographic knowledge has been used to find the angle of walls and ceiling which is to be used for the solar collectors. For increasing wind velocity, the inclination of walls and ceiling curve also have been used.

Solar energy: Both the electricity and the heat energy are produced from solar energy. The long side of the club building is located toward south-east in order to achieve the solar radiation maximum. The solar panels are also located on the roof with the angle which gives the maximum efficiency according to the solar radiation and the distance between them is calculated. In the meantime, the long side wall toward south-east is designed as a trombe all which consists of glass–air-glass-water-glass layers. The heating of the building will be achieved by heat transfer from trombe wall as additional heat energy. At this point the different types of wall materials are calculated for heat transmission and energy gain. Secondly geometry of walls is adjusted for more solar energy gain.

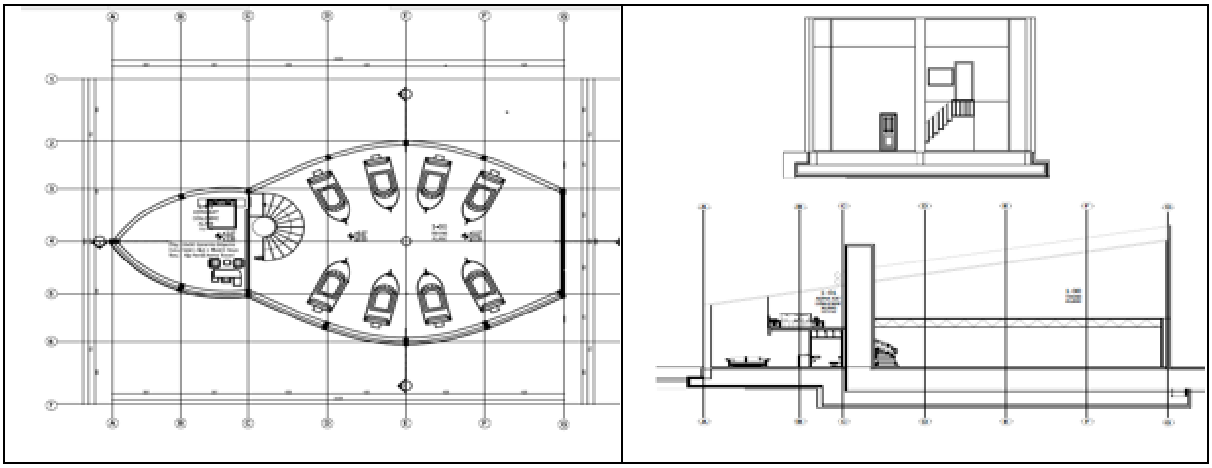


Figure 4*. Ankara sailing club project in Gölbaşı (longitudinal section and cross section plan)*

Wind energy: On the roof an inclined channel is designed which takes the wind from 10 m height and carries to 5 m height as a nozzle which satisfies the velocity of the wind increased. The wind turbine is located at the end of the channel in order to produce electricity.
In Figure 5 two location directions for the sailing club is shown. In Fig.5 (a) the long side of the building is located towards the south and in Fig.5 (b) the direction is selected according to the incoming of the sailboats and also dominant wind direction of North-East.

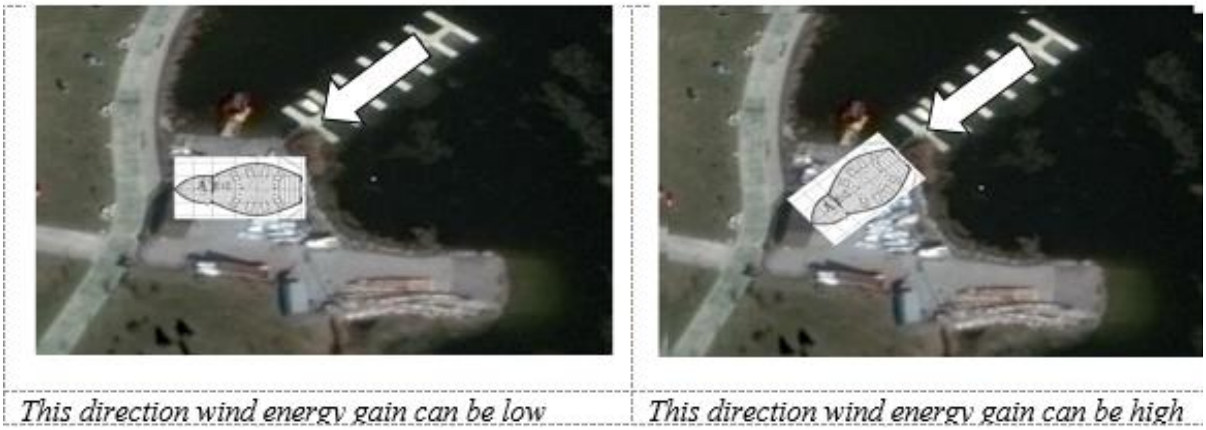


Figure 5. *The location for sailing club (Dominant wind direction is North-East)*

2.4. Energy calculations

Energy consumption in buildings represents approximately 40% of the worldwide energy demand, and more than half of this amount is attributed to HVAC (Heating, Ventilation, and Air Conditioning) systems [23]. The major attention is given on how the electricity requirement of the club can be met and how the heating and cooling requirement can be minimized. The first step in the calculations related with energy is the energy need of such a sailing club. The electricity required for the club is determined to be 8.14 kWh /day and the cost of this consumption will be 100.60 TL [24]. The photovoltaic panels are located forwarding to the south and the average sun shine duration is taken to be 6.8 h. According to these assumptions 5 panels each capacity is 250 watts will meet the electricity need of the club and the payback time will be 8 years. When 30 panels are used, that is also possible, 1530 kWh/month electrical energy can be generated and the payback time will be the same. The second step is to use the benefit of wind energy. The average wind speed is 2.1 m/s at that location. Actually it is very low for a wind turbine. However, the design of the roof is adjusted such that the velocity can be increased and by using shrouded type of turbine the efficiency will be increased. The efficiency of these turbines can reach 60 % at 4.2 m/s wind velocity. So some additional electrical energy can be gained from a shrouded type of wind turbine located at the end of a nozzle on the roof. The roof is inclined towards the front side and by architectural design, a 0.1732 kW additional power can be achieved. The other step is to build a trombe wall to the south-east side of the club.

2.5. Trombe wall calculations

The heat transfer from a trombe wall designed by glass–air-glass-water-glass layers, the front side is exposed to solar radiation and the back side is looking at the inside of the sailing club. The heat transfer calculations have been performed using the basic principles of solar radiation, conduction and convection mechanisms [25,26]. The main equations for the mechanisms are the followings:

$$\dot{q}_{net,rad} = \sum E_{absorbed} - \sum E_{emitted} = \alpha_S G_{solar} + \varepsilon\sigma (T_s^{\,4} - T_{surr}^{\,4}) \tag{1}$$

$$\dot{q}_{conv} = h_{conv}(T_s - T_{surr}) \tag{2}$$

$$\dot{q}_{outside} = \dot{q}_{rad} + \dot{q}_{conv} \tag{3}$$

$$\dot{q}_{cond} = k_{cond}(T_{in} - T_{out}) / \Delta x \tag{4}$$

$$\dot{q}_{trombe} = h_{trombe}(T_{in} - T_{out}) \tag{5}$$

The energy balances around each layer of the wall, air and water are formulated as unsteady energy balances as follows;

$$\dot{E}_{in} - \dot{E}_{out} = \frac{dE}{dt} = \rho V C_p \frac{dT}{dt} \tag{6}$$

$$\dot{q}_{in} - \dot{q}_{out} = \rho \Delta x C_p \frac{dT}{dt} \tag{7}$$

where $\dot{q}$: heat transfer rate per area, ρ : density of the layer material, $\dot{E}$: energy transfer rate, V: volume of the layer, C_p : the specific heat of the layer material, α_S : absorptivity, G_{solar}: solar radiation, ε : emissivity, σ : Stefan-Boltzmann constant.

3. RESULTS AND DISCUSSION

The heat transfer calculations including radiation, convection and conduction heat transfer according to the layers' properties are performed using the hourly data for radiation and the temperature in the month January 2012 for Ankara [27]. Fig. 6 shows the global hourly solar radiation values for January, 2012 according to the days. It can be said that the maximum radiation occurs between the time interval 9.00-14.00 UTC (Coordinated Universal Time), and it can also be seen from Fig. 7 that the outside temperatures have maximum between the same time limits. The maximum radiation is 35730.7 W/m^2 (hourly total global solar radiation) on 31 January 2012.

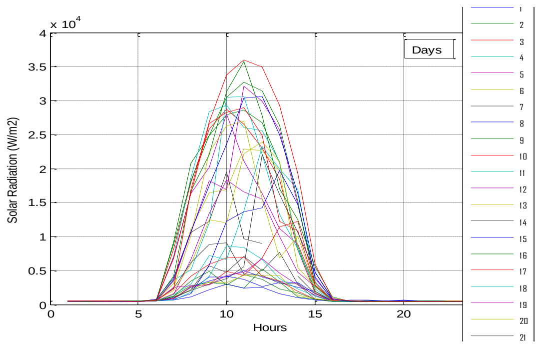


Figure 6. *Global radiation hourly data*

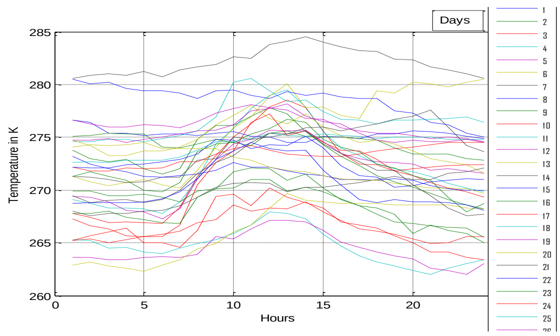
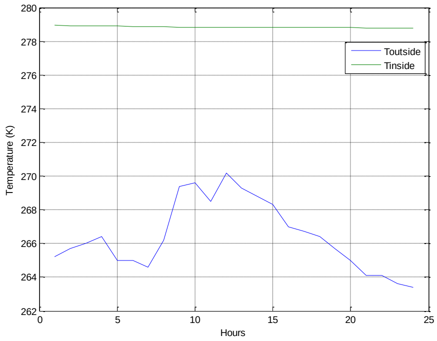
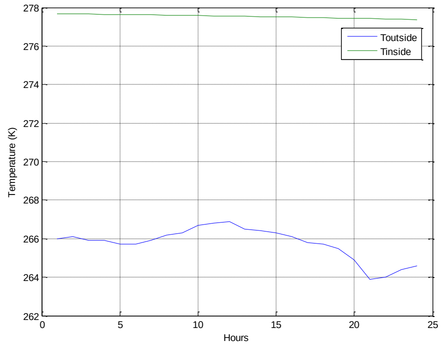


Figure 7. *Outside temperature hourly data*

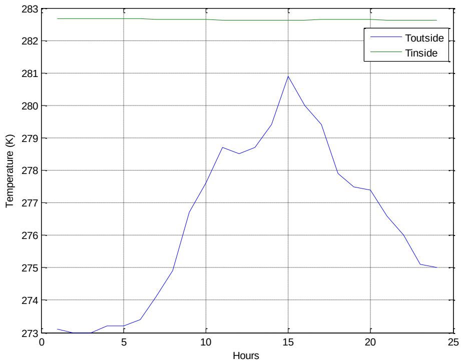
In the calculations, 10 different temperatures location are selected and ten differential equations are solved simultaneously every minute for 24 hours and 31 days. Figure 8 (a) shows the outside hourly temperatures measured on 31 January 2012 (blue line), whereas the green line shows the temperature inside the sailing club determined by a simulation algorithm. The simulation algorithm has been written by MATLAB codes [28] using the trombe wall calculations for radiation, conduction and convection heat transfer equations and the dynamic energy balances given in Section 2.5 for the hangar side. The initial temperatures at the hangar side are assigned as 15°C for each layer at the beginning of the simulation for the first day of January and the temperatures evaluated on January 31st are used as the initial temperatures of the each layer on February, 1st and the simulations continue consecutively in the same manner. Fig.8 (b, c, d) show the comparison of the temperatures at the last day of the given months, measured outside temperature and temperature inside the club building hourly. At the end of the 4th month, on 30th April, the temperatures at each layer of the trombe wall together with the outside temperature and the inside temperature of the hangar are plotted against time (h) in the last figure (Fig.9). Temperature numbers are given starting from outside to inside layer.



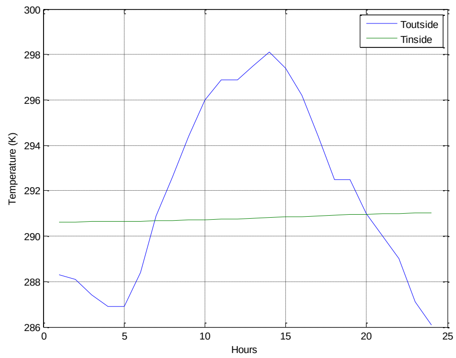
(a) *Hourly data for 31 January 2012*



(b) Hourly data for 29 February 2012



(c) Hourly data for 31 March 2012



(d) Hourly data for 30 April 2012

Figure 8. *Outside and inside temperature hourly data at the end of 4 months*

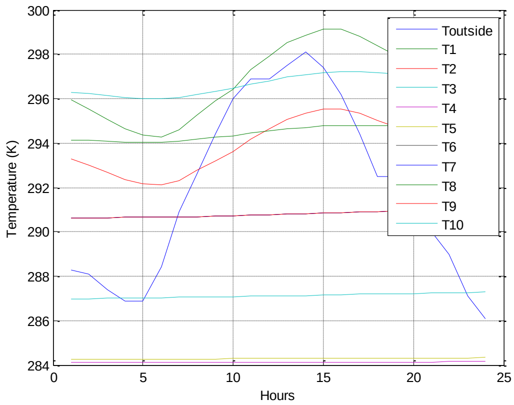


Figure 9. *Temperatures at each layer for 24 hours at the end of 4 months*

Buildings have a long lifetime, and it is possible and feasible to halve the energy consumption over this long period of time, but there is a need for taking the precautions today. There is a special need to reduce the consumption in the new buildings and the existing buildings by renovation, improvement or refurbishment in the future, if they were not project before their construction. At the design stage of the building's architectural projects, the energy gains and losses can correctly be calculated and by the correct design, the construction cost will be lower compared with subsequent renovations. In this research, Ankara sailing club building project has been selected as a case study and designed as a low CO_2 building. There are two important reasons why a sailing club building project is selected for the case study. The first one is; the peak time used by athletes, guests and coaches is the sunshine and windy days and the maximum energy can be gained by natural renewable energy sources during the same times. As a result, the energy consumption and the gain periods coincide. The other reason is; the location of the sailing clubs is generally outside of the municipality areas which use the facilities of municipality like electricity or natural gas. So, it can be a necessity to provide its own energy. In the study, all the natural sources have been considered, and the solar and the wind energy are determined to be worth analyzing at the first glance. The solar energy is used both by photovoltaic cells as an electrical energy source and by a trombe wall as the heat energy source. Wind energy will be used by a wind shrouded turbine. According to the calculations, it is seen that it is possible to design a building as a low CO_2 building using natural renewable energy sources and project the building architecturally to have the maximum energy gain. If it is thought that the architectural form of the building is like a cruciform, the long side directed from North-East to South-West, then, the wind energy can be utilized as maximum. Long side facade is also at South-East and easily gains solar radiation; additionally its architectural form is oval shape and can easily take east, south and west solar radiation. So, because of the curve form, it can gain solar energy more than a flat facade. The long wall in the direction of South-East is designed as a trombe wall. In the trombe wall, the inside wall is selected as an aquarium type wall instead of brick type. The wall consists of glass-water-glass layers and keeps the heat gained by solar radiation during longer periods as an advantage. The results of the simulation studies indicate that the temperatures in the hangar side can be kept above 0°C even in the coldest days of January and February when the long side of the sailing club is constructed as a trombe wall. Due to several reasons like global warming, the importance of energy, especially clean energy, will rise. In this study, the different types of energy are used as the solar and the wind energy, and the advantage of a trombe wall is utilized. The calculations showed how beneficial it can be, if different types of renewable energy sources are combined with enhanced architectural design. The most important energy source is the solar energy which can be resulted from the present study and the others can be used as an additional energy sources for Ankara Sailing Club in Gölbaşı.

In the present study a sailing club in Gölbaşı area is selected as a case study. The aim is to research a new and energy efficient club construction instead of old and small one. In order to reach this aim, together with the architectural design, the climate and the renewable energy sources at that region are searched, the best position and form for the building from the viewpoint of energy gain are determined. A water-layer-trombe-wall in the hangar section is recommended in order to prevent freezing in the winter conditions. At the results of all these studies it can be concluded to design the buildings in energy efficient architectural form before their construction makes it possible to meet the electrical and heat energy requirements at minimum cost and environmentally friendly.

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CONFLICTS OF INTEREST

No conflict of interest was declared by the authors.

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