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ENERGY CONSCIOUS DWELLING DESIGN FOR ANKARA

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Abstract
The study aims to develop energy conscious dwellings in climatic conditions of Ankara. Since the computer program SUNCODE-PC is used for the thermal performance analysis, an hourly climatic data set for an average year has been prepared. Two design proposals are developed and compared: one of them is designed with conventional features and the other is designed energy consciously. Improvement studies are conducted on the energy conscious design.

Keywords: Passive architecture, Low-energy architecture

1. Introduction

The client (Yüksel Project International Inc.) asked for a new-built dwelling design scheme to fulfill the requirements of an overall approach in developing passive solar designs and energy conscious dwellings in climatic conditions of Ankara at 39°57’N latitude and 32°53’E longitude with 895m altitude. The client also asked the design of a conventional dwelling which he could compare thermally with the energy conscious dwelling under local climatic conditions. Therefore, the primary intention of this study is to develop an energy conscious dwelling design and determine the energy savings of this design when compared with the conventional designs. In this context, first an energy conscious dwelling is designed, then another building with the same plan but having the main facade facing the main road at north and only fulfilling the minimum requirements of the Building Insulation Regulations of Turkey (BIY, 1985) is designed. The thermal evaluation of the building which can also be named as conventional design and the energy conscious design are presented in a comparative form by the aid of SUNCODE-PC (Demirbilek, et.al., 1993). Improvement studies covered in this paper are the additions and contributions of:

- solar water heating system;
- insulation materials on walls, floor, and roof;
- different sizes of Trombe walls;
- different sized greenhouses;
- rockbin; and
- night insulation on energy savings.

2. Simulation program

2.1. SUNCODE-PC

Computer simulation technique is used for parametric studies to differentiate relative performance. SUNCODE-PC, which is a general purpose thermal analysis program for residential and small commercial buildings, has been utilized as the software. SUNCODE-PC is the microcomputer version of SERI/RES, a mainframe program (DeLaHunt, 1985). The choice of SUNCODE-PC is done referring to a study that had been carried out to establish the reliability of eleven well known computer based thermal performance programs. The results achieved by the computer runs of those programs were compared with the actual measurements and only two of them, one of which is SUNCODE, had close values with the measurements (Holtz, 1990).

2.2. Weather Tapes

The hourly climatic data of direct normal solar radiation (KJ/m²), total horizontal radiation (KJ/m²), ambient and dew point temperatures (°C), and wind speed (m/sec) for the whole year have been prepared to be conducted in the program. Hourly direct normal radiation and total horizontal radiation data is produced by using the model illustrated by Fakýoðlu, T. and Ecevit, A. (1995). Hourly ambient temperature, dew point temperature and wind speed data are prepared by taking the hourly average values of data collected for five years.

3. Design criteria

3.1. Concept of form and site layout

Both of the designs are two story dwellings each having a floor area of 152m^2. These two dwellings are designed as a twin house separated with each other by a stagger. As the result of fulfilling the company's commercial approach which aims to visually link the main facade of the conventional building to the passing road, the main facade is oriented towards north. In order to be passively heated, the main facade of the energy conscious dwelling is oriented towards south. The architectural drawings and a photograph of the model are given in Fig. 1 and Fig. 2, respectively.

3.2. Concept of plan

In both designs living room, kitchen, and dining hall are located on the ground floor and three bedrooms and two bathrooms are placed on the first floor. In the conventional design, the living areas and sleeping areas are oriented towards north where the road is passing. In the energy conscious design, the living areas and the sleeping areas are oriented towards south whereas, the service areas are located in north to act as a buffer zone in both floors. The apertures are mainly placed on south and are kept minimum in north, west, and east. A greenhouse which serves to two floors is added in the energy conscious dwelling.

3.3 Building materials

Both in the conventional and energy conscious designs, building materials are chosen so as to fulfill the requirements of Thermal Regulations of Turkey. They are listed from inside to outside in Table 1.

The building materials of the energy conscious dwelling are improved by increasing the insulation material thickness from 4.5 cm to 7 cm for floor, 10 cm to 15 cm for roof, and from 1.2 cm to 2-4 cm for exterior walls. In order to minimize heat transfer between these two dwellings, an in-between wall composed of 2 cm plaster, 19 cm brick, 20 cm polystyrene foam, 19 cm brick, and 2 cm plaster is designed.

3.4 Additional features of the energy conscious dwelling

3.4.1 Night insulation and shading coefficient of glazing

Double glazing with a U-value of 2.9 W/m^2K, shading coefficient of 0.94, extinction coefficient of 0.0197 1/mm and index of refraction value of 1.526 is applied to all windows. As night insulation just simple curtains, which has a common use for privacy in Turkey anyway, that decreases the U-value of the glazing to 2.0 W/m^2K is assumed to be applied to windows in winter nights between 7:00 p.m. and 7:00 a.m.

In summer, a simple inside medium roller shade is assumed to be drawn on windows. Therefore, shading coefficient of glazing is taken as 0.80 for summers.

3.4.2 Trombe wall

Trombe wall is applied on the south facades of the living room and master bedroom which require more amount of energy demand due to their large floor and facade area compared to other parts of the dwelling. Application of night insulation to Trombe walls in winter nights is found essential to decrease the heat loss to outside from the Trombe walls. Moreover, application of shading on Trombe walls is recommended for both achieving thermal comfort and decreasing the cooling load in summer.

3.4.3 Greenhouse

The greenhouse is located on south serving both to living room and kitchen on the ground floor and to three bedrooms on the first floor. A balcony is designed within the greenhouse in the first floor.

3.4.4 Stairwell and water heating system

Stairwell is designed so as to act as a ventilation chimney in summer. To provide this feature, ventilation openings are added to the north wall of the stairwell. Moreover, solar water heating system is placed on top of the stairwell in order to provide the hot water supply to the occupants. As 40° inclined surface is needed for solar water heating system in Ankara, the roof of the stairwell is elevated and inclined apart from the roof as seen in the section and model of the building. Water tank is placed in the attic space of the stairwell.

The collector (Fig. 3) is dimensioned as 200 x 100 x 1 cm. The top part is composed of double glass and 8 cm polystyrene foam. Water circulation between the tank having a floor area of $1m^2$ and the collector is provided by the aid of a pump (P). Water inlet (A) of collector is 15 cm below the water level. The 2 m^2 collector is planned to heat 170 lt. water. Hot water outlet (C) is situated at 2 cm below the top of the tank. The consumed water will be replaced with the control of a float. Water collected at the bottom part of the tank is recommended to be used as a cold water supply to the dwelling when needed. The capacity of cold water can be arranged by changing the height (H). By opening the valve, V1, and check-valve (D), collector circulation can be done. In order to prevent freezing in extreme cold winter conditions, V1 valve should be closed and by opening the V2 valve water should be emptied. In order to use cold water from tank, V3 valve should be opened (Ecevit).

3.4.5 Rockbin

A level difference is created between dining room and living room, and the rockbin storage is planned to be placed under the dining room. The warm air which will be collected from the greenhouse is blown through the rockbin storage towards the living room from the in-between vents by the aid of a fan. The details of the rockbin storage is given in Fig. 4.

3.4.6 Fireplace

Apart from the heating system, a fireplace is placed between the living room and dining hall where its chimney passes through the two bedrooms in the first floor. Normally, efficiency of fireplaces are very low due to energy loss of chimney gasses but since they add an important character to the architectural features of dwellings, it is planned to design a more efficient one for the project.. Efficiency of fireplaces can be increased by utilizing the heat energy of out-given gasses. Therefore, a specially designed fireplace and chimney is designed as seen in Fig. 5. In order to increase the heat transfer, two metal chimneys are placed, one inside the other, leaving an air space in-between. While the hot chimney gasses and smoke are passing through the inner chimney, they heat up the air located in-between the inner and outer metal chimneys. The naturally rising hot air can be taken to the inside of the master bedroom through perforated chimney surface at the first floor. Although the same detail could be applied to the other bedroom, it is not preferred due to a possible speech transfer between bedrooms.

4. Method and discussion

4.1 Analysis

This study is directed towards evaluating the thermal performances of conventionally designed dwelling and energy conscious dwelling determining the contribution of passive solar elements by the aid of SUNCODE-PC. The effort was directed towards exploring the advantages and contributions of the additional features of energy conscious dwelling conducted on conventionally designed dwelling in terms of orientation, insulation material thickness, Trombe wall, greenhouse, and rockbin.

Annual heating, cooling, and total energy loads are calculated. The energy amount saved in GJ and the percentage saved with the addition and modification of each energy conscious design feature are compared with the conventionally designed dwelling (Table 2).

Heating, cooling, and venting setpoints of HVAC unit are determined as 18°C, 26°C, and 24°C, respectively. That is, it is assumed that the heating unit starts to work when zone temperature falls below 18°C in winter. In summer, venting process starts to work when zone temperature exceeds 24°C and venting process stops and cooling unit starts to work when zone temperature exceeds 26°C despite the venting process.

<u>Orientation:</u> The heating and cooling loads of the conventionally designed dwelling (labeled as CDD in Table 2) are 90.7 GJ and 0, respectively. The first run for energy conscious design (ECD-1) is achieved by orienting the main facade of the building labeled as CDD to south. The heating and cooling loads for ECD-1 are 83.5 GJ and 0.3 GJ, respectively.

Insulation material: When 2 cm polystyrene foam is applied to the exterior walls instead of 1.2 cm (ECD-2), the heating and cooling loads change to 65.1 GJ and 0.6 GJ, respectively. Then, floor insulation is increased to 7 cm from 4.5 cm and roof insulation is changed to 15 cm from 10 cm (ECD-3) and the heating and cooling loads are found out as 60.7 GJ and 0.6 GJ. Further, the insulation material applied to walls is increased to 4 cm from 2 cm (ECD-4). The results for heating and cooling loads are 50 GJ and 0.8 GJ.

Trombe wall: The building labeled as ECD-4 is chosen and different areas of Trombe Wall (7.7 m^2, 5.1 m^2, and 2.5 m^2) are applied on ground and first floors to see the effect of Trombe wall on thermal performance. The building with 7.7 m^2 Trombe wall area (ECD-5) has 48.7 GJ heating load. The buildings with 5.1 m^2 and 2.5 m^2 Trombe wall areas (ECD-6 and ECD-7) have 48.8 and 48.9 GJ heating loads, respectively.

Greenhouse: The building labeled as ECD-4 is chosen and different areas of greenhouse (9 m^2, 14.25 m^2, and 21.25 m^2) are applied. The heating and cooling loads for ECD-8 having 9 m^2 greenhouse, for ECD-9 having 14.25 m^2 greenhouse, and for ECD-10 having 21.25 m^2 greenhouse are 34.3 and 2.4 GJ, 33.4 and 3.3 GJ, and 30 GJ and 6.2 GJ, respectively.

At this stage, building with 14.25 m^2 area greenhouse (ECD-9) is chosen and different areas of Trombe Wall (7.7 m^2, 5.1 m^2, and 2.5 m^2) are applied on ground and first floors. The heating loads for ECD-11 having 15.4 m^2 total Trombe wall, for ECD-12 having 10.2 m^2 total Trombe wall, and for ECD-13 having 5 m^2 total Trombe wall are found to be 32.1, 32.5 and 32.9 GJ, respectively.

Rockbin: The building labeled as ECD-12 is chosen and different areas of rockbin storage (3x5 m^2, 4x2 m^2, and 3x1 m^2) having 30 cm thickness are applied. The heating loads for ECD-14 having 3x5 m^2 area rockbin storage, ECD-15 having 4x2 m^2 area rockbin storage, and ECD-16 having 3x1 m^2 area rockbin storage are 32.4, 32.6, and 32.8 GJ, respectively.

4.2 Results and discussion

The conventionally designed dwelling (CDD) has a total energy demand of 90.7 GJ whereas the energy conscious dwelling which has been established through several runs (ECD-16) has a minimum total energy demand of 35 GJ. The percent of energy saved is about 64 GJ.

In the modification steps which aim to develop an energy conscious dwelling from a conventionally designed one it is observed that after proper orientation of the building, significant factors are insulation material thickness and greenhouse. Just by changing the orientation of a dwelling from north to south, 7.9% of the energy is saved. The designed wall which has a better U-value than the Thermal Insulation Regulations of Turkey results in 37% less energy demand. Addition of greenhouse is also very beneficial, however, it is observed that the difference between energy savings of the three different sized greenhouses is not vital. Therefore, the middle sized greenhouse is chosen due to economical aspects and architectural preferences. On the other hand, although the application of Trombe walls and rockbin storage of different sizes does not seem to be effective in improving the energy savings notably, they are found helpful in achieving thermal comfort by regulating the inside temperature differences. Among the different sized Trombe walls, the middle sized one is found feasible. The case with 10.2 m^2 total Trombe wall area requires only 0.5 GJ more energy then the case with 15.4 m^2 one.

Among the cases utilizing different sized rockbin storage, the case with smallest rockbin storage is chosen taking into account the company's commercial approach and the fact that rockbin storage does not effect the energy demand of the dwelling positively, but only regulates the inside temperature differences. Parametric studies have been carried on cases in which rockbin storage utilized and not utilized. It has been observed that in January, February, November, and December, when the intensity of solar radiation is low, utilization of rockbin storage causes a 0.5°C decrease in interior temperature. On the other hand, in March, April, and May utilization of rockbin causes a remarkable increase in interior temperature all through the day and night when compared with cases in which rockbin storage is not utilized.

The summer and winter usage of the energy conscious dwelling for maximum efficiency is shown in Fig. 6. Natural ventilation and preventing solar radiation is established as the key processes in summer. In winter, acceptance of maximum solar radiation, utilization of convective heat transfer between the greenhouse and the interior spaces, thermal storage, and application of night insulation are taken as the main features of energy efficiency.

5. Further remarks and conclusion

The study is carried out to demonstrate the advantages of an energy conscious dwelling over a conventionally designed one in terms of thermal efficiency in climatic conditions of Ankara. The results of the design and simulation procedure have shown that by only utilizing the correct orientation, insulation material, and passive solar applications, it is possible to achieve climate responsive and energy efficient architecture with energy savings more than 60%.

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LIST OF FIGURE CAPTIONS

Fig. 1. Plans, section, and elevations of the conventionally designed and the energy consciously designed dwellings.

Fig. 2. Model of the conventionally designed and the energy consciously designed dwellings.

Fig. 3. Detailed drawing of water heating system.

Fig. 4. Detailed drawing of rockbin storage.

Fig. 5. Detailed drawing of fireplace.

Fig. 6. Summer and winter usage of energy conscious dwelling.

Table 1. Building materials of the twinhouse.

Conventional Design					
Floor:	1 cm parquet	5 cm concrete	4.5 cm polystyrene foam	15 cm concrete	
Flat roof:	2 cm plaster	12 cm concrete	10 cm polystyrene foam	5 cm concrete	
Windows:	Wooden sash with double glazing having a 2.9 W/m^2K U-value.				
Exterior wall:	2 cm plaster	19 cm brick	3 mm polystyrene foam	9 cm brick	3 cm plaster
Energy Conscious Design					
Floor:	1 cm parquet	5 cm concrete	4.5 cm polystyrene foam	15 cm concrete	
Flat roof:	2 cm plaster	12 cm concrete	10 cm polystyrene foam	5 cm concrete	
Windows:	Wooden sash with double glazing having a 2.9 W/m^2K U-value.				
Exterior wall:	2 cm plaster	19 cm brick	1.2 cm polystyrene foam	9 cm brick	3 cm plaster