PERGAMON

Building and Environment 35 (2000) 33–40

BUILDING AND ENVIRONMENT

www.elsevier.com/locate/buildenv

# Energy conscious dwelling design for Ankara

F. Nur Demirbilek[a,*], Ugur G. Yalçiner[a], Mehlika N. Inanici[a], Ahmet Ecevit[b], Oya Saritabak Demirbilek[a]

[a]*Middle East Technical University, Faculty of Architecture, 06531, Ankara, Turkey*
[b]*Middle East Technical University, Department of Physics, 06531, Ankara, Turkey*

Received 8 June 1998; accepted 12 August 1998

**Abstract**

The study aims to develop energy conscious dwellings in climatic conditions of Ankara. Since the computer program SUNCODE-PC is used for 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. 

## 1. Introduction

The client (Yüksel Project International Inc.) asked for a new-built dwelling design scheme to fulfil 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°59′ E longitude with 895 m altitude. The client also asked for 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 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 [1] 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 [2]. 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;
- night insulation on energy savings.

## 2. Simulation program

### 2.1. SUNCODE-PC

A 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 [3]. The choice of SUNCODE-PC is done referring to a study that had been carried out to establish the reliability of eleven

* Corresponding author. Tel.: +90-312-210-6233; fax: +90-312-210-1249.
*E-mail address:* demirbil@vitruvius.arch.metu.edu.tr (F.N. Demirbilek)

0360-1323/00/$ - see front matter 
PII: S0360-1323(98)00069-9

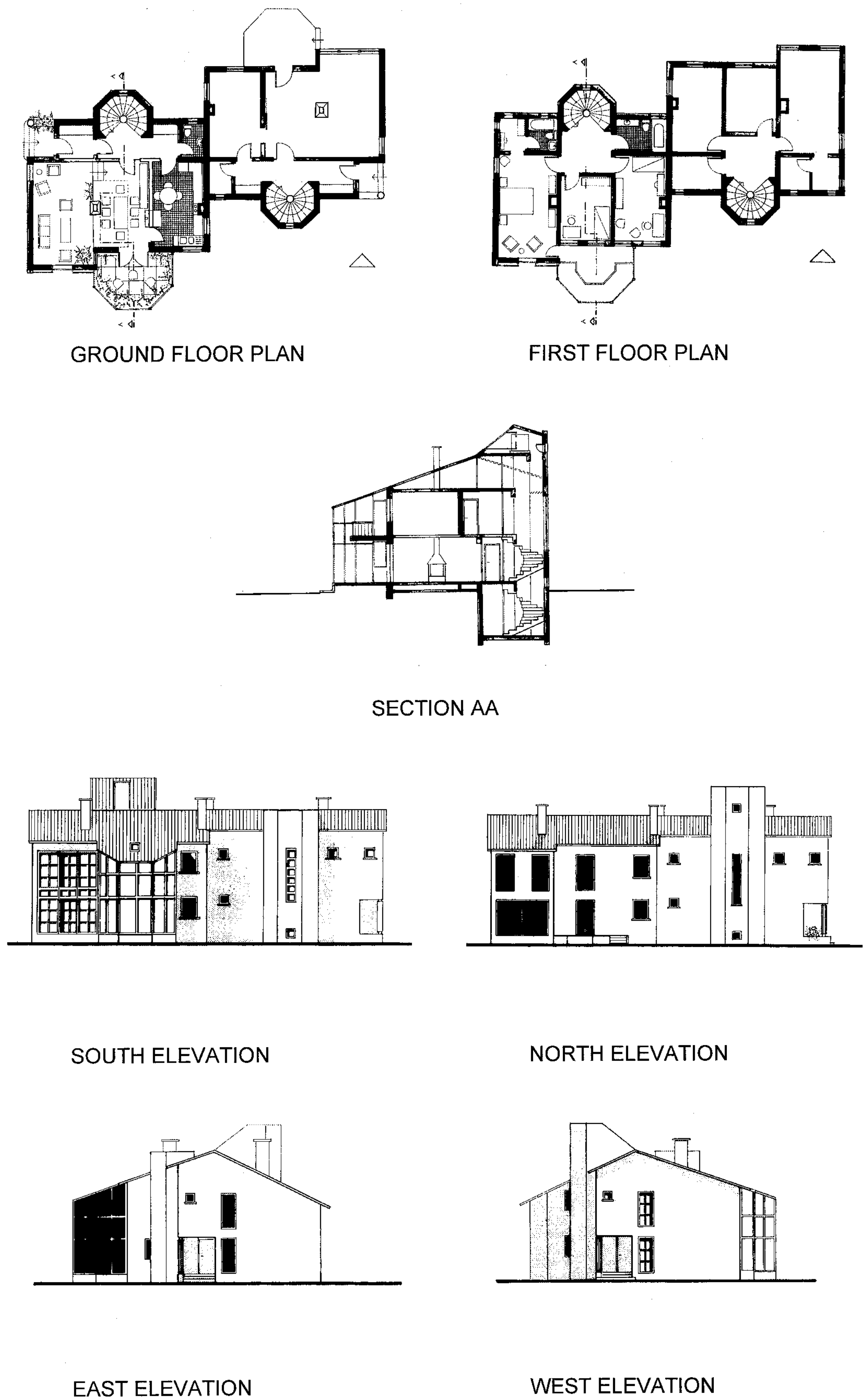


Fig. 1. Plans, section, and elevations of the conventionally designed (CDD) and the energy consciously designed (ECD) dwellings.

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

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 [4].

### 2.2. Weather tapes

The hourly climatic data of direct normal solar radiation (KJ/m$^2$), total horizontal radiation (KJ/m$^2$), ambient and dew point temperatures (°C), and wind speed (m/s) 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 Fakioglu and Ecevit [5]. 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 152 m$^2$. These two dwellings are designed as a twin house separated from 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 photographs of the model are given in Figs. 1 and 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 the north to act as a buffer zone in both floors. The apertures are mainly placed south and are kept minimum in north, west, and east. A greenhouse which serves to two floors is added in the energy conscious dwelling.

Table 1
Building materials of the twinhouse

| | | | | | |
|---|---|---|---|---|---|
| Conventional design (CDD) | | | | | |
| 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$^2$K $U$-value | | | | |
| Exterior wall | 2 cm plaster | 19 cm brick | 3 mm polystyrene foam | 9 cm brick | 3 cm plaster |
| Energy conscious design (ECD) | | | | | |
| 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$^2$K $U$-value | | | | |
| Exterior wall | 2 cm plaster | 19 cm brick | 1.2 cm polystyrene foam | 9 cm brick | 3 cm plaster |

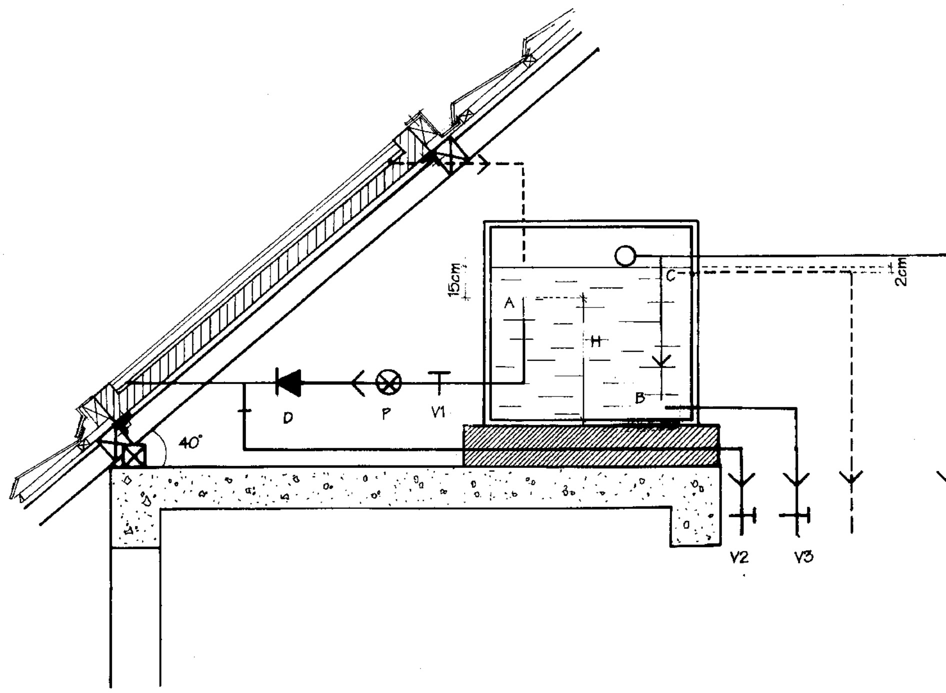


Fig. 3. Detailed drawing of water heating system.

### 3.3. Building materials

Both in the conventional and energy conscious designs, building materials are chosen so as to fulfil 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 to 7 cm for floor, 10 to 15 cm for roof, and from 1.2 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$^2$K, 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 have a common use for privacy in Turkey anyway, decreases the $U$-value of the glazing to 2.0 W/m$^2$K and is assumed to be applied to windows in winter nights between 19:00 and 07:00 h.

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

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

#### 3.4.3. Greenhouse

The greenhouse is located 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 on the first floor.

#### 3.4.4. Stairwell and water heating system

The 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, the solar water heating system is placed on top of the stairwell in order to provide the hot water supply to the occupants. As a 40° inclined surface is needed for solar water heating systems 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. A water tank is placed in the attic space of the stairwell.

The collector (Fig. 3) is dimensioned as

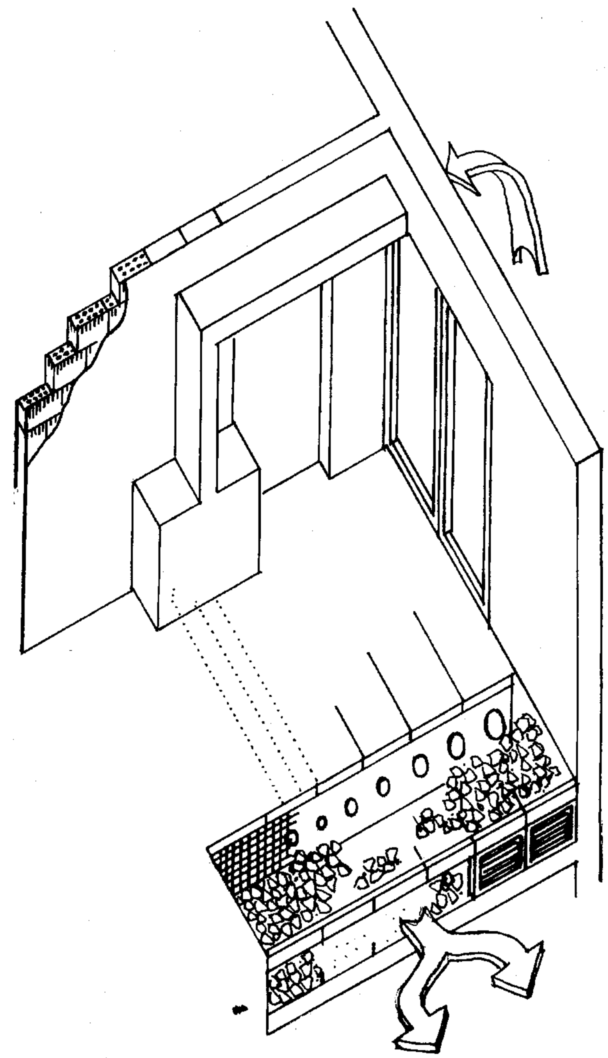

Fig. 4. Detailed drawing of rockbin storage.

200 × 100 × 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 1 $m^2$ and the collector is provided by the aid of a pump (P). The water inlet (A) of the collector is 15 cm below the water level. The 2 $m^2$ collector is planned to heat 170 lt water. The hot water outlet (C) is situated 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 the tank, V3 valve should be opened [6].

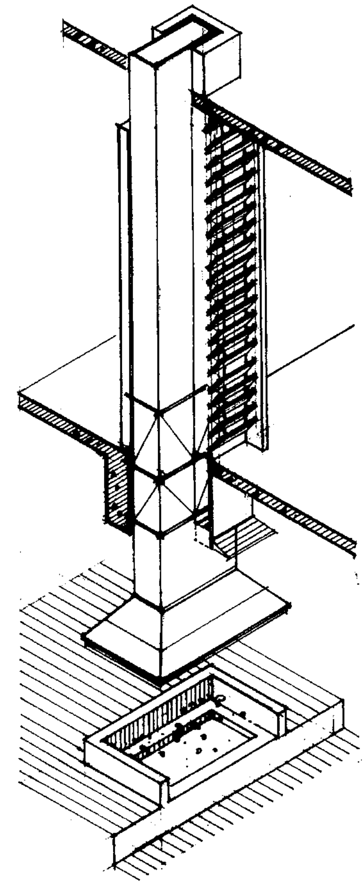

Fig. 5. Detailed drawing of fireplace.

### 3.4.5. Rockbin

A level difference is created between the 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 are 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, the efficiency of fireplaces is 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. The efficiency of fireplaces can be increased by utilizing the heat energy of outgiven 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

Table 2
Results of thermal performance analysis in terms of GJ and percentage

| Label | Heating load (GJ) | Cooling load (GJ) | Total load (GJ) | Amount of heating load saved w.r.t. CDD (GJ) | Percentage of heating load saved (%) |
|---|---|---|---|---|---|
| CDD | 90.7 | 0.0 | 90.7 | – | – |
| ECD-1 | 83.5 | 0.3 | 83.8 | 7.2 | 7.9 |
| ECD-2 | 65.1 | 0.6 | 65.7 | 25.6 | 28.2 |
| ECD-3 | 60.7 | 0.6 | 61.3 | 30.0 | 33.1 |
| ECD-4 | 50.0 | 0.8 | 50.8 | 40.7 | 44.9 |
| ECD-5 | 48.7 | 0.4 | 49.1 | 42.0 | 46.3 |
| ECD-6 | 48.8 | 0.5 | 49.3 | 41.9 | 46.2 |
| ECD-7 | 48.9 | 0.7 | 49.6 | 41.8 | 46.1 |
| ECD-8 | 34.3 | 2.4 | 36.7 | 56.4 | 62.2 |
| ECD-9 | 33.4 | 3.3 | 36.7 | 57.3 | 63.2 |
| ECD-10 | 30.0 | 6.2 | 36.2 | 60.7 | 66.9 |
| ECD-11 | 32.1 | 2.9 | 35.0 | 58.6 | 64.6 |
| ECD-12 | 32.5 | 3.0 | 35.5 | 58.2 | 64.2 |
| ECD-13 | 32.9 | 3.2 | 36.1 | 57.8 | 63.7 |
| ECD-14 | 32.4 | 3.1 | 35.5 | 58.3 | 64.3 |
| ECD-15 | 32.6 | 3.1 | 35.7 | 58.1 | 64.1 |
| ECD-16 | 32.8 | 3.1 | 35.9 | 57.9 | 63.8 |

between. While the hot chimney gasses and smoke are passing through the inner chimney, they heat up the air located between the inner and outer metal chimneys. The naturally rising hot air can be taken to the inside of the master bedroom through a perforated chimney surface on 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

### *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.

The 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 conventially designed dwelling (Table 2).

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

#### *4.1.1. Orientation*

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 and 0.3 GJ, respectively.

#### *4.1.2. 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 and 0.6 GJ, respectively. Then, floor insulation is increased to 7 cm from 4.5 cm and the roof insulation is changed to 15 cm from 10 cm (ECD-3) and the heating and cooling loads are found to be 60.7 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 and 0.8 GJ.

#### *4.1.3. Trombe wall*

The building labeled as ECD-4 is chosen and different areas of Trombe wall (7.7, 5.1, and 2.5 $m^2$) are applied on ground and first floors to see the effect of the 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 and 2.5 $m^2$

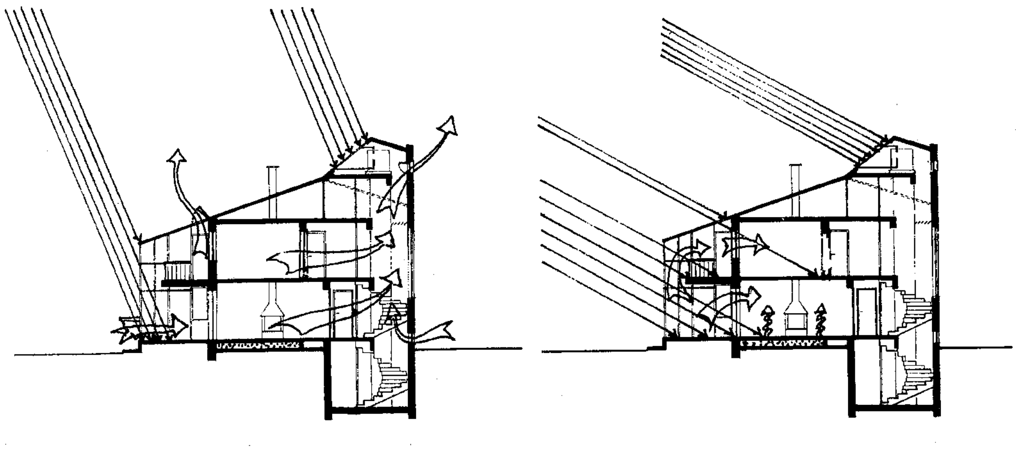


Fig. 6. Summer and winter usage of energy conscious dwelling.

Trombe wall areas (ECD-6 and ECD-7) have 48.8 and 48.9 GJ heating loads, respectively.

*4.1.4. Greenhouse*

The building labeled as ECD-4 is chosen and different areas of greenhouse (9, 14.25, 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, 33.4 and 3.3, and 30 and 6.2 GJ, respectively.

At this stage, a building with 14.25 $m^2$ area greenhouse (ECD-9) is chosen and different areas of Trombe wall (7.7, 5.1, 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.

*4.1.5. Rockbin*

The building labeled ECD-12 is chosen and different areas of rockbin storage ($3 \times 5$, $4 \times 2$, and $3 \times 1$ $m^2$) having 30 cm thickness, are applied. The heating loads for ECD-14 having $3 \times 5$ $m^2$ area rockbin storage, ECD-15 having $4 \times 2$ $m^2$ area rockbin storage, and ECD-16 having $3 \times 1$ $m^2$ area rockbin storage, are 32.4, 32.6, and 32.8 GJ, respectively.

## 5. 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. The addition of a 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 notably effective in improving energy savings, they are found to be 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 than the case with 15.4 $m^2$ area.

Among the cases utilizing different sized rockbin storage, the case with the smallest rockbin storage is chosen, taking into account the company's commercial approach and the fact that rockbin storage does not affect the energy demand of the dwelling positively, but only regulates inside temperature differences. Parametric studies have been carried out on cases in which rockbin storage is 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 the rockbin causes a remarkable increase in interior temperature all through the day and night 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 are 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.

## 6. 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 the climatic conditions of Ankara. The results of the design and simulation procedure have shown that by utilizing only 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%.

## Acknowledgements

The work at the METU was sponsored by the Yüksel Project International Inc. under contract METU-AGÜDÖS 93-02-01-12. The authors wish to express their appreciation to Nezih Kirbeyi, Irfan Uygur, Beril Baysal, and Ebru Yilmaz for help in carrying out the research.

## References

[1] BIY, Building insulation regulation of Turkey, 16 Ocak 1985 tarihli Resmi Gazete, Ankara, 9-35, 1985 [in Turkish].

[2] Demirbilek FN, Yalçiner U, Ecevit A, Baysal B, Inanici M, Kirbeyi N, Saritabak O, Uygur I. Energy efficient building design for climatic conditions of Ankara, ODTÜ-AGÜDÖS Project No: 93-02-01-12 Ankara, 1993 [in Turkish].

[3] DeLaHunt MJ. SUNCODE-PC. A program user's manual. Seattle: Ecotope Inc, 1985.

[4] Holtz MJ. Passive and hybrid low energy buildings (vol. 3. Design guidelines: An international summary). Washington: US Government Printing Office, 1990.

[5] Fakioglu T, Ecevit A. A procedure to obtain the average daily total and the hourly values of solar radiation for Turkey. TR Journal of Physics 1995;19:681–8.

[6] Ecevit A. Personal communication.