# COVER SHEET

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# A Study on Sizing Solar Apertures for Ankara

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*Abstract*

*This study aims to find optimum values for sizing the windows and Trombe walls and to develop rules of thumb for the climatic conditions of Ankara, which has cold and long winters and hot summers. On a test building having a floor area of 100 m² and a test room with a floor area changing from 10 to 50 m², the effect of the size of windows and Trombe walls on heating, cooling, and total energy needs of the room have been analysed by the help of the computer program named "SUNCODE". Computer simulations are carried out and optimum values for energy demand are obtained and tables are prepared.*

## 1. INTRODUCTION

Solar apertures play an important role in buildings from the energy efficiency point of view. Direct gain windows and Trombe walls are common passive solar apertures in residential energy design. In energy conscious buildings heat gains through carefully sized equatorial-facing window areas may be twice the solar gain of an average home.

During the design phase, rules of thumb are necessary for the designer to determine relative sizes of the solar apertures. Rules of thumb are generally climate dependent ratios of building elements relative to the other dimensions of the building. So for almost every location a set of rules of thumb is necessary since both climatic factors and widely used materials, and design and construction techniques may vary.

Within the framework of the study, a parametric study for sizing solar apertures for the conditions of Ankara is carried out by means of computer simulation. Ankara, capital city of Turkey, is located at 39°57'N latitude and 32°53'E longitude at Central Anatolia with an 895m altitude. Being away from seas, it shows temperate-arid climatic characteristics having long and cold winters, short and dry summers with a 90% heating ratio, 10% cooling ratio (Inanici, M. and Demirbilek, F.N., 2000). Table 1 gives a brief idea of the climate of Ankara (Mean and Extreme Meteorological Bulletin, 1974).

**Table 1. Monthly Average Temperature Data of Ankara (°C).**

| Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.1 | 0.6 | 5.8 | 10.6 | 15.0 | 19.0 | 22.1 | 22.1 | 18.0 | 12.6 | 7.9 | 3.5 |

### 1.1. Weather Tapes

The hourly climatic data of direct normal solar radiation (KJ/m²), total horizontal radiation (KJ/m²), ambient and dew point temperatures (K), 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 Fakioglu, 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.

### 1.2. Software

SUNCODE-PC, the microcomputer version of SERI/RES, has been utilized as the software for the parametric runs. Parametric study consists of the systematic manipulation of one variable (independent), making measurements on another variable (dependent) thought to be directly influenced by the independent variable, while keeping all other conditions constant by means of control variables. The independent variable is the size of apertures, i.e. size of window in the study of window + wall configuration and size of Trombe wall in the study of Trombe wall + window + wall configuration. On the other hand, the dependent variable is the yearly energy need for cooling, heating, and energy need for the sum of these two whereas control variables are orientation, building form, interior zones, building materials, heating and venting set-points, and night insulation which are kept unchanged for all cases.

## 2. DESCRIPTION OF THE TEST BUILDING AND ASSUMPTIONS

The test building to be used in parametric runs is a simple building designed with the following assumptions:

### 2.1. Orientation

Mazria (1979) defines the best orientation for the solar apertures of a building as one, which receives the maximum amount of solar radiation in winter and the minimum amount in summer. In the northern hemisphere, southern facades of buildings receive the maximum amount of solar radiation in winter and the minimum amount in summer and some variation from true south does not affect the heat balance of buildings much. Thus, in the study of sizing solar apertures, building apertures are oriented towards south.

### 2.2. Building Form

Designing the building form from the perspective of energy efficiency means considering floor area, perimeter, building height and aspect ratio. Since a previous study, gave out an aspect ratio of 1:1.25 for Ankara (Demirbilek *et al*, 1994) this value is accepted for buildings with a 100 m² floor area.

### 2.3. Interior Zones

The building is simply a rectangle with the dimensions of 11.2 m. by 8.9 m. and having mainly two zones. One of the zones is the room for which solar aperture optimization is carried out (Zone A in Fig.1) and the second zone is the rest of the building (Zone B in Fig.1). Zone A has only the southern facade as an exterior wall on which aperture sizes are studied. Other walls of Zone A are all interior walls looking to Zone B, hence the situation where Zone A has another exterior wall is not studied. Zone B is designed to have no windows. In this way it is assumed that the temperature of Zone B would not change very rapidly and would not fluctuate much so that heat transfer from Zone A to Zone B would not vary much, so the effects of solar apertures on the room's (Zone A) energy demand for cooling and heating would be more easy to predict.

### 2.4. Building Materials

Energy conscious design requires at least the minimum thermal values for building elements defined by building codes and regulations. Exterior walls, floor, and ceiling must be designed according to the minimum U-values determined in the "Building Thermal Insulation Regulations" prepared by the Ministry of Reconstruction (1985). From the commonly used building construction types a massive combination of materials for exterior walls is chosen to increase thermal storage capacity and decrease interior temperature fluctuations, fulfilling the requirements, as 3 cm exterior plaster, 9 cm hollow brick, 2.5 cm polystyrene as insulation material, 19 cm hollow brick, and 2 cm interior plaster. Floor is composed of 1 cm parquet, 5 cm leveling concrete, 4.5 cm polystyrene and 15 cm concrete whereas ceiling has 2 cm inner plaster, 12 cm reinforced concrete and 10 cm polystyrene.

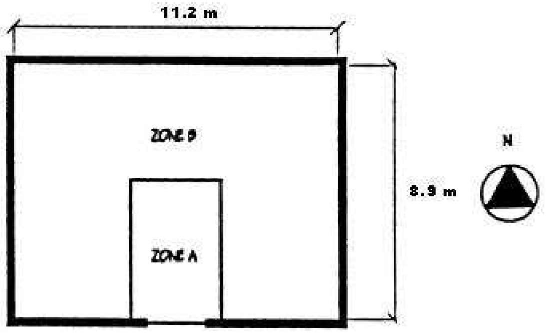


**Figure 1. Plan of the test building showing interior zones**

## 2.5. Heating and Venting Set-points

Comfort temperature can be defined as 2l°C indoors in dwellings or offices, when mean radiant temperature is equal to air temperature, for 40-60% relative humidity range, for a person with an activity level of 1.3 Met, which corresponds to light household work or office work, and a clothing level of 0.8 Clo (Arens, *et al*, 1980). It is assumed that heat radiated from lighting and cooking appliances and from people with a normal activity level having winter clothes, increase the indoor air temperature by 3°C. Hence, heating set-point of HVAC unit is set as l8°C. Ventilation set-point is set as 24°C. Cooling set-point of HVAC unit is set as 26°C, so that HVAC unit starts to cool the interior when interior temperature exceeds 26°C.

## 2.6. Night Insulation

Movable insulation devices increase the energy efficiency of direct solar systems during long winter nights. However, system most probably will not operate efficiently since the operation of movable insulation is dependent on the inhabitants in common use of manual devices. However, simple curtains used for privacy act as simple but effective night insulation to reduce heat losses through apertures. Thus, it is assumed that curtains are closed between 19:00 and 7:00 hours and U-values of windows are taken into consideration as 2.9 W/m² K for the daytime and as 2.0 W/m² K for the nighttime.

# 3. RESULTS AND DISCUSSION OF SOLAR APERTURE OPTIMIZATION

The study is carried out for 44 different room alternatives with and without the application of ventilation. In the design stage, architects who have decided the area required for a room can choose one of the dimension alternatives which is closer to the one in their minds and design according to the optimum values found for the glazing area. Dimensions for different room areas are shown in Table 2. Room dimensions in the table present the width and depth of the room, respectively.

**Table 2. Room dimensions for different room areas analyzed in solar aperture optimization study.**

| Area (m²) | Room Dimensions (m x m) | | | | | | |
|---|---|---|---|---|---|---|---|
| 10 | 2.5 x 4.0 | 2.8 x 3.5 | 3.0 x 3.3 | 3.3 x 3.0 | 3.5 x 2.8 | 4.0 x 2.5 | |
| 15 | 3.0 x 5.0 | 3.3 x 4.5 | 3.75 x 4.0 | 4.0 x 3.75 | 4.5 x 3.3 | 5.0 x 3.0 | |
| 20 | 3.5 x 5.7 | 4.0 x 5.0 | 4.4 x 4.5 | 4.5 x 4.4 | 5.0 x 4.0 | 5.7 x 3.5 | |
| 25 | 4.0 x 6.3 | 4.5 x 5.6 | 5.0 x 5.0 | 5.6 x 4.5 | 6.3 x 4.0 | | |
| 30 | 4.0 x 7.5 | 4.5 x 6.7 | 5.0 x 6.0 | 5.5 x 5.5 | 6.0 x 5.0 | 6.7 x 4.5 | 7.5 x 4.0 |
| 40 | 4.5 x 8.9 | 5.0 x 8.0 | 6.0 x 6.7 | 6.3 x 6.3 | 6.7 x 6.0 | 8.0 x 5.0 | 8.9 x 4.5 |
| 50 | 5.0 x 10.0 | 5.6 x 9.0 | 6.3 x 8.0 | 7.1 x 7.1 | 8.0 x 6.3 | 9.0 x 5.6 | 10.0 x 5.0 |

Unventilated case is the situation, which occurs when the inhabitants are not at home. Conversely, ventilated case is the situation that occurs when the inhabitants are at home and open the windows when overheating occurs. An architect, when designing, should consider the user occupancy and choose optimum values accordingly. For this reasons the study is made both for an unventilated and ventilated case.

### 3.1. Window + Wall Configuration Study

In this part of the study, annual energy consumption for heating, cooling, and sum of cooling and heating are studied as a function of glazing area to southern wall area ratio increasing with 10% increments. The results are plotted to form charts. Heating, cooling, and total energy needs of rooms with a floor area of 10 m² and varying dimensions for ventilated case are given as an example to the resulted charts of the computer runs in Fig. 2. Then optimum demand for heating, cooling, and total energy needs are read from these charts and tables are prepared in order to decrease the number of resulting charts into a compact form to be used in the design stage.

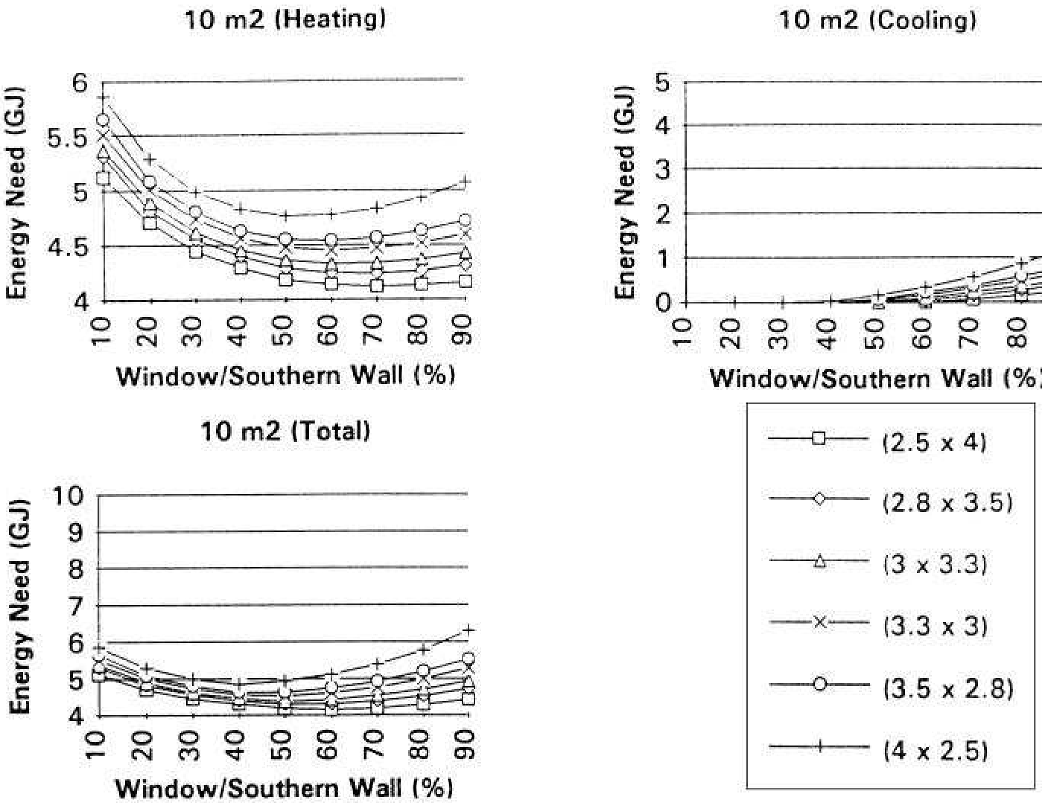


**Figure 2. An example to the resulting charts for window + wall configuration study: Heating, cooling, and total energy needs of a room with a floor area of 10 m² and varying dimensions for ventilated case.**

The results showed that in both ventilated and unventilated cases there is an optimum area of glazing for each different room alternative. For glazing area percentages that are bigger than the optimum percentage, increase in energy demand for cooling is much higher compared to the decrease in energy need for heating.

Apparently energy need for heating does not change much between the unventilated and ventilated cases hence, optimum-glazing area for heating energy need does not change between these two. On the other hand, energy need for cooling is smaller in the ventilated case, since overheating is prevented most of the time by ventilation when the interior temperature exceeds 24°C. In the analysis of results for cooling it can be seen that there is no need for cooling until a certain glazing percentage. From that point on energy need for cooling starts to increase as the glazing area increases. Although the amount of energy need differ considerably for high percentages of glazing area, optimum-glazing area does not show a big difference between the unventilated and ventilated cases.

Total energy need decrease considerably in high percentages of glazing area in the ventilated case, when compared with that of the unventilated case. An increase of 10% to 20% is seen in optimum glazing area for total energy need of the ventilated case due to the effect of venting.

Since optimum glazing area is mostly stated as a ratio of glazing to floor area ratio, optimum glazing to wall area ratios are converted to glazing / floor area ratio to make the results comparable with the optimums found in literature. Table 3 shows upper and lower levels of optimum glazing area / floor area ratios for heating, cooling, and total energy need of specific room areas and can be accepted as a general rule of thumb for Ankara. Table shows that as the rooms' floor area increases, allowed range of optimum glazing area decreases in both ventilated and unventilated cases and it can be seen that ventilated case allows higher ratios of glazing.

**Table 3. Upper and lower levels of optimum glazing area / floor area ratios for the unventilated and ventilated cases.**

| Room Area | Optimum Glazing / Floor Area | | | |
|---|---|---|---|---|
| | Heating | Cooling | | Total |
| | | Unventilated | Ventilated | |
| 10 | 0.52-0.72 | 0.31-0.40 | 0.40-0.48 | 0.42-0.49 |
| 15 | 0.53-0.70 | 0.27-0.33 | 0.36-0.40 | 0.37-0.45 |
| 20 | 0.53-0.60 | 0.22-0.27 | 0.33-0.37 | 0.36-0.42 |
| 25 | 0.43-0.60 | 0.23-0.27 | 0.30-0.33 | 0.33-0.40 |
| 30 | 0.36-0.60 | 0.20-0.25 | 0.28-0.30 | 0.3l-0.38 |
| 40 | 0.30-0.60 | 0.18-0.20 | 0.25-0.28 | 0.33-0.36 |
| 50 | 0.27-0.54 | 0.16-0.20 | 0.23-0.27 | 0.27-0.36 |

### 3.2. Trombe Wall + Window + Wall Configuration Study

Due to architectural considerations like natural lighting, natural ventilation and having vista, in most energy conscious buildings Trombe wall is used in combination with direct gain glazing rather than alone. Thus, in this part of the study Trombe wall + window + wall configuration is analyzed in order to obtain optimum Trombe wall / southern wall ratios. Annual energy consumption for heating, cooling, and sum of cooling and heating are studied as a function of Trombe wall area to southern wall area ratio increasing with 10% increments and results are plotted to form charts. Heating, cooling, and total energy needs of rooms with a floor area of 10 $m^2$ and varying dimensions for ventilated case are given as an example to the resulted charts of the computer runs in Fig.4.

Glazing areas of 8%, 12%, 16%, and 20% of the room's floor area are kept constant and Trombe wall area to southern wall area ratio is studied. Here, 12% glazing corresponds to 1/8 of the room's floor area, which should be the minimum glazing area for day lighting in living rooms and bedrooms according to Building Codes and Regulations of Ankara (1991) and 8% glazing corresponds to 1/12 of room's floor area, which should be the minimum glazing area for day lighting in other rooms.

Neither the energy need for heating nor the optimum Trombe wall area changes much between the unventilated and ventilated cases. Energy need for cooling is smaller in the ventilated case, since overheating is prevented. Although energy need for cooling differ considerably, optimum-glazing area for cooling energy need does not change between the unventilated and ventilated cases. In unventilated case there is an optimum area of Trombe wall for total energy need of each, different room alternative and for each specific window / floor percentage (i.e. 8%, 12%, l6%, and 20%). In ventilated case it seems advantageous to use a Trombe wall area as large as possible.

As optimum Trombe wall area is mostly stated as a ratio of glazing to floor area ratio as well, optimum Trombe wall to southern wall area ratios are converted to Trombe wall to rooms' floor area ratio to make the results comparable with the optimums found in literature. Table 4 shows upper and lower levels of optimum Trombe wall to floor area ratios for heating, cooling, and total energy needs of floor areas and can be accepted as a general rule of thumb for climatic conditions of Ankara. It can be seen in the table that as the rooms' floor area increases, allowed range of optimum Trombe wall to floor area ratio area decreases and it can also be seen that allowed range of optimum Trombe wall area to floor area ratio decreases as the window area to floor area increases from 8% to 20%.

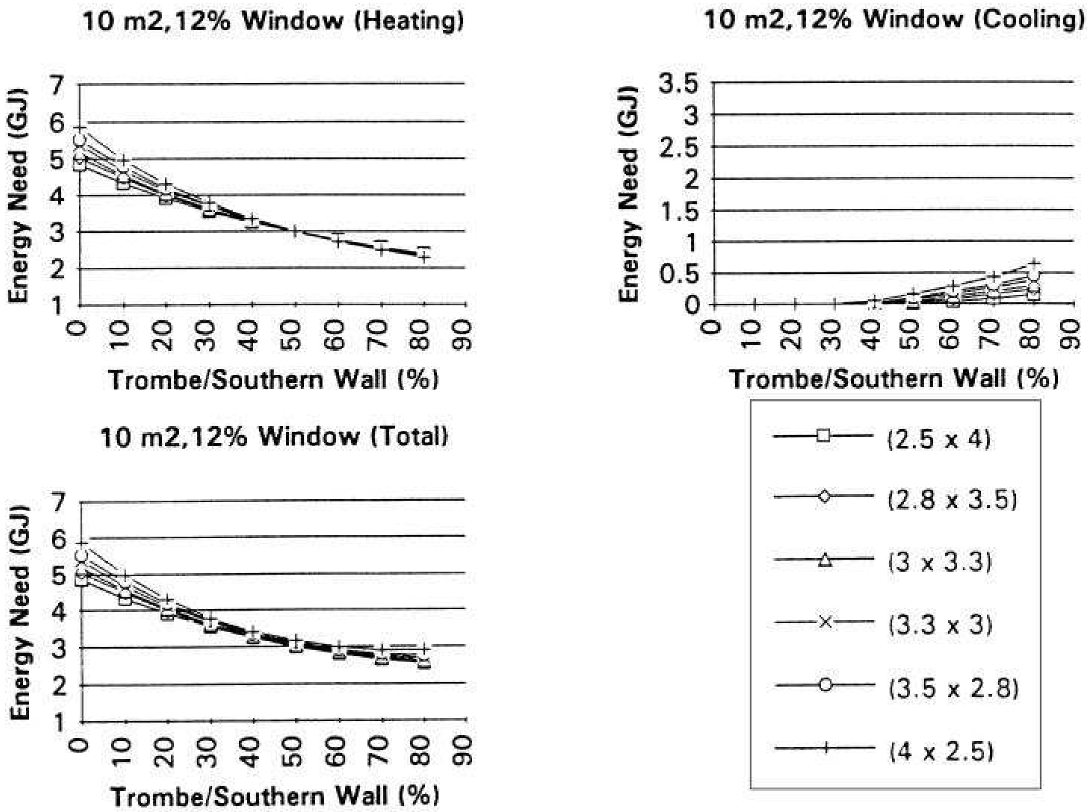


**Figure 4. An example to the resulting charts for Trombe wall + window + wall configuration study: Heating, cooling, and total energy needs of a room with a floor area of 10 m² and varying dimensions for ventilated case.**

## 4. CONCLUSION

Energy efficient building is the end product of energy conscious design. If the designer is not keen –or not able-- to utilize a thermal analysis tool, a set of rules of thumb to be used in different phases of the design stage is necessary. Windows and Trombe walls, two commonly known solar apertures, provide high amounts of solar gain, thus decreasing fuel consumption of a building and saving energy, thus decreasing the environmental pollution caused by building for achieving thermal comfort. The rules of thumb prepared for Ankara are expected to be helpful for architects in the design stage for sizing the solar apertures and guide and encourage them to utilize solar energy.

**Table 4. Upper and lower levels of optimum Trombe wall area / floor area ratios.**

| Room area | Optimum Trombe Wall Area for Window Area / Floor Area of | | | |
|---|---|---|---|---|
| ($m^2$) | 8% | 12% | 16% | 20% |
| Heating | | | | |
| 10 | 0.67-0.98 | 0.60-0.96 | 0.52-0.96 | 0.52-0.96 |
| 15 | 0.48-0.80 | 0.42-0.80 | 0.42-0.80 | 0.36-0.70 |
| 20 | 0.42-0.77 | 0.36-0.68 | 0.31-0.68 | 0.31-0.60 |
| 25 | 0.38-0.60 | 0.34-0.60 | 0.29-0.53 | 0.24-0.53 |
| 30 | 0.28-0.60 | 0.24-0.60 | 0.20-0.52 | 0.16-0.52 |
| 40 | 0.24-0.53 | 0.20-0.53 | 0.l7-0.47 | 0.13-0.40 |
| 50 | 0.21-0.48 | 0.15-0.42 | 0.12-0.42 | 0.09-0.36 |
| Cooling | | | | |
| 10 | 0-0.40 | 0-0.34 | 0-0.30 | 0-0.25 |
| 15 | 0-0.30 | 0-0.26 | 0-0.20 | 0-0.18 |
| 20 | 0-0.27 | 0-0.21 | 0-0.17 | 0-0.10 |
| 25 | 0-0.24 | 0-0.19 | 0-0.14 | 0-0.11 |
| 3 0 | 0-0.22 | 0-0.16 | 0-0.13 | 0-0.07 |
| 40 | 0-0.18 | 0-0.13 | 0-0.07 | - |
| 50 | 0-0.15 | 0-0.10 | 0-0.06 | - |
| Total | | | | |
| 10 | 0.50-0.60 | 0.45-0.52 | 0.42-0.49 | 0.36-0.48 |
| 15 | 0.42-0.50 | 0.40-0.45 | 0.33-0.40 | 0.30-0.36 |
| 20 | 0.40-0.45 | 0.33-0.37 | 0.30-0.34 | 0.20-0.31 |
| 25 | 0.36-0.40 | 0.30-0.34 | 0.27-0.30 | 0.22-0.27 |
| 30 | 0.28-0.38 | 0.24-0.33 | 0.20-0.30 | 0.16-0.22 |
| 40 | 0.22-0.34 | 0.20-0.27 | 0.17-0.24 | 0.13-0.20 |
| 50 | 0.21-0.30 | 0.l5-0.24 | 0.12-0.22 | 0.10-0.18 |

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## 6. ACKNOWLEDGMENTS

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