PERGAMON

Building and Environment 35 (2000) 41–52

BUILDING AND ENVIRONMENT

www.elsevier.com/locate/buildenv

Thermal performance optimization of building aspect ratio and south window size in five cities having different climatic characteristics of Turkey

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Received 8 June 1998; received in revised form 12 August 1998; accepted 11 December 1998

Abstract

The aim of the study is to establish optimum building aspect ratios and south window sizes of residential buildings from thermal performance point of view. The effects of 6 different building aspect ratios and eight different south window sizes for each building aspect ratio are analyzed for apartments located at intermediate floors of buildings, by the aid of the computer based thermal analysis program SUNCODE-PC in five cities of Turkey: Erzurum, Ankara, Diyarbakir, Izmir, and Antalya. The results are evaluated in terms of annual energy consumption and the optimum values are driven. Comparison of optimum values and the total energy consumption rates is made among the analyzed cities. © 1999 Elsevier Science Ltd. All rights reserved.

1. Introduction

Sizing of a passive solar system is a complex procedure, but plays a significant role in the thermal performance of a building and the efficiency of a system. Besides, the size of a passive solar system is a climate-dependent ratio and should be re-sized for each different climatic condition.

The primary intention of this study is the systematic manipulation of building aspect ratio (B.A.R.) and south window size (S.W.S.) of residential buildings. B.A.R. is the ratio of the length of a building to its width whereas S.W.S. is the ratio of the size of a window facing south to the south facade area. As a rule of thumb, it is known that the appropriate use of south glazing reduces heating loads of buildings. A question of much interest, however, is the extent to which adding more south glass area can further improve the thermal performance. Within the framework of the study, optimum values of the parameters which will reduce heating, cooling, and total loads are driven, and it is hoped that they will help architects in designing more energy-conscious and efficient residential buildings.

2. Procedural methods

2.1. SUNCODE-PC

In this study, computer simulation technique is used because it makes it possible to set up parametric studies that generate relative performance data and SUNCODE-PC, which is a general purpose thermal analysis program for residential and small commercial buildings, is chosen as the software for parametric runs. The method of analysis used in the program is simulation. A thermal model of building is created by the user and it is translated into mathematical form by the program. The mathematical equations are then solved repeatedly at time intervals of one hour or less for the period of simulation, usually one year [1].

2.2. Weather data

The parametric study is repeated for different climatic regions of Turkey. Since the climatic data is

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0360-1323/00/$ - see front matter
PII: S0360-1323(99)00002-5

Table 1
Geographical information of analyzed cities

City	Latitude	Longitude	Elevation (m)
Ankara	39°57′ N	32°53′ E	894
Antalya	36°53′ N	30°42′ E	42
Diyarbakir	37°55′ N	40°12′ E	660
Erzurum	39°55′ N	41°16′ E	1869
Izmir	38°24′ N	27°10′ E	25

only representative of a limited area around a specific station, five cities have been selected as pilot stations to represent different climatic regions. Gürdil and Turan [2] divided Turkey into five climatic regions as follows: cold, temperate-arid, temperate-humid, hot-humid, and hot-arid. High degree of mass-housing potential and being a representative of one of the climatic regions are taken as the selection criteria for the selection of the cities and Erzurum, Ankara, Izmir, Antalya, and Diyarbakir are chosen as the representatives of the regions respectively. Geographical information of the analyzed cities is given in Table 1, their

Fig. 1. The location of the analyzed cities on the map of Turkey.

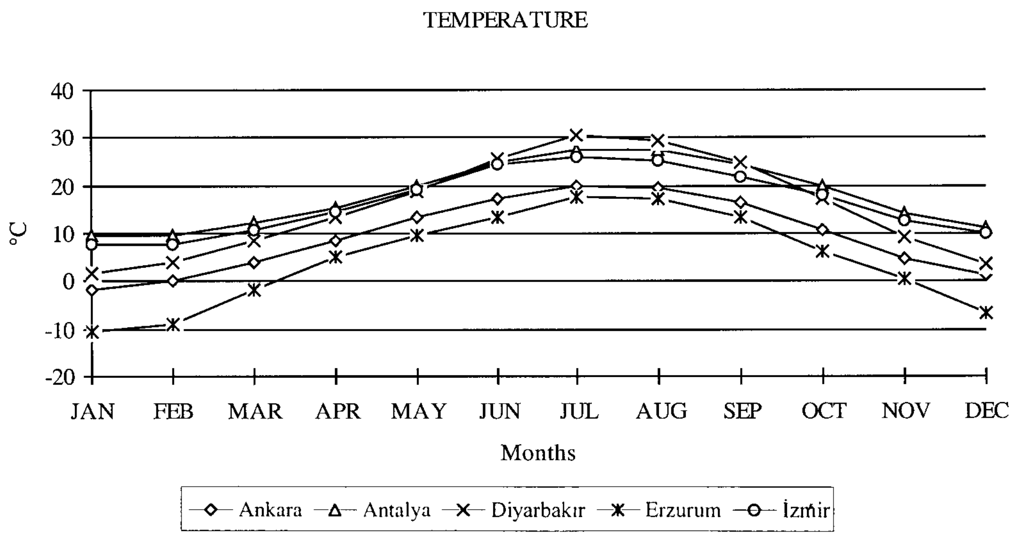

Fig. 2. Monthly mean temperatures of the analyzed cities.

locations are shown on the map of Turkey in Fig. 1, and monthly mean temperatures are presented in Fig. 2.

Hourly ($365 \times 24 = 8760$) direct normal solar radiation (KJ/m^2), total horizontal radiation (KJ/m^2), ambient temperature (°C), dew point temperature (°C), and wind speed (m/s) data are expected as climatic input to the software in a weather file.

Apart from the weather file, SUNCODE-PC requires extra weather information like ground temperature, summer and winter schedules in the building description file. Ground temperature of the cities is assigned from the measurements of monthly average ground temperature taken under 50 cm below surface [3]. Summer and winter schedules for each city are determined by establishing a reference outdoor temperature value for daily average temperatures. A day is accepted as a winter day or a summer day when the mean outdoor temperature is lower or higher than the base temperature (which is taken as 15°C in this study). Summer and winter schedules for the analyzed cities are given in Table 2.

2.3. Description of the basic building model

Within the framework of the study, a building model is developed for simulation purposes. This model represents the scale and occupancy patterns of single family residential units of an apartment building. It is a three-storey building having single zones at the ground and top floors each. The intermediate floor is composed of four zones, representing four units, each having a 100 m^2 floor area and 3 m height which is a common residential building type in Turkey. Plans of the basic building are given in Fig. 3, details of which can be found elsewhere [4]. Zones only located at the intermediate floor are evaluated throughout this parametric study.

2.3.1. The independent variables

The independent variables for each city are B.A.R. and S.W.S., whereas among cities, they are weather data, soil temperature, and summer and winter schedules. The studied B.A.R. are 1:1, 1:1.2, 1:1.4, 1:1.6, 1:1.8, and 1:2. In each case, first analysis is carried out

Table 2
Summer and winter schedules for the analyzed cities

	Winter		Summer	
Cities	From	To	From	To
Ankara	1 October	14 May	15 May	30 September
Antalya	15 November	31 March	1 April	14 November
Diyarbakir	1 November	30 April	1 May	31 October
Erzurum	15 September	14 June	15 June	14 September
Izmir	15 November	31 March	1 April	14 November

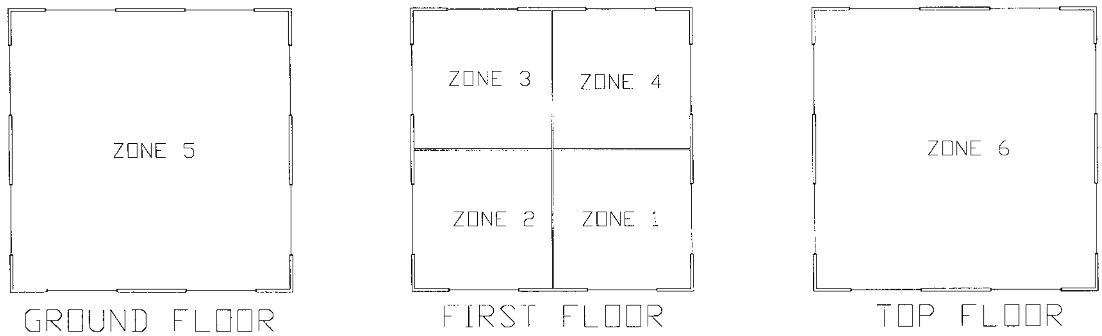

Fig. 3. Plans of the studied building having 1:1 B.A.R.

with 15 m^2 window area which is 15% of the floor area; 15% of window area/floor area is the maximum allowable window size defined by Turkish Insulation Regulation [5] in cases for which thermal insulation projects are not prepared. Total window area in each zone is distributed to facades according to the aspect ratio, i.e., window area/wall area ratio come out as 25% for all facades at the first analysis. At the next stage, the south window area/south wall area ratio is increased to 30% and, then up to 90% by 10% increments. Description of building surfaces of the analyzed building for different building aspect ratios are illustrated in Table 3.

2.3.2. Dependent variables

The dependent variable for the whole parametric study is the annual heating, cooling, and total loads of the building in GJ.

2.3.3. Control variables

Control variables are orientation, building U-value, heating, venting, and cooling set points, night insulation, and shading of glazing.

Orientation: within the context of this parametric study, a storey with four zones representing four units is taken into consideration. Zone 1 faces south and east; zone 2 faces south and west; zone 3 faces north and west; and zone 4 faces north and east.

Building U-value: according to 'Building Thermal Insulation Regulation of Turkey' prepared by the Ministry of Reconstruction [5], Turkey is divided into three climatic regions. Among the cities which have been chosen for this study, Antalya and Izmir are located in the first region, Diyarbakir in the second region, and Ankara and Erzurum in the third region. The minimum allowable R-conduction values for a unit square of exterior walls (R-cond) of regions 1, 2, and 3 are 0.40, 0.60, and 0.79 m^2 K/W respectively. They are 0.56, 0.80, and 1.29 m^2 K/W for floors, and 1.29, 2.07, and 2.58 m^2 K/W for roofs. The maximum allowable overall U-value (window + door + outside wall mean total heat transfer coefficients) for regions 1, 2, and 3 are 2.26, 1.51, and 1.34 W/m^2 K respectively.

Throughout the study, as the S.W.S. changes from 25 to 90% of the south wall area, R-cond value of outside wall should be changed in order to keep a constant overall U-value that satisfies the Building Thermal Insulation Regulation. Therefore, in regions 2 and 3, the thickness of insulation material (styraphor with k value of 0.039 W/m °C) has been increased as window area increases. Insulation thickness varies between 0.6 and 3.6 cm in region 2, and between 0.6 and 9.3 cm in region 3 for the 48 (6 B.A.R. × 8 S.W.S.) different cases. In region 1, as 19 cm brick wall satisfies the Building Thermal Insulation Regulation for all 48 cases, insulation material is not used (Table 4).

Heating, cooling, and venting setpoints: heating, cooling, and venting setpoints of HVAC unit are determined as 18, 26, and 24°C respectively: that is, it is assumed that 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.

Glazing and night insulation: double glazing with a U-value of 2.9 W/m^2 K, extinction coefficient of 0.0197 1/mm and index of refraction value of 1.526 mm is applied to all windows. Night insulation is assumed to be applied to windows in winter nights between 19:00 and 07:00. In order to consider optimal conditions, not a specially designed insulation device, but a simple curtain for windows which also provides privacy, is accepted as night insulation. Therefore, U-values of windows are taken as 2.9 W/m^2 K for daytime and 2.0 W/m^2 K for nighttime.

Shading coefficient of glazing: double glazing with 0.94 shading coefficient is applied to all windows. In summer, a simple inside medium color roller shade is assumed to be half drawn on windows. Therefore,

Table 3
Description of building surfaces of analyzed building for different B.A.R

Ratio 1:1
Building length: 20 m
Building width: 20 m
East and west walls for all zones: 22.5 m^2
East and west windows for all zones: 7.5 m^2
North wall for one zone: 22.5 m^2

Window ratio (%)	South wall (m^2)	South window
25	22.50	7.50
30	21.00	9.00
40	18.00	12.00
50	15.00	15.00
60	12.00	18.00
70	9.00	21.00
80	6.00	24.00
90	3.00	27.00

Ratio 1:1.2
Building length: 22 m
Building width 18.2 m
East and west walls for all zones: 20.55 m^2
East and west windows for all zones: 6.75 m^2
North wall for one zone: 24.75 m^2

Window ratio (%)	South wall (m^2)	South window
25	24.75	8.25
30	23.10	9.90
40	19.80	13.20
50	16.50	16.50
60	13.20	19.80
70	9.90	23.10
80	6.60	26.40
90	3.30	29.70

Ratio 1:1.4
Building length: 23.6 m
Building width: 17 m
East and west walls for all zones: 19.35 m^2
East and west windows for all zones: 6.15 m^2
North wall for one zone: 26.55 m^2

Window ratio (%)	South wall (m^2)	South window
25	26.55	8.85
30	24.78	10.62
40	21.24	14.16
50	17.70	17.70
60	14.16	21.24
70	10.62	24.78
80	7.08	28.32
90	3.54	31.86

Ratio 1:1.6
Building length: 25.4 m
Building width 15.8 m
East and west walls for all zones: 18.2 m^2
East and west windows for all zones: 5.5 m^2
North wall for one zone: 28.6 m^2

Window ratio (%)	South wall (m^2)	South window
25	28.60	9.50
30	26.67	11.43
40	22.86	15.24
50	19.05	19.05
60	15.24	22.86
70	11.43	26.67
80	7.62	30.48
90	3.81	34.29

Ratio 1:1.8
Building length: 26.6 m
Building width: 15 m
East and west walls for all zones: 17.5 m^2
East and west windows for all zones: 5 m^2
North wall for one zone: 29.9 m^2

Window ratio (%)	South wall (m^2)	South window
25	29.90	10.00
30	27.93	11.97
40	23.94	15.96
50	19.95	19.95
60	15.96	23.94
70	11.97	27.93
80	7.98	31.92
90	3.99	35.91

Ratio 1:2
Building length: 28.2 m
Building width 14.2 m
East and west walls for all zones: 16.9 m^2
East and west windows for all zones: 4.4 m^2
North wall for one zone: 31.7 m^2

Window ratio (%)	South wall (m^2)	South window
25	31.70	10.60
30	29.61	12.69
40	25.38	16.92
50	21.15	21.15
60	16.92	25.38
70	12.69	29.61
80	8.46	33.84
90	4.23	38.07

shading coefficient of glazing is taken as 0.80 for summer.

3. Simulation studies

As mentioned in Section 2.3, the analyzed building floor is divided into four zones. The results of the parametric study showed that total energy demand difference between east and west zones is not highly significant. That is, difference between a south (or north) and east facing zone and a south (or north) and west facing zone can be neglected. Therefore, in order to simplify the analysis of the results, evaluation is done using the sum of south zones (zone 1 + zone 2) and sum of the north zones (zone 3 + zone 4).

3.1. Parametric study on building aspect ratio

The effects of different B.A.R. on annual total energy consumption of studied zones are examined as seen in the flow chart given as Fig. 4. The window area is kept as 15% of the floor area (25% of the southern facade) in all cases in order to achieve an op-

Table 4
Exterior wall material combinations for different climatic regions

	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5
Region 1					
Exterior wall	2 cm inner plaster	19 cm brick	3 cm outer plaster		
Floor	1 cm parquet	5 cm concrete	1.6 cm polystyrene	15 cm concrete	
Roof	2 cm inner plaster	12 cm reinforced concrete	4.7 cm polystyrene	5 cm concrete	
Region 2					
Exterior wall	2 cm inner plaster	19 cm brick	0.6–3.6 cm Styraphor	3 cm outer plaster	
Floor	1 cm parquet	5 cm concrete	2.5 cm polystyrene	15 cm concrete	
Roof	2 cm inner plaster	12 cm reinforced concrete	7.8 cm polystyrene	5 cm concrete	
Region 3					
Exterior wall	2 cm inner plaster	19 cm brick	0.6–9.3 cm Styraphor	9 cm brick	3 cm outer plaster
Floor	1 cm parquet	5 cm concrete	4.5 cm polystyrene	15 cm concrete	
Roof	2 cm inner plaster	12 cm reinforced concrete	9.9 cm polystyrene	5 cm concrete	

timum aspect ratio. In total, 30 computer runs (6 B.A.R. × 5 cities) of hourly simulation have been carried out for a whole year.

Table 5 shows the total loads of different B.A.R. and the total load difference percentages between the minimum and maximum load requiring building aspect ratios in five cities. In Erzurum and Ankara, optimum building aspect ratio is 1:1.2. In Diyarbakir, Izmir, and Antalya optimum building aspect ratio came out as 1:2.

Although in all of the cities in one of the B.A.R.s, the energy demand reaches a minimum value and displays an optimum status graphically, the numerical difference among the cases is not highly significant (3–6%). Therefore, it can be concluded that, changing aspect ratios that have standard window areas do not notably affect the energy demand in the studied locations.

3.2. Parametric study on south window sizes for different building aspect ratios

The effects of different S.W.S. and different B.A.R. on annual total energy consumption are analyzed in this part of the study. The flow chart of the parametric study is shown in Fig. 5. In each case, the first analysis is carried out with 25% of the southern facade being window, and the rest being wall. Total window area in each zone is distributed to facades according to aspect ratio. At the next stages, south window area/south wall area ratio is increased to 30% and then up to 90% by 10% increments while keeping window areas fixed in all other directions. As the B.A.R. is varied and S.W.S. is increased, *R*-cond value of outside walls has to be changed to achieve a constant overall *U*-value. A change in insulation thickness rather than a change in material is preferred for the study. In total 240 computer runs (6 B.A.R. × 8 S.W.S. × 5 cities) of

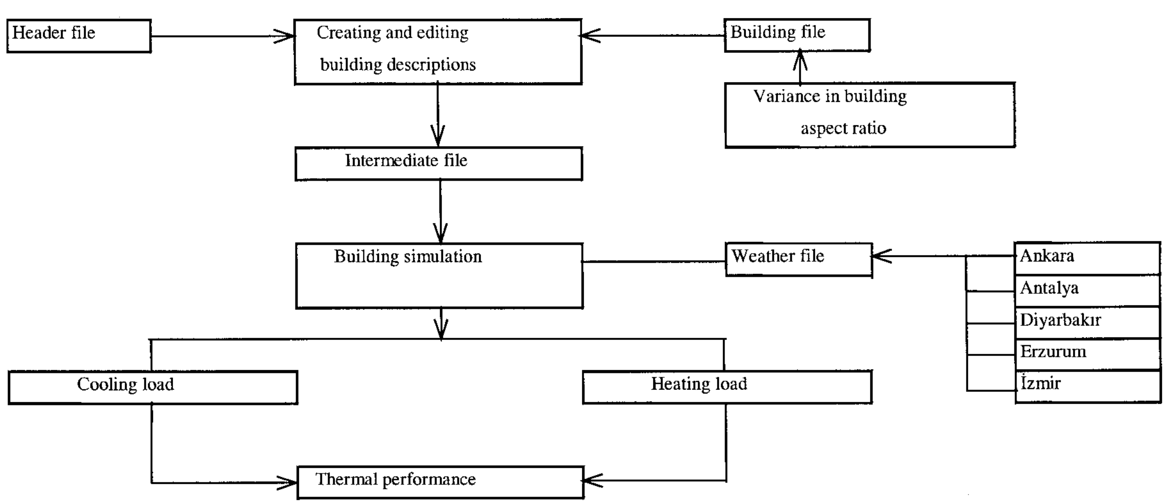

Fig. 4. Flow chart of parametric study on B.A.R.

Table 5
Comparison of total loads for different B.A.R. in five cities (GJ)

	Ratio 1:1	Ratio 1:1.2	Ratio 1:1.4	Ratio 1:1.6	Ratio 1:1.8	Ratio 1:2	Differential (%)
Ankara	38.06	**37.92**	38.38	38.45	38.51	39.27	3.45
Antalya	22.68	22.25	21.96	21.66	21.45	**21.25**	6.30
Diyarbakir	47.90	47.36	47.03	46.72	46.50	**46.38**	3.16
Erzurum	66.80	**66.70**	67.55	67.78	67.96	69.31	3.76
Izmir	25.90	25.55	25.31	25.12	24.98	**24.89**	3.88

hourly simulation have been carried out for a whole year.

The results have showed that changing S.W.S. and B.A.R. together does not affect the previously found fact that B.A.R. in all the analyzed locations has an optimum value which is not significantly different from other B.A.R. On the other hand, changing S.W.S. significantly affects the total energy demand. Therefore, results of the parametric runs on S.W.S. for optimum B.A.R. will be analyzed for each city individually. The total energy load required for south and north zones in each parametric run is presented in Fig. 6.

When the sum of heating and cooling loads is calculated for south zones (zone 1 + zone 2) in Erzurum, it is seen that total energy demand decreases as the south window area ratio increases. Heating demand decreases and cooling demand increases as S.W.S. increases. In the overall results, total loads decrease as S.W.S. is increased in Erzurum. Insulation thickness varies between 0.6 and 6 cm for the outside walls of the building when the B.A.R. is 1:1.2 and the S.W.S. is changed from 25 to 90% of the south wall area. The heat transfer from south zones and the increase in insulation thickness have improved the thermal performance of north zones. As the insulation material increases, the total load of north zones decreases. In the changing ranges of 70 and 80% S.W.S. per south wall area (2.9 and 4.1 cm insulation thickness), total loads of north and south zones become almost equal (53 GJ). Beyond that S.W.S. and insulation thickness, the total demand of north zones continues decreasing while the heating demand of south zones increases.

In Ankara, when the sum of heating and cooling loads are analyzed for south zones, it is seen that total energy demand decreases as the south window area ratio increases. This means that, the more window size the architects design, the better thermal performance they achieve. In order to obtain the allowable values, insulation thickness again varies between 0.6 and 6 cm for the outside walls of the building with B.A.R. of 1:1.2 and S.W.S. of 25–90% in Ankara. Obviously, the increase in insulation thickness has improved the thermal performance of the north zones. The total load of each north zone decreases, as the insulation material thickness increases. Besides, heat transfer from south zones has improved the thermal performance of north zones, such that, beyond a certain point, the total load of north zones turns out to be smaller than south zones. In the changing ranges of 50 and 70% S.W.S. per south wall area (and 1.5 and 2.6 cm insulation thickness), the total loads of north zones become as large (33 GJ) as the south zones. After that point, due to large heat loss during the night time, the total demand of north zones continues decreasing due to high *R*-cond value, whereas the heating demand of the south zones increases.

Total energy demand increases as the S.W.S. is increased for the building having 1:2 B.A.R. in

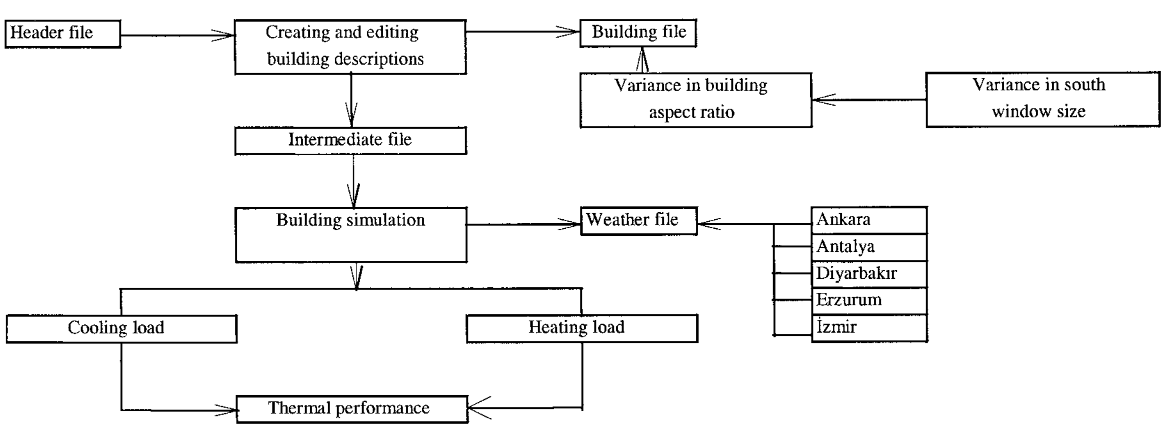

Fig. 5. Flow chart of parametric study on S.W.S.

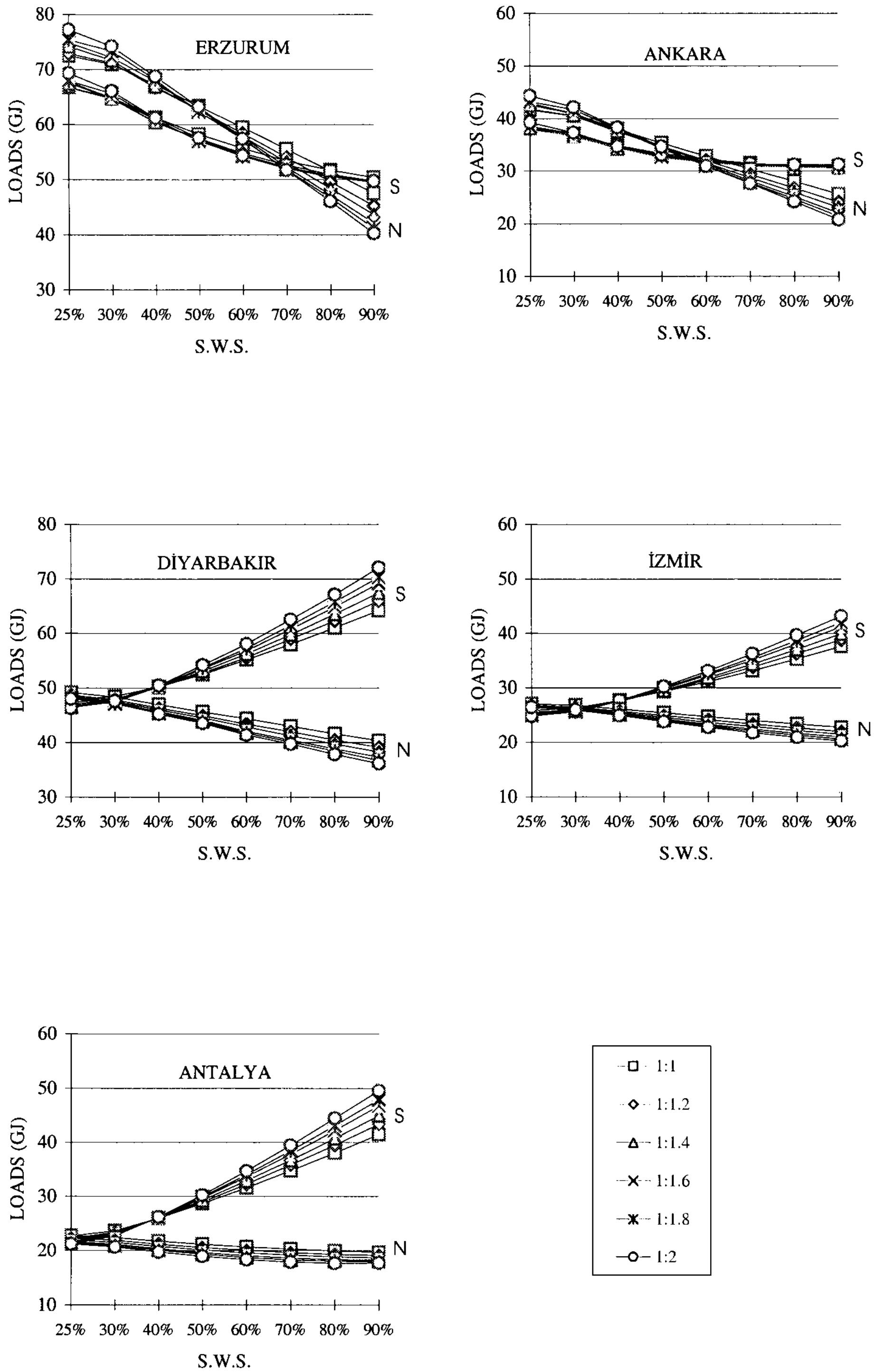

Fig. 6. Comparison of different B.A.R. with different S.W.S. for south and north zones in five cities.

Diyarbakir. This means that the conventional window size (25%) gives the best result for thermal performance in Diyarbakir. Heating demand decreases and the cooling demand obviously increases as S.W.S. increases. In the overall results, the total load increases as S.W.S. increases in Diyarbakir. The insulation thickness varies between 0.6 to 3.6 cm for the outside walls of the building with the variation of B.A.R. and S.W.S. As the cooling load is very important in determining the total energy demand in Diyarbakir, the north zones achieve an advantage. Besides, the increase in insulation thickness and heat transfer from south zones decreases the heating energy demand of north zones. Beyond 30% S.W.S., total loads of north zones turn out to be smaller than south zones. After that point, total loads of north zones continue decreasing

Table 6
Comparison of total loads for different S.W.S. with required insulation thicknesses in Erzurum (GJ)

S.W.S.	Insulation							
	0.6 cm	0.7 cm	1.1 cm	1.5 cm	2.1 cm	2.9 cm	4.1 cm	6 cm
25%	**66.70**	66.01	63.54	61.47	58.92	56.27	53.34	50.22
30%		**64.74**	62.40	60.43	58.01	55.49	52.71	49.75
40%			**60.51**	58.74	56.57	54.31	51.83	49.19
50%				**57.47**	55.54	53.53	51.31	48.95
60%					**54.78**	52.98	51.01	**48.90**
70%						**52.64**	**50.90**	49.04
80%							50.96	49.34
90%								49.78

while heating loads of south zones increase as south window size and insulation thickness are increased.

When the increase of S.W.S. is analyzed in Izmir, an increase of the sum of heating and cooling loads is observed. As in Diyarbakir, the conventional window size performs the best result for thermal performance. Heating demand decreases and cooling demand increases as S.W.S. increases, but in the overall results, the total load notably increases as S.W.S. increases in Izmir. Regarding the mild winter climatic conditions, no insulation material is required for outside walls in all 48 cases. North zones become advantageous against cooling problem when compared with south zones. In 30% S.W.S., the total demand of north zones and south zones is approximately equal. Beyond this point, S.W.S. total loads of north zones turn out to be smaller than south zones.

In Antalya, when the sum of heating and cooling loads are calculated for south zones, it is seen that total energy demand increases as the S.W.S. ratio increases. Like all the other analyzed hot climate cities, a conventional window size gives the best result for thermal performance. Naturally, an increase in S.W.S. causes a decrease in heating demand and an increase in cooling demand. In the overall results, the total load notably increases as S.W.S. increases. Insulation material is not required for outside walls in any of the 48 cases. North zones become advantageous in this location against cooling problem when compared with south zones. In 25% S.W.S., the total demand of north zones and south zones is approximately equal. Beyond 25% S.W.S., total loads of north zones come out to be smaller than of south zones.

3.3. Further study on thermal performance optimization

The results of the parametric study have shown that in hot climates (Antalya, Diyarbakir, and Izmir), 25% S.W.S. is the best solution in 100 m^2 residential buildings. However, in cooler climates (Ankara and Erzurum), the best S.W.S. comes out to be as large as possible. During the improvement process, while increasing the S.W.S., two parameters are used as variables. One is the additional glazing area and the other is the additional insulation thickness that is required to achieve the maximum allowable *U*-value according to the Thermal Insulation regulations of Turkey.

It is known that an additional south window increases the heat gain during sunny hours, but heat loss becomes a great problem in cloudy hours and at night. At this point, instead of increasing S.W.S. and insulation thickness together, a parametric study is carried out only by increasing insulation thickness for the optimum B.A.R. which is 1:1.2 in Ankara and Erzurum. For 25% S.W.S., first the required insulation thickness is applied. Then, without increasing S.W.S., insulation thickness is increased as if S.W.S. has been increased. This study is repeated for all S.W.S. In total 72 computer runs of hourly simulation have been carried out for a whole year for these two cities.

In Erzurum, for 1:1.2 B.A.R. insulation thickness has to be increased from 0.6 cm to 6 cm as S.W.S. is increased. It is seen in Table 6 that, increasing both S.W.S. and insulation thickness is better than increasing only the insulation thickness up to 70% S.W.S. from only the thermal point of view. For instance, the total load for 30% S.W.S. and 0.7 cm insulation is 64.74 GJ, whereas for 25% S.W.S. and 0.7 cm insulation is 66.01 GJ: so increasing S.W.S. and insulation thickness is better than increasing insulation thickness only. However, this trend changes at 70% S.W.S. Instead of increasing S.W.S. to 80% and insulation thickness to 4.1 cm, just increasing insulation thickness to 4.1 at 70% S.W.S. results in better thermal performance.

The best south window size percentage had been found as 90% in the previous parametric study. With the aid of the new outcome, it can be concluded that increasing S.W.S. above 70% is not wise in Erzurum. Instead of increasing window size, increasing insulation thickness is better from a thermal point of view. On the other hand, the best case in this study comes out as the case which has 60% S.W.S. and 6 cm insulation thickness.

Table 7
Comparison of total loads for different S.W.S. with required insulation thicknesses in Ankara (GJ)

	Insulation							
S.W.S.	0.6 cm	0.7 cm	1.1 cm	1.5 cm	2.1 cm	2.9 cm	4.1 cm	6 cm
25%	**37.92**	37.49	35.95	34.66	33.09	31.47	29.69	27.81
30%		**36.69**	35.25	34.05	32.59	31.07	29.40	**27.65**
40%			**34.35**	33.30	32.01	30.68	**29.23**	27.71
50%				**32.93**	**31.80**	**30.65**	29.39	28.07
60%					31.86	30.86	29.75	28.57
70%						31.20	30.22	29.17
80%							30.79	29.86
90%								30.60

When Ankara is analyzed, increasing both S.W.S. and the insulation thickness is better than increasing only the insulation thickness up to 50% S.W.S. (Table 7). However, after 50% S.W.S., instead of increasing S.W.S. to 60% and the thickness of insulation to 2.1 cm from 1.5 cm, just increasing insulation thickness to 2.1 cm at 50% S.W.S. results in better thermal performance. Again, although the best south window

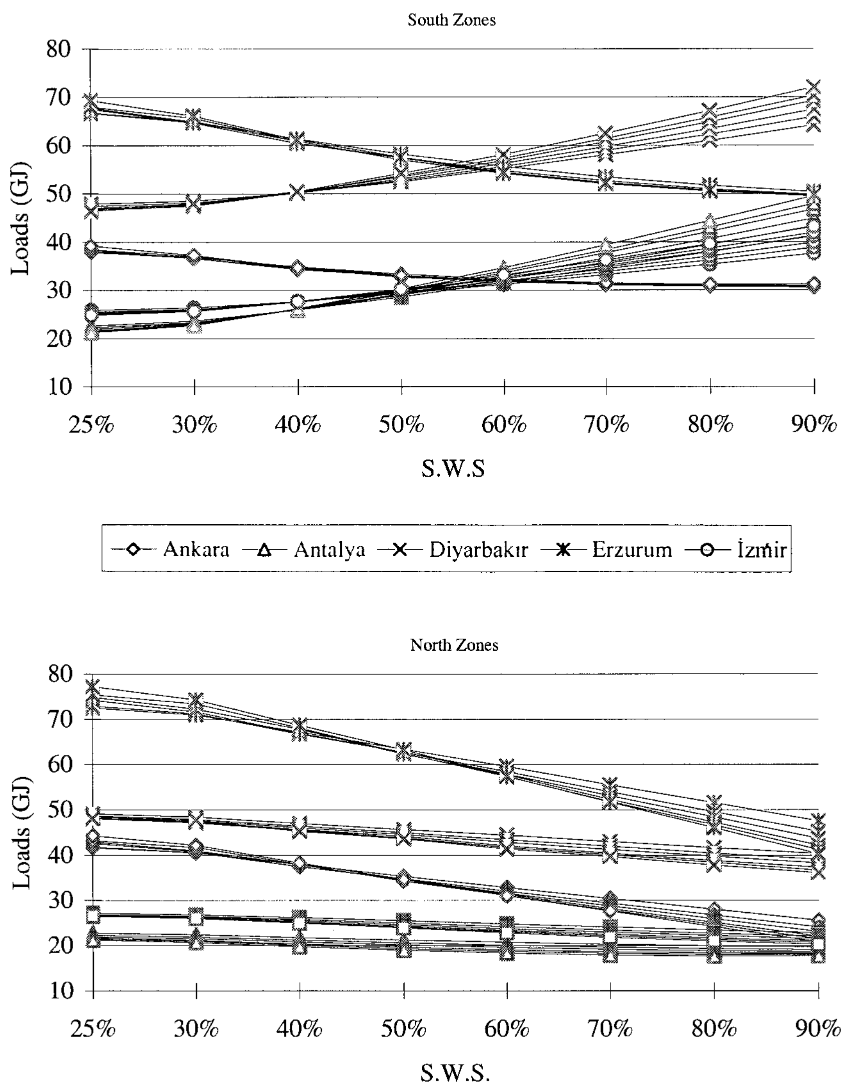

Fig. 7. Total loads of different B.A.R. with different S.W.S. for all cities (GJ).

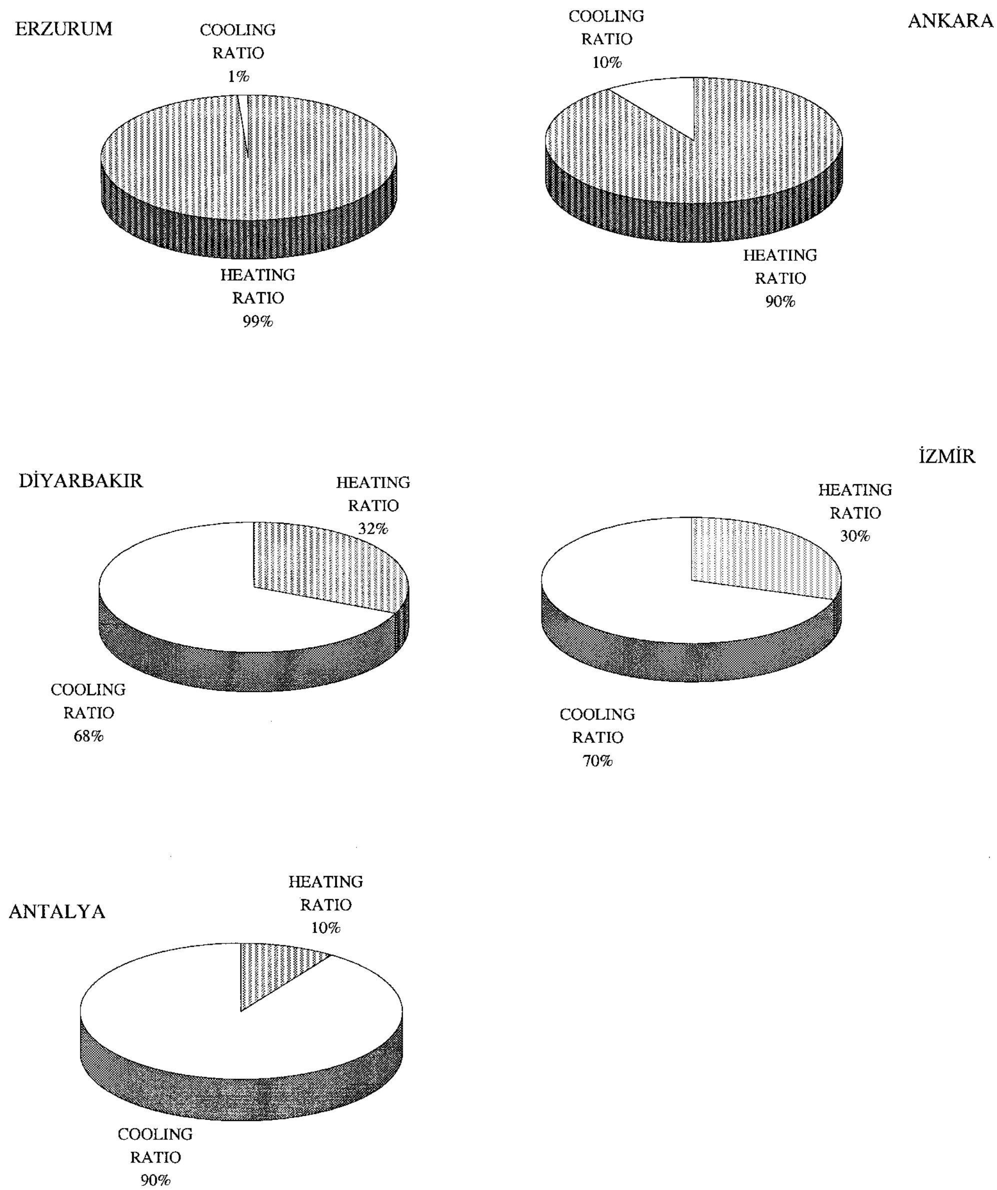

Fig. 8. Percentages of heating and cooling loads in five cities.

size percentage had been found as 90% in the previous parametric study, it can be concluded that increasing S.W.S. above 50% is not advisable. Instead of increasing window size, increasing insulation thickness is better both thermally and economically. The best case in this study comes out as the case which has 30% S.W.S. and 6 cm insulation thickness.

4. Comparison of the results

Results of the parametric studies carried out for the optimization of B.A.R. and S.W.S for apartments of intermediate floors in five different cities of Turkey will be discussed for each city and then comparisons will be made among the cities.

In this part of the parametric study, optimum width/length of the building with 25% S.W.S. has been found as follows for each city:

Erzurum	1:1.2 B.A.R.
Ankara	1:1.2 B.A.R.
Diyarbakir	1:2 B.A.R.
Izmir	1:2 B.A.R.
Antalya	1:2 B.A.R.

The parametric studies made for achieving optimum S.W.S. values for six different B.A.R. in five different cities of Turkey can be summarized as follows:

Erzurum:	90% S.W.S. in all B.A.R.
Ankara:	90% S.W.S. in all B.A.R.
Diyarbakir:	25% S.W.S. in all B.A.R.
Izmir:	25% S.W.S. in all B.A.R.
Antalya:	25% S.W.S. in all B.A.R.

A comparison of different B.A.R. with different S.W.S. and total loads of south and north zones is illustrated in Fig. 7. It is clearly seen that minimum analyzed south window area (15% of the floor area as suggested in the regulation which makes 25% of southern facade) is the optimum situation in hot climates. In cool climates, increase in south window area is appreciated. In all regions, total loads of north zones decrease as S.W.S. increases. The reasons for this decrease are increase in insulation material thickness in order to keep the overall *U*-value constant (at the maximum allowable value for Ankara, Diyarbakir, and Erzurum), heat transfer between zones, and effect of cooling loads.

Further study has been carried out by keeping the S.W.S. constant and only increasing insulation thickness as if S.W.S. is increased. The results of this study have implied that:

- In Erzurum, 70% S.W.S. is the optimum condition.
- In Ankara, 50% S.W.S. is the optimum condition. Additional insulation thickness is advantageous in both cities.

The outcomes of this study have revealed a large difference between Ankara and Erzurum which has shown a parallel tendency up to this point. In Ankara, among the analyzed S.W.S. and insulation thickness, the most energy efficient case is the one which has 30% S.W.S. and 6 cm insulation thickness: i.e., increasing insulation thickness ends up with better results than increasing S.W.S. However, in Erzurum among the analyzed S.W.S. and insulation thickness, the most energy efficient case is the one which has 70% S.W.S. and 6 cm insulation thickness: i.e., increasing both S.W.S. and insulation thickness ends up with better results.The energy consumption of each city is different from others due to its different climatic characteristics. In cool climates, heating loads and in hot climates, cooling loads become the dominating factor in determining the total energy demand. Percentage of heating and cooling loads are shown in Fig. 8.

5. Conclusion

Thermal performance optimization of passive solar building components plays an important role in the energy efficiency of buildings. The consequence of energy efficiency is better perceived when the amount of energy sources that are spent for heating of buildings is considered.

From the literature survey, B.A.R., south window size and insulation value are found to be the most remarkable features of direct gain systems from thermal point of view. Therefore, a parametric study is carried out for sizing these features in mass-housing by means of computer simulation technique in five cities of Turkey having different climatic regions. The results of the study on B.A.R. have showed that, maximum elongation in east–west axis (1:2) is preferable in hot climates (Diyarbakir, Izmir, Antalya). For cold climates, building having a compact form with B.A.R. of 1:1.2 turns out to be the optimum case. Deciding on the S.W.S. of residential buildings depends on the effect of window on heat gain and loss values. A building that has conventional (25%) S.W.S. is preferable in hot climates (Diyarbakir, Izmir, Antalya) due to the need for decreasing heat gain in summer. In cold climates, larger S.W.S. up to a certain point are preferred due to the need for increasing heat gains in winters. It should be noted that the results only apply to apartment units with no roof or ground contact. For the units located at top and ground floors of buildings, the results of this study will not be strictly applicable due to the energy loads through the roof and floor.

The aim of this parametric study is to give architects shortcuts and rules of thumb in designing energy-conscious residential buildings.

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