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Investigation of the Effects of Orientation and Window Usage on External Walls in Terms of Heating and Cooling Energy

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Abstract

This study investigated effective ways of minimizing the amount of energy used for heating and cooling caused by windows in the building envelope. The use of glass material in windows is discussed in terms of reducing heating and cooling energy consumption. The hourly total heating and cooling energy calculations were carried out for the 1^{st}, 11^{th}, and 21^{st} days of each month using the previous 10-year period's meteorological data for Elazığ. Energy loads of windows were estimated using a computer program written in MATLAB. Energy requirements of different building facade examples caused by window glass were evaluated and the optimum facades determined among different alternatives. In conclusion, OR1/1 (square formed) buildings have the minimum heating and cooling requirements. Among 5 different glass alternatives, xenon filled double glass units require 33%-82% less heating and cooling energy than the others.

Key words: Energy conservation, Double-glass, Heating and cooling energy requirements, Windows

Introduction

The energy expended in buildings makes up an important proportion of energy consumption in countries all over the world. In Turkey, most of the energy is used up in buildings for heating and cooling, with a ratio of 80% (Kavak, 2005). The main reasons for high energy consumption are the high number of old buildings and the design intellect that neglects passive design parameters for reducing energy needs. During the design period, selection of inappropriate building materials and negligence of some basic decision and applications cause high energy expenses for owners and have a negative effect on the environment through the use of fossil fuels (Bektaş and Aksoy, 2005). Therefore, it is essential to minimize the amount of energy used in buildings for heating and cooling, especially in countries that import large amounts of the energy they consume, like Turkey. In spite of the fact that Turkey has plenty of solar energy, almost no building uses passive solar techniques to benefit from this source (Dilmaç and Kesen, 2003).

Windows have a significant role in ventilating, lighting, connecting indoors and outdoors, and providing a thermally comfortable indoor environment. Thermal comfort of a building is defined as a condition for a person working using minimum energy for physical and mental performance and who expresses satisfaction with the thermal environment. It is one of the factors that causes energy necessities in buildings (Oral and Yılmaz, 2003). Windows are the parts of the building envelope where most heat losses occur and most solar gains are achieved. Because of this, first precautionary measures must be taken in windows to prevent heat losses and undesirable solar gains.

One of the most important applications preventing these losses and gains through windows is double glazing. Double glass window units are composed of 2 glass skins and a cavity in between. This cavity behaves as a thermal buffer zone that decreases heat transitions (Cetiner and Özkan, 2004). Usually dry air is filled in this cavity, but recently, in order to reduce the amount of losses, some other gases that have low heat conductivities have started to be used. Heat conductivities and refraction indexes of some gases (Bektaş, 2006) used in double glazing applications are given below in Table 1.

Table 1. Heat conductivities (k) and refractive (n) indexes of gases.

Gases	k value (W/m°K)	n index
Air	0.02730	1.00029
Argon	0.01772	1.000281
Krypton	0.00949	1.000427
Xenon	0.00569	1.000702

Using alternative glazing units, sizing windows, and determination of building form are important topics in the energy efficiency of buildings. In the literature, Nielson et al. (2001) show a simple method to determine net energy gain of glazing and compare the energy performances of different types of glazing and windows. Khaled (1998) investigated the ways of sizing windows to achieve passive heating, cooling, and day-lighting in hot arid regions. Oral and Yılmaz (2003) presented a methodology for building form factor that provides minimum heat loss through the whole building envelope.

The purpose of this study was to determine the effects of physical environmental and artificial design parameters on the energy consumption of buildings caused by glass sections of windows. Physical environmental design parameters such as hourly outdoor temperature (°C), solar radiation (W/m^2), and wind velocity (m/s), and artificial design parameters like transparency ratio, orientation ratio of the building, and thermo-physical properties of window glass and inner gases are considered in the calculations. The transparency ratio is the percent area of a wall covered by windows. The orientation ratio of a rectangular building in this study can be explained as the ratio of the areas of south and north facades to east and west facade areas. The equations used in this study are widely used in many studies (Aksoy, 2002; Özel, 2003). Most of these studies investigate only a few of these parameters. This method is new because the energy performances of different window units and their energy loads on buildings are evaluated by considering many parameters. The hourly heating and cooling energy needs of building examples were calculated for 36 days a year with the last 10 years' meteorological data by a computer program (Bektaş, 2006) written in MATLAB. The program is capable of calculating the annual hourly heating and cooling loads of all building samples but in order to shorten the calculation period and simplify the model the 1st, 11th, and 21st days of each month were taken into consideration like in Elagöz's study (Elagöz, 1989). By using the values for these days, the daily average loads of each month and average annual loads are calculated.

Calculation of total heat loss and gain through the glass surfaces of windows

The performance of transparent surfaces on passive heating and cooling are evaluated based on the total solar radiation on building surfaces, the transparency ratio, the ratio of transmissivity, reflectivity and absorptivity of transparent surfaces, the temperature differences between the outside and inside environment, and wind velocity.

Total radiation on a building surface is calculated by Eq. (1) (Duffie and Beckman, 1991).

$$I = R_d I_d + I_{dif}\left[\frac{1+\cos\beta}{2}\right] + (I_{ref})\,\rho_g\left[\frac{1-\cos\beta}{2}\right] \tag{1}$$

where I$_d$, I$_{dif}$, and I$_{ref}$ are the direct, diffuse, and reflected solar radiations, respectively, and ρ_g is the reflectivity of the ground and it is assumed as 0.2 in calculations in the present study. β is the slope angle of the building facade and is assumed to be 90° in the calculations. The R$_d$ value in Eq. (1) can be calculated as follows in Eq. (2)

$$R_d = \frac{\cos\delta.\sin\Phi.\cos\gamma.\cos\omega + \cos\delta.\sin\gamma.\sin\omega - \sin\delta.\cos\Phi.\cos\gamma}{\cos\Phi.\cos\delta.\cos\omega + \sin\Phi.\sin\delta} \tag{2}$$

where δ is the declination angle (°), ϕ is latitude angle and it is 38.4° for the Elazığ region, ω is the hour angle (°), and γ is the surface azimuth angle (γ_{south} = 0°, γ_{north} = 180°, γ_{west} = 90°, γ_{east} = -90°). Direct, diffuse, and reflected radiations can be calculated by Eqs. (3)-(5) given below respectively:

$$I_d = I_{sc} f \cos\vartheta_z \tag{3}$$

$$I_{dif} = I_y \frac{(1+\cos\beta)}{2} \tag{4}$$

$$I_{ref} = \rho_g I_a \left(\frac{1-\cos\beta}{2}\right) \tag{5}$$

where I_{sc} is the solar constant (= 1353 W/m^2), f is the ratio between the radiation intensity and solar constant, and ϑ_z is the zenith angle. I_y and I_a are the instant diffuse and instant total solar radiations on horizontal surfaces respectively and calculated according to Duffie and Beckman (1991). The f value can be calculated by the formula below.

$$f = 1 + 0.033\cos(360\frac{n}{365}) \tag{6}$$

Fresnell explained the behavior of the unpolarized solar radiation passing from n_1 environment to n_2, shown in Figure 1. The average reflection of the interface (ρ_{int}) is formulated with Eq. (6) below (Yıldız, 1990).

$$\rho_{int} = \frac{1}{2}\left[\frac{sin^2(\theta-\theta')}{sin^2(\theta+\theta')} + \frac{tan^2(\theta-\theta')}{tan^2(\theta+\theta')}\right] \tag{7}$$

where ϑ and $\vartheta\prime$ are incidence and refractive angles, respectively. When solar radiation passes through a transparent surface, many possibilities (transmission, reflection, absorption) occur in the interface as seen in Figure 2. The transmissivity (τ), reflectivity (ρ_{tot}), and absorptivity (α) of the transparent surfaces of the building envelope can be calculated with Eqs. (8)-(10) (Siegel and Howell, 2002).

$$\tau = a'\left(1-\rho\right)^2\left[1+\rho^2a'^2+\rho^4a'^4+....\right] = \frac{\left(1-\rho\right)^2a'}{1-\rho^2a'^2} \tag{8}$$

$$\begin{aligned}\rho_{tot} &= \rho\left[1+\left(1-\rho\right)^2a'^2\left(1+\rho^2a'^2+\rho^4a'^4+....\right)\right]\\ &= \rho - \frac{\left(1-\rho\right)^2a'^2}{1-\rho^2a'^2}\end{aligned} \tag{9}$$

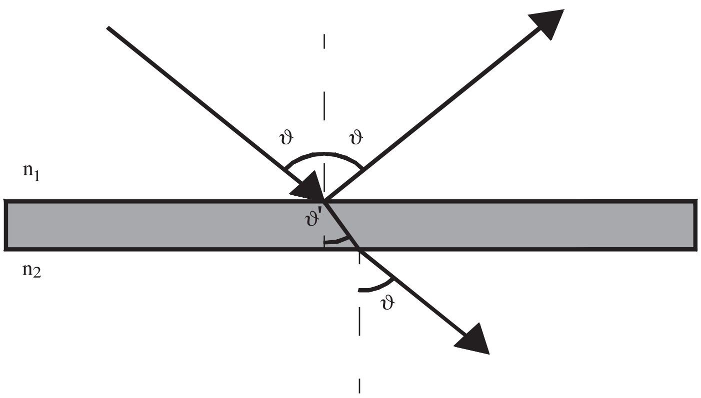

Figure 1. Behavior of unpolarized radiation passing through a transparent surface.

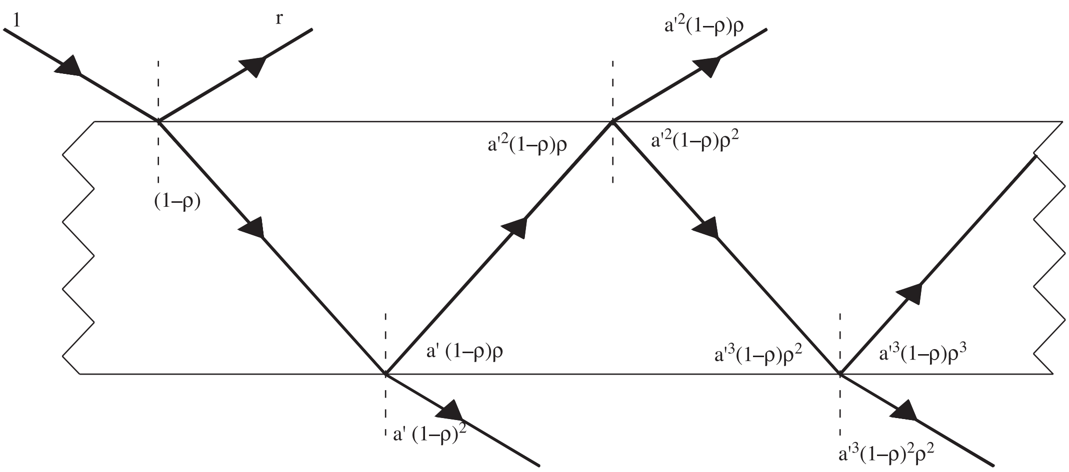

Figure 2. The polarization of radiation in transparent surface.

$$\alpha = 1 - \rho_{tot} - \tau = 1 - \rho - \frac{(1-\rho)^2 a'}{1 - \rho a'} \tag{10}$$

where $a\prime = e^{-KL\prime}$ and K is the radiation reduction coefficient of the homogeneous environment and L is the thickness of the transparent layer $L\prime = L/\mathrm{Cos}\theta\prime$. For double glazing, 1 represents the outer and 2 the inner glass sheet; these ratios can be written as shown in Eqs. (11) and (12) (Siegel and Howell, 2002):

$$\tau_{1,2} = \frac{\tau_1 \tau_2}{1 - \rho_{tot_1} \rho_{tot_2}} \tag{11}$$

$$\rho_{tot_{1,2}} = \rho_{tot_1} + \frac{\tau_1^2 \rho_{tot2}}{1 - \rho_{tot_1} \rho_{tot_2}} \tag{12}$$

The absorptivity values of inner and outer sheets are different and can be calculated respectively by Eqs. (13) and (14) (Siegel and Howell, 2002).

$$\alpha_{1of2} = \frac{\left[1 - (\rho_{tot_1} + \tau_1)\right]\left[1 - \rho_{tot_2}(\rho_{tot_1} - \tau_1)\right]}{1 - \rho_{tot_1} \rho_{tot_2}} \tag{13}$$

$$\alpha_{2of2} = \frac{\left[1 - (\rho_{tot_2} + \tau_2)\right]\tau_1}{1 - \rho_{tot_1} \rho_{tot_2}} \tag{14}$$

The heat loss and gain for single glazing are calculated by Eq. (15) (Threlkeld, 1970),

$$\begin{aligned} q_i &= (F_s \tau_d I_d + \tau_{dif} I_{dif} + \tau_{ref} I_{ref}) \\ &+ \frac{(F_s \alpha_d I_d + \alpha_{dif} I_{dif} + \alpha_{ref} I_{ref})}{1 + \left(\frac{h_o}{h_i}\right)} + U(T_o - T_i) \end{aligned} \tag{15}$$

and for double glazing, calculated by Eq. (16) (Davies, 1980).

$$\begin{aligned} q_i &= F_s \tau_{(1,2)d} I_d + \tau_{(1,2)dif} I_{dif} + \tau_{(1,2)ref} I_{ref} \\ &+ \frac{U}{h_o}\left(F_s \alpha_{(1of2)d} I_d + \alpha_{(1of2)dif} I_{dif} + \alpha_{(1of2)ref} I_{ref}\right) \\ &+ U\left(\frac{1}{h_o} + \frac{1}{h_g}\right)\left(F_s \alpha_{(2of2)d} I_d + \alpha_{(2of2)dif} I_{dif} \right. \\ &\left. + \alpha_{(2of2)ref} I_{ref}\right) + U(T_o - T_i) \end{aligned} \tag{16}$$

T_o and T_i are the outdoor and indoor temperatures (°C), respectively, and F_s is the shading factor taken as '1' in this study. *d, dif*, and *ref* subscripts of transmissivity and the absorptivity values represent direct, diffuse, and reflected radiations respectively. *(1of2)*, *(2of2)*, and $(1,2)$ refer to the outer sheet, inner sheet, and whole of double glass units, respectively. τ_d, α_d, $\tau_{(1,2)d}$, $\alpha_{(1of2)d}$, and $\alpha_{(2of2)d}$ values were calculated by using Eqs. (7)-(13) due to instant variations in incidence and refractive angles (Duffie and Beckman, 1991). However, τ_{dif}, τ_{ref}, α_{dif}, α_{ref}, $\tau_{(1,2)dif}$, $\tau_{(1,2)ref}$, $\alpha_{(1of2)dif}$, and $\alpha_{(1of2)ref}$ were calculated according to the relations given by Brandemuehl and Beckman using Eqs. (7)-(13) for constant incidence and refractive angles (Özel, 2003). By neglecting the thermal resistance of the glass itself, the U value in Eqs. (15) and (16), for single glass can be written as shown in Eq. (17):

$$U = \frac{1}{\frac{1}{h_i} + \frac{1}{h_o}} \tag{17}$$

and for double glass in Eq. (18):

$$U = \frac{1}{\frac{1}{h_i} + \frac{d}{k} + \frac{1}{h_o}} \tag{18}$$

h_i, the indoor heat transfer coefficient, is calculated by using the heat transfer coefficient of forced convection (h_{sk}) and radiative heat transfer coefficient (h_r), respectively, as given in Eq. (19). h_o in Eqs. (15)-(18) can be calculated due to wind velocity (V) and indoor heat transfer coefficient (h_i) with Eqs. (20) and (19) (Duffie and Beckman, 1991).

$$h_i = h_{sk} + h_r \tag{19}$$

$$h_o = h_{zk} + h_r + h_{sk} \tag{20}$$

$$h_{zk} = 2.8 + 3V \tag{21}$$

By using the equations above, h_o can be written as

$$h_o = 2.8 + 3V + h_i \tag{22}$$

Hourly outdoor temperature (T_o) is taken from Turkish State Meteorological Service. As is known, the resistance of gas layers is given with $1/h_g$ (Eq. (16)), where h_g is the heat convection coefficient of the inner gas. However, in small cavities, like in this study, heat transfer by convection is much smaller than conduction, and so it is assumed that heat is transferred only through conduction. Convectional heat transfer is neglected. The 'd' value in Eq. (18) is the distance between glass sheets in double glazing and 'k' is the heat conductivity of the inner gas (W/mK).

Determination of building alternatives depending on the orientation and different transparency ratios

The proposed approach is applied only on the windows of one storied residential buildings assumed to be in Elazığ, to evaluate the thermal performance of different glass alternatives and the effects of orientation ratio on energy requirements. The following assumptions were made for the application.

- Twenty degrees centigrade (20 °C) as indoor air design temperature and based on Threlkeld (1970) a value of 6 W/m^{2}K internal heat transfer coefficient were used in the calculations.
- Floor areas of all building examples are 100 m^2 and the floor heights are 3.00 m.
- Three types of buildings were considered according to their orientation ratios. These are OR1/1, OR1/2, and OR2/1 as shown in Figure 3, where 1/1, 1/2, and 2/1 are the ratios of south and north wall areas to east and west wall areas.
- Each of these building samples has 4 different facade alternatives (1st, 2nd, 3rd, and 4th situations) according to their transparency ratios towards the 4 main directions (north-south-east-west). The transparency ratios of different building samples are given in Table 2.
- Five types of window glass were taken into consideration. These are:
  - 4 mm single glass
  - 4+6+4 mm air filled double glass
  - 4+6+4 mm argon filled double glass
  - 4+6+4 mm krypton filled double glass
  - 4+6+4 mm xenon filled double glass
- Only the heat losses and gains caused by transparent surfaces of buildings are calculated.
- In order to see the performances of different glass sheets, the window units are assumed without casements.
- The 1st, 11th, and 21st days of each month were selected as the design days. By using the energy loads of these days average daily energy loads of the months were calculated.
- Ten-year hourly average outdoor temperature (°C), wind velocity (m/s), and daily sunny period (h) values were provided by the Turkish State Meteorological Service. Daily sunny period values were transformed into hourly direct, diffuse, and reflected radiation values by the equations derived by Angström (Şen, 2007).

Table 2. The transparency ratios and window areas of the building samples for different situations.

Orientation Ratio	East		West		North		South		Situation
	Ratio (%)	Area (m^2)	Ratio (%)	Area (m^2)	Ratio (%)	Area (m^2)	Ratio (%)	Area (m^2)	
OR1/1	20	6	20	6	20	6	20	6	1st
	20	6	20	6	10	3	30	9	2nd
	20	6	20	6	30	9	10	3	3rd
	30	9	30	9	20	6	20	6	4th
OR1/2	20	8.484	20	8.484	20	4.242	20	4.242	1st
	20	8.484	20	8.484	10	2.121	30	6.363	2nd
	20	8.484	20	8.484	30	6.363	10	2.121	3rd
	30	12.726	30	12.726	20	4.242	20	4.242	4th
OR2/1	20	4.242	20	4.242	20	8.484	20	8.484	1st
	20	4.242	20	4.242	10	4.242	30	12.726	2nd
	20	4.242	20	4.242	30	12.726	10	4.242	3rd
	30	6.363	30	6.363	20	8.484	20	8.484	4th

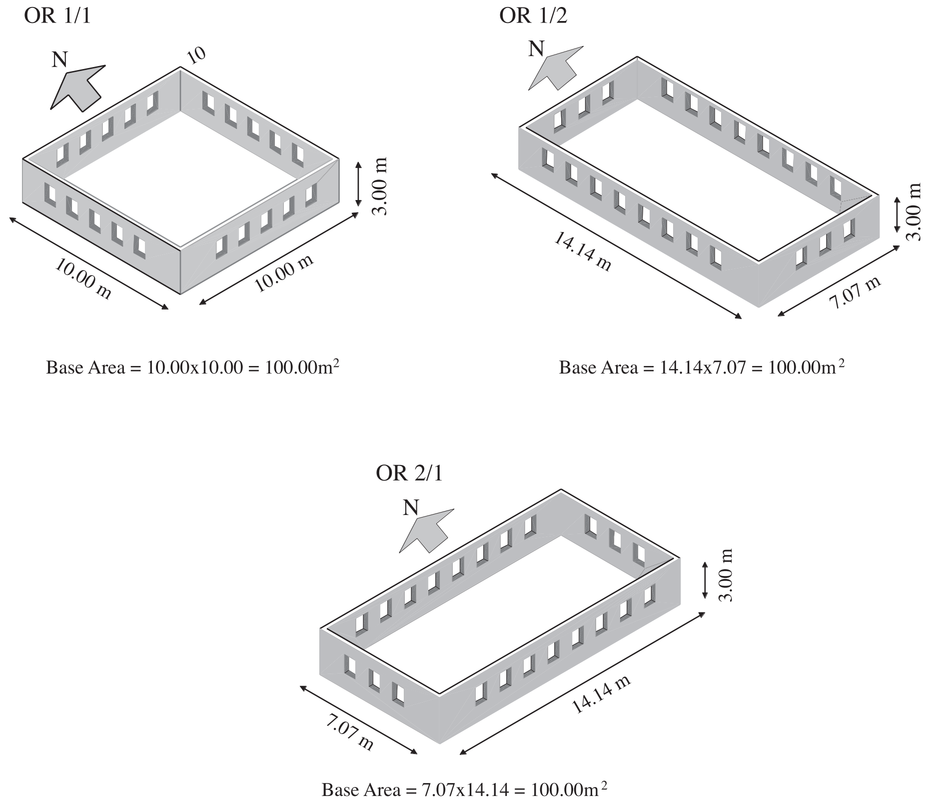

Figure 3. The measurements and orientation of the building samples.

Findings and discussion

Elazığ has a very big potential of benefitting from solar energy because of the 38.4° latitude angle. As seen in Figures 4-6, the situations that achieve much gain are the 4^{th} situations of OR1/1 and OR1/2 and the 2^{nd} situation of OR2/1 in the heating period. The reason for the gains for OR2/1 is the large surface area of south facing windows, which has the ability to gain solar energy during the heating period. Moreover, the minimum north facing window area with the transparency ratio of 10% gives rise to this appropriate situation for minimum heating and cooling energy. However, for OR1/1 and OR1/2, the total areas of east and west facing windows are greater than those for the south facing ones, and so this enables large solar gains from these directions and causes high cooling loads.

According to the results of this study in Figure 7, the building that has the most appropriate properties for benefitting from passive solar energy is the 2^{nd} situation of OR2/1. The reason for this is the south facing windows with the transparency ratio and area of 30% and 12.726 m^2 respectively. However, as is seen in the 3^{rd} situation for OR2/1, the reduction of the south facing windows ratio to 10% and the increasing of the north facing windows to 30% level cause a reduction in solar gains in the heating and cooling seasons with the ratio of 36.98% (for December) and 3.1% (for June), respectively. The north facing openings on the building facade have the least gains in comparison to the other directions.

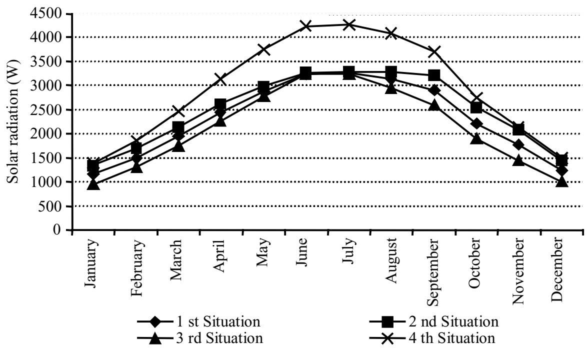

Figure 4. Daily average solar radiation on windows of OR1/1 buildings.

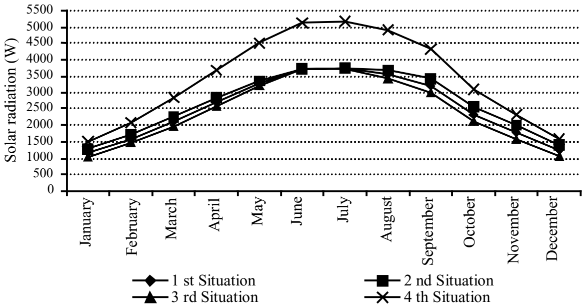

Figure 5. Daily average solar radiation on windows of OR1/2 buildings.

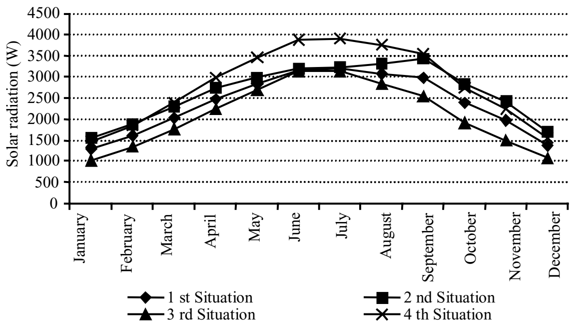

Figure 6. Daily average solar radiation on windows of OR2/1 buildings.

In energy efficient building design, maximum solar gains are wanted during the heating period and minimum ones during the cooling period, because the maximum (for winter) and minimum (for summer) gain means minimum heating and cooling energy respectively. The wisest solution is to minimize the areas on the north face for minimum heating energy and minimize the areas on the east and west faces for minimum cooling energy. The effect of solar energy on east and west directions increases in summer (cooling). The windows in these directions have too much gain in spite of the heating season. Moreover, the south facing windows have less solar gains according to their winter performance. Furthermore, the total gains of east and west windows in winter conditions are 13.28% of the south windows in December. However, in June, the total gains of east and west windows are 219% of the south facing ones. For all building types, the maximum gain is achieved with the 4^{th} situation, in which the transparency ratio of east and west walls is assumed to be 30% of the surface. As seen from Figure 8, however, the 4^{th} situation also causes big cooling problems during summer.

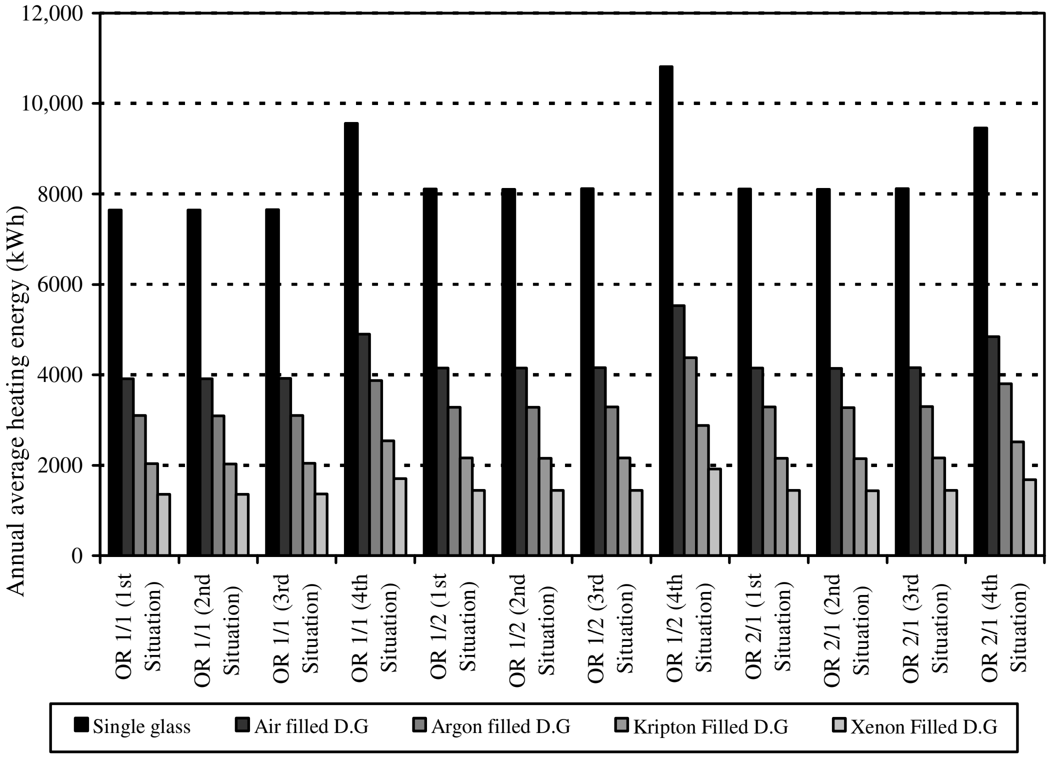

Figure 7. Annual average heating energy requirements of building examples.

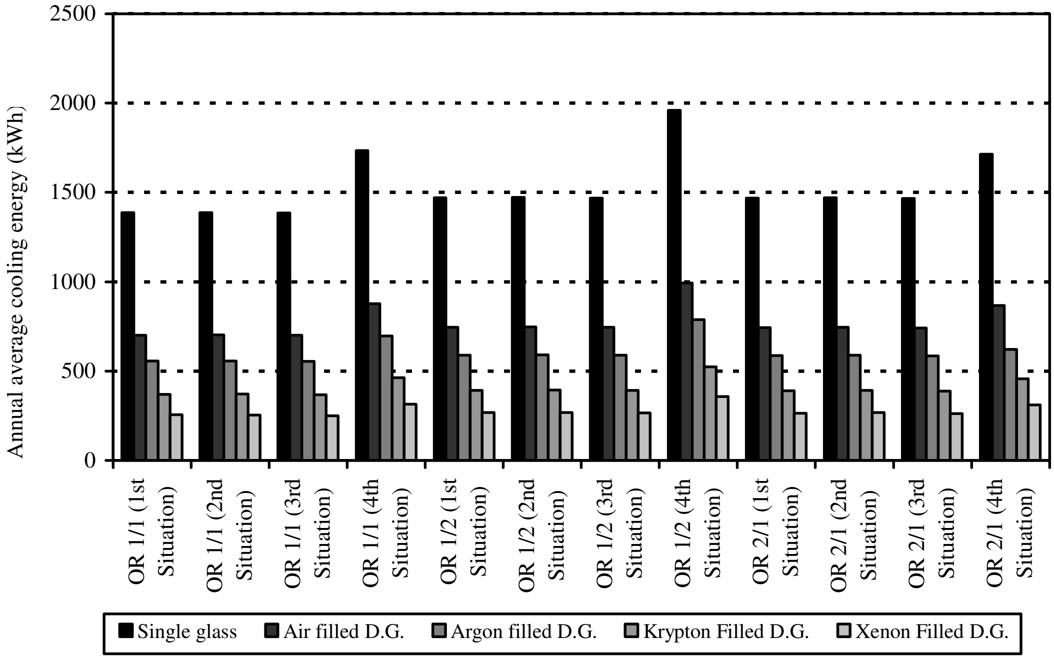

Figure 8. Annual average cooling energy requirements of building examples.

The calculations for 3 orientation ratios and 4 different situations show that OR1/1 buildings require less heating and cooling energy than OR1/2 and OR2/1. The main reason for this is the minimum surface area of OR1/1 buildings as opposed to the same bottom area (100 m^2) with OR1/2 and OR2/1. The lower surface area means less loss through the building envelope. An arrangement according to minimum heating and cooling energy demand of building types can be made as OR1/1 $<$ OR2/1 $<$ OR1/2.

With the application of single glass in windows for the 1^{st}, 2^{nd}, and 3^{rd} situations of OR1/1 buildings, 5.70% average savings can be achieved compared to OR1/2 buildings but 11.60% for the 4^{th} situation. If air filled double glass is used in windows, the savings would be 5.72% for the 1^{st}, 2^{nd}, and 3^{rd} situations and 11.61% for the 4^{th} situation. If it is possible to use gases with low heat transfer coefficients like argon, krypton, and xenon in double glass of window space the savings are on average 5.71% for the 1^{st}, 2^{nd}, and 3^{rd} situations, respectively. For the 4^{th} situation, 11.59% savings would be obtained for argon filled glazing and on average 11.62% for krypton and xenon filled glazing.

The OR2/1 buildings have average 5.7% extra heating and cooling energy needs for the 1^{st}, 2^{nd}, and 3^{rd} situations of buildings for single, air filled, argon filled, krypton filled, and xenon filled double glazing, respectively, compared to OR1/1. However, for the 4^{th} situation, the OR2/1 building has 10.40% average saving in proportion to the OR1/1 building. The heating and cooling necessities of OR1/2 and OR2/1 are nearly the same as the 1^{st}, 2^{nd}, and 3^{rd} situations; however, for the 4^{th} situation the OR2/1 building has 12.50% less energy need in comparison to the OR1/2 building.

It is found that the glazings filled with gases with high heat transfer coefficients may require less heating and cooling loads than those with low heat transfer coefficients because of the orientation and the surface area. For example, for the 1^{st}, 2^{nd}, and 3^{rd} situations of the OR1/1, OR1/2, and OR2/1 buildings where air filled double glass units are used have 5.04%-10.72% advantages in comparison to the 4^{th} situation of the OR1/2 building, which has argon filled double glass window units, because of the orientation ratio and the inappropriate transparency ratios of the facades.

Owing to the hard winter conditions in the region, the energy use for heating caused by window glass is 83% more than the energy use for cooling. When the energy requirements of glass units are taken into consideration, the advantages of xenon filled glass in energy savings can easily be seen. These glass units have 82% reduction in heat losses related to single glass as shown in Figure 9. In addition, it is more advantageous than the other double glass units used in calculations of this study. For example, they provide 64%, 44%, and 33% energy savings compared to air, argon, and krypton filled double glass units respectively as shown in Figures 10 and 11. The krypton filled double glass units are the second best glass types, requiring less energy after xenon filled ones. They achieve conservation in heating and cooling energy caused by window glass with the ratio of 73%, 47%, and 17% in comparison to single, air filled, and argon filled double glass units, respectively. The argon filled glass units cause 67% less energy losses than single glass and 36% less than air filled glass units. By an application with air filled glass units, it is possible to prevent heat losses and unwanted gains with the ratio of 49%.

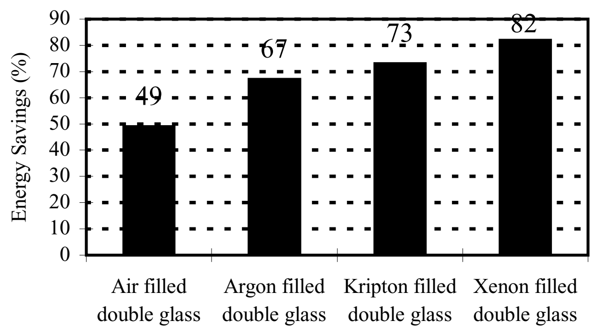

Figure 9. The percentage energy savings of gas filled glass units in comparison to single glass.

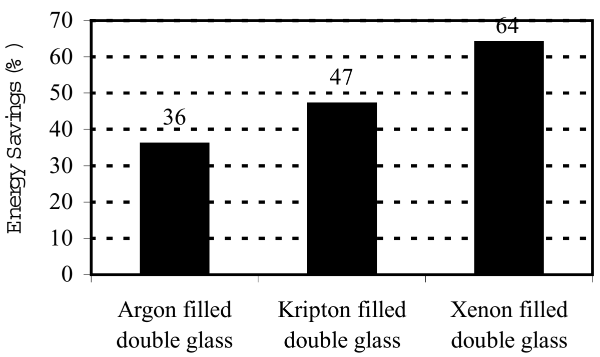

Figure 10. The percentage energy savings of gas filled glass units in comparison to air filled double glass.

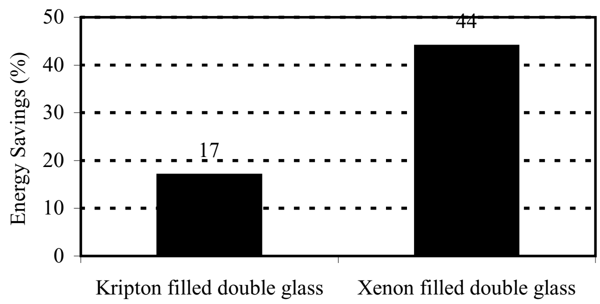

Figure 11. The percentage energy savings of gas filled glass units in comparison to argon filled double glass.

Conclusion

In Turkey most of the energy expended in buildings is met with imported energy from other countries. Therefore, it is necessary to decrease the amount of energy used in buildings for heating and cooling. By looking over the results of this study, it is found out that orientation ratio, glass type, and transparency ratio of the facades are important parameters that determine the energy necessities of buildings. The calculations for Elazığ show that among the building samples OR1/1 are the building types that require the minimum heating and cooling energy with the same bottom area of 100 m^2. OR2/1 and OR1/2 follow this type of building in that order. In order to reduce the heating energy requirements of buildings, it is necessary to increase the area of south facing windows, which have the maximum solar gains in the heating season. When forming the window gaps in the east and west directions, it is necessary to determine the optimum window area in order to protect the indoor conditions against excessive solar gains. It is also necessary to restrict transparency ratios in the north direction to the minimum level needed.

For existing buildings where it is impossible to change the form factor and transparency ratio of the facades, very large benefits can be obtained by changing the glass type. For example, only by changing the single glass of the windows with air filled double glass units, an economy of 50% could be achieved in energy consumption caused by windows. The double glass and gas filled double glass technology is very new for Turkey's conditions. Because of this, they are very expensive compared to single glass, but they will pay for themselves by the beneficial effects on diminishing the energy requirements caused by windows.

Nomenclature

d	distance between glass sheets (m)
f	ratio between the radiation intensity and solar constant
F_s	shading factor
h_g	heat transfer coefficient of the inner gas (W/m^2K)
h_i	indoor heat transfer coefficient (W/m^2K)
h_o	outdoor heat transfer coefficient (W/m^2K)
I	total radiation on a building surface
I_a	diffuse radiation on a tilted surface
I_{sc}	solar constant (1353 W/m^2)
I_y	hourly total radiation on horizontal surface
k	heat conductivity of the inner gas (W/mK)
K	radiation reduction coefficient
L	thickness of the transparent layer (m)
n	number of the day from first of January
q_i	heat loss and gain of glazing
T_o	ambient temperature (°C)
T_i	indoor temperature (°C)
V	hourly wind velocity (m/s)

Greek Letters

α	absorptivity of the transparent surface
β	slope angle of building façade
γ	surface azimuth angle (°)
δ	declination angle (°)
ϑ	incidence angle of the solar radiation (°)
$\vartheta\prime$	refractive angle of the radiation through a transparent surface (°)
ϑ_z	zenith angle (°)
ρ	reflectivity of the transparent surface
ρ_g	reflectivity of the ground
ρ_{int}	average reflection of the interface
τ	transmissivity of the transparent surface
Φ	altitude angle (°)
ω	hour angle (°)

Subscripts

d	direct radiation
dif	diffuse radiation
ref	reflected radiation
1 of 2	outer glass sheet of double glass
2 of 2	inner glass sheet of double glass
1,2	double glass

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