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A comparision of new Turkish thermal insulation standard (TS 825), ISO 9164, EN 832 and German regulation

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Abstract

Nowadays, the most common characteristic of all regulations and buildings is that heat energy requirement of a building is calculated and evaluated for the whole building, not as a sum of those for individual building components. In this paper, first, the recently revised Turkish standard is described in general, and then compared with the ISO 9164, EN 832 and the German regulation. The calculation procedures presented in the standards are evaluated, based on the results of three different types of buildings. The new TS 825 is an application of ISO 9164 in every respect. It uses the same equation, same restriction and same flexibility. EN 832 is basically similar to the ISO 9164 and so is the new TS 825. The most important difference in EN 832 is that solar energy gain is calculated in quite detail including passive solar gains, as well as direct solar gains. This approach gives more accurate results but need huge and detailed database. German regulation is harmonious with ISO 9164, EN 832 and TS 825 only from the point of view of principles and concepts. However, it is a very simplified one, the calculation method defined in the German regulation gave Q_{year} far from the actual heating energy requirement of buildings for the countries with moderate climate. The main differences between the calculation methods presented in the standards are "the acceptance of climatic data," "the calculation method of internal heat gains," "the calculation method of solar heat gains" and "the acceptance of the air change rate values."

The effects of parameters and the building types on the energy demands are discussed in order to determine which parameter should be constant but which ones should be variable, to obtain more simple but accurate results, and to show to designers the parameters to be effectively controlled to decrease the energy requirements of the buildings. Independently of building type, the higher the area of component, the more influential is its *U*-value on the Q_{year} except ground. Ground has always the least effect on the Q_{year}. The effect of air change rate is high being almost similar for all types of buildings, however air change rate affects Q_{year} slightly less at the terraced office building than the others. With lower *U*-values of wall and window, the effects of window area and window directions on the Q_{year} of detached buildings are minimized. Terraced buildings are more sensitive to window area than the window directions. It is clear that the increase in south window area, for all types of buildings, has slightly more effect on Q_{year} than the increase in north, east and west window areas. The effects of *r* and *g* on the Q_{year} increase, when the heat loss decreases but solar gain increases. Therefore, for modern buildings, to accept these parameters as a constant is not fairly significant.

Keywords: Thermal insulation standards; Energy efficient buildings; Solar architecture

1. Introduction

Energy consumption for heating is too high in Turkey because buildings have almost no insulation. Average consumption for heating in dwellings is above 200 kWh/m^2 per year [1]. In addition, almost no building has passive solar techniques and solar energy can not meet a significant part of their heat energy requirements despite the fact that Turkey has plenty of solar energy. For example, daily total global solar energy is about 30 000 kJ/m^2 and sunshine duration is around 10 h in summer and about 9000 kJ/m^2 and 3 h in Winter, in Trakya (north-west of Turkey) [2].

Until recent years, efforts have been made to reduce the energy consumption by imposing restrictions on the *U*-value of building components (such as wall, window, roof, etc.) in both the Turkish and the International standards and regulations [3–8]. This approach has the following shortcomings:

1. With the restriction on only *U*-value of the building components, thermal bridges particularly at joints of building components are virtually ignored. Therefore, actual heat loss of a building is most probably greater

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Nomenclature

A	area of exposed building component (m^2)
A_{sn}	solar effective collecting area of the surface n (m^2)
A_{snj}	solar effective collecting area of the surface n having orientation j (m^2)
A_n	net heating floor area (m^2)
b	width of thermal bridge (m)
F_{Cn}	reduction factor taking into account permanent curtains
F_{Fn}	reduction factor taking into account frames of transparent surfaces
g	solar transmission factor of glazing
$g_{\perp}$	solar transmission factor of glazing for the normal incidence
GLR	gain/loss ratio
H	specific heat loss (W/K)
H_T	specific heat loss by transmission (W/K)
H_V	specific heat loss by ventilation (W/K)
I	solar radiation on vertical surfaces (W/m^2)
k_f	thermal transmittance of transparent surfaces (W/m^2K)
k_{ef}	equivalence thermal transmittance of transparent surfaces (W/m^2K)
l	length of thermal bridge (m)
n_h	air change rate (h^{-1})
q_{sj}	total energy of the global solar radiation on a surface unity having orientation j during the calculation period (J/m^2)
Q_{year}	net space-heating requirement for year (J)
$Q_{h,m}$	net space-heating requirement for month (J)
Q_H	net space-heating requirement for year (kWh per year)
Q_T	heat loss per year by means of transmission (kWh per year)
Q_L	heat loss per year by means of ventilation (kWh per year)
Q_I	internal gains per year (kWh per year)
Q_s	solar gains per year (kWh per year)
r	shading factor for transparent surfaces
s_n	shaded fraction for a surface exposed to the sun
S_F	coefficient for useful solar gains of transparent surfaces (W/m^2K)
t	number of seconds in a month ($60*60*24*30 = 2\,592\,000$; s)
T_i	inside (internal) temperature (K or °C)
$T_{o,m}$	monthly average outside (external) temperature (K or °C)
U	thermal transmittance of exposed building component (W/m^2K)
U_{TB}	thermal transmittance of thermal bridge (W/m^2K)
U_l	linear thermal transmittance of thermal bridge (W/mK)
V_V	ventilated volume (m^3)
V_{gross}	volume of the building calculated by using the external width, length and height (m^3)

Greek letters

η_m	monthly average utilization factor for gains
ϕ_i	internal gains (W)
$\phi_{s,m}$	Monthly average solar gains (W)
ξ	Factor characteristic of thermal bridge expressing lateral heat loss

Indices

i	surface number, direction
j	direction
m	monthly average, value for month
s	solar

than the calculated value based on this approach. In a research on Turkish buildings, there is about 95% increase in U-value of walls due to thermal bridges [9].
2. Heat loss by air infiltration and ventilation are not taken into consideration. This also results in actual heat loss being higher than the expected value.
3. Climatic data (outdoor air temperature, etc.) in the equation are given as average value, minimum value, maximum value or the value expected with 90–95% probability. Particularly in a country with a moderate climate such as Turkey, heat loss calculated by using constant value for the whole heating period incurs considerable deviations from the actual heat loss.

Influenced by the above objections, especially during the last decade, international standards and regulations have been improved. The innovations included in these new international standards are as follows:

1. Restriction about the heat loss of buildings is on the scale of whole building, instead of only on building component. An upper limit is imposed on the Q value, which is the net total heat energy requirement of the whole building, and thermal bridges are included in the calculations procedure for the Q value.
2. Heat losses due to air infiltration and ventilation are taken into account. Air change rate (n_h) is a simple parameter in the equation taking into consideration the quality of framework on the heat loss of buildings.
3. Although calculation based on the unsteady-state regime is the most accurate, equations are very complicated. There have been numerous attempts to implement a computer programme for calculation according to the unsteady-state regime [10], but no international agreement has been yet reached. Therefore, international standards and regulations still accept the use of steady-state regime calculation procedure. But they recommend using climatic data as daily or monthly average values instead of one value for the whole heating period.

Nevertheless, the German regulation proposes a single value of degree days (DD, a constant value of 3500 Kelvin days per year) for the entire country for calculating heat loss, and constant solar radiation for the entire country for calculating solar energy gains [11].
4. Internal and solar heat gains are included in the calculation of energy requirement by subtracting them from heat loss, thus encouraging the use of passive solar techniques.

The main international standards for the European community are EN and ISO. Although it presents the simplest calculation method, the German regulation differs significantly from them. While revising Turkish thermal insulation standard (TS 825), ISO 9164-thermal insulation calculation of space heating requirements for residential buildings, EN 832-thermal performance of buildings calculation of energy use for heating residential buildings and German regulation have been examined and they are evaluated from the point of view of reliability and the country's conditions. Revised Turkish thermal insulation standard has been in effect since 1999. The aims of this standard are:

- restriction of heat loss and fuel consumption of buildings in Turkey;
- encourage architects to use passive solar energy techniques for heating buildings in Turkey.

In this paper, first the revised Turkish standard is described in general, and then points in disagreement with the ISO 9164, EN 832 and the German regulation are shown as well as those in agreement with them. The main differences between the calculation procedures presented in the standards are "the assumption of climatic data," "the calculation procedure of internal heat gains," "the calculation procedure of solar heat gains" and "the assumption of the air change rate values." The effects of the calculation procedures on the results are evaluated by means of the results obtained from three different types of buildings. In addition, the effects of parameters and the building types on the energy demands are discussed in order to determine which parameter should be constant and which ones should be variable, to obtain simpler but more accurate results, and to show to designers which parameters should be effectively controlled to decrease the energy requirements of the buildings. For this reason, the heat energy requirements have been calculated for various values of the parameters affecting the energy demand, for each building separately. ISO 9164, EN 832 and German regulation and the results obtained from them are also evaluated by using these comprehensive results.

2. General description of revised turkish thermal insulation standard—TS 825

According to TS 825, heat requirement of a building for a year (Q_{year}) should be calculated by the sum of the heat requirement per month. Heat requirement per month ($Q_{\text{month}} = Q_{\text{h},m}$) is calculated by using monthly average values [3]:

$$Q_{\text{h},m} = [H(T_{\text{i}} - T_{\text{o},m}) - \eta_m(\phi_{\text{i}} + \phi_{\text{s},m})]^* t \tag{1}$$

The first term is equal to fabric and ventilation heat loss from a building while the second is equal to heat gains of a building.

Specific heat loss (H) indicates thermal insulation performance of a building and it is calculated by the following formulae:

$$H = H_{\text{T}} + H_{\text{V}} \tag{2}$$

$$H_{\text{T}} = \sum AU + lU_{\text{l}} \tag{3}$$

$$H_{\text{V}} = 0.33 n_{\text{h}} V_{\text{V}} \tag{4}$$

$$U_{\text{l}} = b^* U_{\text{TB}} + \xi \tag{5}$$

Interior gains (ϕ_{i}) should be calculated as "$5^* A_{\text{n}}$" or "$10^* A_{\text{n}}$" according to the kinds of building. The $5^* A_{\text{n}}$ is for house, office, etc. While "$10^* A_{\text{n}}$" is for buildings or space only with high electricity or fuel consumption such as food factory, a space with converter or electric furnace, etc.

$$A_{\text{n}} = 0.32\, V_{\text{gross}} \tag{6}$$

A_{n} is the net heating floor area while V_{gross} is the volume of the building calculated by using the external width, length and height.

Monthly average solar gains ($\phi_{\text{s},m}$) should be calculated by the following equation:

$$(\phi_{\text{s},m}) = (r_{\text{so},m}{}^* g_{\text{so},m}{}^* I_{\text{so},m}{}^* A_{\text{so}}) + (r_{\text{n},m}{}^* g_{\text{n},m}{}^* I_{\text{n},m}{}^* A_{\text{n},}) + (r_{\text{e},m}{}^* g_{\text{e},m}{}^* I_{\text{e},m}{}^* A_{\text{e}}) + (r_{\text{w},m}{}^* g_{\text{w},m}{}^* I_{\text{w},m}{}^* A_{\text{w}}) \tag{7}$$

Subscripts on the right of the equation represent the direction, so, n, e, w represent south, north, east and west, respectively, while m represents monthly averaged value. According to the TS 825, shading factor "r" can be equal to 0.8 (for detached, one or two storey buildings), 0.6 (for detached one or two storey buildings but shadowed by trees) or 0.5 (for terraced multistorey buildings in city center).

Solar transmission factor of glazing "g", is equal to 0.80 $g_{\perp}$. $g_{\perp}$ is the solar transmission factor of glazing for the normal incidence. In TS 825, three values (0.85–0.75–0.50) are given for single glazing, clear multiple glazing and shaded multiple glazing of $g_{\perp}$, respectively.

The utilization factor "η_m", should be calculated by the following empirical formulae:

$$\eta_m = 1 - \text{e}^{-(1/\text{GLR}_m)} \tag{8}$$

$$\text{GLR}_m = \frac{\phi_{\text{i}} + \phi_{\text{s},m}}{H(T_{\text{i}} - T_{\text{o},m})} \tag{9}$$

In the last chapter of the standard, how the presence of condensation through the cross-section of building envelope would be monitored, but not been stated how the increase in the heat conductivity (λ) of the materials should be monitored while their humidity is rising due to condensation.

According to the standards, architects can control energy requirement for space heating of their buildings by controlling the following parameters:

- U-value of building component (wall, window, roof, floor);
- air change rate;
- the ratio of building volume (V_{gross}) to area of building envelope (A_{total});
- direction and size of windows;
- shading factor and solar transmission factor of glazing;
- insulation techniques (external or internal insulation, or cavity wall, etc. insulation techniques especially determine the presence of thermal bridges).

3. Comparison of TS 825 with ISO 9164, EN 832 and the German regulation

The main differences in the calculation procedure between the standards are explained below:

- The acceptance of calculation period and climatic data.

The formula proposed in ISO 9164 for calculation of total annual heat energy requirement is almost the same as TS 825 [3,12]. First, heat energy requirement for each month (in TS 825) or each day (in ISO 9164) is calculated and then total annual heat energy requirement is obtained by summing the monthly (or daily) energy requirements that are higher than zero:

$$Q_{year} = \sum Q_{month} \tag{10}$$

$$Q_{month} = Q_m = \sum [H(\theta_i - \theta_e) - \eta_m(\phi_i + \phi_s)]_{d,pos}{}^* t \tag{11}$$

The heating period is not restricted. Positive values for each month (or each day) should be summed. The period to be taken as basis is determined according to the climatic data and building insulation level.

Similar formula is proposed in EN 832, but external temperature is defined as a constant value for a given period of time [13].

On the other hand, in German regulation, the heating period all over the country is adopted as a constant value of 3500 Kelvin days per year, and Q_{year} ($\equiv Q_H$) is calculated directly according to the following equation [11]:

$$Q_H = 0.9(Q_T + Q_L) - (Q_l + Q_s) \tag{12}$$

So, the unit of Q_H is different from that in ISO, EN and TS 825. Its unit is "kWh per year" in German regulation whereas "J" or "kJ" in the others.

In ISO 9164, external temperature is taken as daily average temperature, and Q_{month} is calculated by summing of the daily energy requirements. If this method is used, manual calculation will be impossible. In TS 825, outside (external) temperature ($T_{o,m}$) is given as monthly average temperature and Q_{month} is calculated at once. During the revision of TS 825, the relevant official department has calculated the energy requirement by using both daily average temperature and monthly average temperature, incurring no significant difference. Monthly average outside temperature is used so that manual calculation is possible. EN 832 permits to select the calculation period as month or season, and also to adopt the procedure for DD usage.

One can say that principles of ISO 9164, EN 832 and TS 825 are practically the same. But, in EN 832, external (outside) temperature is included to the formula as a constant term during a given period of time. The German regulation is rather different, however, the main points are still similar.

- The calculation procedure of heat loss.

When we look at sub equations, the difference becomes more significant. In German regulation, thermal bridges are not taken into consideration in the calculations of heat losses by transmission. While ISO 9164 and new TS 825 include heat loss through thermal bridges by adding the term "lU_l" to the term of "ΣAU". In EN 832, it is mentioned that heat loss through thermal bridge should be taken into consideration, but the related procedure is not explained. However, another European norm is being prepared for this purpose.

The other difference among the standards for heat loss, is that the heat loss through the ground is calculated separately only in EN 832. Whereas in TS 825 and German regulation, heat loss through the ground slab is determined by multiplying the product of U-value and area of ground slab by 0.5.

The last difference between the standards for heat loss is the value of air change rate. In the German regulation, air change rate is given as 0.8 h^{-1}. In ISO 9164 and EN 832, this value is approximately the same. However, in new TS 825, this should be 1 or 2. The value of 1 should be used while the window frames have quality certificate from Turkish standards institution or other International institutions. If one uses frame that has no certificate, air change rate should be included in the equation as 2.

- The calculation procedure of internal heat gains.

The approaches of ISO 9164, EN 832 and the German regulation to the heat gains are rather different from one another.

According to the ISO 9164, there is no limit for the maximum value of internal gain. Only gain obtained from certain equipments or functions are declared and the designer is expected to calculate internal gains according to these values and expected functions in the building.

EN 832 recommends, for residential buildings, 5 W/m^2 of net heating floor area in calculating internal heat gains (ϕ_i, in

W). In new TS 825, almost the same value is used, but it suggests that internal heat gains should not exceed 5 W/m^2 of net heating floor area for ordinary buildings, whereas 10 W/m^2 of net heating floor area for high energy consuming buildings such as office buildings with no natural illumination or food factories, etc.

German regulation is rather different. It groups the buildings according to their functions and to their net room height. Internal heat gains (Q_l, in kWh per year) should not exceed the value calculated by the following equations (A_n being as 0.32 V_{gross}):

$Q_l = 8.0\ V_{gross}$ or $Q_l = 25\ A_n$	for residential building
$Q_l = 10.0\ V_{gross}$ or $Q_l = 31.25\ A_n$	for office building

A_n is net total floor area of buildings, and if the net height of buildings is less than or equal to 2.60 m, the equations including A_n may be used.

- The calculation procedure of solar heat gains.

TS 825 and ISO 9164 suggest the same procedure to calculate solar gains with the following equation:

$$\phi_{s,m} = \sum_i (r_{i,m}{}^* g_{i,m}{}^* I_{i,m}{}^* A_i) \quad (13)$$

i represents the direction while m is the month, and the sum is made on direction. According to this equation, it is possible that the values of r, g and I for each direction can vary for each month. This is true and significant for research study; but not for standards or regulations. Because, the calculation process gets complicated and difficult if this equation is used. However, this equation was adopted in new TS 825, incurring serious criticism. In this paper, the effect of the variation of these (r, g) on the yearly energy requirement (Q_{year}) is investigated in detail. The results are shown in Fig. 6 and Tables 12 and 13.

In EN 832, solar gain is calculated by the following equation:

$$Q_s = \sum_j q_{sj}{}^* \sum_n A_{snj} \quad (14)$$

q_{sj} is similar to $I_{i,m}$ in ISO an TS. But $I_{i,m}$ is the monthly average solar intensity at ith direction in W/m^2 whereas q_{sj} is the total energy of global solar radiation during the calculation period in J/m^2. That is $q_{sj} = I_{i,m}t$. On the other hand, A_{snj} is almost equal to the product of "$r_{i,m}{}^* g_{i,m}{}^* A_i$" as in the ISO 9164 and new TS 825. A_{snj} expresses the product in more detail, and is calculated by the following equation:

$$A_{sn} = A_n(1 - s_n)F_{Cn}F_{Fn}g_n \quad (15)$$

In this formula, area of frames and other opaque surfaces and the permanent tulle and curtain in front of the windows are taken into consideration as well as shading factor. EN 832 has proposed a very detailed equation for direct solar gains, and it also gives special calculation methods for passive solar systems such as sunspaces, transparent insulation materials and, etc. This approach is expected to give more accurate results but it is not suitable for countries at which sufficient data is not available.

German regulation contrary to the EN 832, presents much simpler calculation procedures for determination of direct solar energy gains. The first procedure is very similar to that in ISO 9164:

$$Q_s = \sum_{ij} (0.46^* I_j{}^* g_i{}^* A_{ji}) \quad (16)$$

In this equation, indices i represent number of windows at direction j, and shading factor is given a constant value of 0.46 for all types of buildings in Germany. I_j values have been taken to depend on direction only, and therefore, are the same throughout the country, as in TS 825.

In German regulation, the second method is described for calculation of direct solar energy gain. This gain is considered via the reduction in heat loss value of transparent components according to the following formula:

$$k_{ef} = k_f - g^* S_F \quad (17)$$

Values of S_F are given as constant throughout the country but depend on the directions, similar to as I_j.

4. The effects of building types, calculation methods and parameters on the energy requirement (Q_{year})

Energy requirement for heating (Q_{year}) is calculated for three different types of buildings in the same climate by using the formulae in TS 825 (and ISO 9164), EN 832 and the German regulation, in order to evaluate the effects of building types and calculation methods on Q_{year}. In addition, for each building, the heat energy requirements have been calculated for various values of the parameters affecting the energy demand. The effects of parameters on the energy demands (Q_{year}) are discussed in order to determine which parameters can be taken as constant and which ones should be variable, to obtain simpler but accurate procedure, and to show to the designers the parameters that should be effectively controlled to obtain significant decrease in the energy requirements of the buildings.

The properties of buildings are summarised in Table 1 [14].

In Table 2, the calculated gain/loss ratio, the ratios of solar gains to heat loss and utilization factor per month for these buildings are shown. According to this table, the faculty building has a high amount of solar energy gain whereas the other types of buildings have little solar energy gains especially during winter months.

4.1. The effects of building types and calculation methods on Q_{year}

As mentioned above, differences between the calculation methods consist of the assumption of climatic data, the

Table 1
Properties of buildings and the result of calculation

Properties and results	Building 1	Building 2	Building 3
Total area of building envelope (A_{total}, m^2)	221	1001	6991
Brut volume of building (V_{gross}, m^3)	310	1568	28923
A_{total}/V_{gross}	0.71	0.64	0.24
Glazing/wall	0.26	0.28	0.99
Glazing/total vertical surface	0.21	0.22	0.50
Brut total floor area	124	648	9850
$A_n = 0.32\ V_{gross}$ (m^2)	99	502	9255
Ground floor area (m^2)	42	125	1885
U_{wall} (W/m^{2}K)	2.38	2.38	1.16
U_{window} (W/m^{2}K)	4.50	4.50	2.80
U_{roof} (W/m^{2}K)	2.15	2.15	0.80
U_{ground} (W/m^{2}K)	2.86	2.86	0.78
H_i (W/K)	493	2504	8344
n_h	2.0	2.0	1.0
H_h (W/K)	164	828	7636
ϕ_i (W)	823	6477	37408
$\phi_{g,january}$ (W)	591	1515	33983
Q_{year} calculated (kJ)	104601252	461284812	2238159569
Q_{year} calculated (kWh/m^2)	293	256	67
Q_{year} permitted in the standard (kWh/m^2)	81	76	49

Building 1 is detached two storey residential; building 2 is terraced four storey office building; building 3 is detached tree storey (+ 2 basement) faculty building (Çorlu Engineering Faculty).

calculation procedure of internal heat gain and the calculation procedure of solar heat gain. Their effects are evaluated in the following sections in detail.

4.1.1. The effect of climatic data acceptance

The German regulation assumes constant climatic data throughout the country, whereas TS 825 has four different climatic regions and data according to the DD of the region. Fig. 1 shows the variation of the Q_{year} (net space heating requirement for year) with the building type and the DD for Türkiye. Table 3 shows the statistical properties of the Fig. 1. The deviations of maximum Q_{year} from the minimum Q_{year} are more than 250% while the DD is changing from minimum to maximum. The deviations of maximum Q_{year} from the average Q_{year} are more than 100%. These are too high. These values clearly show that usage of constant climatic data for calculation is certainly not suitable for the country that has a moderate climate. The Figure and the Table show more information:

1. The climatic conditions affect the results much more if the building has high solar heat gains (such as the school building). The deviations of the school building's maximum Q_{year} are 135 (from average Q_{year}) to 173% (from minimum Q_{year}), whereas the deviations of other buildings' maximum Q_{year} are 117–151% (terraced office building) and 115–147% (detached house). These buildings have significantly lower solar heat gain than the school building.
2. Q_{year} is more sensitive to the internal air temperature, if the building has less solar heat gains.

4.1.2. The effect of internal heat gain calculation method

Internal heat gains for different building types obtained by using the equations in TS 825 and German regulation are

Table 2
The calculated gain/loss ratio, the ratio of solar gains to heat loss and utilization factor for heating period and the buildings described in Table 1

	Detached house			Terraced office building			Detached faculty building		
	GLR	SG/HL[a]	η	GLR	SG/HL[a]	η	GLR	SG/HL[a]	η
January	0.14	0.06	0.999	0.16	0.03	0.998	0.27	0.13	0.976
February	0.16	0.08	0.998	0.26	0.05	0.995	0.33	0.18	0.953
March	0.23	0.12	0.988	0.55	0.08	0.978	0.46	0.27	0.889
April	0.43	0.23	0.902	0.55	0.19	0.835	0.83	0.52	0.699
October	0.49	0.23	0.871	0.67	0.17	0.776	0.87	0.47	0.684
November	0.21	0.09	0.991	0.27	0.05	0.998	0.40	0.19	0.918
December	0.14	0.06	0.999	0.18	0.03	0.996	0.28	0.12	0.973

[a] SG/HL: solar gain/heat loss.

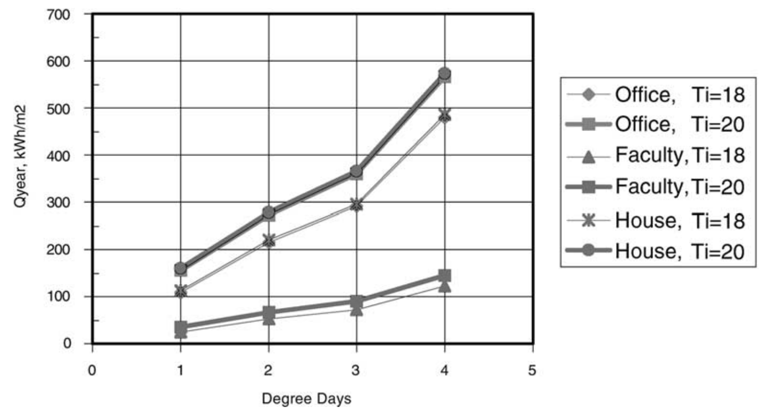

Fig. 1. Variation of Q_{year} with building types, degree days (in TS 825) and internal temperatures (T_i, 18 and 20 °C).

presented in Table 4. To obtain the same unit, internal heat gains calculated in Watt is multiplied by the heating period (TS 825 has four DD regions and the heating period is 7 months for 2 DD).

According to the Table 4, TS 825 (and EN 832) permit slightly more maximum internal heat gains for school and residential buildings but less internal heat gains for official buildings than the German regulation.

4.1.3. The effect of solar heat gain calculation method

The solar heat gains calculated according to the TS 825 and the German regulation are shown in Table 5.

In TS 825, monthly average solar radiation on vertical surfaces ($I_{i,m}$) vary only with the direction. These values are the same throughout the country, but are different from the values given in German regulation. So the difference between the Q_s values in Table 5, are caused by the different "*r*" values and "*I*" values.

In TS 825, "*r*" value can be selected from the values of 0.80, 0.60 and 0.50. If the building is in the region at which there are detached buildings with up to three storeys, and there are no trees shading the buildings; one have to select 0.8 for *r*. If the building is in the region at which there are detached buildings with up to three storeys, but there are trees shading the buildings; one have to select 0.6 for *r*. Finally, if the building is in the city with high buildings; one have to select 0.6 for *r*. Whereas, in the German regulation, "*r*" is constant and equal to 0.46.

I values are also different from TS 825 in the German regulation. These differences are shown in Table 6. In TS 825, there are four different DD regions. The higher the DD, the longer the heating period, and the "*I*" values in kWh per

Table 3
Statistical values of Q_{year} variations (in kWh/m^2) with the climatic conditions (with the degree days defined in TS 825) and internal temperatures

	Detached House		Terrace office building		Detached faculty building	
	$T_i = 18$ °C	$T_i = 20$ °C	$T_i = 18$ °C	$T_i = 20$ °C	$T_i = 18$ °C	$T_i = 20$ °C
Minimum	113	160	109	156	25	36
Maximum	486	573	480	567	123	145
Averaged	279	344	274	339	68	85
Standard deviation	157	174	156	173	41	46
Max.–min.	373	413	371	411	98	109
(Max.–min.)/min.	330	248	340	263	392	303
(Max.–averaged)/averaged	147	115	151	117	173	135

Table 4
Comparison of internal heat gains

Building type	Q_I according to the German regulation (kWh per year)	Q_I[a] according to the TS 825 (2 DD; kWh per year)
Office (terrace)	15675	12649
School (detached)	231384	233423
Residential (detached)	2483	2505

[a] In TS 825, internal heat gains are calculated in W or J per month. In this table, the results are multiplied by the heating period. These buildings are in the region of 2 DD and the heating period are 7 months for 2 DD.

Table 5
Comparison of solar heat gains

Building type	Q_s According to the German regulation (kWh per year)	Q_s[a] according to the TS 825 (2 DD; kWh per year)
Office (terrace)	8750	10794
School (detached)	118664	592340
Residential (detached)	2031	5080

[a] In TS 825, solar heat gains are calculated in W or J per month. In this table, the results are multiplied by the heating period. These buildings are in the region of 2 DD and the heating period are 7 months for 2 DD.

Table 6
Comparison of solar intensities

Degree days	I_{south} (kWh per year)		I_{north} (kWh per year)		$I_{west–east}$ (kWh per year)	
	TS[a]	GR[b]	TS[a]	GR[b]	TS[a]	GR[b]
1 DD	335	400	166	160	249	275
2 DD	394	400	195	160	291	275
3 DD	525	400	293	160	432	275
4 DD	593	400	352	160	520	275

[a] According to the TS 825, to calculate the values in these columns, monthly solar energy intensity values are multiplied by the time of heating period. Heating periods are 6, 7, 9 and 10 months for 1, 2, 3 and 4 DD, respectively.
[b] According to the German regulation.

Table 7
Variation of the Q_{year} with the U-value of building components for different buildings

	Detached house		Terraced office building		Detached faculty building	
	Equation	R^2	Equation	R^2	Equation	R^2
Wall	$Q_{year} = 50U_w + 176$	0.99	$Q_{year} = 56U_w + 124$	0.99	$Q_{year} = 9U_w + 56$	0.99
Window	$Q_{year} = 13U_{ww} + 234$	0.99	$Q_{year} = 15U_{ww} + 186$	0.99	$Q_{year} = 9U_{ww} + 42$	0.99
Roof	$Q_{year} = 30U_R + 230$	0.99	$Q_{year} = 11U_R + 232$	0.99	$Q_{year} = 11U_R + 58$	0.99
Ground floor	$Q_{year} = 12U_{GF} + 260$	0.99	$Q_{year} = 6U_{GF} + 238$	0.99	$Q_{year} = 6U_{GF} + 63$	0.99

Equations are obtained by linear regression analysis.

Table 8
Variation of Q_{year} with the component area

Detached house				Terraced office building				Detached faculty building			
Component	C1	C2	C3	Component	C1	C2	C3	Component	C1	C2	C3
Wall	50	0.40	176	Wall	56	0.57	124	Roof	11	0.28	58
Roof	30	0.30	230	Window	15	0.16	186	Wall	9	0.20	56
Window	13	0.11	234	Roof	11	0.14	232	Window	9	0.20	42
Ground	12	0.19	260	Ground	6	0.13	238	Ground	6	0.26	63

C1: the increase in Q_{year} (kWh/m^2) per 1 W/m^{2}K increment of U-value of a component; C2: the ratio of component area to the total building envelope area; C3: Q_{year} (kWh/m^2) when the U-value of the relevant component is equal to zero.

Table 9
Variation of the Q_{year} with the air change rate for different buildings

Detached house		Terraced office building		Detached faculty building	
Equation	R^2	Equation	R^2	Equation	R^2
$Q_{year} = 45.4.4n_h + 203$	0.99	$Q_{year} = 40.3n_h + 176$	0.99	$Q_{year} = 47.8n_h + 21$	0.99

Equations are obtained by linear regression analysis.

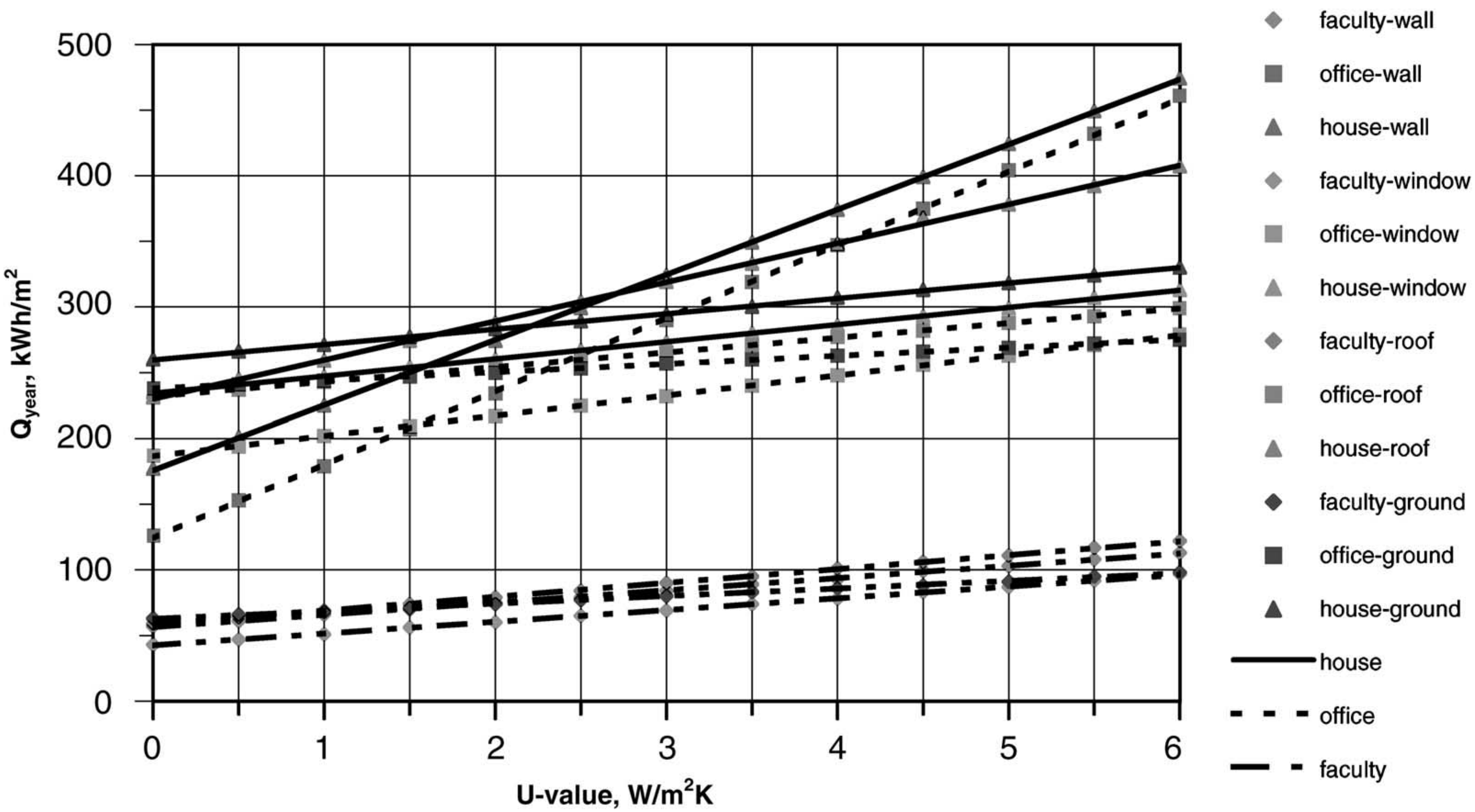

Fig. 2. Variation of Q_{year} with the U-value of building component for different buildings.

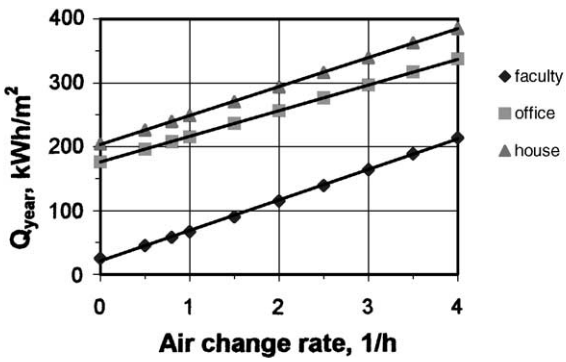

Fig. 3. Variation of Q_{year} with the air change rate for different buildings.

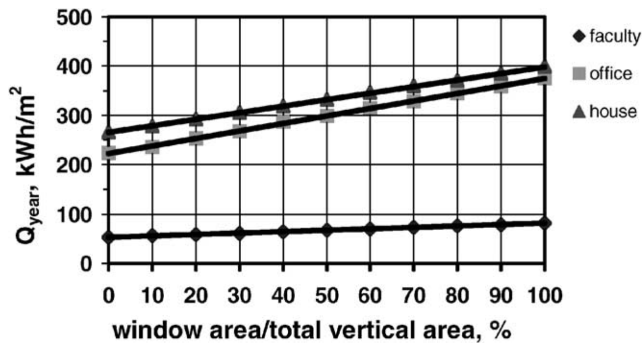

Fig. 4. Variation of Q_{year} with the ratio of window area to total vertical area for different buildings.

year increase with the higher DD, whereas it is also constant throughout the country in German regulation.

As a result, German regulation accepts rather less solar heat gains than that in TS 825, for all types of buildings. Especially for buildings with high solar energy, solar heat gains calculated according to the German regulation is much less than the actual value. These results are clearly seen from Table 5.

On the other hand, EN 832 has one difference from ISO 9164 and TS 825. It suggests two supplementary factors in calculating A_{sn}. These are F_{Cn} and F_{Fn}, which are both less than 1. Therefore, the calculated solar heat gains according to the EN will be less than that according to the ISO and TS. In TS 825, variations of *r*-value impart indirectly the effects of F_{Cn} and F_{Fn} to a certain extent. Other parameters are equivalences to each other.

4.2. The effects of building types and parameters on Q_{year}

If we consider the calculation procedures defined in the standards, we can find the following parameters affecting the Q_{year}:

- *U*-value of the building components;
- air change rate;
- window area;
- window direction;
- *r*-value;
- *g*-value.

The effects of these parameters on Q_{year} are examined comprehensively. In Figs. 2–6, the variation of Q_{year} with the changing of parameters, which can be controlled by architects according to the new TS 825, ISO 9164 and EN 832, are presented. In Tables 7–12, the equations and the figures showing to what degree the Q_{year} is affected by the related parameters are given.

4.2.1. The effect of U-value

The annual energy requirement for the space heating of a building, Q_{year}, is affected by the *U*-value of the building component (Fig. 2). The *U*-value of the ground affects Q_{year} at least, independently of building type. Increases of 1 W/m^{2}K in *U*-value of ground will cause an increment of 6 (school and commercial center) and 12 kWh/m^2 (detached house) in Q_{year}. If the *U*-value of ground is theoretically equal to zero, Q_{year} will still be highest (260 kWh/m^2 for detached house, 238 kWh/m^2 for terraced commercial center and 63 kWh/m^2 for detached house) because of the heat loss through the other components (Table 7). Within the others, wall is the most influential component on the Q_{year} for detached house. The roof has less effect and the window has the least. For this building, an increase of 1 W/m^{2}K in the walls' *U*-value cause an augmentation of 50 kWh/m^2 in

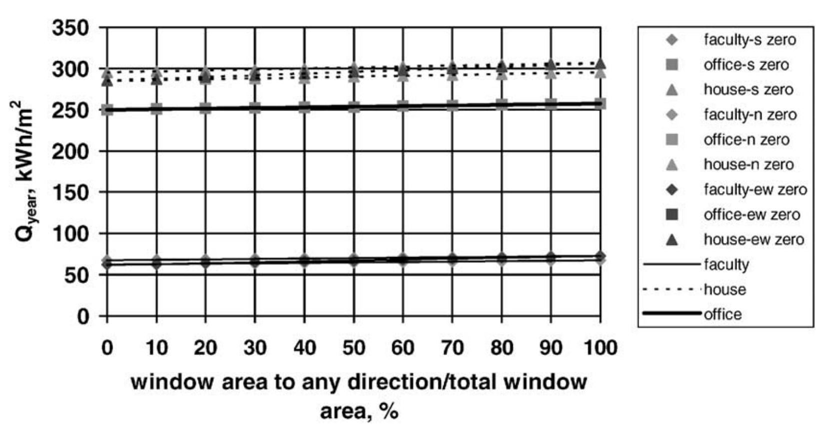

Fig. 5. Variation of Q_{year} with the window direction.

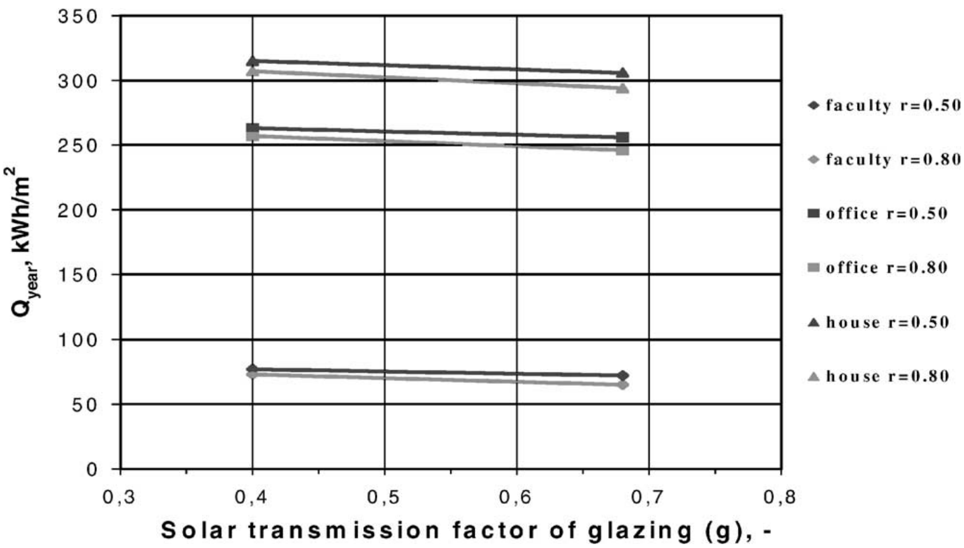

Fig. 6. Variation of Q_{year} with the r and g (r and g have the same value for all directions and for all seasons) for different buildings.

Table 10
Variation of the Q_{year} with the ratio of total window area to total vertical surface area for different buildings

Detached house		Terraced office building		Detached faculty building	
Equation	R^2	Equation	R^2	Equation	R^2
$Q_{year} = 1.3(A_{tw}/A_{tv}) + 265$	0.99	$Q_{year} = 1.5(A_{tw}/A_{tv}) + 223$	0.99	$Q_{year} = 0.29(A_{tw}/A_{tv}) + 53$	0.99

A_{tw} ≡ total window area; A_{tv} ≡ total vertical surface area. Equations are obtained by linear regression analysis.

Table 11
Variation of the Q_{year} with the window directions for different buildings

	Detached house		Terraced office building		Detached faculty building	
	Equation	R^2	Equation	R^2	Equation	R^2
$A_s = 0$	$Q_{year} = 0.12(A_n/A_t) + 295$	0.99	$Q_{year} = 0.07(A_n/A_t) + 250$	0.99	$Q_{year} = 0.05(A_n/A_t) + 68$	0.99
$A_{ew} = 0$	$Q_{year} = 0.21(A_n/A_t) + 285$	0.99			$Q_{year} = 0.11(A_n/A_t) + 62$	0.99
$A_n = 0$	$Q_{year} = 0.10(A_{ew}/A_t) + 285$	0.99			$Q_{year} = 0.06(A_{ew}/A_t) + 62$	0.99

A_n ≡ north windows area; A_s ≡ south windows area; A_{ew} ≡ east and west windows area. Equations are obtained by linear regression analysis.

Q_{year}, whereas the same increment of roofs' or windows' U-values cause 30 and 13 kWh/m^2 increase in Q_{year}, respectively (Table 7).

The listing of the components in the order of their effect is different for terraced office building. Wall–window–roof is the order from maximum to minimum. An increase of 1 W/m^{2}K in U-values of the wall, the window and the roof will cause 56, 15 and 11 kWh/m^2 augmentation in Q_{year}, respectively (Table 7).

Detached school building with more insulation level, more solar gains and less A/V ratio, is less sensitive to the U-value of all components. If the U-values of roof, or wall or window increases by 1 W/m^{2}K, Q_{year} will only increase by 11, 9 and 9 kWh/m^2, respectively. The most effective component is roof for this building while wall and window have less effect (Table 7).

The order of components according to their effect on Q_{year} is the same as that according to the ratio of the component

Table 12
Variation of the Q_{year} with the r and g for different buildings

	Detached house	Terraced office building	Detached faculty building
$r = 0.50$	$Q_{year} = -32g + 328$	$Q_{year} = -25g + 273$	$Q_{year} = -18g + 84$
$r = 0.80$	$Q_{year} = -46g + 326$	$Q_{year} = -39g + 273$	$Q_{year} = -29g + 84$

Equations are obtained by linear regression analysis.

Table 13
Variation of Q_{year} with the degree of sunshine and shadow for different buildings

	Detached house Q_{year} (kWh/m^2)	Terraced office building Q_{year} (kWh/m^2)	Detached faculty building Q_{year} (kWh/m^2)
Min. shadow, max. sunshine; $r = 0.80$, $g = 0.68$	294	246	65
Max. shadow, max. sunshine; $r = 0.50$, $g = 0.68$	306	256	72
Min. shadow, min. sunshine; $r = 0.80$, $g = 0.40$	307	257	73
Max. shadow, min. sunshine; $r = 0.50$, $g = 0.40$	315	263	77

area to the total building envelope area (A_{total}). In Table 8, the ratio of component area to A_{total} is shown in column 2. The increases in Q_{year} per 1 W/m^{2}K increment of U-value of a component are also shown in the same Table (column 1) as well as Q_{year} values when the U-value of the relevant component is equal to zero (column 3). According to the Table, independent of the building type, the higher the area of the component, the more influential is its U-value on the Q_{year} except the ground. The ground has always the least effect on the Q_{year}.

4.2.2. The effect of air change rate

As shown in Fig. 3 and Table 9, another quantity affecting Q_{year} significantly is the air change rate. The degree of its effect is almost similar for all types of buildings, however, air change rate affected Q_{year} less in the terraced office building than the others.

4.2.3. The effects of window area and direction

According to the calculation method described in new TS 825 and ISO 9164, window area and direction do not have much influence on Q_{year} (Figs. 4–5). In Tables 10 and 11, the low slopes of proposed linear correlation have indicated this conclusion. For window area, the slopes are 0.29, 1.3 and 1.5 for detached faculty building, detached house and terraced office building, respectively, while the coefficients of window directions have varied between 0.06 and 0.21. Naturally, these figures will be valid if the rest of the parameters are constant.

With the lower U-values of wall and window, the window area and window directions affect Q_{year} of detached faculty building the least. Terraced office building is more sensitive to window area than the window directions. It is clear that the increase in south window area, for all types of buildings, has slightly more effect on Q_{year} than the increase in north, east and west window areas.

4.2.4. The effects of r- and g-values

In the standards, except the German regulation, r and g can be different, making the calculation method complicated. If they are constant, the procedure will be simpler. In this paper, the effect of r and g on the Q_{year} for different buildings is also investigated. In Fig. 6, the variation of Q_{year} with the r and g is shown. In Tables 12 and 13, the linear correlation between Q_{year} and g is shown when the r is constant. If these parameters differ between the permitted ranges in the standard, Q_{year} can increase by 7% for detached house and terraced office building while 18% for detached faculty building. The effects of r and g on the Q_{year} increase when the heat loss decreases but solar gain increases.

5. Conclusion

Nowadays, the most common property of all regulations and buildings is that heat energy requirement of a building is calculated and evaluated for the whole building, not for the building components. The building is considered as a whole, and the U-value of a building component or the OTTV averaged heat loss value of opaque wall and its transparent component, is not a restriction for energy loss. The restriction is on the annual heat energy requirement value (Q_{year}) that is designated for the whole building. Naturally, ISO 9164 and EN 832 do not give any limitation for the Q_{year}. The restrictions given by new TS 825 and German regulation are shown in Table 14. In TS 825, very high Q_{year} is still permitted.

The new TS 825 is an adaptation of ISO 9164 in every respect. It uses the same equations, same restrictions and the same flexibility. According to the results, the calculation procedure described in new TS 825 based on ISO 9164 and partly on EN 832 is highly accurate and precise for heating

Table 14
The maximum permitted values for Q_{year} given in TS 825 and German regulation

A/V[a] (m)	Q_{year} (kWh/m^2 per year, new TS 825[b])	Q_{year} (kWh/m^2 per year, German regulation[c])
≤ 0.2	27–104	54.0
0.3	31.4–112.5	59.4
0.4	36–120.8	64.8
0.5	40.7–129.1	70.2
0.6	45.4–137.4	75.6
0.7	50–145.7	81.1
0.8	54.7–153.9	86.5
0.9	59.3–162.2	91.9
1.0	64–170.5	97.3
≥ 1.05	66–175	100.0

[a] A: total heat loss area, V: gross volume.
[b] $Q_{year} = 46.62\,A/V + 17.38$ (for 1 DD); $Q_{year} = 68.59\,A/V + 32.30$ (for 2 DD); $Q_{year} = 67.29\,A/V + 50.16$ (for 3 DD); $Q_{year} = 82.81\,A/V + 87.70$ (for 4 DD).
[c] For interval values: $Q_{year} = (1/0.32) \times (13.82 + 17.32(A/V))$.

period. Q_{year} is calculated as 67 kWh/m^2 per year for detached faculty building. The real consumption is about 45 kWh/m^2 per year. It should be noted that the real consumption covers only working days (except Saturdays, Sundays and other official off days) while the calculated results cover all days during the heating period (including Saturdays and Sundays). So the results obtained by using the calculation method described in new TS 825, matches the real consumption significantly. However, during the cooling period, faculty building is overheated and uncomfortable. TS 825 does not control the whole thermal performance of a building. Faculty building with the large south oriented window area and rather low U-value, has a heat requirement quite lower than the other buildings, and close to the standard's requirements while the others do not. However, it is not adequate for the whole year since it lacks necessary solar preventing measures such as overhang, shadowing elements, etc. In addition, it is very suitable for passive solar techniques but none of them has been applied.

EN 832 is similar to the ISO 9164 and to the new TS 825 in principle and in detail. But it requests the calculation of ground heat loss in addition to that of conduction and ventilation losses. Furthermore, energy gains are calculated as total energy covering the whole heating period instead of energy flux as in ISO 9164. The most important difference in EN 832 is that solar energy gain is calculated in quite detail including passive solar gains as well as direct solar gains. This approach gives more accurate results but require huge and detailed database.

German regulation is harmonious with ISO 9164, EN 832 and TS 825 only from the point of view of principles and concepts. But the calculation procedure is reduced to a very simple one. In this regulation, the utilization factor (η) for heat gains is not used and the heat loss is multiplied by the constant multiplier of 0.9 instead of multiplying the heat gain by a variable of η. DD is accepted as a constant of 3500 Kelvin days per year all over the country.

The calculation procedure defined in German regulation (acceptance of constant DD) is expected to give calculated results far from the actual heating energy requirements for the countries with moderate climate. For example, the deviations of calculated maximum Q_{year} from the minimum Q_{year} are more than 250% while the DD is changing from minimum to maximum, and the deviations of maximum Q_{year} from the average Q_{year} are more than 100%, for Turkey. In addition, the climatic conditions affect the results much more if the building has high solar heat gains. But the results obtained by using the procedure described in TS 825 and also ISO 9164 are almost equal to actual heating energy requirements.

In the German regulation, n_h is also constant and equal to 0.8 which is lower than 1 or 2 accepted in TS 825 and also lower than that accepted in EN 832.

According to the German regulation, the maximum value of internal heat gain permitted is a bit higher than that in TS and EN for office buildings; while a bit lower for the others.

On the other hands, solar heat gains calculated by TS 825 (ISO and EN) are also different from that calculated by the German regulation. German regulation suggests quite less solar heat gains especially for the buildings with high solar heat gains.

Finally, the most important difference is that thermal bridges are not considered in German regulation at all.

As a result, the main differences between the calculation methods presented in the standards are "the assumption of climatic data," "the calculation procedure of heat loss," "the calculation procedure of internal heat gains," "the calculation procedure of solar heat gains" and "the assumption of the air change rate values." In addition, one may say that ISO describes the best calculation procedure for heating energy requirement of buildings. EN 832 gives more accurate results but the formulation is complicated and needs huge database while German regulation is very simple but naturally gives quite rough results, especially for the moderate climatic conditions. The German version of EN 832 has been prepared [15], and the German regulation must be revised accordingly.

On the other hand, according to the standards (ISO 9164, EN 832, TS 825), architects can change energy requirement for space heating of their buildings by controlling the parameters of "U-value," "air change rates," "V_{gross}/A_{total} ratios," "direction and size of windows," "r and g factors" and "insulation techniques with or without thermal bridges (internal, external or cavity wall, etc.)."

According to the new TS 825 and ISO 9164 and also EN 832, architects should be careful about the U-value especially when designing small-detached buildings with one or two storeys. The effect of U-value (wall, roof, etc.) on Q_{year} depends strongly on the building type. However, the U-value of the ground affects Q_{year} to the least degree, independently of building type.

Wall is the most influential component on the Q_{year} for detached house with two storeys. The roof has less effect and the window has the least. The listing of the components in the order of their effect is different for terraced office building. Wall–window–roof is the order from maximum to minimum. Detached school building with more insulation level, more solar gains and less A/V ratio, is less sensitive to the U-value of all components.

The list of components in the order of their effects on Q_{year} is the exactly same as the list according to the ratio of the component area to the total building envelope area (A_{total}) for all types of buildings.

The second important parameter affecting Q_{year} is the air change rate. As expected, architects should also make minimum air change rate to obtain minimum Q_{year}. The effect of the air change rate does not change with the building type. However, air change rate affects Q_{year} slightly less at the terraced office building than the others.

The change of the window area or its directions will not cause a considerable improvement in Q_{year}. Especially higher insulation levels results in less sensitivity to window area and direction. However, if the Q_{year} of a building is slightly higher than the limited values in the standard, it is possible to decrease the Q_{year} by changing only the window area and direction (increasing south window area or decreasing total window area) resulting in less Q_{year} than the upper limit value. Terraced buildings are more sensitive to window area than the window directions. It is clear that the increase in south window area, for all types of buildings, has slightly more effect on Q_{year} than the increase in north, east and west window areas.

The r and g values may be constant from direction to direction and from month to month. The calculation procedure becomes complicated when they are taken as variables. If these parameters differ between the permitted ranges in the standard (TS 825), Q_{year} can increase by 7% for detached house and terraced office building while 18% for detached faculty building. The effects of r and g on the Q_{year} increase when the heat loss decreases but solar gain increases. So, for modern buildings, to accept constant values for these parameters is not fairly significant.

To avoid from thermal bridges is of course necessary to decrease energy demands of buildings. The effect of them on Q_{year} should be included in the calculation methods of standard and regulation.

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