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Research Article

ANALYSIS OF ANNUAL ENERGY REQUIREMENT OF A RESIDENTIAL HOUSE WITH TS825 AND ASHRAE HEAT BALANCE METHODS

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ABSTRACT

Energy efficiency in buildings is an important up-to-date topic. For that reason, accurate calculation of heating and cooling loads is essential. In this study, heating and cooling loads of a residential house were determined by using national standards for different climatic zones Mersin, İstanbul, Ankara, Erzincan, and Erzurum. Calculations were performed by using the TS825 method that is based on national mandatory heat insulation standard TS825 and EnergyPlus software that is based on heat balance method. Heating loads obtained from simulations were compared on the monthly and annual basis. The absolute deviation between methods results was obtained in the range of 1.9 % to 39.5 %. The highest deviation was in Mersin where represents the 1st region and the lowest deviation was in Ankara where represents the 3rd region. Since TS825 method has not feature to simulate cooling load, annual cooling load calculated by using EnergyPlus software was 128.2 kWh/m^{2}y for Mersin, 70.7 kWh/m^{2}y for Istanbul, 44.9 kWh/m^{2}y for Ankara, 49.0 kWh/m^{2}y for Erzincan and 26.7 kWh/m^{2}y for Erzurum. Insufficiency of the TS825 method was examined in detail.

Keywords: *Heating Load, Cooling Load, TS825, Heat Balance Method, EnergyPlus*

1. INTRODUCTION

Increasing population and industrialization in global scale lead to an increase in energy demand. Depletion of current energy resources and correspondingly increasing energy cost necessitate efficient consumption of energy resources. Buildings are one of the base energy consumption components and compose 20-40 % of the total energy consumption in worldwide (Perez-Lombard *et al.*, 2008). In the period of 2010-2014, buildings are averagely responsible for 35 % of the total energy consumption in Turkey according to the statistical report published by General Directorate of Energy Affairs (The Republic of Turkey, Ministry of Energy and Natural Resources, 2016). Despite the high energy consumption rate, buildings have energy saving potential. Developed countries attach particular importance to that potential and apply related regulations strictly. Due to a large number of old buildings and lack of inspection in regulation execution, energy consumption rate of buildings are high in Turkey. It is stated that only 16 % of buildings have a double glass window and insulated roof (Keskin, T., 2010). The most effective way of increasing energy efficiency is the energy saving applications. Since 1970, both standards and regulations have been developed to consume energy more efficiently and increase energy savings in Turkey. In this regard, a mandatory standard "TS825 Thermal Insulation Requirements for Buildings" was published in 2000 to increase savings in heating energy consumption rate of buildings. It is possible to save 25-50 % of energy consumption of buildings by only applying thermal insulation on building envelope (The Republic of Turkey, Ministry of Energy and Natural Resources, 2016).

Basically, accurate estimation of building energy demand without compromising on comfort conditions is required for building energy efficiency calculation. Experimental studies about the determination of building energy performance require high cost and long-term measurement period. For that reason, experimental measurement is rarely applied method in this field. In addition to that, high accuracy calculation method is a must to determine the energy demand of the building. Seasonal, hourly and dynamic calculation methods are used in building energy performance analysis. Simulation software codes are developed by using those methods to determine the energy demand of the building. In this study, TS825 method code developed base on seasonal calculation method and EnergyPlus® software developed base on dynamic calculation method are used. In that way, the energy demand of a single family house in different climatic regions of Turkey is calculated by using TS825 standard calculation method and heat balance method. Obtained results are used to compare methods with each other.

2. LITERATURE REVIEW

The simplest way of energy saving in buildings is the thermal insulation applications. By insulating the buildings, the required heating energy is decreased and energy saving is provided. Determining the correct material and optimum insulation thickness are very important issues in thermal insulation (Özkan, D. B., 2009). Required thermal insulation thickness differ according to the fuel type, climatic region, insulation material, window to wall ratio, etc. For all cities of Turkey, optimum insulation of thickness determined for two different fuels (natural gas, coal) and five different insulation material (rock-wool, glass-wool, XPS, EPS, polyurethane) (Kürekçi *et al.*, 2012). In those studies, the TS825 method was used and effect of methodology was not discussed in detail. Besides that, developed countries promote to form standards according to dynamic calculation procedure. ASHRAE heat balance method is referred as the most accurate approach to calculate the thermal loads in literature. EnergyPlus software algorithm was developed based on heat balance method. It is the official building simulation program of the United States Department of Energy, promoted through the Building and Technology Program of the Energy Efficiency and Renewable Energy Office. It is a widespread and accepted tool in the building energy analysis community around the world (Stadler *et al.*, 2006). Among the other simulation programs BLAST, BSim, DeST, DOE-2, ECOTECT, eQuest, ESP-r and TRNSYS, EnergyPlus program is defined as completely implemented for modelling characteristics such as simulation solution, time step approach, simultaneous radiation and convection, combined envelope heat and mass transfer, internal mass considerations, occupant comfort, solar gains, shading, and sky considerations (Harish and Kumar, 2015).

3. METHODOLOGY

In this study, villa type single family house placed in a rural area without any shading around is designed. Isometric view of the house is given in Fig. 1.

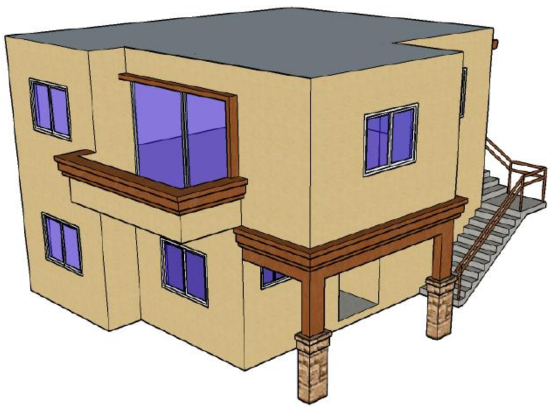

Fig. 1. Isometric view of the designed house

Designed house construction characteristics are designed to increase heat transfer rate. The rectangular form of the house is broken down by adding an overhang room and two balconies in the second floor. Story height of the house is 2.8 m and gross volume is 360.4 m^3. Outside wall surface area is 166.8 m^2 and window surface area is 28.3 m^2. The ratio of the glazing surface area to the outside wall surface area is 0.103 m^2/m^2 for the south facade, 0.038 m^2/m^2 for the north facade, 0.151 m^2/m^2 for the east facade, 0.380 m^2/m^2 for the west facade. Architectural plan of the house is given in Fig. 2.

Simulations were performed in different climatic regions of Turkey. Locations were determined by using heating degree-day (HDD). Accordingly, Ankara (annual

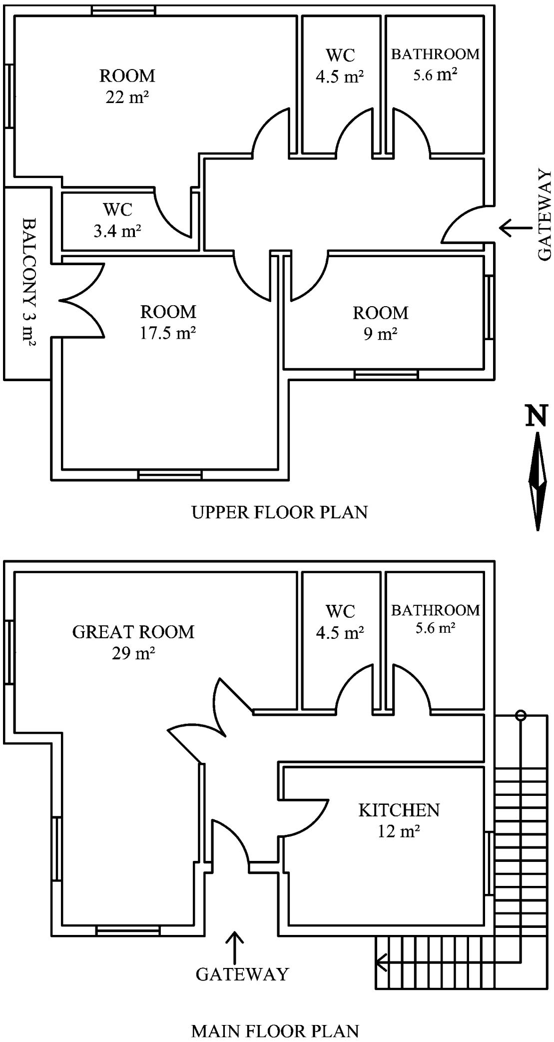

Fig. 2. Architectural plan of the house

HDD 2890), Erzincan (annual HDD 3157), Erzurum (annual HDD 4876), Istanbul (annual HDD 1714) and Mersin (annual HDD 1834) were selected.

In Table 1, overall heat transfer coefficients of the building envelope for different regions were given. Those values were determined in order to obey the maximum allowable values defined in TS825 standard (2013). For not changing the construction components for each location, U-values were modified by only increasing insulation thickness. Adding to that the weighted mean U-value of all components of building envelope was obtained. Mean U-values were 0.51 for Ankara, 0.45 for Erzincan, 0.38 for Erzurum, 0.57 for İstanbul and 0.64 for Mersin.

Table 1. Overall heat transfer coefficient (U) of building envelope

Location	U_{wall}	U_{roof}	U_{floor}	U_{window}
Ankara	0.42	0.28	0.42	1.80
Erzincan	0.34	0.23	0.37	1.80
Erzurum	0.27	0.15	0.29	1.80
İstanbul	0.48	0.32	0.50	1.80
Mersin	0.58	0.35	0.58	1.80

In this study, determination of the annual energy demand of the buildings that have a significant ratio in total energy demand is aimed at using the national standard TS825 method and heat balance method. To compare those methods, parameters such as building geometry, building envelope, heating-cooling setpoints, schedules, etc. should be the same for each one. At that point, it must be taken into account that TS825 calculation procedure requires seasonal average data and heat balance method requires hourly data. To minimize the input differences between two methods will clarify the sufficiency and applicability of the TS825 method. For that reason, details of the methods discussed in detail.

3.1. TS825 Method

In "TS825 Thermal Insulation Requirements for Buildings" standard (2013), only heating load calculation procedure was introduced. This method solves steady state heat conduction equation where required boundary conditions such as convection and solar gain are taken from the monthly average data table. Degree-day approach is used in the calculation procedure and 20 years average meteorological data is used. Turkey is divided into five climatic regions based on degree-day approach. According to that Mersin, Istanbul, Ankara, Erzincan, and Erzurum are selected where are placed in 1st, 2nd, 3rd, 4th and 5th regions, respectively. In the next step, the story height must be checked. Two different approaches are used according to the story height is above or below 2.6 m. To make the analysis more realistic, thermal bridges of the single family house introduced in heating load calculation procedure and given in Table 2. As a result, heating load is calculated by using Eq. (1).

$$Q_{TS} = [(H_T + H_v)(T_i + T_a) - \eta(F_i + F_s)]t \quad (1)$$

Here, Q_{TS} represents heating load according to the TS825 method, H_T is conduction heat transfer rate, H_v is ventilation heat transfer rate, T_i is the average zone air temperature, T_a is the ambient air temperature, η is monthly average usage factor, F_i is internal heat gains and F_s is the solar energy gains.

Table 2. Thermal bridges used in TS825 method

Thermal bridge	Type*	Length, L (m)	Thermal conductivity, k (W/mK)
Balcony	B2	4.5	0.8
Roof	R2	36.6	0.5
Floor	F1	32.5	0.8
Corner	C1	39	0.05
Window	W8	59.9	0.6

* The thermal transmittance type was determined according to TS EN ISO 14683 (2009).

3.2. Heat Balance Method

It is most widely used method by researchers due to its success in approximating heating-cooling loads. To apply this method to the designed single family house, EnergyPlus building energy simulation tool (V8.4) (U.S. Department of Energy, 2017) was used. This software algorithm was formed based on heat balance method in which heat conduction, convection, and radiation equations are solved simultaneously in given timestep. The Conduction Transfer Function (CTF) algorithm is used which utilizes one-dimensional transient heat conduction through multilayers such as walls and floors. Comprehensive convection algorithm was used as Thermal Analysis Research Program (TARP) developed by Walton (Walton G.N., 1983). Heating load is calculated by using Eq. (2).

$$Q_{HB} = \left[h(T_i - T_s)\sum f_{s,s+1}(T_{s+1} - T_s)\right]A + Q_s + Q_l + Q_e \quad (2)$$

Here, Q_{HB} represents heating load according to heat balance method, h is convective heat transfer coefficient, T_s, T_{s+1} are average temperature of interior surface "s" and "$s+1$", f is linearized radiation heat transfer factor, A is area of surface, Q_s is the absorbed solar energy gains, Q_l is the absorbed heat gain from lights sources and Q_e is the absorbed heat gain equipment and occupants sources.

In this study, 15 minutes timestep was used EnergyPlus software requires a detailed hourly meteorological file of the region. TMY (Typical Meteorological Year) file is provided by using Meteonorm©. Heating and cooling load calculations are grouped under 6 different input data module.

- Simulation parameter inputs (heat balance algorithm),
- Regional and meteorological inputs,
- Scheduling input,
- Building construction detail input,
- Zone information input,
- Internal heat gains input.

Parameters required for load calculation used in those two methods are summarized in Table 3.

Table 3. Required parameters for determination of heating-cooling loads

Parameters	Heat balance method	TS825 method
Comfort temperature	19 °C (Heating) 23 °C (Cooling)	19 °C (Heating)
Schedule	Weekdays 5 p.m. – 8 a.m. Weekend 8 a.m. – 5 p.m.	
Ventilation	0.7 hr^{-1} Natural	0.7 hr^{-1} Natural
Lighting density	200 W (compact fluorescence)	5 W/m^2 (sum of whole internal heat gains)
Electric equip.	Refrigerator 80 W, LCD 100 W	
Other equip.	50 W (Avg.)	
Occupancy	0.03 Person/m^2	

3.3. Statistical Analysis

TS825 method and heat balance method were compared with statistical criteria proposed by ASHRAE Guideline 14 (2014). Simulated results were evaluated according to normalized mean bias error (NMBE) and coefficient of variation of the root mean square error (CVRMSE). These parameters were calculated by using Eqs. (3), (4), respectively.

$$NMBE = \frac{\sum_{i=1}^{n}(y_{HB,i} - y_{TS,i})}{n-1}\frac{100}{\bar{y}_{HB}} \quad (3)$$

$$CVRMSE = \left[\frac{\sum_{i=1}^{n}(y_{HB,i} - y_{TS,i})^2}{n-1}\right]^{1/2}\frac{100}{\bar{y}_{HB}} \quad (4)$$

Here, y_{HB}, y_{TS} represent according to heat balance and TS825 methods, respectively. n is the number of simulated value.

According to ASHRAE Guideline 14 (2014), acceptable tolerances for comparison of NMBE and CVRMSE are within ± 10 % and ± 30 %, respectively when monthly data considered.

4. RESULTS AND DISCUSSION

In this study, TS825 national standard and heat balance methods were compared to 5 different climatic regions of Turkey. Firstly, the single-family house was designed to meet all the criteria of TS825 national standard for all climatic regions. In Fig. 3, monthly heating loads obtained from those two methods was given. Acceptable tolerance defined in ASHRAE Guideline 14 was obtained only for Ankara (3th climatic region). Especially for the Mersin (1st climatic region) and Istanbul (2nd climatic region) CVRMSE and NMBE values are higher than the advisable limit. The main reason for this deviation is that local meteorological data was used in heat balance method and regional average meteorological data was used in the TS825 method. It is understood that 5 climatic region is not enough for accurate heating load calculations. Adding to that very low heating loads can be calculated in seasonal transition timeline in heat balance method but TS825 method results were overestimated the heating load at that timeline. The highest difference of calculated heating loads of the methods was obtained for Mersin in November as 3.8 kWh/m^2 and the lowest difference is obtained for Erzurum in June as 1.0 kWh/m^2.

In Fig. 4, comparison of calculated heating loads of the methods was done in annual base. The absolute deviation between methods results was obtained in the range of 1.9 % to 39.5 %. The highest deviation was in Mersin where represents the 1st region and the lowest deviation was in Ankara where represents the 3rd region. For other regions deviations were 11.5 % for Erzincan, 6.5 % for Erzurum, 20.8 % for Istanbul.

In Fig. 5, cooling load obtained in each region was given. Since the TS825 method is not including cooling load calculation procedure, only heat balance method results were given. The highest cooling load was obtained for Mersin where represents the 1st region.

The TS825 method assumes steady-state heat transfer and uses monthly average meteorological data. Heat balance method uses detailed hourly meteorological data. Since outside temperature and solar radiation data change hourly, this method obtained a dynamic solution.

The TS825 method includes 5 different degree-day regions. Outside air dry bulb temperature and solar radiation are assumed constant in a month with its average value for each region. Beside that EnergyPlus uses local and hourly meteorological data. When compared with EnergyPlus dynamic solution results, it is obvious that 5 degree-day regions are not adequate for a consistent solution.

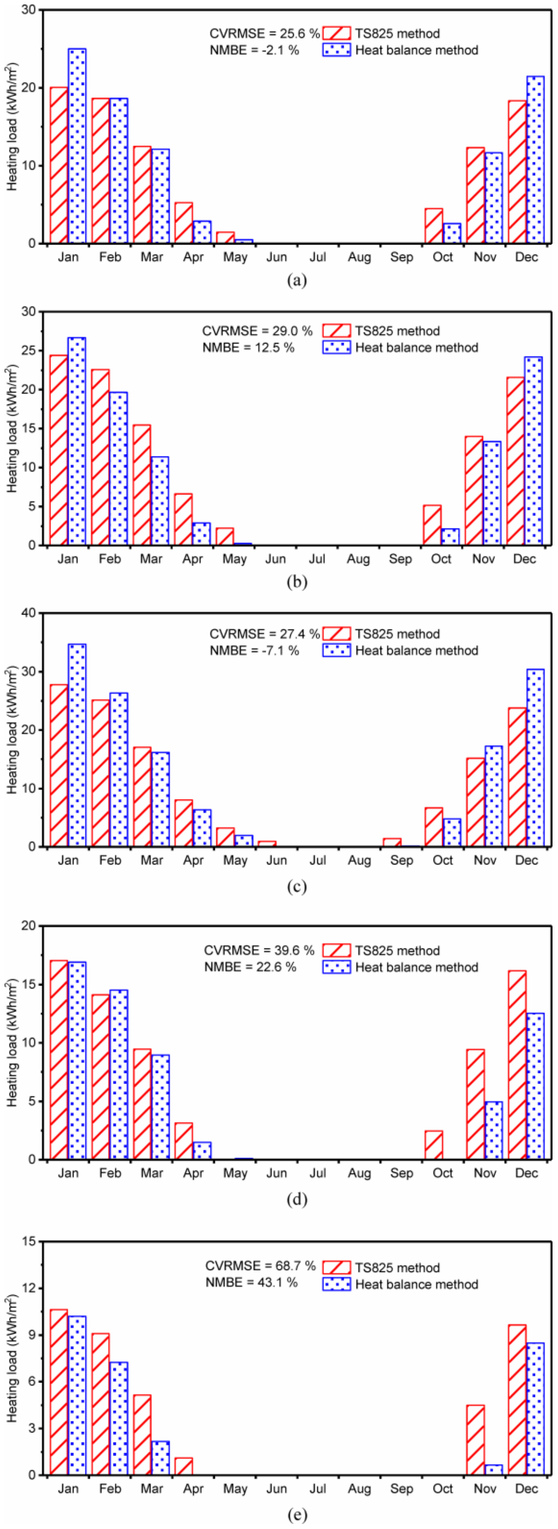

Fig. 3. Heating load on the monthly basis; (a) for Ankara; (b) for Erzincan; (c) for Erzurum; (d) for Istanbul and (e) for Mersin

The maximum allowable overall heat transfer coefficient defined for windows is U_{window}=1.8 W/m^{2}K in the TS825 method. However, in proposed study and practical applications, this criterion cannot be met. The double glazed window is used in this study and the overall heat

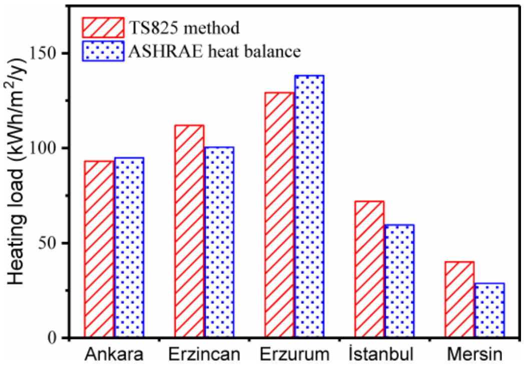

Fig. 4. Heating load on the annual basis

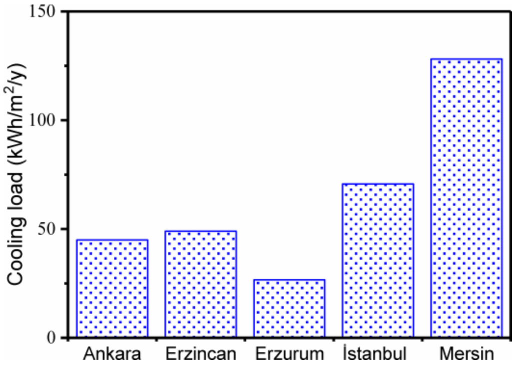

Fig. 5. Cooling load on the annual basis

transfer coefficient is 2.69 W/m^{2}K. In Table 1, construction components overall heat transfer coefficients were given. Glazing has the highest U-value and the most critical component in heating-cooling load calculations. For that reason, glazing total surface area must be determined logically. During daytime, the window provides solar energy heat gain for the building. Beside that higher U-value increases heat loss rate, windows behave like a black body at nights and that will increase heat loss rate, too. The TS825 method uses monthly average solar radiation that is perpendicular to windows surface area on calculation procedure of heating load. However, parameters such as geographical and solar angles are not included in that procedure. In heat balance method, solar gains and long wave solar radiation are solved by applying heat equations, separately. In calculation procedure of heating-cooling loads, solar gain is one of the most important environmental variable. For that reason, heat balance method is more accurate than the other methods.

Another important reason for the differences between the calculated thermal loads of the methods is that the TS825 method does not include the thermal mass calculations. In heat balance methods, energy storage in construction component is included in calculation procedure. By the way, faster cooling in the winter season and an extreme increase of inside temperature in the summer season will be prevented. This approach makes heat balance method more realistic.

The TS825 method only calculates the heating load. Since Mersin is placed in a hot climate region, cooling load is high. Simulation results showed that cooling load is three times higher than the heating load for Mersin. Proper insulation thickness determined according to

TS825 standard is also met required conditions for cooling load. Beside this, heating energy demand can be supplied in a wide range of sources but cooling energy demand is only supplied from electric energy. For that reason, calculation of cooling load accurately is important for energy efficiency.

In the TS825 method, zoning is done if only temperature difference is higher 4 °C between the building subdivisions. In heat balance method, control of zone via scheduling of occupancy, lighting intensity and electric equipment usage is optional. For that reason, simulation in Energy Plus is more realistic and more accurate.

HVAC systems designed based on this simulation program will be more suitable for capacity determination and energy consumption will decrease. In other words, the TS825 method can only be used for efficiency calculation of HVAC systems. Differently, HVAC systems can be designed by using the EnergyPlus software.

5. CONCLUSION

Buildings have a significant portion of total energy demand in both universal and national scales. Energy saving attempts will return buildings into an economic product. Accurate determination of building heating-cooling loads plays important role in energy saving studies. In this study, a national standard developed for building energy performance, the TS825 method was compared with heat balance method that was used in developed countries. A single-family house was analyzed for Mersin, Istanbul, Ankara, Erzincan, and Erzurum where represent the degree-day region from 1 to 5, respectively.

An algorithm was developed based on the TS825 method and compared with EnergyPlus simulation results that was developed based on heat balance method. The comparison can be done only for heating load due to the insufficiency of the TS825 method for calculating the cooling load. In annual scale, the deviation between calculated heating loads were 39.5 % for Mersin (highest) and 1.9 % for Ankara (lowest). According to heat balance method, cooling loads were determined as 128.2 kWh/m^{2}y for Mersin, 70.7 kWh/m^{2}y for Istanbul, 49.0 kWh/m^{2}y for Erzincan, 44.9 kWh/m^{2}y for Ankara and 26.7 kWh/m^{2}y for Erzurum.

TS825 method calculates heating load under steady-state conditions, heat balance method includes instantaneous meteorological data change in heating-cooling load calculations. Moreover, thermal mass calculations which represent energy storage in building construction elements realize the obtained results. Differences between those two methods show that TS825 method is not sufficient for building efficiency studies. Improvement in TS825 method according to other method leads to accurate system selection. In that way, building energy performance will improve, CO_2 emission rate will be decreased.

Finally, attempts to enhance building energy performance and to reduce building energy consumption require accurate methods and logical details. It is obvious that TS825 is not sufficient for building energy efficiency studies. Both using monthly average meteorological data and lack of cooling calculation with HVAC system entry, TS825 standard ignores building energy saving potential.

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