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A PROPOSAL FOR "CORRECTION VALUES" FOR WINTER OUTDOOR DESIGN TEMPERATURES

F. NUR DEMİRBİLEK* and CENGİZ YENER**
*Middle East Technical University, Faculty of Architecture, 06530 Ankara, Turkey and
**Bilkent University, Faculty of Art, Design, and Architecture, Ankara, Turkey

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Abstract—This study aims to find a correlation between winter outdoor design temperature (WDT) and mass of the building envelope. The daily variations of the inside surface temperatures and heat fluxes of the walls under various climatic conditions and different wall constructions have been calculated by a computer program based on the response factor technique, which uses variable outside air temperature and solar radiation and constant inside air temperature values as input climatic data. The analysis of the relation between mass of the walls and inside surface heat fluxes resulted with the correction values for winter design temperature (WDTCV) depending on the mass of the wall and on the direction of facades for different climatic zones. Copyright © 1996 Elsevier Science Ltd.

1. INTRODUCTION

The rate of heat loss through the envelope of a building depends on the temperature difference between the inside and outside surfaces. Obviously, the lower the outside temperature, the greater is the capacity of the heating plant required to keep the indoor temperature constant, and the more prolonged the severe weather, the greater the fuel consumption will be. Therefore, for a given indoor temperature, the capacity of the heating system will be determined by an assumed outdoor temperature, called winter design temperature (WDT). In order to choose an external temperature on which to base the design of a heating system, it is necessary to study the winter temperatures occurring in the location where the building is situated. Design of a building and its heating system, based on the worst climatic conditions that had ever occurred, is impractical and inadvisable. Plants sized for such conditions will be too oversized to be effectively used in a great portion of the lifetime of the building. "The plant accordingly will not operate at design capacity or will operate at short intervals (i.e. cycle frequently). In either case, operation will be inefficient. On the contrary, if heating plants are designed for conditions that occur frequently, the plants will operate more often at design capacity, or cycles of operation will be longer. When extreme outdoor conditions occur, such plants may not be able to maintain design indoor temperatures, but such occurrences are likely to be infrequent and the duration of uncomfortable indoor conditions is likely to be short" as cited by Merrit and Ambrose (1990).

It is more reasonable to design the envelope on the assumption that, in extremely few cases, its heat losses may not be compensated by the heating system and the inside temperature may be a little below the desired temperature on these rare occasions. This significantly reduces the demand for heating system capacity, without leading to a significant drop of inside temperature. In that case a risk is involved; the designer decides how much risk he should take and the meteorologist selects the appropriate value of the weather element to match that risk.

In the literature survey, more or less the same definition of this temperature made by many authors can be found. Thomas (1955) defines the WDT as the coldest temperature which is likely to recur frequently enough during the average winter to justify its use in the design of heating systems for buildings. This temperature is used in calculating the heat loss which such systems may be called upon to overcome in normal operation.

Not only the mechanical engineer, but also the architect, has an important role on maintaining the indoor micro-climatic conditions. Since the size of the heating system depends on WDT and thermophysical properties of the envelope, the importance of the relationship between WDT and building envelope must be clearly understood by the architect. The study aims at the analysis of this relationship by examining the heat flow through the envelope under hourly values of air temperature and solar radiation data.

Most of the conventional methods which have been or are being used in the determination of the WDT since the early 1900s throughout the world have no exact relationship with the building envelope. These studies can be grouped as:

(1) The work done in early years which do not consider the building itself (initial approach mentioned by Close, 1944; Thomas, 1955).
(2) According to most of the others, the designer has choices from the extreme hourly temperature Cumulative Distribution Function as 1, 2.5, 5, 10%, etc., according to the heat capacity of the envelope and use of the building (Thomas, 1955; Thom, 1957; Holladay, 1962; Crow, 1964; Gülferi, 1964; Doesken and McKee, 1983; ASHRAE, 1985).
(3) Selection of the WDT is based on repetition of the temperatures depending on the time-lag of the building element (Richard, 1982).
(4) Average monthly mean temperature for multi-storey heavy buildings, and an addition of 5% system overload capacity for single-storey lightweight buildings (Fowler, 1983).
(5) WDT is corrected by adding 0, 2 and 4°C for buildings having a mass up to 600, 600–1400 and above 1400 kg/m^2, respectively (DIN4701, 1983; Kılkış and Arınç, 1990).

2. EFFECT OF MASS ON WINTER DESIGN TEMPERATURE

In order to prove the effect of mass on WDT, the interrelation between different parameters and the reaction of the building to each of these parametric changes should be analysed. This was possible by having a "parametric study", which has the advantage of giving the opportunity to test the effect of different variables one by one, and to compare the results obtained by each run. In order to investigate the relationship between mass and WDT, the following basic parameters should be analysed in detail and the variables and their variations for parametric study should be determined:

(1) variation of the daily outside weather conditions
(2) thermophysical properties of the building envelope
(3) variation of the daily inside air conditions.

2.1. Thermophysical properties

One of the most important factors affecting the heat transfer through the building envelope is its thermophysical property. The thermophysical property of the envelope consists of surface absorbtivity, thermal conductivity, specific heat, density and thickness. Higher thermal conductivity results in a higher rate of heat flow. Density and specific heat represent the heat-storage capacity (thermal capacity) of the material. Higher thermal capacity delays the transfer of heat under transient conditions. Increasing the thickness of the material decreases the heat-transfer rate but increases the thermal capacity, which delays heat transfer. Those properties described above are the individual thermophysical parameters of the building envelope and a combination of them should be considered for the analysis of heat transfer through the building envelope.

The combined thermophysical properties are conductive thermal resistance and thermal capacity, which are defined for multilayered structures as:

$$R=\sum_{1}^{i} L_i/k_iA_i \quad (1)$$

$$C=\sum_{1}^{i} L_iA_i\rho_iC_{pi} \quad (2)$$

$$M=\sum_{1}^{i} L_iA_i\rho_i \quad (3)$$

The conductive thermal resistance is the thermal resistance between internal and external surfaces and is one of the factors affecting the heat transfer through the building envelope. Different allowable conductive thermal resistance values are given for different climatic conditions in the thermal insulation regulations. According to the Turkish Thermal Insulation Regulation (BIY, 1985), Turkey is divided into three climatic zones and the minimum allowable conductive thermal resistance values for a unit heat transfer area (R_{cond}, m^2 K/W) of different building elements are given for each zone. The allowable R_{cond} for walls having mass per unit area higher than 300 kg/m^2 are given as 0.40, 0.60 and 0.79 m^{2}K/W for climatic zones 1, 2 and 3, respectively.

The thermal capacity of an object is a function of its volume, density and specific heat. The temperature of the object increases as it absorbs heat. The rate of increase in temperature decreases when thermal capacity increases. Thermal capacity of the building envelope does not affect heat flow under steady-state conditions. However, under the cyclic loading conditions present at the outside surfaces of the envelope, higher thermal capacity delays heat loss and gain, reduces diurnal variation in heat gain and loss to a room of constant temperature.

The density of the building materials is more effective on the thermal capacity than specific heat because specific heat is mostly about 800–850 J/kgK, but density varies between 15 and 2600 kg/m^3. The thermal capacity of a unit area of a building material is approximately a function of the density and its thickness, which is analogous to mass per unit heat-transfer area of the wall. The mass per unit heat-transfer area of the building elements will be referred as "mass" (m) in this study, to be in accord with BIY (1985):

$$m = \frac{M}{A} = \sum_{1}^{i} L_i \rho_i \tag{4}$$

2.2. *Inside conditions*

The basic consideration in determination of the inside conditions is thermal comfort conditions. Furthermore, the daily variations of the inside surface heat fluxes are effective on the peak capacity of the heating system. The daily fluctuations of the inside surface temperature are very important from a thermal comfort point of view (Arens *et al.* 1980; Fanger, 1972), and have a direct relationship with the mass of the element. In order to show the variation of inside surface temperatures according to mass, the inside surface temperatures of walls with varying degree of mass but having the same R_{cond} value are calculated by a computer program based on the response factor technique. The difference between the inside surface temperatures of the least and most massive walls are found as in Fig. 1. During the same calculation, the analysis of the daily fluctuations of the inside surface heat fluxes showed an inverse proportion with mass and surface heat flux of the walls: the higher the mass, the lower the heat flux, Fig. 2. The results showed that the daily variation of the inside surface heat flux in different climatic conditions and different constructions is the most important parameter which should be considered in the determination of the relationship between WDT and mass of the envelope.

3. METHOD APPLIED IN THE ANALYSIS

The mass of the building envelope has an important effect on the rate of peak heat flux of the building at the inside surface of the envelope. This heat flux directly affects the indoor thermal comfort conditions and the size of the heating system. For a construction having the same R_{cond} value, but a higher mass, the maximum heat flux will be smaller, therefore the size of the plant will be smaller.

Though the regulations state different minimum R_{cond} values for walls with masses less

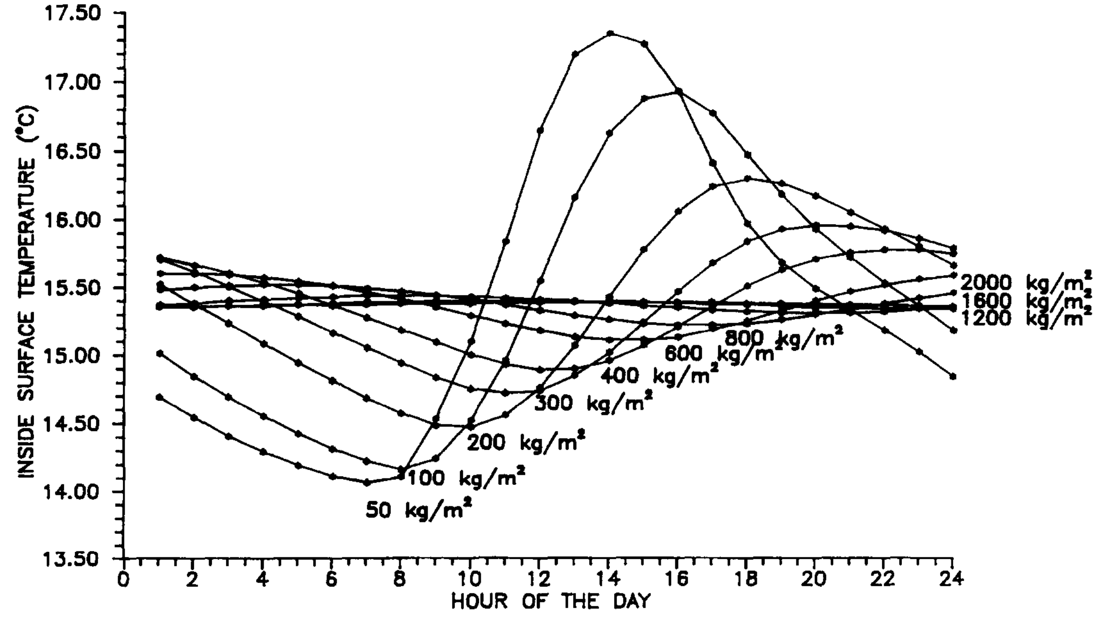

Fig. 1. Inside surface temperatures for walls facing south, having the same R_{cond} value but varying mass with a 0°C daily mean and 10°C daily amplitude.

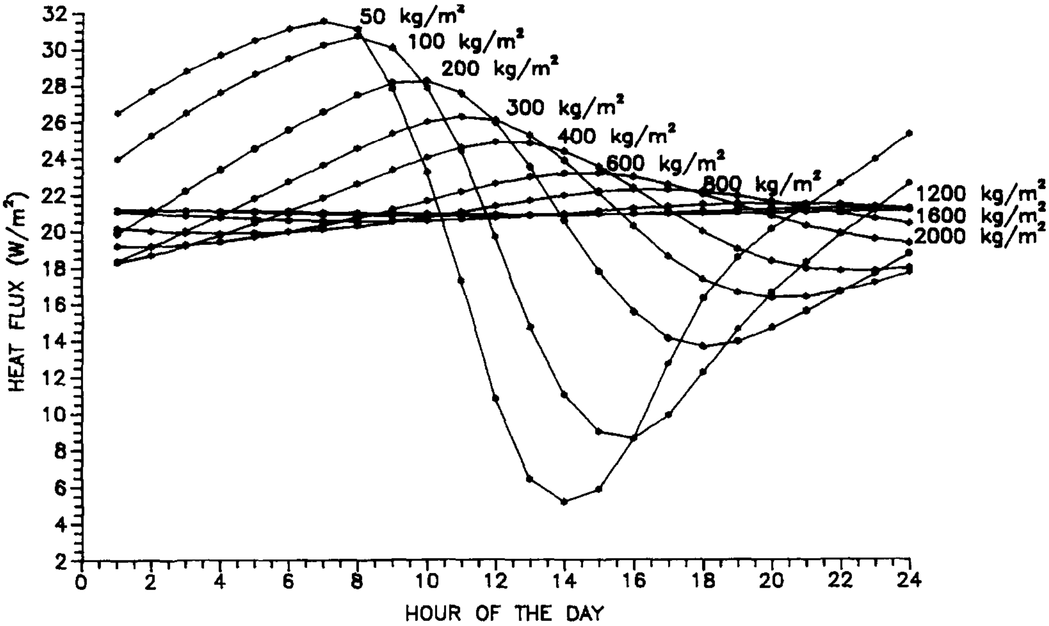

Fig. 2. Heat flux for walls facing south, having the same R_{cond} value but varying mass with a 0°C daily mean and 10°C daily amplitude.

than 300 kg/m², they do not differentiate an element having a mass of either 300 or 2000 kg/m². According to regulations, the WDT of the climatic zone is valid for both masses. But since the maximum heat flux of the lower mass element will be higher, and the regulations accept this heat flux, 300 kg/m² can be accepted as the reference mass for this WDT. In this case it will be reasonable to accept the maximum heat flux of this reference mass as constant, and to decrease the WDT for higher masses. This will direct the designer to use massive materials in climatic zones with high daily amplitudes. The difference between the peak heat fluxes of different masses and the reference mass will give the "winter design temperature correction value" (WDTCV) for these masses.

In order to attempt to predict the heating load under steady-state conditions,

$$Q = UA\Delta T \tag{5}$$

is used, where

$$\Delta T = T_i - T_{\text{design}} \tag{6}$$

The heating load per unit area is

$$Q/A = q = U\Delta T \tag{7}$$

If q_{300} denotes the daily maximum heat flux of a building element having a mass of 300 kg/m², which can be called the reference mass, the design temperature for this mass can be called the design temperature for reference mass ($T_{\text{design},300}$). In this case,

$$q_{300} = U(T_i - T_{\text{design}300}) \tag{8}$$

For a building element having any mass, x, the heat flux can be denoted as q_x and the corresponding design temperature, $T_{\text{design}x}$:

$$q_x = U(T_i - T_{\text{design}}) \tag{9}$$

The difference between these two equations will give

$$q = q_{300} - q_x = U[(T_i - T_{\text{design}300}) - (T_i - T_{\text{design}x})] \tag{10}$$

If both sides are divided by U

$$\frac{q}{U} = T_{\text{design}x} - T_{\text{design}300} \tag{11}$$

will give the WDTCV.

Therefore, the new WDT will be found by adding the WDTCV to the WDT found by conventional methods:

$$T_{\text{design}x} = T_{\text{design}300} + \text{WDTCV} \tag{12}$$

In this study the daily variations of the inside surface temperatures and heat fluxes of the walls under various climatic conditions and different wall constructions have been calculated by a computer program based on the response factor technique (Hittle, 1981), which is accepted as the standard method of modeling building envelope energy usage in the scientific communities throughout the world. The technique uses variable outside air temperature and solar radiation and constant inside air temperature values as input climatic data.

4. RESULTS AND CONCLUSION

The parametric runs, the details of which can be found elsewhere (Demirbilek, 1992), showed higher peak heat fluxes for higher daily amplitudes and lower daily means for the same exterior building elements. The results showed that the savings in average heating loads were negligible as expected, but the minimum inside surface temperatures and heat fluxes showed a direct relationship with the mass of the element (Figs 1 and 2). In the study, the hourly inside surface peak heat fluxes have been calculated under variable ambient air temperature and solar radiation conditions. Then, the deviations of peak heat fluxes from the peak heat flux of the wall having 300 kg/m^2 mass were calculated. The analysis of the relation between the mass of the walls and inside surface heat fluxes resulted in the correction values for winter design temperature (WDTCV) depending on the mass of the wall and different climatic zones. Since the sol–air temperature data are used in the representation of the local climatic conditions, the orientation of the facade has gained importance. For Ankara, 21 January is chosen as the typical day (which is common to choose for architectural studies), and the results of the runs for different facades are plotted in Fig. 3.

The WDTCV value for the facade to be examined can be read from the chart. The user must calculate the mass of the wall by using eqn (4). Addition of the correction value to the WDT of the location will result with the new WDT to be used in the calculation of heat loss through the wall. By using the method, the designer can decide either WDTCV according to the desired mass, or mass according to the desired WDTCV. Each facade has a different WDTCV for the same mass, or a different mass for the same WDTCV.

Further study will/must be:

(1) analysis of walls in different climatic conditions, and generalization of the chart
(2) analysis of non-homogeneous walls by using the same technique
(3) analysis of ceilings facing outside air by using the same technique
(4) analysis of heat loss of a whole building by considering the floors, ceilings, windows and walls
(5) selection of the typical day for constructing the correction value charts instead of 21 January as used in this study
(6) a correlation between the summer design temperature and mass can be produced by applying the same technique.

NOMENCLATURE

A surface area of the envelope (m^2)
C_p specific heat (J/kgK)
k thermal conductivity (W/mK)
ρ density (kg/m^3)
L thickness (m)

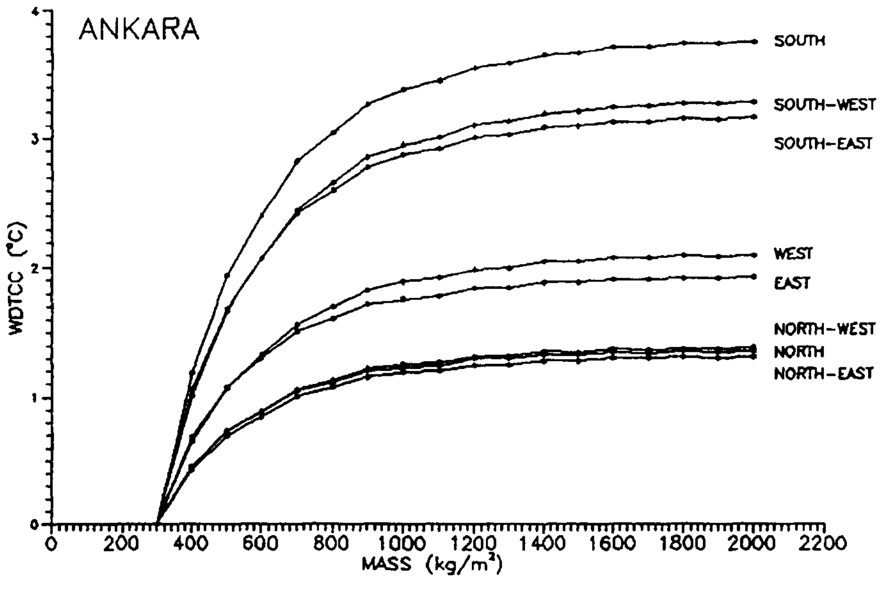

Fig. 3. WDTCV chart for the typical winter day of Ankara (21 January).

M	mass (kg)
m	mass per unit area (kg/m^2)
n	number of layers
Q	heat load (W)
q	heat flux (W/m^2)
R	conductive thermal resistance (K/W)
R_{cond}	conductive thermal resistance for unit heat transfer area (m^2 K/W)
T_{i}	inside air temperature (°C)
T_{design}	design temperature (°C)
U	overall heat-transfer coefficient (W/m^{2}K)
WDT	winter outdoor design temperature (°C)
$WDTCV$	winter design temperature correction value (°C)

Subscripts

300	element with $m = 300$ kg/m^2
x	element with $m = x$ kg/m^2

REFERENCES

Arens E., Zeren L., Gonzalez R., Berglund L. and McNall P. (1980) *A New Bioclimatic Chart for Environmental Design*. National Bureau of Standards, Department of Commerce, New York.

ASHRAE (1985) *Handbook of Fundamentals*. American Society of Heating, Refrigerating, and Air Conditioning Engineers, New York.

(BIY) Bayındırlık Iskan Bakanlığı (1985) Binalarda Isı Yalıtımı Yönetmeliği (Building Insulation Regulation of Turkey). 16 Ocak 1985, tarihli Resmi Gazete, Ankara 9–35.

Close P. (1944) Selecting winter design temperatures. *ASHVE J.*, 437–440.

Crow L. W. (1964) Derivation of outdoor design temperatures from annual extremes. *Trans. ASHRAE*, **70**, 69–74.

Demirbilek F. N. (1992) Correlation between winter design temperature and mass of the building exterior walls. Ph.D. thesis, METU Fac. of Arch., Ankara.

DIN 4701 Teil 1 (1983) *Regeln fur die Berechnung des Warmeberarfs von Gebauden; Grundlagen der Berechnung* (Rules for Calculating the Heat Requirement of Buildings, Basic Rules for Calculation). Deutsches Institut fur Normung, Berlin.

Doesken N. J. and McKee T. M. (1983) Estimating winter design temperatures from daily minimum temperatures. *J. Clim. Appl. Met.*, **22**, 1685–1693.

Fanger P. O. (1972) *Thermal Comfort: Analysis and Applications in Environmental Engineering*. Kingsport Press, New York.

Fowler K. J. V. (1983) *Practical Building Services Design. Vol. One: Indoor/Outdoor Design Conditions and Psychrometry*. George Godwin Pittman Press, Bath, UK.

Gülferi I. (1964) *Meteorolojik Değerler Yardımıyla Kış İçin Dış Hesap Sıcaklığının Bulunmasında Kullanılacak Yeni Bir İstatistiki Metod ve Türkiye'ye Tatbikatı* (A New Statistical Method for the Calculation of Winter Outdoor Design Temperature and its Application to Turkey). İskender Matbaası, İstanbul.

Hittle D. C. (1981) Calculating building heating and cooling loads using the frequency response of multilayered slabs. Technical Manuscript E-169, Construction Engineering Research Laboratory, United States Army Corps of Engineers.

Holladay W. L. (1962) Improved methods of calculation of design temperatures. *Trans. ASHRAE*, **68**, 125–140.

Kılkış B. and Arınç U. D. (1990) Yapıların ısı yükü hesaplarında kullanılacak yeni dış hesap sıcaklıkları üzerine bir çalışma (A study on new winter outdoor design temperatures to be used in the heat load calculation of buildings). *Türkiye 5. Enerji Kongresi Teknik Oturum Tebliğleri* (Proc. 5th Energy Congress of Turkey), İstanbul, Turkey, pp. 435–445.

Merrit F. S. and Ambrose J. (1990) *Building Engineering and System Design*. Van Nostrand Reinhold, New York.

Richard O. E. (1982) Evaluating design temperatures for HVAC applications in extreme climates. *Trans. ASHRAE*, **88**, 1.

Thom H. C. S. (1957) Revised winter outside design temperatures. *Trans. ASHRAE*, **63**, 111–128.

Thomas M. K. (1955) A method of determining winter design temperatures. *Trans. ASHRAE*, **61**, 387–396.