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Outdoor dry bulb heating design temperatures for Hungary

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ABSTRACT

Saving energy is one of the main priorities in the building sector. In countries with temperate climates, heating represents an important share of the total energy use of buildings. It is well known that central heating systems operate most of the time at partial capacity during the heating season. Moreover, the elements of the central heating system are usually over dimensioned. In this paper, the outdoor dry bulb design temperatures for heating are analysed across Hungary. Using outdoor dry bulb temperature data from the last 50 years, cumulative frequency graphs were built and new design values are proposed at 99% and 99.5% confidence levels. For two typical residential buildings, a single family house and a block of flats, the consequences of the higher outdoor design temperature were analysed from the point of view of investment costs, seasonal boiler efficiency and intermittent operation. The investment cost decreased by approximately 10% for the large buildings, the seasonal efficiency of traditional boilers increased by approximately 0.6%, the seasonal efficiency of condensing boilers decreased by approximately 1.2%, and the energy savings from intermittent operation decreased by 2–6%.

1. Introduction

Increasing the energy efficiency of building service systems is one of main purposes of Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings [1]. The share of energy consumption for heating out of the total household consumption in the EU-27 is approximately 70% [2]. Providing the building envelope with proper thermal insulation and continuously improving the energy performance of boilers, circulation pumps and other heating and control equipment will significantly reduce the energy used for heating. Nevertheless, by increasing the accuracy of the design process and properly choosing the heating system elements, the efficiency of the heating system can be further increased. ASHRAE recommends 99.6% and 99% annual cumulative frequency of occurrence for outdoor dry bulb temperature for cold conditions [3]. In practice, this means that during a year the outdoor dry bulb temperature will be less than the design values for 35 h or 88 h, respectively. New outdoor design conditions for space heating were determined for 78 locations within Turkey using the ASHRAE method in the study by Bulut et al. [4]. Gugliermetti and Bisegna recommended creating a design reference day, which is a real day belonging to a typical meteorological year or to a test reference year [5]. Typical principal component years were determined for five major architectural climates across China: severe cold, cold, hot summer and cold winter, mild, and hot summer and warm winter [6]. Several authors affirmed that the stochastic weather model is essential for describing a real climate [7–9].

Lam and Hui compared four approaches to outdoor design conditions for HVAC applications: the ASHRAE method, the CIBSE method, the Australian method and the Chinese method [10]. Lam et al. investigated the frequency of occurrence of three common climatic variables for five cities in China: temperature, solar radiation and wind conditions. The cities were selected to represent the five main architectural climates of China [11]. Furthermore, for Hong Kong, the implications of climate change on the building energy use was analysed assuming a 40-year period (1961–2000) [12]. The frequency of occurrence analysis, however, revealed no significant changes in the outdoor design conditions in this case. Conversely, in Hungary, according to our previous studies, there were important differences identified between the degree-day values developed based on the outdoor temperatures of years 1900–1930 and the degree day values calculated using outdoor temperature data between 1963 and 2012 [13]. The expected energy use for heating can be predicted using simulation programs, which give detailed information on the energy behaviour of a building [14–16]. Nevertheless, the appropriate meteorological

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data have to be known and used. The accuracy of energy calculations can be improved using periodically variable degree day values [17]. However, to minimize the energy use of central heating systems, adequate design methodologies and appropriate design parameters are indispensable [18–20]. In this paper, new design temperatures are proposed for 24 Hungarian settlements assuming different time constants for heated spaces. For two residential building types, the investment costs of the central heating systems were determined for currently used outdoor design temperatures and compared to the required investment costs obtained for the proposed design temperature values. The boiler seasonal efficiency was carried out for different boiler types. In the current study, properly chosen and over-dimensioned systems were considered.

2. Time constant of heated spaces

During the heating season in a closed space, the indoor temperature variation is strongly influenced by the room time constant (T, [h]). The time constant of a closed space is given by the ratio between the heat capacity (C, [J/K]) of thermal mass built in the space envelope and heat loss coefficient of the room (K, [W/K]) [21]:

$$T = \frac{C}{K} \tag{1}$$

The heat capacity of a closed space is given by Eq. (2) [21]:

$$C = \sum_j \sum_i \rho_{ij} c_{ij} d_{ij} A_j \tag{2}$$

where ρ_{ij} is the density of the material of layer i in element j, c_{ij} is the specific heat of the material of layer i in element j, d_{ij} is the thickness of layer i in element j, and Aj is the area of element j.

The heat loss coefficient of the room is given by Eq. (3) [21]:

$$K = \sum A_o U_o + \sum A_t U_t + \sum l\Psi + \rho c n V \tag{3}$$

where A_o is the area of other external opaque surfaces, [m^2]; U_o is the overall heat transfer coefficient of the external opaque surfaces, [W/(m^2·K)]; A_t is the area of the glazed surfaces, [m^2]; U_t is the overall heat transfer coefficient of the glazed surfaces, [W/(m^2·K)]; l is the length of the thermal bridge, [m]; Ψ is the linear heat transfer coefficient of the thermal bridges, [W/(m·K)]; ρ is the air density, [kg/m^3]; c is the specific heat of the air, [J/(kg·K)]; n is the air change rate, [h^{-1}]; and V is the volume of the heated space, [m^3].

In Central European countries, the most used building materials for the last several decades were brick with vertical holes, autoclaved aerated concrete and light structures. Public buildings are equipped with large glazed areas, but the opaque elements are usually built from steel concrete. Because of the tightening energy performance requirements, the opaque structures are provided with external insulation layers. Consequently, the heat loss coefficient is low, while the thermal storage capacity of the rooms is relative high, except for the very light structure buildings. Taking the aforementioned building materials and five different room geometries typical for residential, office and educational buildings, we have determined the time constant of the rooms assuming different overall heat transfer coefficients of opaque elements (0.20–1.40 W/m^{2}K) and transparent elements (1.00–1.60 W/m^{2}K). The number of external building elements of the analysed rooms was one, two or three. The time constant was determined for 144 room models. For an air change rate of 0.5 h^{-1}, the time constant varies between 35 h and 110 h. If the air change rate was reduced to 0.2 h^{-1}, the time constant of the analysed rooms increased to 40 h and 130 h, respectively.

Assuming that the temperature of the active thermal mass is equal to the indoor air temperature, the heat balance equation of the heated room can be written as:

$$KT_e d\tau + C dT_e = \dot{Q}_R d\tau \tag{4}$$

where τ is time; $\dot{Q}_R$ is radiator output, [W]; and T_e is the temperature difference between indoor and outdoor, [K]:

$$T_e = t_i - t_e \tag{5}$$

In the following, the design indoor and outdoor temperatures will be marked with t_{io} and t_{eo}, respectively. If the outdoor temperature differs from its design value and the radiator output is not adjusted to this new external temperature by qualitative or quantitative control, the new value of the indoor temperature will be given by Eq. (6):

$$t_i = t_{i0} + t_e - t_{e0} + (t_{e0} - t_e) e^{-\frac{\tau}{T}} \tag{6}$$

Assuming that $t_{io} = 21$ °C and $t_{eo} = -10$ °C for the design indoor and outdoor temperatures, respectively, to obtain the same indoor temperature, the delivered heat must be adjusted to the ever changing outdoor temperature. If the heat delivered by the radiator cannot be properly adjusted to the heat demand, the indoor temperature will differ from the design value. However, the deviation of the indoor temperature caused by the external temperature depends on the room time constant. Fig. 1 shows the indoor temperature variation during a day for different outdoor temperatures (assumed to be constant) and the room time constant.

A warmer microenvironment is easily tolerated by the occupants, but higher indoor temperatures will lead to excessive energy use. If the outdoor temperature is higher than the design value used for the heat demand calculation, the indoor temperature will fall under the set point value, which is barely tolerated by the occupants. Nevertheless, it is unusual to have −15 °C outdoor temperatures continuously for 24 h, and even in this case, the decrease of the indoor temperature in the analysed cases is 1.0–2.0 K.

3. Outdoor design temperatures

The adjustment of delivered heat to the ever-changing heat demand can be performed only in case of well dimensioned heating systems. The precondition of proper design is to accurately calculate the heat demand of the building. To correctly establish the heat demand, the outdoor design temperature must be chosen as precisely as possible. In the last few decades, climate change has to be taken into account in the design of building service equipment. The aim of our article is to determine new outdoor dry bulb design temperatures for heating in Hungary. The outdoor dry bulb temperatures registered in the last 50 years were analysed for 24 settlements in Hungary. The proposed new design temperature in a region is based on percentiles of the cumulative frequency of the local 1-day, 3-day, 5-day, or 7-day average temperatures.

3.1. Current design temperatures for heating

In Hungary, Macskásy first proposed and published in 1952 design temperatures for 35 localities in Hungary [22]. These outdoor dry bulb temperature values were determined using the following simplified equation:

$$t_{e\_design} = 0.6 t_{emin} + 0.4 t_{em} \tag{7}$$

where t_{emin} is the minimal daily mean outdoor temperature occurred in the last five decades and t_{em} is the monthly mean