Energy 76 (2014) 780–787

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Prediction of energy demand for heating of residential buildings using variable degree day

Zoltán Verbai, Ákos Lakatos, Ferenc Kalmár*

University of Debrecen, Department of Building Services and Building Engineering, 4028 Debrecen, Ótemető Str. 2-4, Hungary

A R T I C L E I N F O

Article history:
Received 18 April 2014
Received in revised form
29 July 2014
Accepted 21 August 2014
Available online 18 September 2014

Keywords:
Degree day
Heating
Energy demand
Building refurbishment

A B S T R A C T

In all European countries the energy and building related legislature stand for energy refurbishment of existing building stock. Depending on the economical situation of countries there are different national programs that help owners to invest in energy related refurbishments of their houses or flats. The financial support is given only in case of a certain payback time, which should be obtained by the proposed project. The payback time for heating related investments in Hungary is calculated based on the theoretical degree day curve, which can lead to inaccurate results. Thus in this paper a long-term analysis of heating degree day, done for Debrecen (the second largest city of Hungary), is presented. We focused our analysis on residential buildings. It was found that the degree day has important variations during the analysed decades, which can lead to deviations of energy consumption up to 15–18%. Furthermore, taking into account the heat island effects in Debrecen, it was proven that differences of about 22% can be obtained between real degree day values in different zones of the city. The interrelation between specific heat gains and balance point temperature, respectively the effects of glazed area of the facades on the balance point temperature was discussed. It was found that for buildings with similar thermal characteristics of the envelope and the same values of specific heat gains, the balance point temperature can be even double for a detached house compared with a block of flats.

1. Introduction

According to Directive 2002/91/EC, buildings accounts for more than 40% of final energy consumption in the Community and is expanding. As a result, this trend will lead to higher carbon dioxide emissions in this sector. The Directive 2010/31/EU highlights that measures to improve the energy performance of buildings further should take climatic and local conditions into account as well as indoor climate environment and cost-effectiveness. In Hungary different national projects were launched in order to help the owners of houses or flats or local governments to enhance the energy characteristics of buildings. In each of these programs one of the main indicators was to decrease the energy demand of the building after refurbishment improving its envelope and its energy supply system. For a typical detached house with average thermal characteristics of the envelope, in central European countries heating represents between 70 and 80% of its energy need. Consequently the establishment of exact energy demand for heating is of crucial importance in such applications. At present in Hungary, heating energy demand is determined using a degree day curve developed based on meteorological data recorded between the period 1900–1930. This should be revised in order to obtain proper data on the energy demand based on which payback time of investments are determined. The importance of this problem is illustrated by the high number of publications dealing with interrelation between economical efficiency of building energy refurbishments – climate. Ref. [1] developed a methodology for evaluating the potential energy savings of retrofitting residential building stocks considering the actual technological and economic constraints of the implementation of feasible energy efficiency measures. The optimal insulation thicknesses for insulating the buildings external elements was analysed by several authors [2–5]. Ref. [6] developed building typologies which can be a useful instrument to facilitate the energy performance assessment of a building stock. Ref. [7] analysed the economic potential of energy-efficient retrofitting in the Swiss residential building sector taking the effects of policy instruments and energy price expectations into account. Ref. [8] studied the potential of residential buildings in Switzerland considering the energy and building technology for the 2000 W society. Nevertheless, besides physical properties of the external building elements and efficiency of heat production and supply system, the balance point temperature of the building

* Corresponding author. Tel.: +36 52 415155; fax: +36 52 418643.
E-mail addresses: verbai@eng.unideb.hu (Z. Verbai), alakatos@eng.unideb.hu (Á. Lakatos), fkalmar@eng.unideb.hu, f_kalmar@yahoo.com (F. Kalmár).

http://dx.doi.org/10.1016/j.energy.2014.08.075
0360-5442/

Nomenclature

Q_t	transmission heat losses, [W]
Q_{tb}	heat losses by thermal bridges, [W]
Q_v	heat losses by ventilation, [W]
Q_{gains}	specific heat gains of the building, [W/m^2]
Q_s	solar gains, [W]
Q_i	internal gains, [W]
Q_h	heat delivered by heating system, [W]
t_b	balance point temperature, [°C]
K	heat loss coefficient of the building, [W/K]
t_i	internal set point temperature, [°C]
$\bar{t}_e$	daily average external temperature, [°C]
t_{base}	base temperature, [°C]
x	the number of days
N	number of days in a heating season
t_{e0}	design value of external temperature, [°C]
t'_b	balance point temperature of the building after refurbishment, [°C]
K'	heat loss coefficient of the building after refurbishmment, [W/K]
N'	number of days in a heating season for refurbished building
E	energy demand for heating, [Wh]
A	envelope of the building's heated volume, [m^2]
V	heated volume of the building, [m^3]
dev_N	deviation between theoretical and real values of the number of days in a heating season, [%]
$N_{theoretical}$	number of days in a heating season calculated based on the theoretical degree day curve
N_{real}	number of days in a heating season calculated based on the real degree day curve
dev_{DD}	deviation between theoretical and real values of degree days in a heating season, [%]
$DD_{theoretical}$	degree days in a heating season calculated based on the theoretical degree day curve
DD_{real}	degree days in a heating season calculated based on the real degree day curve
T	time, [h]
U_{wall}	overall heat transfer coefficient of external walls of the building, [W/m^{2}K]
U_{win}	overall heat transfer coefficient of windows, [W/m^{2}K]
η_g	gain utilisation factor for heating, [-].

and the degree day value are essential to establish the energy demand of heating. Ref. [9] described an application of the degree-hours method estimating the residential heating energy requirement and fuel consumption in Istanbul. Using hourly dry bulb temperature records from the meteorological stations of the National Observatory of Athens and of the Aristotle University of Thessaloniki, the heating and cooling degree-hours for the two main cities in Greece were determined [10]. The heating and cooling degree-days for Turkey were determined by using long-term measured data [11]. Ref. [12] mapped the regional variations of monthly degree–days in Turkey and examined their relation to local topography. Based on daily weather data of 40 meteorological stations of the Hellenic National Weather Service, [13] drew up ten heating degree day maps that have proven to be useful for various energy projects and other environmental applications. Ref. [14] analysed the period between 1898 and 1978 to develop a scenario of possible variation of weather related residential energy consumption. Ref. [15] presented the potential impacts of climate change on heating and cooling energy demand. Ref. [16] analysed the climate extremes and their model shows changes in extreme events for future climates, such as increases to extremely high temperature, decreases to extremely low temperature, and increases in intense precipitation events. Ref. [17] provided a study on the future energy demand during climatic change which also took possible future changes of the German building stock, renovation measures and heating systems into account. Ref. [18] presented a very useful combined dynamic simulation and optimisation model to determine the energy requirements in residential sector, however in his model the effects of degree day variation were not taken into account. Different authors considered even the effects of heat islands in order to have a correct determination of degree day [19,20]. Ref. [21] presented a comparison of different degree day calculation methods. They concluded that if the methods are used for base temperatures lower than the current standard then the uncertainties increase. CIBSE published a guidance (TM41:2006) on this topic in which the calculation methods and the importance of degree day utilisation in energy management of buildings are well described. Ref. [23] developed a formal method for quantifying the uncertainties in degree-day-based energy estimates in buildings. The results show that degree-day uncertainties diminish with longer time frames.

The analysed articles mentioned above emphasised the importance of degree day and proved that without updated degree day values the real energy demand and energy consumption of a building cannot be determined. We considered that data given by the theoretical degree day curve used in Hungary are valid only with assumptions. These data can be used in case of comparing two or more buildings (energy certification), yet cannot serve as a baseline for correct evaluation of the heating energy demand for a building.

Nowadays the energy consumption of buildings is predicted by using simulation programs, which give detailed information on the energy behaviour of a building. However simulation techniques need a series of information which sometimes are difficult to be precisely identified.

There are cases when the available timeframe given for energy calculation is not enough for a complex simulation. For rapid calculations instead of simulations simplified calculation methods, such degree day, are accepted. The disadvantage of degree day techniques is that these can only provide approximate results. Nevertheless for estimations of buildings energy use degree day offers a rapid and easy calculation method. In case of investments related to buildings energy refurbishment the payback time is strongly influenced by the energy savings obtained. The reduction of energy consumption after building refurbishment should be calculated as precisely as possible, otherwise investors will face unpleasant surprises. Based on the international literature analysed above we decided to build up the degree day curve for Debrecen, the second largest city of Hungary, using meteorological data of the last 50 years. In the future we plan to draw up the degree day map of Hungary as well. Based on the hourly dry bulb temperature records we received from Agro-Meteorological Observatory Debrecen (DE-AGTC MÉK) a long term analysis of degree day was done for Debrecen. Moreover, in this article, the effects of degree day curve variation on the energy demand for heating can be found.