Energy and Buildings 41 (2009) 801–808

Contents lists available at ScienceDirect

Energy and Buildings

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

Sensitivity of the total heat loss coefficient determined by the energy signature approach to different time periods and gained energy

J.-U. Sjögren *, S. Andersson, T. Olofsson

Department of Applied Physics and Electronics, Umeå University, SE-901 87 Umeå, Sweden

ARTICLE INFO

Article history:
Received 16 August 2007
Received in revised form 3 February 2009
Accepted 2 March 2009

Keywords:
Energy performance
Total heat loss coefficient
Energy signature
Household electricity
Indoor temperature
Gain factor

ABSTRACT

In order to identify buildings that have energy saving potential there is a need for further development of robust methods for evaluation of energy performance as well as reliable key energy indicators. To be able to evaluate a large database of buildings, the evaluation has to be founded on available data, since an in-depth analysis of each building would require large measurement efforts in terms of both parameters and time. In practice, data are usually available for consumed energy, water, and so on, namely consumption that the tenants or property holder has to pay for. In order to evaluate the energy saving potential and energy management, interesting key energy indicators are the total heat loss coefficient K_{tot} (W/K), the indoor temperature (T_i), and the utilisation of the available heat (solar radiation and electricity primarily used for purposes other than heating). The total heat loss coefficient, K_{tot}, is a measure of the heat lost through the building's envelope, whereas T_i and the gained energy reflect the user's behaviour and efficiency of the control system.

In this study, a linear regression approach (energy signature) has been used to analyse data for 2003–2006 for nine fairly new multifamily buildings located in the Stockholm area, Sweden. The buildings are heated by district heating and the electricity used is for household equipment and the buildings' technical systems. The data consist of monthly energy used for heating and outdoor temperature together with annual water use, and for some buildings data for household electricity are also available. For domestic hot water and electricity, monthly distributions have been assumed based on data from previous studies and energy companies. The impact on K_{tot} and T_i of the time period and assumed values for the utilised energy are investigated.

The results show that the obtained value of K_{tot} is rather insensitive to the time period and utilised energy if the analysis is limited to October–March, the period of the year when the solar radiation in Sweden yields a minor contribution to heating. The results for the total heat loss coefficient were also compared to the calculations performed in the design stage; it was found that K_{tot} was on average 20% larger and that the contribution to heating from solar radiation was substantially lower than predicted. For the indoor temperature, however, the utilised energy had a large impact.

With access to an estimate of K_{tot} and T_i, an improved evaluation of the energy performance may be achieved in the Swedish real estate market. At present the measure commonly used, despite the fact that monthly data is available, is the annual use of energy for space heating per square metre of area to let.

1. Introduction

In literature as well as in practice different methods of evaluating building energy performance and efficiency are used. The methods are based on a steady state, dynamic, or mixed description and applied during the design process or during operation and then based on measured data for the building. In the latter case detailed knowledge from the design stage may also be included.

The models used in the design process are based on detailed physical information in order to forecast as well as evaluate the energy use. A brief overview of the state of the art is given by [1]. During the actual operation, the building may not be exactly consistent with assumed design conditions, for example in terms of occupation, ventilation, insulation, and so on. One way to evaluate the building is then to calibrate the original model used during design, but it can be difficult and also time consuming to collect the necessary data.

* Corresponding author. Fax: +46 858553360.
E-mail address: jan-ulric.sjogren@ncc.se (J.-U. Sjögren).

0378-7788/$ – see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.enbuild.2009.03.001

Nomenclature

c_p	specific heat capacity of water (J kg^{-1} K^{-1})
f	fraction
F	effective shading factor
K_{tot}	total heat loss coefficient (W K^{-1})
K^*_{DH}	heat loss coefficient based on district heating per square metre area to let (W K^{-1} m^{-2})
K^*_{tot}	total heat loss coefficient normalised by square metre area to let (W K^{-1} m^{-2})
MFB	multifamily building
P_{BE}	building electricity per square metre area to let (W m^{-2})
P_{DH}	power for district heating per square metre area to let (W m^{-2})
P_{DHW}	power for domestic hot water per square metre area to let (W m^{-2})
P_E	household and building electricity per square metre area to let (W m^{-2})
P_G	power gained from different sources except heating per square metre area to let (W m^{-2})
P_H	power for the heating system per square metre area to let (W m^{-2})
P_{HE}	household electricity per square metre area to let (W m^{-2})
P_L	heat loss per square metre area to let (W m^{-2})
P_P	power from people per square metre area to let (W m^{-2})
$P_{SUN,THEO}$	theoretical solar radiation per square metre area to let (W m^{-2})
Q_{DCW}	domestic cold water use (m^3/s)
Q_{DHW}	domestic hot water use (m^3/s)
P_{SUN}	solar radiation per square metre area to let (W m^{-2})
P_{SUP}	supplied heat ($P_{DH} - P_{DHW} + P_E + P_P$) (W m^{-2})
T_e	outdoor temperature (°C)
T_i	indoor temperature (°C)
T_{BDH}	building balance point (°C) district heating
T_{DCW}	domestic cold water temperature (°C)
T_{DHW}	domestic hot water temperature (°C)
Tot	total
WA	total window area (m^2)
WA$_G$	glass area (window) (m^2)

Greek symbols

η	gain factor
η_{DHW}	gain factor for domestic hot water
ηP_E	gain factor for electricity
ρ	density of water (kg m^{-3})

An alternative way to investigate an operated building is to use monitored performance data. A broad range of models can be found in the literature. With access to time series data, different data-driven approaches may be used. Madsen and Holst [2] used Kalman filtering to both forecast and simulate the heat dynamics of a building whereas Seem and Braun [3] used the statistical autoregressive moving average (ARMA) method to achieve similar goals. Examples of more complex models are neural networks [4–8], different so-called expert systems [9,10], and multivariate analyses such as Principal Component Analysis (PCA) [11,12], which can handle complex connections in data, but are often more difficult to interpret [13,14]. The choice of model is, however, often determined by the available data in terms of time range and measured parameters. In field applications with access to billing data the information is sparse. Thus, steady-state methods are generally used. Based on one dependent and one independent parameter a simple linear regression can be applied (see for example [15–21]). With access to more than one independent parameter, multiple regression models have been developed by Sonderegger [22]. Using daily or hourly billing data, a variable based degree-day method, PRISM, was developed by Fels [23]. A brief overview of models and related works can be found in ASHRAE [24]. In this work we have used the simple linear regression approach based on the total energy use and outdoor temperatures. The total heat loss coefficient, K_{tot}, and indoor temperature, T_i, are easily determined by regression if K_{tot} and T_i, are constant. But in most cases, only the energy supplied to the heating system is known whereas the gains from solar radiation and from other sources are unknown.

The scope of the work was to investigate the sensitivity of the obtained values of K_{tot} and T_i to different time periods and assumptions for the energy gained from solar radiation, personal heat, domestic hot water, and electricity used by household and building systems. The monthly data used were collected during the years 2003–2006 for nine multifamily buildings (MFBs) in Stockholm, Sweden. With access to an estimate of K_{tot} and T_i, an improved evaluation and benchmarking of the energy performance may be achieved in the Swedish real estate market since today the commonly used measure is the annual use of energy for the heating system per square metre of area to let. The annual use of energy by the heating system is a measure that describes the combined performance of the building and its residents, whereas the measure K_{tot} describes the behaviour of the building.

2. Data

2.1. The buildings

All nine MFBs were completed during the years 1998–2003 and are located in the Stockholm area of Sweden. The MFBs were built and developed by the same company and are today owned by different housing co-operatives. Energy management and maintenance are performed by different small companies. The total area of the nine MFBs is approximately 100 000 m^2, of which 10% are used for commercial purposes. Not included in this area are corridors, stairwells, technical spaces, garages, and so on, which usually represent on average about 20–25% of the total floor area for this type of Swedish building, according to a study made by PROFU [25] and internal guidelines used by the developer. The type of design and construction, total size, size of apartments, installation systems such as the Heating Ventilation and Air Conditioning (HVAC) system, and so on are similar for all MFBs except for MFB #1 which has a significantly larger proportion of windows. The common HVAC system is exhaust fans without recovery for residential areas and supply and exhausts fans with recovery systems for commercial areas and garages. In Table 1 below, an overview of the MFBs is given in terms of the distribution of the area to let, heat recovery system, and window area expressed as a ratio to the area to let (windows [%] = window area/area to let).

2.2. Measured data

All MFBs are connected to district heating (DH) and data for consumption (used for heating and domestic hot water preparation) are accessible on the Internet from the DH suppliers. For three