Energy Conversion and Management xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Energy Conversion and Management

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

Dynamic modeling approach for determining buildings technical system energy performance

Ivan Horvat, Damir Dović *

University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture, Department for Thermal and Process Engineering, Ivana Lučića 5, 10000 Zagreb, Croatia

ARTICLE INFO

Article history:
Received 13 November 2015
Received in revised form 22 March 2016
Accepted 23 March 2016
Available online xxxx

Keywords:
Space heating system
Domestic hot water system
Dynamic simulation
Building energy need
Delivered energy

ABSTRACT

This paper presents new approach for determining buildings technical system energy performance. This new methodology describes a mathematical model for accurately predicting indoor temperature and heat losses of the space heating and domestic hot water system components. The entire model is described by system of ordinary differential equations which can be solved using standard numerical techniques. The innovative aspect of the method is the integral approach in mathematical modeling of buildings energy needs and technical systems heat loss, taking into account heat accumulation in all considered parts (building envelope + technical system). Such approach allows a detailed insight of the system behavior for chosen working conditions. This model can serve for energy performance calculations in a wide variety of buildings types and their technical systems. The calculation example is given for family house, equipped with conventional space heating and domestic hot water heating system, with the time step of 1 min and for characteristic day of each month within a year. The results are compared against those obtain from EN ISO 13790 and standard series EN 15316. The comparison shows significant differences in determination of the annual delivered energy to the heating system (33%), as a consequence of difference in estimation of the energy need for heating (15%) and calculation of the technical systems recoverable heat losses utilization factor, which seems to be underestimated. The delivered energy to the space heating and domestic hot water heating system differs 25%, while the energy delivered to the generation system differs 4%.

1. Introduction

One of the goals of the Directive on energy performance of buildings (EPBD) is application of a common procedure for energy performance calculation. This procedure is provided within a number of CEN standards, dealing each with a particular part of building technical systems and building elements itself. Although, the related calculations are to more or less extent in use in the all Member States, the accuracy has not been confirmed by date.

To validate these calculations, a comparison with more detailed dynamic models, as the present one, for heat transfer determination in building and its technical systems is needed, in addition to the long term measurements of energy consumption.

The model presented in this paper enables realistic simulation of the transient heat transfer through a building envelope and in its space heating and domestic hot water (DHW) system in dependence on the climatic conditions for a given building structure and control set-up of room temperature and DHW system. It takes into account a heat accumulation in all parts of the building structure, technical systems and working fluids, i.e. in the emission, distribution, storage and generation sub-system (as defined in CEN standards [1]). As described in the subsequent text, the other models dealing with this topic available in the literature are focused separately either on building envelope or on the basic technical system components, mainly not taking into account heat accumulation in the system components and working fluids or not even in the building envelope (in case of the integral models dealing both with building envelope and technical systems). Also, unlike the other models, the present one takes into account daily intermittency of the system operation and system shut down during the night.

In [2] the simple hourly method has been described. The method validation is given in [3], using EnergyPlus detailed simulation method as a reference. This method, using simplified expressions, enables the determination of the hourly energy need for heating/cooling. Although, the accuracy is limited, due to reducing the all heat transfer coefficients to the one lumped capacitance, as well as due to modeling of the building envelope heat transfer by the overall heat transfer coefficient (problems regarding heat transfer via the ground), the method provides a good basis for

* Corresponding author.
E-mail addresses: ivan.horvat@fsb.hr (I. Horvat), damir.dovic@fsb.hr (D. Dović).

http://dx.doi.org/10.1016/j.enconman.2016.03.062
0196-8904/

Please cite this article in press as: Horvat I, Dović D. Dynamic modeling approach for determining buildings technical system energy performance. Energy Convers Manage (2016), http://dx.doi.org/10.1016/j.enconman.2016.03.062

development of other mathematical models. Furthermore, this model enables only the hourly calculation, which is too large time interval for system components operation analysis.

The building thermal model demonstrated in [4] enables calculations of the heat transfer through building envelope in arbitrary time intervals, but due to many simplifications (e.g. solar radiation absorption considered in the overall wall volume instead of outer layers important for dynamic simulation, omitted solar radiation absorption in inner walls) it is suspected to be insufficiently accurate. In [5] the detailed building thermal model has been developed, using complex mathematical operations in determination of the heating/cooling energy need. Similar approach is used in [6] but the method, due to neglecting heat accumulation in external walls, is expected to be insufficiently accurate especially in transitional period. In [7], also using similar approach, authors address some important limitations of building heat transfer simulation. In [8], using similar building model as described in [6], heat accumulation effect of internal envelope is investigated. Energy storage capacity of interior thermal mass is also analyzed in [9]. Although, in these five models many of the influencing factors are included, there is no influence of the technical system (system heat losses, room temperature distribution, etc.) taken into account.

The method presented in [10] describes the emission and distribution sub-system dynamic models. Transient heating and cooling system simulation model is demonstrated in [11]. Due to connecting the developed models to the simplified building thermal model and use of an ideal generation sub-system in [10], the model is not expected to provide a reliable insight in the overall system behavior and determination of the heat losses. The detailed physical model of the technical system has been demonstrated in [12]. In this integral model (building thermal model + technical system model) the heat accumulation in the building envelope is neglected. In [13] the developed mathematical models of the system components are not directly linked to the building thermal model and system control. All of the previously described models dealing with the technical systems are not verified by comparison to any other models and/or measurements. In the literature there are only works presented dealing with system modelling performed with the data obtained from the experiment as a boundary condition [14]. Also, experimental investigation of heating system performance is demonstrated in [15]. In this two papers only the performance of one sub-system are measured. They, however, do not include all the input/output parameters of the present model. Therefore, here described integral model is compared with the methodologies from the CEN standards [1] and Croatian national Algorithm [16]. The method described in [16] is demonstrated in [17] through the calculation example. The main novelty of the method is an integral approach in mathematical modeling of a building energy needs and heat losses of buildings technical system components. Unlike in other separate building and system heat transfer models, this integral approach allows for the all recovered system heat losses to be taken into account in dynamic modeling of building energy consumption, which in turns affects operation of the technical system, making all these transient simulations likely more realistic and accurate. In addition, compared to the other described models, the present one enables more detailed definition of all influencing characteristics of building and system parts/components, that all represent input values to the model. Also, the other models, use steady state calculations for modeling of technical systems, or transient calculations for only one subsystem (e.g. distribution [10]). In the present model all subsystems (emitters, distribution pipes, storage, generator) are modeled taking into account heat accumulation which are, therefore, expected to enable more realistic prediction of system output parameters and energy consumption in dependence of all influencing working conditions (climate, room temperature, space heating and DHW control set up). Due to its concept and structure (application of transient heat transfer equations in all parts, mutual connections between sub-systems and building), the present model, unlike the others, can be applied on any building geometry, system configuration and for any working conditions.

2. Methods

2.1. Building model

Here presented dynamic heat transfer model of residential building is based on application of the transient energy balance equations on different parts of building structure.

Due to the difference in the layers of each building element (external wall, floor, roof) the heat losses through external wall, roof and the floor on the ground are separately modeled. Each building element is divided into three domains: internal and external layer and the center of the mass. The transient energy balance equations are then written for each layer. Solar radiation coming directly into the room space through openings does not directly warm up the indoor air, yet it is mostly absorbed by floor and interior walls. Therefore, the transient energy balance equations are additionally written for the interior walls, and separately for the internal air volume. In this way, the entire building is described by a system of ordinary differential equations, which can be solved using standard numerical techniques.

2.1.1. Building indoor zone

The building indoor zone has been described as a single isothermal air volume with a unique thermal capacitance. This bounded air volume exchanges heat with the internal layers of the walls and external air through the windows and receives heat via internal gains and solar irradiation. The model also takes into the account the heat transfer due to air exchange by infiltration and the window openings.

The transient energy balance equation for the internal air volume can be written according to Eq. (1):

$$V_{\mathrm{zone}} \cdot \rho_{\mathrm{air}} \cdot c_{\mathrm{p,air}} \cdot \frac{\Delta \vartheta_{\mathrm{air}}}{\Delta t} = \phi_{\mathrm{int}} - \phi_{\mathrm{ve}} - \sum_{\mathrm{i}=1}^{n} \phi_{\mathrm{i}} - \sum_{\mathrm{j}=1}^{k} \phi_{\mathrm{win}} + \phi_{\mathrm{heating}} \quad (1)$$

where

ϕ_{int} represents the internal heat gains (W);
ϕ_{ve} heat flow due to ventilation considering the minimum suitable value of air exchange (W);
ϕ_{i} is heat flow through the opaque building elements (W);
ϕ_{win} is heat flow through the windows (W);
ϕ_{heating} is the space heating load (W).

Space heating load ϕ_{heating} consists of useful heat flow delivered by the emission sub-system $\phi_{\mathrm{rad,heating}}$ and also recoverable heat losses of each sub-system. In this way, all recovered system heat losses are taken into account in dynamic modeling of building indoor air temperature, which is input to the space heating control system (Fig. 3).

2.1.2. Building indoor zone

Each opaque building element is divided into three different domains (Fig. 1): the internal layer, which is subjected to the combined effect of internal air convection and solar irradiation coming directly through openings, external layer, which is subjected to the combined effect of internal air convection and solar irradiation, and the center of the wall mass, which exchanges heat with the

Please cite this article in press as: Horvat I, Dović D. Dynamic modeling approach for determining buildings technical system energy performance. Energy Convers Manage (2016), http://dx.doi.org/10.1016/j.enconman.2016.03.062