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Renewable energy for passive house heating II. Model

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Abstract

The evaluation of renewable energy used to increase the environmental friendliness of passive houses (PH) is the topic of this paper. A time-dependent model of passive house thermal behavior is developed. The heat-transfer through the high thermal inertia elements is analyzed by using a 1D time-dependent conduction heat-transfer equation that is solved numerically by using a standard Netlib solver (PDECHEB). Appropriate models for the conduction through the low thermal inertia elements are used, as well as a simple approach of the solar radiation transmission through the windows. The model takes into account in a detailed fashion the internal heat sources. Also, the operation of ventilation/heating system is described and common practice control strategies are implemented. Three renewable energy sources are considered. First, there is the passive solar heating due to the large window on the façade oriented south. Second, the active solar collectors system provides thermal energy for space heating or hot domestic water preparation. Third, a ground heat exchanger (GHE) increases the fresh air temperature during the cold season. The model was applied to the Pirmasens Passive House (Rhineland Palatinate, Germany). The passive solar heating system provides most part of the heating energy during November, December, February and March while in January the ground heat exchanger is the most important renewable energy source. January and February require use of additional conventional energy sources. A clever use of the active solar heating system could avoid consuming classical fuels during November, December and March. The ground heat exchanger is a reliable renewable source of energy. It provides heat during all the day and its (rather small) heat flux is increasing when the weather becomes colder. The air temperature at heater exit is normally lower than 46 °C. This is a good reason for the use of renewable energy to replace the classical fuel or the wood to be burn in the heater.

Keywords: Sustainable building technology; Energy efficiency; Renewable energy; Passive house

1. Introduction

"Passive houses" (PH) are buildings which assure a comfortable indoor climate in summer and in winter without needing a conventional heating or cooling system. Due to its specific construction design, a passive house can manage throughout the heating period with more than 10 times less heat energy than the same building designed to standards presently applicable across Europe. Consequently, the space heating in a passive house can be entirely assured by a ventilation system by heating the supply air.

In this paper, we propose a model to compute the heating demand for a three-zone passive house. The model is time-dependent in order to take into account properly the thermal inertia of the very thick walls of passive house's envelope. The three zones refer to those areas with quite similar indoor features (in terms of temperature and humidity), namely to (1) the kitchen, (2) the bathroom and (3) the remaining parts of the house. The model was presented in part in [1]. Here, new features are described. In a companion paper [2] (later on referred to as paper I), we described in detail the Pirmasens Passive House (Rhineland Palatinate, Germany). The thermal load model developed here will be applied to that passive house.

The building thermal load model is coupled with another module modeling a high efficient mechanical hot air ventilation unit. This allows to determining the passive house's yearly energy demand for heat supply purpose.

The extended thermal insulation and the enhanced air tightness of a passive house remove the need for temperatures higher than 50 °C. This makes renewable energy sources particularly suitable for space heating, cooling and

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domestic hot water preparation. The Workgroup Cost Efficient Passive Houses as European Standards (CEPHEUS) vowed that "the remaining energy demand of a passive house can completely been met by renewable sources" [3]. However, the limited time availability of some renewable energy sources induces partial over-sizing of receptors and supply uncertainty that leads to the definition of a range of performance. The main idea of our approach is to details in time the heat loads and sinks that enable the investigation of the suitability of renewable energies as warmth and coldness suppliers to passive houses [4]. Our investigation focuses on the outcome of these varying performances on the building heating demand as well as on the indoor thermal comfort.

Details about several time-dependent models are presented in the following and some preliminary results are reported.

2. Building thermal load model

The building thermal load (sometimes referred to as building heating/cooling demand) mainly depends on the heat loss of the building. It results of the sum of the transmission and ventilation heat losses as well as of the internal and passive solar gains. We remind that the definition of space heating/cooling demand includes four items:

(i) heat flux escaping the building envelope;
(ii) heat loss due to air circulating through the walls, through small fugues or cracks;
(iii) heat gain due to the solar irradiation passing through the windows;
(iv) heat released by the building occupants or by household appliances.

As far as space heating demand is concerned, the first two items tend to increase it while the last two tend to decrease it.

The building thermal load Q_{TL} changes continuously due to variations in ambient temperature and solar irradiance. As a consequence, Q_{TL} is generally positive or negative. When Q_{TL} is positive, two cases could arise. First, when buildings provided with climatization systems are considered, Q_{TL} equals the minimum heat flux to be extracted from the building. In the other case (climatization system is missing), Q_{TL} contributes to the increase of indoor air temperature. When negative, Q_{TL} equals the minimum heat flux to be supplied to the building. In case of passive houses this heat flux is provided through the heated-up fresh air moved by the ventilation system.

A model to evaluate the thermal load for the four spaces (i.e. living, toilet, kitchen and bathroom) of the Pirmasens Passive House is presented below. As usual, each space is modeled using a single node approach (see, for example [5]). The following effects are taken into account: heat conduction through walls, windows and doors, light transmission through windows and internal heat sources. Heats input and output through the ventilation air are also included. A time-dependent model for heat-transfer through high thermal inertia elements is developed. Appropriate models for the heat conduction through the low thermal inertia elements like windows and doors are used, as well as a simple approach of the solar radiation transmission through the windows, together with the associated heat gain inside the building. Some details follow.

2.1. Time-dependent heat-transfer through walls

The heat-transfer through the high thermal inertia elements (i.e. walls, roof and floor) is analyzed by using a 1D time-dependent conduction heat-transfer equation. Any of the 22 separation elements consists of a number of layers N_{layer} with homogeneous physical properties (see Table 2 of paper I). N_{layer} varies between 3 and 6.

The walls are grouped into internal walls and external walls. The external walls have one of the space 0 (i.e. the atmosphere) or space 5 (i.e. the soil) in Table 1 of paper I as a neighboring space. Fig. 1 shows an external wall of total thickness δ_{tot} whose left surface is irradiated by global solar radiation (irradiance $G(t)$). The time-dependent air temperature on the two sides of the wall is $T_1(t)$ and $T_2(t)$, respectively. Note that the indices 1 and 2 refer to the wall sides and *not* to the space numbers in Table 1 of paper I. Also, the appropriate convection heat-transfer coefficients are denoted α_1 and α_2.

The 1D heat-transfer equation through the external wall of Fig. 1 is

$$\rho c_p \frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(\lambda \frac{\partial T}{\partial x}\right) \quad (2.1)$$

where $T(x)$ is the distribution of temperature inside the wall while ρ, c_p and λ are the mass density, the specific heat and the thermal conductivity, respectively, all of them dependent on space. The boundary conditions are as follows.

$$-\lambda \left.\frac{\partial T}{\partial x}\right|_{x=0} = \alpha_2[T_2(t) - T(x=0,t)] + a_{wall}G \quad (2.2)$$

$$-\lambda \left.\frac{\partial T}{\partial x}\right|_{x=\delta_{tot}} = \alpha_1[T(x=\delta_{tot},t) - T_1(t)] \quad (2.3)$$

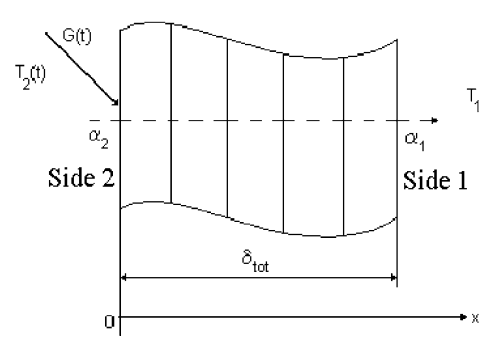

Fig. 1. Heat-transfer through an external wall.