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Ground contact heat losses: Simplified calculation method for residential buildings

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ABSTRACT

Heat loss through building elements in contact with the ground plays an important role in a building's thermal behaviour, therefore its estimation and management is relevant when assessing a building's energy performance. The EN ISO 13370 standard provides a method for calculating heat loss through the ground that takes into account steady state heat loss as well as heat loss due to temperature variations throughout the year (on a monthly or seasonal basis). It is based on calculating thermal transmittance for floors and walls in contact with the ground and differs greatly from the method established in the Portuguese building regulation codes. The EN ISO 13370 method requires a large input of data. This paper presents an alternative simplified version of the method that is more suitable for general building energy performance calculation procedures since it requires fewer calculation parameters and steps. The proposed method is mainly conservative and overestimates slightly heat transfer via the ground when compared to the EN ISO 13370 standard method.

1. Introduction

As a result of people's growing expectations regarding thermal comfort and their increasing concern towards energy consumption reduction, researchers have been progressively more motivated to develop models for predicting heat transfer [1,2] namely, putting further emphasis on calculating heat loss via the ground when assessing energy performance of buildings.

To this date a number of studies have been carried out in order to define a method for calculating heat loss via the ground. This particular kind of heat transfer is hard to characterize due, not only to the three-dimensional nature of the heat flow and the variability in ground properties, but also because of the large thermal inertia of the ground, which leads to annual periodic heat flows rather than just daily periodic heat flows. For steady-state conditions numerous experimental, analytical and numerical models have been developed, which further demonstrates the complexity of this issue. Hagentoft studied the influence of thermal insulation thickness [3] and ground water flow [4,5] in ground temperature. Anderson developed a formula for calculating heat loss through slab-on-ground floors with or without thermal insulation, based on the fundamental equation of heat transfer [6]. In his work Anderson introduced the notion of "characteristic dimension" of the floor. This parameter given by the floor area divided by half of the floor's perimeter was intended to simplify the calculation for different floor geometries and allowed for a calculation method based on external wall thickness, surface resistance and insulation thickness. Anderson also studied the effect of placing the edge insulation layer in ground floors vertically or horizontally and established parameters related to the thickness of the insulation layer and its thermal conductivity, width and placement [7]. More recently Hagentoft, developed an analytical model for calculating heat loss through the ground in steady state conditions, taking into account edge insulation [8]. Subsequently these studies established the basis for the EN ISO 13370:2007 for calculation of heat transfer through elements in contact with the ground [9]. Medved and Cerne developed a simplified calculation method for previous versions of this European Standard based on weighing factors determined to reduce the number of variables involved in the calculation [10].

The EN ISO 13370:2007 European Standard [9] provides methods, which will be explained further on this paper, for calculating heat transfer coefficients and heat flow rates for building elements in contact with the ground, including walls, slab-on-ground floors and suspended floors. The steady-state part of the heat transfer which relates the average heat flow to average temperature difference between indoor and the ground is considered a good approximation to the average heat flow over the

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heating season. However, this standard also includes the calculation procedure for determining heat transfer relative to the annual periodic heat flow related to the difference between the indoor temperature and the temperature of the ground, which is due to the large thermal inertia of the ground. The standard gives equations which depend on the geometric properties of the floor, on the thermal resistance of the building elements (walls and floors) as well as the annual variation in monthly average temperature.

In order to further reduce the European Union's energy dependence and greenhouse gas emissions, the European Directive 2010/31/EU 19 May 2010 on the energy performance of buildings (EPBD) [11] recast the goals set out in the European Directive 2002/91/EC [12] regarding energy consumption in the building sector. In the new EPBD it is said that energy performance in buildings shall be assessed by a method which may be differentiated at national and regional level but should take into account existing European standards. This implies that member states should revise existing regulations. In Portugal this means revising the Decree-Law no. 80/2006 which sets the national regulation regarding characteristics of thermal behaviour of buildings (RCCTE) [13].

In most European legislation the calculation of the energy performance of buildings is a complex procedure that requires the use of government approved software. The methods often include the calculation of specific input parameters such as the thermal transmittance through the ground, consistent with national and European standards. In Italy national legislation [14], and [15], requires that the calculation methodology complies with the current UNI and CEN standards, namely UNI EN ISO 13370 [16]. Calculation method (Methode Th CE) provided in French law [17] also requires the application of EN ISO 13370. In the UK, the Standard Assessment Procedure for the Energy Rating of Dwellings (SAP) [18] requires that thermal transmittance values (U-values) for ground floors and basements are calculated using the procedure described in BS EN ISO 13370 [9] or in the CIBSE Guide [19].

In the current RCCTE, heat loss through the ground is determined by means of a simplified approach in terms of linear heat loss through walls and floors, which diverges considerably from the one proposed by EN ISO 13370:2007. Largely due to the great number of input parameters involved, implementing the methodology proposed by this standard proves to be a demanding task. Spanish law [20] proposes the use of EN ISO 13370, but it also presents an alternative simplified methodology. The CIBSE Guide is consistent with BS EN ISO 13370 and offers tables of U-values for ground floors and basements, suggesting that linear interpolation may be used for intermediate values between those given in the tables. Portuguese national regulation does not require the use of government approved software for the calculation of energy performance of buildings and it is generally based on gathering input data from tables of values. Therefore, in order for the EN ISO 13370:2007 to integrate the Portuguese national regulation, it is considered that an alternative simplified approach to the calculation of heat transfer through the ground is necessary. In this paper we propose a simplified method consistent with the aforementioned standard, based on reducing the number of input parameters, which may be applied in a faster and easier fashion while producing the minimum possible error when compared to EN ISO 13370:2007 standard results.

In this paper, the EN ISO 13370:2007 method is explained and a sensitivity analysis is performed in order to determine the influence of the different parameters involved in the calculation and to establish the existing relations between parameters. A method consisting of a set of tabulated values and simple calculations is proposed. The RCCTE method is briefly explained and the proposed method results are compared to the ones provided by the EN ISO 13370:2007 and by the RCCTE for a reference building. Finally, the influence of the assumptions made on overall energy demand for heating is shown for an example building.

2. EN ISO 13370:2007 method analysis - simplified method development

The following paragraphs describe the assumptions that were made while developing the simplified method based on the reduction of the number of parameters needed to calculate thermal transmittance for building elements in contact with the ground according to EN ISO 13370:2007. The first step was to analyse carefully the methodology present in EN ISO 13370:2007, aiming at identifying the parameters that generally have the least influence on the final results. Finally, tables of values were elaborated in order to produce fairly accurate results.

2.1. Thermal transmittance for building elements in contact with the ground

Heat loss through the ground is defined by the steady state heat transfer that occurs through the building elements surface and in the wall/floor junction. The steady-state heat transfer coefficient is given by the following equation:

$$H_g = \left(A \times U_{bf}\right) + (z \times P \times U_{bw}) + (P \times \Psi_g) \quad (\mathrm{W/^\circ C}) \tag{1}$$

A is the inside floor area in m^2; U_{bf} is the thermal transmittance of the floor in W/(m^2.°C); z is the floor depth below ground level in m; U_{bw} is the thermal transmittance of the walls in W/(m^2.°C); P is the exposed perimeter of the wall in m, which is the length of wall that separates the conditioned space from the outside environment and/or from an unheated space, and Ψ_g is the linear thermal transmittance, in W/(m.°C), obtained in accordance with European Standards ISO 10211:2007 [21] or ISO 14683:2007 [22].

Calculation of thermal transmittance through the ground, according to the European Standard, depends on the thermal properties of both the ground and the building elements. This is expressed in terms of the "characteristic dimension" and "equivalent thickness" parameters.

The "characteristic dimension" of the floor takes into account the three-dimensional nature of heat flow through the ground and is calculated by the following expression:

$$B' = \frac{A}{0.5\,P} \quad (\mathrm{m}) \tag{2}$$

The parameter "equivalent thickness" for the floor in contact with the ground represents the depth of ground which has the same thermal resistance as the floor. It depends on thickness of the adjacent walls (w), ground conductivity (λ) and on internal and external surface thermal resistance (R_{si} and R_{se}), as well as thermal resistance of the floor (R_f). It is given by the following expression:

$$d_t = w + \lambda\left(R_{si} + R_f + R_{se}\right) \quad (\mathrm{m}) \tag{3}$$

The floor thermal transmittance in W/(m^2.°C) is calculated according to Eqns. (4) and (5):

$$U_{bf} = \frac{2\lambda}{\pi B' + d_t + 0.5z}\ln\left(\frac{\pi B'}{d_t + 0.5z} + 1\right) \quad \text{if}\,(d_t + 0.5\,z) < B', \tag{4}$$

$$U_{bf} = \frac{\lambda}{0.457\,B' + d_t + 0.5z} \quad \text{if}\,(d_t + 0.5z) \geq B', \tag{5}$$

The parameter "equivalent thickness" for walls in contact with the ground is the depth of ground that has the same thermal