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Annual heating energy requirements of office buildings in a European climate

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ABSTRACT

The concept of implementing energy savings to reduce greenhouse gas emissions has become a key element of energy policies of any industrialized country. In the civil sector and specifically, energy savings for office buildings, there are still opportunities for further enhancements related to correctly determining the air conditioning thermal requirements. However, there is a lack of simple correlations that allow a preliminary assessment for a single building or correlations that can be quickly applied at the district level. This paper proposes several simple correlations that determine the heating loads of a typical office building by only knowing the Degree-Days of a specific European location. The authors have developed a dynamic model of an office building, considering the different energy regulations in force in several European countries such that the building model is as energy-efficient as possible in each examined location. Furthermore, the standard requirements related to the employment rate, indoor ventilation and indoor gain have been included. The results from several simulations performed in the TRNSYS environment have enabled the development of mathematical relationships valid for seven European countries and three continental zones (northern, central and southern) with notably high correlation coefficients. The proposed equations can be useful for determining the heating load of non-residential buildings with an appropriate level of detail for a rough energy plan at the district level.

1. Introduction

The European Union (EU) has always paid attention to environmental issues (Commission of the European Communities, 1992) and energy supply (Climate Change, 2008). Since its formation, the EU identified various actions to be implemented (European Parliament, 1996, 1998) to achieve very specific and important standards for CO_2 emission reduction (European Parliament, 2003), energy saving and renewable energy production (European Parliament, 2009). In 2013, the EU made another step forward by defining the 2030 Framework for Climate and Energy Policies (European Commission, 2013). The 2030 Framework outlines the continuation of the important path to energy savings and energy efficiency that member states have already started. The proposed targets that each member state has to achieve are:

To reduce emissions by 40% compared to 1990 levels.
To promote the production of at least 27% renewable energy in the EU.

In this context, the interventions necessary to achieve the energy target especially affect key economic sectors of individual member states (Beccali, Bonomolo, Ciulla, Galatioto, & Lo Brano, 2015), particularly the industry, the civil sector and transportation sectors. In the civil sector, nevertheless, it is important to assess the contribution of all the activities that take place within office buildings in terms of energy consumptions. In fact, the regularity of energy demand, both daily but also monthly and seasonally, makes energy assessment predictable. Local energy policies that pursue energy efficiency targets for office buildings can lead to concrete results in the short and medium term.

Studying the factors that affect the energy performance of office buildings and the energy characteristics of building constructions is essential for a better understanding of energy policies, design principles and operational strategies (Piacentino et al., 2015).

The most important factors are climatic parameters because they represents important boundary conditions for building design and affect the transient behaviour of the building envelope during its service life (Eskin & Türkmen, 2008).

Among the climatic parameters, the Degree-Days (DD) indicator can be used to quantify the heating and cooling energy demands. DD is one of the simplest way to estimate the energy consumptions of a building; it is a climatic indicator that can be used in

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the assessment and analysis of weather related to energy consumption of buildings. Many studies used DD for analysing regional characteristics and to predict energy demand (Christenson, Manz, & Gyalistras, 2006). For example, in Lee, Baek, and Cho (2014), Amato, Ruth, Kirshen, and Horwitz (2005), the authors explored regional building energy demand related to climate change by assessing demands for electricity and heating fuels in the Commonwealth of Massachusetts and found notable changes in the overall building energy consumption and its energy mix. Kim and Suh (2006) used the ASHRAE procedure based on Heating Degree Days (HDD) and Cooling Degree-Days (CDD) to estimate the heating and cooling energy demand in a building based on climate change scenarios from several global climate models. In Yi-Ling, Hai-Zhen, Guang-Tao, and Jun (2014), the authors used the relationships between energy consumption and HDD and CDD to investigate the heating consumption in cold months and cooling consumption in hot months. In a review of the USA literature concerning heating/cooling demands (Wilbanks et al., 2008), the heating and cooling demand is influenced by climate change; the overall effect on the final energy demand for residential and commercial sectors is likely to be a net savings of delivered energy.

As previously underlined, it is necessary to investigate this close relationship between climate indicators and internal loads. To address this need, the authors propose simple correlations to obtain the value of the heating thermal loads by varying only the HDD index. For seven different European countries, the authors have developed a TRNSYS dynamic model of an office building that accounts for the different energy regulations in each countries. This allowed the development of seven mathematical relationships valid for the seven countries and three mathematical relationships valid for the continental zones (northern, central and southern Europe) with very high correlation coefficients. In this study, an evaluation of cooling loads has not been addressed because of the difficulty of reaching a uniform definition of the cooling period and corresponding evaluation of the CDD index.

2. Building energy balance

In the field of building energy planning, often a first summary evaluation of the indoor heating/cooling load is necessary. Obviously, a proper evaluation involves a complex analysis of the heat transfer phenomena, shape factor value, orientation, climate, and internal and solar gains. Indeed, as is well known, the energy balance of a building includes all indoor sources and sinks of energy as well as all energy flows through the envelope. The envelope encloses the heated/cooled volume, which is kept above a set temperature of generally 18–20 °C in winter and below 24–26 °C in summer for any weather condition using HVAC systems.

As depicted in Fig. 1, the energy balance of a building is characterized by energy losses and gains (http://nesa1.uni-siegen.de/wwwextern/idea/keytopic/3.htm. Accessed 22.04.15); furthermore, the climate context, as well as the use of the building and building construction type, strongly influence the heat exchange of the building-plant system.

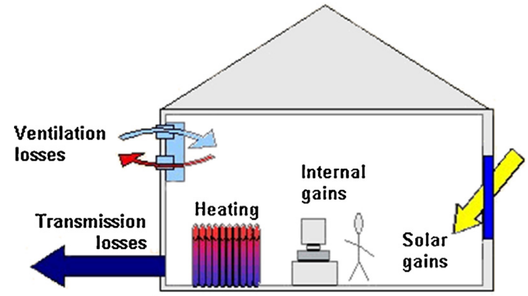

Fig. 1. Sketch of a building energy balance (TRNSYS).

To solve this balance and determine the heating (H_d) or cooling demand (C_d), it is necessary to known the DD index and to evaluate the following heat fluxes:

1. Transmission losses (Q_T).
2. Ventilation losses (Q_V).
3. Solar gains (Q_S).
4. Internal gains (Q_G).

The balance equation makes it possible to exactly determine the necessary amount of energy to maintain the desired ambient temperature by compensating for the excess of losses (1 and 2) in heating season, or, on the contrary, compensating for the gains (3 and 4) in cooling season.

Generally, it is possible to state that H_d or C_d is a function of:

$$H_d = f(\text{HDD}, Q_T, Q_V, Q_S, Q_G) \quad \text{and} \quad C_d = f(\text{CDD}, Q_T, Q_V, Q_S, Q_G) \tag{1}$$

where the Q_T parameter is dependent on the construction type of the building and also on the thermal transmittance of all the enclosure surfaces; the Q_V and Q_G parameters are generally reported in the actual standards and laws (ISO 13790) and they depend on the intended use; the Q_S parameter depends on the relationship between the glass surface and the opaque surface, on the thermal transmittance of the window frames and on the exposure.

The determination of each parameter is based on specific technical standards. The EN ISO 13790 (ISO 13790) provides the calculation methods to assess the yearly energy use for space heating and cooling of a residential or a non-residential building. Furthermore, in Annex G, the standard specifies the default internal load values for office buildings (Tables 1 and 2). The ventilation airflow rate was evaluated following Annex C of ISO 13790.

Table 1
Specific heat flow rate due to occupants and appliances (http://nesa1.uni-siegen.de/wwwextern/idea/keytopic/3.htm. Accessed 22.04.15).

Days	Hours	Office spaces (60% of useful floor area) [W/m^2]	Other room, lobbies, corridors (40% of useful floor area) [W/m^2]
Monday–Friday	07.00–17.00	20.0	8.0
	17.00–23.00	2.0	1.0
	23.00–07.00	2.0	1.0
	Average	9.50	3.92
Saturday–Sunday	07.00–17.00	2.0	1.0
	17.00–23.00	2.0	1.0
	23.00–07.00	2.0	1.0
	Average	2.0	1.0
Average		7.4	3.1
Average only equipment, machinery, appliances		3.0	–