INDOOR THERMAL COMFORT AND ENERGY CONSUMPTION IN A ROMANIAN APARTAMENT

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ABSTRACT

Energy consumption and indoor thermal comfort represent two important aspects in residential buildings. By using the Matlab software platform and the International Building Physics Toolbox, this paper tries to quantify the influence of a simplistic indoor thermal comfort control on energy consumption in a residential apartment in Romania. The main idea is to compare the energy consumption of a normal household when the control criterion is based on air temperature or on thermal comfort criteria. The analysis will be made using a software tool available for free that can be used for building physics simulations by any student or researcher that wants to model and simulate air, heat and moisture in buildings.

Keywords: thermal comfort, residential energy consumption, temperature control, thermal comfort control

1. Introduction

Reducing building energy consumption has presented, in the last years, a great interest due to the growing of the building sector and the energy policies adopted by the European Union.

One of the main goals concerning building energy consumption is to ensure thermal comfort conditions with regard to energy consumption and carbon emissions. Different strategies are researched to achieve these goals. In [1] different cooling technologies have been evaluated with respect to both thermal comfort and energy savings. Low-energy technologies prove to be an efficient solution to keep indoor thermal comfort and to reduce energy consumptions. Authors in [2] present a combined experimental and computational fluid dynamics (CFD) study to analyze indoor thermal comfort in a test room equipped with a cooling ceiling. Authors have investigated in [3] the effect of building envelope regulations on PMV based comfort control. Even though the studied example has a higher energy consumption when the interior control condition is based on the PMV, energy savings can still be achieved if the envelope is carefully designed.

References [4–6] compare different control strategies to achieve a desired indoor environmental quality and to minimize energy costs involved. Although advanced control techniques help improve the quality of the indoor environment, there are important issues that still need to be discussed. The need to measure a large number of variables that influence the thermal behavior of indoor environment (e.g. temperature, humidity, air velocity, solar radiation, etc.) increase the costs of such controllers. New buildings can be fitted with different sensors and energy management systems (EMS) from the design stage. The outfitting of existing residential buildings with different sensors and controllers can be expensive and create discomfort to users.

The paper is divided into … chapters. The second chapter explains the thermal comfort index used for the simulation, the third chapter presents the toolbox used for the simulation, the fourth chapter present the model used and the last chapter presents the conclusions.

2. Thermal comfort

Thermal comfort represents an important aspect in today's building energy consumption. Both energy consumption and occupants are influenced by thermal conditions in building environments. Even though there is a large number of comfort indexes [7], one of the most used is the PMV (Predicted Mean Vote) index. The PMV index is based on Fanger thermal comfort index and was first developed in 1970 [8]. This index takes into account thermoregulation between the human body and its surrounding environment. There are two personal variables (activity and clothing) and four physical variables (air temperature, radiant temperature, relative humidity and air velocity) that affect the interior comfort conditions.

The PMV index is described by equation (1):

$$PMV = (0.303e^{-0.036M} + 0.028)(H - L) \quad (1)$$

where: PMV is the predicted mean vote, M is the metabolic rate [W/m^2], H is the internal heat production rate of the metabolism [W/m^2] and L represents the heat loss of the human body [W/m^2].

The ASHRAE standard also provides a thermal sensation scale which corresponds to the values of the PMV.

Table 1 ASHRAE Thermal Sensation Scale

-3	-2	-1	0	1	2	3
Cold	Cool	Slightly Cool	Neutral	Slightly warm	Warm	Hot

One of the most important parameter that influences the PMV index is the mean radiant temperature. This parameter has a great influence on the thermal regulation of the human body and is calculated, according to Fanger with equation (3):

$$T_r = \sqrt[4]{\sum_i^n F_{n-1} \cdot t_i^4} \quad (3)$$

where: F_{n-i} represents the angle factor between surface n and the person and t_i represents the temperature of the surface n [°C]. Due to the fact that is very difficult to know where a person is in the room at any given time, the mean radiant temperature in this paper is calculated with the next equation:

$$T_r = \frac{\sum_{i=1}^n \varepsilon_i \cdot A_i \cdot T_i}{\sum_{i=1}^n \varepsilon_i \cdot A_i} \quad (4)$$

where: ε_i represents the surface emissivity, A is the surface area and T represents the surface temperature. The zone averaged radiant temperature was first implemented in EnergyPlus simulation software (see Engineering Reference from EnergyPlus documentation) and is used in [9] to study and compare the effect of exterior surface temperature on the thermal comfort of a person.

Based on the PMV index, Fanger introduced the PPD (predicted percentage of dissatisfied) index that shows the number of persons unsatisfied by the interior comfort conditions and is described by equation (5):

$$PPD = 100 - 95e^{[-(0.03353PMV^4 + 0.2179PMV^2)]} \quad (5)$$

Figure (1) presents the relationship between the two indices:

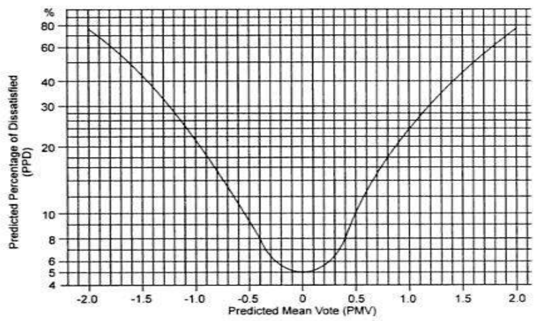

Figure 1 Relationship between PPD and PMV

3. IBPT Toolbox

The IBPT (International Building Physics Toolbox) is a special Matlab\Simulink toolbox developed by two research groups (Chalmers University of Technology and Technical University of Denmark) with the aim to help students and researchers that want to simulate heat, air and moisture transfer through building envelope[10,11]. Based on the Simulink software platform, the IBP Toolbox allows users to model different aspects of building physics without the need of having extensive programming skills. Another advantage is that the entire toolbox and manuals can be downloaded for free from www.ibpt.org.

The toolbox is divided into five distinct categories (fig.2). Each category is used to model a part of the building. Systems contain HVAC models used for heating or ventilation of the building. Construction contains different models of windows and walls. Zones represent the room models developed. Helpers handle real weather data that can be used during the simulations and gains contain different internal heat gains that can be added to the model for a more realistic representation. Even though the toolbox comes with a set of predefined data, advanced users can modify the data in accordance with a set of rules implemented by the developers.

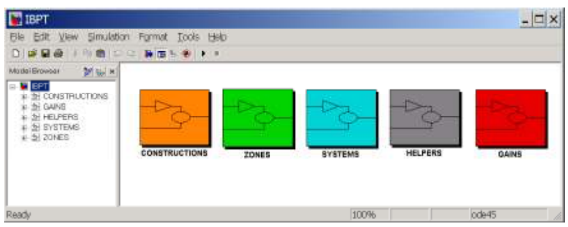

Figure 2 IBPT Toolbox

The validation of the toolbox was made with the help of the BESTEST [12] which represents a procedure to test and evaluate the accuracy of simulation software programs to accurately determine the energy consumption of households. Another validation of the toolbox was made during the HAMSTAD project.

4. House model

The room simulated in this paper is situated in a usual Romanian apartment. The room has two exterior walls and one exterior window. It is considered that there is no heat loss to any of the adjacent room or apartments. The Simulink model can be seen in figure 2. Table 2 shows the thermal properties of the exterior walls.

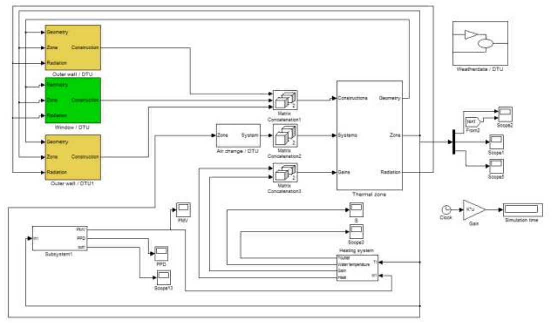

Fig. 3 Room model in Matlab/Simulink

The room has a total surface area of 11.86 m^2 and a volume of 30.84 m^3. Due to the fact that the toolbox works with control volumes, the exterior walls were divided in six layers. Each layer represents a control volume. Figure 4 shows the internal discretization of the exterior wall.

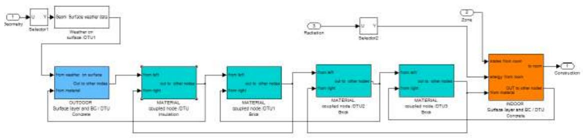

Fig. 4 Exterior wall discretization

The interior and exterior cement plaster layers are considered individual control volumes due to different convection coefficients that influence the heat balance. According to Normatice C107/3-1997, the interior heat convection coefficient is limited to 8[$W/m^2\cdot k$] and the exterior heat convection coefficient is limited to 24[$W/m^2\cdot K$].

The room is heated by a panel radiator, which is linked to the district heating. If we know the supply temperature and the mass flow of the heating agent, the return temperature of the heating agent can be easily calculated according to equation (6) [13,14]:

$$\frac{\partial T}{\partial t} = \frac{\dot{m} \cdot c \cdot \Delta T - U \cdot A \cdot \theta^n}{m \cdot c} \tag{6}$$

where: $\dot{m}$ represents the mass flow of the thermal agent [Kg/m^3], c is the specific heat of the thermal agent [J/Kg·K], ΔT represents the difference between the inlet and outlet temperatures of the heating agent [°C], U is the overall heating coefficient of the radiator [$W/m^2\cdot K$], A is the total area of the radiator [m^2] and m represents the mass of the heating agent within the radiator. θ^n from equation (6) expresses the logarithmic temperature difference:

$$\theta = \frac{T_{inlet} - T_{outlet}}{\ln \frac{(T_{inlet} - T_{in})}{(T_{outlet} - T_{in})}} \tag{7}$$

where: T_{in} is the indoor temperature [°C], T_{inlet} is the inlet temperature of the thermal agent and T_{outlet} represents the return temperature of the agent.

Table 2 Wall thermal properties

Wall type	Layer	Material	Thickness [cm]	λ [W/m·K]	α [$W/m^2\cdot K$]	Emissivity [-]	Density [Kg/m^3]	Cp [J/Kg·K]
Exterior wall	Layer 1	Cement plaster	0.02	1.5	24	0.9	2400	1800
	Layer 2	Concrete	0.1	1.5	-	-	2400	1800
	Layer 3	Concrete	0.1	1.5	-	-	2400	1800
	Layer 4	Mineral wool	0.1	0.03	-	-	30	800
	Layer 5	Concrete	0.1	1.5				1800
	Layer 6	Cement plaster	0.02	1.5	8	0.9	2400	1800

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