Energy Efficiency in a Thermal Comfort Field Work in Spain

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ABSTRACT

It is estimated that HVAC systems represent the highest energy consumption (approximately half of the total energy consumed) and one of the highest cost, especially in non-residential buildings. Therefore, that energy consumption in related to the cost of the building, the energy consumption and the thermal comfort.
Although the comfort of the users should be a factor to be aware of, it may not be the only one. It is advisable to have a balance between this variable and energy consumption, because of its impact on the environment and climate change.

KEYWORDS

Adaptive thermal comfort, energy efficiency, HVAC system

1 INTRODUCTION

Global energy dependence has grown exponentially. According to the International Energy Agency from 1971 to 2014 global energy consumption increased by 92% and continues increasing (Martinez-Molina, Tort-Ausina, Cho, & Vivancos, 2016).
This, together with the existing debate on climate change and the depletion of fossil fuels, highlights the need for a more sustainable environment in order to reduce energy consumption and greenhouse gases emissions to the environment.
Achieving these goals is a challenge that requires innovative research to improve the use of energy sources and new technologies and methodologies. However, reducing the associated energy and environmental impact is a difficult task (Soares et al., 2017).
The construction sector is one of the largest energy consumers, representing a higher percentage than industry and transportation together. In 2004 the construction sector accounted for 40%, 39% and 37% of the total energy demand in the EE.UU., UK and EU respectively (Yang, Yan, & Lam, 2014). Globally, buildings contribute to more than 30% of CO2 emissions and account for around 40% of the total energy demand and this ratio is

expected to soon reach 60% (Shaikh, Nor, Nallagownden, Elamvazuthi, & Ibrahim, 2014), accounting the HVAC systems for approximately half of the total energy consumed.
Moreover, it is estimated that people spend 60-90% of their time inside buildings, so the assurance of comfort has become increasingly important in recent years.
The concept of comfort has undergone an important transformation, all due to the exponential growth of the results of the investigations that in that field have taken place in the last years. Initially, the key magnitude in comfort was simply an acceptable air quality inside the buildings. At present, however, users have certain expectations about comfort and a greater degree of exigency. The term comfort has become a complex concept determined by three basic factors: thermal comfort, visual quality and air quality and other acoustic and ergonomic conditioners (Dounis & Caraiscos, 2009).
Among all of them, thermal comfort is a decisive factor in health, productivity in working environments and comfort in general and from which significant economic and social costs can be derived (Soares et al., 2017).
Although the comfort of the users should be a factor to be aware of, it may not be the only one. It is advisable to have a balance between this variable and energy consumption, because of its impact on the environment and climate change.

2 COMFORT AND ENERGY EFFICIENCY

The thermal comfort-energy efficiency balance represents a major challenge in the operation and management of buildings.
In the field of thermal comfort many studies have been carried out in buildings of different nature and in areas with different climatology (Pellegrino, Simonetti, & Chiesa, 2016).
The conventional thermal comfort model based on PMV and PPD was derived from climate chamber experiments where in most cases users wore standardized clothing and carried out sedentary activities. Numerous subsequent studies demonstrated that this stationary approximation fails. Most criticisms of the PMV and the PPD are based on the fact that they do not take into account the adaptation that takes place in changing thermal environments due to the thermal perception, also changing, of the users of such buildings.
People are able to adapt to the changing conditions of the thermal environment, which forms the basis of the adaptive theory of thermal comfort. Likewise, the adaptive principle also states that if there is a change that leads to discomfort, people react in such a way that they tend to restore their sense of comfort (Bhaskoro, Gilani, & Aris, 2013).
The inside temperature where most people are comfortable is known as neutral temperature or comfort temperature. Nicol and Humphreys proposed that such temperature was closely correlated with the outside temperature.
They also suggested that an algorithm could be constructed to determine the optimum indoor temperature as a linear function of the mean outdoor temperature and to use that reference for both the FR buildings and the HVAC system of conditioned buildings (McCartney & Nicol, 2002).
In many countries researches has been carried out to develop comfort temperature models. The results agree that an indoor comfort temperature could reduce the energy consumption of HVAC systems without sacrificing the comfort of the users (Bhaskoro, Gilani, & Aris, 2013) and that the use of temperatures based on the adaptive approach instead of fixed temperatures lead to energy savings without increasing the thermal discomfort of the occupants (Yang, Zheng, Mao, Lam, & Zhai, 2015).
Until recently, problems related with thermal comfort had been approached separately from the problems related to energy efficiency, so that in the literature studies can be found in the two fields separately, but there is a smaller number of investigations integrating both concepts simultaneously.

3 METHODOLOGY

In the present work we intend to investigate the relationship between thermal comfort based on adaptive theory and energy efficiency, all based on a real field study.
Figure 1 represents the research methodology. The objective of the first phase is to analyse the comfort range of the users, the second phase is the implementation of the adaptive law and in the third phase it is intended to carry out the verification of energy saving.

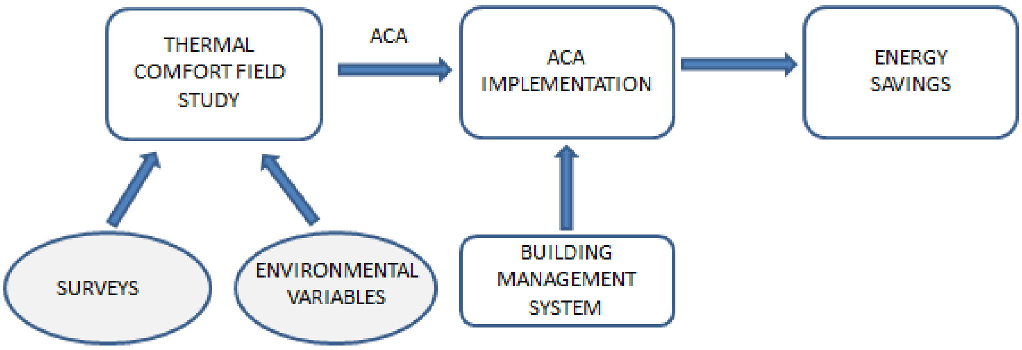

Figure 1 : Research methodology

3.1 Field study

The study design, the methods used in the field study and the data analysis were based on the methodology of the ASHRAE model and the SCATs project (McCartney & Nicol, 2002), (de Dear & Brager, 1998).
The field study was carried out in three buildings of the tertiary sector, non-residential and dedicated to university teaching (11 office spaces) in the South area of Spain.
The field study was carried out for a year collecting about 4,000 thermal sensation data.
In relation to the indoor environment, the variables of air temperature, relative humidity, globe temperature, air velocity, surface temperature, CO_2 concentration and luminosity were monitored by sensors that were installed in the rooms.
To evaluate the thermal comfort of the occupants, a longitudinal questionnaire and two additional questionnaires on clothing and satisfaction with other environmental factors were elaborated. A thermal sensation scale based on the ASHRAE scale was used for the thermal sensation vote.
For the analysis of the data, the interaction between the thermal sensation and the indoor environment was first analysed, and secondly the relation between the comfort temperature and the external temperature, based on the adaptive principles (equation 1 and equation 2).

$$Tcomfort=Tglobe-TSV/G \quad (1)$$

$$Tcomfort=a+b*Trm \quad (2)$$

Where Tcomfort is the inside comfort temperature, Tglobe is the globe temperature, TSV is the thermal sensation vote, G is the Griffith constant and Trm the running mean temperature.
As a result of the field study, an adaptive comfort algorithm (ACA) was obtained. A clear dependence between the temperature of comfort and the outside temperature was identified.

3.2 ACA implementation

The validation of the adaptive law and the quantification of the energy saving will be carried out in the monitored spaces of one of the three buildings in the field study.
The building has a centralized HVAC system. Each room in the building has a ventilation grille and one or two fans-coils for heating and air-conditioning. The fan-coils are controlled by the users of the room through a thermostat located in the same that also has a sensor to control the ambient temperature.
The implementation of the ACA obtained from the field study was carried out using a control module available in the application of the system.
The implementation of the new control law took place both during a winter period and during a summer period. During this implementation, the environmental variables of the rooms and the thermal perception of the users continued to be monitored.

3.3 Verification of energy saving

In order to evaluate the energy savings derived from the implementation of the adaptive comfort algorithm it is necessary to develop a model since it is not possible to evaluate simultaneously the same situation: with the ACA and without it.
For this purpose, a simplified characterization model (SCM) based on transfer functions (Stephenson & Mitalas, 1971) and (Ponsoda, Blanes, & Bader, 2011) will be used. Models based on transfer functions are used in all scientific fields to evaluate dynamic responses.
Figure 2 represents the methodology used, in which the developed model will provide the energy consumption that would have been if the building had not been improved, that is to say, if the building continued in the initial situation.
Obtaining the model requires a period of monitoring on the starting situation of the building, so it requires the monitoring of a base period that represents the energy performance of the building.
Finally, having the SCM identified, it could be excited with the measured data of the improved situation, that is to say, with the real interior conditions. These excitations will result in the consumptions that would have been obtained if the improvement would not have taken place (Figure 3).

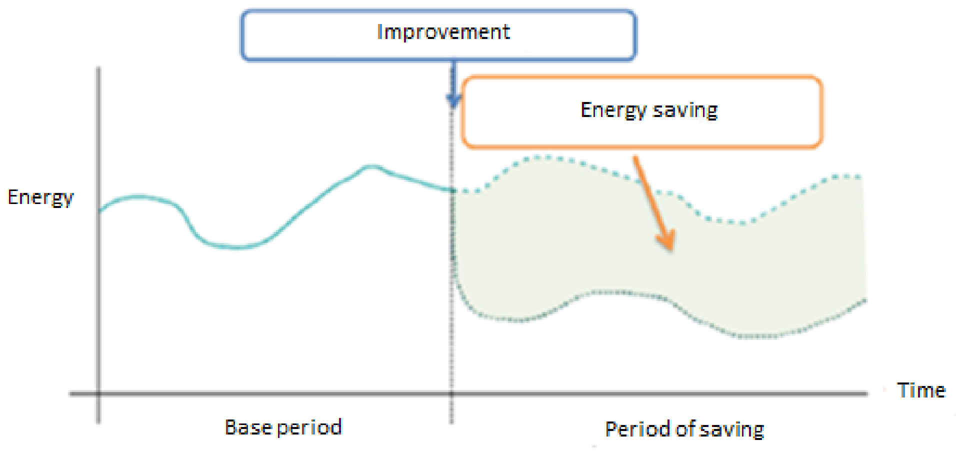

Figure 2 : Verification of energy saving-I

The saving is obtained by comparing the actual measured value and the value estimated by the SCM with the actual excitations of the improved situation measured.

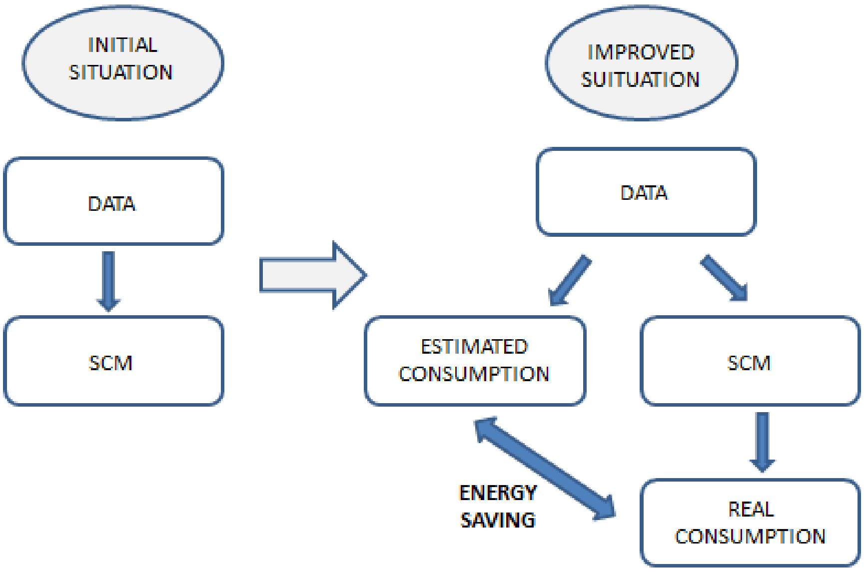

Figure 3 : Verification of energy saving-II

4 CONCLUSIONS AND FUTURE DEVELOPMENTS

A field study was carried out in three buildings in order to investigate the comfort of the users. A relation between indoor comfort temperature and outdoor temperature was identified (ACA), based on the adaptive thermal comfort theory. Actually the ACA has been implemented in the building management system of the building and we are developing a model based on transfer functions in order to evaluate the expected energy saving.

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