www.revistadyo.com

Methodology for analysis and decision making by sampling in buildings
Metodología para el análisis y toma de decisiones mediante muestreo en los edificios

Pablo Aparicio, José Guadix, Luis Onieva y Alejandro Escudero

Departamento de Organización Industrial y Gestión de Empresas II. Escuela Técnica Superior de Ingenieros. Universidad de Sevilla. Camino de los Descubrimientos s/n 41092.
pabloaparicio@us.es, guadix@us.es, onieva@us.es , alejandroescudero@us.es

Fecha de recepción: 01-10-2013
Fecha de aceptación: 10-06-2014

Abstract: (English) The sampling of the users comfort, allows observing and predicting the level of comfort on the HVAC system. The development of online sampling systems assists in the recognition of the behaviour patterns that occur in the offices. This paper presents a methodology specially designed and developed in order to make easier knowledge extraction and representation, in this way it possible to make decisions about the comfort in buildings. The methodology used provides important and useful information to select the comfort set-point of the rooms of a central HVAC system without the need to use fixed values based on programmed time schedules or any other methodology. In this methodology, the users are evaluated by using a standard set of key questions in order to measure the level of satisfaction respect to environmental factors, thanks to a questionnaire of imprecise answers. We seek an improvement in the building users, regardless of their particularities.

Keywords: comfort; HVAC; expert system; occupant; sampling;

Resumen: El muestreo del confort de los usuarios, permite observar y predecir el nivel de confort en el sistema de aire acondicionado. El desarrollo de los sistemas de muestreo online ayuda en el reconocimiento de patrones de comportamiento que se producen en las oficinas. En este trabajo se presenta una metodología especialmente diseñada y desarrollada con el fin de facilitar la extracción y representación del conocimiento, de esta manera es posible tomar decisiones sobre el confort en los edificios. La metodología utilizada proporciona información importante y útil para seleccionar el punto de ajuste del confort de las habitaciones para un sistema de climatización central, sin la necesidad de utilizar valores fijos, basados en horarios programados o cualquier otra metodología. En esta metodología, los usuarios son evaluados mediante el uso de un conjunto estándar de preguntas clave para medir el nivel de satisfacción respecto a los factores ambientales, gracias a un cuestionario de respuestas imprecisas. Buscamos una mejora en los usuarios de los edificios, independientemente de sus particularidades.

Palabras clave: confort, climatización, sistema experto; ocupante; muestreo.

1. Introduction

Efficient design tools for the thermal performance of buildings have a huge potential to slow down the profligate use of energy and reduce global environmental and housing problems. Consequently, a new philosophy is proposed which will ensure the development of efficient design tools in future, while also taking into account the interests of our occupants. Based on this philosophy, a new design tool was proposed a new model of decision for the parameters in the building (Aparicio, 2011).

Many human comfort models were developed in the last years attempt to predict a better approximation to reality, such as a human feels in a given environment. In general, the patterns of thermal comfort models are based on studies carried out on specific populations in a specific space, which are often analysed using models that follow the idea that these can be used in all building types in the same manner. This happens in many research studies which focus on how to reach or maintain a room's temperature based on the PMV index (Predicted Mean Vote) (Soyguder, 2009). Table 1 shows some model of the existing advanced control systems based on energy saving and comfort management in buildings. The temperature controls are based on the PMV in most studies. However, many authors are critical of this (Van Hoof, 2008), although it is not fully applicable to all parts of the globe, PMV models approaches us the reality, but can be improved with one design for each building. This model is based in real data, but with imprecise answers of comfort and precise data of environment.

In table 1 also can be seen that many of the common algorithms applied research, such as fuzzy logic, neural networks or genetic algorithms. In addition, this table shows whether these systems are learning ap-

Table 1

Several studies in the past

PMV or/and PID	Use a common algorithm	Learning	Fixed or reactive preferences	Survey preferences	Temperature	Humidity	Ventilating	CO2 Quality	Lighting	Energy Consumption	
■	■	■			■	■	■	■		■	Argiriou et al., 2004
■	■				■	■				■	Calvino et al., 2004
■	■	■	■		■	■	■	■	■		Dalamagkidis et al., 2007
			■		■	■			■	■	Davidsson y Boman, 2005
■	■	■	■		■	■	■	■		■	Doctor et al., 2005
■	■				■	■	■			■	Dounis y Manolakis, 2001
■	■	■	■		■	■	■	■	■	■	Dounis y Caraiscos, 2008
		■	■		■	■			■	■	Duangsuwan y Liu, 2009
■	■	■	■		■	■			■		Gouda et al., 2006
■	■	■	■				■	■	■	■	Guillemin et al., 2002
	■	■	■		■		■		■		Hagras et al., 2003
■	■	■	■		■	■	■	■	■	■	Hagras et al., 2004
■	■		■	■	■	■		■	■	■	Hamdi y Lachiever, 1998
	■		■		■						Huang y Lan, 1997
■	■				■	■	■	■	■	■	Kolokotsa, 2003
■	■	■	■		■	■	■			■	Liang y Du, 2008
■	■	■			■	■	■			■	Magnier y Haghighat, 2010
		■		■		■	■	■	■		McCartney y Nicol, 2002
■		■	■		■	■	■	■	■	■	Mo y Mahdani, 2003
■	■	■	■		■	■	■			■	Moon y Kim, 2010
■	■	■								■	Morel et al., 2001
		■		■	■	■	■				Nicol y Humphreys, 2010
■		■	■		■	■	■	■	■	■	Qiao et al., 2006
■	■	■	■		■	■	■	■	■	■	Rutishauser et al., 2005
	■				■	■	■			■	Shahnawaz Ahmed et al., 2007
	■				■	■			■		Shepherd y Batty, 2003
	■				■	■	■				Soyguder y Alli, 2010
■	■				■	■	■	■	■	■	Tripolitakis et al., 2004
■			■		■	■	■	■		■	Wang et al., 2004
■	■	■	■		■	■	■			■	Wright et al., 2002
	■	■	■		■	■				■	Yalcitas y Akkurt, 2005

ply fixed values or reactive preferences, as opposed to surveys' model proposed in this paper. You may also see information is taken into account by these systems: temperature, humidity, ventilation, air quality, lighting or energy consumed. All these factors except the last, affect the comfort of the occupants.

An HVAC system in which is poorly selected operating parameters may cause reduced productivity, because thermal comfort is known to have a significant influence on the productivity and satisfaction of occupants in a building environment (Akimoto, 2009).

These systems obviously need to have sufficient decision-making ability to be able to take action on the level of comfort while saving as much energy as possible. However, there are certain situations where maximising comfort must take precedence over savings. Adjusting comfort in order to maximise savings may result in a lower quality of comfort; nevertheless, maximising comfort during a period of time to allow the users to adjust to the environment, waiting and then reducing it to values which maximise savings may help improve the quality and acceptance of these savings. This will improve the building's energy efficiency along with a high level of acceptance from the users compared to the currently energy that is wasted in buildings.

Due to differing perceptions of what is 'comfortable', that occur because some people are more tolerant to broader climatic conditions than others. Obviously, whether the standard is accepted or not clearly depends on the place's weather and the building's conditions. Therefore, without questioning the standard, comfort systems whose ventilation and air-conditioning is based on personalised comfort models must be developed.

The energy saving should not take precedence over comfort, especially in certain situations comfort should take precedence over energy saving as the users have to adapt to the changes in temperatures caused by the variations in the building's occupation, low body temperature at the beginning of the day (Almirall, 1995), after breakfast and meals, etc. These all have an effect on human's thermal sensation and usually occur in conjunction with one another.

There are different examples both in printed or internet-based studies, where the sampling was based on surveys using sampling methods. The aim of these surveys was to obtain the staff's general level of comfort at the start or end of the day. These studies, that included many different types of buildings, used information on the physical characteristics of the buildings and the work spaces. However, comfort values associated with the room were not taken into account in these studies (Huizenga, 2002). But as Brager says "An important premise of the adaptive model is that the person is no longer a passive recipient of the given thermal environment, but instead is an active agent interacting with the person-environment system via multiple feedback loops." (Brager, 1998).

2. Methodology

The methodology is presented in figure 1, for making decision of the parameters of an HVAC system. First, it is performed comfort samplings of the occupants, and at the same time it is obtained the space parameters of study. This data is stored and processed. With this information processed, the system obtains the decision criteria to be applied to the search for a solution that will improve comfort and save energy in the building. Once this information is made available (Phase 1), it must make a study of the cost of modifying the parameters of temperature and humidity respect to the variation of comfort for the users, based on the information stored. The system must select the value that satisfies (Phase 2), in the

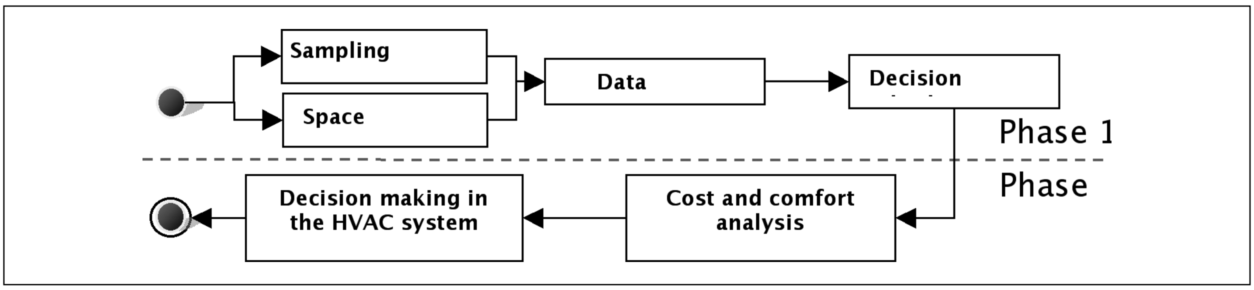

Figure 1
Methodology

best way possible, the criteria selected in the previous phase. Finally, we must apply the settings in the system.

2.1. Sampling, the online comfort survey

It has been shown that there is often an acute discrepancy between the comfort objective and subjective comfort (Meir et al., 2009). In view of the objective of comfort presented by ASHRAE thermal comfort in this methodology is used the survey as a fundamental element of subjective data collection (Ashrae, 1997).

The survey allows knowing the different perceptions of the users about indoors comfort levels. The system stores information relating to the comfort related to the temperature and humidity at the moment when the survey data are collected. It is selected the international standard ISO 10551:1995 which looks at the ergonomics of the thermal environment as a basis employing subjective judgment scales. Even so, in spite of the requests of those surveyed, all systems must be limited to certain norms whether determined by the ergonomics expert or by the laws or regulations of a country. The survey was performed using seven judgment values: three based on personal thermal condition (perceptual and emotional evaluation and temperature preferences), two based on the thermal environment (personal acceptance and tolerance) and two based on emotional state (level of stress and worker's mood). The information from the perceptual evaluation was used in the system developed and the main questionnaire is shown in (Aparicio, 2011). The users filled in a second survey in addition to these questions, which was performed at the same time as the first one. Both surveys were performed only once during the day. The second survey contained questions which focused on personal information, sex, age, height, weight and type of clothing.

2.2. The system architecture

The structure of the system is being investigated, as shown in the figure 2, it is based on the user's response to the surveys, rather than being controlled by a remote control to select the set-point of the

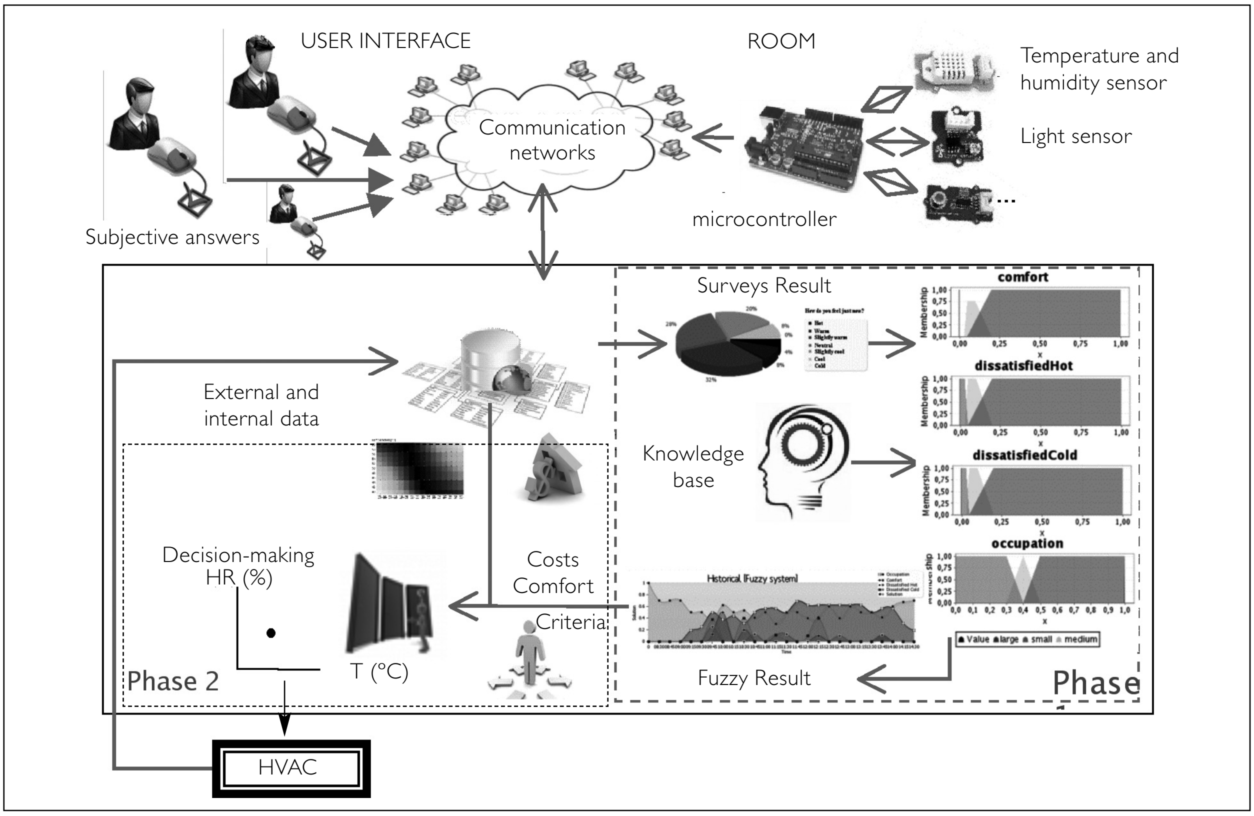

Figure 2
The system architecture

temperature. This allows to control the humidity, which generally could not be chosen by users.

The survey information together with the data of temperature, humidity and occupation given by the sensors are stored in a database. The fuzzy logic system gets the information to examine the criteria for selecting the proper temperature and humidity in this first phase. The term fuzzy logic was introduced by (Zadeh, 1965) and is a type of logic where the propositions can be represented with degrees of truthfulness and falsehood. Fuzzy logic has been extended to handle the concept of partial truth, where the truth value may range between completely true and completely false. Furthermore, when linguistic variables are used, these degrees may be managed by specific functions. Through fuzzy logic it is possible to represent the detect behaviour patterns that generally occur in a building (Aparicio, 2009).

The reasoning of fuzzy logic (FL) are very simple and flexible, the «naturalness» of its approach and not its far-reaching complexity. FL is suitable with imprecise data as comfort, this is used in everyday language, but the same vocabulary to different people may have different values, these values are known thanks to a questionnaire of imprecise answers. The fuzzy logic allows to ensure the reaction of the system on based to the experience of people. The design provides an online reliable pattern detection system but at the same time, an easy implementation. The situational patterns search permit to obtain useful information in takes decision.

Through sensors and thanks to the current technological tools with Internet access, the users could be assessed and their comfort could be personalized, in all situations and wherever. In addition, they can register the desired changes about the room states.

The objective of the model is to provide a reliable system with an easy implementation, hence the simplicity of the inputs required (variables): percentage and variation of occupancy, the evaluation may be dissatisfied by heat, satisfied and dissatisfied by cold. During the process, the system applied the fuzzy logic to convert the variables to fuzzy variables (fuzzification). Once the components of each variable are obtained, a set of logical rules is calculated considering the variation from the previous period (inference process). An example of rule is, «The preference that should be given to the saving energy if the occupation of the building is low, its variation is negative (the users are leaving the rooms), the number of users dissatisfied by heat is decreasing and its variation is also negative». The answers of the fuzzy rules (comfort, neutral and savings) are used to show that a significant change in global level exists of comfort and represents the configuration to which the system must give preference. Finally, to make a decision about which demand that must prevail (the user comfort or saving into a central system), it is necessary to transform the previous results of the inference process into a single interpretable result mathematically in the form of probability (defuzzification).

Furthermore, as not only the flow size is considered but also this variation in a period before, through the careful preparation of the rules, not only the pattern of comfort can be detected, but also the error in next period can be predicted with a very small probability. All this, using a little amount of possible information and independently of temperature or the particularities of each user. The decision logics rules, in case that several types would be detected, the answer would be given with greater probability value. This analysis is always made after a specific time period and a subsequent decision is made with regard to the climate setting type.

In a second phase of the system, taking into account the outcome of the fuzzy logic system, and information stored in the comfort of each individual, together with the data or cost function of the change of condition, the change value is the value at which the change in the measurement result is considered desirable due to the comfort and saving criterias. This second system takes the decision on the HVAC, it must be preserved and implemented in the following periods of time.

Individual user values are grouped in the system, generating rates of states of comfort regarding different climatic conditions of the rooms (after training the system). In figure 2, based on these values, it is known the difference of comfort regarding the current room status. Furthermore, if it is known the consumption differential for a temperature change in a room. The most interested change is selected with respect to the criterion given by the fuzzy logic system.

The survey responses are stored individually for each user, the system learns the individual results, and these can be compacted into a general model or for each room.

It is stored for each interval of temperature and humidity, the average acceptance by the user group. After the first day, we find temperature and humidity ranges for which we would not know any data, in (Figure 3) is represented by crosses.

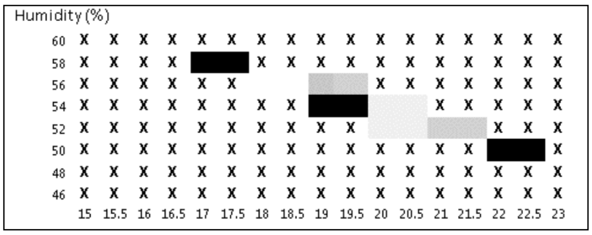

Figure 3
First Day

But over time, we will found similar comfort models which will follow the Fanger comfort curve (Figure 4a), but certainly more real to user comfort (Figure 4b).

As shown in figure 4b, assuming that we are at a point (22°C, 50% RH) only has to calculate the differential of comfort with respect to the closest points. The amount of energy that must be applied, must be lower due to evaporative systems, those systems can significantly reduce the energy consumed to a change in the degree of comfort. This kind of systems has shown around 15% savings in annual energy consumption of the building, while maintaining the comfort most of the hours in the year. (Khandelwal, 2011).

The architecture of this system aims to bring new decisions to be taken on such systems, where users are aware of the humidity, but they will not be able to control their changes.

3. Experiment and discussions

The model has been checked in one real case scenario in two work spaces of the Higher Technical School of Engineering of the University of Seville. The area was heated by two fan-coil units which were part of a central heating system. For this experiment the study was performed with a single central heating system and the same temperature decision was taken for all the equipment of the different areas. The area had 16 workspaces installed overall. The study was carried out between 8:30 am and 2:30 pm. The ages of the users studied ranged from 25 to 29 years old, who were all healthy and physically fit. On the whole, the users were wearing suit trousers, long-sleeve shirts, long-sleeve jumpers, thick socks and shoes. The outside conditions during the day remained between 9-13°C and over 80% humidity. The temperature and relative humidity inside the work area was measured during the study. In (Aparicio, 2011) could be seen an example of survey result as comfort condition, personal and thermal condition or the emotional condition, and an example of one of the response to one of the questions on the comfort. Besides, you can see the temperature and humidity along the day.

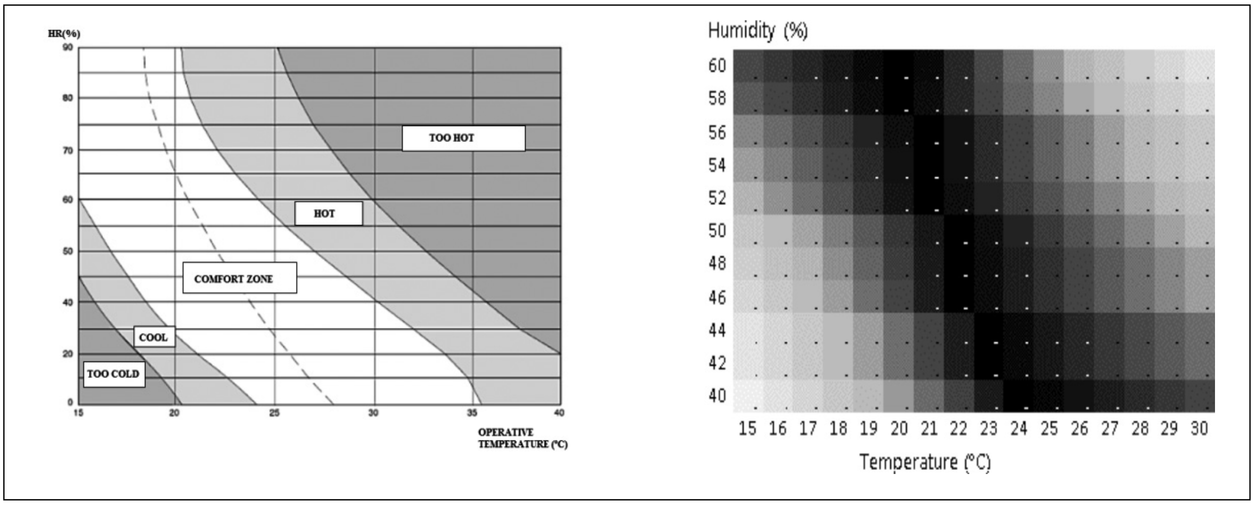

Figure 4
(a) The figure at left shows the comfort curve of Fanger (Mondelo, 1995). (b) The figure at right shows a possible degree of comfort in a building

The answers to each question as well as the level of occupation are shown in figure 5. The solution's weighting is shown where a one represents maximise saving and a zero maximise comfort. Furthermore, this figure presents the results of occupation and the answers of comfort, dissatisfied by hot and by cold.

For these results to arise there needs to be very large difference between the answers. This may have happened at 9:45 am. However, given that many users found the temperature acceptable, the request to maximise comfort was lower, meaning the need for this was decreased. However, moments when comfort took precedence were seen at 11:15 am, 12:15 pm and 12:45 pm, compared to the beginning and end of the working day when the building occupation meant that the system tended clearly towards energy saving.

This system reflects the need to look for savings and comfort, although the tendency leant more towards comfort due to the high occupation of the space, which was modified according to the users' answers to the questionnaire.

The trend in the system, allows you to be away from specific situations, due to psychological factors, health (body temperature), the menstrual cycle in women (Figure 6b), etc. For these reasons, some people may require a specific temperature due to the difference in the corporal temperature as you can see in (Figure 6a). However, in the building the user should adapt to the group. The needs of comfort are related to the body thermal curve, and at the beginning in the morning, the results in (Figure 5) is shown needs of comfort which are reduced in the same way as body temperature increases.

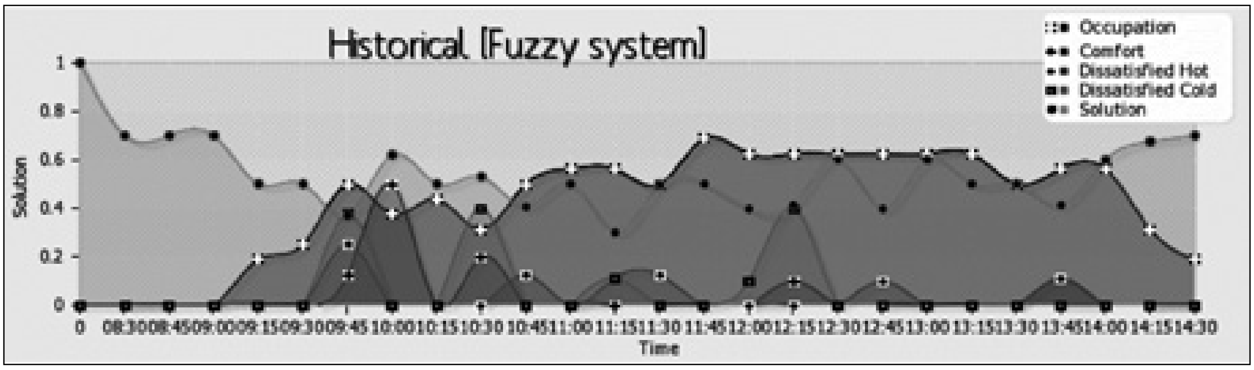

Figure 5
Chronological results of the fuzzy-logic system

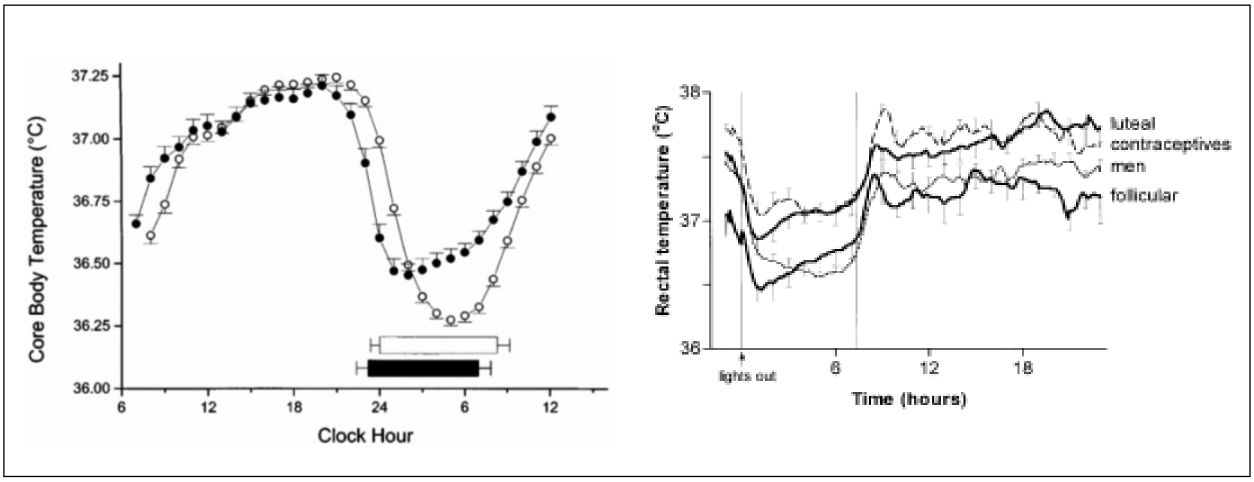

Figure 6
(a) The figure at left shows the core body temperature waveforms averaged with respect to time of day for young and older subjects (Duffy, 1998). (b) The figure at right shows the rectal temperatures in men, women taking hormonal contraceptives, and women in the phases of their menstrual cycles (Backer, 2001)

This methodology is developed to create an automatic own model of comfort in each building. A dynamic comfort model is developed as alternative to the comfort based on fixed values.

Noting the scientific community studies (Table 1), we see appropriate to use this system to conduct user studies in buildings and at the same time would be of interest to the scientific community compare the solution with the PMV, this is possible thanks to sensors and web pages.

In the future we plan to show that this approach is better suited to the reality; however, attention also must be shown in the adaptive comfort models, though the adaptive comfort model is not design to be applied in buildings with HVAC systems.

The corpus of this other research line is based in the idea of the human body maintains thermal equilibrium with its environment by means of physiological thermoregulation. But beyond these automatic processes, there is a suite of responses which enable building occupants to adapt to indoor and outdoor climates by means of behavioural adjustments (clothing, windows, fans, etc.), physiological adaptations (acclimatisation), and psychological adjustments (expectations). This idea is included in the methodology shown by means of sampling by survey, with which this information is captured. It is therefore necessary to study, as the adaptive model can help improve this methodology.

The potential energy savings of this model, compared to fixed systems, is based in the selection of different temperatures during the day. The system provides a methodology to achieve the energy requirements of the EU in 2020, while is limited with an expanded healthy range, on temperature and humidity values. The methodology together with a rise energy consumption coming from renewable sources would be a significant step forward for reaching the EU 20-20-20 goals. The methodology can only be applied in office buildings in where users are in similar conditions with regard to metabolic activity and clothing.

4. Conclusion

The methodology proposed to control system allows easier evaluation of the indoor climate by using surveys. It is expected that the outcome of this project will show that the control based on thermal comfort surveys provides better comfort at a lower cost than that provided by thermostatic control techniques.

There is a need to assure that the saving energy consumption perspective is explicitly present, without prejudice to the comfort in the building occupants. Nowadays, these two perspectives are not connected. This research is an opportunity to balance comfort and energy.

The HVAC systems efficiency and flexibility need to be balanced with considerations of users. A new methodology and HVAC control strategy and decision criteria that regulates thermal comfort levels was presented.

The system will dynamically adapt to changes in comfort, will store the user responses dynamically to meet your individual comfort. This allows knowing the effect of changes in the decisions of the system.

Logically, we are developing a technique in order to prevent the problems and infighting for the selection of temperature within a workspace, where the air conditioning is not to everyone's taste. However, this decision problem can be solved by this system, by obtaining a decision criterion based on sampling, in order to create indoor comfort and energy savings that the EU requires us for the year 2020.

References

AKIMOTO, T., TANABE, S., YANAI, T., SASAKI, M. (2010). «Thermal comfort and productivity - Evaluation of workplace environment in a task conditioned office». *Building and Environment,* 45 (1), pp. 45-50.

APARICIO, P., FERNÁNDEZ, J., ONIEVA, L. (2009). «Expert system based on fuzzy logic to detect configurations associated to climatic comfort». *Dirección y Organización,* 42(1), pp. 38-45.

APARICIO, P., GUADIX, J., MUÑUZURI, J., ONIEVA, L. (2011). «Detecting Comfort-Based Climate Settings Using Surveys». *Lecture Notes in Engineering and Computer Science,* 2191(1), pp. 1021-1026.

ALMIRALL, H., MARCET, C. (1995). «Evolution of body temperature during the day, and chronotype growth function. Evolución de la temperatura corporal a lo largo del día, función de crecimiento y cronotipo». *Psicothermal,* 7 (2), pp. 317-326.

ARGIRIOU, A.A., BELLAS-VELIDIS, I., KUMMERT, M., ANDRÉ, P. (2004). «A neural network controller for hydronic heating systems of solar buildings». *Neural Networks,* 17 (3), pp. 427-440.

ASHRAE (1997). *Ashrae handbook-fundamentals.* American Society of Heating, Refrigerating and Air Conditioning Engineers, Atlanta.

BAKER, F.C., WANER, J.I., VIEIRA, E.F., TAYLOR, S.R., DRIVER, H.S., MITCHELL, D. (2001). «Sleep and 24 hour body temperatures: a comparison in young men, naturally cycling women and women taking hormonal contraceptives». *Journal of Physiology,* 530 (3), pp. 565-74.

BRAGER, G.S., DEAR, R.J. (1998). «Thermal adaptation in the built environment: a literature review». *Energy and Buildings,* 27 (1), pp. 83-96.

CALVINO, F., GENNUSCA, M.L., RIZZO, G., SCACCIANOCE, G. (2004). «The control of indoor thermal comfort conditions: introducing a fuzzy adaptive controller». *Energy and Buildings,* 36, pp. 97-102.

DALAMAGKIDIS, K., KOLOKOTSA, D., KALAITZAKIS, K., STAVRAKAKIS, G.S. (2007). «Reinforcement learning for energy conservation and comfort in buildings». *Building and Environment,* 42 (7), pp. 2686-2698.

DAVIDSSON, P., BOMAN, M. (2005). «Distributed monitoring and control of office buildings by embedded agents». *Information Sciences,* 171 (4), pp. 293-307.

DOCTOR, F., HAGRAS, H., CALLAGHAN., V. (2005). «A Fuzzy embedded agent-based approach for realizing ambient intelligence in intelligent inhabited environments». *IEEE Transactions on Systems, Man, and Cybernetics Part A: Systems and Humans,* 35 (1), pp. 55-65.

DOUNIS, A.I., MANOLAKIS, D.E. (2001). «Design of a fuzzy system for living space thermal-comfort regulation». *Applied Energy,* 69, pp. 119-144.

DOUNIS, A.I., CARAISCOS, C. (2008). «Fuzzy comfort and its use in the design of an intelligent coordinator of fuzzy controller-agents for environmental conditions control in buildings». *Journal of Uncertain Systems,* 2, pp. 101-112.

DUANGSUWAN, J., LIU, K. (2009). «Normative Multiagent System for Intelligent Building Control». *Pacific-Asia Conference on Knowledge Engineering and Software Engineering,* pp. 197-200.

DUFFY, J.F., DIJK, D.J., KLERMAN, E.B., CZEISLER, C.A. (1998). «Later endogenous circadian temperature nadir relative to an earlier wake time in older people». *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology,* 275 (5), pp. 1478-1487.

GOUDA, M.M., DANAHER, S., UNDERWOOD, C.P. (2006). «Quasi-adaptive fuzzy heating control of solar buildings». *Building and Environment,* 41, pp. 1881-1891.

GUILLEMIN, A., MOLTENI, S. (2002). «An energy-efficient controller for shading devices self-adapting to the user wishes». *Building and Environment,* 37 (11), pp. 1091-1097.

HAGRAS, H., CALLAGHAN, V., COLLEY, M., CLARKE, G. (2003). «A hierarchical fuzzy-genetic multi-agent architecture for intelligent buildings online learning, adaptation and control». *Information Sciences,* 150 (1-2), pp. 33-57.

HAGRAS, H., CALLAGHAN, V., COLLEY, M., CLARKE, G., POUNDS-CORNISH, A., DUMAN, H. (2004). «Creating an ambient-intelligence environment using embedded agents». *IEEE Intelligent Systems,* 19 (6), pp. 12-20.

HAMDI, M., LACHIEVER, G. (1998). «A fuzzy control system based on the human sensation of thermal comfort». *The 1998 IEEE international conference on Fuzzy Systems,* 1, pp. 487-492.

HUANG, W., LAM, H.N. (1997). «Using genetic algorithms to optimize controller parameters for HVAC systems», *Energy and Buildings,* 26 (3), pp. 277-282.

HUIZENGA, C., LAESER, K., ARENS, E. (2002). «A web-based occupant satisfaction survey for benchmarking building quality». *Indoor Air,* pp. 1-6.

ISO 10551 (1995). *Ergonomics of the Thermal Environment: Assessment of the Influence of the Thermal. Environment Using Subjective Judgement Scales,* International Organization for Standardization, Geneva.

KHANDELWAL, A., TALUKDAR, P., JAIN, S. (2011). «Energy savings in a building using regenerative evaporative cooling». *Energy and Buildings,* 43, pp. 581–591.

KOLOKOTSA, D. (2003). «Comparison of the performance of fuzzy controllers for the management of the indoor environment». *Building and Environment,* 38, pp. 1439-1450.

LIANG, J., DU, R. (2008). «Design of intelligent comfort control system with human learning and minimum power control strategies». *Energy Conversion and Management,* 49 (4), pp. 517-528.

MAGNIER, L., HAGHIGHAT, F. (2010). «Multiobjective optimization of building design using TRNSYS simulations, genetic algorithm, and Artificial Neural Network». *Building and Environment,* 45 (3), pp. 739-746.

MCCARTNEY, K.J., NICOL, J.F. (2002). «Developing an adaptive control algorithm for Europe». *Energy and Buildings,* 34 (6), pp. 623-635.

MEIR, I.A., GARB, Y., JIAO, D., CICELSKY, A. (2009). «Post Occupancy Evaluation: An Inevitable Step Toward Sustainability». *Advances in Building Energy Research,* 3, pp. 189-220.

MO, Z., MAHDANI, A. (2003). *An agent-based simulation-assisted approach to bi-lateral building systems control,* pp. 11-14. Eindhoven: Eighth international IBPSA conference.

MONDELO, P.R., GREGORI, E., COMAS, S., CASTEJÓN, E., BARTOLOMÉ, E. (1995). *Ergonomía 2: Confort y estrés térmico,* Volumen 2. Mutua universal.

MOON, J.W., KIM, J.J. (2010). «ANN-based thermal control models for residential buildings». *Building and Environment,* 45, pp. 1612-1625.

MOREL, N., BAUER, M., EL-KHOURY, M., KRAUSS, J. (2001). «Neurobat, a predictive and adaptive heating control system using artificial neural networks». *International Journal of Solar Energy,* 21 (2-3), pp. 161-202.

NICOL, F., HUMPHREYS, M. (2010). «Derivation of the adaptive equations for thermal comfort in free-running buildings in European standard EN15251». *Building and Environment,* 45 (1), pp. 11-17.

QIAO, B., LIU, K., GUY, C. (2006). *A multi-agent for building control.* Hong Kong: Proceedings of the IEEE/WIC/ACM international conference on intelligent agent technology, pp. 653-659.

RUTISHAUSER, U., JOLLER, J., DOUGLAS, R. (2005). «Control and learning of ambience by an intelligent building». *IEEE Transactions on Systems, Man, and Cybernetics Part A:Systems and Humans,* 35 (1), pp. 121-132.

SHAHNAWAZ AHMED, S., SHAH MAJID, MD., NOVIA, H., ABD RAHMAN, H. (2007). «Fuzzy logic based energy saving technique for a central air conditioning system». *Energy,* 32, pp. 1222-1234.

SHEPHERD, A.B., BATTY, W.J. (2003). «Fuzzy control strategies to provide cost and energy efficient high quality indoor environments in buildings with high occupant densities». *Building Services Engineering Research and Technology,* 24 (1) pp. 35-45.

SOYGUDER, S., ALLI, H. (2009). «An expert system for the humidity and temperature control in HVAC systems using ANFIS and optimization with Fuzzy Modeling Approach». *Energy and Buildings,* 41 (8), pp. 814-822.

SOYGUDER, S., ALLI, H. (2010). «Fuzzy adaptive control for the actuators position control and modeling of an expert system». *Expert Systems with Applications,* 37 (3), pp. 2072-2080.

TRIPOLITAKIS, E., KOLOKOTSA, D., KALAITZAKIS, K., STAVRAKAKIS, G. (2004). «Study and implementation of a fuzzy PD thermal comfort controller for embedded fieldbus systems applications». *WSEAS Trans. on Circuits and Systems,* 9 (3), pp. 2051-2057.

VAN HOOF, J. (2008). «Forty years of Fanger's model of thermal comfort: Comfort for all?». *Indoor Air,* 18, pp. 182-201.

WANG, S., XU, X. (2004). «Optimal and robust control of outdoor ventilation airflow rate for improving energy efficiency and IAQ». *Building and Environment,* 39 (7), pp. 763-773.

WRIGHT, J.A., LOOSEMORE, H.A., FARMANI, R. (2002). «Optimization of building thermal design and control by multi-criterion genetic algorithm». *Energy and Buildings,* 34, pp. 959-972.

YALCINTAS, M.; AKKURT, S. (2005). «Artificial neural networks applications in building energy predictions and a case study for tropical climates». *International Journal of Energy Research,* 29 (10), pp. 891-901.

ZADEH, L.A. (1965). «Fuzzy sets». *Information and Control,* 8(3), pp. 338-353.