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A new HVAC control system for improving perception of indoor ambiences

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1. Introduction

Thermal comfort plays a vital role in any working environment. However, it is a very ambiguous term and a concept that is difficult to represent on modern computers. It is best defined as a condition of the mind which expresses satisfaction with the thermal environment, and therefore, it is dependent on the individual's physiology and psychology.

Most often the set point and working periods of the Heating Ventilating and Air Conditioning system (HVAC) can be adjusted to suit the indoor conditions expected within a building. Despite this, as each building presents its own constructional characteristics and habits of its occupants, most common control systems do not factor in these variations. Consequently, the thermal comfort conditions are beyond the range of optimal behaviour, and further, of energy consumption.

To solve this problem several researchers have investigated the relationships between room conditions and thermal comfort. Normally, statistical approaches were employed, while recently, fuzzy and neural approaches have been proposed.

In this context, most control systems present an adequate accuracy in controlling indoor ambiences but, as mentioned earlier, this is insufficient. Therefore, a new algorithm is needed for this control system, which must necessarily consider the real construction characteristics of the indoor ambience as well as the occupants' habits. The comfort equation obtained by (Fanger, 1970) is observed to be too complicated to be solved using manual procedures, and more simplified models are needed as described in the following sections.

In this chapter a new methodology to control Heating Ventilating and Air Conditioning systems (HVAC) is discussed. This new methodology allows us to define the actual indoor ambiences, obtain an adequate model for each particular room, and employ this information to minimize the percentage of dissatisfaction, and simultaneously, reduce the energy consumption. Identical results can be obtained using expensive sampling apparatuses like thermal comfort modules and general HVAC control systems. Despite this, our new procedure, University of A Coruña patent P200801036, is based on the fact that simple models, adapted for each particular indoor ambience, will permit us to sample the principal related variables with low-cost sampling methods, such as data loggers. Finally, in this chapter the different ambiences where it can be employed will be dealt with.

2. Prior research

Thermal comfort can accurately be defined as the state of mind which expresses satisfaction with the thermal environment, and therefore, it depends on the individual's physiology and psychology (ISO 7730, 2005). This concept greatly influences any working environment; however, it remains a very vague term and a very difficult concept to represent on modern computers. Research conducted in the field of thermal comfort has proved that the required indoor temperature in a building is not a fixed value, and that the PMV index, which indirectly indicates satisfaction with the thermal comfort, is defined based on the six most important thermal variables: the human activity level, clothing insulation, mean radiant temperature, humidity, temperature and velocity of the indoor air, as seen in Fig. 1.

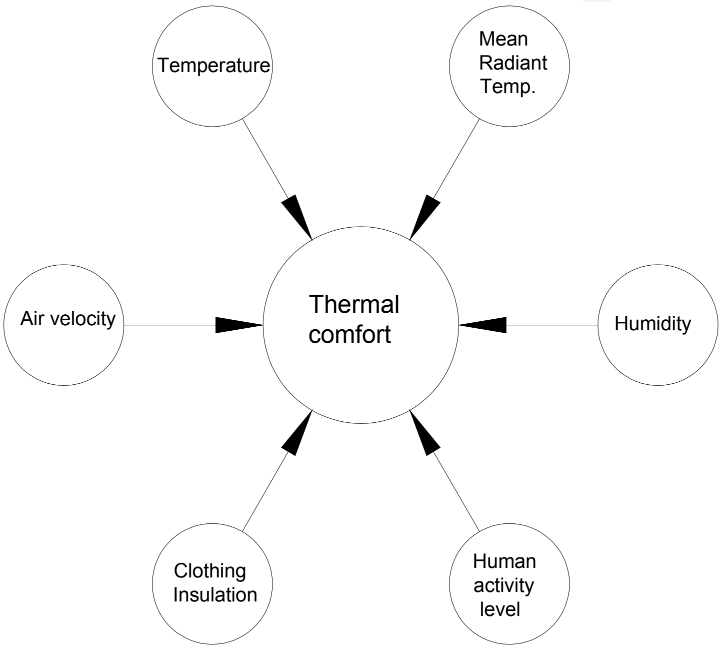

Fig. 1. Important variables that control thermal comfort.

In such a control scheme, the temperature and velocity of the indoor air have been commonly accepted as controlled variables for the HVAC system to keep the PMV index at comfort range. Energy saving was also reported to be achieved by this comfort-based control (Atthajariyakul and Leephakpreeda, 2004) and that a certain temperature range is sufficient to create a comfortable ambience.

Further, by controlling the heating and ventilation and by installing the air conditioning in that temperature zone, it will be interesting to obtain the lowest operating cost of the HVAC installation (Lute and van Paassen, 1995). To achieve these objectives different techniques like neuronal networks, adaptive models and regression models can be employed.

In the recent past, significant progress has been made in the fields of nonlinear pattern recognition, and thus a system control theory has been advanced in the branch of artificial neural networks (ANNs) (Mechaqrane and Zouak, 2004). It has also marked the progress of the neural network (FNN). However, most often, fuzzy logic controllers were employed because of their flexibility and intuitive uses. Basically, they have two control loops, one regulating the lighting and the other, the thermal aspects (Kristl *et al.*, 2008). In this case, the physical model of the chamber test with the measuring-regulation equipment was constructed attempting to develop a control system using fuzzy logic control support, which would enable the harmonious operation of both the thermal and lighting systems.

The results of the experiments conducted by simultaneously running both the control loops prove that the system based on the fuzzy approach functions is much softer and closer to human reasoning than the classical Yes/No regime (Chen *et al.*, 2006).

Another method used was based on the climatic conditions. Humphrey and Nicol, 1998, established a strong relationship between comfort and the mean outdoor temperature by suggesting that, in office buildings, the occupants may fall back on a type of thermal memory to meet their comfort expectations. Humphreys concluded that particularly the daily exposure to outdoor and many indoor temperatures varies according to the climate zones and certain social factors, and that exposure to these temperatures in daily life is a key factor in establishing the perception of indoor thermal environments, and not solely based on the prevailing indoor parameters.

Finally, the regression models are the last method used to display the dynamic heat of a building. De Dear and Brager, 1998, suggested that thermal comfort can be related to the exposure thermal history (Chung *et al.*, 2008), the globe temperature (Leephakpreeda, 2008) and other indoor parameters by regression models.

Once the HVAC control techniques are described, a new procedure for controlling indoor ambience will be discussed in the sections that follow.

3. Materials and Methods

3.1. Standards

To investigate such types of environments, specific standards need to be considered. In this context, the ASHRAE Handbook Fundamentals, 2005, in chapter 40, titled "Codes and Standards" reminds us of the principal standards to be considered on HVAC Applications.

The first parameter is the comfort condition, defined by ASHRAE in the ANSI/ASHRAE 55-2004, "Thermal Environmental Conditions for Human Occupancy", which closely agrees with ISO Standards 7726:1998 "Ergonomics of the thermal environment-Instruments for measuring physical quantities" and the ISO 7730-1994 "Moderate Thermal Environments—Determination of the PMV and PPD Indices and specification of the Conditions for Thermal Comfort". These standards are principally based on Fanger's studies. ASHRAE emphasises that no lower humidity limits have been established for thermal comfort; consequently, this standard does not specify a minimum humidity level.

However, this same standard shows that systems designed to control humidity shall be able to maintain a humidity ratio at or below 0.012, which corresponds to a water vapour pressure of 1.910 kPa at standard pressure or a dew point temperature of 6.8 ºC.

3.2. Sampling process

The methodology employed in this research work is based on sampling indoor comfort conditions, based on ISO 7730, and relates it with indoor the parameters like temperature and partial vapour pressure by curve fitting.

To collect the thermal comfort data, we can employ transducers similar to those utilised by the thermal comfort module of Innova Airtech 1221, 2009.

Using Gemini® dataloggers, air temperature and relative humidity monitoring has been conducted in a merchant vessel and buildings.

At the same time, outdoor data have been also obtained for comparison purposes. More than 11,000 measurements have been collected.
Later, the model thus obtained will be introduced in the HVAC control system of Simulink Ham Tools to simulate its behaviour in real buildings.

3.3. Thermal comfort models

Now, the principal models that enable us to define the thermal comfort in an indoor ambience will be analysed to select the one most adequate to be employed as the main algorithm of the HVAC control system.

3.3.1. Thermal balance model

Thermal balance is wholly accepted and followed by ISO 7730 for the study of comfort conditions, irrespective of the climatic region. Thermal balance begins with two mandatory initial conditions to maintain thermal comfort:

1) A neutral thermal sensation must be obtained from the combination of skin temperature and full body temperature.

2) In a full body energy balance, the amount of heat produced by metabolism must be equal to that lost to the atmosphere (steady state).

Applying the above principles, Equations 1 and 2 were obtained,

$$M - W = q_{sk} + q_{res} + S \tag{1}$$

$$M - W = (C + R + E_{sk}) + (C_{res} + E_{res}) + (S_{sk} + S_{cr}) \tag{2}$$

Where

M rate of metabolic heat production (W/m^2)
W rate of mechanical work accomplished (W/m^2)
qsk total rate of heat loss from skin (W/m^2)
qres total rate of heat loss through respiration (W/m^2)
C+R sensible heat loss from skin (W/m^2)
Cres rate of convective heat loss from respiration (W/m^2)
Eres rate of evaporative heat loss from respiration (W/m^2)
Ssk rate of heat storage in skin compartment (W/m^2)
Scr rate of heat storage in core compartment (W/m^2)

The comfort equation can be obtained by setting the heat balance in thermally comfortable conditions for an individual, as Equation 1 shows. Based on these parameters the indices used in general to define a thermal environment can be established, as shown in Equation 3, that predicts the mean vote, and 4 of the percentage of dissatisfied.

$$PMV = \left(0.303 \cdot e^{-0.036 \cdot M} + 0.028\right) \cdot L \tag{3}$$

$$PPD = 100 - 95 \cdot e^{-\left(0{,}03353 PMV^4 + 0.2179 PMV^2\right)} \tag{4}$$

where L is the thermal load on the body, defined as the difference between the internal heat produced and the heat lost to the actual environment.

Once the equations were explained, the comfort equation obtained by Fanger is confirmed as being too complicated to be solved through manual procedures. Therefore, more simplified models are necessary as shown in the following sections.

3.3.2. Thermal sensation models

Of all the thermal environment indices, PMV is the principal one. The work done by Oseland, and subsequently reflected by ASHRAE, concluded that the PMV can be used to predict the neutral temperature, with a margin of error of 1.4ºC compared with the neutral temperature, defined by the equation of thermal sensation. This thermal sensation expresses an index equivalent to the PMV, with the principal difference being that thermal sensation is obtained by a regression of surveys to different individuals located in an environment.
An example of a thermal sensation model that considers the effect of clothes (clo), has been developed by Berglund, 1978, and is shown in Equation 5.

$$T_{sens} = 0.305 \cdot T + 0.996 \cdot clo - 8.08 \tag{5}$$

It is interesting to note that Brager and de Dear, 1998, also showed that the PMV was found to be lower (colder) than the obtained thermal sensation when they studied office buildings.

3.3.3. Adaptive models

Another group of alternative models used to define thermal comfort are the adaptive models. In their research, Nicol and Humphrey challenged the steady-state comfort theories by introducing the adaptive comfort theory (Kristl *et al.*, 2008). The theory proposes that occupants of an indoor ambience can support conditions over steady-state as they can adapt to their environment. Eight years later, in 1978, Humphrey introduced the argument that this comfort temperature is related to the external temperature at the location (Humphreys, 1976), as seen in Equation 6.

$$T_c = b + aT_o \tag{6}$$

Where T_c is the comfort temperature and T_o is the outside temperature index, and a, b are constants.

Nicol and Roaf, 1996, particularly recommended Equation 7 for occupants of naturally ventilated buildings. Several other adaptive models have also been proposed. For example, Humphreys, 1976, developed two models for neutral temperature, as given in Equation 8 and 9, and Auliciems and de Dear developed the relations to help predict group neutralities based on mean indoor and outdoor temperatures, as shown in Equations 10, 11 and 12, which were employed by the ASHRAE in Equation 13.

$$T_{n,o} = 17 + 0.38T_o \tag{7}$$

$$T_{n,1} = 2.6 + 0.831T_i \tag{8}$$

$$T_{n,o} = 11.9 + 0.534T_o \tag{9}$$

$$T_{n,i} = 5.41 + 0.731T_i \tag{10}$$

$$T_{n,o} = 17.6 + 0.31T_o \tag{11}$$

$$T_{n,i,o} = 9.22 + 0.48T_i + 0.14T_o \tag{12}$$

ASHRAE:

$$T_c = 17.8 + 0.31T_o \tag{13}$$

Where T_c is the comfort temperature, T_o is the outdoor air temperature, T_i is the mean indoor air temperature, $T_{n,i}$ is neutral temperature based on mean indoor air temperature and $T_{n,o}$ is neutral temperature based on mean outdoor air temperature.

Recent researches, however, such as 'Smart controls and thermal Comfort (SCATs)' project, funded by the European Commission in 1997–2000, sampled the indoor conditions in 26 offices in various countries, particularly France, Greece, Portugal, Sweden, and the United Kingdom. After relating the sampled values with the survey's results, it has concluded that comfort temperature (T_c) is a function of the exponentially weighted running mean of the daily mean outdoor temperature (T_{rm}) with $\alpha = 0.8$, as seen in Equations 14 and 15. This α is a constant between 0 and 1, which defines the speed at which the running mean responds to the outdoor temperature.

For running operation
$$T_c = 0.33 \cdot T_{rm} + 18.8 \tag{14}$$

For heated or cooled operation
$$T_c = 0.09 \cdot T_{rm} + 22.6 \tag{15}$$

3.3.4. Solution: selected model

The Institute for Environmental Research at Kansas State University, under ASHRAE contract, has conducted an extensive research on the subject of thermal comfort in the sedentary regime. The purpose of this investigation was to obtain a model to express the PMV in terms of parameters easily sampled in an environment.

Therefore, an investigation of 1600 school-age students revealed statistical correlations between the comfort level, temperature, humidity, gender, and exposure duration.

Groups of five men and five women were exposed to a range of temperatures between 15.6ºC and 36.7ºC, with increases of 1.1ºC at eight different relative humidities of 15, 25, 34, 45, 55, 65, 75 and 85%, and for air speeds of less than 0.17 m/s.

During a three-hour study period with half-hour intervals, subjects reported their thermal sensations on a ballot paper with seven categories ranging between -3 and 3. These categories show a thermal sensation that varies between cold to warm, passing through 0 that indicates thermal neutrality. The results have yielded an expression as shown in Equation 16.

$$PMV = a \cdot t + b \cdot p_v - c \tag{16}$$

By using this equation and considering gender and exposure time to the indoor environment, different constants need to be used. These constants were obtained by regression from the original PMV of the thermal balance model showed in Equation 3.
Now, this model can be implemented in the control system, and energy saving can be defined.

3.3.5. Solution: selected software

As shown, a host of commercially available computer tool models already exist for modelling single components or whole buildings. For modelling whole buildings, there are models for the hourly energy balance like Bsim1, ESP-r2, and EnergyPlus3 etc. While these tools are fully appropriate for designing standard buildings, they are not suitable for modelling innovative building elements such as building integrated heating and cooling systems, ventilated glass facades and solar walls, as these have not been defined in the program, 2008.

Thus far it has been observed that the major shortcomings of building energy simulation programs have been unable to accurately model HVAC systems that are not “standard”. This argument can easily be extended to include advanced building elements. Modular models, however, have the advantage that the components and systems can be modelled as the need is encountered. Also, transparency of the existing components is essential, if the user/developer wishes to implement any modifications. A transparent, modular and open source system for modelling heat and moisture flows in buildings should therefore be a user-friendly tool that can be extended as needed in the future.

The above-mentioned concerns have given authors the impetus to develop an open and freely available building physics toolbox. The initiation of the International Building Physics Toolbox (IBPT) was thus begun by two groups of researchers working independently of each other, developing building physics models in Simulink.

For both groups, the reason for using Simulink as the development environment stemmed from the need to model, in great detail, the processes of heat, air and moisture transfer. In both groups, Simulink, which is part of the Matlab package, was chosen for its high degree of flexibility, modular structure, transparency of the models, and ease of use in the modelling process.

Simulink has earlier been used by other research communities (SIMBAD and CARNOT), but the models have either not been an open source, free of cost, or have not been directly applicable to building physics modelling.

Simulink’s modular structure - using systems and subsystems - makes it easier to maintain an overview of the models, and new models can just as easily be added to the pool of existing models.

Another advantage of using Simulink is the graphical programming language based on blocks with different properties such as arithmetic functions, input/output, data handling, transfer functions, state space models etc. Further, Simulink has built-in state-of-the-art ordinary differential equation (ODE) solvers, which are automatically configured at the run-time of the model.

Therefore, only the physical model needs to be implemented, and not the solver. Further, models can be created using several different approaches, including assembling models directly in Simulink, using the standard blocks, Matlab m-files, S-functions, and Femlab9 models using one-, two-, or three-dimensional finite element calculations. This wide variety of modelling techniques with different advantages and disadvantages indicates that the optimal choice can always be made, to suit the task.

Finally, the graphical approach also makes it easy to express the very complex interaction between the different parts of the model. Besides, those unfamiliar with programming too can easily start building their own models or altering the existing ones. Therefore, the toolbox also represents a good method of teaching building physics.

Once the selected software is defined, the next step would be to define the mathematical model to be employed. The mathematical model employed in this simulation is the result of whole building Heat, Air and Moisture (HAM) (Kalagasidis, 2008 and 2009) balance, and depends on the moisture generated from occupant activities, moisture input or removed by ventilation, and moisture transported and exchanged between indoor air and the envelope (Nielsen *et al.,* 2002).

The mathematical model is based on the numerical resolution of the energy and moisture balance through the building. The obtained discretized heat and moisture balance equations are shown in Equations 17 and 18.

$$\frac{T_i^{n+1}-T_i^n}{\Delta t}=\frac{1}{C^n}\cdot\left\{\left[\frac{(T_{i-1}-T_i)}{R_{i-1}+R_i}+\frac{(T_{i+1}-T_i)}{R_{i+1}+R_i}\right]-h_{evap}\cdot\left[\frac{(p_{i-1}-p_i)}{R_{p,i-1}+R_{p,i}}+\frac{(p_{i+1}-p_i)}{R_{p,i+1}+R_{p,i}}\right]\right\}\ldots$$
$$+\begin{Bmatrix} m_a\cdot c_{pa}\cdot(T_{i-1}-T_i)^n, m_a>0 \\ m_a\cdot c_{pa}\cdot(T_1-T_{i+1})^n, m_a<0 \end{Bmatrix} \tag{17}$$

$$\frac{w_i^{n+1}-w_i^n}{\Delta t}=\frac{1}{d}\cdot\left\{\left[\frac{(p_{i-1}-p_i)}{R_{p,i-1}+R_{p,i}}+\frac{(p_{i+1}-p_i)}{R_{p,i+1}+R_{p,i}}\right]-\left[\frac{(P_{suc,i-1}-P_{isuc,i})}{R_{suc,i-1}+R_{suc,i}}+\frac{(P_{suc,i+1}-p_{suc,i})}{R_{suc,i+1}+R_{suc,i}}\right]\right\}\ldots$$
$$+\begin{Bmatrix} 6.21\cdot10^{-6}\cdot m_a\cdot(p_{i-1}-p_i)^n, m_a>0 \\ 6.21\cdot10^{-6}\cdot m_a\cdot(p_i-p_{i+1})^n, m_a<0 \end{Bmatrix} \tag{18}$$

Where $_i$ is the objective node and $_{i+1}$ and $_{i-1}$ are the preceding and following nodes and $_n$ and $_{n+1}$ the previous and corresponding time steps.

To solve these balance equations, room models were created from the individual Building Physics Toolbox (Rode *et al.,* 2002). Ham–tools library is a Simulink model upgraded version of H-Tools with a similar structure and specially constructed for thermal system analysis in building physics.

The library contains blocks for 1-D calculation of Heat, Air and Moisture transfer throughout the building envelope components and ventilated spaces. The library is a part of the IBPT-International Building Physics Toolbox, and available as a free download.

This library presents two main blocks; a building envelope construction (walls, windows) and a thermal zone (ventilated spaces), enclosed by the building envelope. Component models provide detailed calculations of the hydrothermal state of each subcomponent in the structure, based on the surrounding conditions to which it is exposed.

In Fig. 2, we can see the principal blocks employed for a building simulation. Here, a block representing the different exterior/interior walls, floor, roof and windows components can be observed. These constructions are defined with respect to the physical properties (density of the dry material and open porosity), thermal properties (specific heat capacity of the dry material and thermal conductivity), and moisture properties (sorption isotherm, moisture capacity, water vapour permeability and liquid water conductivity) in line with the BESTEST structure.

Other parameters are also considered in the heat and moisture building balance, for example, internal gains (convective gains, radioactive gains and moisture gains), air change and heating/ cooling system.

The building's characteristics are defined in the thermal zone block, indicating the surface areas, orientations and tilts of each wall. Room volume, ambient air gain from the heat originated from solar energy and initial temperature is thus adjusted.

The Thermal model of the classroom is based on the WAVO model described by de Witt (2000), and developed assuming that long-wave radiation is equally distributed over the walls; room air has uniform temperature, the surface coefficients for convection and radiation are constant, and finally, that all radioactive heat input is distributed so that all the surfaces, except the windows, absorb the same amount of that energy per unit of surface area.

To introduce the PMV models obtained in the HVAC system, a diagram of a proposed control system is illustrated in Fig. 3. The controlled variables of indoor air are measured to be compared with the desired reference. By using the difference obtained, the controller manipulates the air-handling unit (AHU) to reduce the difference between the actual indoor air conditions and the reference ones.

The results showed that the optimal indoor-air condition for the HVAC system presented acceptable thermal comfort and indoor air quality with efficient energy consumption. Four controlled variables were specifically identified:

1. Indoor-air temperature

2. Indoor-air humidity

3. Indoor-air velocity

4. Air ventilation rate

These variables were determined for the indoor-air condition which efficiently provided the thermal comfort, and the indoor air quality, at the desired level and also reduced the cooling load in real-time implementation.

In our case, two different HVAC systems were proposed and simulated under real weather conditions.
One with a constant and another with a variable set point. In the variable set point HVAC control system each proposed set point temperature was observed to depend clearly on the indoor temperature, relative humidity and model constants for the heating and cooling periods.

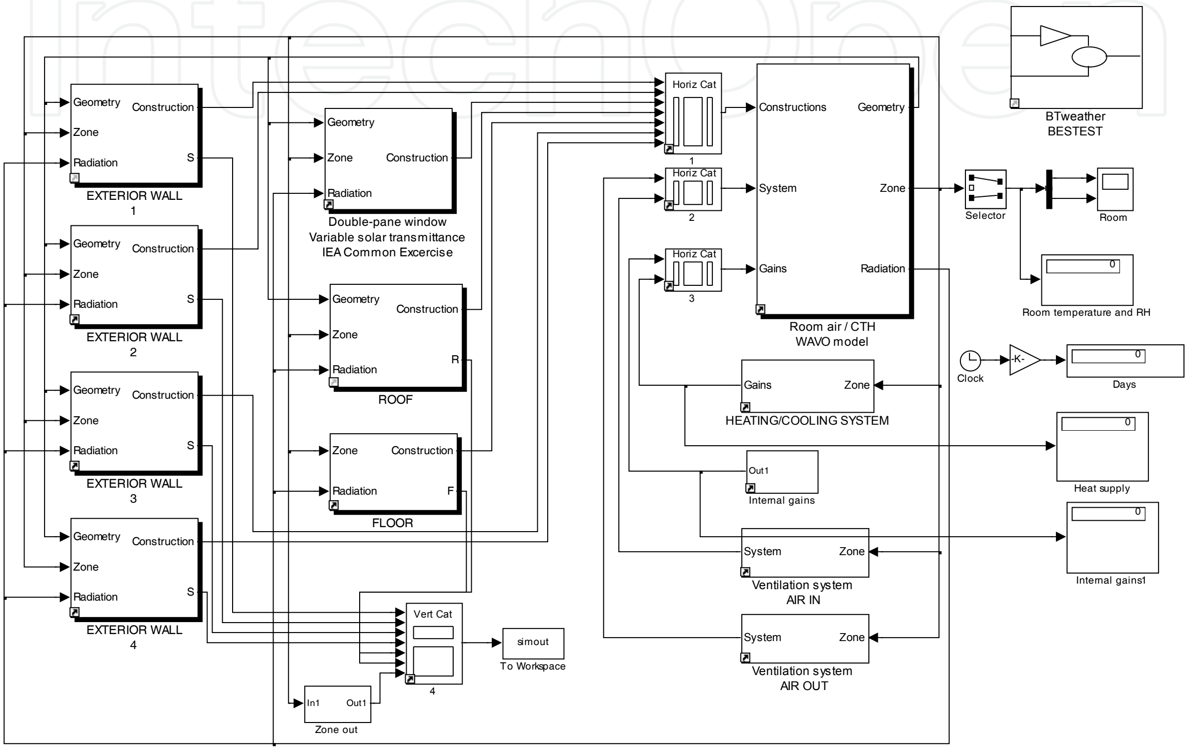

Fig. 2. Matlab blocks for building simulations.

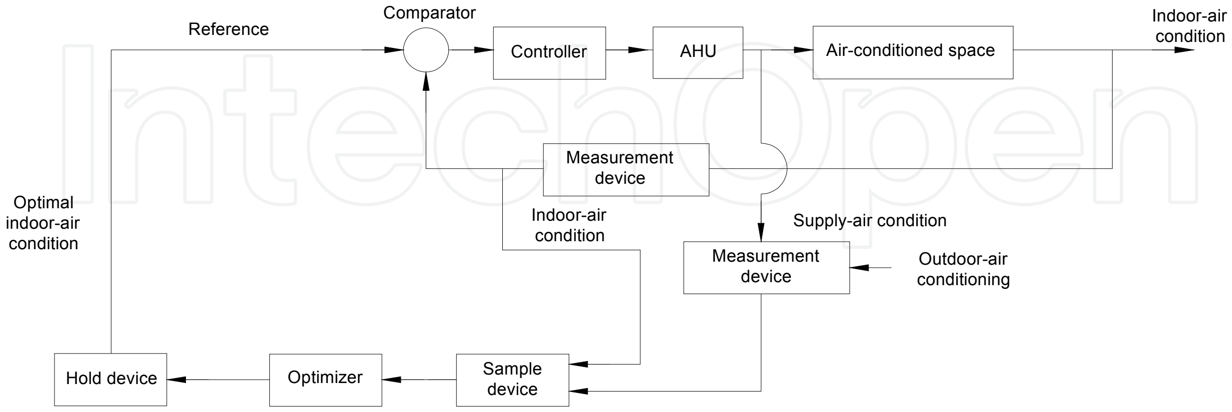

Fig. 3. Proposed implementation for HVAC control system.

3.4. Energy consumption

The energy performance aspect must always be considered. Once obtained, the neutral temperature proposed by the different models as set point-temperature must be simulated and compared with the variable set point temperatures proposed.

With these values, the perceptual increment of energy to air conditioning in indoor air can be calculated.

The methodology described (by Olalekan *et al.,* 2006) was employed to calculate the energy consumption needed to achieve ideal comfort conditions.

In this research work, the seasonal energy consumption is estimated as a function of the ventilation rate of outdoor air and enthalpy difference between the indoor and desired air conditions, as seen in Equations 19 and 20.

$$Q = \dot{m}_{ventilation} \int \Delta h \cdot dt \tag{19}$$

Where;

$$\Delta h = h_{indoor} - h_{desired} \tag{20}$$

h_{indoor} is the indoor enthalpy

$h_{desired}$ is the desired indoor enthalpy.

Finally, to study thermal neutral comfort conditions, comfort temperature-adapted index presented by ASHRAE has been used in Equation 3.

3.5. Indoor ambiences

3.5.1. Buildings

Two schools were sampled and simulated. One of the areas of the older school was built in 1890, and the other portion was built in 1960, and the new school was built in 1999, as seen in Fig. 4. Consequently, the old school presents 0.43 m of stone and 0.5 cm of concrete in the indoor side of the wall.

The wall of the new building consisted of insulation, brick, concrete and plaster arranged symmetrically in layers with respect to the middle of the wall, reaching 0.30 m of total thickness.

The classroom sampled in the old building is located on the second floor has a volume of 210 m^3, while the new is located on the first floor with a volume of 150 m^3.

All these buildings present a working period from February to June, and an unoccupied period during weekends and holidays.

During those periods, the classrooms are under natural ventilation and the central heating system was not employed. The active period ends in June, and therefore, energy saving during summer period was not of interest. Further, during the extreme conditions in winter, these schools do not function and therefore, the heating system will work only when the indoor conditions exceed the thermal comfort during winter and spring.

Fig. 4. A building in A Coruña.

3.5.2. Ships

An air conditioning control system in the control engine room is known to obviously lower the temperature to 20ºC, see Fig. 5.

Despite this, marine engineers will require that these values be corrected for each different indoor situation of the voyage, to reduce the workplace risk of thermal shock and heat stress in contrast to that in the engine room where the typical values of temperature are around 38ºC.

However, in practice this set point is almost never changed, and consequently, we find engineers suffering from headache and muscular pain.

Fig. 5. Control engine room of a ship.

4. Results and Discussion

This procedure was employed in two different ambiences; in a building and in a control engine room of a ship.

4.1. Buildings

To define the static set point in buildings adaptive methods are employed. In this context, the mean Galician outdoor temperature during the winter period ranges between 10 and 12 ºC, which represents a comfortable indoor temperature of 17.78ºC to 21.18ºC for each adapted model.

The highest value, which was obtained by the Nicol and Roaf model, shows the typical starting point temperature employed in indoor ambiences of this humid region.

On the contrary, the Humphreys' model showed an indoor temperature of 17.78ºC, which correlates with the energetic temperature suggested by the INEGA (Energetic Institute of Galicia) for energy saving in air conditioning during the winter period.

Once the fixed starting point temperatures were defined, along with the PMV index samples according to the partial vapour pressure and the indoor temperature, a curve was fitted based on the model of Equation 16.

This model was well adjusted with a correlation factor of 0.92 and it was introduced in the HVAC control system of HAM tools to fix a starting point according to a limit value. The limit value, during the winter season, will be of PMV=-0.5, indicating that the indoor temperature, which is the only controlled variable, will be set to reach a PMV value of –0.5 in a psychometric heating process of the moist air. In the summer this PMV value will change to 0.5.

The results obtained during the summer season showed that with a fixed starting point value of 20ºC, the indoor conditions will be automatically corrected from lower to equal or higher values than 20ºC, irrespective of the indoor comfort conditions being higher than the lower comfort limits.

Finally, the indoor relative humidity will experiment a similar behaviour when the indoor air is controlled with a fixed or a variable starting point. Despite this, the indoor relative humidity will reach, in both cases, a value higher than a 100% and therefore, there is a risk of condensation and mould.

This will happen particularly when the indoor air temperature drops to lower values. For example, with a variable starting point, the indoor temperature, which will differ from the fixed starting point, sometimes reaches values of 17.5ºC, while the indoor relative humidity will reach 100%. Despite this, with a fixed starting point the indoor conditions will show a similar relative humidity, and consequently, the solution will have a reduced margin in comfort limits, like PMV values of 0.4.

Once the hourly energy consumption is simulated, we can conclude that a variable starting point will reveal lower energy peaks than a fixed one, so such a control system will work for less time compared with the old method. Further, if the electricity cost in such buildings is assumed to be 0.09 €/kWh, we can conclude that during the winter months the energy consumption will be 33% lower than with a constant starting point value.

This result is related to the results (of Lute *et al.*, 1995) where a predictive control system (LPC) saves about 30% of energy consumption related to the conventional on/off and PI during the winter season, with the same type of comfort requirements.

To summarise, this methodology is noted to control indoor air conditions and is quite accurate as it suggests temperatures in line with the current HVAC standards. However, despite adaptive models showing adequate values for thermal neutralities, they are not at all suitable for energy saving.

4.2. Ship

As a possible solution to the extreme environment of an engine room and control engine room of a ship, a self-adjustment control system accounting for the indoor temperature and relative humidity is proposed, and the hottest set point temperature within the thermal comfort limits P.O. Fanger suggested was (PMV=+0.5). Matlab Simulink simulated this control system.

The indoor temperature and relative humidity at the control engine room were sampled and curve fitted to enable easy simulation in the software.

Once the control system was designed, it was used to simulate the sampled conditions representing the thermal comfort range within which work was possible in the control engine room, and compared them with the actual data generated by the samples.

This range is indirectly represented by the temperature and relative humidity curves of PMV=+0.5.

Results revealed that the new control system suggested a temperature of about 28ºC and a relative humidity of 28% for a PMV of 0.5 and an initial fixed value of 20ºC.

In our study, setting the control system to a PMV value of 0.5 appeared useful because it would reduce the operator's thermal shock when he came out after working in the engine room, and released the accumulated heat in the control engine room.

Besides, this set point adjustment would prevent physical hazards and could be expected to reduce the working hours of the HVAC system, and thereby extend the average life of the equipment. While these are the advantages, this high temperature was observed to reduce the environmental relative humidity to very low values, and despite this being beneficial for the electrical environment, the human occupants could be expected to suffer dehydration.

A solution attempted for this last problem was to reduce the adjusted PMV to a lower value like 0.4, which would in turn reduce the indoor temperature set point and, consequently, raise the indoor relative humidity.

Another possible solution was to increase the number of air changes per hour in the control engine room. Using outdoor air particularly, would be especially advantageous because of its low values of temperature and high values of relative humidity.

Finally, bibliographic conclusions suggest that future works must be conducted based on a variable operational starting point for air-conditioned buildings and they should also extend their research to more data samples such as other indoor ambiences during a whole year (Mechaqrane and Zouak, 2004).

5. Conclusions

A particular procedure was described and developed in this study, with the aim of presenting a new tool for energy saving in buildings, and workplace risk prevention for future use in international shipping worldwide.

This procedure is based on a new thermal comfort model which was advanced based on the P.O. Fanger PMV index, according to the Institute of the University of Kansa, and adapted to a specific indoor ambience, with a thermal comfort logger.

The results proved that this methodology was sufficiently accurate in buildings, and suggests temperatures according to the actual HVAC standards. The adaptive models also reveal adequate values for thermal neutralities, although they are not suitable for energy saving, due to their static value for a daily period. The Humphreys model alone shows a fixed starting point temperature similar to that proposed by the variable PMV model. Further, due to the mould risk under the higher indoor air relative humidity, it is interesting to define stricter PMV limits to reduce higher relative humidity values.

The indoor conditions of the engine room and the control engine room of a merchant ship, however, when investigated during a sea voyage, showed the following findings: the low indoor temperature conditions observed in the control engine room were a definite source of physical hazards for marine engineers who came in from the hot environment of the engine room.

Therefore, a new control system to reduce this workplace risk was developed, based on the general thermal comfort level and the conditions simulated. This simulation, based on real data generated by the sample, showed the new expected environment that could be obtained. For example, indoor temperatures of 28ºC were proposed by which a reduced thermal shock could be expected. Besides this, these modifications could be expected to reduce the working hours of the HVAC system, thus extending the average life of the equipment.

Finally, more research is warranted to define better PMV and adaptive models based on continuous sample data.

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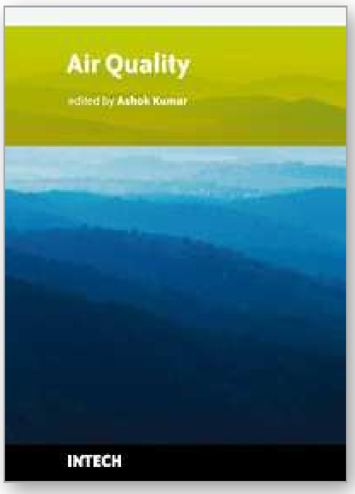

Air Quality
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Air pollution is about five decades or so old field and continues to be a global concern. Therefore, the governments around the world are involved in managing air quality in their countries for the welfare of their citizens. The management of air pollution involves understanding air pollution sources, monitoring of contaminants, modeling air quality, performing laboratory experiments, the use of satellite images for quantifying air quality levels, indoor air pollution, and elimination of contaminants through control. Research activities are being performed on every aspect of air pollution throughout the world, in order to respond to public concerns. The book is grouped in five different sections. Some topics are more detailed than others. The readers should be aware that multi-authored books have difficulty maintaining consistency. A reader will find, however, that each chapter is intellectually stimulating. Our goal was to provide current information and present a reasonable analysis of air quality data compiled by knowledgeable professionals in the field of air pollution.

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