Analysis of the Potential of Controlled Air Movement for Improving Comfort Conditions in an Ambient Chamber

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ABSTRACT: The interaction of the climatic external variables and the buildings properties determines the occupants´ perception of the comfort conditions as well as the energy consumption. Recent studies, based on the adaptive model have demonstrated that behavioural and psychological factors have a direct relationship in people's perception of hyrothermal comfort. This research work presents a field study carried out in an experimental controlled ambient chamber with individuals exposed to typical hot humid conditions. The occupant's perception has been estimated using questionnaires concurrently under a given set of conditions and compared with the case of the influence of air movement at a typical speed. The results have shown that by implementing air movement indoors, the upper comfort zone limit can be extended from 4 to 6 K. This extension represents a significant contribution for reducing energy consumption in buildings, particularly in hot regions and this can lead to other economic and global environmental benefits, aimed at achieving sustainability and people's quality of living.

Keywords: Air movement, climate, comfort, buildings, occupants, ambient chamber

1. INTRODUCTION. ENERGY CONSUMPTION IN BUIDINGS AND THEIR RESPONSE TO CLIMATE

The reduction of energy consumption in buildings whilst keeping suitable thermal comfort conditions must be two important issues to be met in contemporary architecture.

The interaction of man with his surrounding environment has led historically to a wide variety of architectural examples. Empirical solutions of buildings started to emerge, according to the diverse climatic regions. A Regional and traditional architecture developed gradually in several locations. Knowledge of construction methods was transferred from generation to generation and the result of this lengthy historical process generated an architecture that has been characterized by a suitable response to different climatic conditions. Under this approach, many buildings were historically built to satisfy basic human needs to achieve appropriate shelter conditions. Traditional architecture emerged by transferring knowledge and practical experience from generation to generation. The main premise of a traditional building was to offer a dynamic and effective "response" to surrounding factors of climate and other living forces. The "response" of a building to the climatic conditions of a given site was determined from the particular characteristics of the typology and design criteria of the architectural project as well as from the building materials used.

However, nowadays, most modern buildings incorporate architectural styles and materials that ignore the local climatic conditions as well as its culture and traditions. This is the predominant case of many contemporary buildings located mainly in large urban centres. As a result, such buildings are highly dependent on mechanical and electrical systems to control the indoor environment. This situation causes the consumption of large quantities of energy and thus high running costs for both artificial lighting and air-conditioning (AC), associated with problems of occupants' discomfort, both thermal and visual, among others.

Therefore, people who live in air-conditioning buildings have to pay huge energy bills and confront also serious maintenance and economic problems. Furthermore, those people who can not afford to have mechanical ventilation or air-conditioning systems, their building interiors become severely unbearable and their health is seriously affected. The lack of ambient comfort conditions is also a burden for people’s efficiency, productivity and competitiveness. These matters are also crucial for promoting a favorable local economic development.

Certainly, the psycho-physiological function of occupants as well as their efficiency and productivity are strongly related to the comfort conditions available in a building space. The “desirable” hygrothermal comfort conditions within a building interior can be achieved “naturally” by means of the application of bioclimatic design strategies. This is a suitable alternative to air-conditioning as it has a potential for reducing both capital and energy running costs, and for improving indoor hygrothermal comfort conditions of people as well as for supplying air quality in their indoor spaces, whilst providing the basis for preserving the environment and promoting sustainability.

2. THE ROLE AND IMPORTANCE OF HUMAN COMFORT IN BUILDINGS

2.1 Influence of Thermal Comfort in Buildings

The ASHRAE (American Society of Heating, Refrigerating and Air Conditioning Engineers) has been a leading group in the efforts to understand and characterize thermal comfort and its role and importance for occupants and their building spaces.

Thermal comfort can be defined as:

“The condition of mind, which expresses satisfaction with the thermal environment”

(ANSI/ASHRAE 55-2004, ISO 7730, 1993)

This definition emphasizes that the judgment of comfort is a cognitive process involving a great number of inputs influenced by physical, physiological, psychological, and other processes. Therefore, the conscious mind appears to reach a specific judgment about thermal comfort and discomfort from the effects of direct temperature and moisture sensations from the skin, mean radiant temperature, as well as deep body temperatures, and the efforts necessary to regulate body temperatures. Usually, thermal comfort occurs when body temperatures are held within narrow ranges, skin moisture is low, and the physiological effort of regulation is minimized. Under this approach, many of the issues of thermal comfort can be understood by examining a heat balance on an individual, whilst recognizing that a quantitative analysis of heat and mass flow will only provide an incomplete picture of the thermal comfort conditions, and some other objective and subjective parameters need to be considered in the whole equation, to be able to depict a more approximated idea of what thermal comfort really means, particularly related to occupants and their indoor space buildings.

There are environmental and personal parameters that determine human thermal comfort conditions in buildings.

The main environmental components that determine thermal comfort for the human body are: Air temperature, radiant temperature, humidity, and air velocity or air movement

The personal parameters related to human thermal comfort conditions are: clothing and activity.

Furthermore, there are other environmental parameters that can cause local thermal discomfort such as draught, a high vertical temperature difference between head, hand palms, ankles and feet, or too high radiant temperature asymmetry. Other relatively subjective parameters that influence human comfort conditions can include: Psychological and emotional issues, gender, and colour of the skin, among others.

Certainly, human comfort is an elusive and subjective concept. Although thermal comfort can be estimated quantitatively in terms of the interaction of influential variables such as air temperature, radiant temperature, and air velocity. To effectively control these variables, systems for heating and cooling, either by mechanical or by passive natural means, can be applied. However, these actions will inherently be limited by the reality that thermal comfort is affected by a wide variety of other uncontrollable factors, ranging from the clothing and textile fashions of the day to the amount of beverages, such as coffee consumed by the occupants, and social status, among other influential factors.

2.2 Comfort Models. Methods for Setting Thermal Comfort Standards

2.2.1 Traditional vs. adaptive thermal comfort models

Previous and current comfort standards, such as ISO/EN 7730 [1] and ANSI/ASHRAE 55-92 [2], respectively, are based on a more or less static model of human thermal comfort. These models assume that the physiological and psychological response to the thermal environment is basically the same throughout the year. The only issue that changes is clothing and this results in different preferred temperatures for winter and summer. The current ISO/EN 7730 presents a generic model according to Fanger [3], [4]. However, more recently, other considerations have been included in ANSI/ASHRAE 55 [5]. Therefore, in common applications of the comfort requirements two categories are presented, one for winter (the heating season), and one for summer (the cooling season), with parameters as shown in Table 1.

Table 1: Recommended operative temperature levels predicting an acceptable thermal sensation for 90 % of the occupants during light, mainly sedentary activity with other environmental parameters within specified limits according to ISO/EN 7730

Season	Clothing Insulation (CLO)	Activity Level (MET)	Optimum Operative Temperature (“C)	Operative Temp. Range (“C)
Winter	1.0	1.2	22	20-24
Summer	0.5	1.2	24.5	23-26

Therefore, two approaches have been developed for thermal comfort, the first one which is based on the notion that thermal comfort is best described by thermal neutrality brought about by a steady state heat balance (a static model); and the second one, that establishes that thermal comfort conditions can be achieved within a wide range of thermal sensations, provided *adaptive behaviour as well as psychological factors and building occupants expectations are possible (adaptive model)*. The first approach, uses climate study data to support its theory, and is based on the historical work by Fanger [3], whilst the latter uses evidence and extensive field studies from subjects carried out in real buildings, typified by the pioneer work of Humphreys and Nicol [6], among others authors. Under this approach and for finding out what conditions are comfortable it is proposed to conduct surveys in existing buildings. Conditions are left to vary as they will and the subjects to dress and behave as they would normally do. The experimenter then measures the physical characteristics of the environment and relates these to the subjects' feeling of comfort or discomfort, using interactive questionnaires to find the relationships.

A variant of this approach can be experimental work carried out in a climate chamber. Climate chambers can enable the researcher to adjust the environmental conditions with regard to air and radiant temperature, humidity and air velocity, among other factors. Such chambers have been widely used in controlled experiments investigating the effect of physical parameters on comfort.

The subjective sensation of warmth, or thermal comfort, of the subject has traditionally been measured using a seven-point scale. The subject is asked to rate his or her feelings on a descriptive scale such as the ASHRAE or the Bedford scales (Table 2).

Table 2: ASHRAE and Bedford descriptive scales for estimating the subjective sensations of occupants

ASHRAE	Vote	Bedford
Hot	+3	Too much warm
Warm	+2	Too warm
Slightly warm	+1	Comfortably warm
Neutral	0	Comfortable, neither warm nor cool
Slightly cool	-1	Comfortably cool
Cool	-2	Too cool
Cold	-3	Too much cool
The resulting number is called the Comfort Vote		

The underlying assumption of the field survey is that people are able to act as sensors of their surrounding environment. This assumption is based on the findings of psychophysics. As a matter of a fact, the subject is used as a comfort sensor, not of temperature alone but of all the environmental and social variables simultaneously. The results obtained from such surveys are very specific to the conditions measured. This means that any equation resulting from the statistical process must be treated with extreme caution, and any such equation should be judged on physical as well as statistical basis. Nevertheless the field survey is the key to understanding thermal comfort. Any theoretical model which does not explain the results of measurements in the field among real people cannot be trusted to set standards which will have meaning among those same real people.

In order for the field results to have general applicability we have to produce general rules from the individual results.

2.2.2 Problems with the applicability of the Fanger method

Prediction of conditions for optimal comfort, using the Predicted Mean Vote (PMV) or the Percentage of People Dissatisfied (PPD), developed by Fanger, requires knowledge of the clothing insulation and the metabolic rate values. In fact, it is necessary to know what clothing the occupants of the building will be wearing, and what activity they will be engaged in. There is also an additional problem for buildings where a number of activities are taking place in the same space. These considerations render the method very difficult to apply to buildings with no mechanical heating and ventilation. The temperature in a free-running building will almost certainly change continually with time, particularly *if the inhabitants are able to control it to some extent*. So to the difficulty in predicting clothing and metabolic rate is added the problem of applying a steady-state model to an intrinsically variable situation, which is the real condition in existing buildings.

This method is currently used by the heating and ventilation industry internationally to set indoor temperatures and this in turn provokes the over consumption of energy that comes mainly from fossil fuels which causes a significant emission of pollutants to the atmosphere and a sever impact on the environment with adverse global consequences.

2.2.3 The *adaptive mechanism*

The adaptive approach to thermal comfort starts, not from a consideration of the heat exchange between man and the environment, but from the observation that there are a relatively wide range of actions and reactions that buildings occupants carry out in order for them to achieve thermal comfort conditions. If a change occurs in the environment or elsewhere, causing the brain temperature to deviate from the thermal comfort close limits, then an action or reaction is taken by the occupant, aimed at restoring the tolerable limits of the thermal condition.

For example, under a typical overheating condition in summer, the types of actions or reactions which taken by the occupants can be the modification of the thermal environment or the built environment: opening a window, to enhance ventilation through air movement, or by insulating the loft or by implementing bioclimatic passive heating or cooling systems in the building. All these are but few examples of some reactions which occupants can conduct, among hundred of others, which are nothing but *adaptive actions* the occupant have as choices to counteract an unbearable thermal ambient conditions in a given building.

Other factor that plays a very important role to achieve comfort under difficult and harsh climate conditions is *acclimatization*. In fact, local people are more capable to tolerate relatively harsh climate conditions that people from other locations of different climate conditions might find difficult to withstand.

This research work emphasizes in the importance to promote air movement in a typical hot humid conditions and to establish the practical limits of hygrothermal comfort for the occupants.

3. INFLUENCE OF AIR MOVEMENT IN OCCUPANTS´ THERMAL COMFORT. EXPERIMENTAL STUDIES IN A CONTROLLED AMBIENT CHAMBER

3.1. Air movement in buildings

Air movement plays a very important role in buildings to obtain comfortable conditions, particularly in those located in prevailing hot regions. Depending of its physical characteristics, direction, frequency and speed, the air movement can be used effectively inside buildings to achieve hygrothermal comfort. Either by using direct, induced or forced forms of air movement, the building's occupants can receive the benefits to accomplish convective comfort conditions.

This research work presents the experimental work conducted in an ambient comfort chamber.

3.2. The Ambient Comfort Chamber

The Laboratory of Controlled Ambient Conditions (LAC) has been built to investigate the energy efficiency of air conditioning systems and refrigerators, as well as to study and evaluate the hygrothermal comfort conditions of occupants under a wide variety of climatic conditions. This experimental chamber is divided in two sections called: Hot chamber and cold chamber. This later chamber is used to conduct experiments on thermal comfort of occupants. This space permits occupancy of twelve people. The temperatures can be varied from 0 to 50 “C and from 10% to 90% relative humidity (Fig. 1). This experimental chamber was built under current international standards. An automated data acquisition system was integrated in the LAC, to control and register the information obtained in the two experimental chambers (Fig. 2).

Figure 1: Laboratory of Controlled Ambient Conditions. Cold chamber

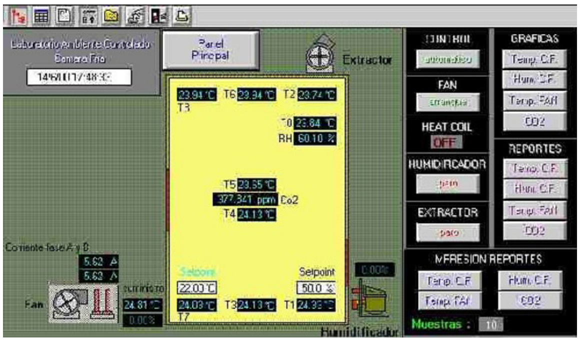

Figure 2: Data acquisition system of the Laboratory of Controlled Ambient Conditions, showing monitoring parameters

Previous studies have shown the usefulness and applicability of this experimental space [7] and [8].

4. EXPERIMENTAL WORK IN THE AMBIENT COMFORT CHAMBER

The main objective of this research work was to investigate the perception of occupants within the chamber under prevailing conditions in a typical hot humid location, without the presence of air movement in the first part, and with the presence of air movement in the second part of the experiment. The occupant's comfort perception was estimated using questionnaires concurrently with the monitoring process under a given set of conditions without any air movement in the first part of the experiments, and compared in the second part, with the case of the influence of air movement at a given speed (Fig. 3).

During the experimental study, thirty six young adults, twenty seven men and nine women participated in four sessions during one week, with nine occupants at a time. The average age of the occupants was 28 years old; average weight: 74 kgs; metabolism: 70 W/m2, equivalent to 1.2 MET, according to ISO 7730, for office space buildings: clothing: 0.155 m2K/W, that is a mean value of 1.0 CLO. Evaluation period was 60 minutes, with occupants conducting typical office activities.

Figure 3: Laboratory of Controlled Ambient Conditions Calibration of fans used in the experiment

Figure 4: Experiment running with occupants in the Laboratory of Controlled Ambient Conditions

Each session consisted of four experimental stages at 15 minutes intervals each. During the first stage, initial temperature was set at 15”C. with relative humidity 80%, no fans were activated. This stage was set for 15 minutes. The conditions of the following stage were set for the next 15 minutes with dry bulb temperature of 31”C and 80% relative humidity, no fans were activated. The third stage: Same conditions as the second stage, but with three fans separated symmetrically at the back of the space and activated at 1 m/sec, measured at 1.5 mt separated from the centre of the central fan axis (Table 3).

These conditions remained until the end of the session. Concurrently with the experiments, interviews and questionnaires with the occupants, based on the Bedford scale, were conducted to establish their sensations relative to the temperature and humidity conditions and referred to their perception of the thermal conditions inside the space.

Table 3: Experimental Conditions in each stage

EXPERIMENTAL CONDITIONS IN THE CHAMBER				
STAGE	1ST STAGE	2ND STAGE	3RD STAGE	4TH STAGE
CONDITION	15 MIN	30 MIN	45 MIN	60 MIN
TEMPERATURE ("C)	15 "C	31 "C	31 "C	15 "C
RELATIVE HUMIDITY (%)	80%	80%	80%	80%
AIR MOVEMENT (M/S)	0 M/S	0 M/S	1 M/S	1 M/S

4.1. Analysis of results and interpretation

Results have shown that when temperature was gradually increased from the initial value of 15”C, until reaching 31” C, at 30 minutes, the occupants vote preferences were between the ranges of +1 and +2 of the Bedford scale and this perception remained until the stage corresponding to 45 minutes. Just after this point, three fans were activated at 1 m/s speed. The occupants located in the first half of the space closer to the fans, indicated that their preferences were neutral or comfortable conditions, whereas for those located in the second half of the space farther from the fans, their vote was +1, corresponding to comfortably warm conditions (Fig. 5).

This condition can be equivalent in a real space to a behavioural action to allow air movement through the space by means of opening windows or other natural mechanism for the occupants to *naturally adapt* to the existing harsh climate conditions.

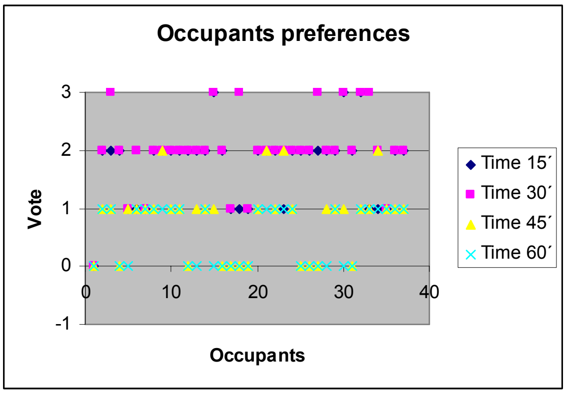

Figure 5: Occupants preferences in the experimental work

Results showed that by implementing an air movement speed of 1 m/s, the occupants preferences can be predominantly within the comfort zone and if taking into account their typical adaptive behavior as well their expectations, as well as the concept of acclimatization, it is possible to extend the upper limit of the comfort zone. In fact, previous studies have demonstrated that this boundary can be extended to 29”C [7] and [8], which roughly represents a comfort zone extension of 4K, beyond those predicted by ISO 7730 and ASHRAE RP-884. As a result of this extension of the comfort zone, energy consumption can be reduced whilst diminishing the emission of pollutants to the atmosphere and the negative impact on the natural environment. It is worth mentioning that the energy required for moving an air mass and to promote natural ventilation is much lower than that needed to extract energy to that air mass to reduce its temperature, and this in turn represents both energy saving and environmental benefits.

5. ECONOMICAL BENEFITS

Saving energy in buildings is directly related to important economical benefits, and this is more significant in buildings located in hot climates. For example, according to the current international standards, compared with a maximum upper comfort zone limit of 25” C as a design temperature for most commercial buildings located in hot regions of Mexico, the daily consumption is equivalent to 1.8 kWh/m^2, during an average of 300 days of operation/year, resulting in an annual consumption of 540 kWh/m^2. By applying the results of this research work, extending the limits of the upper comfort zone from 25”C to 29”C, energy savings can be 40%, resulting in an energy consumption value of 324 kWh/m^2, and 216 kWh/m^2, if the extension of the upper limit of the comfort zone is 31”C. Taking into account these figures, a commercial building of about 1000 m^2 of floor plant area can have annual energy saving of 324,000 kWh, and of 216,000 kWh, if the upper limit of the comfort zone can be extended to 29”C and 31”C, respectively.

6. ENVIRONMENTAL BENEFITS

Reducing the energy consumption, that comes mainly from fossil fuels, prevents the emission of pollutants, that is, greenhouse gasses to the atmosphere. Therefore, for every kilowatt hour the final user saves from electricity generated by a typical thermal electric power plant, it can be prevented the emission of the following:

- 681 grams of CO2
- 5.8 grams of SO2
- 2.5 grams of NOx
- 0.35 grams of dust and suspended particles, and
- 3.6 m^3 of water

These figures reveal that for the same building of 1000 m^2 floor area, and if the upper limit of the comfort zone is extended 4K, every year can be prevented the emission of the following:

- 147.096 Tons of CO_2
- 1.2528 Tons of SO_2
- 0.540 Tons of NOx
- 0.756 Tons of dust and suspended particles, and
- The consumption of 777,600 m^3 of water

7. CONCLUSIONS

The results of this research work have demonstrated that air movement inside the architectural spaces is a very important factor to promote thermal comfort conditions for occupants, particularly for those buildings located in hot climates. Other recent studies have also obtained similar conclusions [9].

It is recommended that the results, knowledge and experiences obtained from this research work can be widely published at massive level so that they achieve a positive and multiple cascade effect, which in turn can promote important economic and environmental benefits, whilst improving the quality of living of building occupants at global levels.

REFERENCES

[1] ISO 7730,1993.“Moderate Thermal Environments. Determination of the PMV and PPD indices and specification of the conditions for thermal comfort”, International Standardization Organization.
2] ANSI/ASHRAE 55-1992. “Thermal Environmental Conditions for Human Occupancy”. American National Standards Institute, and American Society of Heating, Refrigerating and Air-conditioning Engineers, Atlanta, GA.
[3] FANGER, P.O. (1970).Thermal Comfort. McGraw-Hill, New York.
[4] Fanger, P.O. 1972. “Thermal comfort; analysis and applications in environmental engineering”, McGraw-Hill, New York.
[5] ANSI/ASHRAE 55-2004. “Thermal Environmental Conditions for Human Occupancy”. American National Standards Institute, and American Society of Heating, Refrigerating and Air-conditioning Engineers, Atlanta, GA., 2005.
[6]Humphreys, M., Nicol, F. (1996). Conflicting Criteria for Thermal Sensation with the Fanger PMV Equation. CISBE&ASHRAE Joint National Conference, London.
[7] García-Chávez, J. R. et al. Análisis Experimental del Umbral de las Condiciones de Confort Térmico En Ocupantes. Proceedings. ENCAC-COTEDI, Curitiba, Brasil, 2003.
[8] García-Chávez, J. R. et al. Determinación del Umbral de las Condiciones de Confort Higrotérmico y su Relación con el Movimiento del Aire. Proceedings, COTEDI 2005, Mexico City. Mexico.
[9] Givoni, B. et al. Comfort formula for Thailand. ASES 2004. Colorado. US.