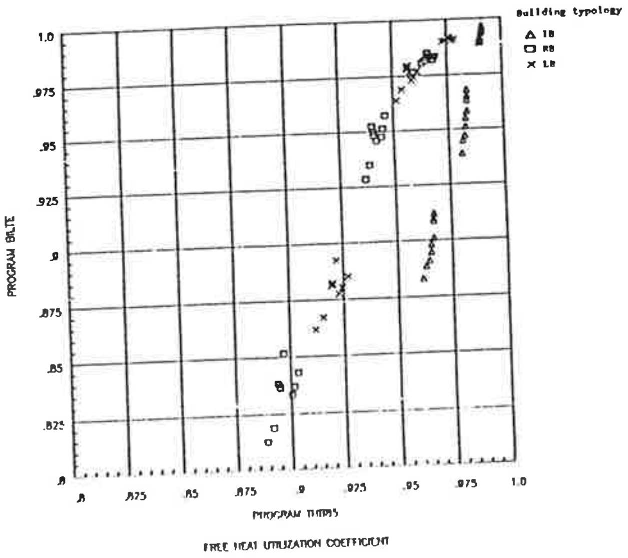

Fig. 3. Range of BILTE and THB85 free heat utilization coefficient

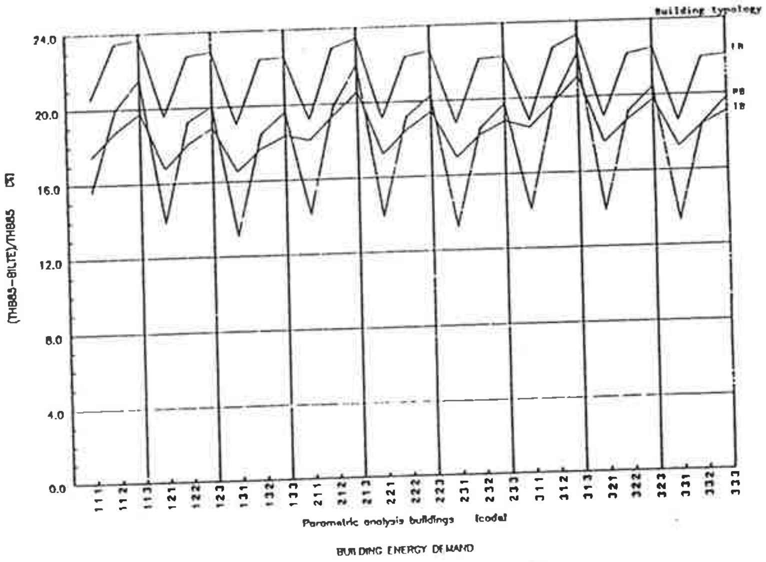

Fig. 4. Energy demand - Difference between BILTE and THB85.

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ENVIRONMENTAL QUALITY PROFILES: A TOOL FOR AN EFFECTIVE USE OF ENERGY IN CONDITIONING SYSTEMS.

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Introduction

The evaluation of the system which combines an environment and its conditioning plant must be accomplished with regard not only to its efficiency in using energy but also to its effectiveness in realizing whole-ambient thermal comfort conditions and adequate indoor air contaminants control, being effectiveness a system goal itself but having it a role on energy consumption as well (1).

The design and construction of a conditioning system assume as a direct purpose creating an optimum comfort level within a "reference zone" of the environment. The conditions really obtained within the occupied zone of the conditioned volume are frequently affected by some level of non-uniformity, mostly depending on building and thermal plant features and on outside climate too.

Such a non-uniformity is usually made up of (2,3,4,5):

- space gradients and time dependent fluctuations of main thermal ambient variables that cause whole-body thermal comfort: air temperature, mean velocity and humidity and mean radiant temperature;
- localized thermal exchanges of the body that do not have a sensible effect on the whole-body thermal balance but that can heavily affect the comfort level of subjects;
- poor air quality in some zones of (or in the whole) environment due to ventilation air lack or wrong distribution.

Ambient non-uniformity in this wide meaning is a factor of drastic reduction of the comfort level in a surprisingly high number of work environments. When a system shows design or construction faults or a reduced performance level and whenever a check of system suitability to generally grant high levels of thermal comfort is needed, an ambient-uniformity evaluation criteria may be required.

This paper deals with an effectiveness evaluation method which allows a rather complete quality estimate of a system and gives valuable help in its analysis, provided some fitting of the measurement organisation to the specific system features and by assuming that in the reference zone thermal comfort requirements are met. More in general it may be joined to a global comfort criteria (!PMV!<0.5 for instance) to give a complete view of system effectiveness also when system faults also affect the reference zone.

The ambient quality profile construction methodology here presented is suitable for moderate environments and has the following two features:

- it holds main non-uniformity factors in due consideration;
- it brings their impact on comfort level into appropriate and measurable figures of merit.

Thus it can be helpful (and it is, on our experience of use) in giving easier understanding of the reasons of system-users level of satisfaction/unsatisfaction and consequently valuable insight in building and plant dependent factors of discomfort.

Method description

The derivation of an environmental quality profile requires first of all considering space gradients and time dependent fluctuations of the main whole-body thermal balance variables.

However, as to the environment evaluation, the corresponding values can be usefully replaced by some comprehensive thermal comfort index (as PMV and PPD indices) whose use allows to become aware of the effect of the quoted variables gradients and fluctuations on comfort levels.

Then local thermal exchange phenomena must be considered and related measurable parameters evaluated, namely:

- air temperature difference between head and ankles level;
- plane radiant temperature difference between opposite directions;
- local air velocity and temperature at the neck level;
- floor temperature.

Finally a comprehensive evaluation of the environment must take into account the required and actual rate of air change within the same, with regard to ambient total ventilation air flow and to environmental zones local supply rate.

The evaluation criteria here presented is a modification and completion of the UCRES profile method by Dessagne (5). It takes into account a series of eight variables strictly related to both the ambient quality and the sensation of the inhabitants.

The variables are measured or calculated in a number "n" of points of a three dimensions network extended within the occupied zone to appropriately cover the requirements of a discomfort-factors hunting methodology (see also the following section on measurements). The set of "n" values of each of the eight discomfort variables is then distributed into three classes: the comfort class "0" and the increasing discomfort level classes "1" and "2". The values of the three class standard frequencies can then be evaluated, namely by use of the following equation

for the discomfort variable "i" and for the class "0":

$$f_{i0} = \frac{F_{i0}}{F_{i0} + F_{i1} + F_{i2}} \qquad (1)$$

where:

$F_{i0} + F_{i1} + F_{i2} = n$;

The number of values of the variable "i" put into the class "0", "1" and "2" are respectively expressed by F_{i0}, F_{i1}, F_{i2}

The environmental index Ni for the discomfort variable "i" is a figure of merit referred to a value scale lying from 0 to 5 in order of increasing predictable discomfort level. It can be calculated by use of the equation (5):

$$N_i = 1.8 \ln (1 + 3 f_{i1} + 15 f_{i2}) \qquad (2)$$

The function $N_i = g(f_{i1}, f_{i2})$ has the following main features:

- $N_i = 0$ if $f_{i1} = f_{i2} = 0$ (all the values fall in class "0");
- $N_i = 5$ if $f_{i1} = 0$ and $f_{i2} = 1$ (all the values in class "2");
- one point in class "2" equals five points in class "1".

Evaluation criteria

The values obtained for the eight indices Ni strictly depend not only on the values of the discomfort variables within the environment but also on the limits of the three discomfort classes.

The last ones have been generally obtained by examination of the current literature on main thermal discomfort causing factors within moderate environments (see references 1 to 8). Some calculations and some choices have been made to pass from a variable to another one, to make the right space for the class "1" lying between a class of comfort and another one of clear discomfort, sometimes to better fit our judgement based on a moderate system evaluation experience.

Therefore the total number and kind of criteria, the discomfort variables chosen and the limiting values of the classes should be retained as tentatively proposed and requiring some more field checking, being subject to changement on the basis of new laboratory and field studies.

The following discomfort variables have been chosen with the limiting values of Table 1.

Global comfort **level** gradients: the criteria variable is the PPD value in each point of the environment calculated with reference to conditions where the ambient mean PMV equals zero, following (2) and keeping constant the levels of metabolic rate and thermal resistance of clothing.

Global comfort **level** fluctuations: the criteria variable DF is the daily maximum absolute value of the ratio between the peak to peak amplitude of the PMV fluctuations within a reference time period and the same time period (a reference time of 1 hr is suggested).

Vertical air temperature gradient: the criteria variable is the difference of air temperature DTAV between the head and the ankle levels.

Index	Variable	Class 0	Class 1	Class 2
N1	PPD (%)	5 TO 6	6 TO 10	> 10
N2	DF (1/hr)	< 0.15	0.15 TO 0.30	> 0.30
N3	DTAV (C)	0 TO 3	3 TO 5	> 5
N4	DTRV (C)	0 TO 8	8 TO 12	> 12
N5	DTRO (C)	0 TO 4	4 TO 6	> 6
N6	TFL (C)	17 TO 26	17 TO 15 26 TO 28	< 15 > 28
N7	PD (%)	< 5	5 TO 10	> 10
N8	QAIR	> QR	QR TO QM	< QM

* Values coinciding with class limits are assigned to the lower class.

Table 1. Limits of the discomfort classes (*).

Asymmetric radiation field with reference to vertical surfaces: the criteria variable is the maximum vertical plane radiant temperature asymmetry DTRV at an height from ground corresponding to the centre of the body.

Asymmetric radiation field with reference to horizontal surfaces: the criteria variable is the horizontal plane radiant temperature asymmetry DTRO at an height from ground corresponding to the centre of the body.

Floor temperature: the criteria variable is the floor temperature TFL

Air draughts: the criteria variable is the predictable percentage of dissatisfied because of air draughts evaluated by use of the equation:

$$PD = 13800 \left(\left(\frac{Va - 0.04}{ta - 13.7} + 0.0293 \right)^{2} - 0.000857 \right) \qquad (4)$$

where:

Va and ta are respectively the mean velocity and temperature of air at the height of the neck.

Air quality: the ventilation air flow rate per person QAIR is assumed as the criteria variable and it is compared with minimum required QM and recommended QR air flow rates.

Profile construction

The use of the methodology here presented requires first to define the environment to be evaluated. An operative definition could be: a space made up of one or more zones but whose zones are not separated by physical barriers or they are, but, in this case a moderate to high movement of persons usually takes place among the various rooms of the environment.

The required measurements can be organized and performed according to national and international standards.

When a complete characterisation of the environment is needed, measurements should be performed within a network of points covering all the occupied space and repeated following the outside conditions during the day and the year thus giving rise to a considerable work for the collection of data and their processing to obtain a representative set of profiles for the environment.

Many situations do not require such an analysis, being the purpose more to understand the inhabitants-complaints causing factors than give a complete description of the thermal environment. Therefore the methodology should be used with some fitting to the specific needs, and as a reference scheme of analysis, thus getting a reasonable amount of required measurement and processing work.

The number and types of measurements to be taken should be established mainly by using professional judgement, but a "strategy of reduction" is suggested to be performed before performing measurements. To this purpose the following points should be emphasized.

It is expedient to collect the subjective inhabitants opinions on the environment before carrying out the objective analysis of it (9). This should be accomplished by use of some interviews based on a reference questionnaire whose main goals should include:
- to assess the claims/discomfort really attributable to the conditioning system (rather than to work postures, work organisation, etc.);
- to make easier ascribing some specific discomfort to specific situations and zones and to measurable variables;

- to keep separate thermal sensation (cold/warm) from evaluation (pleasant/unpleasant) and whole-body sensation from localized one.

The need to get such a specific kind of information often requires reducing the number of subjects asked for, but going deep into their opinions.

It is often useful to examine the environment to the purpose of chosing and selecting the variables to be measured and the measurement conditions with regard to space density and time frequency of measurement taking. Moreover it is always useful to verify if a sample analysis can be performed with regard to large homogeneous zones or series of rooms that are alike.

The collection of data should be performed in two phases:

- the first one of general checking and observation to mainly assess the level of environmental discomfort objectively due to the conditioning system; this will also allow to find locations and conditions to perform the following phase;
- the second one, a deeper technical analysis phase, mostly directed towards the collection of data with the goal to strictly relate them to building, plant and control system features and to outdoor climate.

The automatic collection and processing of measurement data, namely by use of a portable personal computer, strongly reduce and make easier the required work; the use of simple computerized models of the thermal environment (10) has often reduced the number of measurements required to fully describe its behaviour.

Application results

The proposed profiles construction method has been used to evaluate some conditioned and heated environments. Some representative results are presented in the following sections.

Case A: open-space office

A wide (2000 sqm) conditioned office usually having a high solar thermal load and thus often requiring ambient cooling, has been evaluated.

In fig. 1a one of the most representative ambient profiles for the cooling season is reported (shaded bars) together with the corresponding users complaints profile (white bars) obtained on the basis of some interviews to the inhabitants. The profiles do not allow any quantitative mutual comparison due to the arbitrary scales ratio but they show good agreement, giving the same relative importance to the different profile indices and emphasizing that users discomfort should first be due to draughts and low ventilation rates and then to some difficulty of the system to keep uniform and constant environmental conditions.

A thorough examination of locations and variables giving the highest contribution to non-uniformity indices 7 and 8 emphasized the role of the air-distribution system features on the existence of draughts zones and (distinct) ventilation-air lack zones and suggested limit values of air temperature and air flow from diffusers to grant inhabitants comfort within the particular environment. Similar examination of the indices 1 and 2 showed that gradients and fluctuations of thermohygrometrical parameters were still more due to air-distribution system faults than to poor conditioning units performance.

According to this analysis and by use of a simplified computer model of the environment, modifications of the system to improve the environmental conditions could be proposed.

Case B: offices, computer and assembly rooms.

A set of offices, computer and assembly rooms (about 200 sqm total surface) provided with natural convection heating appliances has been evaluated during the winter season. The environment was almost exclusively ventilated by natural means and the rate of air change was not estimated, thus the measurement profiles obtained do not have any bar for the index n. 8.

A representative profile (shaded bars) is reported in fig. 1b together with the corresponding interview-obtained profile. As in the preceding case they show good agreement about indices 1, 2 and 7, and they indicate that main causes of discomfort could be: sensible gradients and fluctuations of thermal conditions and air-draughts. Disagreement is observed, on the contrary, about the index 4 referring to vertical plane radiant temperature asymmetry, perhaps indicating that the limits chosen for the discomfort class "0" could perhaps be not fit to a high level of thermal comfort.

A thorough analysis by use of the profiles construction methodology and results showed that the environmental level of discomfort could be ascribed to poor air temperature and air change control and to excessive heating appliances temperatures.

Conclusions

The method proposed to evaluate human comfort performances of heating and conditioning systems was tested with reference to moderate environments. It shows to be helpful:

- in assessing users complaints really attributable to the conditioning system;
- in helping the understanding of the technical reasons of system-user level of satisfaction/unsatisfaction;
- in correlating this level to conditioning plant and building features and in giving valuable directions for the required technical measures.

However some more extensive checking is required both for the method as a whole and with reference to someone of the profile indices.