Assessing Environmental Comfort

Towards a systemic *quantitative* and *qualitative* approach

A. POTVIN*, A. L.HEUREUX, B.SARICOGLU, K.ZARNOVICAN

GRAP (Groupe de recherche en ambiances physiques), École d'architecture
Université Laval, (Québec), Canada, G1K7P4
tel.: (418) 656 2131 ext: 4814, fax: (418) 656 2785
andre.potvin@arc.ulaval.ca <www.grap.arc.ulaval.ca>

Abstract

This paper presents the preliminary results of the first stage of a research grant from SSHRCC (Social Sciences and Humanities Research Council of Canada) on the control of physical ambiences and the nature of internal-external transactions in a Nordic climate[1]. The main objective of this research is to investigate the impact of environmental step-changes on the sensation of comfort in order to diminish the thermal gradient between indoor and outdoor in Nordic climate without sacrificing comfort. This, in parallel with the recent adaptive model for thermal comfort, could serve reducing further the energy consumption in buildings. The first stage of the research consisted in the development of a combined quantitative and qualitative method for the assessment of global environmental comfort in transient conditions based on previous work by the author. The quantitative measurement of ambient conditions is assessed by a portable array whilst the qualitative aspects of comfort are assessed via an extensive WEB based questionnaire. The theoretical background behind that research and the development of the portable array and electronic questionnaires are the main subject of this paper.

Conference topic : thermal comfort

Keywords : architecture, thermal comfort, environmental control, field study, questionnaire, internet

THEORETICAL BACKGROUND – THE ADAPTIVE MODEL AND SYSTEMIC NATURE OF COMFORT

Environmental perception

The properties of our environment are only perceivable by our senses. Throughout history, there has not always been agreement on the number of senses and their relative importance. The five primary senses of sight, hearing, taste, smell and touch originate from Aristotle who wanted to relate each of them with the natural elements. Since Plato, sight has been the most venerated sense in the Western world but anthropology made the evidence that different cultures possess different ways of making sense of their environment [2]. For the Tzotzil of Mexico, heat constituted the basic force of the cosmos. Their world was therefore ordered according to temperature; their major task being to maintain themselves and their immediate environment at a proper temperature level. For such society, the sense of touch should have been very important. By focusing mainly on visual stimuli, Western civilisation remains ignorant of the important function and symbolism of the other senses.

Gibson [3] was the first to propose that the five senses overlap one another and are not exclusive so that the study of a particular comfort conditions can not exclude the incidence of the four others. Moreover, to express their systemic nature, he redefines the list of the senses as the visual system, the auditory system, the taste-smell system, the basic-orienting system and the haptic system. They work only when stimulated and the environment, natural or artificial, is the source of all stimulation.

The experience of space in architecture is dynamic with periodic or constant movement between areas of a building or between inside and outside. By moving to an adjacent space, the occupant becomes aware of the dominance of a new environment. This phenomenon of transition may be developed to provide a sense of continuity or a sense of contrast in the environmental stimuli that are the degree of brightness, temperature, sound and air flow. Figure 1 illustrates that when moving from a space where the environmental condition is inadequate to a space where it is greater in intensity, a sensation of comfort is felt. If in successive steps or in a steep change the stimuli increase too much, the positive sensation wanes and becomes negative [4]. An occupant is thus momentarily conscious of a positive change in his environmental conditions, followed by a neutral step where the comfort range is attained and then a negative change occurs.

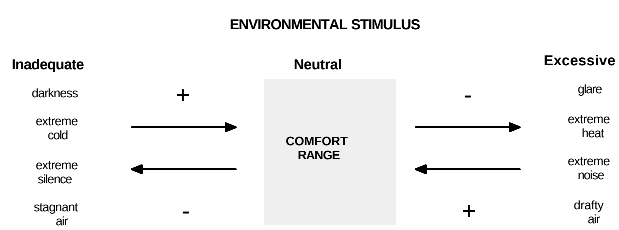

Figure 1 Environmental transitions (from Flynn et al. 1992, p.110)

Two users will therefore judge the conditions in a space differently if they experience the sequence in opposite directions. The subjective judgements of environmental conditions are always affected by the preceding environmental condition or reference level. When the environmental conditions change very slowly, below the threshold of sensation, the change may be subliminal. The body mechanisms tend to adapt to accommodate each successive change, making the subjective effect almost imperceptible. This phenomenon of adaptation occurs both in increasing and decreasing of a stimulus. Thus, when environmental continuity is required, changes in the intensity of different environmental stimuli should be subliminal to avoid the sensation of discomfort.

Gibson recognised that all five senses are working together in actively seeking information but, he postulated that the basic-orienting and haptic systems are particularly relevant to the perception of the third dimension since they encompass the entire body [5]. By placing the entire body at the centre of the perceptual experience, he affirms that no other sense deals as directly with space as the haptic-orienting system, engaging simultaneously feelings of temperature and movement. Thus, the movement between spaces of different thermal conditions must have a profound effect on our perception and appreciation of the environment.

Recent researches on thermal comfort have brought two models: the static and the adaptive one acknowledging the dynamic nature of environmental perception. Whilst the static model has been universally accepted for the development of environmental norms in buildings such as ASHRAE 55-92, the adaptive hypothesis that contextual factors and past thermal history modify building occupants' thermal expectations and preferences is much more difficult to develop. DeDear [6] considered the thermal adaptation on the basis of three distinct but interrelated processes by the occupants:

-physiological reaction by spontaneous thermoregulation;
-behavioural reaction by clothing, opening, shading adjustments; and
-psychological reaction by expectation of the coming environmental conditions.

Expectation is particularly important when occupants are expected to move from one given environment with a specific set of environmental conditions to another. That is particularly the case in free-running buildings since the environmental conditions of passive zones are expected to vary more widely than in mechanically controlled buildings. DeDear concluded that occupants in naturally ventilated buildings were tolerant of a significantly wider ranges of temperature, explained by a combination of both behavioural adjustment and psychological adaptation. But to what extent does the movement between zones of different environmental conditions will affect the global sensation of comfort? That is the main objective of the present research project and especially under Nordic climatic conditions.

Thermal transients

Few researchers have studied the dynamic impact of environmental variation on the sensation of comfort. Knudsen and Fanger [7] investigated the impact of temperature step-changes on thermal comfort in a climate chamber. This study demonstrated that there is a greater sensitivity to cold steps than to warm steps. Moreover, it also highlighted that the speed of adaptation to a new environment depends on whether the step change is directed away or towards neutral conditions as suggested by the acceptability vote. For the two step-changes away from neutral, the acceptability decreases to below the steady-state level, and at least 20 minutes is needed before the votes reach the steady-state level. This is in contrast to the step-changes towards neutral, where the steady-state level of acceptability is reached within five minutes.

In both cases, the immediacy of the thermal sensation response to temperature step-changes supported the hypothesis that it is the rate of change of the skin temperature rather than the actual skin temperature that is responsible for thermal sensation during fast thermal transients in the environment. Knudsen concludes that behavioural thermoregulation may be more important for survival in cold environments than in warm environments. High sensitivity to cold steps is probably a warning meant to trigger an early reaction of the human behaviour to prevent a cooling, which in the long run, might be unpleasant or even hazardous to health. Knudsen's conclusions suggest that it might be more important to prevent important cold steps when moving from one space to another than warm steps, since the latter is more likely to trigger a behavioural response than the former. Extreme behavioural response such as increasing the metabolic rate by faster movement may have serious effects on the perception of space, social behaviour, and the overall environmental satisfaction.

So the research was set to investigate the impact of global environmental step changes on the sensation of comfort. The challenge being to devise a mean of measuring quantitatively the spatial and environmental transition between interior and exterior, as well as the qualitative, or subjective sensation on global comfort namely thermal, visual, acoustical, and olfactory comfort.

THE SYSTEMIC APPROACH

Quantitative approach-The portable array

Baker and Standeven [8] have first devised a custom portable array for the assessment of thermal comfort. Potvin [9] devised a similar array named PAMPA-1 (Portable Array for the Measurement of Physical Ambiences), although made of an assemblage of precalibrated sensors, for the environmental study of urban transitional spaces. The addition of a light sensor allowed for the comparison of thermal and visual comfort in transient conditions. Potvin [10] later devised another portable array, the PAMPA-2, for the study of Nordic urban microclimates.

The PAMPA-3 (Figures 3 and 4) was therefore developed according to experience gained from these previous versions. This version of the portable array innovates in that it is no longer limited to the measurements of the determinants of thermal comfort alone (ambient and radiant temperatures, relative humidity, and air movement) but also incorporates light, noise and VOC sensors that allow for a more systemic assessment of environmental comfort taking into account all senses. As with previous versions, the PAMPA3 is worn on the head of the user and is therefore non-obstructive for the user and non-invasive for the other occupants of the space. A portable case worn at waist level contains the microcontroller, sensors' circuitry, memory and battery. It is responsible the power supply to the sensors, the data collection and saving. The headset is connected to the case by a flat 16-wire cable. Both the micrologger case and headset mounts have been custom designed to be minimal in size and weight.

The PAMPA-3 senses, analyses and records the following eight environmental comfort parameters:

1. ambient temperature (-20 to 50^{o} C)
2. left radiant temperature (-20 to 50^{o} C)
3. right radiant temperature (-20 to 50^{o} C)
4. relative humidity (0 to 100%)
5. ambient lighting (0 to 10000 Lux)
6. ambient acoustic intensity (0 to 80 dB)
7. air movement (0 to 1,5 m/s)
8. air pollutants –VOC (0 to 100%)

The recording of the eight parameters takes place at ten second intervals and the memory capacity of the array reaches 12 hours before battery recharging. A combined cable allows the simultaneous connection to the PC station for downloading of the data and recharging of the battery (Figure 2).

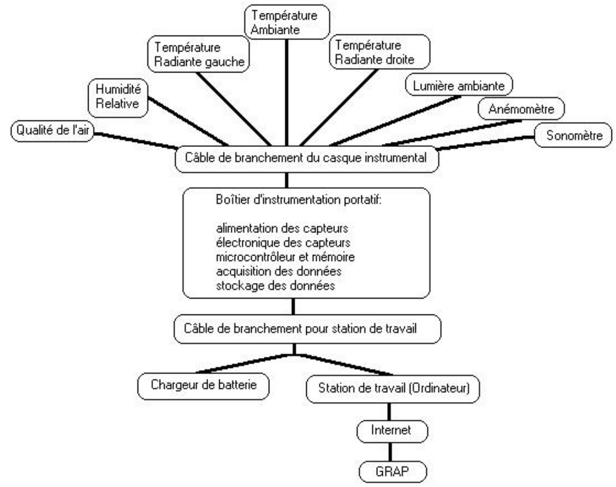

Figure 2: Concept mapping of the PAMPA-3.

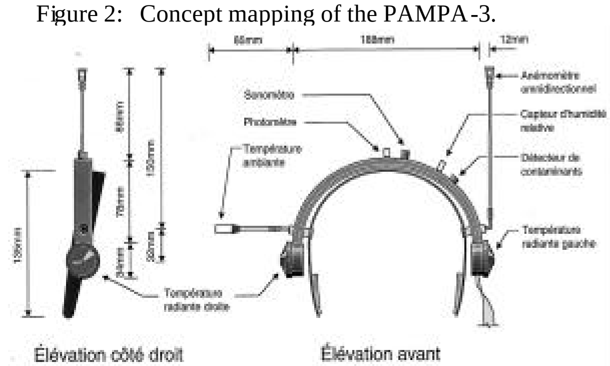

Figure 3: Side and front views of the PAMPA-3's headset with references to the sensors.

The sensors

Sensors have been chosen for their availability and minimal cost.

Temperatures (both ambient and radiant) are measured with three precalibrated LM335 cells from National Semiconductor. The ambient temperature sensor has been distanced from the head with a 100mm long peg in order to avoid the body plume laminar layer.

The radiant temperature sensors have been housed in two airtight hemispheric domes made of light aluminium. A light layer of enamel flat black paint increase its absorption and therefore makes it reacts much like a black body. The two opposite location of the sensors on both sides of the array allows for the assessment of asymmetrical discomfort.

A Honeywell precalibrated HIH-3605-B sensor measures relative humidity.

Ambient light is measured with a precalibrated PN335 sensor form Panasonic, which electric signal curve has been correlated with artificial and natural lighting.

Acoustic level is measured with an omnidirectional P9959 Panasonic microphone. This was the only economical mean of measuring noise levels but the dB absolute unit is of little use in acoustical comfort. Test is under way to try to convert dB units in dB(A) to account for the sensibility of the human ear.

Air quality is measured with a THS-2602 VOC sensor from Figaro Sensors. Although CO_2 would have been a more widely accepted indicator of air quality, it was concluded that VOC would better express olfactory comfort which is the most common way of assessing air quality by a lay person.

Air movement is measured using a custom setting of two 235-1058 thermistors from Thermometrics. The 0-1,5m/s range was agreed after several tests that showed that acceptable accuracy was not possible at air speeds higher than 1,5m/s.

Data treatment

The eight sensors signals are treated via analogical circuitry designed to make the optimal use of the 5 Volts range available for the analogical-numerical conversion.

Microcontroller

A MicroCore 2010 from Zworld contains the controller, the program and log memories as well as a Real Time Clock in C language. User's controls have been designed to be minimal to avoid false recording.

Figure 4: PAMPA-3's headset as worn.

Figure 5 illustrates a typical logging of the eight environmental parameters with the PAMPA-3. This particular log highlights the variability of radiant temperatures (curved lines) when subjected to radiation and their time of response.

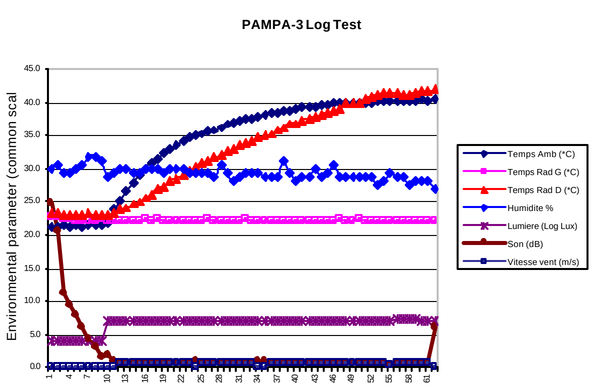

Figure 5: Typical 10 second logging graph of environmental parameter as recorded by the PAMPA-3.

Qualitative approach-Questionnaires to space users

The questionnaire contains five sub-questionnaires namely the personal, morning, hourly, evening and weekly questionnaires. The questionnaires allow for the assessment of the user's satisfaction in regard to hygrothermal, visual, acoustic, and olfactory physical ambiences.

Personal questionnaire allows for the identification of individual's physiological characteristics, the overall seasonal appreciation of one's work place, the available means to adapt, and most importantly, the daily number of interior-exterior movements.

Morning questionnaire allows for the qualification of the participant's residential environment (including the use of air-conditioning unit) as well as the environmental conditions during the participant's journey to the workplace.

Hourly questionnaires are the most important in the assessment of global environmental satisfaction. They are based on the PMV –3 to +3 vote. They identify the user's satisfaction as well as all the means whether physiological or behavioural to reach environmental comfort, if the case arises.

Evening and weekly questionnaires draw daily and weekly summaries of the user's environmental satisfaction and allows for the crosschecking of the robustness of the user's vote.

DATA COLLECTION AND RETRIEVAL

Typical logging

A typical log in would start in the morning at residence place and would last all day long until the return to the participant's residence. The participant is asked to ware the PAMPA during all his daily activities to gather a global environmental history.

Physical ambient conditions are logged at 15 seconds interval for a daily maximum log time of 12 hours. They can then be transferred to the project main server via the GRAP web site <www.grap.arc.ulaval.ca>. Completed questionnaires are transferred instantly to the project server and then classified via a FILEMAKER application. (see Figure 6). Further analysis takes place within an EXCEL spreadsheet.

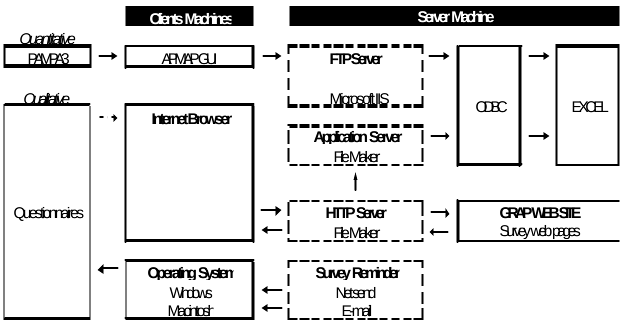

Figure 6: Concept mapping showing the numerical flow of data from quantitative and qualitative surveys from and fro participants' PCs and the GRAP Server.

DATA ANALYSIS

Both quantitative and qualitative data can be remotely accessed via the WEB and compared using FILEMAKER according to the Julian day of the survey, the time of the survey, the identification of the participant, the type of questionnaire and/or the specific answer to a question. Typically, hourly subjective vote to the measured thermal conditions of the space will be compared to the corresponding PMV (Predicted Mean Vote) for the given set of thermal ambient conditions. The visual, acoustic, and olfactory votes will serve to discuss the deviation from normal, if need be.

FURTHER RESEARCH

A global comfort index

The proposed systemic approach to the assessment of comfort will provide numerous data but these will only make sense with a robust multicriteria mean of analysis that would be able to ponder the respective weight of each parameter. Ultimately, the development of a global comfort index integrating the four dimensions of comfort, namely thermal, visual, acoustical and olfactory would help promote free-running buildings and the notion of high environmental quality in architecture.

Surveys

The next part of this research is to proceed to extensive surveys using the combined approach presented in this paper. A pilot study will be held during the spring of 2002 at Laval University School of Architecture. Whilst a study of the environment of traditional urban Vietnamese housing in Hanoi is scheduled to take place next summer; the aim of the latter being to compare subjective vote to the predicted mean vote and to discuss further the phenomenon of acclimatisation in free-running (open to the outside) buildings. This study is motivated by the recent move to the air-conditioning of the housing park in Vietnam and the resulting negative impact on natural resources, urban pollution, heat-island effect, CO_2 emission and ultimately global warming.

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