Environmental Satisfaction and Adaptability:

The Physical Ambience Rose as a global comfort representation

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ABSTRACT: This paper presents the development of a Physical Ambience Rose (PAR) that provides a graphical record of occupants' global environmental satisfaction and adaptive opportunities. The PAR is derived from a particular questionnaire which, contrary to the majority of existing questionnaires in environmental sciences, does not aim at the evaluation of nuisance of environmental stimuli but rather concentrates on their quality or pleasantness. The satisfaction scale thus varies from "very pleasant", to "neutral", and "intolerable" according to the level of quality, scale and duration of the thermal, luminous, visual and olfactory stimuli. A PAR therefore illustrates in only one graph the satisfaction level of occupants in relation to their environmental conditions (thermal, luminous, acoustical and olfactory) according to their physiological adaptation. The paper presents the methodology that led to this representation tool followed by a demonstration of its advantages in presenting the results of a post-occupancy evaluation of a bioclimatic administrative building in Montreal, Canada.

Keywords: occupants' satisfaction, qualitative analysis, post-occupancy evaluation, comfort

INTRODUCTION

A review of field evidence shows the distinction between environmental comfort responses in air-conditioned buildings versus 'bioclimatic' (naturally lit and ventilated) buildings. Occupants of the latter have moderate expectations and are more tolerant to environmental variations due to their past stimuli and perceived control over their environment. Baker [1] first introduced this notion of *adaptive opportunities* to explain the important discrepancy between predicted comfort and field observations represented respectively by the pioneer works of Fanger [2] and Humphreys [3]. DeDear et al. [4] conducted extensive field studies of adaptive thermal comfort leading to the adaptive comfort standard for naturally ventilated buildings in the ASHRAE Standard 55. The adaptive principle is based on a biological insight asserting that if a change occurs such as to produce discomfort, people will react in ways that tend to restore their comfort. Unlike the previous static approach derived from controlled laboratory experiments, the adaptive opportunity theory asks for a more dynamic multi-sensory approach derived from empirical knowledge through extensive field surveys.

This research proposes a new graphical tool, the Physical Ambience Rose (PAR), to represent the relativity of environmental satisfaction through such a multi-sensory approach integrating occupants' adaptive opportunities. The representation therefore takes into consideration all senses commonly at play in spatial perception namely thermal, visual, acoustical and olfactory. Each environmental stimulus can be qualified by the user to provide a representation of the perceived environmental satisfaction. Two types of data are obtained through a specially devised questionnaire: a stimulus score (from -1 to +1) for each sensory dimension and an adaptability index (from 0 to 1).

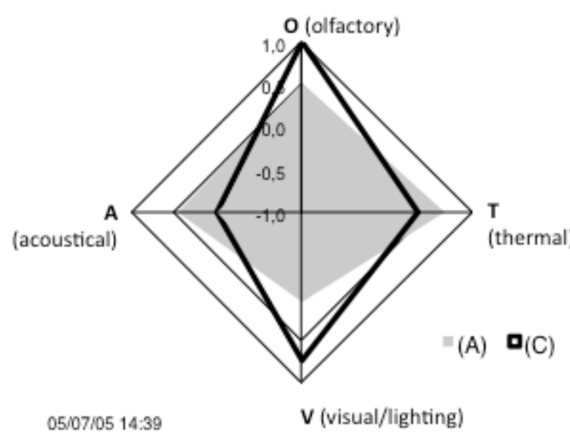


Figure 1: The Physical Ambience Rose (PAR).

Figure 1 illustrates a typical PAR displaying the stimuli (grey zone) and adaptability (thick outline) for all four sensory dimensions on a polar graph. It shows, that adaptability was highly praised for the olfactory and visual stimuli of this particular occupant operating a window, however resulting in less satisfaction for the acoustical and thermal stimuli. Figure 2 illustrates the theoretical range of PARs according to levels of stimuli and adaptability. The upper right PAR would represent a 'very pleasant' space offering maximal adaptive opportunities whereas the lower left PAR would represent an 'intolerable' space offering no adaptive opportunities.

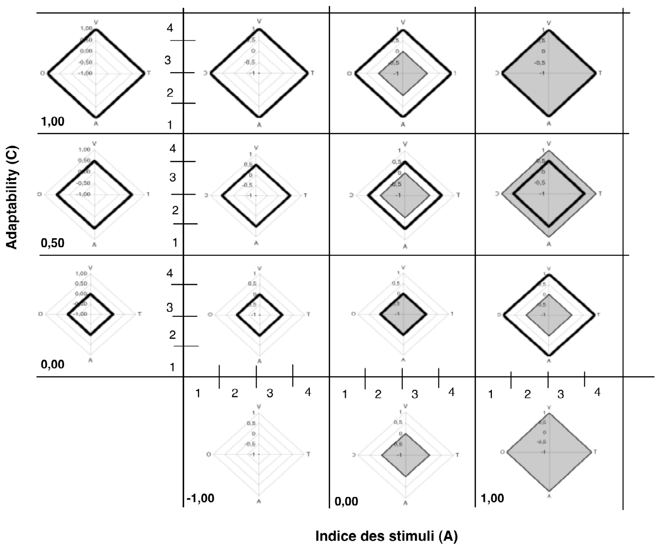


Figure 2: Range of Physical Ambience Roses (PAR) according to levels of stimuli and adaptability.

METHODOLOGY

Online hourly questionnaires provide answers that are transposed into spreadsheets to calculate the following values corresponding to each sensory dimension:

(A) the stimulus value (Ψ_i);
(B) the adaptive satisfaction (ϕ_i); and
(C) the adaptability (Ω_i).

The detailed equations determining these values can be found in previously published paper by Potvin, Demers, Dubois [5]. They are summarized here for the clarity of the paper. The stimulus is described in terms of its quality, spatial scale, and time duration, based on a model proposed by Siret and Woloszyn [6]. The *stimulus value* provides a mean to identify the most determinant stimuli within a space. The value of the stimulus may be calculated with equation 1:

$$\psi_i = Q_i \cdot S_i \cdot T_i \qquad (1)$$

where

Ψ_i = stimulus value for the i[th] sensory stimulus (thermal, visual, acoustic, olfactive)
Q_i = quality score attributed by the subject for this i[th] sensory stimulus (ranging from -1, intolerable to +1, very pleasant)
S_i = spatial scale of the stimulus ranging from 0,1 (scale of a body part e.g. hand) to +1 (entire body)
T_i = time scale ranging from 0,1 (short duration) to +1 (permanent).

In equation 1, the stimulus is weighted by the spatial and temporal scales. A negative quality score (e.g. -1) attributed to the whole body (+1), which also relates to a permanent duration (+1) will thus generate the most negative stimulus value (-1). However, if the quality score of a particular stimulus is intolerable (-1) but only pertained to a body part, e.g. the feet (thus 0,1), and has permanent duration (+1), the stimulus value will be reasonably higher (-0,1) reflecting the fact that the environment is not as negative as in the previous case.

The adaptive satisfaction (ϕ_i) is interpreted as the effectiveness of any adaptive opportunity taken by the occupant to re-establish comfort. It can be calculated with equations (2) and (3):

$$\text{If } \Psi_i < 0, \text{ then } \phi_i = \psi_i + \left| A_i \cdot \psi_i \right| \qquad (2)$$

$$\text{If } \Psi_i > 0, \text{ then } \phi_i = \psi_i + \left| A_i \cdot (1 - \psi_i) \right| \qquad (3)$$

where

ϕ_I = adaptive satisfaction
Ψ_i = stimulus value
A_i = adaptive satisfaction (ranging from 0 to +1)

An initial negative stimulus (e.g. -0,9) can thus be increased by a moderately successful adaptive action yielding a moderate adaptive satisfaction (0,5) resulting in an adaptive stimulus value of -0,45 (-0,9+|0,5*-0,9|= -0,45). Conversely, if the environment is initially moderately pleasant (Ψ_i = 0,6) and that an adaptive action leads to a moderate adaptive satisfaction (0,5), the adaptive stimulus will also increase (0,6+|0,5*(1-0,60)|=0,8), expressing the fact that the stimulus has been upgraded by the adaptive action.

Finally, the *adaptive index* simply consists in the difference between the initial and the adaptive stimulus values calculated with equation 4:

$$\Omega_i = \psi_i - \phi_i \qquad (4)$$

The interest of finding an adaptive index relies in its eventual integration to the existing predictive models for comfort. It is expected that an environment with low (initial) quality scores but high adaptability (large potential to adapt or high adaptive index) would generally be rated more positively than an environment with both low stimulus quality and low adaptability.

IN SITU SURVEYS

Longitudinal surveys were conducted in May and July 2005 to measure the occupants' environmental satisfaction and adaptability of the new headquarters of the *Caisse de depot et de placement du Québec* (CDP) in Montreal, Canada. An Integrated Design Process led to the specification of a unique double-skin façade that optimises the thermal, visual, acoustical and indoor air quality (IAQ) while neutralising the severe Canadian climate [7]. Unlike traditional administrative buildings, the CDP allows occupants to interact with environmental control systems (ECS), which can be switched to a manual mode. For instance, artificial lighting, blinds and windows can be fully controlled by the occupant, providing optimal adaptive opportunities. This building is therefore ideal for the study of the adaptability theory and the illustration of the graphical representation introduced in this research. Figure 3 illustrates a typical floor plan of the L-shaped CDP Building consisting of three interconnected blocks linked by a central longitudinal atrium. Each block provides space for enclosed offices on its periphery and open offices wrapped around three smaller central atria designed for daylighting and exhaust ventilation.

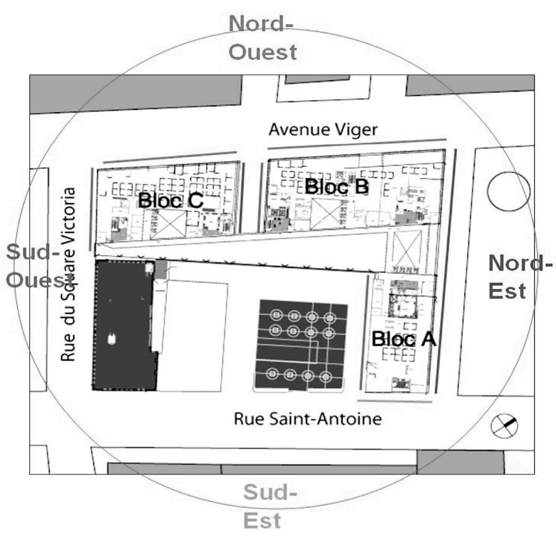


Figure 3: CDP Building floor plan.

A total of 22 participants on Floor 6, distributed in 8 enclosed offices and 14 open offices answered a total of 313 hourly questionnaires during two two-week periods (2-13 May and 4-15 July 2005), respectively representing the Spring and Summer seasons (Tab. 1). Participants were located in offices on the SW, NE and NW façades.

Table 1: Longitudinal Questionnaire Participation According to Office Types and Orientations.

Formulaire	Type	Orientation	Répondant	Longitudinal			
				S1	S2	S3	S4
1	O		1	0	0	20	27
2	F	SO	1	11	10	3	8
3	F	SO	1	7	12	6	0
4	F	NE	1	7	4	0	0
5	O		1	14	13	9	8
6	O		1	0	0	1	4
7	F	SO	1	0	3	0	0
8	O		1	0	1	0	0
9	F	NO	1	0	2	3	5
10	O		1	0	0	12	13
11	OP	NE	1	1	0	0	0
12			1	1	0	0	0
13	O		1	0	0	0	1
14	O		1	0	0	8	12
15	O		1	3	15	0	0
16	OP	NE	1	9	4	0	0
17	F	NO	1	15	4	7	4
18	O		1	0	1	0	0
19	O		0	3	7	0	1
20	F	NE	1	1	0	0	0
21	O	SO	0	2	0	0	0
22	F		1	2	4	1	1
23	FC		1	0	0	0	0
24	OP	SO	1	2	0	0	0
25	O		0	1	0	0	0
			22	79	80	70	84

Office Types :

F : Enclosed Peripheral Office	*OP : Open Peripheral Office*
O : Open Central Office	*FC : Enclosed Central Office*

Figure 4: Interior view of the CDP Building showing "open" offices surrounding the atrium of Block C.

RESULTS

Physical Ambience Roses (PAR) can be generated either for individuals or groups of occupants. Table 2 presents an excerpt of data obtained for a specific occupant on July 5th. Olfactory, thermal, visual and acoustical data issued from the on-line questionnaire located in column (A) relate to the Stimulus value, and in column (C) to the Adaptability index. Comments are indicated as the questionnaire enables user to add information whenever an adaptation was performed to respond to an unsatisfactory physical condition. As an example, the table shows that the user's perception of thermal comfort considerably varied during the day. Although the relative temperature was relatively uniform (24,3 °C +/- 0,25°C) and varied only slightly from 8:40 (first PAR on the left of Table 2) to 9:30 (third PAR), the user felt that the space was getting uncomfortable and too cool as the stimulus value gradually dropped from 67% (relatively comfortable) to -58% (relatively uncomfortable). The questionnaire indicates that the occupant did not activate the user's controls to adjust the temperature but rather used on-hand materials to block the floor ventilation traps of the displacement ventilation system that provided cooler air. Although such behavior was not predicted by the design team, this particular occupant considered it as a good adaptive opportunity that clearly enhanced thermal satisfaction as depicted by a perfect stimulus value (very pleasant) and high adaptability in the fourth PAR. The same pattern was somehow repeated in the afternoon but resulted in less optimal conditions. The visual stimulus always scored high apart from the fifth PAR where visual conditions deteriorated. Here again, the high adaptability of the working environment allowed the visual stimulus to be pleasant to very pleasant in the following PARs. The olfactory and acoustical stimuli were consistently well perceived throughout the day even if the occupants clearly acknowledged the absence of adaptive acoustical opportunities.

Table 3: Weekly averaged PARs for open and enclosed offices between May 9-13th 2005.

	Stimulus Value		Adaptive Satisfaction		Adaptability Index	
	Ouverts	Fermés	Ouverts	Fermés	Ouverts	Fermés
Air	0,28	0,53	na	0,53	na	1,00
Thermique	0,12	0,28	0,08	0,17	0,62	0,56
Visuel	0,35	0,62	na	0,45	na	0,60
Sonore	0,11	0,29	na	0,10	na	0,27

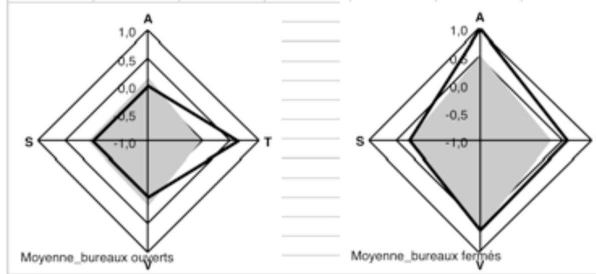


Table 3 illustrates the weekly comparative mean Physical Ambience Roses (PAR) for open (left PAR) and enclosed (right PAR) offices during the May survey. The overall advantage of the enclosed offices over the open working area is clearly illustrated in the larger diamond graph shape with higher Stimulus and Adaptability Index values. The global environmental quality was 64% in the open central offices compared with 75% for the enclosed peripheral offices. Stimulus values (always pleasant) were consistently higher in enclosed offices, and adaptability also rated higher for visual, acoustical, and olfactory stimuli. The almost equal thermal adaptability scores in open and enclosed offices was questionable considering that only enclosed offices have access to operable windows. The questionnaire revealed that most of the adaptive actions taken by the occupants during May were about raising the temperature of their offices or opening the windows. These seemingly contradictory behaviors can be explained by the fact that occupants were aware of the instantaneous cut-off of mechanical ventilation (intake and return) when opening a window.

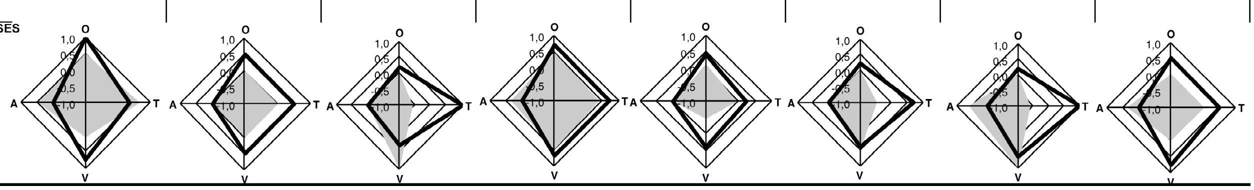
Table 2: Daily PARs of an occupant in the open central office, on Tuesday July 5th 2005. Main task during observations is clerical work.

	5/7/05 8:40		5/7/05 9:12		5/7/05 9:17		5/7/05 9:39		5/7/05 10:13		5/7/05 10:58		5/7/05 13:47		5/7/05 13:58	
	(A)	(C)	(A)	(C)	(A)	(C)	(A)	(C)	(A)	(C)	(A)	(C)	(A)	(C)	(A)	(C)
O	0,52	1,00	0,00	0,50	0,00	0,20	0,47	0,71	0,14	0,42	0,03	0,23	0,00	0,20	0,03	0,52
T	0,67	0,36	0,00	0,50	-0,58	1,00	0,39	0,70	-0,05	0,23	-0,47	0,70	-0,60	1,00	0,03	0,50
V	0,05	0,74	0,00	0,50	1,00	0,25	0,49	0,68	-0,49	0,37	0,50	0,39	1,00	0,64	0,02	0,77
A	0,46	0,00	0,00	0,00	0,00	0,00	0,35	0,00	-0,02	0,00	0,04	0,00	0,60	0,00	0,37	0,00

Comments

	8:40	9:12	9:17	9:39	10:13	10:58	13:47	13:58
O								
T			Blocked the air trap with a garbage can and a pack of printing paper				I have blocked the second (other) air trap because I was still too cold	
V				Turned the lamp away on my working table	I moved the lamp that stands on my table			
A								

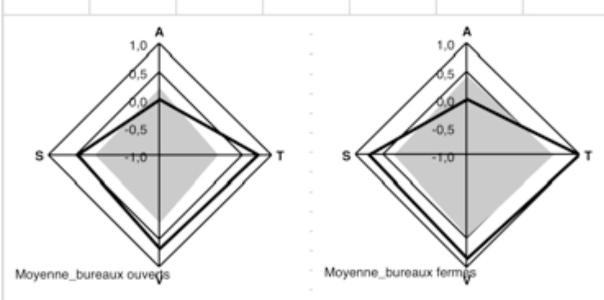
ROSES



A closer look at the comments reported on the questionnaire clearly shows that the adaptive satisfaction after raising the temperature was very low (~23%). Therefore, and as a last resort, occupants of the enclosed peripheral offices simply opened their windows to shut down the mechanical system and take advantage of exceptional outdoor warm conditions of 26.5ºC to warm up the space. Questionnaires also show that the adaptive satisfaction became very high (over 76%) and compensated for the previous deceptive action of raising the thermostat set point temperature.

Table 4: Weekly averaged Physical Ambience Roses (PAR) for open and enclosed offices between July 11-15th 2005.

	Stimulus Value		Adaptive Satisfaction		Adaptability Index	
	Ouverts	Fermés	Ouverts	Fermés	Ouverts	Fermés
Air	0,21	0,42	na	na	na	na
Thermique	0,05	0,54	0,04	0,54	0,76	1,00
Visuel	0,21	0,45	0,15	0,40	0,67	0,85
Sonore	0,16	0,31	0,08	0,25	0,47	0,75



During the July survey, the enclosed offices (right PAR) not surprisingly outperformed the open offices (left PAR) in terms of stimulus values an adaptability (Tab. 4). Global environmental quality was 57% in the open central offices compared with 78% for the enclosed peripheral offices. Here again, a similar high thermal adaptability prevails in both office configurations. Comments gathered on the electronic questionnaires from occupants of the open central office show that none of the adaptive actions were related to window operation but rather to the blocking of the displacement ventilation air supply system because of colder uncomfortable sensations.

Figure 5 illustrates an example of an entire façade survey performed in May and July. On this spreadsheet, each floor is depicted by two rows of information, whereas the upper and lower rows represent respectively the blinds and operable window states for each office on the South-West façade. A colored cell signifies that the blind are drawn or the window is open. The figure clearly shows that although the exterior ambient temperature was 24^{0}C on this exceptionally warm Spring afternoon, only 4% of the operable windows were opened. Floor 6 performed exceptionally well with 13% of open windows. Occupants appeared to interact more freely with blinds, results showing that nearly 30% of the blinds were either 100% or 50% retracted. Note that the automatic default position of the blinds is 'drawn' during the night so that a white or light grey scale clearly represents and occupant's interaction with this visual/thermal control feature.

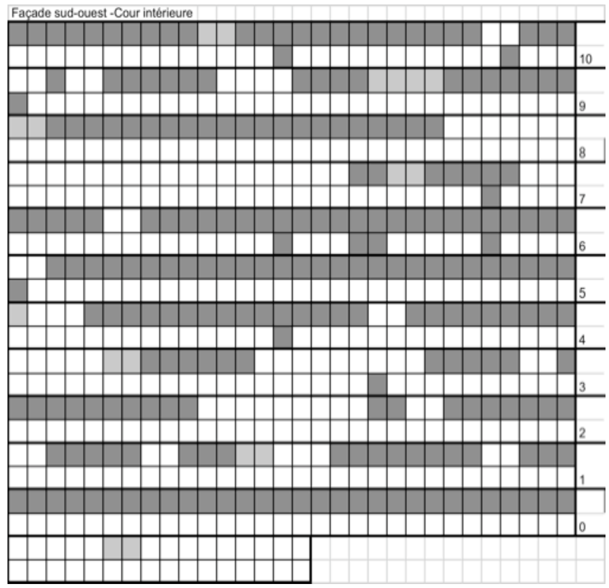


Figure 5: Distribution of Operable Window and Blind Position (dark-open, white-closed) on the South-West façade of the CDP Building.

Results from the PARs can also be presented in bar histograms of occupants' satisfaction. Figure 6 shows the mean environmental satisfaction relative to each stimulus according to façade orientation for enclosed offices. The overall environmental conditions at the CDP Building were highly praised ranging from neutral to very pleasant. The southeast façade has received a poor acoustical assessment due to the nearby construction site that was generating great amount of noise even with windows being closed.

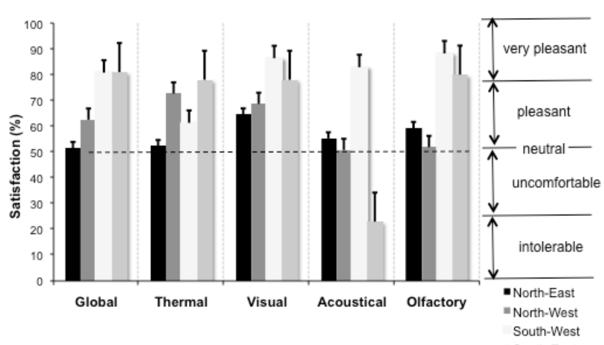


Figure 6: Environmental satisfaction for each stimulus according to façade orientations.

CONCLUSION

The aim of this in-situ survey was to propose a new global representation of environmental satisfaction and adaptability. The Physical Ambience Rose (PAR) calculation integrating the quality, scale and temporality of four environmental stimuli provides a graphical mean of expressing the complex environmental perception that ultimately depends on occupants' interaction with the building.

Individual daily and mean weekly Physical Ambience Rose (PAR) representations were illustrated through the results of extensive in-situ surveys at the CDP Building in Montreal. These results clearly demonstrate the PAR's ability to represent the occupants' satisfaction as well as adaptability for a given space, although great care should be taken in their interpretation as participants occasionally confused personal adaptability with environmental adaptability in their responses. The results of the survey highlight that the operable window, main passive thermal adaptive opportunity provided to the users, was not very well exploited in the CDP Building. Several reasons may explain this very low number of user interactions:

- The culture of environmental control:

Environmental control in Canada, like most of western countries, is mostly exclusive of ambient outdoor conditions through the mechanization of interior environments. Therefore, when moving to the new CDP Building from a sealed deep plan original headquarter, very few, if no occupant at all, expected adaptive opportunities such as operable windows, and were never even informed of that possibility. Consistent relatively high window interaction on Level 6 suggests the presence of active occupants that should contaminate other occupants after few years of occupation;

- The high performance of the mechanical system:

Due to the lack of conclusive precedents of passively cooled large-scale administrative buildings in the Quebec climate, the design team took no chance and specified a hybrid ventilation system that could alternate from natural to mechanical ventilation with full load cooling capacity. They even specified the first large-scale displacement ventilation system in this part of the country. This state-of-the-art mechanical system coupled with the innovative double-façade, were specified to optimize environmental comfort and productivity. Therefore, there was no reason for an occupant to perform adaptive opportunities. However, as depicted in Table 2, this complex mechanical system seems to have generated some discomfort to occupants due to cool air intake at the feet level. This led the occupants to perform awkward adaptive actions such as blocking the floor air diffusers with piles of paper and opening the windows to warm up their offices. These behaviors support the very definition of discomfort where occupants will take any possible action to maintain their comfort level.

In future studies on adaptive opportunities, the survey team should therefore organize focus groups to teach occupants the nature of adaptive choices provided by the building. The questionnaires should clearly ask to identify personal adaptive actions versus environmental adaptive actions to generate a more representative Physical Ambience Rose (PAR) for architects. The study should be performed again a few more years after occupation to represent the evolution of users' response to the passive environmental controls. This is particularly crucial if conducting the surveys in fully hybrid buildings where users may have little motivation to interact with the adaptive features of the building, the environmental conditions being constantly optimized.

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