687: The ‘Pleasant’ Temperature Window Manipulation and Dynamics of Thermal Comfort in a Naturally Conditioned Space

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Abstract

Windows are one of the major means by which building occupants control indoor environment. This paper explores the improvement of acoustic, visual, olfactory and thermal occupant comfort thought window opening/closing operations in a selected naturally conditioned classroom without mechanical ventilation in a Nordic climate. The survey gathered 425 records of actual sensations and their corresponding thermal parameters. Participants reported 196 adaptive actions taken to improve comfort. Most of windows manipulations were related to thermal comfort. *Pleasant Temperature* represents the temperature range where occupants are satisfied by the thermal environment and show that the percentage of dissatisfaction against thermal sensations is lower than the one expected by standard. This study supports the theory that the width of temperature range can be highly variable when adaptive opportunities such as window opening are provided.

Keywords: operable windows, environmental comfort, natural ventilation, passive cooling

1. Introduction

The window is a fundamental element in architecture. It provides natural light, solar penetration, outside/inside view, and allows the exchange of air, sound and odours with the outdoor environment. It constitutes an important operable instrument to adjust the thermal, acoustical, visual and olfactory ambiences and improve occupant’s *multi-sensory* comfort. The relative importance of each environmental stimulus differs from peoples and individuals [1].

Operable windows are essential for passive cooling and its potential energy savings. Figure 1 shows the main parameters that affect daily indoor temperature in a passive cooled space. It suggests that occupants play an important role in sustainable buildings by manipulating the windows. Window design and state (open/closed) influence heat loads and evacuations to the surroundings through day/night ventilation (heat sinks). A significant correlation between the proportion of open windows and the interior operative temperature has been observed [2].

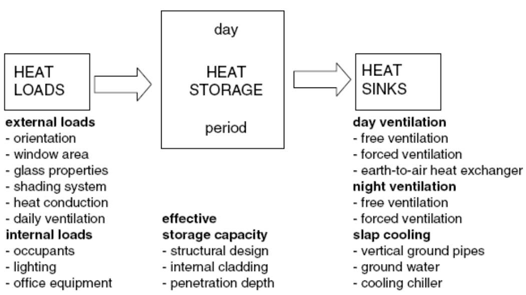

Fig 1.Main parameters influencing indoor Top for passive cooling [3].

Field studies show that occupants in naturally ventilated offices tolerate a wider temperature range and have more relaxed thermal expectations than what laboratory studies and standards (i.e. standard55 and ISO 7730) anticipate [4]. This discrepancy has been explained by a greater degree of thermal control (flexible thermal environments), a closer contact with the outdoor conditions and the influence of non-thermal factors [4,5,6]. Only few studies have been conducted in classrooms and they have often failed to support the applicability of Standard 55 [7,8,9,10]. According to Health Canada natural ventilation allows good air quality and thermal comfort for classrooms [Canada].

Adaptive principle states that “*If a change occurs such as to produce discomfort, people react in ways that tend to restore their comfort*” [6]. Figure 2 illustrates common adaptive opportunities that consist of personal and environmental adjustments. When occupants have access to these actions a greater thermal tolerance is observed [11]. ASHRAE standard55-04 and European prEN15251 standards integrate an adaptive section for naturally conditioned buildings.

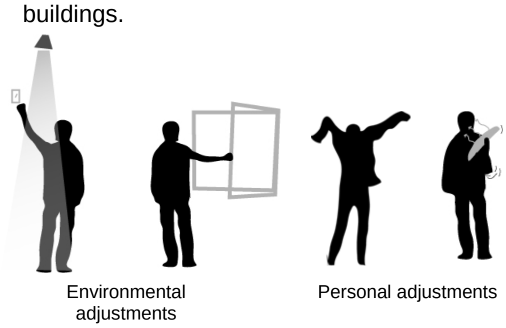

Fig 2.Common adaptive opportunities: Control of lights and windows, change cloths and manual ventilation.

This paper analyses multi-sensorial improvement by opening/closing windows operations and focuses on thermal comfort. The post-occupancy evaluation was conducted in a naturally conditioned classroom. *Pleasant Temperature* represents the temperature range where occupants are satisfied by the thermal environment and it is compared with C*omfort temperature,* conventionally associated with thermal sensations of "slightly warm," neutral," and "slightly cool". Real thermal sensation is compared with standard55-04 predictions.

2. Survey method

2.1 Description of the classroom

Figure 3 shows classroom layout, students' positions (dotted points) and the position of participants wearing portable arrays for the measurement of physical ambiences. The 200m^2 E-W orientated classroom is located in the attic of the Séminaire de Québec, a 17th century building occupied by Laval University School of Architecture. Refurbishments had avoided mechanical ventilation and the thermal conditions of the *space are regulated primarily by the occupant through opening and closing of windows*, which correspond to the definition of a naturally conditioned space [12]. Classroom is cross-ventilated through operable windows by the occupants. Students have control on door, blinds, and lights. Heating is centrally controlled and wasn't in function during the post-occupancy evaluation. No dress code is compulsory.

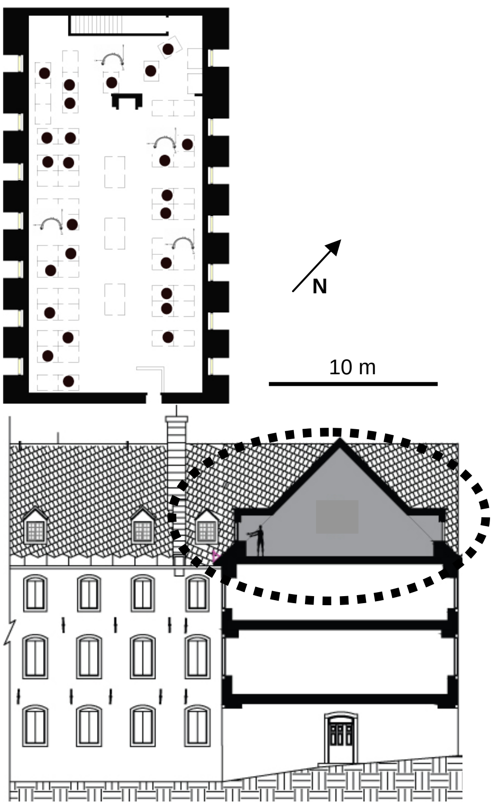

Fig 3. Classroom layout and longitudinal section. Classroom is in the attic.

Figure 4 shows one of the classroom wood framed windows with six operable hoppers. These allow four primary opened (white) or closed (gray) configurations to control the amount of fresh air. For this study "0" is considered as a closed window, while ¼, ½ and 1 are considered as an open window. Windows have two opaque blinds.

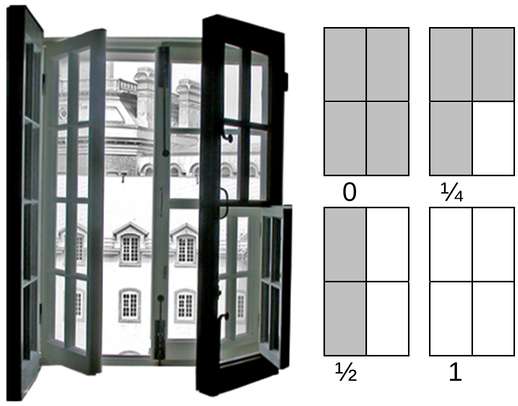

Fig 4. Example of a classroom window and possible states of opened (white) or closed (gray) configuration.

2.2 Quantitative survey

The quantitative measurement of ambient conditions was monitored by four Portable Arrays for the Measurement of Physical Ambiences (PAMPA) developed by Potvin [13,14]. This innovative equipment allows the dynamic assessment of personal physical ambiences over an eight-hour period. As shown in figure 3, the participant wore PAMPA on the head. It is non-obstructive for the user and non-invasive for the other occupants. This instrument is connected to a portable logger worn at waist level. It contains the memory and the battery. Participant's votes were associated to the nearest PAMPA. The PAMPA´s sensors recorded the following environmental comfort parameters:

1. ambient temperature (-20 to 50o C)
2. radiant temperature (-20 to 50o C)
3. relative humidity (0 to 100%)
4. ambient lighting (0 to 10000 lx)
5. ambient acoustic intensity (0 to 80 dB)
6. air movement (0 to 1.5 m/s).

PAMPA is not a precision instrument certified for field thermal comfort evaluations. This could cause quantitative changes. But this would not affect the qualitative results. Outdoor temperature was obtained from QUEBEC/JEAN LESAGE INTL A meteorological station.

2.3 Qualitative survey

Students completed five different web-based-surveys namely the personal, morning, hourly, evening and weekly questionnaires developed by the GRAP (Groupe de recherche en ambiance physique). Surveys description is available on [13,14]. This paper focuses on the results from the hourly-questionnaires, the first questionnaire being completed at the end of the first hour in the classroom. It is divided in two sections. First, satisfaction against each environmental stimulus (thermal, acoustical, visual and olfactory) is evaluated through a five-point scale ranged from "intolerable" to "very pleasant". Thermal sensation was evaluated with the ASHRAE 7-point scale. The ratings for air movement sensation were: "no feeling," "a little," "moderate," and "a lot". Air movement preference scale asked "want more," "no change," or "want less". Participants indicated their clothing insulation and activity (i.e. building a mock-up). Then, the participant was asked to indicate if they had taken any action(s) to improve their comfort and to qualify their satisfaction concerning this adaptive action:

During the past hour, have you made any adjustments to improve your comfort?
(1) «yes»; (0) «no»

If «yes»:
Please indicate the adopted action
«opened answer»
At which level these adjustments managed to improve your comfort?
(0) «defeat», (4) «Success »

Participation in this study was voluntary and the survey protocol was approved by the Comité d'éthique de la recherche avec des êtres humains de l'Université Laval (CÉRUL)

Fig 3. Participant wearing a PAMPA and completing the web-hourly-questionnaire.

3. Discussion of the results

Table 1 summarizes the distribution of mean indoor operative temperature and the values of key survey questions assessing the thermal environment acceptability. 424 records of actual sensations and adaptive actions taken to improve comfort by 29 students -mainly aged between 18 and 23- were gathered through the survey. This post-occupancy evaluation recorded a very high level of satisfaction. The visual and the olfactory environments were rated 97% and 98% respectively while the thermal and the acoustic ambiences were rated 91% and 86%.

Table 1. Statistical summary of key survey results.

			Nbr of adjustments	
date	**Nbr votes**	**mean Top**	**personal**	**environmental**
20-Sep	49	26.2	10	18
24-Sep	44	25.2	6	15
27-Sep	76	25.3	10	23
01-Oct	15	23.5	2	9
04-Oct	84	23.7	15	26
11-Oct	89	23.3	14	18
15-Oct	29	21.7	5	11
18-Oct	39	21.5	7	6

Thermal Sensation	%
(+3) hot	2%
(+2) warm	10%
(+1) slightly warm	30%
(0) neutral	47%
(–1) slightly cool	10%
(–2) cool	1%
(–3) cold	0%

Satisfaction scale	%
(5) very pleasant	16%
(4)	51%
(3)neutral	23%
(2)	10%
(1) intolerable	0%

Air Movement Sensation	%
(0) no feeling	38%
(1) a little	46%
(2) moderate	16%
(3) a lot	1%

Air Movement preference	%
(1) want more	36%
(2) no change	59%
(3) want less	4%

Table 1 indicates that personal adjustments account for 35% of adaptive actions while environmental adjustments represent 65%. Data confirm that people who are satisfied with their thermal environment do not tend to modify it. In contrast, only 5% of people dissatisfied do not take any action to change the situation, 17% of adaptive actions were not successful to improve comfort. Personal adjustments were found to be more efficient to improve thermal comfort for warm and cool sensations, probably due to a faster response. This calls attention on the importance of relaxed dress codes. Thermal and acoustical discomforts explain 80% of overall adjustments reported by the occupants. Most of the personal adjustments consisted in dress changes (13%) and the use of digital audio player (15%). On the other hand, windows operations represent 62% of environmental adjustments. Most of windows operations are related to thermal comfort (82%) and 10% to visual comfort (blinds manipulations). The improvement of indoor air quality, by opening windows (i.e. to evacuate glue vapors when building a mock-up), represents only 6% of the operations. On the other hand, the reduction of noise from outside by closing the windows accounts for 1%.

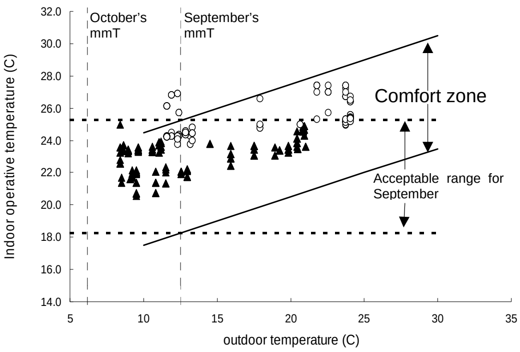

Fig 4. Corresponding Indoor operative and outdoor temperatures for September (circles) and October (triangles) plotted over the adaptive standard55 comfort zone.

Figure 4 shows the hourly Top as a function of simultaneous outdoor temperature plotted over the standard55-04 comfort zone for naturally conditioned buildings. This chart specifies the acceptable indoor Top range as a function of outdoor mean monthly temperature (mmT). Adaptive standard55 only applies when mmT is ranged between 10 °C and 33 °C. Following this principle for Québec City, natural ventilation applies during the September evaluation period (mmT=12.5 °C) while it is suggested that the classroom should be heated along October (mmT=6.2 °C). Corresponding acceptable range of indoor Top for September is 18-25 °C. With this criterion only 21% of the measurements were within the comfort zone. When overall indoor hourly temperatures are included (October and September), 84% of measurements are within the comfort zone. As shown in figure 5, this result is not significantly lower than subjective evaluation of thermal sensation, 87% of the votes are within the three central categories of the ASHRAE 7 points scale (“slightly warm,” neutral,” and “slightly cool”). This result suggests that the use of daily – instead of monthly - mean outdoor temperature could make comfort standard for naturally conditioned buildings more useful as noted by Hensen [15].

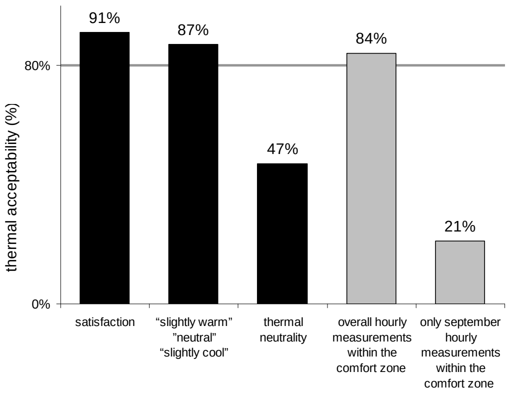

Fig 5.Qualitative (black) and quantitative (grey) surveys results of thermal acceptability.

Figure 5 shows that the highest level of acceptability is obtained from the satisfaction scale (91%). In fact, a percentage of people voting outside the three central categories still expresses being satisfied. Figure 6 shows that the level of dissatisfaction within the three central and “warmer” categories is significantly lower than what is expected by PPD (percentage of dissatisfied) index. PPD is calculated as a function of thermal sensation by formula (1):

PPD=*100-(95*EXP(-0.03353*thsen^4-0.2179*thsen^2))*

PPD assumes that dissatisfaction is a “mirror effect”. It predicts that 26% of people will be dissatisfied if thermal sensation is “slightly warm” or “slightly cool”. However, only 3.1% and 19% were dissatisfied at respective sensations. PPD can not calculate dissatisfaction when hot (+3) or cold (-3) sensations are expressed; three participants out of 7 have expressed to be satisfied even with a hot thermal sensation (+3). Ideal temperature is conventionally defined as a temperature that provokes a “neutral” thermal sensation for the group. A very high level of satisfaction occurred at neutral thermal sensation (99%). Nonetheless, as shown in figure 5, with this criterion only 47% of thermal acceptability is obtained. This corroborates Heschong’s idea that thermal sensation can create pleasantness and delight through a felt thermal environment [16].

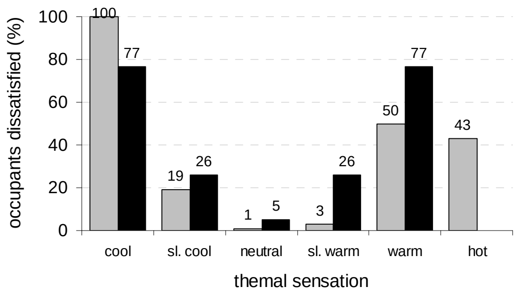

Fig 6. Predicted (black) and real (grey) dissatisfaction.

Figure 7 shows a cross-comparison of air movement preferences and thermal sensation, as well as their associated percentage of the percentage people that mentioned to open a window. The number of people who want a higher air movement increases as the thermal sensation tends to “hot”. Only 2% of people voting “slightly cool” wanted more air movement while 57% of people voting “slightly warm” wanted more air motion. On the other hand, when thermal sensation was “slightly cool” 24% demanded less air movement and only 2% demanded less air movement at “slightly warm” sensation. Despite the low sample of votes, these results are consistent with those of Zhang & coll. [17] and show that the control of air movement can improve comfort. Figure 6 also shows that the percentage of people who open a window increases when warm sensations are felt, this confirms some participants’ comments about opening the window in order to increase the air movement and improve their thermal comfort.

Future analyses will relate the percentage of open windows with indoor Top.

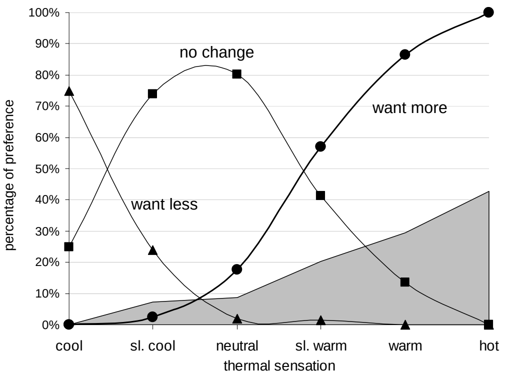

Fig 7. Cross-comparison of air movement preferences - thermal sensation and percentage of people that mentioned to open a window (gray zone)

Figure 8 represents the calculated comfort and pleasant temperatures as a function of the subsequent outside temperature. The former expresses the temperature at which the thermal sensation was "slightly warm," "neutral," and "slightly cool." The latter represents the temperature where occupants expressed pleasantness (satisfaction) against the thermal environment. Comfort temperature has the same tendency of ideal Standard55-04 indoor temperature expectation. The pleasant temperature line has a wider inclination because the percentage of dissatisfaction against thermal sensations is lower than the one expected by formula (1), especially for warm sensations. The performance of personal and environmental adjustments can explain these discrepancies. Pleasant temperature suggests that the amplitude of comfort range can be highly variable when adaptive opportunities such as window opening are provided by architecture

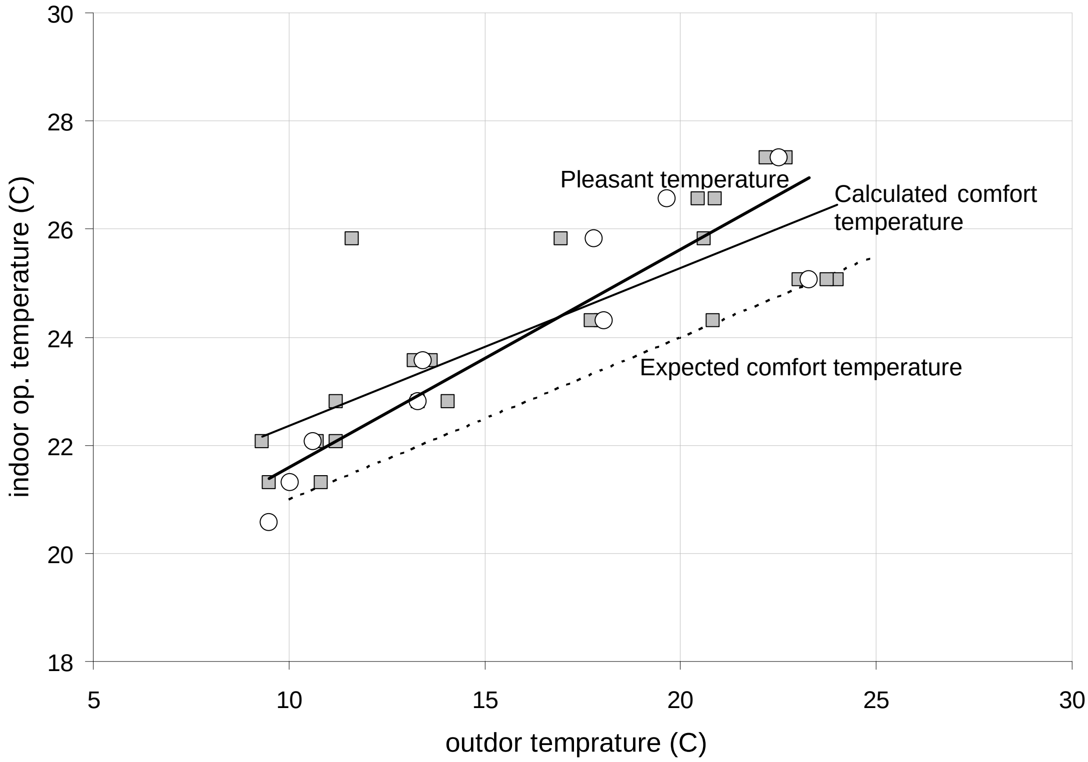

Fig 8. Calculated comfort and pleasant temperatures

4. Conclusion

In this paper, window operation by the occupants was analyzed in order to measure their impact on multi-sensory comfort. Surveys pointed out that manipulations were related to thermal comfort. Windows were opened to modify the thermal environment by allowing fresh air and increasing air motion. However, personal adjustments were found to be more efficient for warm and cold sensations. The highest level of thermal acceptability was obtained by subjective evaluation of satisfaction "pleasant temperature".

With a criterion of hourly, instead of monthly mean outdoor temperature the adaptive Standard55 prediction of comfort temperature was much closer to the thermal sensations expressed by the group. This supports the idea that systems flexibility and passive cooling can generate energy savings without compromising occupants' comfort.

5. Acknowledgement
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6. References
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