GREEN BUILDINGS - GREY OCCUPANTS?

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ABSTRACT

This paper reports on a comparative analysis of two innovative naturally conditioned office buildings -- one in Switzerland and one in Canada. The intent was to discover the extent of satisfaction with environmental conditions and levels of engagement with the control of heating, cooling, ventilation and lighting. The potential cultural differences between occupants in the two case-study projects affecting satisfaction with environmental conditions and the use of manual controls, were not as evident as anticipated. By contrast greater differences occurred within each building as a result of occupants access to the controls. Results support the notion that occupant behaviour must be embraced more explicitly in the discussion and design of environmentally responsive buildings.

1. INTRODUCTION

The past decade has provided a wealth of information on how building occupants respond to environmental conditions in buildings. Post-occupancy evaluations show that occupants engage in numerous coping mechanisms to solve discomfort problems (dismantling daylight control sensors and occupancy sensors, delamping spaces to reduce VDT glare) or simply take breaks, go for walks or complain to co-workers and facilities managers (Heerwagen, 1999). There is now ample evidence that personal control over indoor environmental conditions is central to occupant comfort and satisfaction (Wilson and Hedge, 1987; Bordass, Bromley and Leaman, 1995). It is also widely known that actual building performance often differs markedly from that anticipated or predicted during design. This "mismatch" primarily results from the differences between assumed and actual patterns of occupancy, the use of controls, and building operation and management. In contrast to rational models of building operation and use assumed in design, Leaman [1999] presents a list of "real" building user reactions and responses that indicate occupants of buildings tend to:

- Act in response to random, external events.
- Take decisions to use switches or controls only after an event has prompted them to do so (rather than in advance of it).
- Will often wait for some time until taking action and typically when they reach a "crisis of discomfort".
- Tend to over compensate in their reactions for relatively minor annoyances.
- Operate the controls or systems that are most convenient to hand rather than those that would logically be the most appropriate.

- Take the easiest and quickest option, rather than the best for their immediate benefit.
- Consciously or otherwise, leave systems in their switched state, rather than altering them back again later, at least until another crisis of discomfort is reached.

Based on a wealth of experience in evaluating actual building performance, Bordass and Leaman (1997), point to over-complex building systems as a major deterrent for efficient and effective building operation. Bordass and Leaman's work is particularly important in the context of this paper since, in addition to reduced energy use and environmental impact, natural conditioned buildings offer the promise of:

- More varied internal environmental conditions and greater occupant interaction with building systems.
- Simpler, more robust control strategies that are more readily accessible and comprehensible to building users.

Discussion on environmentally responsive building typically focuses on their technical features – the *means* by which occupant needs will be met using fewer resources and environmental degradation – and make scant reference to how users interact with these features and systems. The underlying premise of this paper is that occupant behaviour will ultimately dictate the successful performance of a naturally conditioned building and that occupant behaviour must therefore be embraced much more profoundly in the way environmentally responsive buildings are discussed and designed.

1.1 CULTURAL DIFFERENCES

Statistical evidence related to resource use and air emissions per capita as well as more stringent environmental regulatory requirements in Sweden, Netherlands, Germany and Switzerland, suggests that there is a greater culture of environmental responsibility in Northern European countries than in North America. Indeed approaches to space conditioning in Northern European office buildings have historically favoured natural cooling over mechanical cooling and daylighting over electric lighting.

North American practitioners are increasingly exposed to information on emerging European natural conditioned buildings as a major emphasis to "green" design, and are beginning to incorporate related environmental strategies and technologies in their own work. As geographical and cultural boundaries are transcended in this process, it seems reasonable to ask if potential difficulties may arise regarding their acceptability by users who are not accustomed to more variable interior conditions and direct engagement in building operation.

This paper reports on a detailed comparative analysis of two innovative naturally conditioned case study office buildings, one in Switzerland and one in Canada. A common set of questionnaires was issued to occupants in both buildings to expose levels of satisfaction with environmental conditions and levels of engagement with the control of heating, cooling, ventilation and lighting. Based on the results of the study, the paper examines a number of performance issues related to the way in which occupants interact with the control strategies in naturally conditioned buildings.

2. CASE–STUDY BUILDINGS

The two case study projects are the *Tenum* building, Liestal, Switzerland completed in 1990, and the *C.K. Choi Institute of Asian Research*, University of BC, Canada completed in 1996. The focus of the comparison is on the strategies used in the provision of thermal, lighting and ventilation since these are three building performance areas that are directly related to user behaviour.

2.1 TENUM OFFICE BUILDING

The 5-storey *Tenum* building has a net area of 3200 m^2 and houses 100 workspaces. The individual small firms in the *Tenum* building share an explicitly declared environmental ethic and have a number of communal office infrastructures and services available to them.

2.1.1 Plan Form and Orientation

Tenum has a modified rectangular floor plan with overall dimensions of approximately 35m by 25m. A central atrium space provides a focus, circulation, and daylight. The longer axis is oriented approximately 30 degrees west of N/S.

2.1.2 Window System

Wood framed windows have upper and lower portions:

- Fixed upper clerestory windows (1.16m x 0.4m high) that cannot be opened and are unshaded.
- Lower windows (1.16m x 1.31m high) that can operate either as tilt or casement and have interior and exterior shading according to orientation (see below).
- Although some of the skylight windows enclosing the central lightwell can be opened, windows looking into it cannot.

Glazing:

Three different glazings were incorporated:

- *Silverstar super* (windows and doors): U-value of 0.9W/m^2K, triple insulating glazing, 2 film covered glass surfaces, filled with Argon.
- *Silverstar N* (clerestories): U-value of 1.3W/m^2K, double insulating glazing with 1 film covered surfaces, filled with Argon.
- *Hyalin:* U-value of 0.7W/m^2K, triple insulating glazing with 2 film covered surfaces, filled with Argon. (The Häring firm, which owns its office space located in the south corner on the first story, installed the Hyalin glazing to test their own glass product.)

Solar and Glare Control

- East and southeast façade (east end): Simple (yellow) exterior cloth roller-shades evenly disperse the sunlight over the work area, while providing an unobstructed view.
- Southeast (south end) and southwest façade (south end): Photovoltaic panels encased in glass laminate provide a canopy.
- Northwest façade (west end) and southwest façade (west end): Steel /wood construction serves as balcony, emergency exit stairwell and rain protection for façade.
- Northwest façade (north end): vertical fins create internal shadows that extend over the entire work area
- Northeast façade: No shading necessary.

2.1.3 Lighting Control

Electric lighting is provided by moveable floor metal halide up-lights (3-step) with a design lighting density of 8.5 W/m^2.

2.1.4 Heating Control

- A mechanical displacement ventilation system in combination with a roof mounted heat recovery unit compliments natural ventilation during the transition seasons and is the primary ventilation strategy during the winter.
- Lighting in the washrooms activates a separate ventilator via a delayed timer.
- The heating system is a fully automatic 120 kW central wood chip furnace, combined with a vapour condensate heating system.

2.1.5 Annual Energy Use

Measures heating system operation periods of the *Tenum* building were 18% and 43% less than that of a standard Swiss office building during the 1993 and 1994 heating periods respectively (Tenum AG, 1996:9). The average annual Swiss office building heating/cooling energy use is 575 MJ/m^2/year. *Table 1* shows the *Tenum* performance and the range of performance targets advocated by the Schweizerischer Ingenieur- und Architekten-Verein (SIA).

	Tenum (Design)	**Tenum (Measured)**	**SIA (Goal)**	**SIA (Upper Limit)**
	(MJ/m^2a)	(MJ/m^2a)	(MJ/m^2a)	(MJ/m^2a)
Heating	**150**	**126**	**240**	**340**
Electrical	**100**	**77**	**175**	**175**

Table 1: Comparison of *Tenum* and SIA Goals for Annual Heating and Electrical Energy Use (Tenum AG, 1996:8)

2.2 C.K. CHOI INSTITUTE OF ASIAN RESEARCH

The 2,700 m^2 *C.K. Choi Institute of Asian Research* houses Centres for China, Japan, Korea, India and South Asia, and Southeast Asia Research. It houses offices, graduate student workstations and seminar rooms. The building was designed for up to 120-150 users but since visiting scholars and graduate students only use it periodically and faculty also have offices in their home departments, the occupancy numbers show considerable variation. At the time this study (1998), only about 60 people were working in the building.

2.2.1 Plan Form and Orientation

The site for the building was a former long, narrow 91m by 18 m parking lot bounded by a major vehicular route on the east and a wooded area to the west linking to the existing Asian Centre. The overall form of the building was largely dictated by the proportions of the selected site, the decision not to encroach on the wooded area and retain as much of the existing vegetation, and the programmatic necessity of five distinct sub-groups under one common roof.

The long axis of the building runs approximately north south (34 degrees east of south) creating extensive north-east and south-west facades. This restriction limited the ability to use passive solar gain and placed greater emphasis on high performance windows and daylighting strategies to reduce building energy use.

2.2.2 Window system

Approximately 42% of the west façade and 31% of the north-east façade consists of glazing that permits a high portion of natural light to enter the interior.

Windows

- Windows have clear double glazing with a low emissivity coating, with a U-Value of 0.9 $W/m^2 DegK$, and visible light transmission is 76%.
- The window frames are non-conducting and pressure equalized, multi-chambered modified PVC units.

Solar and Glare Control

- There are no external solar control devices integral to the building.
- The south-west facade is shaded year round by the coniferous forest along the full length of the building. This has a significant impact on daylight and the subsequent use of electric lighting in the enclosed perimeter offices along this façade.
- Interior venetian blinds are provided on all windows on the north-east façade – enclosed offices on the ground floor and the flexible open communal work space on the third floor.

2.2.3 Lighting Control

The design lighting density is 9.7 W/m^2 - less than half that of a typical office building. Lighting is controlled using a combination of manual switches, daylight monitoring dimmer switches, automatic shutoff switches for rooms when vacant.

2.2.4 Heating and Ventilation Control

By creatively using full height atria as the punctuations between the individual centres, stack ventilation is induced throughout all occupied spaces. Air enters through operable windows and fresh air vents beneath them and is exhausted through louvers near the roof in the atria - providing 100% fresh air at all times. The location and operation of the fresh air supply openings is proving crucial to their effective use.

Operable Windows

- Three large operable windows (1.3m x 2.55m high) are provided in the ground floor lounge and exhibit space adjacent to the building entry. These can be opened in one of two configurations – as inward tilted or as casements.
- Window units on the east façade have typically either:
  - Two lites (1m x 2.15m high and 0.75m x 2.15m high) - the narrower one of which can be opened, or,
  - Three lites (0.9m x 2.15m high, 0.9m x 2.15m, and 0.9m x 2.15m high) where the centre lite can be opened.

  In each case the windows can only be tilted inward with a maximum opening of 0.11m at the top.
- In the enclosed offices along the west façade, the window is fixed but additional ventilation is possible by opening doors onto small dedicated balconies or in a tilt function pivoting at their base.

Fixed Air Grilles

- Fixed air grilles consisting of a set of small holes provide a design ventilation rate of 9.4 l/s (20cfm) per person of outdoor air during the winter months. The holes are 10mm diameter on 30mm centres, giving an effective opening of 2600mm^2 per lineal metre of window.
- A sliding cover over these "trickle" vents was initially fixed in the open position to guarantee the required supply air volume.
- In some cases, the vents are beneath the full width of the window (or door) unit, in others a second set is included on the lower edge of the operable window (or door).

2.2.5 Energy Use

Meter readings from November 1998 to January 1999, adjusted to typical weather conditions, indicate that heating requirements were 17% less than the design estimate and 15% more than the *ASHRAE 90.1* prototype building for the same period. Projections suggest that the building will use 72% more heating annually than the ASHRAE 90.1 prototype and 8% less than the design estimate. Electrical metering from September 1997 to January 1999 show an electricity consumption 28% below the design estimate and

69% lower than the *ASHRAE 90.1* prototype (Marques, Pagani and Perdue, 1999). Though daylighting and the control strategies play an important part in the metered lower electrical energy use for the *C.K. Choi* building, the fact that the occupancy numbers are still well below that of its potential may be the more significant cause.

3. FINDINGS

The study both confirmed many of the findings of Bordass and Leaman (whose studies are primarily UK based) and raised other significant questions about the adoption of natural conditioned buildings in a North American context.

3.1 CULTURAL DIFFERENCES

Cultural differences between the occupants in the two case-study projects affecting satisfaction with environmental conditions and the use of manual controls, were not as evident as anticipated. That is, similar observations and trends are evident in both sets of responses. The reasons may be a result of the two projects housing somewhat unique user groups (*Tenum* – where all the tenants share an environmental ethic and *C.K. Choi* – which is the University's "flag-ship" environmental building). A larger sample is obviously necessary to validate the importance of cultural differences.

A perhaps more significant implication – and one that again can only be verified through a larger sample set - is the suggestion that there is a more fundamental and universal set of relationships between building occupants and manual controls that transcend cultural differences. If this proves to be the case, then greater differences may occur between the 'design' cultures in the two locations rather than in occupant expectations and habits. That is, the interpretation of possible occupant behaviour by building owners and the design team and the subsequent provision and sophistication of manual controls is inappropriate. The priorities that shape these differ between North America and Europe. Certainly the economics, training of design professionals, the way in which comfort requirements are codified etc., in North America have historically favoured mechanically conditioned office buildings and automated control. This has been particularly manifest in the treatment of building envelope where European practice has been a greater layering of fixed and moveable shading devices, while North America has favoured the curtain wall with tinted or reflective glazing. This distinction is still evident in the different combinations of fixed and dynamic environmental controls, and the type and location of operable vents in the two case-study buildings:

- The *Tenum* building uses a combination of fixed and dynamic external and internal controls to modify solar, natural lighting and glare, and these strategies vary with orientation. Although contextual differences impact the appropriateness of specific strategies, the *C.K. Choi* only has interior venetian blinds.
- The windows in Tenum have both upper and lower portions with different capabilities of opening, glare and solar control whereas *C.K. Choi* employs singular strategies.

This is perhaps a natural progression in the introduction of natural conditioned buildings, where considerable advances are evident in the sculpting of the *C.K. Choi* building to provide access to daylighting and ventilation, with less emphasis and refinement on the detailed performance of the windows and vents. Moreover the relationship between building form, natural conditioning, control systems and user behaviour is critical.Though *the C.K. Choi* building has a narrow foot print, the extensive coniferous tree growth to the west significantly reduces the daylight access in comparison with the exposed east facing façade. West facing offices invariably have the electric lights on all day. Offices on the ground floor have glazed dividing walls, making the visual contrast with the east-facing offices quite distinctive and the perceived imbalance signals a reaction for occupants to switch the lights on. This is seen as a modest cost compared to the unique quality of being adjacent to and have continuous view into a forest setting. In Tenum, though the depth of space is deeper than the *C.K. Choi*, the central atrium assists in a more uniformly perceived distribution of daylighting.

3.2 ACCESS TO CONTROLS

A significant issue implicit in the questionnaire responses was the occupant's location within the building and, more specifically, their proximity to a window. In most naturally conditioned buildings, the majority of control interfaces are located at the perimeter – air supply vents, solar and glare controls, operable windows etc. As such, individuals located close to a window have greater access to these systems. Occupants in these locations consistently reported a greater satisfaction with their ability to regulate thermal conditions, ventilation, and daylighting. This seems to be the case whether a user actually has greater control over the building features, or simply perceives it. Open communal office spaces have a social dynamic that can affect a person's desire or ability to alter controls, e.g., opening a window may involve "intruding" another occupant's work area. For some, walking over to a window to open it might be an inconvenience. This clearly translated into different levels of engagement with controls by occupants in open or personal offices.

Proximity to controls, however, does not necessarily translate to their effective use. The actual use of window controls depends equally on:

- The comprehension on the part of the user as to how the control strategy works.
- The physical difficulties in making adjustments to the controls.
- The range of possible degrees of change offered by the controls.
- The perceived benefits to the user after making an adjustment to the control.

3.3 VENTILATION CONTROL

The amount of air that flows through a window (ventilation capacity) depends on the *area* and *vertical* distribution of openings. These are dictated by the way and extent that the window can be opened.

In the *C.K. Choi* building:

- The cover over most of the trickle vent holes have now been altered so they can be either open or closed. The vents are typically closed year round because occupants in close proximity to them experience draughts.
- The openable windows pose two problems:
  - The bottom hinged tilt makes the maximum opening at the top of the window, approximately 3 m above floor level, reducing the direct benefits of air flow during warm periods.
  - The size and weight of windows poses ergonomic problems for users.

In *Tenum*, by contrast,

- All the exterior windows can be opened either as hoppers or casements, significantly increasing the ventilation options.
- The smaller physical size of the operable portion of the windows makes them easier to operate.

3.4 LIGHTING CONTROL

Environmental technology is most effective when it recognizes and accounts for the shortcomings of human behaviour. Whereas the occupants enjoy activating systems, automated sensors can be useful in decreasing or shutting systems off. In the *C.K. Choi's* lighting strategy:

- Electric lighting is automatically adjusted in response to the available daylight. As long as the automatic adjustments are not perceived, the occupants will not object to them. If the control technology is not refined enough to be imperceptible, then if user satisfaction is to be ensured a manual override is essential.
- Corridor lights (which cannot be regulated by the users) are automatically shut off at night. Problems only arise when occupants have unusual work schedules and are in the building when the shut-off occurs.
- Occupancy sensors shut lights off when no one is in the room, i.e., the control technology remains unobtrusive to the user. These “absence sensors” are predominantly installed in “owned” spaces and in washrooms. There are no sensors in the open-plan areas where there is a greater need for them since the sense of occupant responsibility is less.

4. CONCLUSIONS

A starting premise for this paper was that the longer tradition in Northern Europe of designing natural conditioned buildings offers direction for emerging North American practice. It was also assumed that the acceptance by users of such strategies may be culturally entrenched. Although this cannot be conclusively supported or refuted, the work points to a clear desire on the part of building occupants for access to control over environmental conditions. The results also highlight the notion that there is currently a serious mismatch between actual user comprehension and operation of control devices and those anticipated and provided by designers. Clearly designing shallow-depth floor plans creates the potential for natural lighting and ventilation, but the design sophistication and use of the operable windows, vents, daylight and solar controls dictates the overall success.

The results of the study reconfirm that building occupant's pleasure, comfort and productivity is closely linked their real and perceived control over interior environmental conditions. Such knowledge has typically translated into guidelines that specify strategies and systems to provide users with adequate control, that are comprehensible, simple to manage and use and that provide quick responses to user induced change. Simply *providing* operable windows is clearly insufficient in designing naturally conditioned buildings. The location, ergonomics and the extent of opening and their distribution profoundly affect performance and use. Design guidelines advocating natural conditioning must seek to embrace the emerging wealth of experience and knowledge on how building users interact with control systems.

There is also a clear need to provide information to owners, operators, and especially the occupants, on how to understand and properly use the skills required to operate the various daylighting and natural ventilation strategies control effectively. This should not be a one-off event at the initial occupancy of a building but an ongoing process until a culture of effective building operation is established.

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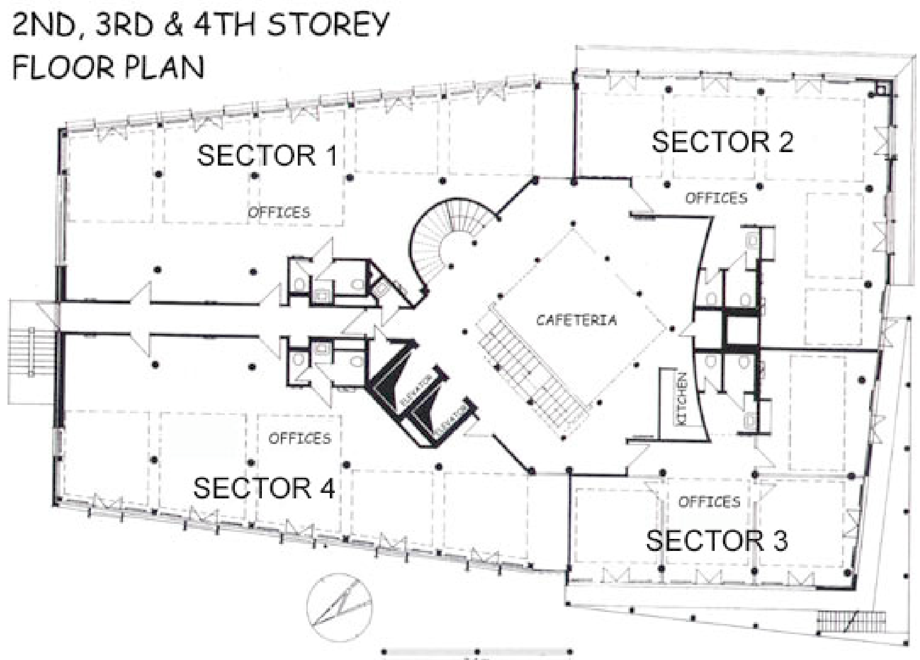

Figure 1a: Tenum Floor Plans (Tenum AG, 1996:6-7)

Figure 1b: East Façade

Figure 1c: Office Interior

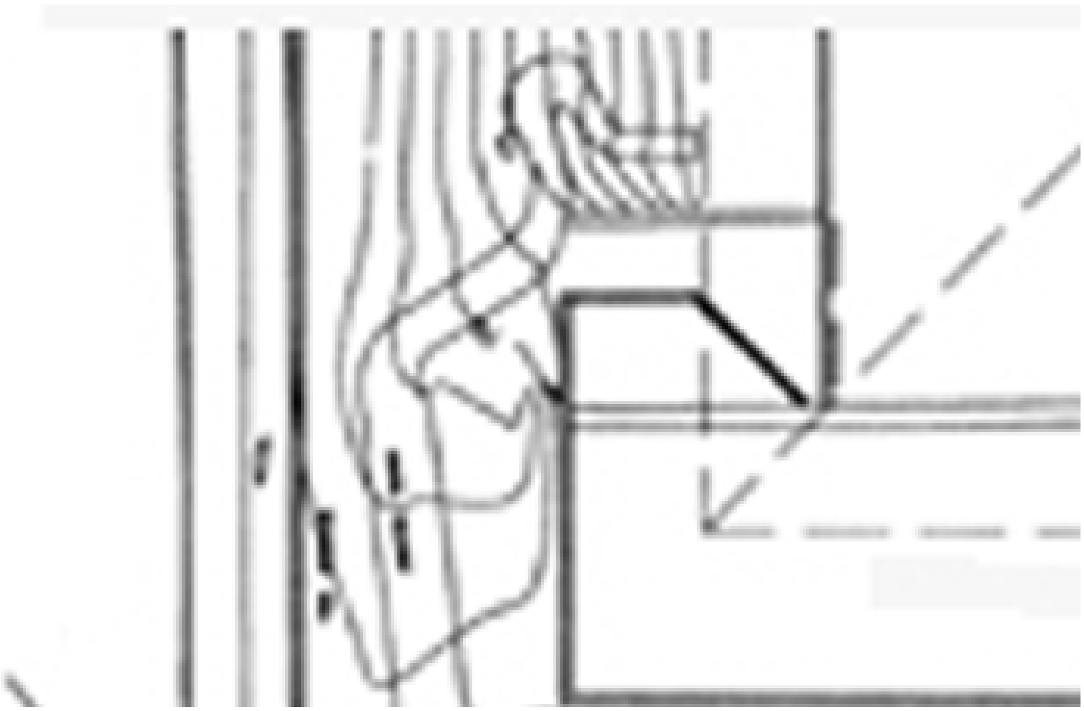

Figure 2a: C.K. Choi Site Plan (Laquian, 1996:2)

Figure 2b: NW Façade

Figure 2c: Interior (3rd Floor)