

Reconciling automated and user control of mixed-mode office buildings

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ABSTRACT

Mixed-mode buildings have the potential to operate with significantly improved energy efficiency compared to fully air conditioned buildings, particularly in moderate climates such as Brisbane. Occupants of mixed-mode buildings can have high levels of user control, which is positively linked to satisfaction and productivity. However, a reliance on user-operated controls and a reduced emphasis on the building's automated control system is difficult to tackle during design, risking poor outcomes in terms of energy efficiency, thermal comfort and user satisfaction. This paper presents results from a post-occupancy evaluation of a mixed-mode office building in suburban Brisbane. It focuses on user perspectives as well as the architectural, mechanical, and building management system design. The results are discussed more broadly in terms of user-centric design approaches for mixed-mode buildings, and emphasise the importance of an overarching control philosophy.

1. INTRODUCTION

Mixed-mode buildings, defined as those which are intended to operate using either active heating, ventilation and air conditioning (HVAC) or passive ventilation, have the potential to significantly improve reduce energy efficiency consumption by reducing HVAC running time. However, mixed mode presents a complex controls design challenge in determining which aspects of the building to automate, and when to rely on manual control by users. This question is relevant to both the selection of operating mode and to fine tuning for user comfort. Each approach has its benefits and drawbacks.

Energy savings from an automated design strategy are easier to predict in design phase, but in practice can cause frustration if the control settings do not align with user preferences. In contrast, the increased personal control which results from a user-controlled strategy is widely understood to enhance thermal comfort^[1] ^[2], and is linked to improved productivity of staff^[3], but the energy savings are more difficult to predict. Research shows that the most comfortable and productive buildings are naturally ventilated, but so too are the worst^[4]. There are therefore significant benefits to be gained by getting right the balance between automation and user control in mixed mode office design. Arguably the greatest challenge lies in achieving user acceptance; for this we must understand the needs and expectations of the users.

Leaman^[4], drawing on the large body of building evaluation research by Building Use Studies (BUS), proposed a set of design strategies aligned with user needs and expectations. The strategy selection depends on the design context:

- Whether it concerns a physical aspect of the building, or a social, cultural, or behavioural aspect of the users; and

- Whether it involves systems or processes specific to the local context, or systems and processes universal to all buildings, such as those mandated by standards and regulation.

The resulting four design contexts are shown in Figure 1 with examples relating to the building, its services, and organisational factors.

		Physical – Relating to the building			
Universal – Applicable to all buildings	1. Physical, Universal eg: Ventilation and main passive design strategies	2. Physical, Local eg: Task devices and shared manual controls	Local – Applicable only to this building		
	3. Social, Universal eg: Responsibilities and decision-making processes in operating the building	4. Social, Local eg: Atypical operating conditions and atypical users			
				Social, cultural, behavioural – Relating to the user	

Figure 1: Design contexts for building, services, and organisational factors^[4].

For each design context, Leaman proposes a general design strategy which must be implemented in order for the building to succeed:

1. Physical, Universal	Systems providing essential functions do not require user interaction and should be largely invisible to users.
2. Physical, Local	Systems providing fine tuning and requiring regular interaction should be easy for users to understand and operate.
3. Social, Universal	Organisational rules and user etiquette which ensure smooth running should be implemented and internalised as habit.
4. Social, Local	The building should be capable of responding to unpredictable changes and individual needs through flexibility and adaptability.

These four principles provide a framework for considering the case of a mixed mode office building with multiple user comfort problems. The building is of ideal climate zone, size, location, and user group profile for the successful implementation of passive design, but is performing poorly. We outline the building, services, and occupants, and describe the performance problems from the perspective of the users (as opposed to the engineers). These are discussed in the context of the approach adopted and contrasted with Leaman’s recommendations. We then describe how a user-centric approach to balancing automation and manual control and a more rigorous implementation of controls design can achieve better mixed mode buildings.

2. CASE STUDY BUILDING

The building is located on Moreton Bay at Manly, Brisbane, the southern façade backing directly only Manly Harbour and the northern façade separated from the bay only by an access road, giving good access to breezes and few constraints to effective passive design.

The climate is characterised by warm, humid summers and cool nights in winter (Figure 2). According to the adaptive comfort standard for naturally ventilated buildings^[6], Brisbane’s climate provides comfortable conditions for around two-thirds of office hours over a year. Mixed mode, utilising passive design strategies which embrace the climate, should be feasible, depending on the building size, site, and purpose.

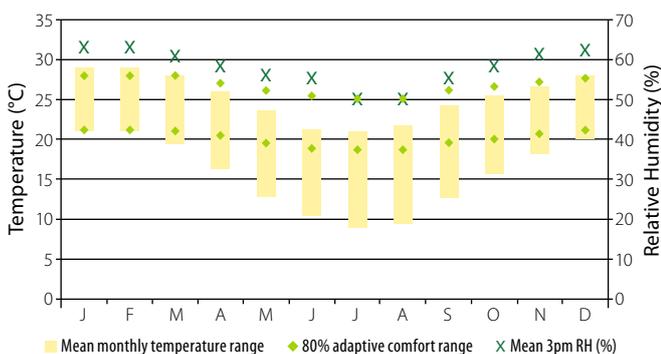


Figure 2: Mean monthly temperature ranges for Brisbane Aero 040842^[5], measured close to the bay, 10km from the site, with adaptive comfort ranges^[6]

The building is a commercial office with a net lettable area of 448m² over two storeys (Figure 3), and is leased by one organisation under a long term arrangement. The building was awarded a 5 Star Green Star Office Design v2 rating, and committed to comprehensive commissioning and building tuning. A handover of information included a design-intent report, as-built drawings and a building users’ guide.



Figure 3: Ground floor and first floor plan. (Images: Abhinav Nunkoo)

The HVAC system uses seawater cooling via a closed condenser loop. Air conditioning is provided by a two-pipe chilled/heating-hot water system which cannot operate in cooling or heating concurrently. The open plan office has floor-mounted constant volume fan coil units (FCUs) in a displacement system, as there is no ceiling for overhead delivery, supplemented by split systems. A separate air-handling unit (AHU) supplies the workstations with 100% outside air at 20°C. The workstations have a small plenum to service two diffusers per desk, similar to a car’s air conditioning system (Figure 4). This system was installed as constant volume, although a variable speed drive was originally specified on the supply fan. Users can control all of the HVAC systems via a wall-mounted rotary switch (Figure 5) which allows all of the HVAC systems, including the workstation diffusers, to be forced on or off or for switching and adjustment to be controlled by the BMS. An indicator panel shows when conditions are suitable for natural ventilation and whether the air conditioning is running (Figure 6).



Figure 4: Personal air diffuser located at workstation.



Figure 5: Wall-mounted rotary switch accessible to all users controlling the air conditioning and ventilation systems.



Figure 6: Wall-mounted natural ventilation indicator panel visible to all users.

The tenant organisation embraces environmental stewardship as a core value, and the user group is comprised of management, administrative, technical and field staff, some of whom are wholly office-based, and others undertaking a mix of office- and field-based responsibilities. The users follow a dress code which allows a wide range of clothing choices.

3. BUILDING PERFORMANCE

3.1 Post-occupancy evaluation

Post-occupancy evaluation (POE) is a process for examining building performance from the perspective of the users. It is usually carried out in the form of an occupant questionnaire covering topics of thermal comfort, air movement, air quality, lighting, acoustics, storage space and fitness for purpose, and is standardised to facilitate comparison and benchmarking.

The BUS workplace survey is a standard POE questionnaire licensed by the Usable Buildings Trust which has been used worldwide since the 1990s, and the results of which informed Leaman's recommendations. The case study users were surveyed in autumn of 2012 with a response rate of 58%. BUS analyses the results and provides benchmarked data comparing against the 49 most recently studied buildings in the Australian database, providing context. The survey was complemented by semi-structured interviews with a subset of users from the open plan space.

The survey showed that the building performed well in terms of outward appearance and image, with ratings for image to visitors, cleaning and meeting rooms being significantly better than the BUS benchmark database. While the users felt the building served their overall needs well, the building scored poorly in terms of comfort, storage space and self-assessed productivity. The users estimated that environmental conditions reduced their productivity by an average of 6%, which places the building in the bottom 20% of the database (Figure 7), indicating a particularly poorly performing building.

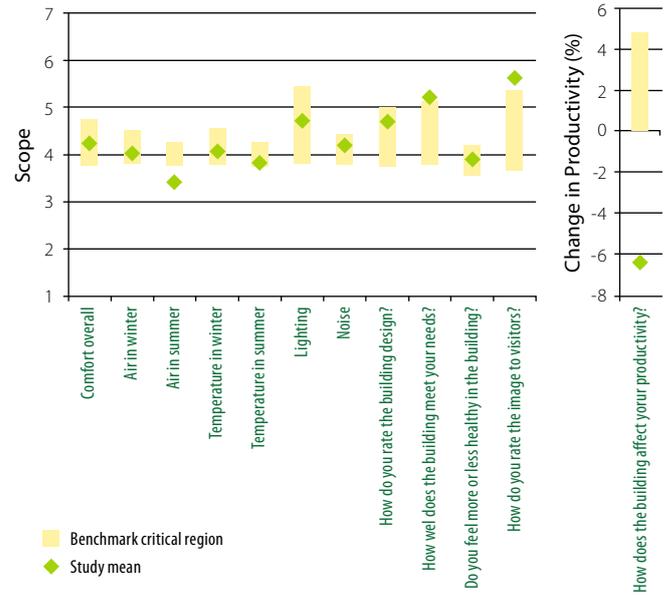


Figure 7: Summarised POE results. The study mean scores are shown in comparison to the critical region of the benchmark database: scores above the critical region are good; below the critical region are poor.

3.2 Usability issues

This section details specific performance problems in terms of their design context and their impact on the users.

3.2.1 Physical, universal systems providing essential functions

Problems with the active physical, universal systems included:

- Frequent HVAC system breakdowns and downtime;
- Excessive HVAC noise leading users to switch it off when they would not otherwise; and
- Discomfort caused by on-floor FCUs delivering excessively cold air.

The HVAC system should be invisible to the users, and should not require their intervention in order for the building to be serviced with universally applicable standards of ventilation and basic thermal comfort. These issues can be linked to a design approach which focused on energy efficiency to the extent that user needs took a back seat.

Problems with the passive physical, universal systems included:

- Extremes of glare, solar radiation and air movement at the perimeter zones; and
- Insufficient air movement in the internal zone.

A naturally ventilated building should limit the extremes of outdoor conditions via the inherent properties of its passive design^[7]. Aspects of the passive design which modulate the extremes of the climate can also be considered as providing essential functions. In achieving this, the design approach must stick to passive fundamentals of site, orientation, shading, and building form. In this case, the cross-ventilation path was too deep, requiring excessive air movement at the perimeter in order to ventilate the internal zones. This means, like the active HVAC mode, user interaction was needed to ameliorate the discomfort effects of passive mode.

Physical, local systems requiring regular interaction

The user-operated controls were either shared (air-conditioning switch, windows, and lights) or personal (workstation air diffusers, task lighting, and user-owned devices such as desk fans).

The shared physical, local systems had the following issues:

- The operating status of the air conditioning system (on, off, or managed automatically by the BMS) was not always evident to users, causing confusion, which was exacerbated by the frequent breakdowns;
- Insufficient zoning meant that areas with different HVAC needs were operated together, leading to HVAC being operated when not wanted, and vice versa; and
- Users found lighting controls confusing due to the location and type of switching provided.

Personal physical, local systems also had performance issues, including:

- Lack of fine adjustment on task air diffusers; and
- The constant volume task air system meant that adjustments by one user affected the air flow to other users sharing the same plenum, and caused warping and leakage.

From a user perspective, both the shared and the personal controls were not simple to understand and operate or lacked the degree of adaptability required. This can be tracked to imprecise specification of the user interfaces in terms of location and appearance, and loss of quality in the finished building occurring between design and construction completion.

3.2.3 Social, universal organisational rules and user etiquette

In a building which relies on a considerable degree of manual control, it makes sense that some responsibility for its correct operation lies with the users. In this case, the following issues existed relating to the social and universal design context:

- Clear processes had not been established for the operation of the shared controls, particularly the air conditioning, instead relying on ad hoc interventions.

According to Leaman, it is essential that simple organisational rules and etiquette are established and habitual. While this is largely in the hands of the occupants, it is also related to the readability of controls, the extent of zoning, and the training provided to users. Users did not know how the system was intended to operate, how to judge whether it was operating as intended, and therefore what their roles and routines should be.

3.2.4 Social, local responses to unpredictable changes and individual needs

The social, local design context relates to flexibility in the face of change or unexpected circumstances. Flexibility is a major determinant in whether a building is liked, or disliked, by users, and in this case was compromised as follows:

- A lack of manual override and an insufficient degree of adaptability; for example, building users were unable to turn off lights in holding areas where oil spill-affected wildlife were being cared for, as they were unable to override the motion sensors; and
- The workstation diffusers do provide cool air during air conditioning mode, when it is less likely to be desired, but provide ambient air during natural ventilation mode when users more sensitive to heat need cooling most, despite being an independent system intended for comfort fine-tuning.

Key to achieving a flexible design is avoiding the assumption that all operational needs have been considered by the design, and therefore a manual override should always be provided. In being able to respond to atypical user needs, the maximum level of personal control is required (although the above example could be seen as a missed opportunity rather than a design deficiency).

4. DISCUSSION

This section describes a user-centric approach to balancing automation and manual control, and proposes a rigorous implementation of controls design and POE.

4.1 Control philosophy

Clearly, the building has a range of issues which affect its usability, ranging from passive design, system faults, and both BMS and user-operated controls. It is argued that a user-centric approach to design would have improved the result and that this approach is applicable to all mixed mode buildings.

4.1.1 Systems operating in the background: simple and supporting

Whilst energy efficiency should be a priority when selecting an HVAC system, a mixed-mode concept plan should consider that greatest efficiency is achieved by a system which is turned off. In order for natural ventilation to be maximised, a simpler concept, familiar to users, would be a better match for user operability. Choosing simple over ultra-efficient has the additional benefit of avoiding reliability issues that further confuse users.

Physical, universal systems should keep necessary functions such as ventilation operating in the background, and assume that task devices will be used regardless of the operating mode. Likewise, the core principles of passive design should not be compromised and should function without user interaction. As with task devices, users will use operable aspects of passive design such as windows regardless of operating mode if they need to, and this should be embraced within the design.

4.1.2 Systems requiring regular interaction: readable and adaptive

Manual controls should be easy to find, use, and understand, and be consistent across disciplines, be they HVAC or lighting. Traditionally, controls are documented within a small section

of each discipline's specification, and the user interfaces may be installed by different contractors. This approach does not focus on the end user. A user-focused approach should explicitly state the relationship between the users (including specific users, where necessary), the building, and the BMS, under each operating mode or circumstance. It should be implemented from concept design and coordinated at design development across all disciplines. User-focused approaches should aim to:

- Match control zones across disciplines;
- Coordinate positioning of switches, with consideration given to user circulation paths and workflow patterns;
- Associate each switch with a visible change, such as a labelled status light or a "tell-tale" on air supply grills;
- Provide fully manual control for small zones such as private offices; and
- Consider systems which enhance adaptability and fine tuning, such as temperature set point adjustment and variable speed drives.

A cross-disciplinary controls specification should be considered, particularly for more complex projects. In documenting the controls:

- Be explicit – assume anything not specified will be installed incorrectly;
- Put user interfaces at the forefront, and use diagrams to show their appearance;
- Specify the controls in a user-focused manner – describe the operating strategy primarily in terms of its goal, then how the goal will be achieved under different modes (Figure 8);
- Review the controls against usability criteria^[8]; and
- Standardise the approach based on (e.g.) NatSpec.

4.1.3 Organisational rules and user etiquette: commission the users

Experience suggests that while design intent documents and building users' guides are being provided far more than in the past, they are not necessarily effective. Buildings designed and built with user needs at the forefront should be commissioned in a similar manner. There is therefore a need to provide training to users at occupancy, and again when they have settled into their roles in relation to building control. Design should focus on being either self-explanatory, or be provided with context-sensitive information such as simple co-located signage. Design teams need to emphasise the value of training, and to incorporate these services into project tenders and budgets. The value proposition is a simple one: training users will help ensure the building operates as intended and paid for, and providing users with well-functioning controls will boost their comfort and therefore productivity.

4.1.4 Unpredictable changes and individual needs: trust the users

The capacity to adapt to unforeseen circumstances should be included within the control philosophy. This means considering the intended level of user control, the building purpose including whether it is purpose-built), and future refurbishments or adaptive reuse. Strategies for making a building capable of responding to change and individual variation include:

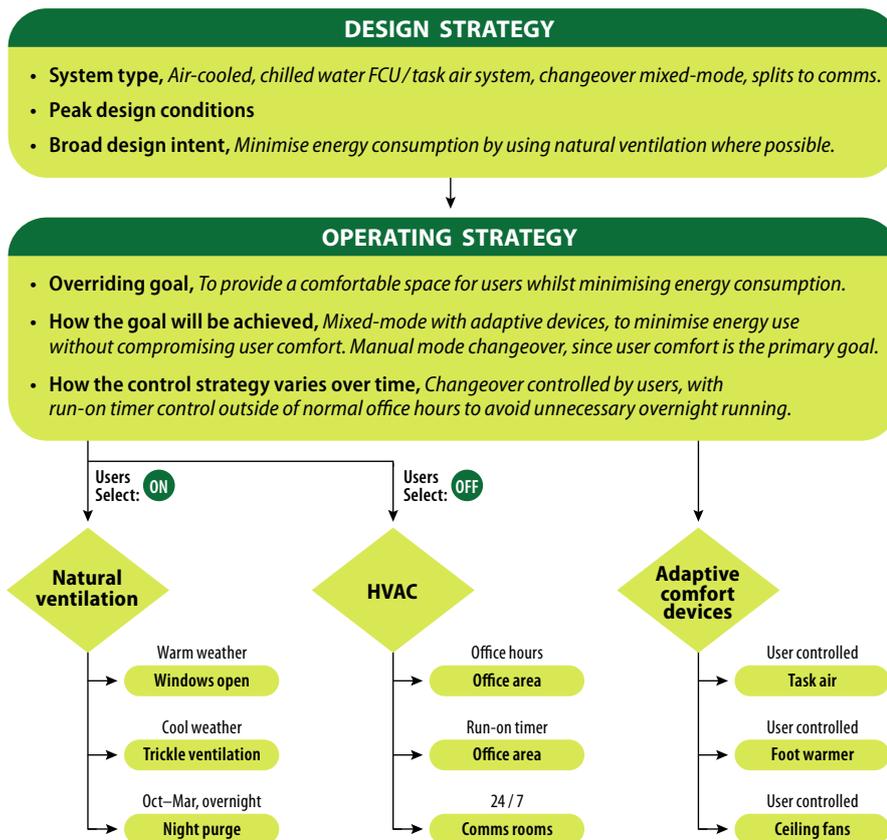


Figure 8: Example descriptive framework for a user-controlled, mixed-mode operating strategy, after^[9].

- Manual override of all automated systems;
- Flexibility in the floor plan, including workstations and partitions, and in the reticulation of services, particularly task devices; and
- Capacity to easily retrofit services in the future, especially communications services – let technology adapt to the building, rather than vice versa^[10].

4.2 Evaluate

POE provides a powerful tool for assessing buildings, identifying user problems, informing future projects, and managing knowledge. The underlying assumption of a building is that it will provide a certain level of service, and POE can provide user-focused quality assurance, similar to an energy rating. Buildings held as exemplars of design and efficiency should also be able to demonstrate that they meet the needs of users. Given that staff salaries are by far the greatest cost over the life of a building, this would seem trivial.

5. CONCLUSIONS

User-centric mixed mode building design should be based on the following principles:

- An over-arching control philosophy focused on simplicity, usability and adaptability. Leave the BMS to regulate essential needs such as ventilation and ambient lighting, and properly apply passive design principles;
- Put comfort and fine tuning in the hands of users by adopting an adaptive comfort approach;
- Document the controls consistently across disciplines, and put user needs at the forefront;
- Budget for and provide training to users, in the right form and at the right time; and
- Evaluate and learn from it.

Mixed mode buildings, implemented well, can have many benefits over fully air conditioned buildings. The risk of creating a poorly performing building can be greatly reduced with a user-focused approach.

5.1 A final note

Aside from the usability issues described, it is worth noting the implied promise to users of a green building, especially those which adopt user-operability and other unconventional designs: that the environmental and cost benefits during operation will justify the alternative approach. When users observe conspicuous wastage in the form of frequent maintenance and repairs, or a lack of off-switches, the promise is broken. ■

6. ACKNOWLEDGEMENTS

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