THERMOSTATS, CLIMATICALLY RESPONSIVE CLOTHING AND REDUCING BUILDINGS' GREENHOUSE GAS EMISSIONS

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Abstract

There has been increasing reliance on mechanical heating, ventilation and air-conditioning (HVAC) systems in order to achieve thermal comfort in office buildings. The use of universal standards for thermal comfort adopted in air-conditioned spaces often results in a large disparity between mean daily external summer temperatures and temperatures experienced indoors. The extensive overuse of air-conditioning in warm climates not only isolates us from the vagaries of the external environment, but is generally dependent on non-renewable energy.

Research conducted at the Queensland University of Technology (QUT) involved altering the thermostat set-points to two or three degrees above the normal summer setting in two air-conditioned buildings during the subtropical summer. It was expected that this minor temperature change would reduce energy usage of air-conditioned buildings and in turn, reduce greenhouse gas emissions. The aim of this project was to measure the social, economic and environmental value of a different approach to thermal comfort, facilities management, corporate culture and acceptance of the benign subtropical climate.

Surveys were administered periodically to workers in the buildings to assess their comfort levels during a four month period. Internal and external temperature, humidity and air movement were measured. Data collected was used to compare weather data and energy use of the buildings from the same period in the previous year; and also to analyse users' physiological and psychological responses, including the acceptance of appropriate climate responsive clothing as acceptable business attire.

This paper presents the findings of the research, including 'lessons learned' and a set of strategies that may be used by facilities managers who adopt a similar initiative, to ensure that users of buildings are positively engaged and consistent protocols are communicated to all stakeholders.

Keywords: thermal comfort; air conditioning; non-renewable energy; corporate culture; climate appropriate clothing;

1. Introduction

This research project set out to confirm whether a simple "no capital cost" approach to reducing a building's energy consumption, such as the adjustment of AC set-points by one or two degrees, can effect significant change in reducing greenhouse gas emissions (GHGE). Together with this technical adjustment, we monitored the occupants' responses and documented the findings of both the energy usage and survey results. From these findings and review of current literature, we share insights from our research in that we need to recognise that holistic and multi-disciplinary approaches to solutions are required to address both the causes and effects of climate change. [1]

The multi-disciplinary project team encompassing the disciplines of engineering and humanities, as well as Facilities Management (FM) staff, undertook the following tasks:

i) Resource Usage. Monitoring and measuring ventilation and cooling cycles, and electricity use during the study period.
ii) Analysis of the data for comparison with previous summer use, including weather data for each period.
iii) Determining savings in kWh, greenhouse gas emissions and actual costs.
iv) Analysis of dollar savings in comparison with total building electricity costs with a view to the potential to fund further resource efficient energy management activities on QUT campuses.
v) Devising and implementing promotional and communication strategies and materials to encourage active participation of stakeholders.
vi) Participant Response and Survey Analysis. Conducting surveys to analyse and evaluate building users' responses, both physiological and psychological.
vii) Review of Current Research. Review of current literature to identify research on the effects of reducing indoor temperature on energy usage and how occupants respond to such an action.

2. Project Setting and Background

The Queensland University of Technology (QUT) is located in Brisbane and operates 4 campuses with over 3000 staff and 38,000 students. Brisbane has a subtropical climate characterized by warm and humid summers with mild and dry winters.[2] The research was carried out at QUT's main campus at Gardens Point in Brisbane's CBD and predominantly involved the staff and buildings of the Faculty of Built Environment and Engineering (BEE). Two buildings used for the alteration of the thermostat set points were selected on the basis of their use (predominantly BEE staff, with some general administration staff), shared AC plant (they are both fully conditioned and use the same chiller plant) and location (adjacent to each other). Conditions of the buildings were varied – Building D was commissioned in 2000 and Building A was constructed circa 1919 and has been retrofitted with air-conditioning.

The spaces included a combination of open plan workstations, individual offices, lecture rooms, meeting rooms, photocopying / resource centre and a public cashier/student payment area. Participant surveys were sent out to all staff in the BEE Faculty on GP campus every two weeks. Although the physical environment would be altered in only two buildings, all staff of QUT's BEE Faculty were invited to participate, offering a "control group" of staff occupying a further four buildings.

The set-point for buildings D and A was raised from 23^{o}C to 25^{o}C on 11th December 2006, one week after notifying staff that the temperature would be changed. Building D remained on this set point until the first week in April. Building A was changed to 24^{o}C on 24 January 2007 due to a high number of combined formal and informal complaints from staff on levels 2 and 3.

3. Measuring Resource Usage

In lieu of actual metered data (because separate metering was not currently available), QUT FM contracted Multitech Solutions (consulting engineers) to undertake a series of energy simulations based

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[1] see full report on our website http://www.subtropicaldesign.bee.qut.edu.au/

[2] S V Szokolay (1983) gives mean maximum temperature as 25.4°C and mean minimum as 16.0°C in *Climatic Data and its use in Design.* Canberra: RAIA. See also Bureau of Meteorology website for climatic information at http://www.bom.gov.au/climate/averages/tables/cw_040214_All.shtml

on D block, for three common occupancy types and temperature set points, to determine energy, water and greenhouse gas emissions from each variation. The aim was "to produce energy and resource usage results that would be applicable to buildings at the University, not to simulate actual energy consumption of existing buildings."[3]

3.1 *Weather Data Collation and Analysis.* Long term climate data for Brisbane was compared with actual weather data for the period of the project to determine if this summer was significantly hotter or colder than long term averages. This data was correlated to the measured temperature and relative humidity data collected from 5 offices in the affected buildings. Further information and associated tables and graphs can be accessed in our full report on our website at http://www.subtropicaldesign.bee.qut.edu.au/

3.2 Savings *Analysis.* Data from each of the modelled scenarios was used to determine, for each occupancy:

i) the total end use electricity per year (in MWh)
ii) the primary energy use (electricity sector efficiency of .32)
iii) greenhouse gas emissions (assuming 1.05 tonnes per MWh)
iv) water usage (litres per day, then litres per year, based on occupancy assumptions)
v) annual costs (assuming 8c/kWh)
vi) chiller plant capacity (size of plant needed to supply the required cooling)

These results are shown in Table 1. It is clear to see that, for all occupancy types, raising the summer thermostat setting 2 degrees would result in savings in end use energy, associated electricity costs, primary energy, greenhouse gas emissions, water use and capital costs in the size of chiller plant required.

Table 1: Resource usage per occupancy under 3 HVAC operational scenarios

	End use Energy MWh/yr	Primary Energy MWh/yr	CO^2 emissions (tonnes/yr)	Water usage L/day	Water L/year	Electricity costs $/yr	Chiller Plant Capacity
Lecture Current	32.51	101.58	34.13	33	8125	$2,600	76
Lecture Summer	30.55	95.47	32.08	29	7150	$2,444	67
Lecture Winter	33.30	104.06	34.96	33	8125	$2,664	76
Office Current	35.86	112.05	37.65	20	4908	$2,868	46
Office Summer	33.39	104.33	35.05	18	4485	$2,671	42
Office Winter	35.78	111.80	37.56	19	4810	$2,862	45
Computer Current	133.50	417.19	140.18	50	17892	$10,680	64
Computer Summer	111.52	348.51	117.10	47	16529	$8,922	59
Computer Winter	116.44	363.88	122.26	50	17892	$9,315	64

Based on the typical occupancy usage of buildings A and D, this data was then used to calculate the savings in electricity usage, greenhouse gas emissions and costs that could be attributed to this project. This data is shown on Table 2.

Table 2: Estimated resource savings for Buildings A and D, QUT

Indicative annual savings from summer thermostat setting at 25°C			
	Block A	Block D	Combined
End Use Energy MWh / yr	13.64	51.33	64.97
Primary Energy MWh / yr	42.63	160.41	203.04
Water Use KL / yr	3.51	10.72	14.23
Greenhouse gas emissions tonnes / yr	17	61	78
Electricity costs $/yr	$1,295	$4,646	$5,941

[3] Energy Analysis for Queensland University of Technology D Block Level 1 and Lecture Theatre, Multitech Solutions, March 2007

The above indicates that there are quantifiable savings in end-use and primary energy, water use, GHGE and electricity costs that are significant enough for a building owner such as QUT, to justify further investigation into this simple method of energy savings via thermostat controls, in addition to the usual Building Management System (BMS) control strategies.

4. Current Research – Energy Usage in Commercial Building Sector

4.1 *Energy Usage*. Current research indicates that the increased need for heating and cooling of commercial buildings in urban centres is being implicated as one of the contributors to increased heat islands in cities. This, in turn, increases energy use and GHGE due to increased burning of fossil fuels.

The Australian Greenhouse Office (AGO) reports in the National Greenhouse Gas Inventory that the "commercial sector has the highest share of energy supplied as electricity and consequently the highest emissions intensity." (Dept of Env. and Heritage 2006) This picture becomes grimmer as the AGO also projects that "GHGE from the operation of commercial buildings will increase by a staggering 94% during the period 1990-2010." (Bldg. Comm. 2007) Although this scenario is in Australia, it would be similar in other developed or developing countries as well.

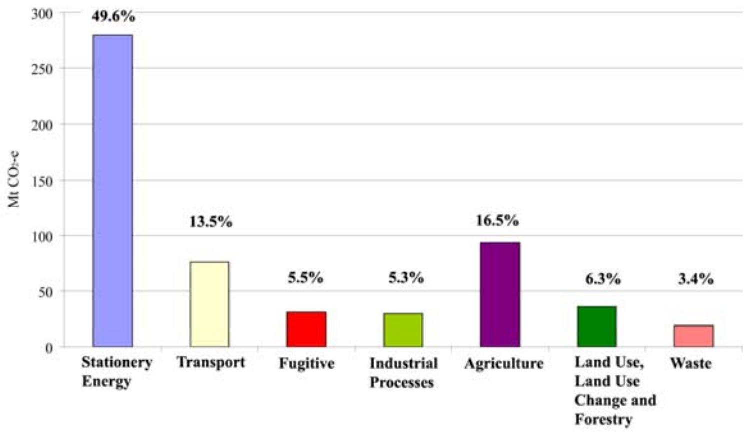

Fig.1 – C0² equivalent emissions by sector showing stationary energy as highest in 2004 in Australia (National Greenhouse Gas Inventory – Dept of Environment and Heritage & AGO, Sept 2006)

4.2 *Thermal Comfort Standards.* It has been accepted industry practice in the design of commercial or institutional buildings in Australia and many parts of the world that internal spaces need to be conditioned (heated or cooled) to between 21ºC and 24ºC. This standard of comfort is assumed as universal without regard to gender, age and level of activity; and thermal variation outside of the band is considered undesirable. However, comfort has different meanings for the mechanical engineer and for a user occupant. Thermal Comfort Standards have been derived from a purely deterministic stimulus response in laboratory settings. Recent work by de Dear, Brager and Cooper promote a more holistic approach to thermal comfort, i.e. an adaptive model of comfort which "embraces the notion that people play an instrumental role in creating their own thermal preferences." (de Dear et. al 1997) These researchers note that the ASHRAE method for defining a comfort range of acceptable temperatures is based on associating the idea of feeling neutral which ignores all contextual and cultural influences.

4.3 *Historical, Social and Cultural Influences.* Methods used to date for defining thermal comfort have placed an undue reliance on laboratory testing. This has led to a "one size fits all" method of determining air conditioning temperature and totally ignores the importance that social and cultural influences have on determining comfort level. The traditional business suit used by most male workers has become the norm in offices around the world and does not respond to local climate, thereby perpetuating a global standardization of indoor thermostat setting.

Cultures in the Middle East, for centuries, have a ritual migration within the house to spaces that are built either for the winter or summer season. This kind of connection to natural seasons seems lost to modern city living where we do not even dress for the season. Morgan and de Dear (2000) conducted a six month study of clothing behaviour of office workers in Sydney and found that "clothing insulation was constant year-round, having no correlation with outdoor temperatures." (Cole & Lorch eds. 2003)

However, countries like Japan have started to see how our cultural notion about clothing can be altered to help combat climate change. In a bid to reach its Kyoto Agreement targets, Japan has adopted a 'CoolBiz' [4] program. Under this program, all government offices were required to set the thermostat to 28°C in summer (2 – 3 degrees higher than Japan's usual practice). The program was championed by former Prime Minister Mr. Koizumi, who signalled an acceptable change of business attire through his well-known "no tie and shirtsleeves approach" which has also been adopted by cabinet ministers and other leaders of the movement. (Min. of Env., Japan 2005) A similar 12-month trial of a new parliamentary dress code is currently promoted in the Queensland Parliament in order to raise air-conditioning temperatures, thereby saving water and energy. (Hon. P. Beattie 2007).

4.4 *Social Influence:* Studies so far have pointed to the fact that social conditioning leads to physiological conditioning. Our expectations of a much cooler or warmer indoor environment in summer / winter respectively, have evolved to the point that our acceptable range has significantly narrowed.

Fishman and Pimberts' (1982) studies into the difference in thermal responses of occupants of air-conditioned and naturally ventilated offices, as cited in de Dear's 1997 report, revealed that people in air-conditioned offices "were less tolerant of higher temperatures and expected homogeneity in their thermal environment." De Dear also cites Rohles' (1977) studies which found that "Michigan subjects were more tolerant of high indoor summer temperatures (32ºC) than Texan subjects." This supports the notion that social conditioning could lead to physiological conditioning in that the "Texans took summer air-conditioning for granted and came to expect or even demand cooler temperatures" than their counterparts in cooler areas of the country. (de Dear et. al 1997, pp.25-26).

4.5 *Historical:* Brager and de Dear traced the formulation of American people's attitudes to air-conditioning back to marketing in the 1950's where increased post-war demand for air-conditioners could have been influenced by advertisements that linked air-conditioning to increased social status. Women whose homes were air-conditioned were portrayed as elegant and free from the toil of housework. People wanting a clean and healthy environment were targeted as providers of homes for happy families. The advertised images gave people "total mastery of the environment" so that "homeowners had the ability to maintain an indoor environment of constancy, independent of the natural diurnal or seasonal fluctuations outdoors" Ironically, pictures of air-conditioners beside elegant women sitting in the great outdoors overlooking mountains and the setting sun actually do not achieve what they claim to do, that is, have a more intimate relationship with nature. (Cole & Lorch eds. 2003).

4.6 *Cultural:* Cultural perceptions also influence our thermal preferences. Stern (1992) as cited by Brager and de Dear, found evidence from various studies to show that "comfort bands do vary across cultural groups." (Cole & Lorch eds. 2003) They also point out that the Japanese view artificial heating and cooling more in terms of heating/cooling the person as opposed to the American view of heating/cooling a space. The Japanese are perceived to readily adopt 'task ambient' air-conditioning systems with more individual control as this seems a logical progression from the traditional Japanese residential heating system 'kotatsu' which is a person heater placed under the dining table.

The rapid increase of a global style of architecture for our commercial buildings with its inherent large internal air-conditioning load has not only resulted in an increased energy use but has succeeded in distancing ourselves from the 'natural' world and the culture around us. Ken Yeang believes that "by designing closer to climate, you are designing closer to culture" [5] Our loss of regional distinctiveness and cultural diversity in buildings has commonly been blamed to our dulling of a sense of place or a sense of climate as well. One of the various possible reasons could be the dulling of our senses by air-conditioned spaces which offer thermal monotony with no opportunity to respond to the changing climate outside.

Real estate agents commonly consider air-conditioning as added property value and whether this promotes or reflects our cultural values may still be a debate – however, the increased use of energy is still present. Guy and Shove as cited by Chappells informs us that "air-conditioning in UK is becoming common not necessarily for comfort but constitutes a signifier of 'quality' and prestige and part of

[4] There is also a WarmBiz program that encourages heavier clothing in winter and building climate control systems are seasonally adjusted.

[5] Informal discussion at RAIA's continuing professional development seminar "Retrofitting using bioclimatic principles : looking for value adding" held in Brisbane 8 May, 2007

property value." (Chappells and Shove 2005). This attitude seems to be reflected in the South-east Queensland real estate market, with many developers believing that they will be unable to sell or rent properties that are not air-conditioned.

5. LOCAL versus CENTRAL CONTROL Over Indoor Climate Conditions

Studies in thermal comfort and office productivity show that users' perception of personal control over their local indoor climate conditions affects their feeling of well-being, level of thermal comfort and productivity level. They know they cannot control the weather but perceive that they should be able to control indoor temperature as it is artificially produced or man-made.

5.1 *Personal Control.* Rowe (1995) in de Dear et al concluded from his studies that "people have a wider tolerance of variations in indoor thermal conditions if they can exert some control over them, and that a considerably higher level of satisfaction will be reached if occupants have means of controlling the upper and lower temperature limits." (de Dear et. al 1997, p.25). It would appear that an adaptive model of comfort as promoted by de Dear would be more useful in defining thermal standards as it acknowledges that occupants play an important role in creating their own thermal preferences.

Khedari 2000 and Nicol 1999 studies cited by Peterson et. al. (2006) show that "residents of temperate climates accept 27º to 30ºC as 'comfortable' in summer, and that native populations of tropical countries will accept over 33ºC if sufficient air flow is in their personal control." This study not only reveals the cultural differences in the level of acceptance of warmer indoor temperatures but also that higher / lower temperature settings can be used for air-conditioning set points if occupants are given some mechanism of personal control. This can be in the form of an operable window and blinds, under desk space heater or small desk fan.

Further research by de Dear (2004, p.37) noted that "thermal environmental conditions perceived as unacceptable by the occupants of centrally air-conditioned buildings can be regarded as perfectly acceptable, if not preferable in a naturally ventilated building." He also concluded that "it was something about the actual context of the buildings in question, and in particular, the expectations that their occupants brought to those contexts." He noted that people who know that they do not have control over their air-conditioning temperature at work have the expectation that their thermal comfort will be automatically achieved at a constant level. On the other hand, people who worked in a naturally ventilated building know that the indoor climate will be more variable and that they need to be more actively engaged in making their indoor environment more pleasant.

5.2 *Central Control.* Though research shows that occupants are able to tolerate lower/higher indoor temperatures if given some degree of control over their indoor environment, our buildings are still mostly constructed with centralized mechanical and electrical control. Bordass (1990) notes in his paper "The Balance between Central and Local Systems" that controls are not usually seen as part of the architectural design as engineers seldom design overall systems and outline limits with the user in mind. It is evident that end users are not consulted and therefore their needs are seldom addressed.

Bordass (2001) also notes that there is a lack of feedback on the energy performance or post occupancy evaluation of a building's system from the user (local control) to facilities management (central control). Centrally controlled systems are designed for the range and not for the mean. Air-conditioning set points are usually viewed as universal settings rather than adjusted to the building or its users. De Dear's research into Adaptive Comfort Standards would encourage management with central control to have more of a connection with the users so that they have more local control. This, in turn, would promote happier occupants and a more productive workplace. Leaman and Bordass (2005) conclude that the absence of effective control adjustments to indoor climate in a building especially in generic space planned offices makes the difference between tolerable comfort and dissatisfaction.

Management with central control should be encouraged to embrace a more customer oriented approach in finetuning the building systems. Bordass advises that:

> "we need appropriate technology, and not always advanced technology: BEMS (Building Energy Management Systems) don't run themselves: they need considerable effort at the design stage to make them user-friendly, care during installation and at handover, careful

training, and constant vigilance during operation. They are a management tool and not a fit-and-forget item" (Bordass 1990).

6. Building Design

Brager and de Dear (Cole & Lorch eds. 2003) also suggest that another contributing factor to the increased use of air-conditioning is the rapid advancement in building technology and cheap energy supply after the Second World War. The ability to build large floor plates and curtain walls with sealed facades soon made mechanical air-conditioning necessary. This type of non-naturally ventilated building has to rely exclusively on a mechanical means to deliver a comfortable working environment. Perhaps this has evolved to our present day dilemma of being socially conditioned to expect an office environment that is unrelated to outside.

Leaman and Bordass (2005) advise that buildings with a management strategy developed from the beginning of design are more likely to perform better. A building is better designed and will function more efficiently if ventilation strategies are integrated with the design process rather than treated as a separate element. Bordass (2001, p.9) notes that "it is easier to design a crude building and use AC to sort out the environment than it is to prepare an integrated design." Very often building design is split into architectural and building services with little integration between them. The management of the facilities or end-user requirements are often not well considered at the design level which would sometimes negate the original intent of the building design.

Leaman and Bordass (2005) also cite Edward Tenner's 'revenge effects' in buildings, where "technical elements often work reasonably well in isolation or in theory but when included as part of a wider system of operation induce inefficiencies which ultimately affect the ability of people to perform their work properly."

Leaman and Bordass (2005) note that naturally ventilated or mixed mode buildings tend to be simpler for users to understand and operate so, in this way, the design intent is better communicated to users. "Because users understand better what ought to happen, they are more tolerant if actual performance does not quite live up to expectations." As the subtropical climate of South East Queensland lends itself to natural ventilation most of the year, it would be highly plausible that building occupants with local control will be more satisfied and productive at their workplace.

Comfort is not only determined from the nature of our physical environment but also from our attitudes. Our individual attitudes that have been moulded from our surrounding social values and our cultural milieu play a role more significant than is accounted for by architects who design buildings and engineers/maintenance personnel who determine set-points of air-conditions in commercial office buildings.

7. Current Literature

Our search of current literature and research projects, as summarised above, supports the intricate relationship between the occupant's perception of thermal comfort and the provision of that comfort via the office's HVAC systems:

i) *Thermal comfort* is difficult to define as a standard as it is perceived by occupants who are humans and thus variable in a biological and cultural sense. Application of universal air-conditioning temperature settings does not contribute to user satisfaction.

ii) *Social* norms and cultural influences define thermal comfort perceptions more strongly than previously realised.

iii) *Local vs. Central Control:* Current literature reveals that building designers struggle with providing enough local control for occupant satisfaction while maintaining adequate central control of the systems in order to run efficiently.

iv) *Building Design*; A building would be able to offer its occupants better thermal comfort if the architectural and mechanical elements were integrated right from the beginning of the design process.

8. Participant Response and Survey Analysis

With the knowledge gathered from our literature research above, the project team incorporated a survey instrument into the study both as a change management and a feedback tool that would enable the project team to monitor general levels of comfort and identify areas where intervention may be required.

Table 3: Measured Office Temperature Jan – Mar 07

		Office Measured Data				
		A105	A204	A312	D318	D521
Daily	Min ^oC	20.8	21.7	22.9	23.2	23.6
	Max ^oC	27.1	31.9	31.1	29.5	29.5
9am	Mean ^oC	25.2	26.7	27.4	27.4	27
	Min ^oC	22	22.1	23.2	25.2	24.4
	Max ^oC	26.3	30.3	29.5	28.7	27.9
	Mean RH	57%	56%	55%	51%	52%
	Max RH	67%	66%	65%	63%	65%
3pm	Mean ^oC	24.4	25.9	25.5	26	26.6
	Min ^oC	22.1	22.5	23.2	25.2	24.8
	Max ^oC	27.1	30.7	30.3	29.1	28.3
	Mean RH	56%	57%	57%	54%	49%
	Max RH	63%	67%	62%	65%	57%

8.1 *Survey Design.* A short questionnaire investigating levels of comfort and related circumstances was administered to building occupants on a fortnightly basis via email. At the conclusion of the project, a small focus voluntary group was also conducted with staff from D block. As a change management tool, it proved particularly useful with 106 staff taking the opportunity to provide feedback via the survey. Of the 106 participants, 47% were male and 53% female.

The survey included questions that enabled exploration of the relationship between levels of comfort and:

i) the age, location and submission times of the answers to the questionnaire
ii) participant llocation by building
iii) survey submission times
iv) respondents' level of clothing including footwear
v) mode of transportation to work
vi) usual method of transport and length of trip
vii) access to and use of air-conditioning in homes and car
viii) activity levels – previous 10 and 30 minutes
ix) internal and external mean temperatures of some rooms

8.2 *Change Management.* Feedback received on thermal discomfort led to data monitors being placed in some individual offices as follows:

A105 - a small cashier's office (8.96m^2) with no exterior windows
A204 - an open plan office (111.41m^2)
A312 - an open plan office (110.09m^2)
D318 - a small office (12.61m^2)
D521 - an office (12.16m^2)

The collection of actual performance data in offices was restricted to access to appropriate measuring devices. The monitors were not in place for the whole 4 months, but for between 28 and 56 days between late January and late March. Office data was analysed for 8am – 6pm only, to reflect usual occupancy parameters. 9am and 3pm data was calculated as mean, max and min as recorded every 10 minutes between 9-10 am and 3-4 pm respectively, to correlate with BOM data.

Note that the mean maximum temperature for each of the offices measured was outside of the operating parameters of the HVAC system (25^{o}C) by 1.3 to 6.9 degrees. Refer to Table 3 below.

Staff discontent in A block in mid January culminated in a meeting of occupants, the project team and Facilities Management to discuss the project and the performance of the building. From a building management perspective, this meeting led to FM looking at the building's BMS more closely whereby it was discovered that raising the set point (to 25^{o}C) had unmasked pre-existing sensor calibration errors and control algorithm errors. The AC system in A block was consequently re-commissioned, allowing the AC system to perform to its design parameters, and there was a subsequent drop in the number of official (and unofficial) complaints from staff (compared to the same period the previous summer).

8.3 *Observations.* Some observations from the survey included:

i) Over half of responses were from individuals wearing short-sleeved shirts (54%) and long trousers (53%). Approximately 8% of responses were from individuals wearing a sweater or a jacket. (This reflects normal standard of attire at QUT).

ii) The most common methods of travelling to work were walking (44%), bus (39%), car (37%) and train (29%). Respondents tended to spend approximately 20 to 30 minutes either travelling by public transport or car or walking to work.

iii) Although most of the sample have air-conditioning in their homes and/or cars, most had not used it on the day of response (e.g. 78% have air-conditioning in their cars, with 33% using air-conditioning in their cars on the day of response).

iv) Most of the sample had been sitting typing in the previous 10 minutes (76%) and previous 30 minutes (59%), with only 18% walking around in the previous 10 minutes and 29% walking around in the previous 30 minutes.

v) Participants generally found their office environments to be quite comfortable, with approximately 57% of participants finding their office environment to be slightly, moderately or very comfortable – see Figure 2.

vi) Respondents were also asked to describe whether they would like to be warmer or cooler, with 39% of respondents identifying that they would like to be cooler, 21% identifying that they would like to be warmer, and 40% saying they would not like a change to how they are feeling.

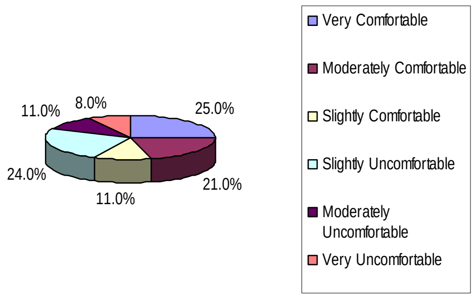

Fig.2 – Level of General Office Comfort (n=273)

Additionally the recorded temperature data for four of the offices show that the AC system was not performing to specified parameters (i.e. the staff thermal discomfort appears to be related to temperature).

Some correlations drawn from this survey include:

i) There was no significant association between general comfort levels and the **participant's location in a building.** This suggests that manipulating the HVAC settings did not significantly affect participant's perceptions of comfort.

ii) Feelings of extreme heat or cold led to feelings of discomfort suggesting that the **'tolerance'** for smaller temperature changes is an important area of investigation.

iii) Perceptions of **air movement** are an important part of people's perceptions of comfort. Refer to Figure 3.

iv) **Comfort levels** were not associated with age or gender; whether they had used air-conditioning on the way to work, the clothing worn or levels of activity prior to completion of the survey.

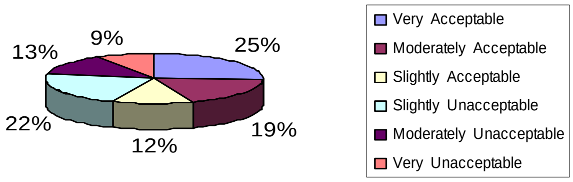

Fig.3 – Level of Acceptability of Air Movement

It is important to note that this survey was limited in a number of areas:

i) The sample size was small.
ii) A self-select sampling method was used where participants may have had particular motivations for participation.
iii) Participants could choose when they participated (e.g.: a participant may choose to participate only when he/she felt uncomfortable).
iv) There was a lack of directly correlating internal and external temperature data which limited exploration of the relationship between perceptions of comfort and internal and external temperature changes.
v) There were uneven participant numbers in experimental and control buildings.

Given these limitations, the findings from the survey cannot be extrapolated beyond this sample. They do, however, suggest some important areas for future research such as research into indoor thermal comfort in relation to occupant expectations; activity levels; past experiences; acclimatization; age; gender; race; cultural influences; and cognition (e.g. of environmental drivers as well as operational issues such as payment of electricity bills). Studies can also be carried out into the perceptions of fashion and comfort; and attitudes towards clothes / status and the adoption of climatically responsible clothing for business.

9. Main Findings

Our initial question was whether GHGE reductions could be achieved in institutional subtropical offices through altering of air-conditioning thermostats and this pilot project has revealed that it is possible to affect energy savings and GHGE reductions through this means. This research confirmed that raising the summer thermostat setting 2 degrees would result in:

i) **Cost savings** to the university through lower electricity usage and lower water usage.
ii) **Reduction in primary energy** that could have significant implications for Queensland's electricity generation and transmission / distribution infrastructure requirements.
iii) **Possible reduction in peak load** through lower AC load, affecting both QUT's electricity costs and south-east Queensland electricity network.
iv) **Reduction capital expenditure on assets** through reduction in chiller plant capacity.
v) **Opportunities for further savings** through behaviour change and procurement and maintenance practices.
vi) **No significant impact on comfort of staff** provided that HVAC systems are operating as per specifications.
vii) **Validation of incorporating a change management strategy** to maximise acceptance of change.

10. Recommendations

From our pilot research project, it was discovered that there was a strong and significant relationship between our technical manipulations of the indoor environment of the offices and the social responses to that technical adjustment. From the findings of our four month project, we share a number of recommendations:

i) **Consider holistic opportunities** and benefits in decision making because cost savings can be achieved through lowered water usage, purchase of Green Power and capital savings benefits.

ii) **Water and Capital cost reductions**: Lowering of thermostat temperature can include additional savings in other areas such as water and capital costs. Cost savings achieved through lower electricity usage also lower water usage. Capital savings can also be realised with lower energy use due to a reduction in chiller plant capacity.

iii) **Potential income** to fund further GHGE reduction strategies through a future carbon trading market. Savings generated through reduced energy usage could be invested in Green Power to further reduce GHGE by 20%.

iv) **Lighting and equipment heat load reduction**: Further energy savings opportunities could be obtained through staff awareness that heat generated from computers and lights contribute to the heat load. Behavioural changes from staff and students such as switching off lights and computers in spaces that are not in use can minimise energy use.

v) **Changes in procurement practices** such as requiring more energy efficient machines or Green star rated equipment are likely to produce significant savings.

vi) **Acknowledge the limitations of HVAC systems** as they are not perfectly calibrated systems that work all the time and in the way that they were originally programmed.

vii) **Ensure HVAC systems** are in good working order and operating correctly.

viii) **Any commissioning process** must involve the occupants and some measure of whether the aim of occupant comfort is being achieved (as opposed to whether the HVAC system is performing to its engineering design parameters).

ix) **Integration of the architectural and mechanical services** at the design stage which includes end-user requirements could lead to a better building design outcome. Our project involved retrofitted buildings where we encountered other associated problems of incorrect equipment calibration and improper commissioning.

x) **Response to cultural influences**: Energy savings have primarily focussed on the physical engineering solutions but our research reveals that energy use can be reduced through an understanding and response to the cultural and social influences of human comfort. Challenge the usual design approach to providing comfort by responding to cultural and social issues in building and HVAC systems design.

xi) **Encourage a dress code** that responds to local climate that would enable adjustment of thermostat set-points to reduce energy use.

xii) **End-users who have a better understanding** of how thermal comfort can be achieved in their space i.e. via timers or individual expectations / adjustments can attain greater satisfaction and productivity with the work space.

xiii) **Better communication:** Facilities maintenance staff who are trained to 'interpret' occupants' complaints are in a better position to identify the mechanical problem and resolve the issue satisfactorily.

xiv) **Establish a corporate environmental sustainability manifesto** for the institution to implement a formalised approach to sustainability practices in its core business.

xv) **Establish a change management process** to acknowledge social impacts of instigating energy saving measures in the work place, thereby achieving more support.

11. Conclusion

Any institution or commercial office desiring to reduce energy use by the adjustment of thermostat settings must consider the social and cultural influences that affect the provision of thermal comfort. This is crucial to the success of such an undertaking.

Our four month pilot project on air-conditioning temperature set points in two of our buildings at QUT has revealed our cultural attitudes, social habits, building design and building service methods need to be revisited in order to accomplish our goal of energy efficient buildings leading to a sustainable world.

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