OCCUPANT INTERACTION WITH A MIXED MEDIA THERMAL CLIMATE CONTROL SYSTEM IMPROVES COMFORT AND SAVES ENERGY.

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Occupants of a suite of seven offices intervene to adjust their thermal environments by manipulation of ventilation through doors and windows and by operation of supplementary cooling and heating equipment when considered necessary. Intervention actions, space temperatures and energy consumption have been monitored continuously for twelve months. Energy simulation models have been used to compare the energy consumption with an estimate of what might be expected with a conventional ducted air conditioning system for the same space. It is reported that the recorded energy consumption is approximately one quarter of that estimated for the alternative system. Occupants rate the space highly for satisfaction with the thermal environment and air quality

1.0 Introduction

Sydney, Australia, enjoys a mild climate with benign winters, mild spring and autumn weather and warm to hot summers. It is possible to be thermally comfortable indoors for much of the year without resorting to mechanical intervention when buildings are designed for passive control of energy flows and windows and doors can be operated to trim conditions as required. More or less similar conditions prevail in the heavily populated regions in Australia and de Dear ref.(1) has demonstrated that this is so for some seasons in many other parts of the world. In most places, however, there will be occasions when indoor conditions will move above or below acceptable comfort limits unless they can be modified by the operation of some form of supplementary cooling and heating equipment.

Despite the frequent availability of favourable outdoor conditions it has become customary in many parts of the world over the last thirty years or so to enclose buildings with fixed windows and to rely on mechanical cooling, heating and ventilation year round to maintain habitable conditions indoors. This is made possible by the expenditure of large quantities of cheap energy to the extent that about half the energy consumed in a typical office building is used by the climate control system.

It is now becoming evident, however, that these arrangements do not satisfy a substantial part of the occupant population. Duffy ref.(2) has suggested that *"The obvious preference for the natural environment, and the hatred of air conditioning, is increasing and is even beginning to be clearly seen in North America.* He goes on to say *"The North American idea that the building is separated from nature, hermetically controlled and engineered in such a way that it provides a stable internal environment, is not a sustainable idea."*

Rowe ref.(3) has presented scores for thermal comfort in twelve suites of offices which were studied in the period from 1992 to 1995. The sample included two in more or less free running spaces, eight that are air conditioned and two that are ventilated through doors and windows and have occupant controlled, on-demand supplementary cooling and heating. As indicated in Fig. 1 the best scores for thermal comfort were achieved in the latter two suites (numbers 1 and 11).

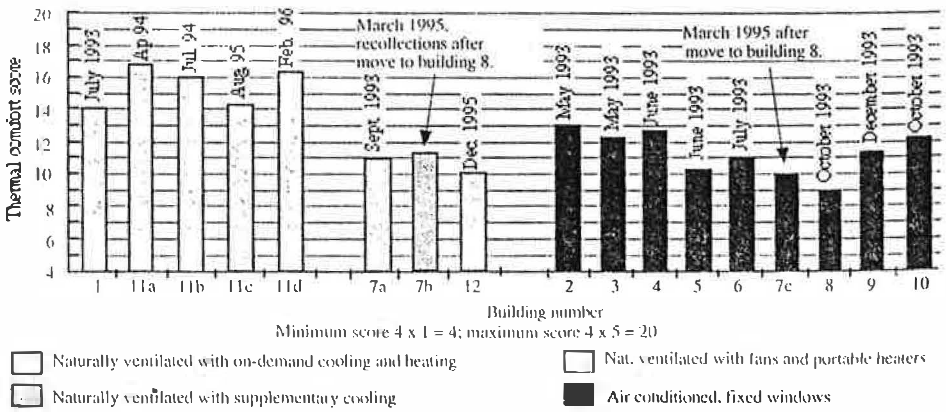

Fig. 1. Thermal comfort scores in twelve buildings. Rowe ref.(3)

This paper presents the results of continuously monitoring occupant interactions with control elements in the suite identified as number 11 in Fig. 1 over the period of twelve months from 1 August 1995 to 31 July 1996. It is reported that energy consumption is approximately a quarter of what would be expected if climate control were provided in the same space by ducted air conditioning with fixed windows. It is concluded that this very considerable saving is due to the intermittent use of the supplementary cooling and heating equipment. It seems probable that a large proportion of the occupants use passive controls by preference to maintain their comfort condition and only resort to mechanical intervention when this is not successful.

As reported in the Sydney Morning Herald ref.(4) Australia has recently come under international criticism for its reluctance to accept firm targets for the reduction of greenhouse gas emissions. In a world where opinion is moving steadily toward an understanding of the need for a the more sustainable relationship with the environment, a mixed media strategy for indoor climate control such as this paper describes represents a reasonable compromise between sustainability and comfort in buildings.

2.0 About the Project

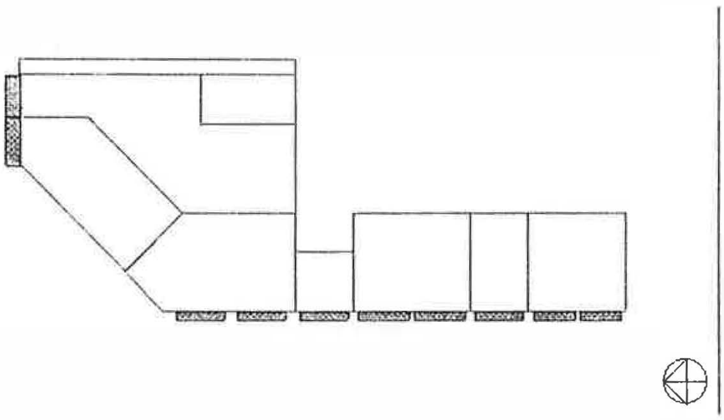

Fig. 2. The project site.

Twelve people occupy a suite of seven rooms used as offices in the architecture building at Sydney University. Total area is 210 m^2. The rooms are ventilated through windows and doors which can be adjusted as required by the occupants. The rooms have been equipped with reverse cycle refrigerated fancoil units which are available for supplementary cooling and heating under direct occupant control. Temperature set point, fan speed and direction of air supply are independently adjustable in each room. Background heating is available during the three winter months of June, July and August from the original installation of hot water panel radiators, also under direct control of occupants. The area under investigation is shown in Fig. 2.

It will be observed that all spaces are located in perimeter zones and are subject to direct influence of outdoor conditions. Main orientation is to the west with lesser exposures to north and east. External sunshades give some protection from solar heat gains. Ceilings at 3,500 mm. above the floor allow warm air to rise above the occupied zone. Heavy weight masonry construction provides thermal inertia to damp outdoor temperature swings.

Sensors on windows, external doors, fancoil units and panel heaters and temperature sensors in each room were monitored continuously to record status throughout a year of operation from 31 July 1995 till 1 August 1996. Energy consumed by the refrigeration system has been recorded from kWh meters on the supply at weekly intervals throughout the period. For comparison the energy that would be consumed by a ducted air conditioning system for the same suite of rooms was estimated using the energy simulation package ESPII ref.(5). The model operated an air cooled packaged unit with variable volume air distribution and an outdoor air economiser cycle on an hour by hour file of Sydney weather data for the test reference year 1981. As a check a simulation using the same weather data was run independently using the American simulation package DOE-2. Occupants were asked to indicate their satisfaction with thermal comfort over time on four occasions in April 1994, July 1994, August 1995 and February 1996 and the results were reported previously by Rowe ref.(3) as illustrated in Fig. 1.

3.0 Results

Mean indoor temperature was maintained on working days throughout the year in the range from 20 to 25^{0}C. During this period outdoor temperatures varied between a low of 12^{0}C in winter and a high of 37^{0}C in summer. A strong tendency was observed toward selection of indoor temperatures that were higher on warm days and lower on cool days. Temperatures in individual rooms regularly showed variations up to 2^{0}C on either side of the mean. The daily temperature range at 3 pm is illustrated in Fig. 3.

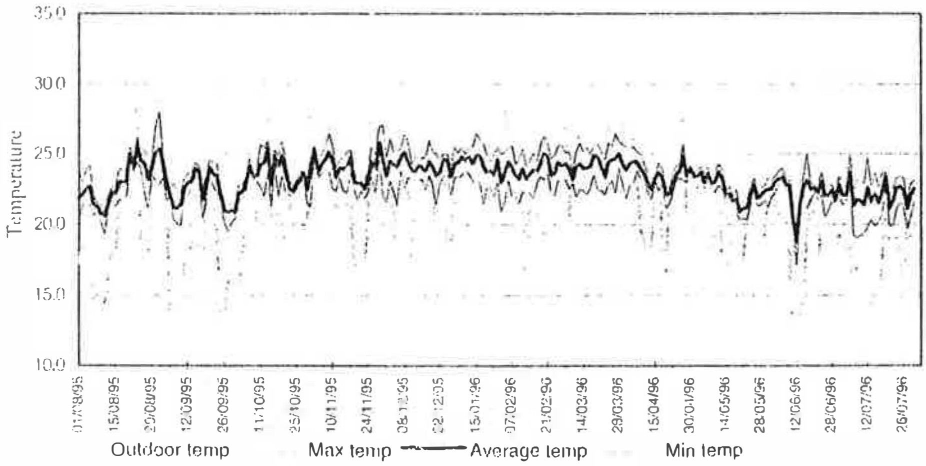

Fig. 3. Daily range of indoor and outdoor temperatures at 3 pm.

Use of the fancoil units is illustrated in figure 4 which indicates the number of units in operation on each work day at 3 pm with the concurrent outdoor temperature. It is observed that on 72 of 236 days (31 percent) no units were in operation at this time of day and on another 74 days (also 31 percent) only one was in use. Figure 4 shows that all units were in use at this time of day on only two days in mid January with four or more units used on 26 days (11 percent) in the period between early November and the end of March. This pattern suggests a tendency to turn units on only when it is necessary to modify conditions that are considered unsatisfactory.

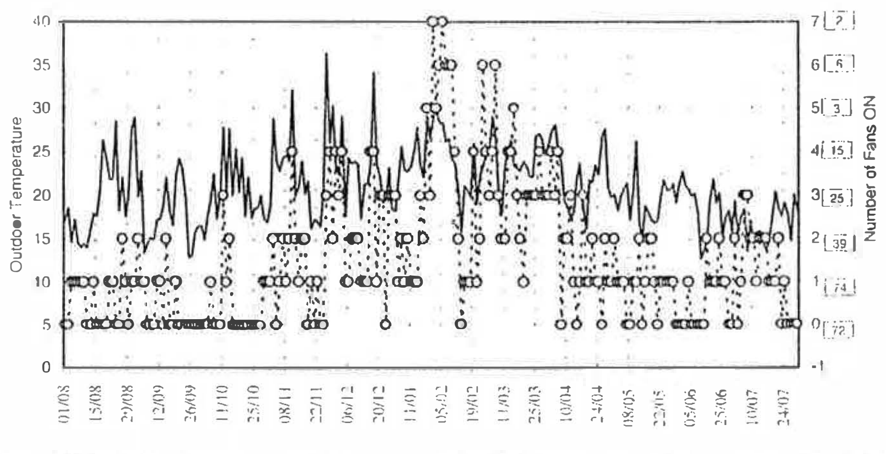

Fig. 4. Number of fancoil units operating at 3 pm on work days between 1 August 1995 and 31 July 1996.

Use of windows and external doors at the same time of day is illustrated in Fig. 5. Five of the rooms have two operable windows with one in each of the remaining two. It is noted that more than half of the windows are opened on only four occasions during the year. The relationship between outdoor temperature and number of open windows is not as distinct as that observed with fancoil units although there is a discernible tendency for more windows to be open on the milder days. These rooms are provided with adjustable glass louvres above the main window sets and infiltration is sufficient for adequate ventilation even when both windows and louvres are closed.

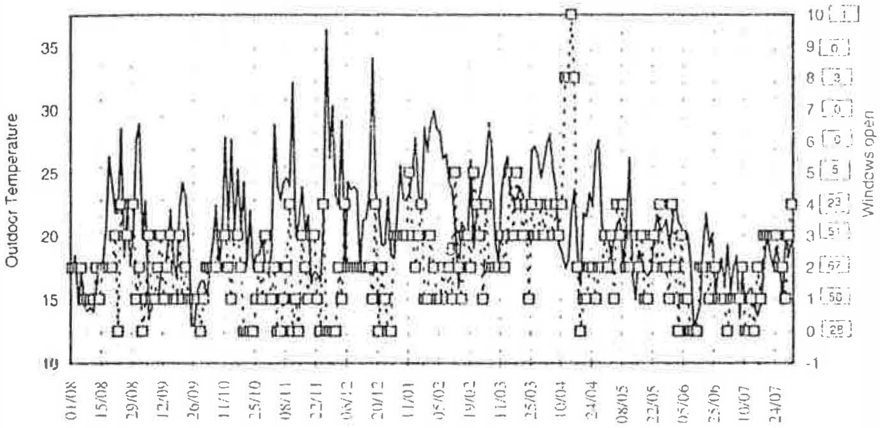

Fig. 5. Number of windows open at 3 pm on each work day between 1 August 1995 and 31 July 1996.

A total of 4115 kWh of energy was consumed by the supplementary refrigeration system in the year. Some of this was used during winter months when the system was operated in reverse cycle mode to augment the heating provided by the hotwater panel radiators. Direct comparison with the estimated total energy consumption by the alternative packaged air conditioning system is not possible because the input to the hotwater radiators could not be isolated. Compensation for this was introduced by accumulating only cooling energy in the energy simulations. The simulation with the package ESPII indicated an expected annual consumption for cooling of 15,519 kWh. The DOE-2 simulation yielded an estimate of 15,760 kWh. Figure 6 shows the monthly distribution of actual energy consumption and a comparison with estimated monthly consumption by the packaged air conditioning system as simulated by the ESPII software model.

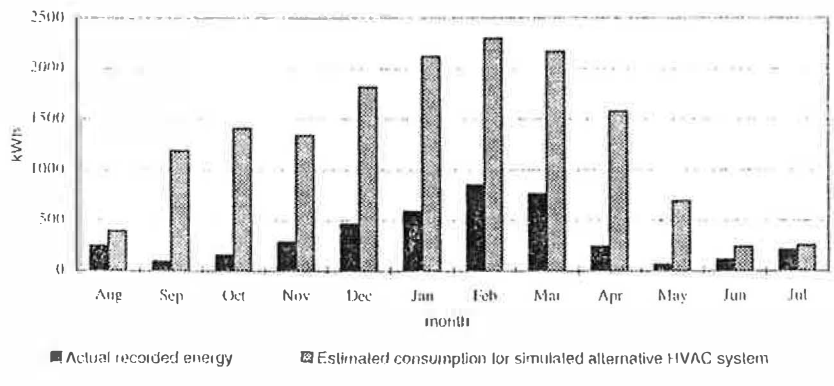

Fig. 6. Actual monthly energy consumption compared with estimated requirements for a conventional air conditioning system.

4.0 Discussion

The thermal comfort satisfaction score for this group of four men and eight women, although high, is not perfect. This is probably due, at least in part, to the shared occupancy of two rooms by three people in each and another by two with resultant compromises that are not necessary when a room has a sole occupant. A perfect score may never be achieved even without these compromises. Nevertheless scores for thermal comfort in this building are higher than those found in eight conventionally air conditioned and two free running naturally ventilated buildings.

The results are the more exciting in the light of the very low consumption of energy in comparison with what would be expected from a conventional air conditioning system. No doubt this result is to some extent due to the passive design of the building with external shading, high ceilings and heavyweight construction. However most buildings would provide occupants with opportunity for passive thermal control for part of the annual weather cycle. There is also little doubt that high comfort scores would not be recorded without the availability of supplementary mechanical control elements for use when the need is perceived.

The results reported above accord well with the findings of Bordass, Bromley and Leaman ref.(6) that building occupants are better satisfied with the indoor environment, and use less energy to achieve the desired result, when adequate control options are available to them and they can take action to rapidly correct a condition that is perceived as unsatisfactory.

5.0 Conclusions

The need to use energy in a more sustainable way and to reduce greenhouse gas emissions is being recognised widely around the world as it becomes more certain that global warming is a reality. Concurrently many people are realising that the artificial climates provided by air conditioning in modern commercial buildings are less than completely satisfactory.

This study of a mixed media office environment has shown that the occupants can achieve high levels of thermal comfort by manipulation of passive control elements with mechanical supplementation when necessary. Indoor temperatures were maintained within the range from 19 to 26°C, while outdoor temperatures ranged annually between 12 and 37°C. This was accomplished by opening windows and doors when conditions were judged to be favourable; or by the use of refrigerated cooling and reverse cycle heating when they were considered necessary. The result was achieved with an annual energy consumption estimated to be about a quarter of what would have been used by a well designed conventional air conditioning system.

Although the scale of this experiment is small and the building construction favours passive climate control the results suggest that a wider application of mixed media technology is likely to produce a more satisfactory thermal environment for the expenditure of a fraction of the energy used for full scale air conditioning, at least in the many small scale buildings that make up a large part of the urban commercial building stock and which tend to be the most wasteful of energy and the least comfortable.

It is even possible to suggest that the technique might be applied to tall buildings if those concerned could be persuaded to take a different approach to design. Mention of the idea that occupants of these structures might be allowed to open windows commonly draws negative responses. Yet early tall buildings at the end of the nineteenth century were naturally ventilated. And in the last few years a number of former tall office buildings in Sydney have been converted to residential use and, guess what! they now have operable windows and doors onto balconies because, one suspects, buyers would reject a sealed envelope.

Much is said these days about "the intelligent building". In this example sophisticated intelligence in the refrigeration equipment permits operation over a wide range of loads. Thus individuals can use their intelligence to establish conditions to their liking. If personal liking is for a gentle breeze through an open window then so much the better for personal comfort and the good of the environment.

6.0 Acknowledgements

This work was supported by funding from the Australian Department of Employment, Education, Training and Youth Affairs through the Australian Research Council. Daikin Australia Pty. Ltd. donated variable refrigerant volume equipment for the supplementary cooling and heating system; and Honeywell Ltd. donated the monitoring equipment. Colleagues participated patiently and with goodwill in the experiment; and Phil Granger and Ric Moss carried out the installation among their many other tasks.

7.0 References

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