THE SUCCESSFUL MANAGEMENT OF AIR CONDITIONED ENVIRONMENTS FOR THE CONSTRUCTION INDUSTRY

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Investment in commercial construction in Australia is being compromised by poor environmental systems management. This paper begins by explaining how building related illness, sick building syndrome and physical discomfort may negatively impact investment in construction and property.

The latest data from a unique 10 year study of 875 air-conditioned commercial buildings in Australia is presented; findings confirm the effects of widespread ignorance and poor system performance arising at all stages of the development process. While this unsatisfactory position applies to the survey sample generally, speculative low cost developments are for the first time clearly identified in the worst light.

As an aid to members of the construction and property professions not expert in matters concerning air-conditioning plant and air-handling systems an explanation of proactive and remedial measures designed to ensure the successful management of commercial environments is presented with the case study data.

Keywords: Australia, best practice, environmental systems.

INTRODUCTION

Although efficient, productive work output is seen as the essential purpose of commercial accommodation, conditions of inadequate climate control, or poor indoor air quality will inevitably affect building occupants by bringing about some degree of physical discomfort and/or illness. While personal well-being and quality of life will suffer, reduced work output and absenteeism must also be a matter of serious concern, not just to directly affected staff and their employers but all those associated with the provision of workplace accommodation. In recent years however, complaints of less than adequate conditions have become increasingly prevalent. Both naturally ventilated and mechanically ventilated/air-conditioned buildings have been implicated although comparative studies have more often than not concluded that the latter are at greater risk (Sykes 1989).

In spite of a plethora of published work dealing with issues of occupant illness and discomfort associated with building environments, there remains an appalling lack of understanding of the most basic issues even among those who ought to be responsible within the construction and property professions. Also, there would appear to be considerable confusion and bewilderment in the minds of those building occupants who are themselves the victims of unsatisfactory conditions. This paper sets out to highlight a range of commonly occurring inadequacies, improvements to which are likely to significantly reduce the incidence of illness and discomfort arising in air-

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conditioned buildings. A disturbing picture of the state of existing air-conditioned buildings provided by a decade-long evaluation of predominantly office stock is presented.

BUILDING RELATED ILLNESS AND SICK BUILDING SYNDROME

Illnesses arising in indoor environments may broadly be classified as falling into the category of *Building Related Illness* (including legionnaires disease, pontiac fever, humidifier fever, hypersensitivity pneumonitis, occupational asthma and allergic rhinitis) or *Sick Building Syndrome*. While cause may clearly be established for the former, Sick Building Syndrome is relatively ill-defined, covering a range of symptoms which tend to be short-term, including eye, nose, throat and skin irritation, dry mucous membranes, fatigue, headaches, seeming airway infections, coughing, hoarseness, wheezing, hypersensitivity, nausea and dizziness. It is also important to appreciate that while Building Related Illnesses may at one extreme be fatal, as in the case of legionnaires disease, and Sick Building Syndrome is in contrast characterized by low-level malaise, the latter is considered to be a much more widespread problem, possibly effecting individuals in up to 30% of new and remodelled buildings.

Building Related Illnesses arise through airborne contamination of one form or another as is mostly thought to be the case with Sick Building Syndrome. Healthy buildings must therefore account for the control of problematic airborne particles and micro-organisms, as well as gas and vapour contamination (Williams 1993). It is also worth noting that

1. A range of important other influences may exacerbate or speed up the onset of illnesses. Such include a run-down state of health, poor comfort, lighting and acoustics and the psychological effects resulting from lack of freedom, insufficient intellectual challenge and an inability to personally control environmental conditions while at work.
2. Building Related Illnesses will typically be accompanied by Sick Building Syndrome although Sick Building Syndrome itself will more usually be found in isolation.
3. Sick Building Syndrome may be caused by a combination of two or more contaminants the concentrations of which are typically extremely low.

AIRBORNE CONTAMINATION

Particles and biological contaminants

Of greatest concern will be the many different airborne allergic and pathogenic (i.e. allergy and infection causing) contaminants that are so small as to be able to reach into the very smallest airways in the lungs.

The extent of contamination is highly variable, being effected by such factors as the amount of the fresh air being added to systems; the cleanliness of both fresh and return air supplies and air-handling equipment itself; the state of dehumidification equipment; the type of ductwork and associated lining (if any) in use; the class and state of filter employed; the quality of housekeeping within the building itself and the extent of cooling tower maintenance. Efficient control of respirable suspended particles (RSPs) may be achieved through effective ventilation for dilution and good quality filtration together with responsible source control.

The position regarding biological contaminants is complicated by the fact that parts of air-conditioning systems are able to function as sites for the proliferation of harmful micro-organisms. Dirty and moist or wet components may provide ideal environments for fungal and bacterial growth because nutrients exist in the presence of moisture and conducive temperatures. Such a combination may well arise for instance in condensate drain pans where microbial slimes may develop in stagnant water, and on duct surfaces immediately downstream of cooling coils where relative humidity may approach 100% and dust and fibres tend to adhere to moist, rarely (if ever) cleaned surfaces. Insulation fixed as acoustic lining to ducts and air handling units may also become moist and dirty and act as a nutrient niche for microbial growth.

Unless consciously planned for, regular cleaning of air-conditioning system components is an awkward procedure which will all too often be set aside. By way of example, in a large building, numerous air handling units may be installed, each requiring time to expose the condensate pans and cooling coils; often such an installation will have taken place without the expectation of regular maintenance. Air handling units are frequently not provided with access doors or are otherwise inaccessible, such as above ceiling tiles, and maintenance consequently is difficult to perform. But rigorous maintenance is essential since it is particularly easy for fungal spores, for instance, to be airborne from proliferation sites thereby provoking allergic reactions.

Legionella pneumophila is the most undesirable bacteria that may be distributed by air handling systems; such may easily infest cooling tower plant since it naturally exists widely outdoors, particularly in soils, and thrives in the ideal conditions of temperature, nutrient and moisture offered by condenser water. Pathogenic aerosols will arise when the water itself has been contaminated, with potentially disastrous results for the condition of air in the vicinity of the cooling tower. Legionella bacteria may be transmitted in concentrated dose for instance, via fresh air intakes serving either the subject or adjacent buildings. Responsibility for rigorous maintenance of cooling tower plant together with appropriate juxtapositioning of cooling tower and fresh air intakes should be clearly understood by all those concerned with the design and maintenance of systems.

That the building interior irrevocably forms an integral part of any air handling system is a key factor often lost on those who occupy buildings. But in fact interior spaces may well give rise to airborne particle and biological contamination; for instance carpets and fabrics which are capable of harbouring considerable nutrient are known to represent fertile sites for micro-organic growth, once exposed to dampness. Chemical dusts may also arise where carpets have been shampooed. A rigorous cleaning regime is required in such circumstances.

Gas and vapour contaminants

This category includes human biofluents as well as tobacco smoke and it is essential that ventilation to AS 1668 Part 2 be put in place.

Volatile organic compounds (VOCs) which are typically associated with materials derived from petroleum products, arise in off-gassing from a variety of building products, furnishings, cleaning products and a number of other indoor and outdoor sources. Formaldehyde is one of the most commonly encountered being sourced from certain glues and resins used in wood-based products such as particle board and plywood and a variety of other widely used products including urea formaldehyde foam insulation. It is known to irritate the eyes and respiratory tract and is a suspected carcinogen. But over 5,000 VOCs have been identified in building air, including toluene, benzene, trychorethane styrene and zylene. The off-gassing is normally greatest when products are new and may continue for months or years. Even at peak output concentrations are however extremely low relative to occupational health standards applying to industrial workers.

The effects of exposure to organic compounds vary greatly and range from unpleasant odours, mucous membrane, respiratory and eye irritation to fatigue, nausea and, as mentioned, suspected cancer. It is important to note that building occupants may be exposed to many pollutants, simultaneously, and that although exposure to individual contaminants may well be extremely low, the combined effects over time may be much more significant. It is recommended that this potential hazard be approached responsibly by means of source control (including selective materials specification) and fresh air ventilation.

THE CASE STUDIES

It will be apparent from the above discussion that a range of weaknesses to do with buildings themselves have the potential, solely or in some combination, to give rise to indoor air quality problems and discomfort. In a comprehensive evaluation Grimsud *et al.* (1988) report that such will often concern air conditioning plant and air handling systems although other diverse aspects of the physical building and its use may be responsible. But the problems may commonly be overcome without a lot of effort or cost; not much more than an intelligent understanding and an appreciation of the profit to be gained through improved occupant well being is needed. Detailed explanations of regimes for improvement are provided by Hona (1997) and Ruksenas (1997).

In response to an apparently widespread lack of awareness of indoor air quality issues arising at all stages of the building procurement and post occupancy phases, a decade-long study of 875 air-conditioned buildings in Melbourne was undertaken by the author between 1989 and 1998. During the years 1989 to 1995 relatively small and low cost speculative office buildings were chosen as the focus of the study because of the rapid increase in this class of accommodation in recent years (such category now comprises approximately 50% of the available office space in Melbourne), the significant proportion of all office workers now accommodated and the relatively low standard of performance to be expected from investment buildings of this kind. From 1996 however no such restriction was applied and while a range of different building types were examined, there was also a tendency for evaluations to be performed on buildings of generally improved quality where first cost had not necessarily been so critical a driving force in the development. Important components of the study together with pertinent comment on these and related issues follows:

When digesting the data provided, it is important to note -

1. that figures are generally first provided for case study evaluations conducted during the period 1990 to 1998 i.e. a stock of 810 buildings.
2. Supplementary figures in brackets are given for evaluations of 228 small speculative office buildings conducted during the year 1990 to 1992. These figures are provided since they clearly emphasize the poorer performance arising in this category.

3. At times it is appropriate to provide figures drawn from Part 1 (1989) of the study since this varied in some ways from that which followed.

AIR SUPPLY AND DISTRIBUTION

Responsible building design should ensure that fresh air intakes are juxtaposed so that they themselves are not contaminated. The following should be borne in mind:

- contamination may be due to emissions from the building in question itself, as well as other buildings/sites in the vicinity.
- while re-entrainment of exhausts is common at roof level where sanitary vents, kitchen, toilet, air conditioning system, boiler stack and cooling tower discharges are typically located, this does not rule out problems arising elsewhere.
- unpredictable and variable wind currents may transfer outdoor contaminants to unexpected situations.
- It is difficult to set general rules for the separation of intakes and exhausts. AS1668 Part 2 does at least state however that intakes are not to be situated anywhere that will reduce intake air to a quality lower than that found in the general locality or where adjacent structures or wind effects are likely to reduce outdoor air intakes below recommended levels although it is clear that these provisions are poorly, if ever, policed.
- Air intakes should be located as far as possible from sources of motor vehicle exhaust including street traffic, car parks and loading docks.
- Airborne contamination from industry, streets, construction sites, etc. should be taken into early consideration as part of the site selection process.
- Not only is occupant health potentially effected by airborne contaminants, but undesirable odours may invade the building.
- Apart from effecting air intakes, outdoor contamination may present other problems of local or general infiltration of the building.

Results of the main survey of 810 (228) buildings showed that in 46% (63%) of cases the intakes were considered to be compromised by contamination emanating from or arising in the immediate vicinity of the subject building. Examples of sources of contamination were toilet exhaust, car park, kitchen exhaust, cooling tower, plant exhaust, spill air, truck exhaust, chemicals, fume cupboard and boiler stack, and it should be noted that more than one source may have been present in the vicinity of any particular intake. Of the main sample of 810 (228) buildings 35% (54%) of fresh air intakes were considered to be compromised by outdoor air contamination arising from other close to hand sources such as exhausts from adjacent buildings; examples of some of the external sources arising were building site, traffic, factory discharge, car park, toilet exhaust, petrol station, kitchen exhaust, incinerator, hospital exhaust, cooling tower, boiler stack.

Contaminated air generated by motor vehicles is a potential problem where there is a possible connection between car parks and occupied spaces. Such may arise by way of lift shafts or stairwells where, for instance, negative pressure in the occupied spaces developed by the air handling system together with natural thermosyphon “stack” effect or the pump action of lifts may promote infiltration of carbon monoxide (which is insidious, since it is colourless and odourless as well as being cumulative in the blood) and other contaminants. Of the 65 buildings studied in Part 1 of the investigation, 32% possessed interconnecting basement parking and interconnecting lift shafts and stairwells providing potential for contamination. It should be noted however that most of the buildings studied were of low rise form, not being equipped with lifts or subject to the sort of stack effects associated with high buildings.

The need to consider the building interior as an integral part of any air handling system has already been explained since it is here that significant problems of airborne contamination may often be sourced. Photocopiers may often arise as one such source capable of emitting a variety of particulate and gaseous contaminants as well as adding unwanted heat to the environment; chemicals used for cleaning and other purposes may often contain undesirable VOCs and odours. The investigation reported specifically on the extent of photocopiers, and whether these were mechanically exhausted, as is desirable. Of the total stock of 810 (228) buildings, 84% (90%) contained photocopiers that were not exhausted. Significantly, Part 1 (1989) of the study showed that only those buildings containing four or less copiers had exhaust systems fitted, or by contrast, the more photocopiers contained in a building the less likely they were to be exhausted.

Reduced and inadequate fresh air ventilation which arose as a cost-cutting response to the oil crisis of the early 1970s is often cited as the most significant cause of indoor air quality problems afflicting existing air-conditioned building stock. But minimum rates have in fact been recommended for many years by Ashrae and the Standards Association of Australia with the aim of avoiding unacceptable levels of human bioeffluents (including CO_2) and tobacco smoke in the first instance. The current standard AS1668-2 (1991) sets 10 l/s/person as the recommended level for office space where moderate smoking is expected. It will be apparent that apart from controlling bioeffluents and tobacco smoke, fresh air is also capable of diluting all airborne contaminants; such a strategy is advanced by those favouring the “building systems” as opposed to “source control” approach to contaminant control.

Many of the buildings investigated were in fact built at a time when the minimum Australian requirement for fresh air was set at only 3.5 l/s/p (AS 1668-1978). This aspect was examined in the 65 buildings investigated in Part 1 of the study in 1989; while 10% of the sample even failed to meet this requirement, it is of some significance that 82% of the sample failed current criteria.

An “economy cycle” enabling air handling plant to operate entirely on fresh air is a most desirable feature that may be fitted to air-conditioning systems. Such an arrangement is certainly of benefit in the Melbourne climate, since energy savings for space cooling may be obtained when outside air is cooler than return air, with refrigeration plant operation being substantially reduced. Systems fitted with air economy cycles provide the added advantage of being able to fully flush occupied spaces with fresh air, thereby promoting dilution of contaminants beyond that possible with minimum recommended rates. Significantly, systems were not fitted with economy cycles in 56% (88%) of the main sample of 810 (228) buildings.

Once air has been supplied to occupied spaces the adequacy of its distribution will be effected in part by whether or not complimentary supply and return provisions have been provided for each room, whether or not internal room obstructions impeding the ready distribution of air in occupied areas are in place, and whether or not supply air diffusers themselves are properly placed to ensure adequate air distribution in the first place. The investigation reported inadequacies in these three categories at 31% (33%), 37% (32%), and 25% (26%) of the main sample of 810 (228) buildings.

From a vital comfort perspective it must be remembered that individuals are extremely sensitive to air movement to the extent that draughts and stuffiness may readily be perceived. ISO7730 (1984) recommends maximum velocities of .15m/sec in winter and .25m/sec in summer; a lower limit of .lm/s is also desirable to avoid stuffiness. But widespread cost-cutting at the commissioning/air balancing stage often ignores the need to accommodate these levels of sensitivity, and all too frequently too much air is delivered to parts of the building and not enough to others. VAV systems should be singled out for special attention in this latter regard, to ensure that minimum air flow is in fact adequate. A lack of priority given accurate commissioning together with the inadequate maintenance already discussed, was widely evident in distortions to air distribution in the building stock examined. Sensations of cold draught were reported significantly effecting 59% (63%) of the total stock and unacceptably stuffy, drowsy conditions significantly effecting 57% (62%) of all cases.

SYSTEMS IN OPERATION

Sykes (1989) accepts, in a thorough evaluation of SBS that the incidence of the illness is far higher among air-conditioned rather than naturally ventilated buildings and, in the absence of any other clear direction, emphasizes the importance of adequate attention being given to the design, installation, commissioning and maintenance of air-conditioning systems.

There is widespread support for this view; Burge *et al.* (1987) conclude that the level of SBS is often best correlated with standards of system operation and maintenance and of general cleanliness of air conditioning systems and interior building spaces. Such attitudes are reinforced by studies of problem buildings (NIOSH 1984, HBI 1993). The former deals with 529 buildings during 1988, the latter with 412 buildings during the period 1981 to 1988. Ventilation problems were found by NIOSH in 53% and HBI in 62% of their respective samples, 33% of the HBI buildings being without any source of fresh air at all; air in 34% of the NIOSH sample was classified as contaminated; of the HBI sample 61% suffered from unsatisfactory air filter installations, 58% from demonstrably unclean air handling equipment, only 25% being regarded as well ventilated, efficiently filtered, clean and well maintained.

The need to keep air handling systems clean and dry so as to control the amplification and airborne distribution of particles and micro-organisms will already be evident. It follows that plant and plant rooms should be designed so as to facilitate rather than impede cleaning and maintenance. But alarmingly, in 37% (47%) of the main stock of 810(228) buildings significant problems of either inadequate access or unclean components were found. Often even the most basic needs of access had been overlooked, unsatisfactory provision to key components being found in the following percentages of cases: filters 21% (25%) cooling coils 23% (25%); fans 22% (24%), cooling towers/evaporative condensers 17% (24%). Filters were “locked in” with inadequate space for physical withdrawal in 10% (11%) of the stock.

The problems of inaccessibility undoubtedly gave rise in part to a significant lack of cleanliness or fouling which was reported at the following rates for individual system components over the total building stock: ducts 12% (18%); and cooling coils 11% (17%); cooling towers/evaporative condensers 7% (14%); fans 8% (12%).

And while the type of air filter employed is acknowledged as a key factor in the endeavour of keeping systems clean the survey showed that, by and large, lip service only had been paid to this function, 64% (88%) of the total building stock examined being equipped with poor performance dry or impregnated flat media panels, and only 33% (12%) being fitted with improved quality arrestance such as that provided by V form/pleated or bag type filters. The above figures clearly reflected attitudes of low priority widely afflicting the air-conditioning industry.

The need to regard occupied spaces as an integral part of air handling systems and of necessity maintain good standards of interior housekeeping was addressed by the investigation. 48% (53%) of total cases were reported with questionable fouled return air grilles, indicative of inadequate attention being given the housekeeping function.

Because of the critical influence of thermal comfort on occupant well-being in general, temperature levels were examined, general dissatisfaction being recorded at a rate of 43% (54%). Unsatisfactory temperature differentials affecting adjacent spaces were also reported in 49% (64%) of cases.

Impacting on the ability to control temperature will be thermostats that are inadequately located, adjusted or otherwise out of order. Poor location in a situation which is not properly representative of the zone being controlled is an all too common problem; the investigation variously found thermostats adversely effected by the heat output of electronic equipment, situated in sunlight or an incorrect zone. In fact weaknesses in thermostat locations were reported potentially capable of effecting 40% (47%) of the total building stock with unsatisfactorily regulated temperatures confirmed in 31% (40%) of all cases.

The lack of control afforded individuals whereby thermostats typically cannot be adjusted/accessed has, incidentally, been suggested as an unnatural feature of air-conditioned environments; a positive cost-benefit case may in fact be made for the use of small zones whereby individuals or small groups may more effectively control their own destinies. But it must be generally accepted that from a maintenance perspective that unnecessarily complex systems will complicate work. For instance elements of plant may be dispersed in numerous different locations with functions fragmented and repeated. In 54% (71%) of the total stock such was in fact the case, i.e. in only 46% (29%) was the maintenance process consciously facilitated by a centralized plant approach.

Systems should, of course, be maintained regularly by appropriately qualified individuals although it became clear during the course of the study that inadequately trained staff were often employed by contractors and that, worse still, the work of maintenance organizations themselves was rarely effectively supervised by owners, tenants or their agents. Insufficient time and resources were often devoted to contracts in a situation of little understanding of the system as installed. While 84% (92%) of the total building stock was reported to be under some sort of maintenance contract, this was guarantee that work would be satisfactorily carried out; in fact regular maintenance was found not to be followed in 16% (20%) of cases, procedures were comprehensive in only 80% (76%) of cases, and maintenance did not appear to be of a good standard in 17% (23%) of cases. As an indication of maintenance standards generally, filters were found not properly fitted thereby permitting unfiltered air bypass in 11% (18%) of the total stock, filter maintenance was excessively infrequent in 16% (18%) and irregular in 15% (13%) of all cases.

The lack of any formal post-occupancy inspection procedures by either public authority or, as is thought much more preferable, accredited consultant, to ensure adequate system performance over time, is a matter of concern. Apart from the issues already discussed, ventilation systems may be improperly adjusted, for instance, so as not to provide sufficient fresh air or, in the extreme, no fresh air at all (e.g. to conserve running costs). Ventilation controls may also be faulty; VAV boxes may be improperly adjusted/controlled so as to provide insufficient, if any air, at low load. Although continued system performance to standards such as those provided by BOMA (1991) are desirable, 80% (95%) of the total building stock investigated had not been the subject of any such post-occupancy evaluation.

CONCLUSIONS

Numerous weaknesses in the performance of air-conditioning systems and the potential effect of these weaknesses on ill health and discomfort have been identified. These concern simple physical faults in air conditioning systems and their management that should usually be possible to remedy without much difficulty or cost. A unique picture of their incidence in 875 Australian buildings is provided.

Low priority and ignorance in matters concerning the design, installation, commissioning, and on-going operation of air-conditioning systems is widely and negatively affecting the performance of commercial buildings. While this position applies to all building types generally, data presented in this paper clearly identifies speculative developers' stock in the worst light. It is apparent that where low first cost is an overriding consideration and subsequent owners and managers remain either incapable or unconvinced of the benefits to be gained that performance in indoor air quality matters is likely to be particularly poor. There is an urgent need to raise industry performance by better informing its members about the impact of simple air-conditioning system inadequacies on indoor air quality.

REFERENCES

Standards Association Australia(1978) *The use of mechanical ventilation and air-conditioning in buildings. AS1668 Part 2*. Sydney: Standards Association Australia.

Standards Association Australia(1991) *The use of mechanical ventilation and air-conditioning in buildings. AS1668 Part 2*. Sydney: Standards Association Australia.

BOAMA (1991) *Indoor air quality management: interim guidelines*. Sydney: Building Owners and Managers Association Australia.

Burge, S, Hedge, A, Wilson, S, Bass, J.H., Robertson, A (1987) Sick building syndrome: a study of 4373 office workers. *Annals of Occupational Hygiene.* **31**(44), 493–504.

Grimsud, R and Fisk, D.G. (1988) The indoor environment of commercial buildings. EM-5884 Research Project 2024-18. Berkeley: Lawrence Berkeley Laboratory.

Runeson, G. (1993) Sick building syndrome: causes and cures. Fairfax, VA: Healthy Buildings International (HBI).

Hona, T. (1997) Air-conditioning design and preventative maintenance. *In: Procs Managing Indoor Air Quality Conference*, Melbourne, October. Melbourne: Australian Institute of Refrigeration Air-conditioning and Heating.

ISO 7730 (1984) *International Standard ISO 7730: Moderate thermal environments - determination of the PMV and PPD indices and specification of the conditions for thermal comfort.* Geneva: ISO

NIOSH (1987) *Guidance for indoor air quality investigation hazard evaluations and technical assistance branch, January*. Cincinnati, Ohio: National Institute of Occupational Safety and Health.

Ruksenas, J. (1997) Air-conditioning design and preventative maintenance. *In: Procs Managing Indoor Air Quality Conference*. Australian Institute of Refrigeration Air-conditioning and Heating, Melbourne, October. Melbourne: Australian Institute of Refrigeration Air-conditioning and Heating.

Sykes, J.M. (1989) Sick building syndrome. *Building Services Engineering Research and Technology*. **10**(1), 1–11

Williams, P. (1993) An appraisal of occupant illness and discomfort in air-conditioned environments. *In: Procs IIR Improving Air Quality Conference*, Sydney, August. Sydney: International Institute of Research.