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PERCEIVED BARRIERS TO MIXED-MODE VENTILATION IN MELBOURNE COMMERCIAL BUILDINGS

An Interactive Qualifying Project Report

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by

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ABSTRACT

This project was completed for CSIRO to identify perceived barriers to implementing mixed-mode ventilation systems in commercial buildings in Melbourne, Australia. Use of the systems will reduce energy consumption, thereby lowering CO_2 production. Interviews were conducted with designers and decision makers and building occupants were surveyed about workplace conditions and environmental concern. It was determined that there is potential for the use of mixed-mode ventilation in Melbourne, but many barriers do exist, particularly lack of information about the system.

EXECUTIVE SUMMARY

We conducted our IQP with Australia's Commonwealth Scientific and Industrial Research Organization (CSIRO) from March 16th through May 3rd. The goal of the project was to investigate the barriers perceived by designers and decision makers, as well as possible user related barriers, to the implementation of mixed-mode ventilation systems in Melbourne commercial buildings. Mixed-mode systems utilize both mechanical and natural ventilation systems for the ventilation, heating, and cooling of a building. Mixed-mode ventilation systems are more efficient than conventional mechanical systems and significantly reduce energy use. This is important for many reasons. Economically it can save substantial amounts of money, and using less energy cuts down on the production of greenhouse gases such as CO_2. Mixed-mode ventilation systems take advantage of natural wind and buoyancy currents to provide a building with fresh air. Where natural openings and building shape cannot be used to provide enough comfort, low-energy mechanical fans are used.

Work on the project began at Worcester Polytechnic Institute (WPI) in Worcester, Massachusetts, with background research on the various types of ventilation, focusing on mixed-mode ventilation and studies done on barriers to its use. A methodology was then developed for assessing the barriers to mixed-mode systems in the Melbourne area. Once in Australia, background research continued and the methodology revised.

To determine the barriers to the use of mixed-mode ventilation, we spoke with two groups of people. The first was designers and decision makers. This group was made up of architects, consulting engineers, contractors, developers, and building owners. We selected interviewees based on suggestions made by our sponsor, lists of corporations found on the internet, and the suggestions of other interviewees. In all, we conducted 18 interviews:

- *7 Architects*
- *5 Consulting engineers*
- *2 Contractors*
- *2 Developers*
- *2 Building Owners*

Interviews involved filling out two questionnaires, one about the general views of the professional on mechanical and mixed-mode systems and the second on a specific building project they had worked on. Time restrictions prevented some interviewees from completing the second questionnaire. Both questionnaires were modeled after those used in the Nat**Vent**™ study conducted in Europe, with modifications made to better suite the Melbourne location and to clarify some of the questions.

The purpose of the general views questionnaire was to assess professionals' knowledge of mixed-mode ventilation systems and their perception of how its performance compares to that of more widely used mechanical systems. The questionnaire asked about general knowledge and experience, as well as comparing the two systems in both open plan and cellular offices. It also asked about expected future use of mixed-mode ventilation, government regulations restricting its use, and desirable design tools and system components.

The goal of the specific building questionnaire was to assess the importance of various parameters during the design phase of a building project. In addition to looking at the design parameters used, we also looked at who or what has the biggest influence on the final chosen design used for a building. The interviewees were given the freedom to choose any building project that they were involved with to base their responses on. Most of the projects chosen were office buildings, educational institutions, or high-rise residential/hotel buildings situated in urban areas.

In addition to the Nat**Vent**™ derived questionnaires for designers and decision makers, the group drafted an occupant survey to distribute in various office buildings in Melbourne. The goal of the survey was to gauge how office workers viewed their workplace, what their environment concerns were in a global sense, their knowledge and concern about global warming, and whether these views could be a possible barrier to the implementation of mixed-mode systems. A trial survey was conducted at the CSIRO complex to test the effectiveness of the survey. Modifications to make the survey more clear were made before its distribution to other offices. The occupant survey was distributed in four buildings in various parts of Melbourne. The surveys were dropped off at each site and collected several days later. Of the 215 surveys distributed, 93 were completed and returned.

Once all interviews had been conducted and all surveys collected, the data was analyzed for trends that may indicate what barriers existed to the use of mixed-mode ventilation. The results from the general views questionnaires given to designers and decision makers were entered into a database. Queries were made to determine how members of each profession felt about mechanical and mixed-mode systems. The data obtained by the specific building questionnaire was tallied and entered into spreadsheets, making the information easily accessible. Records of comments made during the interviews were also compiled and reviewed to find relevant information. The occupant surveys were entered into a database so that queries could be made and general trends among office workers could be established. The results were presented in charts and graphs.

Based on the data gathered, conclusions were drawn about the barriers to mixed-mode ventilation in Melbourne. Recommendations were made to CSIRO regarding the development of design materials, education of designers and the general public, and support for government regulations. Suggestions for future project work included a study on the building process, a more widespread occupant survey, and the development of marketing materials for the system targeting specific audiences. Prototypes for marketing pamphlets were drawn up as part of the project.

Mixed-mode ventilation is a technology that has the potential to improve the lives of people in Melbourne. While exact figures are not known, its widespread use would significantly reduce the consumption of energy by the commercial sector. Such a reduction could lead to decreases in carbon dioxide levels in the atmosphere, curbing the effects of global warming and providing a higher level of outdoor air quality. A reduction in energy consumption would also slow the depletion of fossil fuels as a resource.

The energy savings provided by a mixed-mode system would translate into lower running costs for owners and tenants. The potential for less expensive installation and maintenance also exists, further reducing the cost of providing a building with adequate ventilation and thermal comfort.

The occupants of buildings using mixed-mode systems would benefit from possible improvements to thermal comfort, controllability, and air quality provided by mixed-mode ventilation. For people who spend the majority of their working day in the office, providing a healthy environment that they can control is essential. Increased user satisfaction and happiness has the potential to raise productivity levels and result in a decline in absenteeism. In this way, it is possible for mixed-mode ventilation to benefit the companies that own or lease buildings in yet another manner.

By determining the barriers to the use of mixed-mode systems and suggesting ways in which these barriers can be overcome, this project has provided the information needed to promote the implementation of mixed-mode ventilation in Melbourne. It has provided CSIRO with a starting point from which it can develop strategies to increase use of the system. Work can now be done to design the materials needed to market the system to those most likely to adopt and benefit from it.

ACKNOWLEDGEMENTS

Throughout the course of this project, many people provided us with assistance in obtaining materials, locating and reaching contacts, and providing information. We would like to thank the staff at CSIRO for their help in getting needed materials and taking part in our trial survey. We would also like to thank all those who took part in our interviews and surveys for the project. Finally, we would like to acknowledge Dr. Angelo Delsante, Dr. Yuguo Li, and Mr. Steve Moller of CSIRO for the recommendations and input that helped make this project possible.

AUTHORSHIP PAGE

This report was created through the combined efforts of Seth McNear, Bradford Snow, and Phong Pham. Each group member contributed equally and was involved in the authorship of all chapters.

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1.0 INTRODUCTION

The goal of the Interactive Qualifying Project, called the IQP, is for students of Worcester Polytechnic Institute to complete a social science project relating technology and its societal implications. Beyond being a requirement for graduation, the IQP is meant to give students experience within the sphere of social science, something few technical students have. It also allows them to look at the ways in which technology impacts society, hopefully making them aware that the work they do in their chosen profession will have an effect on the world around them and forcing them to consider what that effect may be.

We conducted our IQP with Australia's Commonwealth Scientific and Industrial Research Organization (CSIRO) from March 16^{th} to May 3^{rd}. CSIRO is one of the largest scientific and industrial research institutions in the world. Created under the *Science and Industry Research Act 1949*, CSIRO is an independent statutory authority. CSIRO's vision is "to be a world-class organization vital to Australia's future". Its mission is to develop programs that will benefit Australia's industry, economy, and environment, providing social benefits to Australians and supporting Australian national and international objectives.

Our project was to investigate the barriers perceived by designers and decision makers, as well as possible user-related barriers, to the implementation of mixed-mode ventilation systems in Melbourne commercial buildings. Mixed-mode systems utilize both mechanical and natural ventilation systems for the ventilation, heating, and cooling of a building. Mixed-mode ventilation systems are more efficient than conventional mechanical systems and significantly reduce energy use. This is important for many reasons. Economically it can save substantial amounts of money, and using less energy cuts down on the production of greenhouse gases such as CO_2. Mixed-mode ventilation systems take advantage of natural wind and buoyancy currents to provide a building with fresh air. Where natural openings and building shape cannot be used to provide enough comfort, low-energy mechanical fans can be used. However, mixed-mode ventilation systems depend greatly on the climatic conditions of where they are being used. Therefore, mixed-mode ventilation systems cannot work in all geographical location.

To reach our goal of assessing perceived barriers, our IQP employed interview and survey techniques. Architects, consulting engineers, contractors, developers, and building owners were interviewed about their knowledge and experience with mixed mode systems, their perceptions of the performance of the systems, and what factors are most important when selecting the ventilation system for a building. Building occupants were surveyed to determine what aspects of the work environment most affected their ability to work, as well as how much concern they have about the natural environment. Hopefully our results can be used to promote and increase the use of mixed-mode ventilation systems in Melbourne commercial buildings, thereby improving environmental conditions in that area. The study was carried out over a seven-week period.

The results of our investigation were presented in a report. Our report will help CSIRO understand what issues need to be addressed in Melbourne in order to use the more environmentally friendly and energy efficient mixed-mode ventilation systems. Chapter 2 of this report, the Literature Review, summarizes the background information that was gathered for the project. The Methodology of Chapter 3 gives a detailed description of the procedures followed in the completion of the project. Chapters 4 and 5 contain the Results for the project and the Conclusions and Suggestions, respectively.

2.0 LITERATURE REVIEW

"Mechanical ventilation systems are often installed in office buildings where good natural ventilation would have been sufficient to obtain comfortable indoor climate and good air quality" (Aggerholm, 1998b, p. 2).

2.1 Introduction

Heating, ventilating, and cooling a commercial building is the single most important factor that contributes to the health and comfort of its occupants. An effective heating, ventilation, and air-conditioning system, from here on referred to as HVAC, upholds indoor air quality. In this report, indoor air quality refers to indoor pollution, humidity, and odor. The job of the HVAC system is to circulate the indoor air, making sure that there are air exchanges going on at all times, and to maintain the thermal comfort level the occupants desire.

There are many methods for heating, ventilating, and cooling a commercial building. The prevalent method is the use of mechanical systems. Mechanical systems meet all the demands of providing adequate heating, ventilating, and cooling to a commercial building. Mechanical HVAC systems provide the users with a great deal of flexibility in terms of controlling the system in order to meet comfort needs. These HVAC systems work well in all geographic locations, their functionality not being affected by local climate. While they usually achieve their purpose, traditional mechanical ventilation systems sometimes produce results that are more damaging than beneficial. Pollutants released by mechanical ventilation with defective filters, for example, worsen the indoor air quality. Bad indoor air quality can lead to office workers experiencing sick building syndrome. This condition leads to reduced worker productivity and more absentees. Mechanical systems can also be quite noisy, which also reduces productivity. In addition, mechanical means of ventilation require massive amounts of energy. Production of energy requires the burning of fossil fuel, a process that releases a large amount of carbon dioxide into the atmosphere. Carbon dioxide, while in moderate quantities is ecologically stable, is a major contributor to global warming when present in large amounts.

Natural ventilation is another method that can be used for ventilating and cooling a commercial building. Natural ventilation existed before mechanical systems of any kind. Natural ventilation can be as simple as opening a window or door, or as complex as having specialized channels that bring fresh outdoor air into the building. Some of the major advantages of natural ventilation are that it uses little energy, is relatively noiseless, and tends to be maintenance free. The drawbacks of natural ventilation are little or no control, dependency on local climate, and its being affected by outside air quality and, potentially, by outdoor noise.

In the global sense, the concept of mixed-mode (or hybrid) ventilation is a fairly new one, with very little information available on its design, implementation, or barriers to its use. However, mixed-mode systems have been used in the United Kingdom for the past 20 years. A recent study conducted on buildings that use the systems concluded that the implementations are generally successful and the occupants are happy with the system (Arnold, 1996).

The purpose of this literature review is to document what information exists pertaining to hybrid ventilation. It begins with a description of what hybrid ventilation is and why it is important to consider its use. Studies comparable to this project have not been conducted on hybrid ventilation. However, many studies on natural ventilation, a key component of hybrid ventilation, have been completed. The most extensive of these is the Nat**Vent**™ study conducted in Europe. It was used as a guideline for parts of this project.

For that reason, the majority of the literature used for this review pertains to natural ventilation. The framework, and many of the results of these studies, can be applied appropriately to mixed-mode ventilation. References to mixed-mode systems are made whenever possible.

Although a great deal of literature on the subject of natural ventilation exists, much of it is technical writing concerned with the mechanics of systems and their behaviors. There have been very few studies conducted to determine any barriers to the implementation of natural ventilation. This literature review examines the small number of studies that have been conducted and their results, and explains why further studies are important. Studies examining public response to attempts at implementing low energy methods are examined as well to show that correlations can be found between the two. We have also gathered information on issues that we believe are possible barriers to the success of a ventilation system, including air quality and comfort level studies. Barriers specific to Melbourne are also discussed.

2.2 Mixed-Mode Ventilation Systems

Traditionally a building's ventilation strategy was seen as either a) open and exclusively naturally ventilated through air intakes, windows and ductworks; or b) completely sealed and exclusively mechanically ventilated through fans, air-conditioning systems, and filters. Many buildings have started to use both mechanical and natural means to ventilate. Mixed-mode ventilation systems are a strategic combination of both natural and mechanical means. In order to be a true mixed-mode system, both the natural and mechanical systems must work together to provide ventilation and cooling. Figure 2.1 shows an example of a building using mixed-mode ventilation.

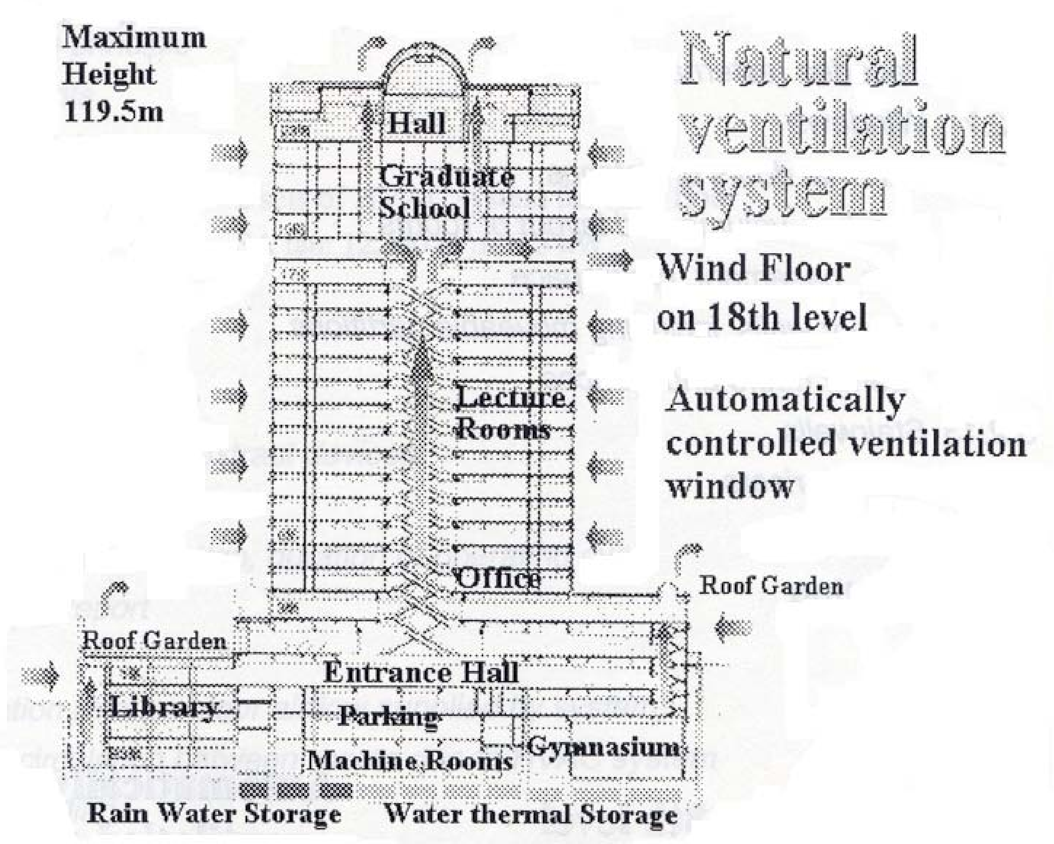

Figure 2.1: Liberty Tower of Meiji University, Tokyo, Japan (Chikamoto, Kato, and Ikaga, 1999).

2.2.1 Approaches to Mixed-Mode Systems

In their paper Mixed-mode Ventilation for Buildings, Bordass and Jaunzens (1998) describe what mixed-mode ventilation is, the approaches to designing it, and the benefits of its use. They are the source for information found in Sections 2.2 and 2.3.

There are three common approaches to the design of a mixed-mode ventilation system:

1. Contingency Basis – This approach involves installing systems designed to account for future changes in the use of the building.

2. Complementary Basis – In this method, mechanical and natural ventilation systems are present together but working in parallel or on a system of controlled changeover.

3. Zoned Basis – This approach allows for different uses for conditions in different areas of the building.

Contingency Design

The goal of a contingency-based design is to plan for the future. With this approach provisions are made to allow for the future addition or removal of mechanical systems. This provides a means for changes in the use of a building such as from storage to human occupancy, or an increase in the building's occupant density. Provisions are made to greatly increase the building's ability to adapt to new roles and changes in the environment. Contingency designs provide designated routes and holes for future services and extra space to allow changes to happen quickly and easily. Such changes could take place in individual rooms, sections of a building or whole floors at a time (Bordass & Jaunzens, 1996).

Complementary

Complementary designs combine both natural and mechanical cooling ventilation systems. This is the most common approach. A complementary system can be operated either concurrently or by changeover.

Concurrent Operation

When operated in this mode the natural and mechanical systems work together. A common example is a building with mechanical ventilation that has opening windows. When used in a building that has been designed with high thermal stability, heat recovery, night cooling, and efficient fans, this can be a very energy efficient solution. The mechanical ventilation systems can also be used to remove hot or polluted air.

Changeover Operation

With a changeover based system, the mechanical and natural ventilation components of the ventilation solution operate together in a variety of ways and can be changed depending on the season, time of day, occupancy levels, or weather. Changeover systems have the ability to be very energy efficient as they adapt to changes and provide the most effective solution for current conditions. Their disadvantage is that they often require sophisticated sensors and control logic, which can be expensive. They can also be very complicated systems that are difficult for occupants to use (Bordass & Jaunzens, 1996). It should be noted that it is very important to have a proper and simple control strategy in order to keep the system from accidentally switching over to only mechanical ventilation and losing the advantages of the natural system.

Zoned

A zone-based design has different systems for different locations in the building. The system used is based on the room size, what the room is used for, occupancy levels, and objects contained within the room. Careful planning is required in a zone design because certain parts of the building may be cooled better than others and this may cause conflict among the occupants of different zones.

2.3 Reasons for Using Mixed-Mode Systems

Mixed-mode systems have a number of potential benefits if designed correctly. When compared to a mechanical system, a hybrid solution uses less energy, has lower running costs, is more environmentally friendly, and enhances occupant satisfaction. When compared to a fully naturally ventilated solution a hybrid system provides far more flexibility for space and building layout, more user control, adaptability for upgrades, and enhanced occupant satisfaction.

2.3.1 Adaptability

A building that is adaptable will provide more enduring value over time to its owners and occupants. For instance, changes in the local temperature over the years could have serious impact on an exclusively naturally ventilated building. If a building went from being an open plan to being partitioned, in the case, for example, of turning a warehouse into an office building, the mechanical ventilation capabilities would provide far more flexibility than natural ventilation alone. According to Bordass and Jaunzens (1996), the adaptability of the system has the potential to be a strong selling point but needs to be stressed to building owners and users more effectively.

2.3.2 User Satisfaction

Regardless of how comfortable an artificial, mechanically generated environment is, users appreciate the added control and comfort that comes from being able to open a window. Surveys have shown that users prefer to have a window that opens if at all possible (Bordass and Jaunzens, 1998).

2.3.3 Energy Conservation and Pollution Reduction

Mixed-mode systems save energy and use less refrigerants, thereby emitting fewer pollutants and cutting down on greenhouse gas production. When a mixed-mode system is properly installed, less mechanical ventilation is needed, cutting energy requirements. In addition, the less time mechanical systems are running the less greenhouse gases and pollutants will be produced.

2.3.4 Environmental Concerns

Since mixed-mode buildings are more adaptable to change, they can survive longer, so there is less need for constructing new buildings to replace old ones. This fact, coupled with the energy saving aspects of a mixed-mode ventilation solution, reduces the impact of a building on the environment.

2.3.5 Cost

Since mechanical systems are only installed and used when needed to supplement the natural ventilation system, the overall cost of running the system can be dramatically less than purely mechanical systems. The mechanical portion of a mixed-mode system will, in most cases, be less complex than that of a system relying solely on mechanical components, making maintenance easier and less expensive. Even if the system costs more initially, the long- term savings on operating costs could potentially pay for it.

2.4 The Melbourne Project

Melbourne, where the climate is mild, is a promising location for using mixed-mode systems in office buildings. In the state of Victoria, Australia, 49% of the energy used by the commercial sector is used for heating, ventilating and air-conditioning (Prasad, 1994). Mixed-mode systems are far more energy efficient which, when implemented properly, can help reduce energy consumption.

A study done by Deni Greene Consulting Services (1990) found that if rapid implementation of energy efficiency in buildings were carried out, there would be a 60% improvement in efficiency for HVAC systems (Prasad, 1994). Nevertheless, implementation of mixed-mode systems has been virtually nonexistent in Melbourne. However, studies of energy saving potential in buildings point to the need for the implementation of such an energy efficient system (Prasad, 1994).

2.4.1 Energy Consumption and Carbon Dioxide Emission

Reduced energy consumption is an important reason to use mixed-mode systems instead of pure mechanical ventilation systems. Energy is produced from the combustion of fossil fuels (coal, oil, and natural gas), a process that emits a tremendous amount of carbon dioxide. At the current rate of growth, world demand for energy will increase by almost 65% between 1995 and 2020. Since there are few alternative means of energy production, most of the need for energy will be met by fossil fuels, which will make CO_2 emission increase at a comparable rate (Priddle, 1998).

In industrialized countries, this process accounts for about 80% of all greenhouse gas emission. Consequently, this leads to global warming, which is discussed in the next section. Seventy percent of energy use and 63% of CO_2 emissions (the primary greenhouse gas) in the commercial sector of Australia is attributed to the heating, ventilation and cooling systems in office buildings (Australian Greenhouse Office, 1999). According to Dr. Yuguo Li, the building sector of Australia contributes more than 20% of the country's greenhouse gas, 40% of which comes from the commercial sector (CSIRO, 1999).

2.4.2 Global Warming (The Greenhouse Effect)

The emission of certain gases creates a serious environmental problem. These gases, known as greenhouse gases, remain in the Earth's atmosphere. They cause the sun's rays to become trapped in the atmosphere rather than bouncing off the planet and into space. It is believed that this occurrence is slowly causing the atmospheric temperature of the planet to rise, a trend known as global warming or the Greenhouse Effect. The implications of the Greenhouse Effect include drastic climate changes affecting global weather patterns and the melting of the polar ice caps.

The Kyoto Protocol on Climate Change is an agreement adopted by 38 industrialized countries to reduce their greenhouse gas emissions by an overall 5% from 1990 levels between 2008 and 2012. Under the Kyoto Protocol, Australia is obligated to reduce its rate of greenhouse gas emissions to 8% above the 1990 level by 2008-2012 (Australian Greenhouse Office, 1999). In order to reach this target, the Australian government has adopted an interim target goal to reduce greenhouse gas emissions by 20% of the 1988 level by 2005. This is the minimum level that is needed, given that the level required to stabilize the atmosphere is much higher. The Inter-Governmental Panel on Climate Change (IPCC) reported that a reduction in greenhouse gas emissions of 60% is needed in order to stabilize the atmosphere (Lowe, 1994).

Currently, Australia emits more carbon dioxide per person than most other countries. Thus a solution to global warming would be a different approach to the use of energy in cities. At the 16th AIVC Conference, guest speaker John Millhone suggested that because energy production is the main source of carbon dioxide (through the burning of fossil fuels), the best way to "contain" the problem of the Greenhouse Effect is through energy efficiency efforts (Orme, 1995). According to Mr. Lee Solsbery, head of the IEA's Energy and Environment Division, the energy demand must be reduced in order to address CO_2 emissions related to energy production, which is 33% of Australia's total emissions (Prasad, 1994).

In Australia, offices account for 27% of the total greenhouse gas emission in the commercial sector. Since HVAC contributes a significant amount to energy usage in commercial buildings, the use of mixed-mode ventilation systems is imperative to energy reduction efforts.

2.5 Existing Studies of Barriers and Case Studies

There have been few studies conducted on the barriers that inhibit the implementation of natural ventilation in office buildings. The most comprehensive to date is the Nat**Vent**™ study conducted in Europe between 1996 and 1997. It is our primary source for information pertaining to barriers to natural ventilation. The study had three parts, or work packages. The first focused on the barriers perceived by those in charge of the design and decision making regarding ventilation systems. The second part involved the monitoring of 19 naturally ventilated buildings to measure their effectiveness. Air flow, temperature, humidity, and carbon dioxide levels were monitored in both winter and summer. The work package also included surveys of the occupants' comfort levels. The responses to these surveys were used to determine comfort levels by comparing them to the results of the monitoring activities at the time the survey was conducted. The third work package focused on the development of components for systems such as heat recovery systems, air-flow inlets, and controls for night cooling (Nat**Vent**™ Work Package 2, 1998).

The first part of the study, the work package most closely related to this project, spanned 7 European nations and involved interviews with 107 professionals. Table 2.1 shows the breakdown of countries and interviewees.

Table 2.1: Extent of Nat**Vent**™ Study (Adapted from Aggerholm, 1998c, p. 5).

	Architects	Consultant Engineers	Contractors	Developers	Owners	Government dec. makers	Total
Belgium	7	3	1	1	1	1	14
Denmark	5	3	2	2	2	1	15
Switzerland	5	3	2	2	2	1	15
Norway	5	3	2	2	2	1	15
Netherlands	5	2	-	-	2	-	9
Sweden	5	3	2	-	2	1	13
Great Britain	10	7	2	2	3	2	26
Total	42	24	11	9	14	7	107

In each country the professionals were given a questionnaire regarding general views on the use of natural ventilation. Most participants were also given a second questionnaire pertaining to specific building projects. The general questionnaire asked about the knowledge and experience with natural ventilation of the designers and decision makers. They were questioned regarding the project fee, ease of design, effectiveness, performance, and restrictions associated with natural ventilation. Finally, they were asked what new tools and components would contribute to an increase in the use of natural ventilation, and about their predictions for its use in the future.

The specific questionnaire pertaining to building projects had the professionals describe a specific project, the types of rooms within that project, and what factors had influenced their choice of ventilation system for each room.

A second source that provides some insight into the effectiveness of mixed-mode system is a technical brochure from CADDET that describes a building in Zurich that utilizes a combination of mechanical and natural ventilation. The triangular building contains four atria, each mechanically ventilated, that increase the amount of daylight allowed into the building and are used to ventilate surrounding offices (CADDET, 1997).

In a study conducted by David Rowe and Cong Truc Dinh at the University of Sydney, naturally ventilated rooms were equipped with heating and cooling equipment, allowing the occupant to control their environment by opening a window or running one of the mechanical apparatus. The goal was to establish how use of the mechanical systems to supplement the natural one varied from season to season as well as the temperatures the occupants attempted to maintain. A comparison was then made between the amount of energy consumed by the mixed-mode rooms and similar rooms using only mechanical systems (Rowe & Dinh, 1999). They concluded that the mixed-mode room consumed less energy and the mechanical heating and cooling was not used often.

2.6 Knowledge of Natural Ventilation

As with any new technique, the extent to which people are aware of it has an enormous impact on how much it is used and therefore, how mainstream it will become. The logical approach to exploring the barriers to a given idea or technology is to first find out how much is known about it outside the small circle of specialists who have made it their focus.

2.6.1 Extent of Knowledge

The Nat**Vent**™ study found that the knowledge of natural ventilation among the professionals of Europe was somewhat varied. Almost all of the people interviewed felt that their knowledge of ordinary natural ventilation was equal to that of mechanical ventilation. However, their level of knowledge was significantly less for specially designed natural ventilation systems (Aggerholm, 1998c). The same pattern was found regarding experience with natural ventilation. Most study participants had experience with ordinary natural ventilation but not with special design ventilation.

2.6.2 Design Perceptions

The extent to which architects and consultant engineers feel competent to design a ventilation system will play a role in how often it is used. Perhaps the most important is the ease of design. If a system takes twice as many hours to design with little advantage to the building's function, it is far less likely to be implemented. The results of the European study show that the interviewees all thought that natural ventilation systems would be just as easy to design as mechanical ones. They were questioned regarding four different cases. These were natural ventilation in open air and cellular offices and mechanical ventilation in open air and cellular offices (Aggerholm, 1998c).

2.6.3 Areas Where Knowledge is Lacking

Lack of knowledge is one of the major barriers to the use of natural ventilation. As the interviewees of the Nat**Vent**™ study observed, the absence of any guidelines for designing buildings with natural ventilation, namely specially designed systems, is very prohibitive. Nearly all of the professionals interviewed stated that no handbooks, standards, or studies are available for use in designing buildings with natural ventilation. Architects participating in the study mentioned that because mechanical ventilation is the standard approach, more people are experienced with it, making it currently easier to design (Aggerholm, 1998c).

Paralleling the results of the Nat**Vent**™ study were statements made by Ake Blomsterberg (J&W Consulting Engineers, Sweden) at the 20th AIVC conference. He stressed that the design of traditional ventilation systems requires few complex calculations on the part of designers. Instead, they are able to take information from handbooks, computer programs, "rules of thumb" and other guidelines. This method is much easier and as a result, preferred. Blomsterberg cites this as being the main reason that newer systems that use less energy are not introduced (Orme, 1999). Until similar materials are available for natural ventilation, it will not gain acceptance nor see widespread use.

2.6.4 Solutions to the Problem of Information

The most obvious solution to the lack of information is to provide more information. The question then becomes, "What sort of information is most needed?" The professionals interviewed in Europe made many suggestions about design tools that would help make the use of natural ventilation more widespread. Some of the tools mentioned include better guidelines and design rules, graphic computer programs (both simple and advanced), case studies of buildings using natural ventilation, calculation standards for the system, and long-term performance studies (Aggerholm, 1998c). The second Work Package of the Nat**Vent**™ study states that what information is available needs to be distributed among designers and decision makers so that they are aware of the potential benefits of natural ventilation systems (Nat**Vent**™ Work Package 2, 1998).

The HybVent conference was an effort by the International Energy Agency (IEA) to promote the use of hybrid ventilation in new and retrofitted office buildings. It attempted to do so through the development of control strategies and performance prediction methods. The goals of the conference included creating methods of predicting how a hybrid system would perform in a given building, techniques for measuring its effectiveness, ways to control the system efficiently, and methods for promoting the use of hybrid systems. The three-year working phase began in August 1998 and is expect to conclude in July 2001 (Heiselberg, 1998).

However, increased knowledge can also be a detriment to the widespread use of hybrid systems. It is possible to misuse what information is available, thereby making it a barrier to the realization of mixed-mode systems. Complex, detailed programs allow designers to develop systems that are far more elaborate than necessary and are not used because of their complexity. Depending on the building, a simple design is more appropriate and functional than an intricate one (Bordass & Jaunzens, 1996).

2.7 Perceived Performance

The perceived performance of natural ventilation among the people in charge of deciding what mode of ventilation a building uses represents another possible barrier to its implementation. If designers and decision makers feel that the system will not perform well, then they will not use it.

2.7.1 Effectiveness

The study conducted in Europe shows that many believed mechanical ventilation to be superior to natural ventilation. They felt mechanical systems perform better in the areas of cooling, removing pollutants and smells, stopping outside noise and pollutants from entering the building, and preventing draught (Aggerholm, 1998c).

The effectiveness of a mixed-mode system is more difficult to compare to mechanical due to the relatively small number of real world examples of its use. Overall operation of hybrid ventilation systems is easy, and, when designed properly, they are effective at providing a comfortable indoor environment. However, experience has shown that changeover systems can accidentally run the mechanical ventilation portions for longer than the designers expected. This results in energy loss. Regardless of such difficulties, the potential for energy efficiency is present. When the outside temperature is lower than that inside the building, the use of natural ventilation is appropriate (Arnold, 1996). In places where there is a potential for a long period of natural ventilation use, there would be a great potential for reducing energy use.

In general, when compared to a fully air-conditioned system a mixed-mode system will use less energy. However, systems using high-powered fans with long hours of operation can still waste energy. It is important to choose the right types of components for a system (Bordass & Jaunzens, 1998).

2.7.2 User Satisfaction

The satisfaction of the people using a ventilation system must be anticipated by designers when they select a system. If the occupants of a building are not satisfied with the system, the time and money spent building it are wasted. When questioned about user satisfaction with natural ventilation systems, participants in the Nat**Vent**™ study felt that building occupants would be as happy with natural ventilation as they would be with mechanical. One nation's study indicated that users might even prefer natural ventilation over mechanical (Aggerholm, 1998a). Studies done by Finnegan and cited by Rowe and Dinh (1999) suggest that fewer people reported the symptoms of sick building syndrome in naturally ventilated buildings than in their air conditioned counter parts. There is also evidence that user satisfaction with natural ventilation is higher because occupants of mechanically ventilated buildings have higher expectations of the environment created by the system (Oseland, 1998).

2.8 Economic Factors

Economic factors that may act as barriers to the implementation of natural ventilation include the overall cost of installing, operating, and maintaining the system, how these costs compare to those of mechanical systems, and the availability of the resources required to construct the system.

2.8.1 Cost

When compared to mechanical systems, the cost of construction, operation and maintenance is less for natural ventilation. Exceptions to this include when the heat recovery of natural ventilation is very low or when the system has special requirements such as chimneys or increased volume (Aggerholm, 1998c).

The cost of mixed-mode systems is highly variable because they are usually custom-designed for the building and the surrounding environment. A hybrid ventilation system that provides the needed comfort and meets all safety guidelines could therefore potentially be very costly. It must be remembered that economic comparison is generally made between a fully naturally ventilated and a fully mechanically ventilated system. Maintenance costs tend to be lower for a mixed-mode solution than for a purely mechanical solution. Furthermore, the cost of implementing a mixed-mode system should not be more than that of the operating cost of a mechanical system over its life cycle (Bordass & Jaunzens, 1998). In the University of Sydney study, the rooms fitted with the mechanical components used less energy than similar rooms using only a mechanical system (Rowe & Dinh, 1999). Likewise, Delsante and Vik (2000) state that as long as electrical heating is not used, mixed-mode systems will require less power than mechanical ones.

2.8.2 Material Supply

The availability of the materials and components needed to construct a natural ventilation system will quite obviously vary from location to location. Such components could include special openings, windows, and vents, among others. There was no mention of material supply in the European study. Delsante and Vik (2000) suggest that until mixed-mode systems are widely used, many components will have to be custom-made, greatly increasing the installation costs for the system.

2.9 Safety

The safety of the people building and using a ventilation system is yet another factor in its selection. In order for a system to be used, it must meet the construction codes and regulations of the local government. However, as pointed out by Delsante and Vik (2000), "….codes and standards are not barriers unless they are more restrictive than requirements from users or building owners".

2.9.1 Government Codes and Regulations

The study conducted in Europe showed that, in general, architects and building owners think that local regulations are very limiting while, not surprisingly, government decision makers think that their regulations are the least limiting (Aggerholm, 1998c).

The most common government regulation involves requirements for compartmentalizing a building to prevent the possible spread of fire, which can occur through openings between rooms such as those used for natural ventilation. Other regulations exist regarding the removal of smoke from areas of the building that people must pass through in order to exit during a fire. Australia has such regulations requiring that a building have a way to control smoke. The cross sections of openings between compartments in a building would have to be small for the purpose of reducing the spread of fire and smoke. This would necessitate the use of fans to achieve normal ventilation, raising energy consumption (Delsante & Vik, 2000).

In Australia, a provision for permanent windows that can be opened as well as mechanical ventilation that meets Australian Standards is required by the Building Code of Australia (1990) (Brown, 1997). However, Australia also has regulations pertaining to the noise levels permitted in offices and schools. In offices it is generally 35-45 db and for schools it is 25-40 db. Components to reduce noise transmission would also block airflow paths. Like smaller openings for fire regulations, this too would require the use of fan power to ventilate a building, meaning more spent on installation and running costs (Delsante & Vik, 2000).

There is some question as to whether current international standards for ventilation are adequate for ensuring the health of building occupants. In many cases, complaints have been made about buildings that meet local standards and regulations. Abdou and Lorsch

(1994) suggest that the standards used in buildings may need to be reevaluated to better meet the needs of occupants.

2.9.2 Adequate Air Flow and Filtration

Adequate airflow is essential to the health of the occupants of a building. If the airflow provided by a ventilation system is not sufficient to maintain high levels of air quality, the system is not safe to use. Airflow is usually measured as volumetric flow rate (liters or cubic meters per second), per occupant airflow rate (liters or meters per second per person), air change rate (hourly air change rate), or mass flow rate (kilograms per second) (www.aivc.org/faq/faq20.html).

In some types of buildings in Australia, high airflow rates are required. In order to achieve such rates, widespread use of fans is necessary, leading to the use of a great deal of energy. Current airflow requirements are 36^3 $m^3/(h*p)$ in offices and 36^4 $m^3/(h*p)$ for schools (Delsante and Vik, 2000).

As with any form of ventilation, the effectiveness of hybrid ventilation at filtering out contaminants that are hazardous to the occupants' health will depend largely on the air quality of the surrounding area. The effects of the surrounding area are discussed in a later section.

2.9.3 Building Security

When natural ventilation is considered in the design of the building, there are security issues as well. A building with large external openings is more susceptible to theft than one with a completely sealed exterior. According to the Nat**Vent**™ report, ventilation components such as grills are available to prevent burglary (Nat**Vent**™ Work Package 2, 1998).

2.10 Known Barriers in Australia

Implementation of strategies for making an energy efficient building in Australia has always been the responsibility of the designers. Even so, this has not been successful. There are various reasons for this, which range from the lack of appropriate knowledge to being restricted by the cost of the project. There is also no need for developers to implement mixed-mode systems if operational costs are the responsibility of tenants. Therefore, client awareness and motivation is often a barrier. Another problem is the climatic conditions in Australia. It does not get cold enough in the winter to demand enforcement of any energy efficiency standards for heating buildings. However, summer temperatures are high enough so that standards could be set for energy efficiency regarding the air conditioning of buildings. Despite this fact, no such standards are currently in place for commercial buildings.

2.11 Renovation of Existing Buildings

Very little information is currently available regarding renovating existing buildings to use natural or mixed-mode ventilation. Much more needs to be done by way of studies analyzing the processes involved and the barriers that exist. “Retrofit activities are very important, because the existing building stock is substantially larger in size than the new building stock. The number of buildings in need of renovation is therefore significant” (Orme, 1995). For the past twenty years or more, buildings have been designed so that they are sealed off from their surroundings. This makes it difficult to renovate such buildings to use mixed-mode systems. For this reason, the International Energy Agency believes the potential of older buildings to be renovated for using a hybrid ventilation system is greater than that of newer more recently built buildings (Heiselberg, 1998).

2.12 User Studies

While the Nat**Vent**^{TM} study provides useful insights into the barriers to natural ventilation as perceived by designers and decision makers, it does not address barriers that may exist from the users' point of view. That was not its purpose. However, that does not mean user-oriented barriers should or can be dismissed. At the Roomvent '98 conference, Professors Eimund Skaret (Norwegian Building Research Institute) and P. Ole Fanger (Technical University of Denmark) emphasized the key role played by user acceptance on the implementation of natural ventilation. Professor Fanger promoted user-oriented solutions to ventilation "by stressing that air distribution in rooms must serve human occupants and that any measure of 'quality' should include the extent to which human requirements are met" (Orme, 1998). He then went on to list these requirements. He emphasized the sense of indoor air quality of the occupants, that no health problems should be caused by the air quality, no draughts allowed, noise kept to a minimum, and that thermal comfort levels should be met.

User acceptance and satisfaction derive from the comfort levels provided by the system and in the case of natural ventilation, environmental concerns. The main reason for implementing natural ventilation is to reduce energy consumption, thereby reducing CO_2 production. If users are not concerned about the environment, they are far less likely to be accepting of a new system that may reduce their comfort, even to a small degree. These aspects of user-related barriers are examined in the following sections.

2.13 Comfort Levels

The comfort of the occupants of a building is an important factor when considering the ventilation system to be used. Comfort may derive from temperature, air quality, and noise level. In addition to being one of the most important factors in ventilation design, user comfort is also one of the more difficult to attain while using low-energy methods. It is often difficult to simultaneously achieve all aspects of user comfort with a ventilation system, especially with natural ventilation. This may be a barrier to its use. Citing Peter Wouters at the 18th AIVC Conference, Orme states,

> "Amongst other things, his conclusions took the view that natural ventilation for IAQ (indoor air quality) control requires completely different provisions than natural ventilation for thermal comfort control in summer. Furthermore, he proposed that the attainment of an optimum balance between IAQ and energy use is not evident with the natural ventilation devices presently available, although self-regulating devices may further remedy this situation" (Orme, 1997).

The second part of the Nat**Vent**™ study also comments on the two conflicting goals of natural ventilation, noting that the inlet opening sizes and air flow requirements for each are different. For instance, during the winter season when heating is used, airflow for ventilation (indoor air quality) results in the loss of energy. However, in the summer the airflow required for obtaining thermal comfort is far greater than that needed for IAQ (Nat**Vent**™ Work Package 2, 1998).

Temperature

One of the biggest factors in user satisfaction within a building is the temperature that is maintained by the ventilation system. It has been shown to have a direct effect on the productivity of workers. In a study on the effects of temperature on productivity, Lorsch and Abdou (1994, p. 895) found, "When temperatures were either too high or too low, error rates and accident rates increased." The lowest occurrence of accidents is between temperatures of 19.4^{o}C and 20.6^{o}C, but these temperatures do not reflect the greatest comfort levels (Lorsch & Abdou, 1994, p. 900).

The type of system used in a building can have an effect on what is considered by occupants to be acceptable temperature ranges. In his study on acceptable temperature ranges, Oseland (1998) found that the range of temperatures over which people feel comfortable is greater in naturally ventilated offices than in air-conditioned ones. The study also found that people using natural ventilation were accepting of temperatures 1.9^{o}C cooler than in mechanically ventilated offices in winter. However, for the summer, the acceptable temperature of naturally ventilated offices is 1.8^{o}C cooler than in air-conditioned ones (Oseland, 1998, 1023). Overall user satisfaction was calculated in terms of percentages. The percentage of building occupants who found temperature conditions acceptable in winter in natural ventilation environments was 76.0% (73.8% found conditions comfortable) versus 70.0% (71.7% comfortable) in air-conditioned buildings. In the summer, 69.0% of natural ventilation users found temperatures acceptable (64.2% comfortable) while 73.0% of air-conditioning users felt the temperature were acceptable (72.5% comfortable) (Oseland, 1998, p. 1026).

The study done by Rowe and Dinh found that the preferred summer temperature range in the rooms was 22 to 26 degrees Celsius. The range in winter was 20 to 24 degrees Celsius. When temperatures fell outside of these ranges, the room occupants tended to use the heating or cooling apparatus to achieve thermal comfort (Rowe & Dinh, 1999, p. 116).

The Nat**Vent**^{TM} study found that many of the 19 buildings monitored had problems with summertime temperatures being too high, this complaint being widespread among occupants. It suggests that more acceptable temperature ranges can be achieved by minimizing the effects of solar loads on a building (Nat**Vent**™ Work Package 2, 1998). The Zurich building cited earlier is able to maintain temperatures of less than 28°C during hot stretches in summer (CADDET, 1997). Due to the difference in climate between Zurich and Melbourne, it is unclear how effective a similar system would be at keeping Australian buildings cool. In Sydney, Rowe and Dinh (1999) found that occupant satisfaction with both the temperature and air quality of the retrofitted rooms improved after the devices were added and consumed comparatively less energy. It was also shown that thermal comfort can have an effect on how people perceive the air quality of their environment (Rowe & Dinh, 1999).

Air Quality

The level of air quality provided by a building's ventilation system is of great importance, because it affects both the health and productivity of the inhabitants. Some indoor pollutants are radon, formaldehyde, asbestos and mineral fibers, ammonia, mercury, allergens, hydrocarbons, lead, and carbon dioxide (Brown, 1997). Exposure to indoor pollutants can be a major health issue. Exposure of building occupants to indoor pollutants in Australia is regulated by occupational health and safety legislation that is enacted at the state level (Brown, 1997).

Often occupants' perceptions of air quality count as much as actual conditions. There have been cases where, due to employee complaints, tests were run on the indoor air of a building. The test results showed no grounds for the complaints, but the building was purged anyway. After the ventilation, tests were again run. The results were no different than before, yet employee complaints dropped significantly (Abdou & Lorsch, 1994). "The reason is that the belief itself may affect productivity…..and the belief is likely to affect many other aspects of working life" (Abdou & Lorsch, 1994, p. 910).

Poor indoor air quality can be costly in other ways as well. According to Larry Little, Chief of CSIRO Building Construction and Engineering, daily exposure to indoor pollutants could be costing Australia up to $12 billion per year in health related and productivity issues (CSIRO, 1999).

Concern for air quality is a barrier to natural ventilation systems with intakes on lower storeys and exhaust at the upper levels. Air travels up through the building due to temperature differences between the air outside and inside the building. This phenomenon is known as the stack effect. Often stagnant air accumulates on the upper storeys of buildings using this type of ventilation, lowering air quality significantly (Tassou, 1998).

The effectiveness of ventilation systems at providing good quality indoor air varies. Abdou and Lorsch, citing a study done by Woods, claim that often indoor air is four to ten times more contaminated than outdoor air (Abdou and Lorsch, 1994). This claim is supported by the United States Environmental Protection Agency, which ranks pollution within buildings in the top five risks to public health (United States Environmental Protection Agency, 1998). Each building in the Nat**Vent**™ study was found to have acceptable levels of indoor air quality (Nat**Vent**™ Work Package 2, 1998). In the building described by CADDET, "Good quality air is provided to the naturally ventilated offices all around the atria" (CADDET, 1997). It is unclear whether the air used in this 'natural ventilation' is produced by the mechanical systems within the atria or is taken directly from the outside environment.

Since indoor air quality is a major issue, in order to fully promote the use of mixed-mode systems in Melbourne, more studies should be conducted on indoor air quality and occupants' perceptions of it.

Noise

The amount of noise associated with a ventilation system can also have an impact on the comfort of the occupants of a building. Sources can include the ventilation system itself or the amount of outdoor noise it allows into the building. Designers and decision makers in Europe felt that the amount of noise produced by natural and mechanical systems would be similar, but that natural ventilation allows more noise to penetrate the building from outside (Aggerholm, 1998c). The second work package reiterates the acoustical problems associated with external openings for natural ventilation but suggests that openings that prevent the ingress of noise (as well as pollutants) have been developed and are available (Nat**Vent**^{TM} Work Package 2, 1998).

Level of Control

One of the primary concerns of occupants in a building is the level of control they have over their environment. Most people like to have some of control over the temperature, noise, or some other aspect of their surroundings. The level of control can have a dramatic effect on productivity and the number of complaints about an office. "There are some indications that giving occupants greater local control over their environmental conditions improves their work performance and their work commitment and morale, with other positive implications for improving overall productivity within an organization" (Abdou & Lorsch, 1994, p. 902). In mechanically ventilated offices, complaints from workers are fewer if occupants have the ability to open windows, and the range of temperatures they will tolerate is greater (Bordass & Jaunzens, 1996).

The European study touched briefly on the controllability of natural ventilation versus that of mechanical ventilation. As a general rule, professionals felt that mechanical systems offered higher levels of central and individual control than natural ventilation, especially in cellular offices (Aggerholm, 1998c). Work Package 2 of the study stressed that if a system provides control to individual users, the occupants must be educated about how the system works and how it is controlled in order for the system to work effectively and efficiently. The user must be an active participant if a natural or mixed-mode system is to function successfully (Nat**Vent**™ Work Package 2, 1998). As Bordass and Jaunzens (1996) point out, systems are often operated much differently than how they were designed to run due to the building inhabitants controlling the system in a way that works best for them. This fact further emphasizes the need for user education.

Environmental Knowledge and Concern

The knowledge and concern of building occupants about environmental issues may also play a role in their acceptance of hybrid ventilation systems. Users not aware of or not concerned about environmental problems will not be as willing to make small sacrifices to improve conditions. Although media coverage of environmental issues has created some public awareness, globally there are still a lot of misconceptions about various environmental issues. In particular, public knowledge of global climate change seems limited. Almost all of the subjects in a study conducted by Bostrom et al. (1994) knew that global warming was a problem and that the ozone layer was a cause for concern. However, many confused the two issues, believing that warming was caused by the ozone layer trapping ultraviolet rays in the earth's atmosphere, when in reality holes in the ozone are allowing more ultraviolet rays into the atmosphere where they are trapped by greenhouse gases.

A study conducted in the United States by O'Connor et al. (1999) concluded that once people have an understanding of environmental issues, they would be willing to cut back on the use of air conditioning and heating in order to help prevent changes to global climates. Work Package 2 of the Nat**Vent**™ Study (1998) also states that the use of natural ventilation is encouraged because people are becoming more concerned about environmental issues and energy consumption.

Effects of Development

A possible barrier to the implementation of natural ventilation that seems to be overlooked in most studies is the effect of development around a building using the system. Little is said about the requirements of the system regarding the surrounding cityscape. The construction of new buildings in the vicinity is bound to have an impact on the wind patterns in the area. It may block wind completely. If the new, neighboring buildings produce pollutants or the streets around the building become busy, this too will have an effect on the efficiency of a natural ventilation system.

Wind Patterns

The construction of new buildings in close proximity to a building using mixed- mode ventilation will cause changes in the wind patterns used for natural ventilation. This could have adverse effects on the ventilation capabilities of the building. The rate of airflow in a building depends heavily on how a building is placed with respect to the winds around it (Beccali, et al., 1993). As stated by Deaves and Lines, "Although very light winds would often present the worst case of high concentrations (of hazardous gases), especially in the near field, or of poor ventilation, their effects are not often assessed" (Deaves & Lines, 1998). The study conducted by Deaves and Lines calculated the impact of low wind speed on natural ventilation. They concluded that while low speed has a significant effect on ventilation, it only does so when it persists for long periods of time. The results of the study showed slow wind speeds generally span short time periods and for that reason, pose few problems as far as natural ventilation is concerned (Deaves & Lines, 1998). However, in the event of newly constructed buildings blocking wind or altering its flow, it is entirely possible that low speed wind conditions will occur frequently, even becoming constant. This would cause the problems highlighted by Deaves and Lines to occur, making the ventilation system ineffective at meeting the needs of the building's occupants.

Similarly, a presentation given by Matheos Santamouris (University of Athens, Greece) at the 20th AIVC conference supported the idea that buildings using natural ventilation are adversely affected by surrounding structures. The study conducted by Santamouris involved taking measurements from 'urban street canyons' and using these measurements to calculate ventilation rate models. The results showed that the flow rate for the buildings in the urban settings could be as little as 1/10 that of a building without any kind of obstruction (Ventilation Technologies in Urban Areas: 19th Annual AIVC Conference Report, 1998).

Jozwiak, Kacprzyk, and Zuranski (1996), doing a study on naturally ventilated buildings, state that the interference of surrounding buildings on natural ventilation is great and suggest that it should be taken into consideration when designing buildings. "This type of research, conducted before construction, would allow verification of the relative locations of buildings and would help prevent unfortunate intoxication accidents" (Jozwiak, R., Kacprzyk, J. & Zuranski, J.A., 1996, p. 176). This statement was made after several deaths due to carbon monoxide poisoning occurred in a Polish apartment complex.

Increased Pollution

The area surrounding a building dictates the level of pollution that the ventilation system must contend with when providing the occupants with clean air. The problem of outdoor contaminants, according to European professionals, is considered a major problem in city centers (Aggerholm, 1998c).

> "Locations in urban and city areas, for example, can suffer from poor outdoor air quality derived from traffic fumes, and industrial pollutants, while outside noise from passing traffic can be excessive, thus restricting the potential for window opening. Adjacent buildings could create conflict in relation to pre-existing air intakes and exhaust points" (www.aivc.org/faq/faq14.html).

The building in Zurich described by CADDET was constructed so that it was bordered by two busy roads, exposing it to a great deal of outside noise and air pollution (CADDET, 1997). The brochure states that the building was designed to minimize the impacts of such outside elements on the occupants, but fails to describe how effective the building was in doing so. The brochure provides little information on the effectiveness of natural ventilation systems at filtration or noise reduction in urban areas.

As a possible remedy to traffic pollution, David Etheridge demonstrated at the 19th AIVC conference that the amount of pollution taken in by a building's ventilation system from a busy street outside the building could be reduced by as much as one third if the intakes were positioned at the roof or on the leeward face (Ventilation Technologies in Urban Areas: 19th Annual AIVC Conference Report, 1998). The study did not suggest possible solutions to pollution from other buildings located nearby.

2.17 Summary

Mixed-mode (or hybrid) ventilation systems are systems that combine natural and mechanical ventilation to cool and ventilate a building. Advantages to using the system include adaptability, lower cost, and reduced energy consumption leading to a decrease in pollution. However, many barriers may exist to the use of mixed-mode ventilation in both the design and operational stages of a building. Among these are lack of knowledge about the system, the perceived performance of the system, the comparative cost, the ability of the system to work effectively in changing environments, and user satisfaction with the system. Using the knowledge gained from our research, we have developed a methodology for determining perceived barriers to the implementation of hybrid ventilation in Melbourne, Australia.

3.0 METHODOLOGY

3.1 Introduction

The goal for this project was to discover the perceived barriers to mixed-mode ventilation in Melbourne commercial buildings. We gained this information from specific groups of people: building designers, constructors, government officials, and occupants, so they were our target sample. We decided the most effective way to gather the information we needed was through personal interviews, questionnaires and surveys. The project was completed over a seven-week period.

3.2 Background Research

We started the project by doing extensive background research on ventilation systems, particularly mixed-mode systems. We used the research facilities at Worcester Polytechnic Institute (Worcester, MA), Massachusetts Institute of Technology (Cambridge, MA), and Clark University (Worcester, MA) to locate sources and conduct our background research. Our research encompassed mechanical, natural, and mixed-mode ventilation, each being related to our project. Since our project was on perceived barriers to mixed-mode ventilation systems, we tried to find as many sources as possible on the topic of barriers. Because of the lack of previous study on this subject, the number of sources we found was minimal. To locate various resources, we utilized the libraries at each of the above-mentioned universities, searching online databases and card catalogues. Our liaison at CSIRO also provided us with some material, namely the first Work Package of the Nat**Vent**™ Study, on which our project was to be based. We thoroughly reviewed the European Report as well as the Denmark National Report of the Nat**Vent**™ study. When we arrived in Melbourne, we acquired more background materials from our sponsor, including the second Work Package of Nat**Vent**™. These materials were reviewed and added to our Literature Review (see Chapter 2).

3.3 Target Groups

3.3.1 Designers and Decision Makers

The first group of people we wanted to interview in trying to establish perceived barriers to mixed-mode ventilation were the people responsible for making decisions regarding what ventilation system a building uses. This portion of the project was modeled after the Nat**Vent**™ study conducted in Europe in 1996 and 1997. Our target audience consisted of:

- Architects and consultant engineers, who are responsible for the design and feasibility of the buildings in question. They make the initial decision on what form of ventilation is to be used.
- Contractors and developers, who must actually create the physical building, making what the architects and engineers have designed a reality. Developers also deal with the cost of the building.
- Building owners, who will be paying for the construction as well as the operation and maintenance of the systems. They also rely on the productivity of the people in the buildings.
- Government decision makers, who are in control of setting policies for buildings within an area. Such policies can determine how a building is constructed and which ventilation systems are approved for use in commercial buildings.

A face-to-face questionnaire was the method used for the designers and decision makers, as was done with the Nat**Vent**™ Study. Barriers to mixed-mode ventilation perceived by any of the individuals listed might substantially limit its use. This fact made their input vital to our project.

3.3.2 Building Occupants

The second group of people we wanted to gain information from about mixed-mode ventilation was those who would directly feel its effects, the people who work in commercial buildings. An occupant survey was conducted in the nineteen monitored buildings as part of the Nat**Vent**™ Work Performance Package 2. However, the purpose of this survey was not to determine possible user related barriers. Instead, the survey simply asked about user comfort levels on a particular day for comparison with monitored values such as temperature and airflow. We were interested in finding out how occupant views about their office environment and environmental issues globally might be a barrier to mixed-mode ventilation systems.

In order to do this we developed our own occupant survey for distribution in Melbourne buildings. This process is described in the next section.

3.4 Development of Questionnaires and Surveys

3.4.1 Questionnaires for Designers and Decision Makers

General Views Questionnaire

The General Views Questionnaire from the Nat**Vent**™ study was used as a starting point for our questionnaire. Designers and decision-makers were asked the same basic questions which had been modified to include mixed-mode (or natural) ventilation rather than just natural ventilation.

The same four ventilation scenarios were used; mechanical in cellular and open plan and mixed-mode in cellular and open plan. For these sections on perceptions of mechanical and mixed-mode ventilation systems in the two office, designers and decision makers rated what they perceived about various aspects of the system's design, performance, control, and cost on a scale of five ranging from *Poor* to *Excellent*. As stated above, we created a more defined scale than was used in the Nat**Vent**^{TM} study. Instead of having arrows going from *Poor* to *Excellent,* we used *Poor, Fair, Moderate, Very Good,* and *Excellent*. This limited differences in the interpretation of the scale from one interviewee to another.

Two questions were added to the original questionnaire. One was on the adaptability of the ventilation system to future development in surrounding areas such as new buildings, and another was on the effectiveness of such a system in Melbourne conditions. Since heat recovery is not a concern in Melbourne's climate, questions regarding knowledge and perception of heat recovery that exist in the original Nat**Vent**^{TM} questionnaire were removed for our project. A copy of the finalized General Views Questionnaire is attached in Appendix B.

Specific Building Questionnaire

We also gave a questionnaire on specific building projects as was done for Nat**Vent**^{TM}. With this questionnaire, designers and decision-makers chose a specific building project that they have been involved with and answered questions regarding design decisions for that project. No changes were made to this questionnaire before initial interviews were conducted. Appendix B also contains a copy of the Specific Building Questionnaire.

3.4.2 Occupant Survey

We completed the first draft of the occupant survey while at WPI to test it on our classmates. The survey was designed to provide information on current satisfaction levels, user expectations, and the environmental concern of building occupants. When we started work at CSIRO, the draft of the occupant survey was put through a significant revision. A lot of the questions were changed to a format that would allow for the quantification of responses. We added more questions and removed ones that would not contribute to the project. We attempted to keep the survey as short as possible, while trying to gain as much information from the responses as we could.

Occupants of buildings have many expectations of their ventilation systems with respect to temperature, cleanliness, humidity, odors, noise and controllability. We wanted to identify the extent to which people are willing to change from their current ventilation system to something new, given their current satisfaction level. The anticipated comfort of people affected by a ventilation system can be a barrier to its use.

The people who work in a building also have differing levels of concern for the environment. We wanted to establish how important environmental issues are to office workers. This information was used to gauge how much occupants are willing to change their current work environment. The occupant survey can be found in Appendix B with the questionnaires.

3.5 Topics Covered in Questionnaires and Surveys

3.5.1 The General Views Questionnaire

The General Views questionnaire consisted of thirteen sections;

1. Background on the organization
2. Knowledge of ventilation systems
3. Experience with ventilation systems
4. Project fee

5. Perceptions of mechanical ventilation in cellular offices
6. Perceptions of mechanical ventilation in open plan offices
7. Perceptions of mixed-mode ventilation in cellular offices
8. Perceptions of mixed-mode in open plan offices
9. Source of knowledge for mixed-mode ventilation
10. Expected future use of mixed-mode
11. Government restrictions to the use of mixed-mode
12. Desirable design tools
13. Desirable new components.

The background questions on an interviewee's organization were used to establish the professionals working there, the types of buildings worked on, and the size of the company.

The knowledge section of the questionnaire assessed the familiarity of designers and decision-makers on different ventilation systems, i.e. mechanical, natural, or mixed-mode. Respondents rated their knowledge on a scale from *None* to *Thorough*.

The experience section asked the designers and decision-makers to list their previous experience. Here, they listed the number of new and refurbish buildings that they were involved with per year, and out of those, how many use mechanical, natural, or mixed-mode ventilation.

The project fee section assessed the percentage breakdown of how a project is generally charged by the firm. The breakdown is between fixed fee, percentage of construction cost, or per hour charge.

The four sections on mechanical and mixed-mode in different office plans were used to determine the following possible barriers.

Technical Barriers

The designers and decision-makers were interviewed about what technical barriers to mixed-mode ventilation they foresaw. Perceived barriers having to do with the system itself as well as its reliability and maintenance were investigated. Questions having to do with perceived shortcomings of the system were also asked.

Effects of Changing Cityscape

A subset of technical barriers investigated among the designers was the effect of a changing city on the performance of the mixed-mode system. The questions focused on whether or not the wind patterns of Melbourne will allow for the use of mixed-mode ventilation. We also explored the impact of the height and density of existing or new buildings constructed in close proximity to a building using the mixed-mode systems.

Economic Barriers

The economic barriers to implementing the mixed-mode system included the perceived comparative cost and availability of needed materials. The architects, engineers, contractors, developers, owners and government officials were asked about the comparative costs between mechanical and mixed-mode ventilation. The costs of installation, maintenance and operation were investigated to see whether people felt it is a barrier to the system being used. A complete cost accounting of the mixed-mode system was beyond the scope of the project. Instead, we collected the general views of the interviewees pertaining to cost. A second economic factor that was looked into was the availability of resources needed to construct the system. The designers were asked if all of the needed components are readily available or whether acquiring them would prove difficult.

Safety Barriers

We asked the designers and decision-makers for information about the perceived safety of mixed-mode systems. The objective was to establish the perceived barriers related to safety. Specific areas included whether the system met all Australian construction codes and safety standards and the filtration effectiveness under the existing conditions in Melbourne.

3.5.2 The Specific Building Questionnaire

The specific questionnaire asked detailed questions about a specific project with which designers and decision makers were involved. This questionnaire consisted of four sections: Building, the Design, Background for the Design, and Biggest Influence on Chosen Design. It assessed the various ventilation aspects that are taken into consideration during the design phase of the project.

The section on building established a background for the project in question. It consisted of general questions regarding the building, such as building type, year constructed and/or refurbished, location, number of storeys, and area.

The design section assessed the different types of ventilation systems and other HVAC characteristics that were used in different type of rooms within the project in question.

The section on background for the design of the questionnaire asked the designers and decision-makers to choose five parameters from a list of seventeen that they considered critical during the design process for each type of room. Once the five parameters were chosen, they were given a rank from 1 (highest) to 5 (lowest).

In the section on biggest influence on the chosen design of the specific questionnaire, the interviewees selected five factors, such as architects, users, and codes, that influence the selection of a chosen design. Again, the ranking system was changed to one that uses 1 ‘highest’ to 5 ‘lowest.’

3.5.3 Building Occupant Survey

While the designers who would be working with mixed-mode ventilation systems were asked their opinions about the user satisfaction of the system, the occupants of office buildings were the main subject group used for determining possible barriers having to do with user satisfaction. The building occupant survey consisted of fifteen questions. The questions were a combination of closed response and open-ended formats. We attempted to determine what occupants considered acceptable working ranges for temperature and noise. Questions having to do with air quality were used to establish the extent to which occupants notice and are affected by the indoor air quality as well as in what areas they would like to see improvement. Questions were asked to determine the level of control occupants feel they need to be comfortable. They were also asked about their environmental concerns such as global warming, pollution, and deforestation and how much effort they thought should be put into designing environmentally friendly buildings.

3.6 Trial Interviews and Surveys

When the questionnaires had been completed, two trial interviews were conducted. We tested our initial interview methodology and questionnaires on the two contacts set up for us by Dr. Angelo Delsante, our liaison. The results of these two interviews aided us in revising our questionnaires to make them clearer to the interviewee.

We also did a trial run with our occupant surveys, distributing them to two buildings in the CSIRO complex. We distributed fifty surveys and received thirty responses. The surveys were then analyzed to identify any ambiguities that existed in our questions based on how people had responded.

3.6.1 Revision of Designers and Decision-Makers Questionnaires

From our observations during our trial interviews, we made changes to both the general and the specific building questionnaires to make them easier for the interviewees to understand. In the original Nat**Vent**^{TM} general views questionnaire, the experience section asked for the percentage breakdown of buildings that interviewees were involved in for each of the different type of ventilation systems. We found that it was hard for our interviewees to answer this in terms of percentage. Therefore, the question was rephrased in terms of the number of projects that use each different type of ventilation. There were some other questions that the interviewees found to be confusing. These questions were reworded to clarify what we were looking for.

For the specific building survey, we found that the rating system used in the Nat**Vent**^{TM} study was ambiguous. In this section, the original questionnaire from the Nat**Vent**^{TM} study indicated that the interviewee could choose "up to" five parameters, and to *rate* them from 1 'lowest' to 5 'highest.' During the trial interview, we found this to be confusing for the professionals with whom we spoke. We changed it to ask the interviewee to choose five (not up to) critical parameters, and then *rank* them from 1 'highest' to 5 'lowest.' The specific questionnaire also contained a section with a grid of check boxes matching rows and columns of text. We noticed it was difficult for the interviewee to keep track of the category of the check boxes when they moved further down the columns. To overcome this, we shaded every other column, which greatly improved readability. We also added horizontal shading to the last section on design influences to make filling it out easier.

3.6.2 Revision of the Occupant Survey

The responses we received from our trial survey distribution within the two CSIRO offices provided very helpful feedback for our survey. As a result, we clarified several questions and gave examples of what we were looking for where appropriate.

3.7 Establishing Contacts

3.7.1 Designers and Decision Makers

Once the format for the questionnaires and surveys had been finalized, contacts need to be made for interviews and survey sites. We used various methods for finding contacts. These included suggestions from our sponsor, suggestions from people whom we interviewed, and listings on the web. A contact list was maintained using Microsoft Outlook.

Dr. Angelo Delsante provided our initial contact list. He placed together sets of potential contacts in each of our six categories, including architects, consulting engineers, contractors, developers, building owners, and a government official. To start us off Dr. Delsante contacted two consulting engineers and one government official, informing them of our project and securing their agreement to be interviewed The consulting engineers were used as our trial interviews and are included in the results. In addition to the initial contacts supplied by our sponsor we found extensive online listings (http://www.cybersyte.com.au) of consulting engineers, architects, and building contractors. In order to prevent any potential bias in the results of the interviews we attempted to contact an equal number of sponsor-recommended and randomly selected contacts for each group except the government official. Building owners were more difficult to locate, and we used several methods for making contacts. These included contacts provided by the Australian Property Council, suggestions from people we interviewed, and suggestions from CSIRO.

One essential but difficult skill was to call an organization and actually find someone willing and capable of being interviewed. Many companies had secretaries acting as gatekeepers who act as a go between for people within the company. This made the wording of requests very important. The most successful technique we used was to ask for a recommendation of someone within the company whom we could speak to about ventilation in commercial buildings. Once we reached a potential interviewee, we explained that we were working for CSIRO and the nature of our research. If they were interested we scheduled an interview.

3.7.2 Buildings for Occupant Surveys

Initially buildings using mixed-mode and mechanical ventilation were to be surveyed so the results from each could be compared. However, it was determined that no buildings in the Melbourne area use mixed-mode ventilation, so only occupants of mechanically ventilated buildings were surveyed. Other IQP groups in Melbourne were asked for contact information for someone in their building that could be spoken to about conducting our survey. We also asked some of the designers and decision makers if surveys could be conducted in their buildings.

3.8 Conducting Interviews and Surveys

3.8.1 Face-to-Face Interviews

We were able to conduct 18 interviews for the project. We spoke with 7 architects, 5 consulting engineers, 2 contractors, 2 developers, and 2 building owners. For each interview, one group member was in charge of conducting the discussion, helping the interviewee fill out the questionnaires and facilitating conversation. Notes on the comments made were taken by one of the other group members. At many of the interviews, after permission was received, a recording device was used.

In some cases, the professional was interested in taking part in the study, but did not have time available to take part in an interview. In three cases, the two questionnaires, with instructions attached, were faxed to the interviewee. However, only one fax was returned.

3.8.2 Building Surveys

The occupant surveys were conducted by dropping off the number of forms specified by the contact in the building. Surveys were then picked up several days later. A total of 215 surveys were distributed among 4 buildings in Melbourne. A total of 93 responses were received. To monitor which surveys were distributed and collected for each of the buildings, numbers were affixed to the back of each form.

3.9 Data Analysis

Once all data was collected, the best methods for displaying the results clearly was determined. We decided to enter the results of the General Views Questionnaire and the occupant survey into Microsoft ™ Access database. This would allow queries to made to quickly establish how people responded to the questions. The results from the Specific Building Questionnaires were tallied by hand and entered into several Microsoft ™ Excel spreadsheets, making reading the results fast and effortless. Comments from each interview were compiled and can be found in Appendix E.

3.9.1 Databases

Databases were created for the General Views Questionnaire and the occupant survey. A field was used to represent each question on the questionnaires and surveys. When more than one answer could be selected, more than one field was used or a list of possible responses created within the database. Once the forms were created, all data from the interviews and surveys were entered into their respective database. Queries were written using Standard Query Language (SQL) to extract the data from each database.

Due to the large amount of information contained on the General Views Questionnaire, queries were not written for every question. Instead, queries were written for key points such as:

- Knowledge of ventilation systems
- Ease of design
- Anticipated user satisfaction
- Cooling effectiveness
- Controllability
- Cost
- Expected future use

By using the database, future queries for desired information are possible. The results for each question were grouped by the occupation of the respondents and exported to Excel where they were put into tables and charts. Appendix C is a collection of this data.

Because the amount of information contained on the occupant survey was considerably less than that of the General Views Questionnaire and grouping was simplified, queries were written for all questions. As was done for the questionnaire data, the survey data was also put into tables and charts, making it easy to read. The charts and tables for the occupant survey are found in Appendix F.

3.9.2 Spreadsheets

The structure of the Specific Building Questionnaire would have made creating a database a very difficult, time-consuming task. The sections of the questionnaire on design parameters and influences contained the most useful information, the rest being background on the particular building discussed. For the section on design parameters, spreadsheets were constructed listing the room types and their parameters. Five such sheets were made, one for each possible ranking (1 through 5). The total number of each room selected was counted and entered at the top of each sheet. The number of times each parameter was selected 1, 2, 3, 4, or 5 for each room was counted and entered into the appropriate sheet.

A spreadsheet listing the rankings, again 1 through 5, and the design influences was created for the design influences section of the questionnaire. The number of times each influence was given each rank was counted and entered into the sheet. All spreadsheets can be found in Appendix D.

3.9.3 Comments from Interviews

After each interview was conducted, the comments of the interviewee were compiled from the questionnaires, written notes from the interview, and transcribed from recordings. Appendix E contains a list of these comments grouped by interviewee.

3.10 Conclusions and Recommendations

Once all data had been collected and entered into databases or spreadsheets, it was analyzed for general trends. The results of this analysis can be found in the next chapter. Using the trends found for the questionnaires, surveys, and interview comments, conclusions were drawn about the barriers to mixed-mode ventilation. Recommendations were then made on how to possibly overcome these barriers, as well as future project work that could be completed to gain more understanding about the barriers. A detailed description of the conclusions and recommendations can be found in Chapter 5.

Finally, three prototype-marketing templates were developed based on the information obtained for the project. The prototypes targeted potential users of mixed-mode ventilation; schools, developers, and corporate offices. Each prototype gives a brief description of what mixed-mode ventilation is, followed by a target-specific list of the advantages of using a mixed-mode ventilation system. Comments by professionals promoting the system are also provided. At the bottom of each pamphlet is a list of suggested shortcomings of the system that may need to be overcome before it can be marketed to the target is given. These marketing templates are provided in Appendix G.

4.0 DATA ANALYSIS AND PRESENTATION

4.1 Introduction

Using the methodology described in Chapter 3, we obtained both qualitative and quantitative data on the perceived barriers to mixed-mode ventilation in Melbourne. We decided the most practical way to compile the data was using databases, spreadsheets, and text, simplifying the retrieval of information. The data is as complete as possible, although there were some questions not answered by designers and decision makers on the questionnaires, or by occupants on the survey. This chapter highlights some of the key points about the results. More detailed results can be found in the Appendices referenced in each section.

4.2 Questionnaire on General Views

The information obtained from the Questionnaire on General Views given to designers and decision makers was entered into a database we created using Microsoft Access. Each question on the questionnaire was entered as a field. For questions where more than one answer could be selected, a field was created for each possible answer.

To obtain results that were as representative of professionals in Melbourne as possible, interviews were conducted at firms of different sizes and backgrounds. Interviewees worked at firms that ranged in size from 2 people to over 100 employees. While many had experience working with office buildings, there were some companies that focused more on residential buildings such as large developments and hotels.

The following sections contain figures that summarize many of the results obtained from the interviews. In order to quantify many of the responses, numerical values were assigned to each of the five possible selections that could be made for each question. Before each set of graphs is an explanation of the values associated with the numbers found on the axis of the graphs. Detailed graphs for the General Views Survey can be found in Appendix C. Appendix G contains comments made by designers and decision makers during the interviews.

4.2.1 Ventilation Knowledge

Knowledge of mechanical ventilation is widespread and tends to be greater than for other systems. It has been in use for many years, has well documented guidelines, and has been proven to work. A building owner we interviewed summed it up as follows: “The current system is well known, well understood. You don’t want to be on the bleeding edge of technology. Sometimes you’re the first one in and it’s still very early days on some of the technology, you end up getting burned.” Awareness of mixed-mode systems is much lower for most categories. One of the consulting engineers said, “Awareness of mixed-mode ventilation systems is non-existent. Until the client is aware of its existence, the concept is not going to materialize.” Consulting engineers felt they were the most knowledgeable about each system, and their knowledge appears to be more evenly distributed among the 4 types of ventilation systems. Figure 4.1 is a summary of the knowledge of designers and decision makers about ventilation systems. It shows that in general, consulting engineers feel they have the most knowledge of all forms of ventilation. Nearly every professional, with the exception of building owners, stated that they had the least amount of knowledge about mixed-mode systems, architects having less than any other group.

For this graph:

0 = No responses, 1 = None, 2 = Little, 3 = Moderate, 4 = Much, 5 = Thorough.

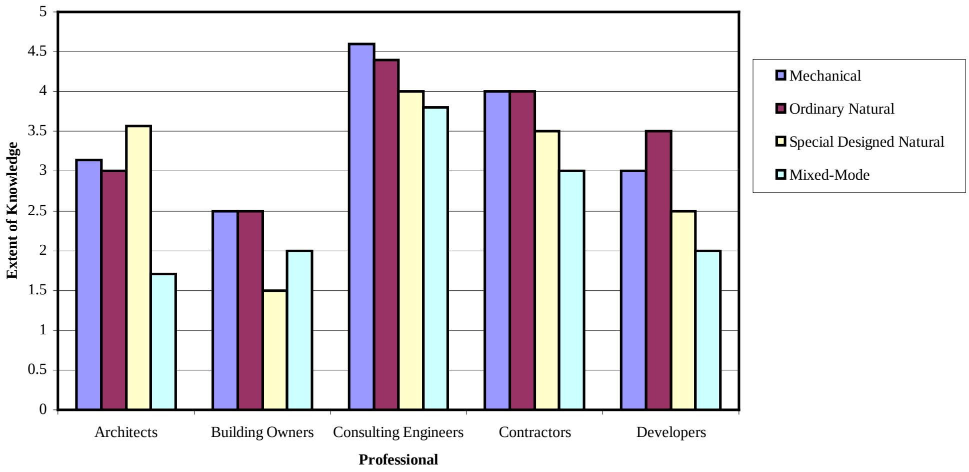

Figure 4.1: Summary of ventilation knowledge.

4.2.2 Experience

There are very few buildings in Melbourne using mixed-mode ventilation. Of the people interviewed, only one had experience with a mixed-mode building in Australia. All other mixed-mode experience was with buildings designed and constructed in Europe. Most natural ventilation experience was through work done on education and housing facilities. Mechanical ventilation experience was the most widespread. All of the office buildings that our interviewees had been involved with were mechanically ventilated. Designers and decision makers tend to settle on mechanical solutions for reasons such as what a consulting engineer said, "There's a lot of people who haven't sort of gone toward these types of systems [mixed-mode] because they just feel that it's all too hard and it's easier just to go and stick in a kit. It's easier just to go and specify some air-conditioning plant, take the fees, and run."

4.2.3 Mechanical Ventilation Design

In general, the design perceptions for mechanical ventilation for cellular and open plan offices were the same. However, it was felt that the ease of design was slightly greater for open plan offices than for cellular. The long-time practice of using mechanical systems, the documented guidelines, and the familiarity with mechanical systems simplifies the design process. According to one developer, "most people stick to the systems [mechanical] that they know most about, because that is the cheapest way to go." Figure 4.2 shows the perceptions of three key design factors; ease of design, anticipated user satisfaction, and the adaptability of the system to future development in the area surrounding a building. For the graphs showing design perceptions, performance in practice, and controllability, the following scale was used:

0 = No responses, 1 = Poor, 2 = Fair, 3 = Good, 4 = Very Good, 5 = Excellent

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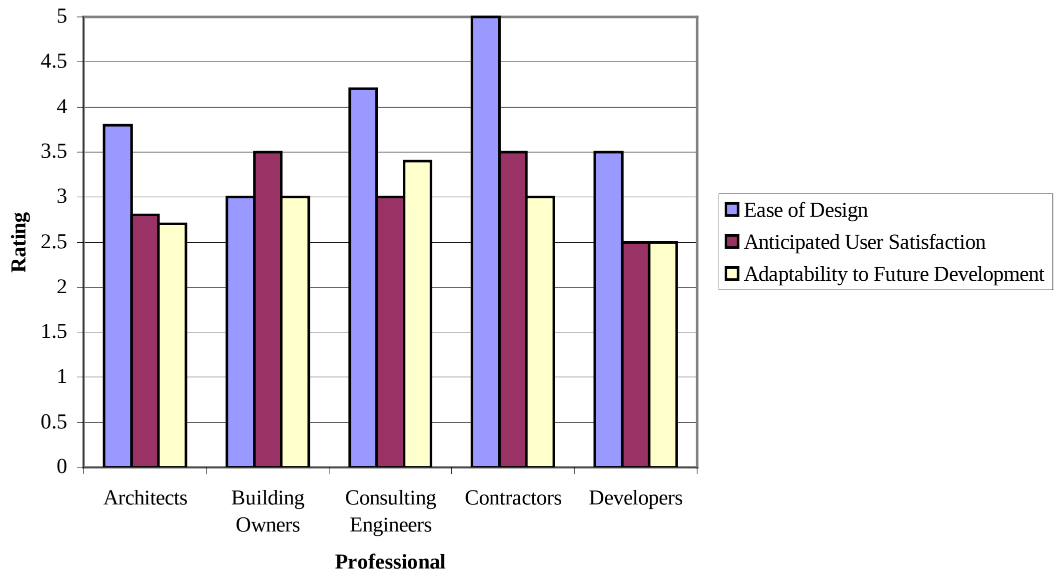

Figure 4.2: Design perceptions for mechanical ventilation.

As can be seen from the graph, the perception of ease of design for mechanical systems was fairly high, especially among consulting engineers and contractors. For all professionals, the anticipated user satisfaction was near ‘Good’ and the adaptability of the system to future development was also ‘Good’.

The availability of design guidelines is also an important design factor. A consulting engineer made the following comment regarding design guidelines: “The problem is with standards and guidelines; they are nonexistent. Designers are reluctant to use a system that is lacking standards and that have no guidelines to go by. If ASHRAE puts out such guidelines, designers will follow it.” Table 4.1 shows how designers and decision makers from each category perceived the availability of guidelines for mechanical systems in cellular offices. Selections for open plan offices were very similar.

Table 4.1: Availability of design guidelines for mechanical systems.

Availability of Design Guidelines	Architects	Owners	Engineers	Contractors	Developers
Poor	1	0	0	0	0
Fair	0	0	0	0	0
Good	2	1	0	1	1
Very Good	2	0	4	0	1
Excellent	1	0	1	0	0

4.2.4 Performance in Practice of Mechanical Ventilation

Small differences existed between interviewees’ perceptions of mechanical ventilation in cellular and open plan offices. Figure 4.3 shows the results for system performance with regards to cooling effectiveness, removal and prevention of odours (indoor air quality), and effectiveness in Melbourne conditions for cellular offices. Figure 4.4 gives the same information for open plan offices.

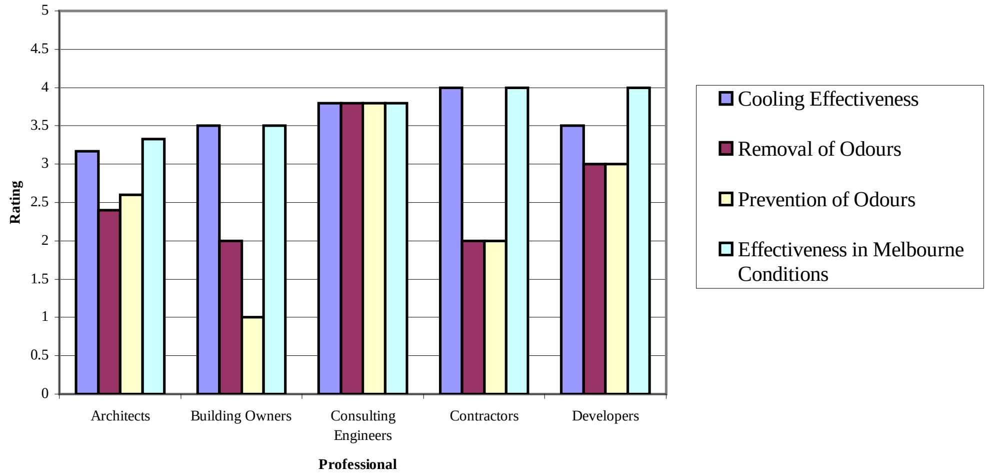

Figure 4.3: Performance perceptions for mechanical ventilation in cellular offices.

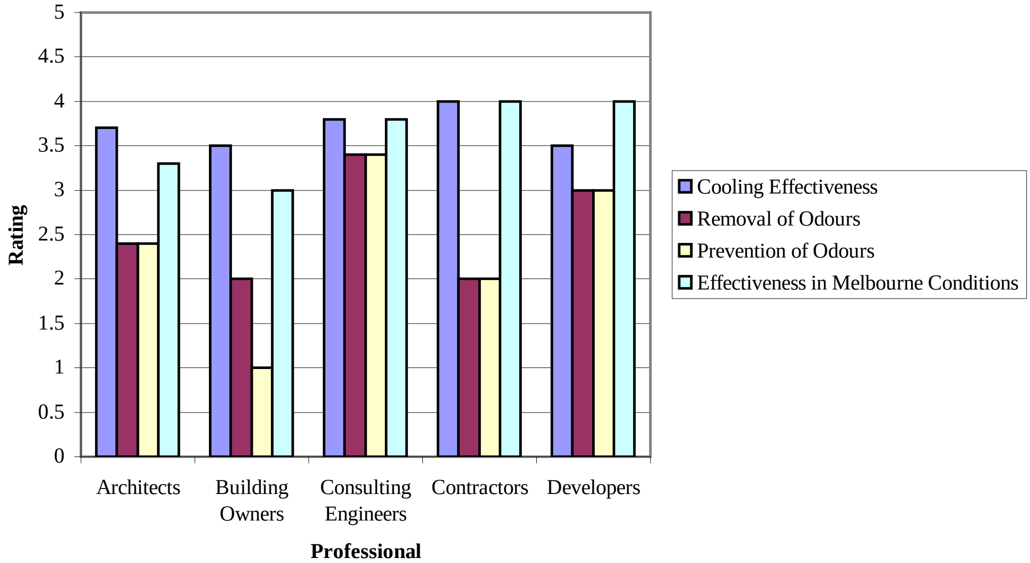

Figure 4.4: Performance perceptions of mechanical ventilation in open plan.

Cooling effectiveness was ranked between ‘Good’ and ‘Very Good’ for both scenarios. There is some variation between professions concerning the ability of the systems to remove or prevent odours. Building owners and contractors do not feel the system is effective, with responses ranging between ‘Poor’ and ‘Fair’, while consulting engineers and developers felt the system is 'Good' at performing these tasks. The effectiveness in Melbourne conditions is very similar for the two cases, with all interviewees giving a rating of 'Good' or better.

4.2.5 Control of Mechanical Ventilation

Some differences exist for the results on the central, local, and individual control provided by mechanical systems in cellular and open plan offices. In general, it was felt that mechanical systems offer adequate central control, but local and individual control is more difficult to obtain. Figures 4.5 and 4.6 show the distribution of responses for cellular and open plan offices, respectively.

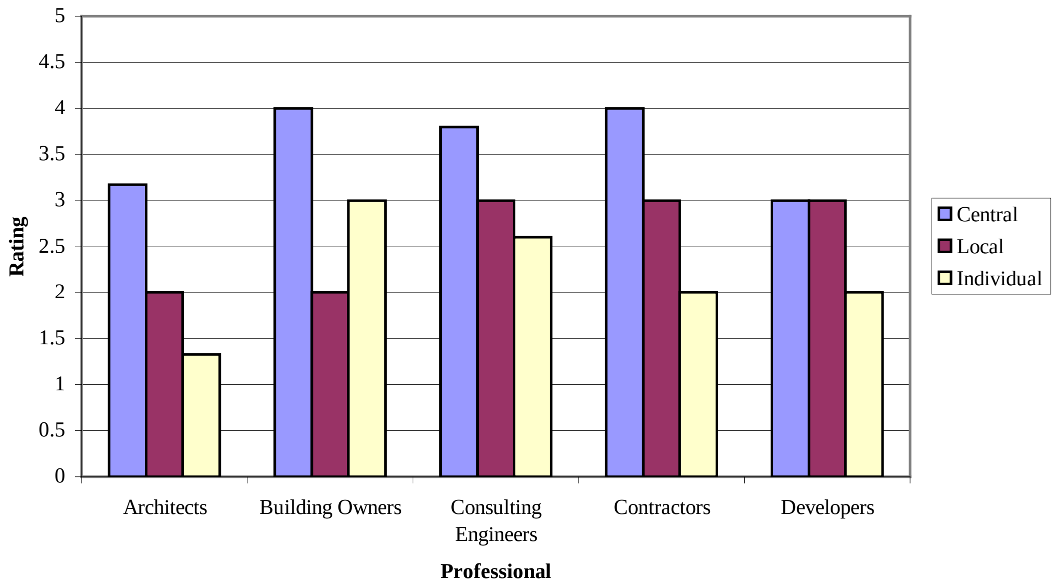

Figure 4.5: Controllability of mechanical ventilation in cellular offices.

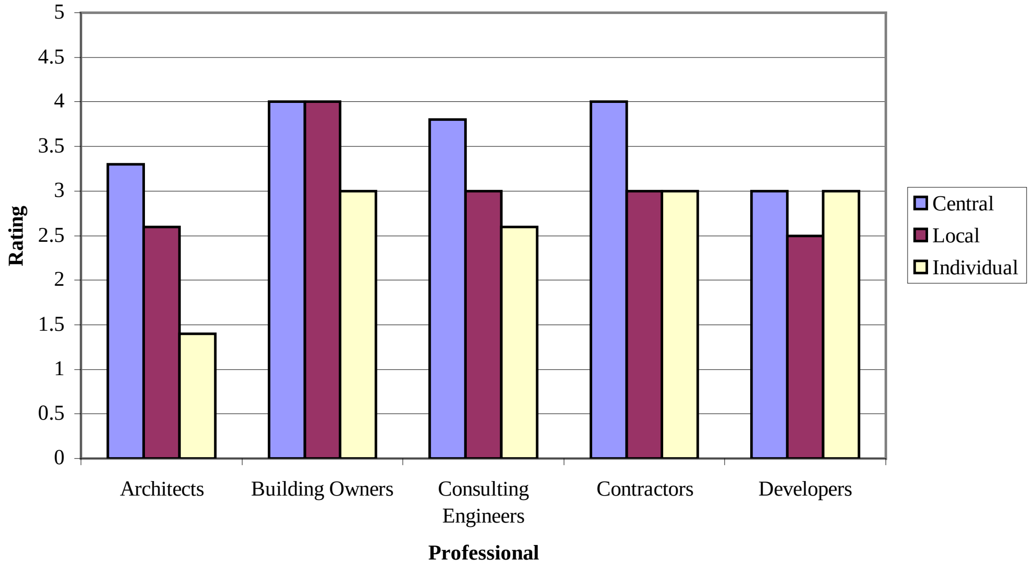

Figure 4.6: Controllability of mechanical ventilation in open plan offices.

The graphs show that some interviewees, building owners and architects, felt that local controllability was greater in open plan offices than in cellular, while others, developers and contractors, felt the open plan provided greater individual control.

4.2.6 Cost of Mechanical Ventilation

Figure 4.7 shows how interviewees rated the installation, running, and maintenance costs for mechanical ventilation in cellular offices. Very few differences existed between the perceptions for cellular and open plan. The following scale was used in creating the cost graphs for mechanical and mixed-mode systems:

0 = No response

1 = Inexpensive

2 = Somewhat Inexpensive

3 = Moderate

4 = Somewhat Expensive

5 = Expensive

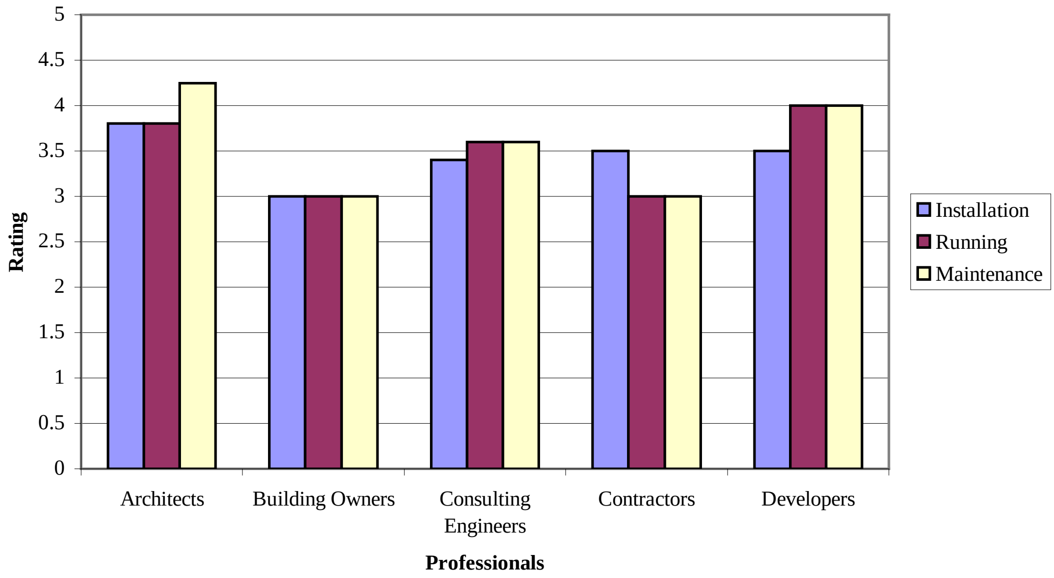

Figure 4.7: Cost perceptions for mechanical ventilation in cellular offices.

Of the professionals interviewed, building owners rated the cost of mechanical ventilation the most favorably, feeling the costs were ‘Moderate’. Developers and architects gave the highest ratings to cost, in the range of ‘Somewhat Expensive’.

4.2.7 Design of Mixed-Mode Ventilation

Some of the design perceptions of mixed-mode ventilation are shown in Figure 4.8. Perceptions were virtually identical for cellular and open plan offices. Some felt that divisions present in cellular offices would make design somewhat more difficult. Because of the similarities between the two, only the results for cellular plan are shown. The same scale as was used for mechanical ventilation is used for mixed-mode also.

0 = No response, 1 = Poor, 2 = Fair, 3 = Good, 4 = Very Good, 5 = Excellent

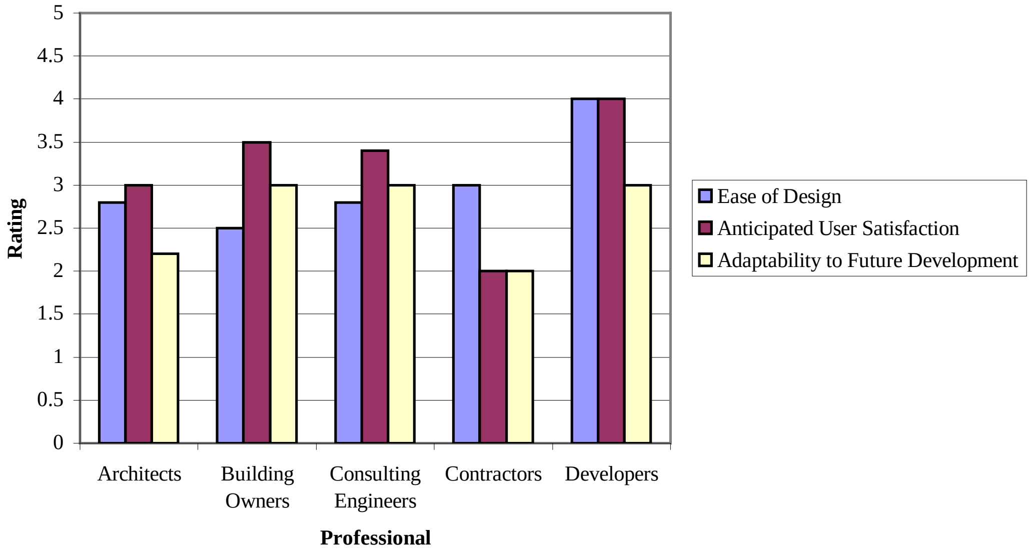

Figure 4.8: Design perceptions of mixed-mode systems.

The ease of design for mixed-mode systems is ranked lower than for mechanical systems. A consulting engineer said, "It's [mixed-mode] not easy, it's not as easy as putting in other ones." Most designers felt the ease of design ranged from 'Fair' to 'Good', except for developers who felt it was 'Very Good'. The anticipated user satisfaction with mixed-mode ventilation averages 'Good', as was the case with mechanical. Developers and building owners rated it higher than the other interviewees. The ability of mixed-mode ventilation to adapt to future development is perceived as being 'Fair' to 'Good', placing it below mechanical in that regard. The availability of design tools for mixed-mode systems is shown below in Table 4.2.

Table 4.2: Availability of design guidelines for mixed-mode systems.

Availability of Design Guidelines	Architects	Owners	Engineers	Contractors	Developers
Poor	1	0	0	0	0
Fair	3	1	3	0	0
Good	1	1	1	1	0
Very Good	0	0	1	0	1
Excellent	0	0	0	0	0

4.2.8 Performance in Practice of Mixed-Mode Ventilation

The majority of the perceptions of the people we interviewed were that mixed-mode ventilation would provide very good cooling effectiveness. The areas where it was viewed to lack the most would be the ability to remove or prevent odours and pollutants in a building. But as one consulting engineer put it, "one would assume for odours and pollutants, if you had say toilets or a kitchen, one would be putting in a mechanical ventilation system for those anyway." Overall, it was felt that mixed-mode systems would perform effectively in Melbourne conditions, receiving average rating between 'Good' and 'Very Good'. "If you did it properly in Melbourne's climate, if you really took it seriously, you could get some quite good comfort conditions. You should be able to get it to work," said an architect. Figure 4.9 displays this data.

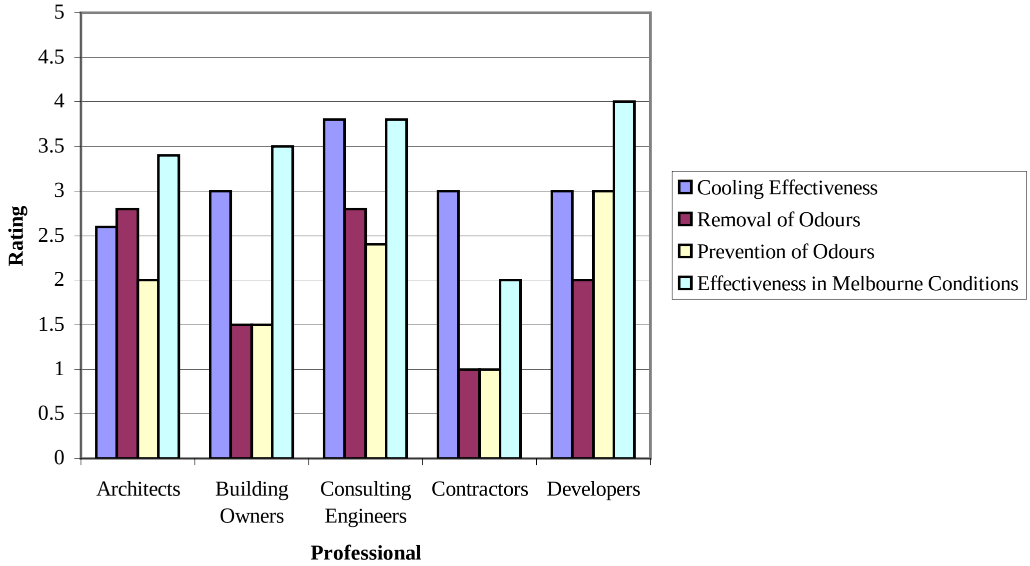

Figure 4.9: Performance perceptions for mixed-mode ventilation.

4.2.9 Control of Mixed-Mode Ventilation

In general the controllability of mixed-mode ventilation systems was perceived to be the same for cellular and open plan offices. Architects, consulting engineers and contractors distinguished between the two, as can be seen in Figures 4.10 and 4.11.

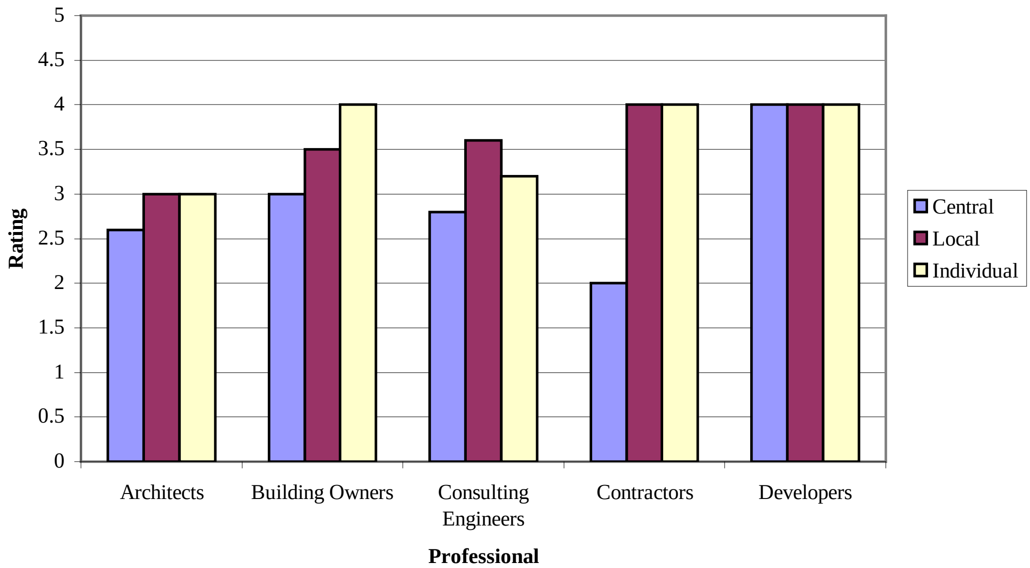

Figure 4.10: Controllability of mixed-mode in cellular offices.

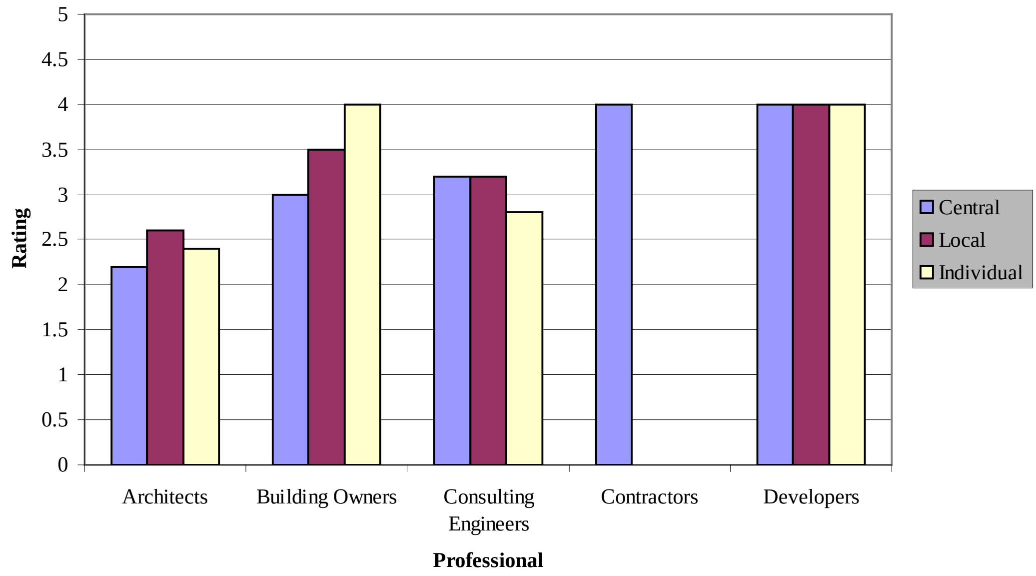

Figure 4.11: Controllability of mixed-mode in open plan offices. Contractors did not respond about local and individual controllability.

Most interviewees felt that mixed-mode systems would provide control that was ‘Good’ to ‘Very Good’, with local and individual control being ranked higher by building owners and consulting engineers (for cellular offices). Architects were the exception, rating the controllability of the system as ‘Fair’ to ‘Good’.

4.2.10 Cost of Mixed-Mode Ventilation

Based on our collected data, the perception of the costs of a mixed-mode system is the same for both cellular and open plan offices. For this reason, Figure 4.12 displays only the data for cellular plan offices. Again, the scale used is:

0 = No response

1 = Inexpensive

2 = Somewhat Inexpensive

3 = Moderate

4 = Somewhat Expensive

5 = Expensive

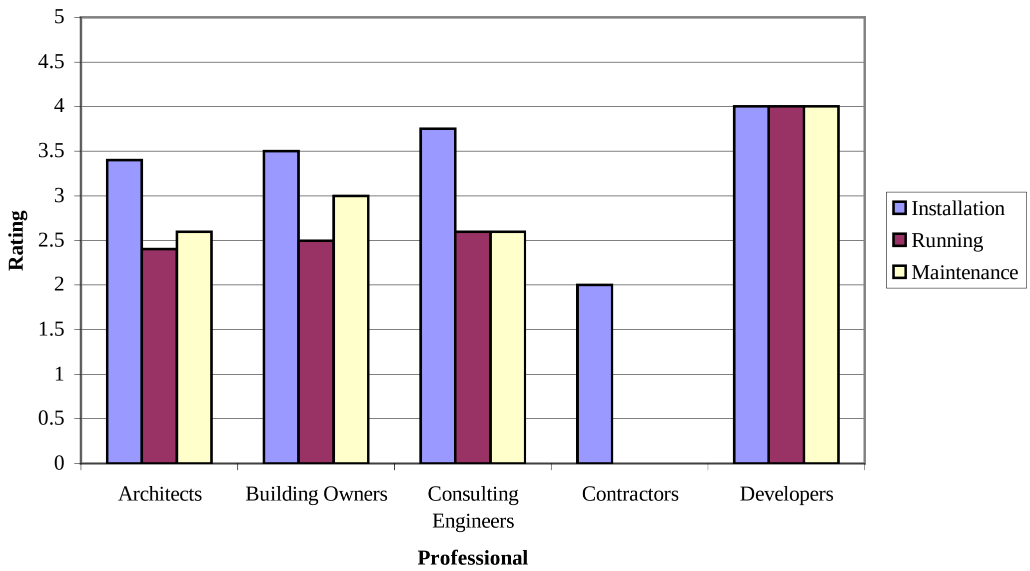

Figure 4.12: Cost of mixed-mode systems. Contractors did not respond about running and maintenance costs.

Of the three costs, designers and decision makers thought that comparatively, the installation costs would be the greatest. Most felt that running and maintenance costs would be ‘Somewhat Inexpensive’ to ‘Moderate’. Compared to the perceptions of mechanical systems, mixed-mode is seen as being more economical. The exception to this was developers who perceive mixed-mode ventilation to be ‘Somewhat Expensive’ for all three costs.

4.2.11 Sources For Mixed-Mode Information

The sources most often cited by interviewees included some guidelines, building studies, and experience. Many architects, contractors and developers stated that the information they receive about ventilation comes from the consultants they work with on projects. For example, an architect said, “You [architects] don’t have the time to do the work, therefore you would rely on the consultants to do it and suggest a method.”

4.2.12 Expected Future Use of Mixed-Mode Ventilation

Nearly all of the people interviewed felt that the use of mixed-mode and natural ventilation would be increasing to some degree in the future. Most thought that it would be 'Somewhat Increasing'. This is shown in Figure 4.13. The scale is

1 = Decreasing

2 = Somewhat Decreasing

3 = Unchanged

4 = Somewhat Increasing

5 = Increasing

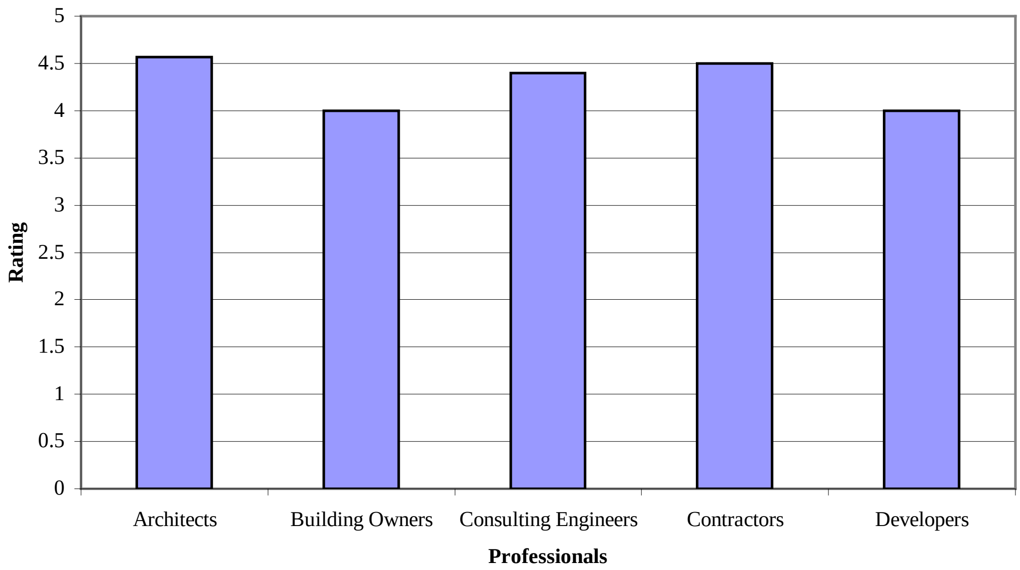

Figure 4.13: Expected future use of mixed-mode ventilation.

The reasons given for the expected rise in use included increased environmental awareness, financial savings from using the system, increased demand for indoor comfort, and need to find alternatives to burning fossil fuels. As another architect that we interviewed put it, "Future use will be increasing because there are increasing awareness of environmental impacts."

4.2.13 Government Regulations Restricting Use of Mixed-Mode

With the exception of developers, most people did not feel that government regulations restrict the use of mixed-mode ventilation. Consulting engineers rated the extent to be between 'None' and 'Few'. Many interviewees stated that regulations do not limit mixed-mode systems at all. Instead, they felt that regulations did not do enough to promote the system. "Government restrictions could encourage the use of mixed-mode systems more, but don't prevent it," said a consulting engineer. Those who said that there were 'Few' or 'Some' restrictions cited mostly fire related codes and regulations. Figure 4.14 shows the data for government regulations. The scale used was:

1 = None, 2 = Few, 3 = Some, 4 = Many, 5 = Extensive

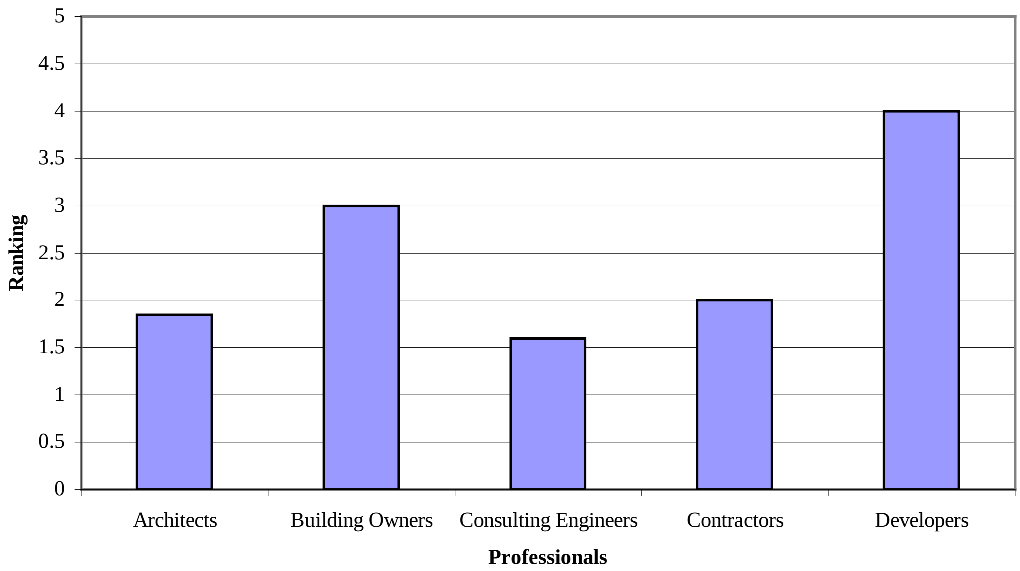

Figure 4.14: Extent of government restrictions to mixed-mode systems.

4.3 Specific Building Questionnaire

4.3.1 Background for the Design

For design parameters, there were seventeen criteria that the interviewees chose from. Although the list was extensive and the interviewees come from different disciplines, the questionnaire results show that some parameters were considered critical and used all the time, while others were not selected at all. The results also showed the design parameters for the different room types were often the same.

The questionnaire showed that in general, for residential/hotel projects, the design parameters used most often were (in no particular rank): construction costs, internal noise, summer room temperature, and operating costs. Other design parameters were also used, but those listed above were dominant for the different disciplines. For office buildings, the most used parameters were: summer room temperature, solar loads, and indoor air quality. Since office buildings serve purposes that are different than residential/hotel buildings, it was expected that different parameters would be used.

With educational institution projects, summer room temperature was the criteria used most often, but after that, the parameters used varied greatly. Despite this, many of the same parameters used for other buildings were used for schools. It was the order of importance that varied.

In general, summer room temperature was listed as most important by the most number of interviewees. Winter room temperature was rarely a parameter that was used; however, some commented that it could be combined with summer under the heading ‘room temperature’. Other design parameters commonly selected fro all buildings were construction costs, internal noise, and solar loads. Appendix D contains spreadsheets detailing the number of times each parameter was ranked 1 through 5 for each room type.

4.3.2 Biggest Influence on Chosen Design

As with the design parameters, there were dominant people or factors that came up frequently as having the most influence on the chosen design for a ventilation system. Unlike what we saw for design parameters, the people or factors that have an influence were similar for all the different project types (residential/hotels, offices, and educational institution). For residential/hotel projects, the people and factors that have the most influence were (no particular rank): architects, consultant engineers, developers, building site, and requirement in building codes. For offices, they were: architects, owners, users, consulting engineers, and requirements in building codes. With educational institutions, the people or factors with influences were: architects, owners, users, requirement in building codes, and consulting engineers.

Overall, the people and factors that were believed to have the most influence on the chosen designs were architects, consulting engineers, owners, users, and requirements codes, norms and standards. Appendix D also contains a spreadsheet showing the number of times each design influence was ranked 1 through 5.

4.4 Occupant Surveys

Detailed results from the occupant survey are found in Appendix F.

4.4.1 Air Quality

An equal number of occupants surveyed said that they notice the air quality in their workplace 'Not Very Often', 'Sometimes', and 'Often'. Fifty percent said they didn't noticed odours very often, but twenty-five percent claimed to notice odours often. Figures

4.15 and 4.16 show how often occupants notice the air quality and odours in their work environment.

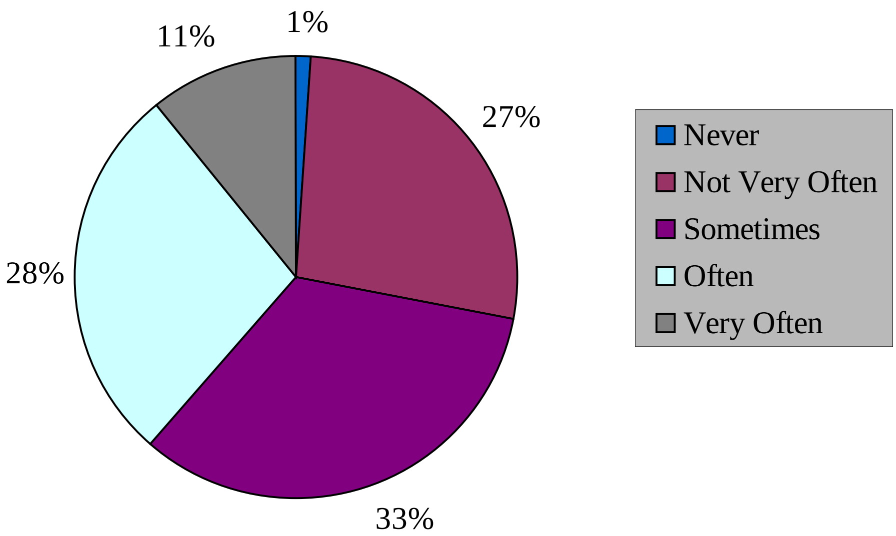

Figure 4.15. Frequency that occupants notice air quality.

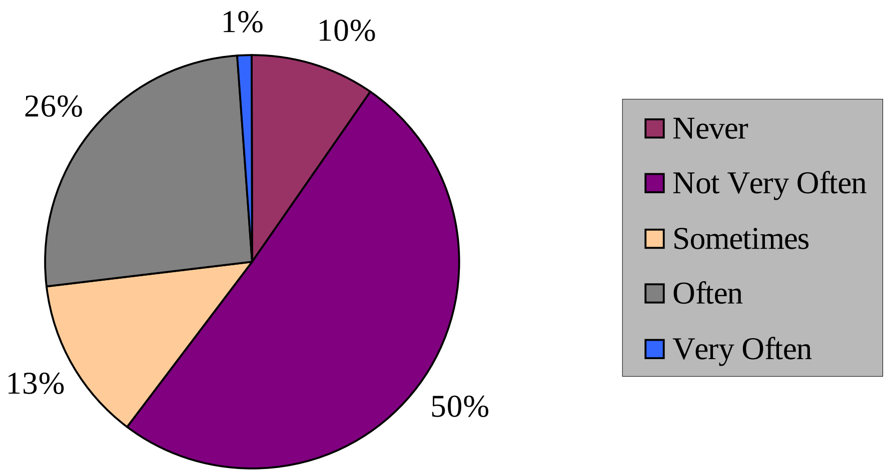

Figure 4.16. Frequency that occupants notice odours.

4.4.2 Effects of Noise

In general, noise did not seem to be a major issue with the occupants surveyed. Few felt that it had a major impact on their ability to work; most saying it had little impact (see Appendix F). The types of noise people found to be most distracting included talking, machinery, and telephones from adjacent offices.

4.4.3 Temperature Ranges

The majority (63%) of building occupants surveyed prefer to work in temperatures between 19 and 21 degrees Celsius. The second largest range selected was 22 to 24 degrees, as shown in Figure 4.17. Many occupants, however, expressed that they were not sure of the ranges they were selecting. It is possible that occupants could not effectively judge the temperatures at which they were most comfortable.

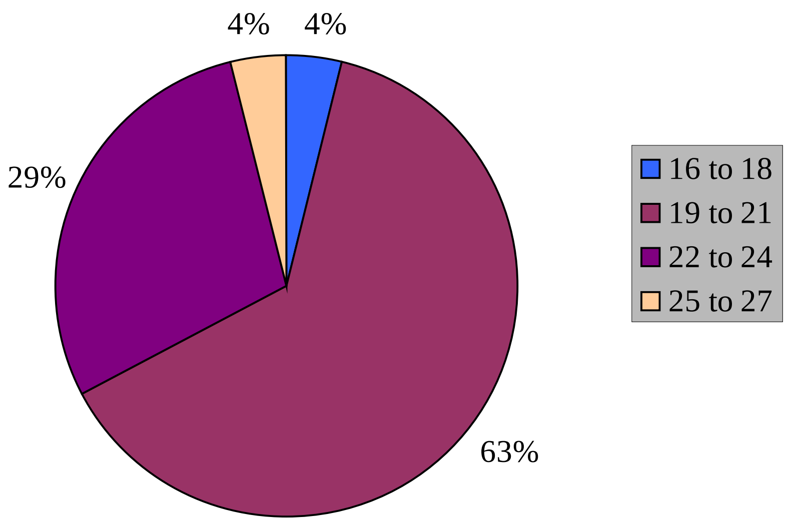

Figure 4.17. Preferred temperature ranges.

4.4.4 Controllability

Many building occupants would like the individual control that a mixed-mode system provides. While few people felt they needed complete control, most wanted to have some control over their environment at work. Figure 4.18 reflects these trends. The areas which people wanted the most control included temperature, airflow, and light levels.

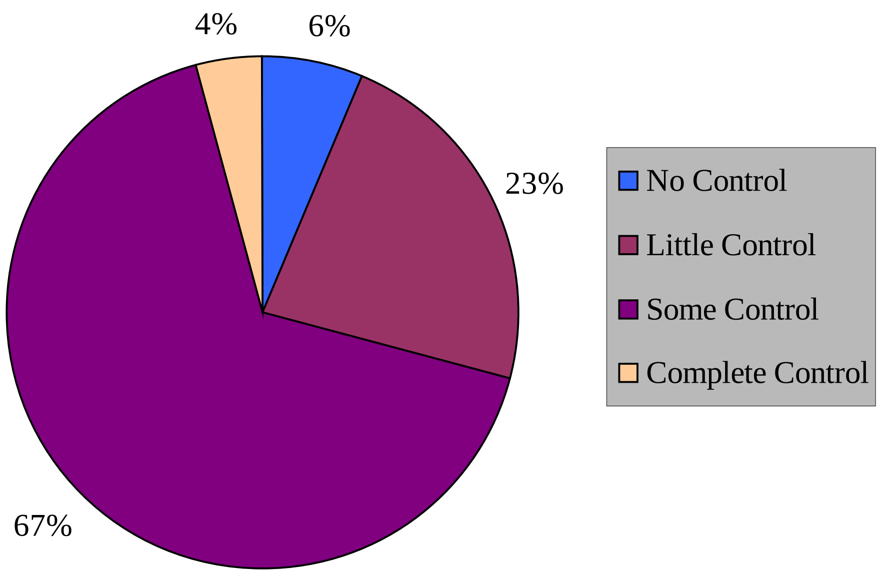

Figure 4.18. Desired level of control.

4.4.5 Current Satisfaction Levels

While a majority of users (58%) were reasonably satisfied with the ventilation system in their building, a large number (24%) were somewhat unsatisfied. More occupants were very unsatisfied than were very satisfied.

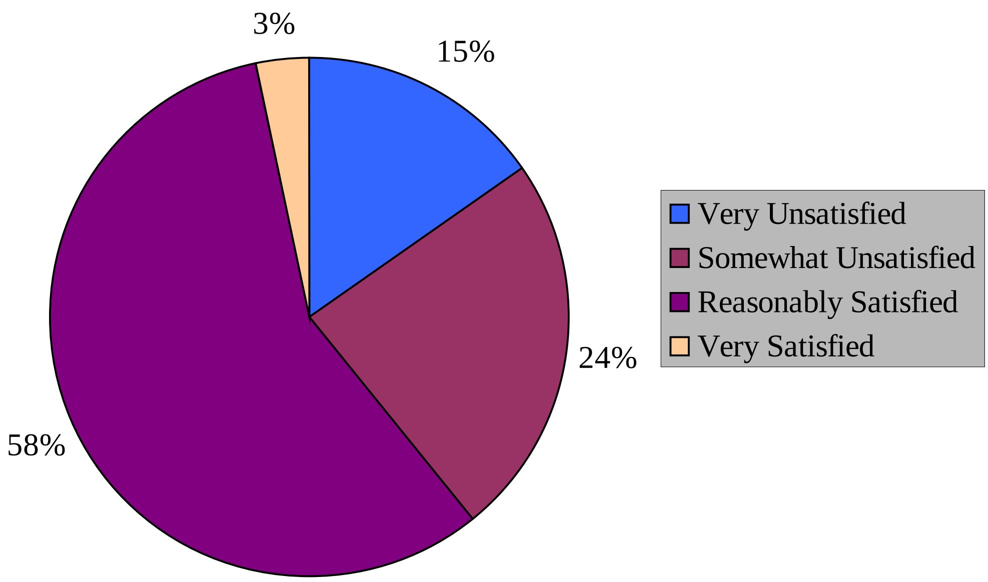

Figure 4.19. Satisfaction with current system.

4.4.6 Environmental Concern

Environmental concern among Melbourne office workers surveyed was high. Nearly all respondents expressed concern about the Earth's environment and the factors that are threatening it. Issues most frequently mentioned were pollution, deforestation, waste disposal and the ozone layer.

4.4.7 Global Warming

Eighty percent of those surveyed expressed concern about global warming. Only 11% said they did not feel it was an issue, and 9% were not sure, as Figure 4.20 shows. Reasons given for concern included changes to the global climate and impact on human quality of life. However, many occupants confused global warming with the problem of the hole in the ozone layer. Reasons given for lack of concern were that it may be part of a natural weather cycle, the effects aren't noticed, and more temperate weather is good.

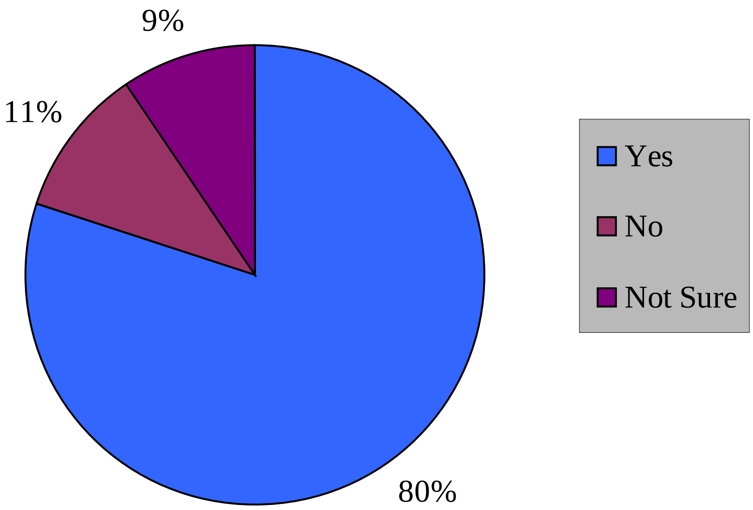

Figure 4.20. Occupant concern about global warming.

4.4.8 Effort to Design Environmentally Friendly Buildings

When asked how much effort should be put into the design of buildings less damaging to the environment, a large majority (87%) felt that the effort should be mandatory. The remaining 13% felt that at least a modest effort should be made.

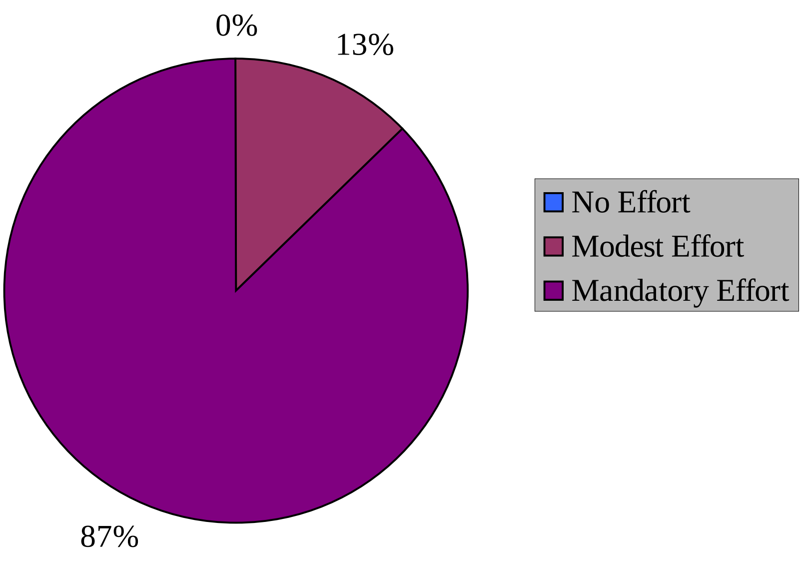

Figure 4.21. Level of effort for environmentally friendly buildings.

4.5 Conclusions

Using the data presented in this chapter and in the Appendices, conclusions were drawn about the barriers to mixed-mode ventilation and recommendations on how to overcome those barriers were made. The conclusions and recommendations can be found in the next chapter.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Project Summary

5.1.1 Background Work

Work on the project began at Worcester Polytechnic Institute (WPI) in Worcester, Massachusetts, with background research on the various types of ventilation, focusing on mixed-mode ventilation and studies done on barriers to its use. A methodology was then developed for assessing the barriers to mixed-mode systems in the Melbourne area. Once in Australia, background research continued and the methodology was revised.

5.1.2 Interviews with Designers and Decision Makers

To determine the barriers to the use of mixed-mode ventilation, we spoke with two groups of people. The first was designers and decision makers. This group was made up of architects, consulting engineers, contractors, developers, and building owners. We selected interviewees based on suggestions made by our sponsor, lists of corporations found on the Internet, and the suggestions of other interviewees. Table 5.1 shows how many professionals in each occupation were interviewed.

Table 5.1: Number of Professionals Interviewed

Architects	Consulting Engineers	Contractors	Developers	Building Owners
7	5	2	2	2
				Total: 18

Interviews involved filling out two questionnaires, one about the general views of the professional on mechanical and mixed-mode systems and the second on a specific building project they had worked on. Time restrictions prevented some interviewees from completing the second questionnaire. Both questionnaires were modeled after those used in the Nat**Vent**™ study conducted in Europe, with modifications made to better suite the Melbourne location and to clarify some of the questions.

The purpose of the general views questionnaire was to assess professionals' knowledge of mixed-mode ventilation systems and their perception of how its performance compares to that of more widely used mechanical systems. The questionnaire asked about general knowledge and experience, as well as comparing the two systems in both open plan and cellular offices. It also asked about expected future use of mixed-mode ventilation, government regulations restricting its use, and desirable design tools and system components. The general views questionnaire can be found in Appendix B.

The goal of the specific building questionnaire was to assess the importance of various parameters during the design phase of a building project. In addition to looking at the design parameters used, we also looked at who or what has the biggest influence on the final chosen design used for a building. The interviewees were given the freedom to choose any building project that they were involved with to base their responses on. Most of the projects chosen were office buildings, educational institutions, or high-rise residential/hotel buildings situated in urban areas. Appendix B also contains a copy of the specific building questionnaire.

5.1.3 Occupant Survey

In addition to the Nat**Vent**™ derived questionnaires for designers and decision makers, the project team drafted an occupant survey to distribute in various office buildings in Melbourne. The goal of the survey was to gauge how office workers viewed their workplace, what their environment concerns were in a global sense, their knowledge and concern about global warming, and whether these views could be a possible barrier to the implementation of mixed-mode systems. A trial survey was conducted at the CSIRO complex to test the effectiveness of the survey. Modifications to make the survey more clear were made before its distribution to other offices. The occupant survey was distributed in four buildings in various parts of Melbourne. The surveys were dropped off at each site and collected several days later. Of the 200 surveys distributed, 93 were completed and returned. The occupant survey is located in Appendix B, following the questionnaires for designers and decision makers.

5.1.4 Data Analysis and Results

Once all interviews had been conducted and all surveys collected, the data was analyzed for trends that may indicate what barriers existed to the use of mixed-mode ventilation. The results from the general views questionnaires given to designers and decision makers were entered into a database. Queries were made to determine how members of each profession felt about mechanical and mixed-mode systems. The data obtained by the specific building questionnaire was tallied and entered into spreadsheets, making the information easily accessible. Records of comments made during the interviews were also compiled and reviewed to find relevant information. The occupant surveys were entered into a database so that queries could be made and general trends among office workers could be established. The results were presented in charts and graphs found in Appendix C, D, and F.

5.2 Conclusions

Many barriers exist to the use of mixed-mode ventilation systems in Melbourne. The largest of these barriers is inertia. Mechanical systems have been the system of choice for over twenty years, making them well established. There is a great deal of information available on the design, construction, costs, and effectiveness of such systems. Mechanical systems are what most designers are familiar and comfortable with, meaning they can produce designs for buildings more quickly and easily, making them competitive with other designers.

Comparatively, there is little information available on mixed-mode systems. Few designers were familiar with them, how they are designed, their cost, or their performance. The only professionals who seemed to have a good understanding of the systems were those who had worked on the design of buildings in European countries. For this reason, lack of education about the systems, their benefits, and design information, as well as limited numbers of case studies prevent the use of mixed-mode systems.

In many cases, it seems that consulting engineers are the source of information on ventilation systems for other professionals. Often, the architect or contractor simply uses whatever system the consultant tells them to. However, the choice of the consulting engineer can be influenced by the developer or owner of the building, meaning that not only designers, but decision makers require education about mixed-mode systems.

Among users, satisfaction with current systems and concerns about noise levels present possible barriers. Many occupants were reasonably satisfied with the system currently used by their building, suggesting a possible unwillingness to change systems. Many also listed various forms of internal noise as being the most distracting in the work place, something that mixed-mode systems may not be able to remedy.

Despite the barriers, the potential for the use of mixed-mode systems in the Melbourne area is high. Increased awareness and concerns about environmental issues as well as rises in the cost of fossil fuels, are dictating that alternatives to mechanical systems be found. Designers familiar with mixed-mode concepts seem confident that it is a viable alternative to current mechanical systems. The majority of those not familiar showed interest in finding such an alternative to current methods, provided there are design guidelines and performance predicting tools available, as well as information on the cost of mixed-mode systems.

While most occupants seem reasonably satisfied with their environment, satisfaction levels with mechanical systems indicated that mixed-mode systems have a place in Melbourne buildings. There are many areas that can be improved upon in the workplace. Users want the fresh air, control, and environmental friendliness that mixed-mode systems provide. They are also very concerned about environmental issues such as global warming and resource consumption and feel that efforts should be made to improve the efficiency of buildings.

The greatest potential market for mixed-mode systems seems to exist in buildings where the owner of the building occupies it as well. In this situation, the owner has to worry about the cost of running the building instead of simply passing them along to tenants. They may be willing to pay slightly higher design or construction costs to save themselves money in the long run rather than looking for the fastest, least expensive way to complete a building project. Buildings such as schools and corporate offices are examples of potential clients. Schools especially show promise because many are located in suburban areas where concerns about pollution and external noise through openings are often minimized. In corporate offices, the owner has a vested interest in the productivity and happiness of the occupants.

5.3 Recommendations

Increased education is required to promote the use of mixed-mode ventilation in the Melbourne area. Such education should start in schools, training engineering and architectural students about mixed-mode ventilation. Programs to educate professionals already in the work place could also be set up to highlight the reasons for using mixed-mode ventilation as well as how to do it.

More design guidelines and standards are required in order to improve the ease of design of mixed-mode systems. Guidelines need to be produced by organizations such as ASHRAE and need to be widely distributed. In addition, the design of simple mixed-mode system modeling software would lead to a much greater acceptance of mixed-mode solutions. Documentation of case studies in which mixed-mode systems were successful will also further the system's cause.

Nearly all designers felt that building owners would need to be convinced about the effectiveness, user satisfaction, and money saving aspects of mixed-mode ventilation. All of the mixed-mode or natural ventilation projects cited in the specific building questionnaires were promoted and supported by the building owner. Unless the building owner is environmentally concerned, cost is the driving factor. Methods for selling the system to building owners need to be developed, with a highlight on cost effectiveness, if mixed-mode ventilation is to be marketed successfully. Information about the systems and their many advantages could be distributed in journals for building owners and organizations or at conferences for such organizations, particularly the Property Council of Australia.

Efforts could to be made to gain government support for environmentally friendly buildings. Regulation of energy consumption during winter and summer months when air conditioning and heating are operated can be promoted. The government could also reward buildings using energy efficient systems through subsidies and tax breaks. The occupant survey suggests that such legislation would have public support.

Public education about environmental issues, especially global warming, could be increased. Such education could begin with children in schools and public service announcements. The data collected suggests that more awareness of the causes and effects of global warming should be promoted. In many cases, occupants confused the issue of ozone depletion with global warming, making the two interchangeable. More needs to be done to educate people about the causes of global warming as well. In some cases, people listed that they were very concerned about global warming, but were not concerned about the energy used by their building or felt that efforts to design environmentally friendly buildings should be only moderate.

5.4 Future Project Work

Further study of the design phase of a building project could be made to better determine how decisions on ventilation systems are made. This information could be used as a marketing tool, giving a better idea as to who should be targeted regarding the use of mixed-mode systems. It would also provide insight into critical design parameters for different types of rooms and buildings, thereby making clear the capabilities of mixed-mode systems that are most desirable or need improvement. If the system can efficiently satisfy the parameters in almost every aspect, then there will be a greater likelihood that it will be selected.

While much of the information gathered by the occupant survey is useful in determining general trends among office workers, there are many ways in which it could be improved. Three of the four buildings surveyed were occupied by architects or consulting engineers. A future project could conduct a more widely distributed survey of office occupants in Melbourne. It should focus on all types of offices, thereby solving the problem of possible bias existent in our survey. Different numbers of surveys were also distributed at each building. To avoid giving the responses from one building too much weight in the results, the number of surveys distributed to each building should be proportional to building population. Finally, a more advanced survey could also go into more detail about the indoor environment and people's knowledge of environmental issues.

Once target audiences for mixed-mode systems have been established, work could be done on the best ways to market the systems to owners, developers, consulting engineers, architects and the general public. Pamphlets highlighting the advantages of the systems in a variety of circumstances could be developed and distributed, thereby promoting the use of the systems.

5.5 Significance of the Project

The use of mixed-mode ventilation has the potential to improve the lives of the people in Melbourne. While exact figures are not known, its widespread use would significantly reduce the consumption of energy by the commercial sector. Such a reduction could lead to decreases in carbon dioxide levels in the atmosphere, curbing the effects of global warming and providing a higher level of outdoor air quality. A reduction in energy consumption would also slow the depletion of fossil fuels as a resource.

The energy savings provided by a mixed-mode system would translate into lower running costs for owners and tenants. The potential for less expensive installation and maintenance also exists, further reducing the cost of providing a building with adequate ventilation and thermal comfort.

The occupants of buildings using mixed-mode systems would benefit from possible improvements to thermal comfort, controllability, and air quality provided by mixed-mode ventilation. For people who spend the majority of their working day in the office, providing a healthy environment that they can control is essential. Increased user satisfaction and happiness has the potential to raise productivity levels and result in a decline in absenteeism. In this way, it is possible for mixed-mode ventilation to benefit the companies that own or lease buildings in yet another manner.

By determining the barriers to the use of mixed-mode systems and suggesting ways in which these barriers can be overcome, this project has provided the information needed to promote the implementation of mixed-mode ventilation in Melbourne. It has provided CSIRO with a starting point from which it can develop strategies to increase the use of this system. Work can now be done to design the materials needed to market the system to those most likely to adopt and benefit from it.

APPENDIX A: CSIRO

CSIRO

Australia's Commonwealth Scientific and Industrial Research Organization (CSIRO) is one of the world's largest scientific research institutes, with a goal of being a world-class organization vital to Australia's future. The Science and Industry Research Act of 1949 established CSIRO with the mission of conducting research to benefit Australia's industry, economy, environment, and society, and supporting Australian national and international objectives.

The Science and Industry Amendment Act of 1986 established CSIRO's current structure. This created a ten-member CSIRO Board responsible for determining policy and ensuring the efficient function of CSIRO. The Chief Executive, who is also a member of the board, is responsible for the organization's activities.

The staff at CSIRO is employed under Section 32 of the Science and Industry Research Act, 1949. CSIRO currently employs approximately 6,500 people throughout Australia.

CSIRO's research is planned and resourced on a sectored basis. A sector is a part of the Australian economy or natural resources for which CSIRO conducts research and development. There are twenty-two sectors defined by the organization covering research in: agribusiness, environment and natural resources, information technology, infrastructure and services, minerals and energy, and manufacturing. While sectors define the types of research being done within CSIRO, the Business Units organize the people to do the research. Business Units are organized along discipline lines. There are twenty-three divisions in CSIRO, each involved with multiple sectors. The following table gives a breakdown of the infrastructure of the organization by sectors and divisions.

We are working with the Advanced Thermal Technologies Laboratory, which is part of the Building Construction and Engineering Business Unit. The Advanced Thermal Technologies Laboratory is comprised of a team of professional scientists, engineers and technicians with broad expertise and capabilities in the areas of Natural Convection, Forced Convection, Heat Transfer, Fluid Mechanics, Thermodynamics, Mathematical Modeling, Numerical Analysis, Building Thermal Analysis, Building Ventilation, Experimental Modeling, Laser Diagnostics and Computer Technologies. The chart below was sourced from http://www.csiro.au.

CSIRO OPERATIONS AND REPORTING   Acting Chief Executive - Dr Colin Adam

ALLIANCES and SECTORS

Deputy Chief Executives	Field Crops	Food Processing	Forestry, Wood & Paper Industries	Horticulture	Meat, Dairy & Aquaculture	Textiles, Clothing & Footwear	Biodiversity	Climate & Atmosphere	Land & Water	Marine	Built Environment	Chemicals & Plastics	Information Technology & Telecommunications	Integrated Manufactured Products	Measurement Standards	Pharmaceuticals & Human Health	Radio Astronomy	Services	Energy	Mineral Exploration & Mining	Mineral Processing & Metal Production	Petroleum
	Agribusiness						Environment & Natural Resources				Information, Manufacturing & Service Industries								Minerals & Energy			
DIVISIONS																						
Dr Chris Mallett																						
Animal Health		●			●	●	●															
Animal Production					●	●		●		●												
Food Science Australia	●	●		●	●							●		●								
Plant Industry	●	●		●	●	●	●	●						●								
Textile & Fibre Technology						●																
Tropical Agriculture	●				●		●	●	●	●												
Dr Paul Wellings																						
Atmospheric Research								●											●			
Entomology	●		●	●	●		●	●	●		●	●				●						
Forestry & Forest Products			●				●	●	●		●	●										
Land & Water	●		●	●	●		●	●	●	●	●		●					●	●	●	●	●
Marine Research					●		●	●		●												●
Wildlife & Ecology	●		●		●	●	●	●	●	●								●	●	●		
Dr Ron Sandland																						
Australia Telescope National Facility																	●					
Health Sciences and Nutrition	●	●			●											●						
Manufacturing Science & Technology											●	●	●	●		●		●	●	●	●	
Mathematical & Information Sciences	●	●	●	●	●	●	●	●	●	●	●		●	●		●	●	●	●	●	●	●
Molecular Science											●	●		●		●						●
Telecommunications & Industrial Physics						●		●			●	●	●	●	●			●	●	●		●
Dr Bruce Hobbs (Acting)																						
Building Construction & Engineering											●	●		●							●	
Energy Technology								●	●	●									●	●	●	
Exploration & Mining																			●	●		●
Minerals																			●		●	●
Petroleum Resources																			●			●

APPENDIX B: QUESTIONNAIRES AND SURVEYS

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APPENDIX C: GENERAL QUESTIONNAIRE RESULTS

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APPENDIX D: SPECIFIC BUILDING QUESTIONNAIRE RESULTS

Number 1 Ranked Design Parameters

	Offices	Meeting Rooms	Canteen	Corridors	Stairways	Entrance Hall	Atria	Lavatories	Others	Total
Number of Buildings										
Containing Room:	8	6	3	8	4	6	4	4	13	
Room temperatures, winter	1	1	0	0	0	1	0	0	2	**5**
Indoor air quality	0	**0**	0	1	0	0	0	1	2	**4**
Draught, winter	0	0	0	**0**	0	0	0	0	0	**0**
Room temperatures, summer	4	2	1	2	1	3	1	1	5	**20**
Solar loads	0	0	0	0	0	0	0	0	0	**0**
Internal heat loads	1	2	1	1	1	1	1	1	0	**9**
Draught, summer	0	0	0	0	0	0	0	0	0	**0**
Individual control	1	0	0	0	0	0	0	0	0	**1**
Internal noise	0	0	0	1	0	1	0	0	**1**	**3**
External noise	0	0	0	0	0	0	0	0	0	**0**
Internal air pollution/odours	0	**0**	0	**0**	0	**0**	0	**0**	0	**0**
External air pollution/odours	0	0	0	0	0	0	0	0	0	**0**
Fire regulations	0	0	0	1	0	0	0	0	1	**2**
Security	0	0	0	0	0	0	0	0	0	**0**
Construction costs	**1**	1	1	**2**	2	**0**	2	1	2	**12**
Operating costs	0	0	0	0	0	0	0	0	0	**0**
Maintenance cost	0	0	0	0	0	0	0	0	0	**0**

Number 2 Ranked Design Parameters

	Offices	Meeting Rooms	Canteen	Corridors	Stairways	Entrance Hall	Atria	Lavatories	Others	Total
Number of Buildings										
Containing Room:	8	6	3	8	4	6	4	4	13	
Room temperatures, winter	2	1	0	1	1	1	0	1	2	**9**
Indoor air quality	0	**0**	0	0	0	0	0	0	0	**0**
Draught, winter	0	0	0	**0**	0	0	0	0	0	**0**
Room temperatures, summer	1	1	0	0	0	1	0	0	5	**8**
Solar loads	3	2	2	3	1	2	2	1	3	**19**
Internal heat loads	1	0	0	1	1	0	1	0	1	**5**
Draught, summer	0	0	0	0	0	0	0	0	0	**0**
Individual control	0	0	0	0	0	0	0	0	0	**0**
Internal noise	0	1	0	0	0	0	0	1	**0**	**2**
External noise	0	0	0	0	0	1	0	0	0	**1**
Internal air pollution/odours	0	**0**	0	**0**	0	**0**	0	**0**	0	**0**
External air pollution/odours	0	0	0	0	0	0	0	0	0	**0**
Fire regulations	0	0	0	0	0	0	0	0	0	**0**
Security	0	0	0	0	0	0	0	0	0	**0**
Construction costs	**0**	0	0	**1**	0	**0**	0	0	1	**2**
Operating costs	1	1	1	2	1	1	1	1	1	**10**
Maintenance cost	0	0	0	0	0	0	0	0	0	**0**

Number 3 Ranked Design Parameters

	Offices	Meeting Rooms	Canteen	Corridors	Stairways	Entrance Hall	Atria	Lavatories	Others	Total
Number of Buildings										
Containing Room:	8	6	3	8	4	6	4	4	13	
Room temperatures, winter	0	0	1	0	0	0	0	0	2	**3**
Indoor air quality	2	**2**	1	1	0	1	1	0	2	**10**
Draught, winter	0	0	0	**2**	1	0	1	0	0	**4**
Room temperatures, summer	1	0	0	0	0	0	0	0	0	**1**
Solar loads	0	0	0	0	0	0	0	0	0	**0**
Internal heat loads	0	0	0	0	0	0	0	0	0	**0**
Draught, summer	0	0	0	0	0	0	0	0	0	**0**
Individual control	0	0	0	0	0	0	0	0	1	**1**
Internal noise	0	0	0	1	0	1	0	0	**4**	**6**
External noise	0	1	0	0	0	0	0	0	0	**1**
Internal air pollution/odours	2	**2**	0	**2**	1	**2**	1	**3**	1	**14**
External air pollution/odours	0	0	0	0	0	0	0	0	0	**0**
Fire regulations	0	0	0	0	1	0	0	0	0	**1**
Security	0	0	0	0	0	0	0	0	0	**0**
Construction costs	**3**	1	1	**2**	1	**2**	1	1	3	**15**
Operating costs	0	0	0	0	0	0	0	0	0	**0**
Maintenance cost	0	0	0	0	0	0	0	0	0	**0**

Number 4 Ranked Design Parameters

	Offices	Meeting Rooms	Canteen	Corridors	Stairways	Entrance Hall	Atria	Lavatories	Others	Total
Number of Buildings										
Containing Room:	8	6	3	8	4	6	4	4	13	
Room temperatures, winter	1	1	0	1	0	1	1	1	0	**6**
Indoor air quality	0	**0**	0	0	0	1	0	0	0	**1**
Draught, winter	1	0	0	**0**	0	0	0	0	0	**1**
Room temperatures, summer	1	1	2	2	1	1	1	1	2	**12**
Solar loads	0	0	0	0	0	0	0	0	0	**0**
Internal heat loads	0	0	0	0	0	0	0	0	1	**1**
Draught, summer	0	0	0	2	1	0	1	0	1	**5**
Individual control	1	1	1	1	0	1	1	0	2	**8**
Internal noise	2	2	0	1	1	1	0	1	**0**	**8**
External noise	0	0	0	0	0	0	0	0	0	**0**
Internal air pollution/odours	0	**0**	0	**0**	0	**0**	0	**0**	1	**1**
External air pollution/odours	0	0	0	0	0	0	0	0	0	**0**
Fire regulations	0	0	0	0	0	0	0	0	0	**0**
Security	0	0	0	0	1	0	0	0	0	**1**
Construction costs	**0**	1	0	**1**	0	**1**	0	1	2	**6**
Operating costs	2	0	0	0	0	0	0	0	4	**6**
Maintenance cost	0	0	0	0	0	0	0	0	0	**0**

Number 5 Ranked Design Parameters

	Offices	Meeting Rooms	Canteen	Corridors	Stairways	Entrance Hall	Atria	Lavatories	Others	Total
Number of Buildings										
Containing Room:	8	6	3	8	4	6	4	4	13	
Room temperatures, winter	0	1	0	0	0	0	0	0	1	**2**
Indoor air quality	3	**1**	0	1	1	1	0	1	0	**8**
Draught, winter	0	0	0	**0**	0	1	0	0	0	**1**
Room temperatures, summer	1	1	0	2	0	1	1	1	0	**7**
Solar loads	1	0	0	0	0	0	0	0	2	**3**
Internal heat loads	0	0	0	0	0	0	0	0	0	**0**
Draught, summer	0	0	0	0	0	0	0	0	0	**0**
Individual control	0	0	0	0	0	0	0	0	0	**0**
Internal noise	1	1	1	3	2	1	2	1	**1**	**13**
External noise	1	1	0	0	0	1	0	1	0	**4**
Internal air pollution/odours	0	**0**	1	**0**	1	**0**	0	**0**	1	**3**
External air pollution/odours	0	0	0	0	0	0	0	0	0	**0**
Fire regulations	0	0	0	1	0	0	0	0	2	**3**
Security	0	0	0	0	0	0	0	0	1	**1**
Construction costs	**0**	0	0	**0**	0	**0**	0	0	2	**2**
Operating costs	1	1	1	1	0	1	1	0	3	**9**
Maintenance cost	0	0	0	0	0	0	0	0	0	**0**

Biggest Influence On Chosen Design

Influences	Number of Times Ranked 1	Ranked 2	Ranked 3	Ranked 4	Ranked 5	**Total**
Architect	2	**4**	**4**	0	0	**10**
Consulting Engineer	0	3	**4**	2	0	**9**
Contractor	0	0	0	2	2	**4**
Owner	**4**	1	0	1	1	**7**
Developer	3	1	1	1	0	**6**
Investor	0	0	0	0	0	**0**
Users	1	2	0	**3**	1	**7**
The building site	0	0	1	1	**4**	**6**
Requirements in codes, norms, standards, etc.	2	0	1	1	3	**7**

APPENDIX E: COMMENTS FROM INTERVIEWS

Architect 1

That's (natural ventilation) relatively uncommon in commercial buildings. It would tend not to be accepted. In general most of our clients wouldn't accept it. It is only use in old buildings.

Didn't know what mixed-mode was.

(Mechanical ventilation in cellular offices)
For the architect it makes it easy because you don't have to worry about natural ventilation. You just sort of draw a little square anywhere and the mechanical engineer sticks a duct into it and blows air around.

I think the problem is, or partly the problem is the architects tend to rely on the mechanical consultants, and the mechanical consultants have a vested interest in pushing air-conditioning and the clients in these day and ages tend to have an expectation of air-conditioning. So you're only going to get a change away from it when energy costs become glamorous or there is a government intervention.

(On mixed-mode design)
I think it's much more you're sort of putting your finger up in the air and saying oh yeah that will be fine. If you're doing an office building you run various computer models to see how it was going to perform. But with this there just isn't software available, so you have no idea.

If you did it properly with Melbourne's climate, if you really took it seriously, you could get some quite good comfort conditions. You should be able to get it to work.

(Future use)
I think it will be increasing. I think it's from greenhouse concerns, that type of thing.

(Desirable tools)
I think computer programs would be the key one. They're going to have to be fairly simple if the architects are going to use them.

I think a big education program (is needed). I would suggest that most architects knew little about it. And you've got probably an education program at a number of different levels. You need to start at the universities with the students and you'd also have to get at the practitioners. You've got guys who have been in practice for thirty years or something and you've got others guys who've just come out of university, so you're going to have to pick them all up. I think you're major problem is your educational program.

I think the other barrier is a lot of architects aren't really interested. People got very excited about energy conservation during the seventies. And then when the oil crisis turned out to be a bit of a squib, people said oh well that was a waste of time doing those things and probably forgot about it.

Architect 2

Mixed-mode is easy to design because I would just relate it to the mechanical consultants.

Knowledge of mixed-mode system would come from the consultants. Takes advice from the consultants.

You (architects) don't have the time to do the work, therefore you would rely on the consultants to do it and suggest a method.

Would be very interested if informed about it. But who would inform me? The information needs to do comparison between mixed-mode and mechanical systems and show cost effectiveness over mechanical systems.

People in today's society would prefer to have natural ventilation come in along with the mechanical system.

Acrchitect 3

(Future Use)
There is more consciousness of energy use, and natural air (for ventilation) is free.

We need a larger variety of economy cycle units from more than one source.

If the owner occupies a building, they have to pay the running cost, therefore, they would be more interested (in mixed-mode) since it will reduce cost. An example is the corporate offices of a company.

(Installation costs)
They (developers) don't have the patience for a pay back period.

Mixed-mode is available but it's all done around mechanical system design.

Architect 4

The user satisfaction level of mechanical systems is good at best.

Codes could be used not as prevention to mixed-mode system, but as a promotion for it.

Achieving mixed-mode system usage in Melbourne is all in the perception of the ability to do it.

Think that mixed-mode is ideal for Melbourne area.

Future usage depends on more environmental awareness and the cost of fossil fuels.

Architect 5

There is very little information available on mixed-mode ventilation systems.

Case studies on buildings using mixed-mode ventilation systems need to be available. The problem is no one wants to be the subject of such study. People do not want to be the guinea pig of such new systems. Everyone is waiting for someone else to take the initiative and implement such a system in a building.

It costs to implement a mixed-mode system. No one is willing to do it unless it is absolutely necessary.

Feasibility study needs to be conducted for Melbourne to show that mixed-mode ventilation will actually work.

The users are reluctant to accept anything else besides AC.

(Future use)
Increasing awareness of environmental impacts. Spread of diseases through mechanical systems.

(Desirable new tools)
Energy/maintenance benefits
Extent required to achieve comfort conditions

(Desirable new components)
Availability of controllable acoustic external opening systems.

External street noise is a major concern leading to sealing street frontages.

Architect 6

(Future use)
Because we need to make use of the natural systems and be less reliant on systems which use 'fossil fuels'.

(On mixed-mode)
The public has to want it before we can sell it to them.

From an efficiency standpoint, I think that mechanical systems are very ineffective.

(Government regulation)
When people start getting into it (mixed-mode ventilation) they'll start making rules.

Architect 7

(Expected future use)
Future use of the system should be increasing to reduce energy used in buildings.

(Restrictions)
There are some restrictions that would be required for safety, i.e. spread of fire.

(Desirable new tools)
Rules of thumb
Design tools to give economic cost (not performance) of systems in 30 minutes.

(Desirable new components)
Built examples in Australia.

Building Owner 1

You want to know the cost involved, the potential for work in that system in the future, as well as the life cycle of the building.

The current system is well known, well understood. You don't want to be on the bleeding edge of technology. Sometimes you're the first one in and it's still very early days on some of the technology, you end up getting burned.

Would expect this technology if it is workable for our environment and can save us money and be environmentally responsible, then nothing is stopping it. If it passes that entire test, then it would come in. It would need architects and consulting engineers to start championing it. If they are not recommending it, then the owners won't think about it. Only some owners are proactive about it. It is an issue for us to be more energy efficient in the future.

Building Owner 2

The developers look at what the market wants and we got to have what they want. If the public demands an AC system, then we need to have an AC system, otherwise we would not stay in business. Therefore, there needs to be such a demand for mixed-mode.

(Expected future use)
Increase in usage due to Melbourne's change in weather pattern – hotter periods.

(Restrictions)
Finding location for condenser.
Operable windows on high rise construction.

Consulting Engineer 1

We should use economy cycle more readily than we have in the past, but cost is restrictive.

There are more concerns with costs on building installation. They want it as cheaply as possible and don't consider the running costs.

(Desirable components)
They are out there in the market; you just need to know what you want.

(Cost of a system)
It has more to do with money on building installation. They (developers) want it done as cheaply as possible, and don't really consider the running costs.

It should not take a small number of days to design optimum system conditioning.

It is the growth of people and other issues that doesn't allow a system to generate at it's peak.

Consulting Engineer 2

There are just not very many sort of passively designed buildings in Australia, in Melbourne, yet. We've designed some, but they're not built yet. We have some that are in New Zealand and in Sydney.

Often times we'll give a percentage of the construction cost, which is ultimately fixed.

I think there is a lot of interest in the market place. I think there's a lot of people who haven't sort of gone toward these types of systems because they just feel that it's all too hard and it's easier just to go and stick in kit. And because the modeling tools that were available up till now have been very basic and they really just go and work out heating and cooling plans. They haven't been able to do enough analysis to satisfy themselves that the thing is going to go and work and consequently because of that they have taken an easier option. It's easier just to go and specify some air-conditioning plant, take the fees, and run.

We have a really strong interest in developing mixed-mode solutions in other countries.

(Ease of design with mixed-mode)
It's not that easy; it's not as easy as putting in other ones.

A lot of the products that you put in are pretty similar to what goes into a normal building.

If you're relying on the wind patterns to work it, that's too risky because really what you need to do is when you're looking at these types of buildings is develop a number of scenarios.

(Using natural ventilation)

Effectively you can ventilate in about two and a half times the height. If you can get your building set up so that you get good single-sided ventilation, that's going to be quite effective. If you then start getting into deeper buildings you then start having to look at things like putting in wind towers….or putting an atrium in the center.

If you look at putting in an atrium, you may change the rental structure within the building. So in other words, by having an atrium in the middle of the building you can actually create a more marketable building. If there's a fair amount of development going on in the market place, tenants will tend to come to spaces where there is a nicer environment. The developers we've worked with have seen it as an advantage. In the market place I think it's generally true that they wouldn't go and do that.

I think though a lot of the sort of mixed-mode things and so on; pushing them in a development to a developer type situation is much more difficult than if you look at an owner/operator. I mean it would be much harder to go and push a mixed-mode office building to a hard-nosed developer compared to say, a university. Because in a university they're owner occupiers, they own their buildings so that they can reduce their running cost and (increase) occupant satisfaction. I think there will be a change in the market place, that developers are going to become more interested in it. What they're going to be interested in, or people who rent buildings is in achieving better tenant satisfaction. Because as the number of the people in the workforce is going to go down, people are going to be paid more and, therefore, are going to expect a better lifestyle. If you look at the way work patterns are changing, people are working a lot longer in offices, so because of the nature of the working pressure, business and so on. But their expectations of their comfort are much, much higher now. People want to have a more comfortable working environment. Personal comfort and control over ones own environment is going to be more and more important. And I think that is going to be a driving force.

One would assume for odors and pollutants if you had say toilets or a kitchen one would be putting in a mechanical ventilation system for those anyway.

That's the challenge, that's a really hard one, insulation against external noise.

(Installation costs of mixed-mode)
The installation costs are higher because you're essentially putting in two different systems.

(Open vs. closed plan with mixed-mode)
If you were saying that you had a building that had a long central corridor with office on either side and that were in the order of four meters deep, then it's quite easy to naturally ventilate those areas. Once you start to getting into deeper plan buildings it is a lot more difficult. Open plan tends to be a lot easier.

I think one of the things why naturally ventilated and mixed-mode buildings are going to come ahead is people are interested in getting greater thermal satisfaction. I think close control doesn't always equate to thermal satisfaction. There have been studies that have been done that show that if you have control over your own environment, you'll be a lot more comfortable and have less complaints about that environment than if you are in an environment that is closely controlled but you have inability to control that.

Just the ability that people can open a window or turn on a fan or that they're not feeling powerless, they can actually do something about their environment so that I think that's one thing.

There is an increasing environmental awareness, that we cannot continue to use fuel in the way we are at the moment and concern about generation of greenhouse gases. That movement and interest is going to go and continue on and I think that government regulation is going to be such that that is going to force people to start looking at more sustainable ways of designing buildings.

I think the standards are now going to start looking at; there's a lot of work being done at reforming the BCA and I think that's going to lead to more attention being paid to energy use within buildings. Following through with that, that's going to suggest more mixed-mode type situations.

I think some of the design of mixed-mode buildings is driven by the ability to be able to do it now. There are more sophisticated models to be able to do that. I think those models are getting better and better. It will be desirable if development of those continue so that it is possible to model buildings easier

I think the more people write about these things and publish them and talk about not only the successes, but also the difficulties of doing the things, the more discussion that happens, the better I think.

I think development in windows in terms of being able to go and have good automatic control systems for high level windows, the ability to be able to go and have trickle vents in windows as well. That would be good if we could get more of that kind of thing.

And I think there's a bit of work that needs to be done in terms of developing some sort of standardized algorithms associated with the control of natural ventilation for night time strategies.

Fire Codes are somewhat restricting.

I think the real difficulty in getting widespread take up on these is that there's a real expectation say within development companies or letting agents, that air-conditioning will be provided and it is the norm. And that people aren't prepared to go and do without air-conditioning, that they'll expect full air-conditioning. So I think there's going to be a requirement to change people's perceptions that you don't always achieve what you want to in terms of comfort with air-conditioning and that there is a more environmentally sustainable way of actually ventilating buildings that leads to higher client satisfaction. And I think that tenants and so on are becoming much more environmentally aware and will demand these types of buildings. I think there's a real education process that will have to go on with developers and so on. It's easy enough with owner occupiers but it's going to be very hard within the development market to go and change people there. But I think ultimately it will happen.

I think the only other barrier is sort of people's knowledge and perception. It's hard to get people you know to design these buildings because there's not a lot of knowledge. The people we generally find are people who've work in the design and modeling of these type of buildings overseas.

Consulting Engineer 3

It is very difficult to propose a natural ventilation system for refurbish buildings. Therefore mixed-mode system is very hard to accomplish in such a building.

Design guidelines for mixed-mode and natural ventilation are greatly lacking in Melbourne. The sources that he uses are predominantly from the UK, where there is greater availability.

Future use of mixed-mode ventilation system will increase, but there will not be a significant increase.

The environment is not a big factor that drives mixed-mode design. Factors such as cost play a major role in whether a mixed-mode design is use or not.

Mixed-mode is not the only solution to energy reduction. Methods such as solar shading will also be use.

There is a large inertia to change in Melbourne. Someone just needs to take the initiative.

In Melbourne, and Australia as a whole, there is a lack of building standards and no governmental bodies that drives the development of mixed-mode system, such as there are in the UK. Without any standards or requirements to force people to use mixed-mode, people are less inclined to take it upon themselves to do it.

The client plays a major role in deciding whether to use mixed-mode or not. If they do not see any benefits to such a system, or if the initial price of such a system is not justifiable, they are not willing to use it.

The market place for mixed-mode ventilation system in Melbourne is very slow.

Awareness of mixed-mode ventilation systems is non-existent. Until the client is aware of its existence, the concept is not going materialize.

Government restrictions could encourage the use of mixed-mode systems more, but don't prevent it.

It is not design tools that are needed. It is the change of mindset of designers and clients to embrace something different that is needed.

There may be a short-term availability problem for some products. Some components aren't here, and importing them would be expensive. There is a need to see what modern products can be converted for use in mixed-mode systems.

Consulting Engineer 4

According to Building Codes of Australia (BAC), 5% of the floor area must have operable windows for natural ventilation; otherwise a mechanical system has to be used.

It cost more to put in operable windows; therefore the architects do not do it unless it is absolutely necessary.

Most of the buildings where users are not happy with the ventilation system have developers design the HVAC system rather than calling on the consulting engineers.

Melbourne is very suitable for any new developments. The one problem that we have is manufacturing facilities. Most of the products that we used here are manufactured elsewhere and imported. If we manufacture our own products, then it would be easier to implement new systems.

The technology for mixed-mode systems exists and is fantastic, but nobody wants to pay for it.

In Australia, natural resources are abundant and a lot cheaper than most parts of the world. Therefore, no one wants to invest the time or the money into devising energy saving methods.

Solar power is suitable for Australia, but no one wants to pay the upfront cost for it. It takes 7-10 years to recover from the upfront cost of such new system, and no one is willing to do that.

To get an approval for a building permit, which needs the system to be in accordance with the BCA. If you add something onto the existing system, it would cost more to develop and meet the BCA requirements.

Recommend that CSIRO develop guidelines for mixed-mode system since they have a lot of respect in Australia and people would sure to follow what they put out.

Would be interested if CSIRO put out a document on this system.

(Future use)
For reduction of installation and running costs.

(Restrictions)
Simplicity – no guidelines or regulations to accommodate mixed systems.

(Desirable new tools)
CSIRO guidelines distributed to the associated professions and acceptable to building codes.
(Associated weather/wind data)

(Desirable new tools)
Air inlet suppliers details and associated controls

Consulting Engineer 5

We think this is a good idea, but they've (owners) got to sell it to their staff, to their people. To say hey, we're going away from fully air-conditioned, comfortable environment to something possibly not quite as comfortable. The benefits will be energy savings. Most people working for a company say, well, that doesn't bother me, that's not my problem.

The owner is a big issue. They have all the saying in whether a mixed-mode ventilation system would be implemented or not. Therefore, making the owner see its advantages are a critical issue.

If you can sell the greenhouse gases, the environmental benefits of it as an environmental issue, you probably will be able to sell it better.

People are just mindset, air-conditioning, bang, put it in.

When I say less comfortable, you won't get the same comfort conditions in the summer as you would with a mechanical ventilation system. So you've got to be a little bit more flexible. The range, the comfort levels, will have to widen a bit more.

I think the greatest potential would be in the educational systems. Particularly primary, secondary, tertiary universities. So I think that the greatest potential for mixed-mode or natural would be educational facilities because they pay the bills.

People pay rent, and the rent includes air-conditioning, so any savings in energy costs, they would not see any benefits of reducing that because they still pay rent on the basis of dollars per square meter.

One of the issues about this whole thing is understanding the leasing arrangements and how people pay for their space and services.

Generally speaking, the architects haven't come to grips with it yet, and there's no pressure for them to do it.

And it's one of the problems about the industry, it's all so competitive, cut throat, that people then will go and say, look you win this job if you're competitive. And if you're competitive, and want to go in with a low fee, the last thing you'll do is start to introduce new technology that's going to take you effort and time and research and development, so what you do is you offer the same stuff your offered twenty years ago, cause that's the way you can churn it out the door quickly. Unless the client wants something different, it's very hard to sell.

The problem is with standards and guidelines; they are nonexistent. Designers are reluctant to use a system that is lacking standards and that have no guidelines to go by. If ASHRAE puts out such guidelines, designers will follow it.

In order to promote the development of mixed-mode ventilation system, international design guidelines are needed.

This is a very early stage in the "marketing" of natural ventilation/mixed-mode ventilation systems.
(Designing mixed-mode systems)
Well, you need some up front knowledge of what you're doing. It's not just a matter of saying, oh well we're going to do one of those this week. You do need to have the expertise. To do a standard system, we'll know how to do it, but to do a new style of system, you'd have to learn some new fundamentals about the thermal inertia of buildings that's not just the ventilation, but it's the thermal inertia of the mass of what you're putting in there and everything else.

(On changing current buildings over)
Adaptability is very poor because they're sealed buildings already. And, therefore, if you're trying to look at natural ventilation you'll to have to spend a lot of money with your façade, putting in some form of openable windows, control systems, some form of chimney, stack effect, atrium or whatever so you get cross ventilation in getting the air up. So it's almost impossible to adapt to a standard building. They're a block, or a square, it's all sealed glass. It's very difficult.

People may not perceive it as being as good as mechanical systems.

(Design of a building)
Adaptability is not a problem because, as long as you start with an architect up front saying, well these are the fundamental issues we need, we need the stack effect, chimneys, and if that can be designed in a new building, you can achieve it. So I'm saying that it's easy to adapt.

(Changing cityscape)
I see that you can't just say here's a building in the center of the CBD, let's whack a natural ventilation system in it. You've got trucks, pollution, dust, noise. It's very difficult to make it stack up for a building like that. But if you're going to a green belt industrial estate, twenty kilometres out from town where it's open space, you've got trees, you've got grass, you've got buildings spread out, perfect. That's why an educational system where you've got educational facilities away from the CBD, you've got a very good ability to do it because for instance some of the institutions have moved their campuses to where the people are, where the growth has been in housing and people. So they've gone out in the suburbs. And when you go to the suburbs you've got a nicer environment. You haven't got a lot of tall buildings or whatever. So it's easier to do out further from the city. And there's where I think it really stacks up nicely, because you rely on filtration is able to filter out the stuff that comes in. There's also the acoustics part of it, not just air quality.

That's where I suppose the mixed-mode is… at least you can back up and go back to what you had with your mechanical ventilation system. Energy consumption goes up, but you can still provide comfort. But you could still use the mixed-mode in that situation because the prevailing winds aren't always going to be from the same direction. It changes.

With natural ventilation, you'll get the full effect of an odor outside whilst with air-conditioning you're getting part circulation.

(Draught minimization)

That is an excellent feature of a system because most air-conditioning systems with mechanical ventilation, you're blowing air around a lot, there's a lot of energy being spent pushing the air around and it's always drafty, people always complain. So that's a very good point you can sell (for the mixed-mode systems).

(Ability to remove odors and pollutants)
With a mixed-mode I suppose you can do it when you're in the ventilation mode, but not when you're in the natural.

(Noise generation)
We do need white noise for people working in an office environment. If it's too quiet, it's not good. You need a little bit of background noise. So the air-conditioning systems I think provide that little bit of hum at the background which is good for offices. So in terms of mixed-mode, it's probably going to be too quiet, which could be a negative.

Effectiveness in Melbourne conditions would be very good because we have cool winters and cool nights and our summers are not a whole week of really warm weather. We always get an afternoon cool breeze coming through so that could cool the building for the next day.

As long as it's designed properly, you can control it, but the thing about mixed-mode ventilation is that it does give people the ability to open and close (windows) as they see fit. The problem is always who decides whether you open the window a little bit more, or close it a little bit more because everyone's going to have different temperature metabolism rates, so it's always a bit of a problem. So in my view, that sort of control should not be left to the individuals. I think it should be on a temperature control basis so that it's automatic.

I think installation costs are equal (for mixed-mode and mechanical systems).

Ease of design (with open plan) becomes a little bit easier than what we had with cellular.

(Cellular vs. open plan)
Natural ventilation won't be as effective, you being in the middle of a space than it would be being on the outside. With a mixed-mode ventilation, natural ventilation, you'd probably design it without perimeter offices. People would probably have part height offices rather than full height offices.

(On future use)
The architects I talk to want it. But I think this is probably the problem; there's not enough knowledge yet in the industry for us to be able to go and design. We're not sure. That would be stepping outside our comfort zone because we'd be doing something we haven't done before. So definitely it's going to increase. It has already.

Why? Because of our acceptance of the fact that we need to do something about the environment. So the environmental issue.

And what's happening, it's being driven by the public. So what we really need to do to make this happen is instead of saying make building developers change the way they do things (we've got to do that), but we also should be training our four, five-year-old kids at school that this is bad, we shouldn't be polluting the atmosphere and driving cars when you can ride a bike and do all these things and introduce a generation of young people who are going to come through and say it's not good having air-conditioning when we can have mixed-mode ventilation so that the pressure will be put upon the developers from the public themselves by saying, I'm not going to buy your building, I'm not going to buy that apartment because I want one that's naturally ventilated. I don't want one that's got mechanical air-conditioning and I don't want to pay for it because I think it's going to be expensive. The push will have to be two ways. The public is buying into it. They're more aware.

And I honestly believe that a lot of it has got to come from regulations and the government. It's an issue about the environment and I think someone's got to take the lead and say we've got to start changing the way we do things.

Proprietary software programs that can be bought off the shelf so don't have to pay CSIRO or someone else to do the modeling.

For a laboratory system you're trying to control internal environments in terms of pressure differentials between spaces and that would be difficult to achieve with a natural ventilation system. So I think laboratories are probably one of those where it's not adaptable or not easily adaptable to a system.

Temperature is what people ultimately will complain about first. They're not saying there's eight hundred parts per million of carbon dioxide in the air, they wouldn't know. But if they say the temperature's cold, they'll complain so that's important.

There's not enough design guidelines I can buy off the shelf and can now use.

Contractor 1

I haven’t got any in practice yet. I’ve got my doubts about it.

Basically the use of mixed-mode is problems associated with external noise as well as discomfort due to draughts.

There were 2 main reasons where dollar aspect (cheaper to construct and run) and the other being availability of space, which is always a problem.

The other thing which has a marginal effect on system choice is available space provided within the structure to fit mechanical systems. Most of the buildings these days are governed by height restrictions. Therefore the architect has to maximize the height restrictions and what they can get in. And in doing that it usually leaves minimal space for mechanical services. Biggest thing, people want high ceilings.

The use of natural ventilation is by far more cost effective.

(Desirable components)
Control of noise and draughts via natural ventilation.

Contractor 2

Mixed-mode is probably growing. I can't give you an actual figure for it, but people are latching on to it.

The larger mechanical engineering firms like Hoggard and Wilson around Melbourne have their own particular system that they like and use most of the time. It cost them to re-engineer a system, therefore they cannot offer systems other than the ones that they are familiar with.

The thing that is missing is the general knowledge of not just the clients, but also engineers who specify a system.

Have to get it through the minds of the students going through universities.

If I don't know what it is, then I don't like it. Until I see it being used, I will no use it.

There needs to be public awareness of such a system. If they [CSIRO] put it in the weekend paper and explain it in layman's term, then more people will know about it.

Developer 1

Most mechanical systems are established in existing buildings. We just need to cut it down and simplify it.

In many office buildings, there aren't enough natural windows in place, even though there should be.

Having fresh airflow through an office would be nice.

There could be a problem with mixed-mode ventilation system on smoggy days and in high-rise buildings.

Most of the odors and pollutants come from sources within the office.

Designing a mixed-mode system is an easy task, but figuring out how to control it would be difficult.

With buildings that have just a few stories, it works better to have open windows. As the buildings get taller, there are more variables, and safety becomes a problem.

Only high-rise residential buildings can have open windows, but it is not feasible for commercial high rises.

Mixed-mode would be a good thing, just like it would be good for everybody to see out a window.

The consultants have to sell the system to us. We would take it and tell our contractors to use it if it is a good system.

Most people stick to the systems that they know most about, because that is the cheapest way to go.

If someone comes to us with something that will improve the AC, but will cost a lot more to install, we don't care about it. Because it is just electricity that is needed to run it, and the tenants pay for that.

Mixed-mode ventilation could be use to market a building that uses it. If the tenants are paying for electricity, they would be drawn to a building that uses mixed-mode system because it would lower their electric bill.

If it can be sold as cost effective, then it will be adopted.

Developer 2

With my understanding of mixed-mode, I don't see why it would perform differently from mechanical systems.

Cost and consultants' advice are the factors that decide which ventilation systems I use.

Installation and running cost are two major factors that dictate whether mixed-mode would be use or not.

Developers are more concern about upfront costs, since the tenants are the ones paying for the utilities. The way developers work is that they develop, sell, and get out. Therefore they are more concern about the upfront cost that they have to put up.

You can use mixed-mode (low energy usage) as a selling argument for tenants, but it doesn't matter whether it is put in or not. All the buildings claim to be low energy usage. Therefore it is just a relative marketing strategy, whether a building has a mixed-mode system or not, it is still a low energy use building.

Will definitely use if government subsidies or tax breaks exist.

If CSIRO or anybody else does not design it correctly when in practice as is on the paper, then it is a waste of their time at the drawing board.

Think the system would be a good thing from a health perspective. It would give people with medical conditions a much better environment to work in as oppose to a mechanical system. I would prefer to work in an office where there are operable windows.

If the upfront cost is the same as that of a mechanical system, then yes I would use it, otherwise I would not be using it.

Property development has tight cost control. The developer is very cost control conscious.

Have to understand every aspect of real estate business. Just knowing the system is not enough. The consulting engineers does not understand all the other important aspects of real estate, therefore he could design the greatest system, but if it does not meet all the other criteria that the developer is looking for, it will not be used.

APPENDIX F: OCCUPANT SURVEY RESULTS

Occupant Results 1

Occupant Results 2

Occupant Results 3

Occupant Results 4

Occupant Results 5

Occupant Results 6

Occupant Results 7

Occupant Results 8

APPENDIX G: SAMPLE MARKETING MATERIAL

Mixed-Mode Ventilation as an Option for Developers

What is mixed-mode ventilation?

Mixed-mode ventilation is a term used to describe any number of ventilation systems that utilize a strategic combination of **natural ventilation** (open windows, special vents to the outside) and **mechanical ventilation** (fans, air-conditioners, heaters) to provide buildings with ventilation and thermal comfort. The systems are designed to **reduce the amount of energy** used by a building, thereby cutting down on the amount of carbon dioxide released into the atmosphere by power production. **Developers** can benefit from a well designed mixed-mode ventilation system in the following ways…..

- *Allows local control over users' environment*
- *Controls are easy to use*
- *Provides buildings with fresh, outdoor air*
- *Maintains comfortable temperature conditions*
- *Increases user satisfaction*
- *Conserves space (no large, central plant required)*
- *Adapts to changing conditions*
- *Reduces maintenance costs*
- *Reduces energy costs for tenants*
- *Increases marketability from use of atria and courtyards*
- *Increases market appeal due to environmental consciousness*

What professional designers have said about mixed-mode systems

- I think that mixed-mode is ideal for Melbourne area. (Architect)

- People in today's society would prefer to have natural ventilation come in along with the mechanical system. (Architect)

- We have a really strong interest in developing mixed-mode solutions in other countries. (Consulting Engineer)

- There is a large inertia to change in Melbourne. Someone just needs to take the initiative. (Consulting Engineer)

- Mixed-mode would be a good thing, just like it would be good for everybody to see out a window. (Developer)

- Effectiveness in Melbourne conditions would be very good because we have cool winters and cool nights and our summers are not a whole week of really warm weather. We always get an afternoon cool breeze coming through so that could cool the building for the next day. (Consulting Engineer)

Things to consider before choosing mixed-mode

- *Possible increase in design time/costs*
- *Designers cannot predict effectiveness of system*
- *Higher summer temperatures possible*
- *Possible problems with outdoor noise and pollutants*
- *User awareness needed for successful operation*
- *Limited case studies to date to show success*

Mixed-Mode Ventilation in Corporate Offices

What is mixed-mode ventilation?

Mixed-mode ventilation is a term used to describe any number of ventilation systems that utilize a strategic combination of **natural ventilation** (open windows, special vents to the outside) and **mechanical ventilation** (fans, air-conditioners, heaters) to provide buildings with ventilation and thermal comfort. The systems are designed to **reduce the amount of energy** used by a building, thereby cutting down on the amount of carbon dioxide released into the atmosphere by power production. As the **owners/occupiers** of buildings, corporations can benefit from a well designed mixed-mode ventilation system in the following ways…..

- *Allows local control over users' environment*
- *Controls are easy to use*
- *Provides buildings with fresh, outdoor air*
- *Maintains comfortable temperature conditions*
- *Increases user productivity through satisfaction*
- *Conserves space (no large, central plant required)*
- *Adapts to changing conditions*
- *Reduces maintenance costs*
- *Reduces energy costs*
- *Creates public image of environmental friendliness*

What professional designers have said about mixed-mode systems

- The use of natural ventilation is by far more cost effective. (Contractor)
- Mixed-mode would be a good thing, just like it would be good for everybody to see out a window. (Developer)
- People in today's society would prefer to have natural ventilation come in along with the mechanical system. (Architect)

Things to consider before choosing mixed-mode

- *Possible increase in design time/costs*
- *Designers cannot predict effectiveness of system*
- *Higher summer temperatures possible*
- *Possible problems with outdoor noise and pollutants*
- *User awareness needed for successful operation*
- *Limited case studies to date to show success*

Mixed-Mode Ventilation in Schools

What is mixed-mode ventilation?

Mixed-mode ventilation is a term used to describe any number of ventilation systems that utilize a strategic combination of **natural ventilation** (open windows, special vents to the outside) and **mechanical ventilation** (fans, air-conditioners, heaters) to provide buildings with ventilation and thermal comfort. The systems are designed to **reduce the amount of energy** used by a building, thereby cutting down on the amount of carbon dioxide released into the atmosphere by power production. As the **owners/occupiers** of buildings, schools and universities can benefit from a well designed mixed-mode ventilation system in the following ways…..

- *Location of schools in suburban areas provides ideal conditions*
- *Allows local control over users' environment*
- *Controls are easy to use*
- *Provides buildings with fresh, outdoor air*
- *Maintains comfortable temperature conditions*
- *Increases user satisfaction*
- *Conserves space (no large, central plant required)*
- *Reduces maintenance costs*
- *Reduces energy costs*
- *Provides environmentally friendly ventilation*

What professional designers have said about mixed-mode systems

- I think the greatest potential would be in the educational systems. Particularly primary, secondary, tertiary universities. So I think that the greatest potential for mixed-mode or natural would be educational facilities because they pay the bills. (Consulting Engineer)

- Effectiveness in Melbourne conditions would be very good because we have cool winters and cool nights and our summers are not a whole week of really warm weather. We always get an afternoon cool breeze coming through so that could cool the building for the next day. (Consulting Engineer)

- The use of natural ventilation is by far more cost effective. (Contractor)

Problems with mixed-mode systems

- *Possible increase in design time/costs*
- *Designers cannot predict effectiveness of system*
- *Higher summer temperatures possible*
- *User awareness needed for successful operation*

- *Limited case studies to date to show success*

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