ICU helps in building healing environment

I. F. H. E.

In an article that first appeared in the *The Australian Hospital Engineer*, the monthly magazine of the Institute of Hospital Engineering Australia, Arup's Dr Gerard Healey examines the design and construction of a new intensive care unit (ICU) at Melbourne's Alfred Hospital in Victoria, Australia. Two of the project's key goals, and indeed major design drivers, were to reduce to the absolute minimum the risk of hospital-acquired infection, and to provide an environment that 'intentionally fosters staff and patient well-being, rather than just housing staff and patients'.

This is a case study of Melbourne's Alfred Hospital Intensive Care Unit (ICU). It has a building design driven by the risk of hospital-acquired infection, while providing an environment that intentionally fosters staff and patient well-being, rather than just housing staff and patients. Design drivers such as these are having a significant impact on hospital design around the world, and the case of the Alfred ICU can provide insight into potential challenges and solutions.

This article first appeared in the September 2011 issue of *The Australian Hospital Engineer*, the monthly magazine of the Institute of Hospital Engineering Australia. *Health Estate Journal* acknowledges the help of *The Australian Hospital Engineer* and the International Federation of Hospital Engineering (IFHE) in publishing it.

A brief review of literature indicates just how significant the issue of hospital-acquired infection (HAI) is. A World Health Organisation (WHO) survey indicated that an average of almost 9% of patients in Europe, the Eastern Mediterranean, South-East Asia, and Western Pacific, had hospital-acquired infections (WHO 2002). In Australia, it is estimated that, each year, there are in the order of 200,000 hospital-acquired infections, resulting in around two million bed-days lost.[1] While the exact economic impact of HAI is difficult to calculate, it is clearly significant, not to mention the emotional and psychological cost to the patients and their families. Patients in ICUs are particularly susceptible to adverse affects from HAI;[1] they are even at risk of infections from organisms such as *Aspergillus*, which is a common fungus that poses low risk to healthy people, but can prove fatal for immuno-compromised patients.[2]

Impact of building design

While HAI is a serious issue, it is not the only issue in hospital design. It is widely recognised that building design can influence patient and staff well-being.[3,4,5] The Alfred ICU has a focus on providing good daylight and high indoor air quality, both of which can have a positive influence on patient and staff health.

The Alfred ICU is designed to have 45 beds, with approximately 2,000 patients per year passing through the unit. It is regarded as one of Australia's leading intensive care units, with a unique and complex case mix, being Victoria's main burns treatment centre, and providing for heart and lung transplantation, artificial heart technology, adult cystic fibrosis, pulmonary hypertension, adult trauma, and HIV treatment, and bone marrow transplantation. In its first six months of operation it treated patients from Victoria's 2009 'Black Saturday' bushfires,

Courtesy of Rhiannon Slatter

Figure 1: The pre-cast concrete wall.

Courtesy of Arup

Figure 2: The rubberised roof alongside the plant room.

which were among Australia's most lethal and damaging fires, and victims of H1N1 (swine) flu.

The new ICU was designed by architects Billard Leece Partnership (BLP), with services engineering by Arup, and construction management by John Holland.

An overview of the Alfred ICU

This case study is a valuable contribution to knowledge on infection control and healthcare design because it illustrates real-world challenges and solutions, including valuable feedback from construction and operation.

The paper begins with an overview of the ICU and feedback from staff. It then summarises the design drivers, and how they influenced the features of the design process and building. Next, it takes a more detailed look at the key features of the design process and building, before concluding with the key lessons learnt.

The Alfred Hospital is located approximately 5 km south-east of Melbourne's CBD, directly south of open parkland. The ICU is located at the western end of the hospital complex, above the emergency department, and next to the helipad. The new ICU refurbished and extended the previous ICU.

Internally, the ICU is custom designed for its unique case mix, and planned around three pods – general, trauma, and cardiac. The unit includes four 'Class N' negative pressure isolation rooms, four 'Class P' positive pressure isolation rooms, a number of notionally-negative pressure enclosed rooms, and open bays. The staff workflows were extensively studied to inform the design and final layout.

Feedback obtained from the director of the ICU, Dr Carlos Scheinkestel, in February 2011, after six months, and again after three years of operation, was very positive, from both staff and visitors. An overview of feedback at six months is shown in Table 1. At three years, rates of hospital-acquired infection, staff sick leave, and feedback from patients' relatives, had all shown a significant improvement. Feedback on specific design features has been included throughout this paper, and lessons learned are noted at the end.

Table 1: Feedback from the acting nurse manager at the Alfred Hospital ICU on key parameters after six months in operation.

Category		Rating							
Temperature	Unsatisfactory	1	2	3	4	5 ●	6	7	Satisfactory
Air quality	Unsatisfactory	1	2	3	4 ●	5	6	7	Satisfactory
Lighting	Unsatisfactory	1	2	3	4	5	6 ●	7	Satisfactory
Noise, comfort, and design	Unsatisfactory	1	2	3	4	5 ●	6	7	Satisfactory
Response to staff/ patient needs	Unsatisfactory	1	2	3	4	5 ●	6	7	Satisfactory
Health (perceived), image to visitors	Less healthy/ poor	1	2	3	4	5	6 ●	7	More healthy/ excellent
Productivity	Decreased (–20%)	1	2	3	4	5 ●	6	7	Increased (+20%)

Design drivers

In 2005, following a detailed investigation of difficulties experienced in the delivery of services, it was announced that the Alfred Hospital was going to upgrade its ICU.[6] As part of the design process, the design team conducted tours of recently completed intensive care units around Australia. Arup also developed benchmarks based on international best practice, including the US Centre for Disease Control (CDC), and our experience on the west coast of the US, and in the UK.

In consultation with the hospital and staff, a number of design drivers were identified, including:

- The introduction of natural light for each bed and circulation areas.
- Providing good indoor air quality (odours from burns treatments were noted as an issue in the previous ICU).
- The ongoing management of the risk of *Aspergillus* spores.
- The ongoing management of hospital-acquired infection.
- To plan in 45 beds arranged into pods.
- Pods to provide good observation of patient cubicles.
- Finishes to provide a less clinical feel.
- High resilience and reliability.
- Improved maintenance access.

The upgrade of the ICU also provided the hospital with an opportunity to make allowances for an increasing number of immuno-compromised patients, an increasing number of patients with contagious infections, increased storage, and for new (and space-demanding) technologies that provide artificial heart and lung support.

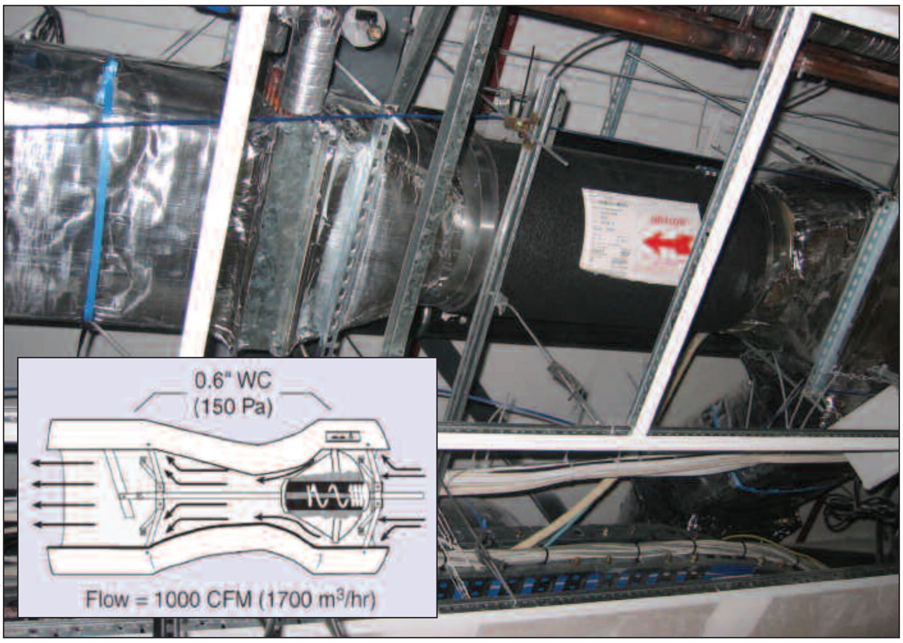
The right connections

Further to these, the new ICU was to be a full refurbishment of the existing ICU patient areas, partial refurbishment of support areas, and expansion to the west. It was above an operating accident and emergency department, and required to connect to existing hospital services with minimal disruption. The following sections will discuss the key features in more detail.

Managing *Aspergillus* spores

As noted earlier, managing *Aspergillus* spores was one of the drivers in the design of the new ICU. This was approached through a variety of measures, including:

- Providing a well-sealed envelope.
- Pressure testing the building following construction.
- Pressurising the ICU relative to outside.
- Minimising access/egress and using air-locks at entries.



Courtesy of Arup

Figure 3: Pressure-independent venturi valves installed. Inset: a valve in section.

A well-sealed building envelope

Providing a well-sealed envelope was a primary concern for the architects Billard Leece Partnership (BLP), and particularly the external walls and roof, which were a source of leaks in the previous ICU.

For the external walls, BLP incorporated pre-cast concrete panels with fixed glazing, which provide a robust and airtight construction, provide an acoustic barrier between the ICU and the nearby helipad, and could be prefabricated offsite and erected quickly (Fig. 1). For the roof, BLP selected a rubberised membrane system bonded to ply over a steel frame. Because it provides a guaranteed weather tight barrier, it can provide a seal across the whole ICU roof and plant room walls, and is trafficable for maintenance. From a building services perspective, the number of roof penetrations was minimised.

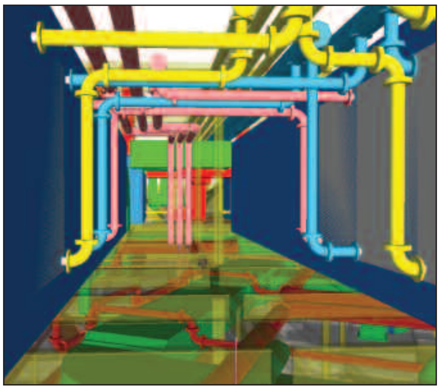
Pressure testing

The builder for the ICU was required to achieve a specified level of sealing of the ICU envelope. To confirm that the envelope was well-sealed, Arup required the mechanical contractor to perform building air leakage in accordance with CIBSE Technical Memoranda TM23 – *Testing buildings for air leakage*. This required that the building be tested to maintain a standard pressure differential at 50 Pa, with smoke visualisation used to identify leakage paths.

Pressurisation

Pressure gradients within the ICU were also used to control the ingress of *Aspergillus* spores, and the spread of contagions within the unit. A differential pressure is maintained between the unit and outside, between the circulation areas of the unit and the positive (Class P) and negative (Class N) isolation rooms, and between circulation areas and notionally negative enclosed bed bays. To maintain this differential, the following strategies were used:

- Central plant air intakes and discharges were located and designed to minimise effects from wind.
- Variable speed fans to correct for changes in filter resistance as they load.
- Pressure-independent venturi valves were used to maintain constant flow rates to and from each space.
- Central HEPA filtration of supply air.
- A well-sealed envelope, as discussed previously.



Courtesy of Arup

Figure 4: Central air handling units with run-around coil supplying 100% outside air during design (above), and as constructed.

The central air handling units for the ICU are located in a roof-top plant room (Fig. 2). Following extensive wind investigations and analysis, there was concern that wind pressure at the air intakes and discharges could adversely affect the air flow within the ICU, and consequently the pressurisation. To manage this risk, the outside air intakes were designed with roof cowls, and exhausts are vertical stacks, rather than louvres in vertical walls.

As a further measure to ensure constant air flow within the ICU, pressure-independent venturi valves were used on all supply and exhaust outlets rather than conventional balancing dampers (Fig. 3). These valves maintain flow using a spring-mounted cone that moves in and out of a venturi orifice, providing more reliable airflows compared with conventional dampers. Venturi valves are common in laboratory and healthcare projects overseas.

Cross-connected air handling units

Pressurisation is an important part of infection control within the ICU, so the central air handling plant consists of two cross-connected AHUs, to provide a level of redundancy. Room pressurisation is monitored, and alarms activated, if the reference differential pressure is lost.

Central HEPA filtration

HEPA filters were used in the central air handling plant to reduce the potential ingress of *Aspergillus* spores and other particulates via the supply air.

Figure 5: Switchable glazing in opaque/transparent modes above a nurses' station.

Courtesy of Rhiannon Slatter

Managing other hospital-acquired infection

Managing cross-infection is a challenge shared by all hospitals – and met by a variety of design features and management procedures. Two design features of the Alfred ICU are particularly worth noting: 100% outside air supply, and switchable glazing.

100% air supply with energy recovery

In traditional air supply, a portion of the air from the space is mixed with outside air and recirculated. This helps to reduce the energy required to heat or cool the outside air, because the return air is already at about room temperature. The drawback of this approach in the ICU is that the return air from the space may not be free of contagions. This could be managed through the use of central HEPA filters, although this shifts the risk of cross-infection to the effectiveness of the maintenance programme. Arup's approach was to design this risk out by using 100% outside air, i.e. exhausting all the return air from the ICU, and supplying air from outside.

The potential drawback of such an approach is that larger heating and cooling coils are required, leading to increased energy consumption. This was mitigated by using a run-around coil (Fig. 4) to provide energy recovery between the exhaust and supply streams. A run-around coil was chosen over a plate heat exchanger or thermal wheel because it had the lowest risk of exhaust air entering the supply air stream. A coil bypass is used to save fan energy when thermal energy recovery is not required. The variable speed drives automatically correct for filter loading and the coil bypass.

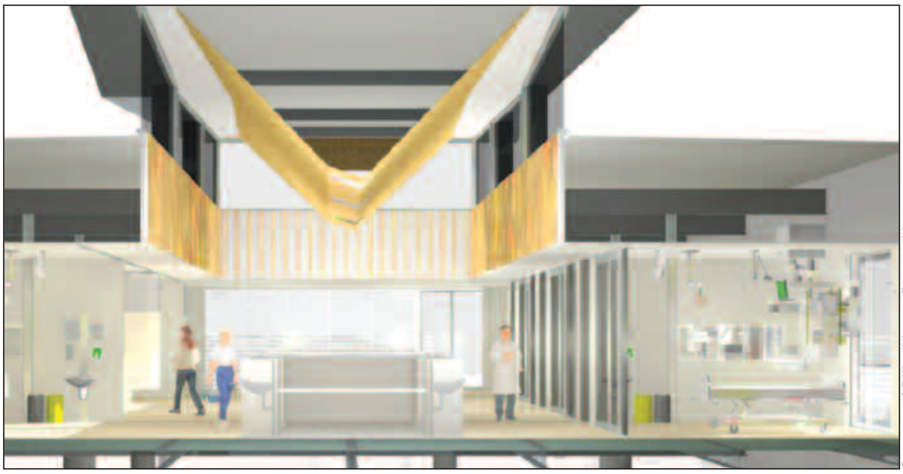
Switchable glazing

Traditionally, fabric-based curtains and blinds provide privacy for patients, and control sunlight and glare. However, they are also a potential infection hazard. To overcome this tension, the design team for the Alfred ICU used switchable glazing (Fig. 5) in the roof lanterns and patients rooms. Switchable glazing uses liquid crystal technology to become transparent when an electric current is applied, and opaque when the current is removed. This enables staff and patients to manage privacy and sunlight, without surfaces or materials that are difficult to clean or disinfect.

Feedback from acting nurse managers is that the switchable glazing has been well received. The only negative comments have related to the automatic timer in the glazing. While it is currently set to automatically frost over at night, some staff were not aware that this setting is adjustable, or that there is a manual override. This has been corrected by increasing staff awareness about how the system operates.

High indoor air quality

Providing high indoor air quality was another design driver. It had been noted by staff that the previous ICU had



Courtesy of Billard Leece Partnership

Figure 6: A section showing the relationship between the roof lanterns, nurses' stations, and patients.

undesirable odours from some of the burns treatments, and that surgery-like procedures were sometimes performed in the ICU because it was not possible to transport the patients to a surgical theatre. Consequently, it was important for staff and patient well-being that the ICU had high indoor air quality. Strategies used to achieve this were:

- 100% outside air supply, as discussed previously.
- Provision for central carbon filters if required.
- Central HEPA filtration.
- Provision of space for humidifiers centrally, and for burns rooms.

Feedback from the acting nurse managers has been that the air quality has improved in the burns treatments rooms.

In addition to assisting with infection control, the 100% outside air system was also expected to improve the indoor air quality. Anecdotally, the nursing managers report that there have been fewer complaints from staff working on burns patients than in the previous ICU. Not all odours have been removed, however, with the nurses noting that it still smells if a patient soils themselves. This is not unexpected given that the ventilation is via an overhead mixed air system.

Carbon filters

The new ICU was always intended to be closer to the ambulance helipad than the previous ICU. There was uncertainty as to whether exhaust fumes from the ambulance helicopter might be drawn into the supply air plant. Given that the issue was uncertain, and the tight construction budget, it was decided to provide space and fan power in the air handling units for carbon filters, but not the filters themselves. Carbon filters are designed to adsorb gaseous pollutants such as SO_2 and NOx, rather than particulates. This low-cost approach maintained the flexibility for later retrofit of the filters if required.

Feedback from the acting nurse managers is that there was not an issue during the first few months of operation over the summer. However, in the last few months in winter, the smell of helicopter exhaust fumes became more noticeable. The reason for this change is not well understood. At the time of writing, Dr Carlos Scheinkestel, ICU director, advised that the carbon filters were going to be installed.

There was concern from Arup that 100% outside air could lead to low relative humidity in the ICU during the colder winter months, and space was provided for the installation of humidifiers.

The Alfred Hospital conducted an

Courtesy of Arup

Figure 7: Roof lanterns over nurses' stations during design (left), and construction (centre).

investigation into the use of high humidity burns rooms nationally, and found that present treatments do not rely on high humidity as they had in the past. Consequently, the burns rooms were not provided with humidifiers, but there is space so that they can be retrofitted in the future, should treatment practices change. The burns rooms are also able to achieve internal temperatures of 29°C, as required by treatment practice.

Daylight

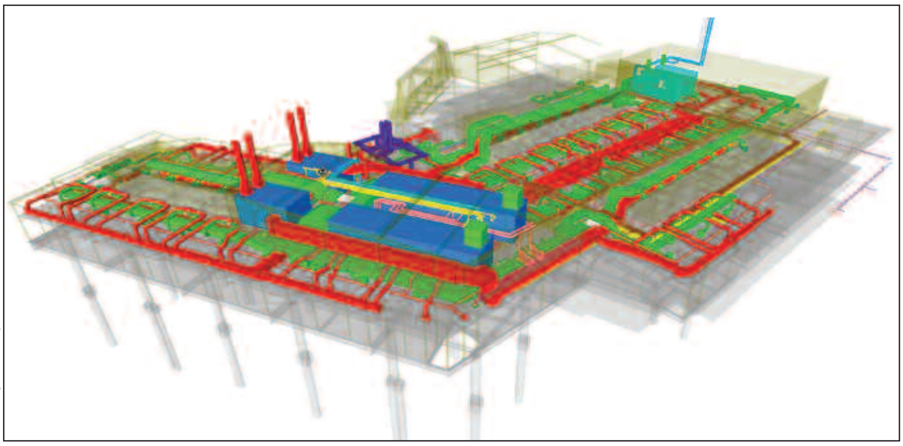
Providing good access to daylight was a key requirement of the new ICU, and the space planning strongly reflects this, along with easier observation of patients. BLP took advantage of the relatively large extent of new building façade to introduce natural light directly into patient bays and, where possible, located cubicles on the external walls of the new building. This also allowed staff and utility areas to be located relatively centrally, with good access and views to patient areas.

Natural light was provided to staff stations and circulation areas via large roof 'lanterns' (Figs. 6 and 7). These also enhanced the quality of space provided to cubicles adjacent to the stations – particularly those without an external window. The team chose roof lanterns over skylights because they provided better views to outside, better control over solar gains, and an opportunity to reticulate services. The lanterns were finished with a light timber veneer, which provides a less clinical feel, a point of visual interest, and acoustic absorption. Switchable glazing was used in the roof lanterns to provide glare control.

Feedback from the acting nurse managers is that staff, patients, and visitors, love the daylight provided by the roof lanterns. The only issue has been with a cubicle opposite a north-facing lantern. At some times of the day, the daylight through the frosted lantern is still quite bright, and creates glare on the patient monitors. This has not been a major issue, because it happens infrequently. It probably could have been mitigated during design if a detailed daylight and glare analysis had been undertaken.

Minimising disruption using 3D modelling

A key goal for the construction of the ICU was to minimise disruption to adjoining hospital spaces. This was a challenge for two particular reasons – firstly, because the ICU site was located above the accident and emergency (A&E) department, with some of the existing ICU services reticulated in the ceiling space, and, secondly, because the intensive care unit had to connect to existing building services for power and water that also supplied the rest of the hospital.



Courtesy of Arup

Figure 8: 3D modelling of building services for the ICU.

To minimise disruption and clashes during construction, Arup used 3D modelling (Figs. 8 and 9) to spatially co-ordinate services with structure and architecture. This proved to be a valuable and effective tool for communicating with the rest of the design team, the building contractor, and Alfred Hospital engineering staff, and led to improved maintenance access, and a far lower number of physical services clashes during the construction phase. For contract purposes, 2D design documentation was extracted from the 3D model.

Improved operation and maintenance

The construction of the new ICU provided an opportunity to improve the operation and maintenance of the ICU. This was achieved through the following features:

- Increased flexibility of bed bays.
- Safer maintenance access.
- Increased resilience.

Flexibility of bed bays

The design of the Alfred ICU is enhanced compared with standard Victorian DHS practice, in that the segregated rooms were made notionally negative in accordance with Centre for Disease Control Guidelines.[7] This has had benefits for the ICU during its first six months of operation. When responding to the large number of burns victims from Victoria's 2009 Black Saturday fires, it enabled the hospital to turn the segregated rooms into temporary burns-style rooms. Similarly, when treating victims of H1N1 (swine) flu, which exceeded the number of Class N negative rooms, it enabled the hospital to put swine flu patients on ventilators in the notionally negative rooms, and provide a measure of infection control (the Class N rooms were prioritised for patients breathing independently).

Other features of the cubicles include:

- They are larger than normal, to allow for the large amount of equipment around patients.
- All power comes from three overhead pendants (2 head, 1 foot), rather than wall outlets, to remove the tripping hazard of cables running across the room.
- Cubicles for burns, ECMO (artificial heart and lung technology), and spinal trauma, are equipped with mobile hoists to assist with moving patients safely.

> To minimise disruption to the ICU operations and risks to patients, all maintenance access is from outside patient rooms, or via the roof plant rooms

Feedback after three years of operation was that room sizes and storage spaces have been sufficient to date. Mobile hoists have now been retrofitted to the majority of rooms. It would have been good to have included these in the original brief, as clashes with services and pendants have meant that it has not been possible to retrofit hoists in all rooms.

Safe and convenient maintenance access

The ongoing operation of the ICU relies on regular maintenance of components. In general, to minimise disruption to the ICU operations and risks to patients, all maintenance access is from outside patient rooms, or via the roof plant rooms.

For high-risk items, such as HEPA filters that could contain contagions, it was imperative that maintenance staff be protected. To achieve this, all HEPA filters on Class N exhaust air were of 'bag-in-bag-out' style. This means that the maintenance worker is not exposed to the HEPA filter itself. Feedback after three years of operation is that there has been no noticeable disruption due to maintenance.

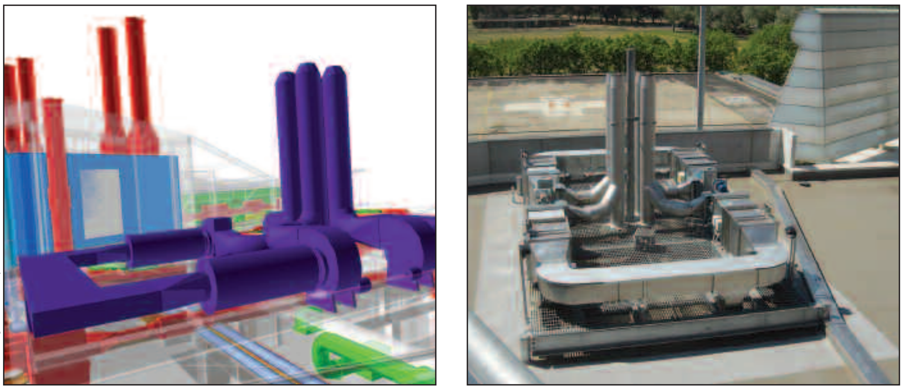


Figure 9: 3D modelling design, and as-built images for the exhaust from the Class N (negative) room.

Resilience and uptime

The ICU was made more resilient by providing UPS back-up power supply, duty/standby air handling fans, and duty/standby HEPA units on the Class N negative rooms.

Lessons learned

As noted in the paper, the feedback from the acting nurse managers has been generally positive, and issues have either been minor (e.g. staff training for switchable glazing), or can be managed within the design (e.g. carbon filters for helicopter exhaust).

The nurses have noted two areas where they have proposed additional works to hospital engineering:

- isolation room intercoms – the nurses noted that it is very difficult for staff within an isolation room to communicate to someone outside the room. To date their techniques have included tapping on the glass, holding up written messages, or pressing their ears against the glass. They have proposed an intercom system to overcome this issue.
- anteroom size – the nurses noted that it is difficult to get medical equipment (e.g. X-ray machines) through the anterooms into an isolation room because both doors open into the anteroom. The nurses suggested that the patient-side door should open into the patient's room, rather than the ante room; however Arup notes that the current arrangement was designed to encourage the room seal, i.e. the negative room pressure sucks the doors against the frame sealing, rather than pulling it away from the frame.

These issues were ongoing at the time of writing.

A further issue noted by Dr Carlos Scheinkestel is that the air conditioning system struggled to cope with the extreme temperature experienced at the start of 2009, which included three consecutive days above 43˚C (BOM 2009).[8] The chiller was sized for 45˚C ambient, and it was subsequently found that it was tripping out due to high pressures, rather than ramping down as intended. These settings have since been changed, and it is expected to perform better in the coming summer.

Conclusions

The Alfred ICU project was a technically challenging project that combined issues of infection control and designing for occupant well-being. The design incorporates many interesting design features that have responded to these issues and opportunities, as described throughout this paper. The design team has delivered a building that has performed successfully during its first six months of operation, and provided a valuable service to the Victorian public. In the words of Phil Nedin, global leader of Arup's healthcare business, the Alfred ICU was "… a good solution and possibly [world's] best practice".

Acknowledgements

The authors would like to acknowledge the staff at the ICU who shared their experiences with us and took the time to review draft versions.

References

1 Cruickshank M, Ferguson J. *Reducing harm to patients from healthcare-associated infection: the role of surveillance*. Australian Commission on Safety and Quality in Health Care, 2008 (http://tinyurl.com/bl9ndbg).

2 Centers for Disease Control and Prevention. *Aspergillosis*. Atlanta: CDC, 2008 (http://tinyurl.com/bp8o82q).

3 Glanville R, Nedin P. Sustainable design for health. In: Rechel B, Wright S, Edwards N, Dowdeswell B, McKee M eds. *Investing in hospitals of the future*. Geneva: WHO, 2009 (http://tinyurl.com/c6uaeyv).

4 Georgia Tech and Center for Health Design. A review of the research literature on evidence-based healthcare design. *Health Environments Reasearch & Design* 2008; 1 (3) (http://tinyurl.com/d272d6t).

5 Rubin H, Owens J, Golden G. An investigation to determine whether the built environment affects patients' medical outcomes. The Centre for Health Design, 1998 (http://tinyurl.com/bva9sye).

6 Nader C. Alfred intensive care unit upgrade to fight fungus. *The Age* April 20, 2006 (http://tinyurl.com/dykwbxr).

7 Sehulster L, Chinn RYW. Guidelines for environmental infection control in health-care facilities. In: *Morbidity & Mortality Week Report* (MMWR). Atlanta: CDC, 2003: 52 (RR10), 1–42 (http://tinyurl.com/ctzwldb).

8 Australian Bureau of Meteorology. Melbourne heatwave approaches Black Friday record. 2009 (http://tinyurl.com/by8yzt).

9 Edwards L, Torcellini P. *A literature review of the effects of natural light on building occupants*. Colorado: National Renewable Energy Laboratory, 2002 (http://tinyurl.com/cc6agxg).

10 Joseph A. *The impact of light on outcomes in healthcare settings*. Concord CA: The Center for Health Design, 2006 (http://tinyurl.com/cnqflu9).

11 World Health Organization. *Prevention of hospital-acquired infections* 2nd edn. Geneva: WHO, 2002 (http://tinyurl.com/cby58ob).

Gerard Healey

Dr Gerard Healey is a mechanical engineer and Green Star-accredited professional with a PhD on how to better foster sustainable technologies. Since joining Arup in 2006, he has been the lead mechanical engineer and building services design coordinator for a university medical imaging project in Victoria, and contributed to the design of another medical imaging facility, a regional Victorian hospital, and the Alfred ICU. His other projects have included offices, education buildings, a brewery, student accommodation, and a rail tunnel. More recently, he has researched the skills required to deliver intelligent buildings, after being awarded the 2009 International Building and Construction Fellowship by Australia's Construction and Property Services Industry Skills Council and the ISS Institute.