SMART BUILDINGS FOR HEALTHY AND SUSTAINABLE WORKPLACES: SCOPING STUDY REPORT

Report 2002-043-B

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1. PREFACE

This scoping study was commissioned by the CRC for Construction Innovation (Project no. 2002-043) and was supported by three industry partners, Bovis Lend Lease, Arup, and The Queensland Department of Public Works. The Authors would like to thank the industry partners for their time and support throughout the project. The authors would also like to thank Project Consultants, Don Townson and James Horne for their valuable contributions to this report and to the project, and Steve Brown, Charles Rono, and Pavan Sikka from CSIRO Manufacturing and Infrastructure Technology for their valuable input.

2. EXECUTIVE SUMMARY

Background and Objectives

Deficiencies in the design and operation of office buildings can give rise to high social, environmental and economic (triple bottom line) costs. As a result, there are significant pressures and incentives to develop 'smart building' technologies that can facilitate improved indoor environment quality (IEQ), and more energy efficient operation of office buildings. IEQ indicators include lighting, ventilation, thermal comfort, indoor air quality and noise.

In response to this, the CRC for Construction Innovation commissioned a six-month scoping study (Project no. 2002-043) to examine how different technologies could be used to improve the 'triple bottom line' for office buildings. The study was supported by three industry partners, Bovis Lend Lease, Arup, and The Queensland Department of Public Works.

The objective of the study was to look at the history, trends, drivers, new technologies and potential application areas related to the operation of healthy and efficient office buildings. The key output from the study was a recommendation for a prototype system for intelligent monitoring and control of an office environment, based on identified market, technical and user requirements and constraints.

Findings

The study found that the current state-of-the-practice in the use of smart office building technologies is presently 'sub-optimal' to say the least. However this is changing, and there are many drivers which will influence further change, including:

- government and industry sustainability initiatives and regulations
- rapidly reducing cost and increasing capability of sensor technologies, information technology and communications.
- tenant desire for flexible and adaptable office floor-space to suit changing workplace practices and business structures
- need for an improved, outsourced user-pays model for the procurement and supply of mechanical and electrical building services to tenants.

Of the technologies that were examined, micro-electromechanical-systems (MEMS) sensors, wireless sensor networks and 'integrated systems' technologies were found to be the most promising currently available technologies that could be utilised in a prototype smart building control system. This is mainly because these technologies are at an appropriate level of maturity, and are generic in their application, since they can be applied beneficially to a range of different application areas.

It was found that the application areas in which these technologies could have the maximum impact, in terms of optimising occupant IEQ, productivity, and energy usage, are those related to:

- Comfort and energy optimised, HVAC systems
- Smarter, integrated lighting systems, and
- Improved energy management and reporting

All of these application areas could benefit from the use of cheap MEMS-based sensors, wireless networking of these sensors, and an integrated, flexible and adaptable backbone for communication between sensors, actuators and occupants.

Implications For Industry and Community

A key finding from the scoping exercise, is that for these new technologies to be most useful, and most likely to be accepted by the different stakeholders, they should have the capability to facilitate a 'user-pays' model for the provision of the building services. Under such a model, a third party could 'own' the building services and then charge tenants a fee for usage. This model has many benefits over the current 'lowest capital cost' driven approach usually taken, since it creates a market incentive for the building services 'owner' to implement efficient and healthy systems through the life cycle of the facility. This model requires that the usage of the building services can be tracked down and charged to individual tenants or building user groups. Under the proposed system, this is feasible, because the measurements needed to optimise IEQ and energy efficiency, can also be used to derive the energy usage at the micro-zone scale. If such a model became the norm, and was implemented widely, the micro-markets could be set up with incentives to encourage higher quality indoor environments, reduced energy usage, and importantly, reduced costs for building users and owners.

Next Steps

It was therefore recommended that a prototype system be developed which can optimise IEQ and energy efficiency using high-density measurement and occupancy-based control of important parameters, and can also measure and break down the energy usage into micro-zones, according to the 'type' of energy (i.e. lighting, HVAC or appliance). This system will provide detailed energy usage data, pinpointing exactly when, where, why and by who each type of energy is being used. A proposal for funding the prototype development is given in Appendix B.

The key features of the proposed prototype include:

- Very high-granularity measurement of temperature, humidity, airflow and light levels using wireless MEMS sensors.
- Energy and comfort optimised, occupancy-based control of micro-zoned HVAC system with improved air balancing and air handling efficiency.
- Energy usage tracked down to micro-zone level (even individual users) and broken down into energy 'type' (i.e. HVAC, lighting or appliances).
- Web-Based energy usage reporting system delivering appropriate and timely information to different stakeholders.
- Daylight harvesting and occupancy-controlled light dimming to give accurately controlled, efficient illumination where it is needed.
- 'Instantly' re-configurable HVAC and lighting to provide completely flexible and adaptable floorplans and workspaces

Benefits

Specific benefits of the proposed system include:

- Improved indoor environment quality. This means improved health, quality of life and productivity of workers/occupants
- Improved worker productivity. This means more profits for business tenants
- Reduced capital costs for HVAC services, and reduced operating and maintenance costs

- Improved value of facilities because of improved rentability and attractiveness to tenants
- Development of new ‘user pays’ model for the provision of HVAC services. Under such a model, a third party could ‘own’ the building services and then charge tenants a fee for usage.
- Improved energy efficiency and reduced greenhouse gas emissions; gain carbon credits and related sustainability incentives
- Provides valuable world-first research platform/environment, and data which can be used to improve and investigate control algorithms, calibrate design and analysis tools, study occupant behaviour and productivity, energy usage patterns, and investigate how energy cost and usage reporting influence behaviour.

3. INTRODUCTION

3.1 Background

There are many initiatives to promote social, economic and environmental sustainability in the built environment. An area of potentially significant impact is the development of 'smart building' technologies that support healthy indoor environments and energy efficient operation and maintenance of workplaces. Deficient building environments (i.e. 'sick buildings') give rise to high social and business costs. According to US studies, poor health and lost productivity associated with office environments alone cost US businesses between $US37 and US$208 billion (Fisk, 2000). It is estimated that the cost in Australia could be up to $10 billion per year. These costs are likely to increase over time unless buildings are designed and operated more efficiently and intelligently in the future.

There is also significant government and community pressure to use energy more efficiently in buildings. The Australian Building Codes Board (ABCB) has made clear its intentions in this area, where it has a stated goal of quickly developing 'cost effective energy efficiency measures suitable for introducing under building law' (ABCB and Australian Greenhouse Office, 2001). also, several industry groups are developing guidelines, voluntary codes and other strategies to promote improved energy efficiency in the non-residential building sector, such as the Property Council of Australia, and ABEC (The Australian Building Energy Council).

The potential benefits from the development of smart building technologies are many; Businesses will benefit through improved worker productivity, and increased workplace flexibility and adaptability. Building owners can benefit through higher rental returns, and building operators and tenants can benefit through reduced building operation (energy) and maintenance costs. In addition to the immediate financial benefits to businesses, there are also obvious long-term environmental benefits to the wider community through reduced energy usage and reduced greenhouse gas emissions.

There is also potential for 'harvesting' the data that can be collected by a smart building to find ways to improve architectural and engineering design, validate and calibrate various building modelling tools, and to improve workplace design and configuration to maximise the productivity and comfort of people that work in buildings. Importantly, a smart building will also be able to tell different stakeholders, exactly where, when, why and by whom the operational energy is used. This information will be vital in developing technologies, strategies and occupant behaviours to deliver more environmentally friendly and healthy buildings.

Given the potential impacts, and the rapidly reducing costs and increasing capabilities of technologies which could underpin the smart building, it is timely that a study is undertaken to assess these technologies and their areas of potential applications in current and future buildings.

3.2 Project Objectives

The long-term goal for this project is to develop and implement technologies to support people-friendly (i.e., healthy), eco-friendly and commercially viable buildings and facilities, and facilitate triple-bottom-line assessment and reporting. This goal will be achieved over four Phases:

1) Scoping study and proposal for prototype system
2) Detailed design of prototype
3) Bench trials of prototype system
4) Implementation in single level of an office building.

This report is related to the scoping exercise and prototype proposal only (Phase 1).

The immediate objectives of the work presented herein are to: (1) review and assess technologies that could measure and control factors important for healthy and sustainable workplaces; and (2) present a proposal for a prototype 'smart building' system for intelligent control of the office environment, given the market, technical and user requirements.

3.3 What is a 'Smart Building'

The 'smart building' concept has been around for at least two decades. The definition and implementation of the concept are varied and have evolved with development of technology and knowledge through the years. A summary of past and present views of 'smart building' technology is given in Table 1.

Kroner (1997) suggests that current smart buildings are 'electronically enhanced buildings', and provides a summary of many different definitions that have been given to the term 'intelligent building'. Arkin and Paciuk (1997) and others have suggested that the 'smartness' of a building is not merely a function of the sophistication of the technologies utilised in individual building systems (e.g. HVAC or lighting), but is also measured by the integration between the various systems.

There are four primary elements that work in an integrated way in a smart building system:

1) sensors
2) integrated information management system and performance models
3) actuators, and importantly,
4) the backbone or nervous system (i.e. the communications infrastructure that connects the sensors, actuators and control systems together).

Figure 1 shows how these elements may be configured for an example eco-smart building.

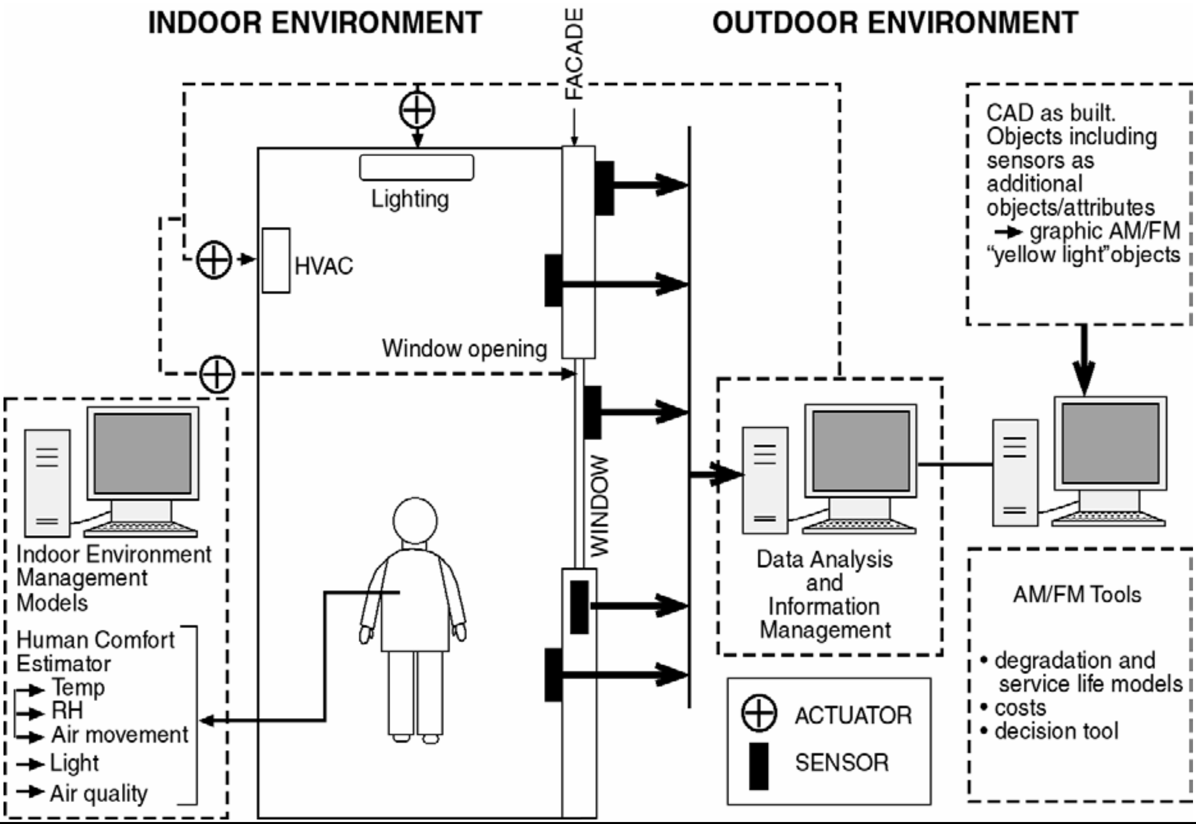
In this project, the primary focus is the drive towards improved social (e.g., occupant health and happiness), economic (e.g., worker production & operational cost reduction) and environmental (less energy) performance. The aim is to cast a wide net and examine a range of technologies and application areas, hence it is not desirable to limit the study with too narrow a definition of a smart building. So we have taken the view that a smart building can be defined as any which can adapt to optimise environmental performance and improve occupant productivity, safety and satisfaction through enhanced comfort, health and mobility features (Table 1, last row). It should also be able to measure and report on different aspects of building performance.

Table 1. Views of intelligent buildings

	Features	Basic Concept
Traditional View 1981-85	Building Management Office Automation Communications	An Intelligent Building is a collection of innovative technologies
Enlightened View 1986-91	Building Management Office Automation Communication Responsive to change	An Intelligent Building is a collection of technologies able to respond to organizational change over time
Advanced View 1992–95	Building Management Space Management Business Management	An Intelligent Building provides a responsive, effective and supportive environment within which the organization can achieve its' business objectives. The Intelligent Building technologies are the tools that help this to happen. An economic benefit is sought.
Holistic View 1995 →	Building Management Space Management Business Management	Improve triple bottom line objectives: Economic – reduced business costs and increased productivity; Environmental – reduced greenhouse gas emissions and energy consumption; Social – improved building occupant health and quality of life

Note: first three rows based on Loe, 1996

Figure 1. Example configuration for an 'eco-smart' building.



3.4 Report Outline

3.4.1 Structure

This report covers a wide range of inter-connected technologies and application areas related to a complex system (a building). To provide a structure for the examination of the varied subject matter, the report has been arranged as follows. Firstly, an overview of the current practice in building control systems and associated technology is given in Section 4. Then in Section 5, some of the key drivers and issues related to smart buildings are discussed. In Section 6, applicable new technologies are described, and then Section 7 outlines some promising application areas where new technologies can be beneficial in an office environment. In Section 8, some of the current research in smart building technologies is presented. Section 9 summarises the most promising technologies and application areas, and in Sections 10 and 11, a recommendation for a prototype smart building system is outlined.

3.4.2 Literature Review

Many of the areas covered in this report are treated as independent topics in the technical literature. However the approach adopted herein is more holistic, drawing on a range of resources from different fields of study. Hence, to avoid repetition and improve clarity, all of the literature that has been reviewed, is discussed in the most appropriate place, distributed throughout the report rather than being lumped into a separate section.

4. OFFICE BULDING TECHNOLOGY – CURRENT PRACTICE

4.1 Brief History of Building Control Systems

During the 1970's, the controls industry was dominated by a combination of pneumatic and electric control systems. Electronic controls became popular, but these were not generally microprocessor based.

During the latter stages of the 1970's and the early 1980's, Building Management Systems (BMS) became prevalent in larger buildings. The first generation of these systems generally required a central mini-computer, with 'non intelligent' field panels. These systems were used for monitoring and very basic stop/start control of major plant items. Whilst some of these systems offered 'energy management' software, these programs rarely worked reliably. Costs were high at approx $1000.00 (1980 values) per point, now down to $350.00 per point.

The mid 1980's was a major technology upgrade period, largely driven by the boom in high rise office construction in Australia from 1985 to 1990, and led by the first intelligent buildings. For the first time distributed DDC (Direct Digital Controllers) controllers became available, and these were the forerunners of current DDC technologies. Many buildings mixed the new technologies with the old (DDC and pneumatics). Intelligent networked security access control systems also became available during this period. The BMS cost per point dropped significantly, allowing new applications that had previously been unaffordable. By 1986 intelligent air conditioning controllers had found their way into office ceilings in the newest intelligent buildings. Mini computers still formed the central platform for the larger systems, and communications networks were of a proprietary nature and were generally slow.

The 1990's saw the gradual improvement in BMS, Security and related systems. Personal computers progressively replaced mini computers as the computer technology of choice. DDC controllers improved through greatly expanded memory capacities and communications interfaces, and the range of small point intelligent controllers exploded. The reliability of the systems also improved dramatically, and this was probably largely due to the significant improvements in manufacturing integrated circuits. The cost per point continued to fall.

4.2 Current Building Control Technologies

The range of building control technologies is now vast. However the (Australian) market has generally maintained its traditional approach to the implementation of the systems due to the structure and conservative nature of many building projects. The major building services systems generally fall into the following categories.

- BMS - Predominantly used for the control and monitoring of HVAC systems, but also for expanded functions such as (basic) lighting control, metering, etc
- Security and access control systems – Specialised systems providing distributed access control for doors, lifts, etc, and also including intruder alarm features, management reporting, etc
- Fire alarm systems – Generally separate to comply with strict Australian standards for fire alarm and life safety systems (making it very difficult to integrate fire alarm technologies into, say the BMS)

- Video surveillance and recording systems – due to public liability issues and an increased need for security recording, and with the implementation of digital video recording (replacing older style high maintenance VCR-based systems), this is now a significant area of expenditure
- Lift systems – Lift systems are now entirely computer controlled.

In addition to the above major categories there are many other specialist products, most having been developed for ‘stand alone’ applications such as generator controls, lighting dimming systems, car park control systems, intelligent (electrical) metering and power management systems, etc. Programmable logic controllers (PLC’s) are used extensively in these stand alone applications. PLC’s are the ‘industrial’ equivalent of ‘DDC units’ but are generally much faster in terms of the speed of operation. Current BMS networks can generally accommodate PLC’s utilising industry standard communications interfaces such as ‘Modbus’.

Special purpose buildings such as airports and hospitals include yet another layer of special purpose systems and communications networks.

4.3 Systems Integration and Interfacing

In general most of the major systems interconnect with one or more of the other major systems. For example when a fire alarm occurs, HVAC plant is stopped and started, security doors may be unlocked, etc. This interfacing is generally performed through ‘direct connections’ but may also be performed using ‘high level’ (generally serial) communications interfaces, such as access control interfaces with lift systems.

It is also possible to implement ‘integrated solutions’ such as combined BMS/access control systems, but this is generally less common. It is unusual that one supplier can provide both functions in one system where the separate functions are both state of the art and cost competitive at the same time. The construction of office buildings is generally lowest cost driven.

It is probably fair to say that if we could combine all of the best features of each of the available systems that we would have close to an ideal solution, although at a very high cost. However the implementation of a system provided by one vendor has many advantages over the piecing together of many different products and solutions from a number of different vendors, and the latter approach is rarely followed. There are considerable contractual, technical and risk issues with the latter approach.

4.4 Typical System Configuration

The typical system used in buildings today comprise of a number of layers:

- Sensors, actuators, other devices; which connect to
- DDC (local) controllers or equivalent controllers; which interconnect over
- Communication networks; to
- Other (global) controllers, networked personal computers (in house); which may also be connected to;
- Remote computers; to monitor and control the systems remotely via
- Web Interface or Dial up Connection

4.5 Industry Standards and Compatibility

In general systems from different vendors are not compatible with other vendor systems. That is, the system controllers, communications networks and computer systems and software are not compatible with other vendor’s systems. Sensors, actuators and most other control/monitoring devices are generally compatible from one system to the next, because they utilise industry standard interfaces. However we have seen no evidence that security/access control systems or fire systems or lift systems are moving to industry standard platforms.

There is an emerging standard for BMS that, in theory, should allow controllers from one vendor to communicate with controllers and computers from another vendor. This standard is 'BACnet' (Bushby, 1997), and has been developed by the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE). BACnet uses the Internet Protocol (IP) and allows any BACnet compliant product to communicate with any other BACnet compliant product over the internet. (Refer www.bacnet.org and Bushby, 1997) However, the current acceptance rate for BACnet is very low, - this can generally be attributed to the industry's major reluctance to purchase BMS components from different vendors, whether they are supposedly BACnet compliant or not. The BACnet protocol is probably not considered to be cost effective nor practical when applied to 'small point' controllers, and has been targeted at larger DDC controllers and BMS vendor front end software packages. The principle has been around for some years without major acceptance, however this is likely to change in the near future.

4.6 Primary Building Management

Computerised building management systems are designed with a 'management by exception' approach. That is, a building manager does not want to know what is operating correctly, but does want to know when a system fails or drifts out of tolerance, or fails to start or stop when it should. Thus a building is automated primarily to reduce (manual) operating costs. The building should start up and stop, and automatically unlock and relock, according to the day of the week and holidays, and should not need to be attended, in theory. Large automated buildings have thousands of associated data points and files, including temperatures, fire detector status, security alarm points, lift position locators, etc. A building manager only needs to view this information when there is a problem.

4.7 Building Management Reporting

Building management reporting takes many forms. All major building management systems record system operating condition and alarm changes onto computer hard drives for later retrieval and management processing, if and when required. In many cases the reports are only accessed or run after an event has occurred.

Items can also be 'trend logged' (samples stored every *X* minutes) where it is important to know the before and after conditions. Most systems offer a comprehensive capability for building management reporting, utilising common industry standard data bases.

4.8 Energy Management

'Management by Exception' design incorporates many energy management fundamentals – on a global scale, such as stopping and starting plant only when required and turning lights on and off automatically.

Energy management is generally considered to be the specialised approach to energy reduction over and above the basic management by exception process. Energy management is generally prioritised on a life cycle cost basis, as it involves additional hardware and/or software investment. The primary targets are therefore the major energy consuming items of plant and/or the primary control strategies that are used to control energy consuming plant. The primary energy sources for buildings are electricity and gas, solar and alternative sources are rare, although some buildings have their own electricity generating capability to complement grid supply.

The major controllable energy consumers are, where applicable:

- Central chiller plant for air conditioning systems (including cooling towers)
- Boiler plant
- Major air handling units, associated cooling and heating sub systems
- Lighting
- Hot water systems

It is therefore of primary importance that the major plant is selected to suit the building's operational profile, both during normal hours of operation and after hours. These decisions have a life time effect on the building, and even the best energy management system cannot solve major equipment selection deficiencies.

The major emphasis of current energy management programs is to:

a) Start plant at the latest possible time but still providing comfortable conditions at 'occupancy', stop the plant at the earliest possible time (sliding stop/start programs)
b) Ensure that the individual air handling plants only run when required (management by exception – time scheduling)
c) Ensure that the air handling plants, which are serviced by the chiller and boiler plants, only 'call up' these major plant items when absolutely necessary (intelligent control programs). Use 'free outside air cycles' when outside conditions allow same. Use 'night purging' to cool buildings after hours when the outside conditions allow it.
d) Stage the major plant on and off in the most efficient manner (intelligent control programs, generally quite sophisticated).
e) Ensure that 'in ceiling' zoned air conditioning controllers operate over a practical temperature/energy band rather than at a fixed temperature, to allow conditions to 'drift' to suit outside/ambient conditions The systems should also readjust setpoints for summer and winter conditions, and perhaps even mid seasons, and this is rarely performed as it is a time consuming task.
f) Reduce lighting, first by exception, secondly with photocells (although this is not common).

It should be noted that lift energy management is largely left to the lift vendors who are the only people experienced enough with their own products to tune the lifts to their most efficient operating levels. Lift codes also prohibit building owner intervention in the lift control systems. Lift system efficiencies are probably poorly understood at this time by the general building owners groups.

4.9 Building Control Systems and the 'Triple Bottom Line'

Current building control systems are not generally designed with a triple bottom line reporting objectives in mind. Initial capital cost is nearly always the primary driver (see Section 5.8). Energy consumption is often considered, although the selection of the expensive major plant items, which can also be the major energy consumers in a building, are almost entirely driven by capital cost alone.

Issues such as air quality are not high on the design agenda, with engineers concentrating on meeting the (minimum) standards and codes for their clients, again to minimise cost. In general, only 'greenfield' building projects, which are often driven by a green-conscious tenant, have a high environmental component in the design. New buildings constructed within existing built up areas generally have minimal environmental consideration in the design of the control systems.

5. DRIVERS, TRENDS & IMPORTANT ISSUES

This scoping study is timely in the current environment. The outline of the current state-of-the-practice given in the previous section highlights that our office buildings are presently 'sub-optimal' to say the least. There are many factors behind the current state of play, and many drivers, trends and issues which are exerting pressure for change.

One major factor lighting the path towards smart and healthy buildings, is the rapidly reducing cost and increasing capability of the technologies which will underpin them. These include some of the technologies already in use, as outlined above, and also new technologies which are currently under development or just coming to market. The downward price shift is a key driver since technologies which would have been economically unviable only a few years ago can now potentially deliver economic benefits that outweigh the costs.

Other drivers include government and industry sustainability initiatives, increased security needs, triple-bottom line reporting requirements, the changing nature of the workplace and business structures, changing real-estate marketplace, the desire to outsource building services and the ongoing business pressures to be able to quickly adapt to change and to increase productivity and reduce costs.

It is important to explore these drivers, and some other key issues such as different stakeholder perspectives, and the interaction between technology and architectural design, in order to evaluate which technologies and applications are the most promising. Some of these topics are explored in more detail in the following sections.

5.1 Sustainable Development

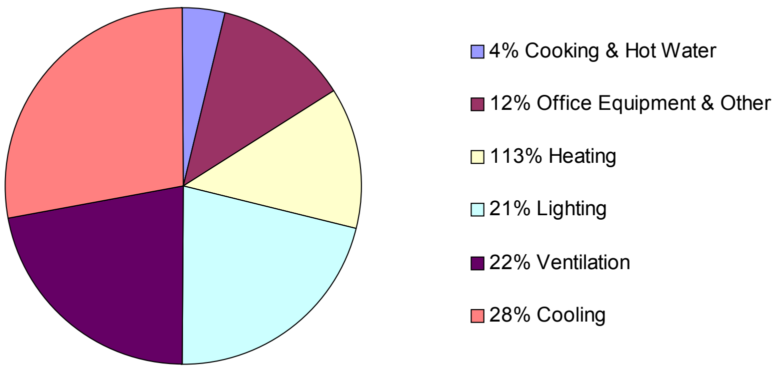
'Sustainability' is undoubtedly the buzz-word of our current time – particularly in government. All levels of government now have entrenched sustainability policies, covering a wide range of their activities. These policies aim to encourage reduced use of energy and other resources, and to minimise greenhouse gas emissions. 'Triple Bottom Line' assessment and reporting for projects involving government is becoming the norm, and may be required in future by businesses wishing to exploit tax incentives such as carbon credit or emission trading.

The built environment sector, and buildings in particular, are increasingly becoming a focus of sustainability policies. This is understandable, as buildings are such an integral part of people's every-day lives, and can serve as lasting political 'markers' of green government initiatives, as well as 'ribbon-cutting' and media exposure opportunities to win the hearts and minds of an increasingly environmentally conscious electorate.

The Victorian government has attempted to introduce a mandatory five-star energy rating for new homes, and there is increasing pressure to extend such requirements to all buildings in the future. The Australian Building Codes Board has also made clear its intentions in this area, where it has a stated goal of quickly developing 'cost effective energy efficiency measures suitable for introducing under building law' (ABCB and Australian Greenhouse Office, 2001).

The environmental impact from buildings is significant and real. Australia's 'commercial' building sector was responsible for producing more than 46 million tonnes of carbon dioxide in 1999. This is expected to increase to over 60 million tonnes by the end of 2010 (Australian Greenhouse Office, 1999). According to a report by the Australian Greenhouse Office (Australian Greenhouse Office, 1999), the use of electricity is responsible for 89% of commercial buildings' greenhouse gas emissions. These operational energy emissions are broken down into cooling (28%), air handling (22%), lighting (21%) and heating (13%). HVAC and lighting together account for 84% of commercial building greenhouse gas emissions. (see Figure 2) These systems in the building, particularly air-handling and lighting, are where technology can have a significant impact in reducing the operational energy requirements (Mysen et al., 2003; Li and Lam, 2001; Bodart and Herde, 2002; Kolokosta et al. 2001).

Figure 2. Commercial building greenhouse gas emissions share



Source: Australian Greenhouse Office, 1999

5.2 Architectural Design and Technology in Smart Buildings

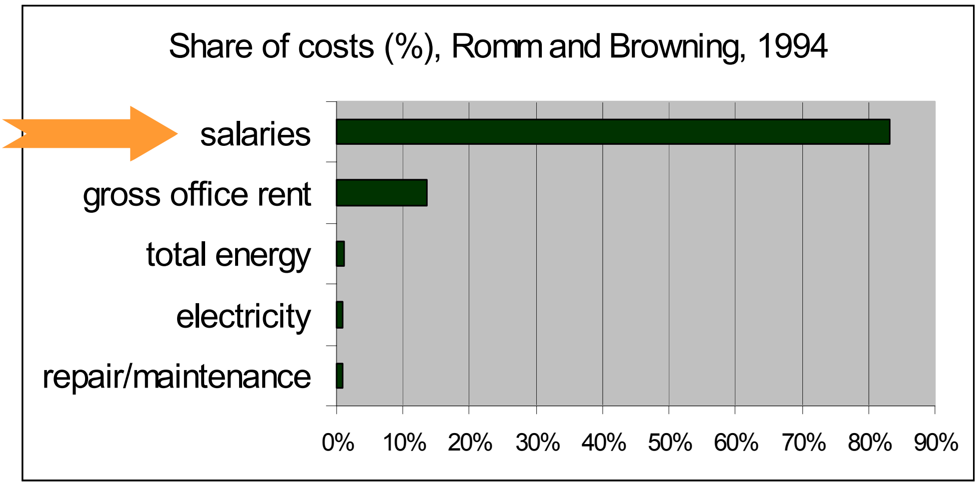
The use of technology does not necessarily make a building 'smart'. Kron (1997) highlights that if a smart building is no more than a container for intelligent technologies, then it is not really smart at all. In fact any benefit gained by the use of the most sophisticated building system technologies can be completely swamped by basic design decisions adopted by the building architects. Early design considerations, such as the amount of glazing, the 'depth' of the floor plans (i.e. maximum distance away from windows) and dimensioning of the interior spaces can double the energy requirements of a finished office building (Gratia and De Herde, 2003). These aspects of a building design can make it 'smart' in a passive sense, regardless of the technologies used in the different building systems. Such considerations are in the realm of architectural design and, although crucially important, are beyond the scope of the current study. The focus herein is on how the 'add-on' technologies can enhance the sustainability of the building, and complement good architectural design.

Despite the importance of intelligent architecture, technology still has an important role to play in the development of sustainable buildings – most notably in terms of the potential to reduce the required operating energy. Adaptive control strategies using the latest sensor and actuator technologies can in some circumstances reduce the operating energy of HVAC and lighting systems by half (Matthews et al. 2001; Atif and Galasiu, 2003).

5.3 Business Trends

As has always been the case, businesses are constantly driving to improve their bottom line. Globalisation of markets for knowledge-based products and services have only increased this drive for many knowledge-based (and therefore usually office-based) businesses. In a typical large office block, by far the single biggest lifetime expense (84%) is the salaries of the workers (See Figure 3). Thus, it is clear that improvement in productivity, when combined with a reduction in the business operating costs are critical issues for improving profitability. This is an important driver for business to adopt technological enhancements to their workplaces to achieve the desired improvement in productivity and cost reduction.

Figure 3. Breakdown of typical business costs



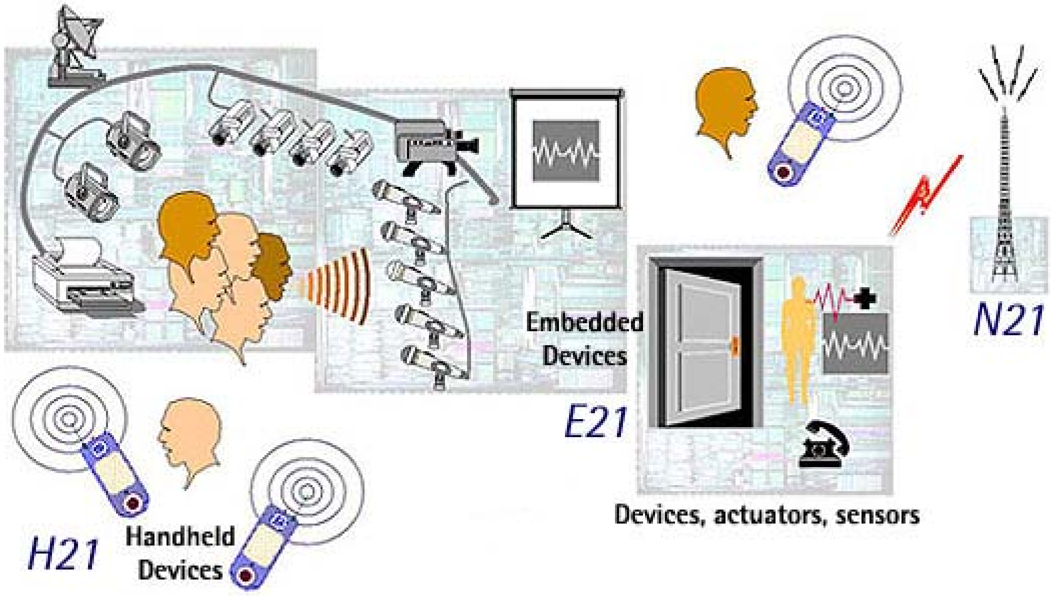
Source: Romm and Browning, 1994

Building technologies can assist in both improving productivity and reducing costs. Costs can be reduced primarily by reduced energy use and maintenance requirements (see Section 7). Productivity can be increased by improving the indoor environment quality (this is addressed in more detail in Sections 5.5, 7.1 and 7.5), but also through intelligent workplace design and improved team collaboration and communication. This is particularly important for knowledge-based businesses.

The Massachusetts Institute of Technology (MIT) ‘Oxygen’ project is a blue sky research project which is working towards integrating technologies with peoples workplaces through ‘human centred pervasive computing’ – which would allow a building to interact with its occupants in their everyday activities, and vastly improve their productivity. The technologies that the MIT project are developing involve the integration of software services to accomplish user-defined tasks. The integration of different networks and devices is shown diagrammatically in Figure 4. An example application is a smart room equipped with embedded speech, video, and motion detectors which automatically records and recalls key meeting events, monitoring and responding to visual and auditory cues that flow naturally from normal interactions among group members. Another example of such technology is location and resource discovery system that enable users to access computers, printers, and remote services by describing what they want to do rather than by remembering computer-coded addresses. The integrated systems could respond to user commands such as ‘Print this picture on the nearest colour printer’.

Improved collaboration and productivity can also be assisted by a flexible workplace layout, where the spaces can be changed easily to suit different activities on daily, weekly, monthly or yearly timescales. This desirable feature of an office floor is an important driver in the design of the lighting, power and HVAC systems, since they need to be able to respond to any floor plan configuration changes to optimise for occupant comfort and energy efficiency. A study of office building tenants conducted by the University of California (CBE, 1999) found that the flexible and adaptable spaces were needed to support rapidly changing business practices and organisational structures. Flexibility of floor-plan was ranked as the third most important factor in choosing real estate behind cost and location.

Figure 4. Diagram showing the integration of different networks and devices in MIT's 'Oxygen' project.



Source: http://oxygen.lcs.mit.edu/Overview.html

It should be noted that the need for communication and team collaboration extend far beyond the walls of the modern office. Globalisation of markets, combined with advances in communications and an increased mobility of the population (we fly more), have been a factor in changing the way many businesses are structured -- in terms of the geographical distribution of the employees. Businesses are more likely to have employees spread across different locations, or working in multiple locations. This is now an important trend which is driving investment in the technologies in buildings. More and more tenants require high bandwidth communications networks, hot-desking capability and video-conferencing facilities.

5.4 Security Concerns

The September 11 terrorist attacks, and other incidents since, have heightened awareness of security issues all over the world. It has become clear that buildings (including office buildings) are possible targets for hostile attacks by terrorist organizations. This has now become, and will continue to be, an important driver for the implementation of improved technologies for various building systems. Firstly and most obviously, there is more focus on access control, and around the clock security monitoring. The perceived increase in risk can only result in increased security costs. Technologies such as people-tracking and occupancy sensing, biometrics and image recognition, when used in conjunction with cheaper hardware such as cameras, sensors and computing power could help in controlling these costs, whilst still achieving the required levels of safety and security. Many of these security-related technologies (such as people tracking, occupancy sensing, cameras, etc.) also have the potential to be beneficially integrated into the control loops for smarter control of other building systems such as HVAC and lighting.

A less obvious ramification of the heightened security concerns is in the design and operation of HVAC systems. A building HVAC system could theoretically be used to spread toxic, chemical or biological agents throughout a building, however, zoning of the HVAC system design can minimise the impact of such hostile acts. Another benefit of a zoned design is that these types of systems also offer the possibility for increased comfort and reduced energy consumption through higher granularity control over the building environment on a more localised scale.

5.5 Worker Health and Productivity

It is not only hostile acts which result in the spread of biological and chemical agents throughout a building, as these exist at non-lethal levels in the air inside a building already. These may be in the form of airborne viruses and bacteria, organic and inorganic particles, and toxins which are emitted from building finishes and furnishings.

Much attention is always given to public health issues and associated outbreaks of disease such as Severe Acute Respiratory Syndrome (SARS), Influenza, and Legionella -- which are often associated with individual buildings (or sourced from a building in the case of Legionella). An outbreak of Legionella at the Melbourne Aquarium in April 2000 affected 100 people and caused 4 deaths. This outbreak prompted initiatives to try and reduce its occurrence and impact, and has become an important driver for improving design, operation and regulation of cooling towers in buildings.

In terms of overall impact on society and the economy, however, a possibly greater issue is the general health and productivity of the workforce and the relationship to the indoor environment quality (IEQ). Many Australians now spend a third of their lives inside office buildings, and the indoor environment of these buildings are therefore profoundly important to occupants health, happiness and quality of life.

Several studies have shown that there is a link between indoor air quality and respiratory illness. Leclair et al. (1980), Brundage et al. (1988), Richards et al. (1993), and Hoge et al. (1994) have confirmed this link in military facilities, jails or hospitals. This is relevant in the current study, because in office environments, it has been shown that a significant proportion of sick leave taken is due to respiratory illness (Nichol et al. 1995; Feeney et al. 1998).

Although data is more difficult to compile for a study on office environment, several studies have been conducted. Milton et al. (2000) and Seppanen et al. (1999) found a relationship between reduced ventilation levels and increased sickness in office environments. A study by Myatt et al. (2002) confirmed this relationship, based on amount of sick leave taken. Another study by Niemela et al. (2002) showed that productivity of workers in a call centre may fall by 5 to 7% when the indoor temperature is elevated.

Overall, the available scientific data have shown that there is a connection between the quality of the indoor environment and the productivity and general health of the occupants (Fisk 2000; Milton et al. 2000; Fisk and Rosenfeld 1997). It should be noted however that there is considerable uncertainty in the estimates of the magnitude of the productivity gains.

Considering that in a typical large office block, by far the single biggest lifetime expense is the salaries of the workers (84% - refer Figure 3), it is clear that improvement to the IEQ has the potential to significantly improve business bottom line by improving health and productivity, and reducing absenteeism. Increasing public awareness of these factors, combined with more aggressive policies and focus on OH&S issues in the workplace are important issues to consider when designing the systems and technologies in a smart building.

5.6 De-Regulation

The de-regulation of the electricity and communications markets in Australia is now an important consideration when deciding on where to implement new technologies into building systems. Large consumers of electricity (such as office building owners or property managers) are now able to negotiate directly with electricity suppliers, and wholesale electricity prices can fluctuate by many orders of magnitude, depending on demand, and availability of supply. This opens up a whole range of opportunities to tailor the design of many of the building systems to exploit fluctuations in electricity price, and to prioritise energy saving strategies.

In a similar vein, information technology and communications (ITC) suppliers offer tailor-made deals for the different services they offer to individuals and businesses. Smart communications infrastructure can be utilised to minimise ITC costs in a building (eg. selecting the least cost carrier for different types of phone calls at different times).

5.7 Different Stakeholder Perspectives

The office property industry is fragmented and complex in its structure and there are many different stakeholders who are not necessarily involved in providing or specifying the technological aspects of an office buildings, even though they are directly affected by such decisions. These include owners, agents, properties and facilities managers, tenants and industry bodies. It is important to outline some key aspects of these different perspectives, in order to understand the wider impact that may come about from the use of new technologies in buildings. The needs and issues of some of these important stakeholders are outlined below.

The Owners

Needs: The owners will support initiatives that improve capital growth and yield, on their buildings. Anything that will increase net return per square metre, reduce their capital outlay, reduce the financial risk, and attract or retain tenants is of interest.

Issues: Owners are not in a position to appreciate the ‘value proposition’ associated with increased worker health and productivity (it does not directly affect them), but this can be the basis for attracting and keeping tenants that seek and pay for this feature in a workplace.

The Agents

Needs: The agents’ aim is to attract and retain tenants as they work on the commission of the space they sell.

Issues: Many agents are sceptical and have a “negative hype” towards technology or green initiatives. They need to be engaged and educated. They need a “sales pitch” which they can communicate to tenants.

The Property and Facilities Managers

Needs: The property and facilities managers’ aim is to manage the tenants and the building with as little time, energy and cost as possible.

Issues: Better real-time management information regarding a building’s performance is critical.

Tenants – Business Owner

Needs: Traditionally, the primary concern for business owners was the net occupancy costs per square metre but this is changing. The results of an international business locations drivers survey undertaken in 2001 (see Figure 5), and an office ‘tenant needs’ study (CBE, 1999) have illustrated the importance and priority of workforce, technology and infrastructure on organisations property selection and decisions.

Issues: Business owners are starting to understand the “value proposition” associated with increased worker health and productivity. The provision of more powerful real-time management information would improve this perspective.

Tenants – Office Staff and Visitors

Needs: The staff and visitors require a healthy, productive and flexible workplace.

Issues: The staff and visitors need to be able to change and adapt their environments in real-time.

Industry Bodies

Needs: To improve the overall performance of the Australian building, construction and property industry.

Issues: Need more accurate data and research to improve and facilitate decision making.

Figure 5. International Business Location drivers.

	Workforce	Tech/Infra.	Quality of Life	Business Environment	Cost
Headquarters	5	5	5	5	1
R & D and Technology	5	5	4	4	2
Administrative/ Customer Care	4	5	2	3	5

Important … Unimportant

Source: Andersen Business Location Services

5.8 Out-sourcing of Building Services

One of the most common frustrations of green and healthy building advocates, office building tenants, and of architects and engineers wanting to implement eco-friendly and healthy technologies, stems from the 'model' for the provision of building mechanical and electrical services in an office building. Currently, the decisions on what types of technologies to use are driven purely by up-front capital costs, where, in many cases, the cheapest solution is the most inefficient. It is also common that below-cost plant supply agreements, based on inefficient systems are given to the developers (designed to win tenders), but these are coupled to expensive long-term maintenance contracts (designed to recoup the up-front discounts).

Ongoing energy and other operational costs are directly passed on to the tenants, so using an inefficient building plant causes no loss for the building developer or owner. This means that an investment in more expensive, but more efficient equipment is rarely undertaken, since the up-front cost must be borne by the building owner or developer without any real benefit from the improved efficiency flowing to them. To make the situation worse, tenancy laws dictate that any savings in energy costs resulting from a landlords actions must be passed on to the tenants, removing any incentive for the owners to strive for improved systems. So it is often the tenants who really have the incentive to drive for efficiency improvement, however, they are often transient, and usually lack bargaining power and the required specialist knowledge, and also usually come into the picture too late to have an influence anyway.

Some large higher-profile tenants will demand that green and healthy technologies are implemented in their buildings, and that this is becoming increasingly important in corporate branding, but this is currently the exception rather than the norm.

The crux of the problem is that there is no market incentive to optimise the ‘total’ life-cycle costs, including ongoing energy, maintenance and replacement costs. The current (sub-optimal) model for procurement and delivery of building services has been identified as the major barrier to adoption of efficient technologies in the US (Koomey at al. 2001), and the same situation exists in Australia. The current situation can be easily rectified, however, by out-sourcing the supply of building services to a third party who owns and pays for the building plant and other service technology, and then sells the services back to the clients at market rates. This is an exciting emerging trend (Australian Financial Review, 2002), which can be applied to both new and existing buildings. Under such an out-sourced arrangement, the party which owns the building services hardware directly profits from reduced energy consumption and life-cycle costs, and can only thrive by making intelligent up-front investments in optimised building technologies. This outsourced model has been identified as desirable in a study of office tenants (CBE, 1999), where one of the key findings of the study was the need to introduce a competitive, deregulated environment for the provision of building services. Most participants in the study expressed frustration with their current arrangements for provision of building services.

Under such a scheme tenants can benefit from having a more realistic and predictable ‘user-pays’ pricing structure, as they do with other services such as telecommunications. Developers and owners benefit by reducing their capital outlay, and being removed from many of the operational functions and associated risks. Enormous savings can be made if the outsourcing model is applied over entire portfolios of buildings. If this model of building service provision takes off, then an enormous increase in energy saving technology uptake is likely to follow.

5.9 Trade-off Between Indoor Environment Quality and Energy Use

Many energy conservation measures that can be applied to office buildings have the potential to either improve, or degrade the quality of the indoor environment, which in turn, can have a positive or negative effect on occupant health and productivity (see Sections 7.1 and 7.5). Since even small changes in occupant health and productivity can have a significant financial impact, it is important that any ‘trade-off’ is considered when selecting technology for a smart building. The inter-relationship between energy conservation and indoor environment quality is complex, and has been discussed in detail in a recent publication sponsored by the US Department of Energy (US Department of Energy 2002). It puts energy conservation measures into the following categories:

- neutral in their impact on indoor air quality
- clearly beneficial, e.g. heat recovery from ventilation air, or
- beneficial or detrimental depending on the situation

An example of such a trade-off is ventilation control. It may be more energy efficient for the HVAC system to recirculate the conditioned air within a building than it is to bring in fresh air from the outside. Introduction of outdoor air is likely to improve (or in some cases degrade) the quality of the indoor air.

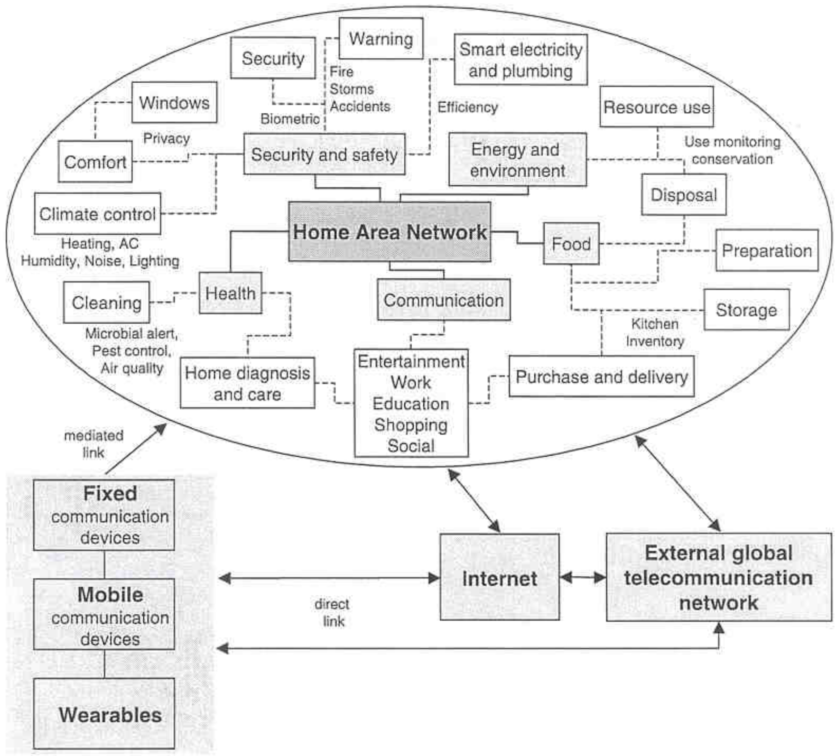
Another example is in the selection of energy efficient lighting. Lighting quality is crucially important to productivity in visually intensive tasks, so it is important that the lighting quality must not be degraded in any way in order to achieve energy efficiency.

6. NEW TECHNOLOGIES FOR SMART BUILDINGS

6.1 Sensor Technologies

Many of the technologies which underpin the smart building are rapidly reducing in cost and increasing in capability -- but probably none more so than sensor technologies. In the not-too-distant future, it will be possible to sense and measure the majority of the important parameters in a building for very little cost (in the order of $1 per sensor). Some of the potential application areas for sensor technology are shown In Figure 6 below. Although the central focus of Figure 6 is residential buildings, many of the applications also apply to office building environments.

Figure 6. Potential impacts of sensor technology



Source: Gassman et al. 2001

6.1.1 MEMS Sensors

MEMS stands for micro-electromechanical-systems. These are basically very small mechanical or physical 'devices' which are manufactured onto a silicon chip. An overview of potential application areas for MEMS sensors technologies is given in Akyildiz et al. (2002). One example application is an 'agricultural multi- sensor' currently being developed by the CRC for Microtechnology (CRC for Microtechnology, 2002). This MEMS-based sensor measures the following on a single chip

- Temperature: 0 to +40 deg. Celsius
- Relative Humidity: near 0 to near 100%
- Light: illuminance level
- Air Speed: 0 - 40m/s (resolution 0.1 m/s)
- Air flow direction

The aim is that once in production, these sensors will be cheap enough to provide detailed environmental information on a very localised scale, and then disposed of at the end of each growing season. These sensors are designed to measure environmental parameters on a farm, but are equally applicable in an office building environment, since they can measure many of the important IEQ parameters. A variation of this type of sensor is the lithographic sensor (Evans et al. 2001), in which the MEMS circuitry is fabricated onto a flexible or curved surface, enable a sensor to be embedded into every-day objects made from plastics or textiles.

6.1.2 Fibre Optic Sensors

Fibre-optic sensors, are based on a ‘Fibre Bragg Grating’, which is an embedded grid inside an optical fibre, that can affect the characteristics of the light which is transmitted through it. Basically, the optical signal in fibre optic sensors can be modulated by the alteration in physical properties and geometry of the grating, which is directly or indirectly related to the variation in its environment. The variation can be mechanical (deformation, vibration, pressure, and flow), chemical (pH value, change due to chemical reactions), physical (temperature, moisture, humidity, salinity, electric field, magnetic field). Its diverse sensing abilities together with its advantages in physical and chemical property have firmly placed the fibre optical sensor at a very significant position in the advanced sensor technologies, particularly in structural health monitoring.

6.2 Wireless Sensor Networks

The cost of running wires for sensors in buildings can be in the range of 50-90% of the cost of the sensors. Hard-wired networks of sensors are also quite inflexible in so far as it is inconvenient and expensive to move them, if there is a re-configuration of the office floor space. Wireless communications can reduce the cost of installing and maintaining sensors, whilst at the same time providing much increased flexibility, since the sensor can be moved or upgraded easily. When wireless technology is combined with MEMS, it may even be possible to embed sensors in ceiling tiles, furniture or people’s ID tags. This combination also allows for a vastly increased granularity of measurements to be obtained for a similar or lower price than is currently possible. The increased granularity of the measured data can be used to harvest information to improve building performance and energy usage, and can also be fed back into more sophisticated and optimised control loops for power lighting and HVAC systems.

There are already wireless products available which can in theory be used in smart building applications, but this generation of products is still probably too expensive and complex for such widespread application. However, technological breakthroughs from companies such as Motorola, and US universities such as University of California (UC) Berkeley (through the ‘Smart Dust’ project) and UC Los Angeles (through the Wireless Integrated Network Sensors) have just recently crossed over to commercial developments and will likely impact the next generation of products. These products will be ultra low cost, self-configuring, self-organising, ultra low power wireless sensor networks. A comprehensive survey of wireless sensor networks is given in Akyildiz et al. (2002).

An example of this technology is the ‘multifunctional Mote’, which are already commercially available, but are not yet at production levels to make them ultra low cost (currently around $50 each). They are self contained wireless communications devices which can process the signals from a MEMS-based sensor. A diagram showing the components of the Mote are given in Figure 7(a). These devices are currently being developed as part of the ‘Smart Dust’ project at UC Berkeley, and as the name of the project suggests, are very small, as indicated by the size comparison of a current generation Mote with a one cent piece shown in Figure 7(b), and the photographs of the next generation smart dust motes shown on Figure 7(c).

Figure 7(a). Diagram showing components of the UC Berkeley Mote.

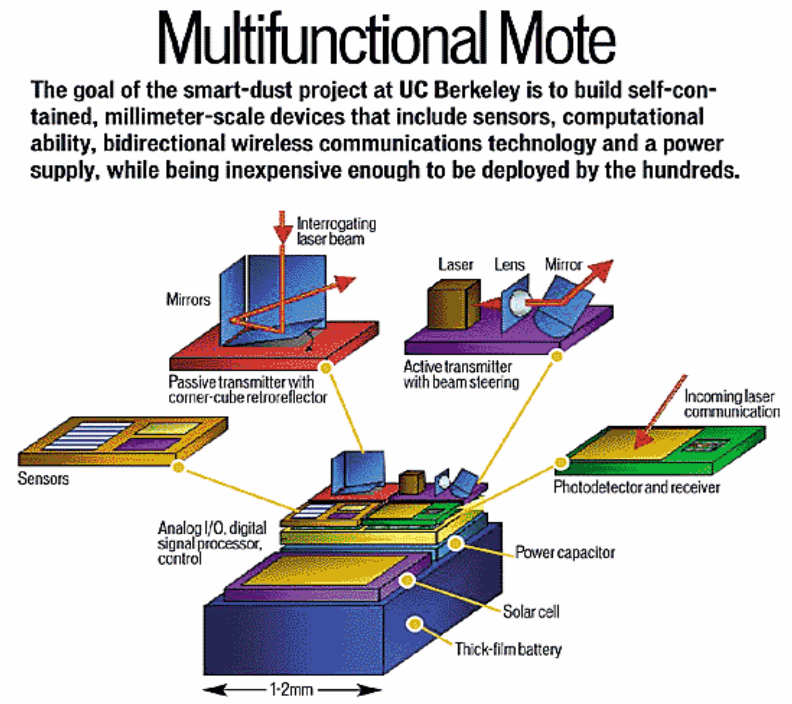
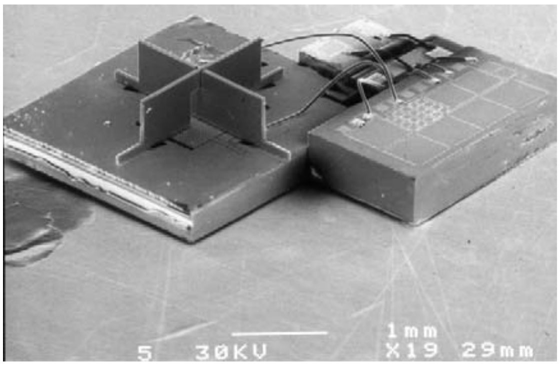
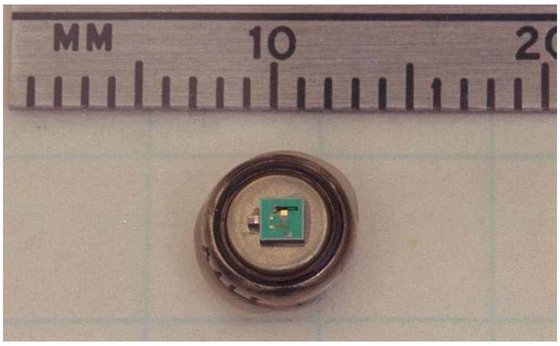


Figure 7 (b). Diagram showing actual size of a current generation Mote compared to one cent piece.

Figure 7 (c). Photographs of next generation 'Smart Dust' – bi-directional communications mote





Source:* *http://robotics.eecs.berkeley.edu/~pister/SmartDust/

6.3 New Materials Technologies

The majority of buildings are constructed from traditional materials such as concrete, steel, glass, wood and plastic. However there is a new generation of 'smart' materials currently under development, which have the ability to change their form, in either a passive or active manner, to suit a variety of different purposes.

In materials science, the word 'smart' was first applied to 'materials' in the late 1980's, initially to categorise materials capable of mimicking characteristics of living things. A smart material has an ability to modify its own physical or chemical characteristics, or geometrical configuration, and even its microstructures in molecular or atomic level to respond to external stimuli in a way to complete its desired function.

Generally, these materials can be categorised as functional materials, adaptive materials, or smart or intelligent materials. Most of 'smart materials' used nowadays belong to the 'functional material' category, which can passively sense external stimuli or actuate in response to the stimuli. These materials basically rely on 'one-way' property coupling between optical and mechanical, thermal and mechanical, electric/magnetic and mechanical, chemical/physical and electric, etc. A few examples are:

- Shape Memory Alloy and Polymer: With the special characteristics of phase transformation between austenite and martensite, the materials can recover its trained geometric shape when temperature reaches a critical point. This property can be used as an actuator, such as on an aircraft wing control.
- Electro-Rheological Fluid and Magneto-Rheological Fluid: The significant behaviour of these materials is that their viscosity changes with applied electric or magnetic field. With this property, they can be used for structural vibration control by actively changing the characteristics (in real time) of large dampers attached to buildings and bridges.
- Electro-Chromic Glass: This is an electronically 'switchable' glass which can darken or lighten under applied electric field.
- Intelligent Polymers: can change state when they come into contact with air or moisture – enabling them to 'self repair' around windows, and ductwork.

An 'adaptive material' not only has an ability to sense its environment, but is also capable of responding to its environment. It normally has 'two-way' property coupling. A typical example is the piezoelectric-based material. The piezoelectric material deforms when it is subject to electric field, and can also produce voltage when it deforms. Its wide applications includes basic acceleration sensor, pressure sensor, surface acoustic wave sensors, shape control, vibration control and more. These types of materials have already been used in military aircraft, so that an aircraft wing can change shape to suit the required flying conditions (i.e. for different speeds and manoeuvrability requirements). This material enables this to occur without the need for any mechanical joints or systems such as hydraulics.

If such adaptive materials were cheap enough in the future, there is no reason why every surface inside a building could not in be an 'active' element of the building. Different panels and surfaces could be used to sense vibrations, temperatures or moisture, monitor premises for intruders, convey information to occupants (i.e. act as TV screens, loud speakers or microphones), cancel street noise in real time, change their optical and thermo-physical characteristics (colour, texture, permeability, thermal resistance, etc.)

Adaptive materials can sense and actuate, but can not 'think'. The true 'smart material' has the capability of 'thinking' – that is, it has a control algorithm that organically links its sensing ability with its activation ability. The response is properly selected and optimised based on sensed information. In most circumstances, however, these are really functional or adaptive materials with intelligence (i.e. a silicon chip) added or embedded into them.

6.4 Robotics

Robotics is an area of technology that has promised much, and captured the imagination of the population over a period of many decades. Although many applications have been found in the manufacturing sector, it would have to be said that people's everyday lives have yet to be significantly impacted by robotics.

Autonomous robotic vacuum cleaners, have just recently come onto the market in Australia, although they have some limitations in suction power and ability to clean corners and other tight spaces.

6.5 Information and Communications Technologies

Although they are not particularly new technologies as such, information and communication technologies (ICT) are constantly changing in price and capability and are increasingly important to businesses. A recent report based on a survey of 634 Australian businesses found that Internet connectivity is almost universal, with 95% of Australian businesses online. (Source: *Built for Business 2: Beyond Basic Connectivity,* Cisco Systems – The Allen Consulting Group, October 2002).

Australian businesses are seeking smart integrated ICT solutions to compete more effectively. The Internet is one of their key business tools and their remote access requirements are growing. Businesses want affordable integrated broadband services that give them freedom to focus on their core business. Additionally, they are becoming focused on speed and flexibility requiring more bandwidth than ever, universal access and "always on" survivable networks. Much of their operations now depend on service portability, outsourcing relationships and on managing multiple collaborations.

There are a number of key trends and new aspects of the ICT used in office buildings that must be considered. These include:

- Tenants are now dependent on Internet, such that it is now considered of equal importance to the telephone. It is likely to be of even higher importance than telephone in the future as bandwidth increases.
- Phones, computers and information services are converging, or have converged.
- Buildings are requiring more cabling; both base building and tenant systems.
- The rapid uptake of wireless LAN's as a "last mile" alternative to cabling.
- The penetration of Public Access Wireless into public and retail spaces within buildings is increasing the tenant footprint.
- Roof top communications becoming more important.
- Technology invading land (wireless, carriers, tenant networks) raising liability and management issues.
- A move towards building management owned base building infrastructure that is utilised by multiple providers.
- Utility providers are starting to provide bundled energy and data services. This trend uses existing spatial infrastructure to provide multiple services.
- An increased uptake in the use of Video Conferencing and Video Security to minimise travel costs and minimise perceived or real human safety risks (i.e. September 11, terrorism etc). In particular, the increase in use of desktop IP based Video Conferencing and IP based Video Surveillance.
- The focus of tenancies on cost reduction has meant that new voice technologies are now becoming viable. Voice over IP is now being combined with existing PABX and PSTN infrastructure to deliver low cost voice alternatives for tenants.
- Application Service Providers are offering outsourced data storage, application hosting and IT departments. These services rely on diverse infrastructures with very low "failure rates".
- There is an increased use of Web based control systems and info-portals.

- Proprietary systems are being adopted. They are expensive to un-hook, have high risk due to escrow issues and are not easily integrated in an “Open Source” fashion.

6.6 Biometrics

Due to generally heightened security concerns (see Section 5.4), there is an increasing demand for biometric identification technologies to be used in security and access control systems. Many old technologies have been enhanced, and new technologies developed. These include:

- Facial Recognition
- Fingerprint Scanning
- Hand Geometry
- Iris Recognition
- Keystroke Pattern Recognition
- Retina Scanning
- Signature Verification
- Voice Recognition.

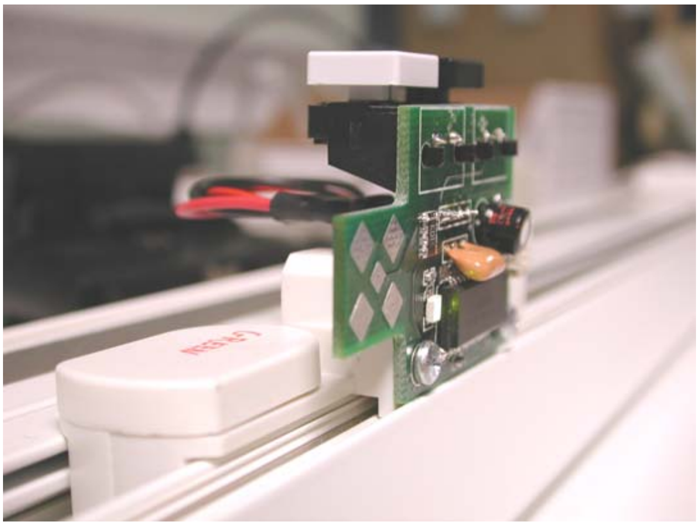
Biometric technologies are usually only applied in high-security environments, but are starting to find their way into a wider range of applications. These technologies also have the potential to be linked into other systems, such as communications, where building user ‘profiles’ can follow them around and be automatically sensed biometrically.

6.7 Integrated Systems

Many of the new and existing technologies that have been described have the potential to be integrated in such a way as to make the functions of a building ‘smarter’. Arkin and Paciuk (1997) and others have suggested that the ‘smartness’ of a building is not merely a function of the sophistication of the technologies utilised in individual building systems (e.g. HVAC or lighting), but is measured more so by the integration between the various systems. There is some merit in this view, although there are practical constraints on the level of integration which can be achieved. One promising overarching technology which lends itself to system integration is IP addressable controllers, sensors and actuators (BACnet – see Section 4.5). These are currently not in widespread use, but their uptake is increasing. The major benefit of this technology is the flexibility it offers, because potentially all controllable things in a building can be integrated via such a platform. Integration with existing buildings communications systems may also be possible (see Section 6.5).

MIT’s Centre for Bits and Atoms, in one of its research projects is developing a ‘programmable building’ (MIT 2002), in which every light switch and fitting, power outlet, sensor and actuator is an addressable device on an internet backbone. Figure 8 shows one of the internet-enabled switches on a specially designed track.

Figure 8. Internet-Enabled switch developed at MIT Media Lab.



Source: Technology Review Magazine, MIT (2002)

7. OPPORTUNITY AREAS FOR NEW TECHNOLOGY IN OFFICE BUILDINGS

7.1 Thermal Comfort and HVAC Control Systems

Overview

The influence of the indoor thermal environment on thermal comfort of the occupants has been studied for many years. This is understandable, since dissatisfaction with thermal comfort is the most common source of occupant complaints in office buildings (Federspiel, 1988). Thermal preferences and comfort tolerances vary among people, and depend on many factors including radiant temperature, air temperature (and gradient), air velocity (or perception of air movement), humidity, activity level, the lighting characteristics (particularly direct sunlight and glare) and type of clothing worn. Psycho–social dimensions such as stress levels, mood, gender (Feeney et al. 1998), rumour-mongering and the presence of HVAC maintenance staff can also have an effect (Lahtinen et al. 2002). Comprehensive review of literature relating to thermal comfort issues can be found elsewhere (Brager and Dear, 1998)

Clearly, the interaction between the occupants of an office building and the indoor thermal environment is complex. In contrast, the measurement of internal building conditions is quite primitive. It would be reasonable to state that, within Australia, over 95% of air conditioned space is controlled based on space temperature alone. Humidity control is rare, and generally is confined to specialised applications in hospitals and laboratories where humidity is a dominating issue because of health or process control requirements.

Whilst the temperature band is one of the most important factors influencing a person's comfort level, the perception of air movement is another major contributing factor. Many air conditioning systems are designed around 'variable volume' concepts, where the space air temperature is controlled by varying the volume of air (supplied at a relatively fixed temperature) to the space, as compared to varying the temperature of the air supplied to the space at a 'constant volume'. Variable volume systems can 'back off' to quite low air flow rates when space conditions reach comfort levels. Whilst the space temperature is 'comfortable', the occupant is not because the air feels 'dead'. Some variable volume systems have incorporated local recirculation fans to overcome this problem (generally called 'fan assisted variable volume). It is quite common within a large office building that the perimeter spaces will have a comfortable air flow rate (required to extract heat entering through the building's curtain wall) whilst the internal zones may be starved of air flow.

Air movement is also dramatically affected by the design of the work space, by the selection of the supply air diffusers and by the methodology used to extract the return air from the space. Smaller enclosed work spaces are generally directly treated, whereas open plan spaces are generically air conditioned in most cases. In nearly all situations the emphasis is simply to supply an adequate amount of conditioned air to the space, and little attention is paid to the exact location of the occupant. Spaces are also dynamic, with the numbers of occupants and their activities varying significantly over time, resulting in over cooling and over heating.

The impact on comfort levels with variances in space humidity is probably not well documented because it is not a parameter that has been extensively monitored in buildings in Australia. It is probably reasonable to state that people in general have a high tolerance to changes in humidity levels over quite a wide band, as compared to space temperature tolerances which must be controlled quite tightly (between 21.5 and 23 degrees C).

However, tolerance to extremes of humidity is low. Low humidity environments impact directly on persons sensitive to dry conditions, and create flow on effects such as static electricity problems. It is not uncommon to see people sensitive to low humidity with portable humidifiers within their office, simply because the control systems cannot offer an alternative solution.

Lighting levels can be impacted by a number of factors. Primarily there are two types of spaces when lighting is considered, spaces with external-ambient light contribution and spaces without. Both types of spaces then have supplementary internal lighting. We have not been associated with any building projects that have seriously addressed the effect of lighting level on occupant comfort through the control of lighting levels on a real time basis (other than through the selection of the light fittings and diffusers and the designed lighting level). Again we believe that occupants have a reasonably high tolerance level to quite diverse ranges in lighting levels, with *extremes* of brightness, glare, lighting flicker and low lighting levels being the major areas of complaint.

Opportunities

Given that air flow rates, humidity and lighting levels all contribute to occupant comfort levels, these parameters are not currently monitored in the majority of buildings and these factors are therefore not directly or actively controlled. (they are, however, indirectly controlled to some degree through the application of historical knowledge related to local geographical conditions, seasonal changes, etc).

A sensor that could measure all of these variables (temperature, air flow rate, humidity, lighting level) could therefore provide the next logical technical advancement in the monitoring, management and control of air conditioned spaces. If the sensor was cheap enough to be able to be deployed at many locations throughout the building, then this would also open up opportunities for new improved control algorithms, tailored to the dynamic nature of the spaces that are being conditioned. This would mean that more efficient systems could be developed, which could direct conditioned air to where it is needed most, whist providing for improved control over comfort levels.

Such a system would allow for a continuous reconfiguration of thermal zones and controllers, and 'micro-zoning' that can be dynamically changed as the floor space configuration changes. A more flexible and controllable system would also have the potential for significantly reduced energy consumption (Loftness et al. 2002) and increased user controllability – resulting in improved satisfaction with thermal comfort.

7.2 Air Balancing for HVAC Systems

Overview

Air handling systems essentially comprise of fans and air distribution duct work systems. This applies for both 'constant volume' and 'variable volume' systems. There is a perception that these systems are flexible in that they can vary the air quantity or the temperature of the supplied air to the spaces within wide bands. This is incorrect.

Every air handling system is unique in design. Air flowing from the supply fan to the space must be initially balanced through the duct work and any associated in ceiling air distribution devices, so that the primary intent of the design is set.

In reality each system is 'air balanced' when it is installed by the placement of static (not controlled) dampers and other quite primitive flaps and other devices in the duct work between the fan and the spaces. These devices are generally located where branch ducts tee off from the main supply ducts, and are difficult to access. Air balancing is very labour intensive and requires specialist knowledge and air flow reading equipment.

If the primary air balance is not performed with due care, the installed system will never perform correctly, with too much air to some locations and too little air to other locations. Compounding this issue are changes to the spaces after the initial air balance. These changes are 'every day' and can be as simple as the installation of a refrigerator in a room not designed for the refrigerator's heat load. It is important to realise that air conditioning designers design to the 'actual' loads and populations that are given to them as part of a project brief.

Opportunities

One of the reasons why this issue is poorly understood and managed is that building managers cannot 'see' the problem. That is, there are no air flow devices in the ductwork, primarily due to cost but also because it has not been industry practice.

Massive waste occurs through out the industry because of poor air balancing and the failure to regularly re-balance systems over time. The first step in overcoming this problem will probably only be taken when a relatively cheap air flow sensor becomes available and some further intelligence is gathered regarding the real cost to the industry.

The application of a new wireless sensor should therefore also be considered for 'in-ceiling' applications such as within duct work systems. The wireless communications hardware may need to be dropped below the ceiling to allow clear communication. This would assist to complete the picture both below and above the ceiling. The in-ceiling applications would not be as high density as below the ceilings, but the implications of improving this aspect of air conditioning systems may be significantly greater.

The ideal is self balancing air handling systems, and we are not aware of any projects targeting this significant problem.

7.3 New Generation Sensors for HVAC System Control

Overview

The technology behind space sensors has not changed dramatically over the last 10 years. Prior to that time, sensors evolved through pneumatics in the 1970's to the early Building Management System electronic applications in the late 1970's and early 1980's (bulky and inaccurate) to gradually improved IC designs through the latter stages of the 1980's. Once the sensors became small (allowing discrete wall and ceiling mounting), accurate (within 0.1 degrees C) and reliable, and no longer required regular calibration, further sensor development has not been a high priority. Current sensors are very low cost, with the major cost being in their installation.

Opportunities

The current range of available sensors matches the current target market very closely. However these sensors are single purpose and have no communications capability. They must be cabled to the nearest logical electronic controller for them to provide accessible information. There is therefore a cost 'at both ends', and this includes a cost at the controller end for the provision of an electronic interface for the sensor circuit. Sensors are also inflexible in terms of their location, and need to be relocated and re-cabled when the occupied space is rearranged. This is probably the major contributor to the ongoing problems with space monitoring, in that spaces are remodelled but sensors are not intelligently relocated, either through oversight or to save cost and inconvenience.

A sensor that did not require cabling (radio communication) and that could communicate on a generic basis would therefore offer many advantages over existing sensor technologies. The sensor data would become more widely accessible to other system programs, and could be more readily offered to occupants through internet browser access.

The sensor would need to be cost competitive *over its life cycle.* A conventional sensor has an approximate 'installed cost' of $300.00 to $350.00. During its life cycle, it may be relocated some 2 or 3 times. Each relocation tends to be inefficient from a cost perspective, costing more on average for each relocation than to install it in the first place. There are associated costs such as damage to ceiling tiles, after hours work, recommissioning, management overheads to organise, etc.

The sensor would need to have its own power source that would have a life of at least 7 to 10 years, which is the approximate life cycle of current Building Management Systems. It would need to be accurate and repeatable, and not require calibration with degradation of its power source. It would also need to report 'low power' or 'error' problems.

7.4 Air Quality – Indoor Pollutants

Overview

Air quality is difficult to define and measure and therefore can be difficult to control using purely technological measures. Wesolowsli (1987) defines indoor air quality as 'the totality of attributes of indoor air that affect a person's health and well-being'. Under this definition, the factors which affect thermal comfort (covered in Section 7.1) therefore overlap with other air quality parameters such as the levels of pollutants and particles. Table 2, reproduced from a report by Brown (1997) presents a summary of indoor pollutants, their major sources, and current response measures. Figure 9, reproduced from Brown (2001), demonstrates the complexity of how pollutants arise and are distributed in a typical office building.

It is expected that pollutants in outdoor air will enter a building with ventilation air, and the level reached indoors will depend on the level of outdoor pollution, the level and type of ventilation used, and the nature of pollutant losses to indoor surfaces. Indoor air pollutants also arise from pollutants emitted from the many building products, equipment and furnishings, and the level of these pollutants changes over time, depending on the initial level of the product emission, the rate of decay of that emission, and the rate of ventilation in the building (Brown et al. 2002; Brown 2002; Brown 2000; Brown 1999; Brown, 1998). It is often the case, especially in new and renovated buildings, that these indoor pollutant sources, where present, are the dominant factor affecting total indoor air pollutant levels.

Opportunities

There are three ways to limit the level of pollutants and particles inside an office building:

1) limit the pollutant sources;
2) filter the air, and
3) increase the ventilation rate.

High efficiency filtering of the air, has been shown to perform well (Fisk et al. 2002) but only for specific particulate pollutants. Increasing the ventilation rate will dilute the pollutant levels and possibly accelerate the decay of emissions, but often not to sufficient levels for occupant health and well-being. Also, the trade-off is increased energy usage and possibly reduced comfort levels. So currently, the most effective way to limit the pollutants is in limiting the indoor sources (Brown 2003).

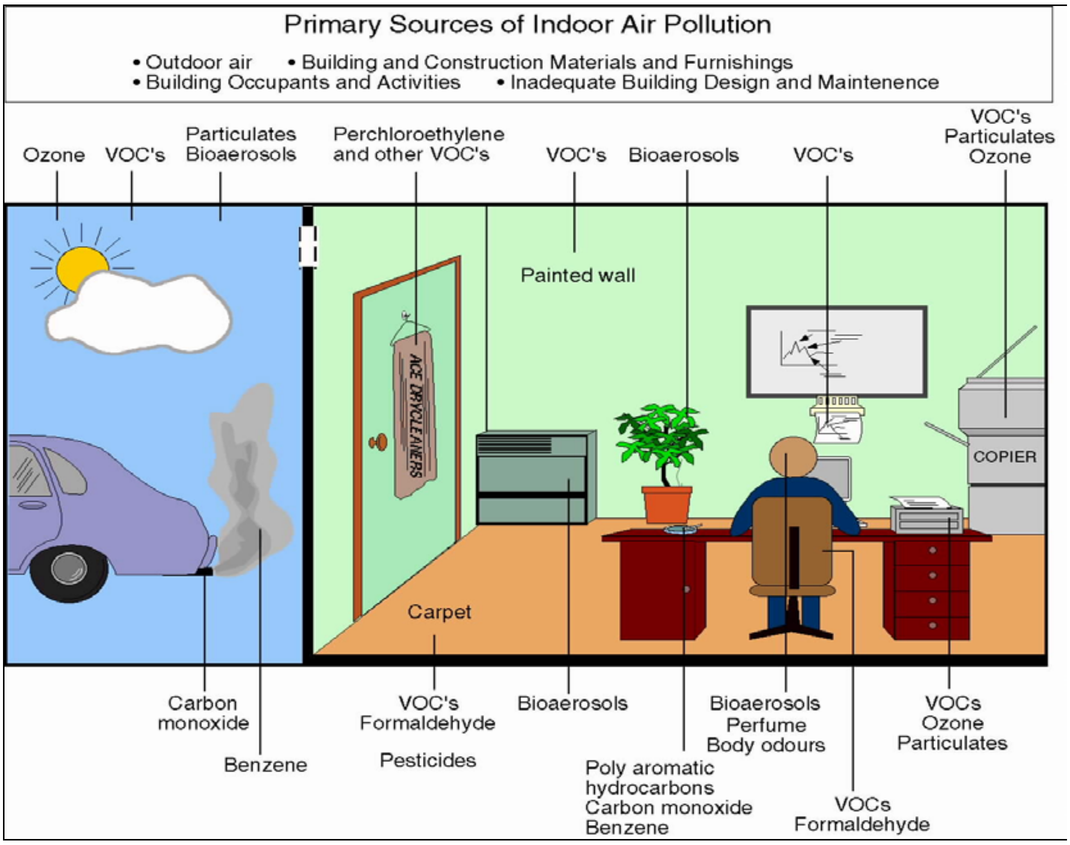
If there were cheap sensors available that could detect the levels of different indoor (and outdoor) pollutants, then there would be an opportunity to introduce these into the control loops for the HVAC system, so that 'targeted' ventilation strategies could be applied. However the number of different pollutants (refer Table 2), and the complexity of the chemistry involved in sensing them (readings often required at very low levels) makes the development of these sensors a real challenge, and possibly unrealistic. The implication is that there are limited opportunities for a sensor-based strategy for reducing indoor pollutant levels in a smart building, and these will be a high-risk approach compared to source control (except in the case of clearly identified, high-impact chemicals or biological agents such as Legionella).

Table 2. Pollutants Measured In Australian Buildings

Pollutant	Indoor concentration range	Major sources	Control
Asbestos fibres	<0.002 f/ml	Friable products	Risk management, removal
Radon	Conventional dwellings: 99.9% <200 Bq/m^3 Earth constructed buildings: ~91% <200 Bq/m^3	Soil under building Earth walls	Siting of building Material selection
Environmental tobacco smoke (ETS)	High in recreational buildings	Cigarette smoke	Prohibition, designated smoking area
Respirable suspended particles	Poorly characterised	ETS, cooking, fuel combustion	Poorly characterised
Legionella spp.	30% of population exposed	Water cooling towers	Maintenance, siting
House dust mites	Coastal areas 10 40 µg/g per pl	Bedding, carpet, furniture	Removal of habitat (humidity control)
Microbial	100s to 18 000 CFU/m^3	Moist/damp surfaces	Control moisture/mould
Formaldehyde	Conventional buildings <100 ppb (1- 3 days average) Mobile buildings 100 1000 ppb	Pressed-wood products	Source emission control, ventilation
Volatile organic compounds	Poorly characterised	'Wet' synthetic materials	Source emission control, ventilation
Pesticides	Limited data, median <5 $\mu g/m^3$	Major sources unknown	Floor structure, inspection, clean-up
Nitrogen dioxide	Up to 1000 ppb	Unflued gas heaters	Source emission control, flued systems ventilation
Carbon monoxide	~10% >9 ppm	Unflued gas heaters	Source emission control, flued systems ventilation
Carbon dioxide	Poorly characterised	Exhaled air	Outdoor air ventilation
Ozone	Poorly characterised	Poorly characterised	Source emission control, ventilation

Source: Brown, 1997

Figure 9. Potential sources of indoor pollution in office buildings



Source: Brown, 2000

7.5 Lighting

Overview

The quality of indoor environment depends significantly on various aspects of the lighting. Factors include illuminance, glare, spectrum of the light and the amount of daylight. The quality is also dependent on the type, location and number of lights and the optical characteristics of the indoor surfaces. Wilkins at al. (1988) showed that there may be a link between the 'flickering' of the lighting and the incidence of headache and eyestrain. Many studies have shown that improved lighting can increase worker satisfaction and performance (Vietch and Newsham 1997; Katzev 1992; Leslie 2003). This is particularly relevant in environments where visually intensive tasks are undertaken (such as mail sorting or electronics fabrication).

Apart from the influence on productivity, the lighting can also dramatically affect mood and perceptions about a space. The method of 'lighting control' can also influence the perceived and actual quality of the lighting (i.e. automatic dimming of natural and artificial light sources, manual control of task lighting). There is evidence that building occupant health and productivity is increased by the use of daylighting whenever possible (Leslie 2003). An overview of daylighting systems is given in Kischkoweit-Lopin (2002).

Because the extremes of lighting quality can have such an obvious impact on performance (i.e. dullness at one end and glare at the other end), lighting levels in office buildings are usually maintained uniformly across the office space within specified limits, however these limits depend on the type of activity, and the age of the occupants (older people generally require brighter lighting).

Opportunities

Lighting accounts for around 25% of the total energy used in operations of a commercial building, and around 20% of the greenhouse gas production. (Australian Greenhouse Office, 1999) and therefore represents a significant opportunity for cost reduction, and improved environmental performance. The advent of IP-based BMS backbones, cheaper photo-sensors, IP addressable light battens, and continuously dimmable energy efficient lights, means that there is ample opportunity for reduced energy usage, based on strategies such as occupancy control, daylight harvesting combined with high granularity illuminance measurement (Leslie 2003). Cheap photo-sensors will enable measurements to be taken at sufficiently high granularity to maximise the use of daylight, whilst still maintaining an even Illumination throughout an office space. Previous systems have been unsatisfactory, because they have been based on switching lights on and off, which is annoying to the occupants, or have not had sufficient measurement density to deliver even lighting levels to all parts of the floor-space.

7.6 Information and Communications Systems

Overview

The technologies outlined in Section 6.5, can be applied in office building environments with a number of key benefits. These are summarised below.

- Wireless technologies offer the opportunity of an increased tenancy footprint as part of the traditional net occupancy cost per square metre equation. They also offer an alternative to expensive vertical and horizontal cabling options in the “last mile” of existing buildings.
- Wireless technologies and IP based devices create a more flexible and scaleable workspace by delivering a “plug and play” environment for the tenant.
- Roof top communications help ensure a competitive low cost telecommunications infrastructure and provide diversity of alternatives for tenant systems. This reduces “single point of failure” risk for the tenant systems.
- Base building infrastructure that is utilised by multiple providers can be leveraged off to install workforce and building performance measure systems at a lower cost. It also drives a more open source and integrated approach to the management of all “smarts” within the building.
- Utility providers are providing bundled energy and data services. This trend uses existing spatial infrastructure to provide multiple services that can be leveraged off to install workforce and building performance measurement systems at a lower cost. It can also be utilised to deliver real-time performance information.
- New video and voice technologies, and web-based control systems are being installed and utilised within tenancies. These ‘change points’ can be utilised to install enhanced building performance measurement systems at a lower cost.

Opportunities

IP-based base building infrastructure could be enhanced so that it could provide an opportunity to monitor building environment and workplace productivity by using existing spatial, cabled and wireless building networks -- if integrated with other building systems during design. Opportunities exist to expand and enhance IP-based standards for all building control platforms and within the overall building design.

The stakeholders outlined in Section 5.7 currently have ‘information overload’ -- of the wrong kind of information. Many of the parameters used to measure building energy performance and IEQ cannot be effectively used or accessed by the different stakeholders because they are measured by different systems in a fragmented fashion. There is an opportunity to utilise better ICT for integration of the data-flow form the different systems. Integrated “Management Information Systems” can be developed that deliver the right type of information, to the right stakeholder, at the right time.

7.7 Energy Management and Reporting

Overview

The consumption of energy in office buildings is well understood on 'global' scales. The proportion of energy consumed by HVAC plant, lifts and escalators, hot water systems and other major plant items compared to the 'general consumption' of energy through lighting and power use by the occupants has been studied and documented for many building types on many occasions.

The consumption of energy on a more 'local' scale, however, is generally treated arbitrarily on a per square meter basis by building type/application, generally through the breaking down of the known consumption rates of the larger consumers by the measurement of the larger consumer electrical mains. Whilst this strategy is quite appropriate in terms of performance comparisons, it does not really attempt to address nor identify what the make up of the smaller components really is, nor to control, measure or limit the energy usage at the local level. Apart from the initial intelligent selection of low energy consuming equipment and lighting technologies, the 'bottom end' or local scale consumption, is not generally pursued in energy conservation processes because it is not seen as a worthwhile cost saving exercise when compared to the cost and labour of data collection.

Similarly with HVAC systems, the energy required to air condition (cool-heat) buildings on a large scale is well understood. The square meter approach then follows. What is not well understood is the real breakdown of this energy across the spaces, on a real time basis. Nor does this approach address the issue of whether various spaces are actually occupied, with virtually all HVAC systems operating on the principle that 'the space is probably occupied so air condition it'.

Opportunities

As has been outlined previously (see Section 5.8), one of the major barriers to the implementation of energy reducing and green technologies into office buildings is that there is no market incentive to optimise the life-cycle costs of these systems, because of a flawed 'model' for procurement and delivery of building services to tenants. However an exciting new model is emerging (Australian Financial Review, 2002) where the supply of building services is outsourced to a third party who owns and pays for the building plant and other service technology, and then sells the services back to the tenants at market rates. For such a model to work, it is essential that energy use can be monitored on a local scale, in such a manner that it can be charged to individual tenants on a user-pays basis.

This could be done by using cheap sensor technology, which is capable of measuring multiple building performance parameters, at a much higher granularity than has ever been thought practical before. A sensor that could measure not only temperature but also humidity, air flow and lighting levels would provide a much greater insight regarding energy consumption in the HVAC and lighting systems on the local scale. This information could then be normalised to the already measured global energy use to ensure that it is defensible. An additional set of simple sensors applied to the individual power outlets could provide 'per point' energy use data for appliances, to complete the picture.

The high-granularity data gathered from such a system is crucial in the implementation of any user-pays model for provision of building services, but it is also valuable in many other ways. It provides a complete breakdown of energy use in the building by 'type' of energy, and exactly where it is used – potentially tracked down to the individual level. Studies could be performed on the effect of individual reporting of energy usage on occupant behaviour. It could be hypothesised that such 'energy accountability' could dramatically reduce consumption alone. The data could also be harvested to look for potential energy-saving strategies, and can be used for individual tenants for triple bottom line reporting, and assessment of their own energy initiatives.

8. CURRENT SMART BUILDING RESEARCH

8.1 Intelligent Workplace at Carnegie Mellon University

The 'Intelligent Workplace' at the Department of Architecture, Carnegie Mellon University opened in December 1997. The mission of the intelligent workplace project is to research and demonstrate advanced building systems and their integration for total building performance. Some photographs of the building are shown in Figure 10.

The project demonstrates the economic feasibility to:

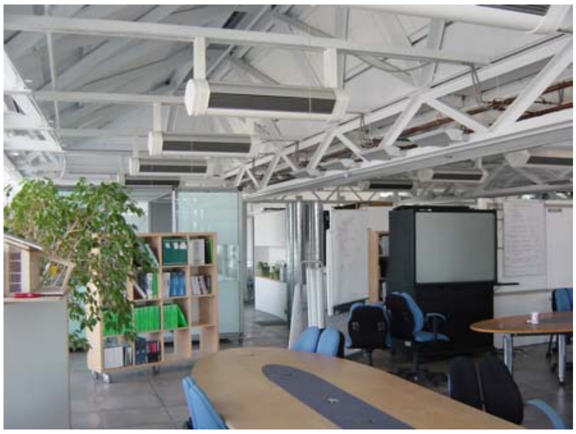
- Improve user satisfaction
- Provide unprecedented levels of organizational flexibility
- Provide unprecedented levels of technological adaptability
- Maximise energy and environmental effectiveness.

It demonstrates the economic feasibility of a four-fold improvement of quality of life (as measured through occupants' satisfaction) and a three- to four-fold reduction in energy consumption and environmental impact. It also demonstrates the potential of reducing greenhouse gas emissions during the life of the project by a factor of three to four while simultaneously improving the quality of life. Although it is not a commercially viable building as a 'one-off', a summary of the building features (sourced from the project website: www.arc.cmu.edu/cbpd/html/iw/iw.html) are outlined here because it is probably the most advanced and all-encompassing 'smart building' which has been built to date. Details of the development of the project are given in Hartkopf et al. (1997). It serves as the most comprehensive demonstration of the advanced concepts and technologies which will underpin the smart office building of the future.

Many of the features are related to the architectural design (i.e. design of structure and enclosure), whilst others are more related to the building system technologies (i.e. HVAC and lighting). However it is the integration of the architecture, engineering, design and technology that makes this building uniquely smart. Some of the features are summarized in Table 3.

Figure 10. Intelligent Workplace at Carnegie Mellon University.

Building Interior



Building Exterior

Building Facade

Control Stack

Table3. Summary of features - Intelligent Workplace at Carnegie Mellon University

Structure	
Provide Spatial Adaptability with Individual Access to the Natural Environment	• Increased periphery • Column- free interiors • Reconfigurable, modular components
Optimise Design/ Engineering to Reduce Material Use	• Use of recycled materials • Low- waste manufacturing • Open web deep trusses for system integration and reduced material • Prefabrication and increased modularity to reduce waste • Design for assembly/ disassembly for re- use and/ or recycling
Maximise Speed of Constructability, No- waste Construction Processes	• Truss and column prefabrication, modularity, bolted not welded • Table structure for ease of erection • Four- day assembly without on- site waste • Floor assembly process
Design/ Engineer Interfaces with Enclosure, Infrastructure & Interior Systems	• Open web trusses for large mechanical ducts, open pathways, full access • Secondary floor structure for telecommunications, open pathways, full access • Structural frame supports uplighting, power distribution and distributed sensors • Structural frame coordinated with enclosure, interior and infrastructure systems • Internalised structure, wrapped by enclosure to eliminate thermal bridging, • Minimise dimensional change and increase longevity
Enclosure	
Maximise Natural Conditioning & Maximise Individual Access to the Natural Environment	• Access to daylight • Access to natural ventilation
Minimise Environmental Load with a Layered Facade	• Highly Insulated Enclosure • Dynamic shading / Light redirection • Load balancing
Design/ Engineer Interfaces with Mechanical System	• Operable windows and constant volume mechanical ventilation • Operable windows and desiccant or radiant cooling • Photovoltaic DC power generation
Maximise Integrity and Material Sustainability	• Prefabrication with in- factory recycling • Prefabrication without on- site waste • Reconfigurable, modular facade • Environmentally responsible materials • Off- site outgassing
HVAC System	
Maximise Use of Natural Conditioning and Thermally Neutralise the Enclosure	• Natural cooling with stack assist/ roof top ventilators • Natural ventilation with stack assist/ roof top ventilators • Dynamic shading, insulation, load balancing
Split Thermal and Ventilation Systems	• Modular water- based cooling, radiant facades, radiant ceilings & displacement ventilation • Workstation mixing boxes, Desiccant cooling (including heat recovery for 100% outside air)
Micro- zoned system with User- based Controls: Split Ambient and Task Conditioning	• Radiant facade temperature controls • Coolwave on/ off controls • PEM air speed, direction and temperature control • PEM local air filtration

	• Intelligent control system - maximise user control and minimise energy use
Design/ Engineer Interfaces with Enclosure, Structure & Interior Systems	• Relocatable, modular, floor- based HVAC integrated with structure • Water- flow mullion facade using waste heat • Relocatable diffusers (location and density) for interior reconfigurability • Sprinkler system as coolwave/ fan- coil loop • Photovoltaic facade for DC power to distributed fans & heat pumps
Advance Resource Effective Technologies and Assemblies	• High efficiency generation, distribution and terminal units
Interior Systems	
Provide Spatially Flexible Environment	• Complete reconfigurability with full infrastructure support • Modular, stackable, storage wall systems • Floor based, modular work surfaces • Ergonomic chairs and furniture • Acoustic control for diverse office configurations
Provide Individually Conditioned Environment	• Flexible Grid, Flexible Density, Flexible Closure HVAC • Relocatable air diffusers (location and density) for interior reconfigurability • Modular cooling for changing densities and functions • Access to windows with load balancing at the facade
Provide Individually Connected Environment	• Flexible Grid, Flexible Density, Flexible Closure data, power, voice, video • Raised- floor based connectivity for furniture reconfigurability
Provide Social Environment	• Daily and seasonally dynamic components for Teaming • Pubs with shared technologies and amenities for Teaming • Outside space for Teaming
Provide Healthy Environment	• Individual control of air, light, temperature, ergonomics • Access to the natural environment • Environmentally responsible, maintainable materials • Off- site outgassing, source/ sink control
Ensure Low Energy/ Low Resource Environment	• Modular components, reconfigurable with minimum obsolescence
Lighting	
Maximise use of Daylighting	• Building massing and orientation for access to daylight • Light redirection louvers - the daylight ‘fixture’ • Diffusing shades for glare control • Distributed sensors & controls for electric lighting interface
Split Task and Ambient Lighting	• Ambient uplighting with individually dimmable ballasts, • high efficiency reflectors, lamps and ballasts • High efficiency, relocatable task lights with daylight spectrum lamps • and occupancy sensors
Maximise User Controls	• Individual ballast/ controllers for each fixture, continuous dimming • Daylight sensors • Occupancy sensors • Intelligent control system to maximise user control and minimise energy use

Controls	
Provide User Control of all Environmental Infrastructures	• Air quantity and quality • Air direction • Air temperature • Radiant temperature • Ambient light level • Task light level and location • Light redirection, diffusion and shading • Operable windows
Provide User Control of all Technical Infrastructures	• Density of data, power, voice, video outlets • Location of outlets
Provide Central Intelligence for Environmental and Technological Resource Management	• Energy conservation • Thermal comfort measurements • Air quality measurements • Visual quality measurements • Power quality measurements • User control feedback to central systems • Central system feed- forward to users (e. g. power shaving) • Expert system learning for distributed control strategies • Remote diagnostics and maintenance of sensor/ controls • Data mining and organizational feedback • Machine learning for environmental management

8.2 Other Research

The following provides a brief summary of some selected major research projects, which are developing technologies for smart buildings.

Lawrence Berkeley National Laboratory Indoor Environment Department

Lawrence Berkeley National Laboratory Indoor Environment Department conducts a range of research projects related to the health, comfort and energy efficiency of the indoor environment. The projects focus on reducing the energy used for thermally conditioning and distributing ventilation air in buildings, improving indoor air quality, thermal comfort and the health and productivity of building occupants, and understanding human exposures to environmental pollutants found in indoor and outdoor air.

UC Berkeley - Center for the Built Environment

Conduct a range of relevant research including:

- Wireless measurement and control of the indoor environment in buildings -- This project will investigate the potential for applying MEMS sensor technology and wireless communication technology to the control of buildings.

- Using occupant feedback to improve building operations -- This project aims to develop internet-based software allowing occupants to provide feedback to the building control system about building operation, and to develop strategies for acting on this feedback to reduce operating costs and improve occupant satisfaction.

- The impact of team space design on collaboration -- The objective of this project is to study the impact of team workplace design on worker satisfaction and group collaboration.

- Operable windows & thermal comfort -- The aim of this project is to determine how the use of operable windows in office settings affects workers' thermal comfort and their acceptance of variable thermal environments.

- The impact of ventilation on work performance -- The objective is to evaluate the impact of ventilation on worker productivity, energy use, and indoor air quality.

Massachusetts Institute of Technology - Media Lab

- Changing Places Projects (MIT Media Lab) – Portable tools for studying the workplace: this project studies existing workplace practices using sensors for device use logging, identity recognition, position recognition, activity recognition and image processing.

- The MIT Oxygen 'Intelligent Room' is a blue sky research project which is working towards integrating technologies with peoples workplaces through 'human centred pervasive computing', For example, a smart room equipped with embedded speech, video, and motion detectors automatically records and recalls key meeting events, monitoring and responding to visual and auditory cues that flow naturally from normal interactions among group members.

- Look for changes in way people conduct their work activities for early intervention of worker health.

- Smart Energy Technology – Data mining energy usage throughout a building UC Berkeley, CITRIS smart energy.

- Programmable building – every light switch, power outlet, doorknob and thermostat is an internet controllable on the internet - MIT Media Lab.

9. SUMMARY OF NEEDS AND OPPORTUNITIES

9.1 Technologies

Section 6 of this report outlined some emerging technologies, including:

- MEMS Sensors
- Fibre Optic Sensors
- Wireless Sensor Networks
- New Materials Technologies
- ICT
- Robotics
- Biometrics
- Integrated Systems

For the purposes of developing a prototype smart building, of the technologies listed above, MEMS sensors, wireless sensor networks and 'integrated systems' technologies (in bold in the list above) show the most promise at present. This is mainly because these technologies are more advanced in their development than the others, are more generic in their application to office buildings (i.e. they can be applied to a range of different application areas), and are rapidly reducing in cost due to developments in the silicon wafer and electronic chip industry. This is discussed in more detail in the following.

As far as application of sensors is concerned, MEMS sensors are currently more viable than fibre-optic sensors. This is because the processing of optical signals is still very expensive (at this time) and specialised, and the only fibre-optic sensors which are readily available are those that measure strain. Fibre-optic sensors that measure other parameters of interest in an office building environment are largely still under development. MEMS-based sensors are more mature in their development, are more widely understood, and more easily integrated into existing control systems because they are based on electronics rather than optics. They are manufactured using similar techniques to integrated circuits for electronics, and can therefore be made relatively cheaply, with much of the infrastructure needed for mass production already in place.

Wireless sensor networks are also quite mature in their development, with many systems (such as UC Berkeley Motes) already commercially available. The price per unit is presently quite high – but mass production will bring this down dramatically. The applications for these devices are also generic, as they can transmit signals from any kind of sensor or actuator in a building.

Integrated system technologies are dependent on the existence of a standard, open protocol of communication. Internet Protocol based BMS hardware is currently available (BACnet – see Section 4.5), and although more expensive than traditional systems, are essential in bringing together smart building technologies to work together.

New materials technologies that were outlined range in their maturity of development in terms of application to an office building. The materials which could be utilised as ‘active’ building surfaces however are still mainly in the realm of research, or aerospace and military application due to the expense

ICT continues to evolve and become more closely linked with the day to day functioning of a wide range of businesses. However, many of the new technologies (e.g. 3G mobile networks, ‘bluetooth’) ultimately depend on the global market for these products to determine their uptake and success. Development and uptake by building users of such technologies is more likely to be driven by other possible end-user applications (i.e. entertainment) – and will be independent of any aspect of the buildings which they are used as part of. The key opportunities for the use of ICT in the smart and healthy building stem from integration of existing, widely used networks and protocols (such as IP) with other building system networks, and also in the development of Web-based building information management systems for the different stakeholders, delivered in real-time.

Robotics is a mature and viable technology, but is not really generic enough to be utilised in a smart building prototype. Robotics could be used where there is a specific application (i.e. vacuuming or photocopying robots), but these require specialist development, independent of the ‘smart building’ itself.

Similarly, biometrics is most applicable to environments which require high security, and is best implemented on an ‘as-needed’ basis for different types of organisations. The use of these technologies needs to be weighed against the needs of the individual organisations which occupy the buildings, considering the ramifications of security breaches, and the costs of more traditional (and less convenient) security systems. Although there may be some non-security, and more generic applications in automatic occupancy sensing, the added convenience of using biometric technologies (instead of cheaper simpler technologies) for this purpose cannot be justified at present.

9.2 Application Areas

Section 6 of this report outlined some promising application areas for technology use in office buildings, including:

- Thermal Comfort
- Air Balancing for HVAC systems
- **New Generation Sensors for HVAC system control**
- Air Quality – Indoor Pollutants
- **Lighting**
- Information and Communications Systems
- **Energy Management and Reporting**

The application areas in which the most viable new technologies (see previous section) could have the maximum impact, in terms of occupant health and productivity, and reduced energy usage, are those related to *improved HVAC systems, smarter lighting*, and *improved energy management and reporting* (in bold in the list above). All of these application areas could benefit from the use of cheap MEMS-based sensors, wireless networking of these sensors, and an integrated, flexible and adaptable backbone for communication between sensors, actuators and occupants.

It was identified in Section 7.1 that significant improvements in the HVAC system performance and efficiency could be possible if it was cheap enough to measure more IEQ parameters (air flow, temperature, humidity and light levels) at a high granularity throughout the building. Another significant potential improvement to HVAC systems was identified as 'air balancing' (Section 7.2). The deployment of many cheap airflow sensors in the ductwork will enable the HVAC system to be continuously balanced, allowing the desired amount of air to be accurately delivered to specific locations throughout the building. This will also allow the system to be adapted 'on the fly' to a changed layout of the building, whilst still achieving the desired flow characteristics at each location.

Another benefit of using a large number of sensors in the HVAC system control, is that the same data can be used for more sophisticated energy usage monitoring and reporting. For the first time, HVAC energy could be apportioned to individual zones or user groups in the building. This is a very important benefit, as it would allow for a user-pays 'model' for the procurement and delivery of HVAC services to building occupants (see Section 5.8 and following section for more detail).

The other application area identified with significant potential to benefit from cheap sensors and integrated systems technologies is lighting (see Section 7.5). If the same sensors that are used for the HVAC system are used to measure illuminance at a high granularity, then the use of daylighting can be maximised, whilst maintaining an even illumination throughout the building. This will result in significant energy savings, since lighting accounts for around 25% of operational energy usage in a building, and can also reduce any unnecessary heating loads for the HVAC system to deal with.

10. RECOMMENDATION FOR PROTOTYPE

The key finding from this scoping exercise is that there is significant potential to use sensor technology to improve HVAC and lighting systems - to optimise IEQ and energy usage in office environments. Unfortunately, there is no incentive for the building owners and developers to implement such improved systems because of the outdated ‘model’ for procurement, management and delivery of building services to the tenants. However there *is* an incentive for the building owners (and all the other stakeholders), to implement technologies which can facilitate a ‘user-pays’ model for the provision of the building services. So for any new system to be successful, its features should be coupled with the capability to distribute costs to individual ‘zones’ within a multi-tenanted building. This is quite possible, since high-granularity energy management and optimisation of IEQ can complement each other nicely.

It is therefore recommended that a system be developed which can measure and break down the energy usage in an office building according to the different users (i.e. user groups or even individual users) and by ‘type’ of energy. The system will be able to distinguish how much energy is being used in a particular zone in the building by the HVAC system, the lighting system, and by other office appliances (individually). This type of system will provide detailed energy usage data, pinpointing exactly when, where, why and by whom each ‘type’ of energy is being used. This valuable information can then be used to determine savings strategies or to influence the behaviour of the energy users via detailed reporting capabilities. Most importantly however, this type of system will pave the way for the introduction of a user-pays model for building services to be implemented. This type of supply model could be the key incentive in the development of smart and eco-friendly office buildings. If such a model takes hold in the industry, the system proposed herein will be crucial in its successful implementation, and will have a huge market potential because it can be potentially applied to both new and existing buildings.

This proposed system will require much higher density and more tightly integrated measurement and control than has been the practice in office buildings in the past. This will therefore provide for new opportunities to improve the performance of the HVAC and lighting systems, which will enhance the IEQ, whilst reducing the energy requirements. It will also provide valuable data for the calibration and validation of energy modelling tools and techniques, more detailed studies of human comfort and productivity, and improved triple-bottom-line reporting capabilities

Because the different building systems will need to be integrated, the addition of new technologies, or additional sensors and actuators will also be relatively simple. It is therefore also recommended that investigations are undertaken into the development or adaptation of a cheap occupancy sensing system, and that this be integrated into the control of the HVAC, lighting and energy reporting systems.

It is recommended that the prototype development be conducted in three phases:

1) Detailed system design

2) Bench or laboratory trials

3) Field trial - implementation into a single level of an office building.

A detailed proposal and costing for the prototype system is given in Appendix B.

11. PROTOTYPE FEATURES AND SPECIFICATION

11.1 System Description and Features

The basic infrastructure behind the proposed system, is an IP-based backbone, capable of reading and controlling all sensors and actuators (both hard-wired and wireless). A micro-zoned HVAC system, with its own air handling unit, and IP addressable MEMS multi-sensors and actuators will be used to control the thermal comfort. The lighting system will be based on continuously dimmable, IP addressable light battens, and will also use data from the MEMS multi-sensor. Occupancy sensing will be developed, based on existing wireless technologies such as 'bluetooth' or similar. The MEMS-based 'multi-sensors' will be distributed throughout the building to measure temperature, humidity, air flow, and lighting levels at many locations. Separate (wireless) power usage sensors will also be applied to each power outlet to measure energy usage by appliances.

Data from the sensors will be used to control the lighting and HVAC systems, to deliver optimum IEQ to each micro-zone and to capture the energy usage. Control algorithms to optimise comfort and energy usage will be developed based on information harvested from the measured data. The readings from the sensors will be categorised according to their location, and from this, the energy usage for each zone, and for each system will be calculated. For lighting and power systems this will be quite simple, but for the HVAC system it will be more involved. The HVAC energy used in each zone will be calculated by using the temperature, humidity and air-flow data to calculate the 'relative' amount of energy being utilised to condition each micro-zone. This will then be used to distribute the 'global' HVAC energy usage (measured by existing conventional metering technology) to each micro-zone. Global lighting and power usage from conventional meters can also be used to cross-check totals of the micro-zone measurements.

A summary of system features is given below:

- Energy usage tracked down to micro-zone level and broken down into energy 'type' (i.e. HVAC, lighting or appliances)
- Web-Based energy usage reporting system with profiles for different stakeholders
- Occupancy based control of micro-zoned HVAC
- Improved air balancing and air handling efficiency
- Daylight harvesting and occupancy-controlled light dimming
- Easily Re-configurable HVAC and lighting to suit different floor layouts

11.2 Hardware requirements

The prototype system will be initially put together in a laboratory, and then field-trialled in a single level of an office building, with its own with own air-handling unit, and a mix of different spaces including shared areas and separate offices.

The basic hardware required for the system is:

- Micro-zoned HVAC system
- IP-based controllers for all sensors and actuators
- MEMS multi-sensors for temperature, light-level, humidity, airflow
- Sensors for appliance power consumption
- IP addressable, continuously dimmable lighting battens
- Wireless platform for sensors (note that not all sensors need to be wireless)
- Occupancy sensors (to be investigated - probably based on 'bluetooth' enabled or similar occupant ID Tags with readers throughout the building)

A more detailed proposal and costing for the prototype system is given in the Appendix of this report.

12. REFERENCES

Akyildiz, I. F., Su, W., Sankarasubramaniam, Y. and Cayirci. (2002), Wireless Sensor Networks: A Survey, *Computer Networks,* 38, 393-422.

Arkin, H. and Paciuk, M. (1997), Evaluating Intelligent Buildings According to Level of Service Systems Integration, *Automation in Construction,* 6, 471-479.

Atif, M. R. and Galasiu, A. D. (2003), Energy Performance of Daylight-linked Automatic Lighting Control Systems in Large Atrium Spaces: Report on Two Filed Monitored Case Studies, *Energy and Buildings,* 35, 441-461.

Australian Building Codes Board and Australian Greenhouse Office (2001), Energy Efficiency in Buildings: Directions Report, (also available on web at www.abcb.gov.au).

Australian Financial Review (2002), article by Tina Perinotto, 29 August, P61.

Australian Greenhouse Office (1999), Australian Commercial Building Sector Greenhouse Gas Emissions: 1990-2010, Australian Greenhouse Office, Canberra.

Bodart, M. and De Herde, A. (2002), Global energy savings in office buildings by the use of daylighting, *Energy and Buildings,* 34, 421-429.

Brager, G. S. and de Dear, R. J. (1998), Thermal Adaptation in the Built Environment: A Literature Review, *Energy and Buildings,* 27, 83-96.

Brown, S.K., Mahoney, K.J. and Cheng, M. (2002), Room Chamber Assessment of Pollutant Emission Properties of Low-emission Unflued Gas Heaters, Proc. of 9th *Int. Conf. on Indoor Air Quality and Climate,* Monterey, June 30–July 5.

Brown, S.K. (2002), Volatile Organic Pollutant Concentrations in New and Established Buildings From Melbourne, Australia, *Indoor Air,* 12, 55-63.

Brown, S.K. (2000), Volatile Organic Pollutant Emissions From Building Materials. Impacts on Indoor Air Quality, PhD Thesis, RMIT University, Melbourne.

Brown, S.K. (1997), Indoor Air Quality – Australia: State of the Environment Technical Paper Series (Atmosphere), Department of Environment, Sports and Territories, Canberra.

Brown, S.K. (1998), VOC Emissions From Interior Coatings - Measurements and Mechanisms. *RACI Symposium on Advances in Polymers V 'Coatings'*, CSIRO Molecular Science, Clayton, Oct 2.

Brown, S.K. (1999a), Assessment of Pollutant Emissions From Dry-process Photocopiers, *Indoor Air,* 9, 259-267.

Brown, S.K. (1999b), Chamber Assessment of Formaldehyde and VOC Emissions From Wood-based Panels, *Indoor Air*, 9, 209-215.

Brown, S.K. (2003), Indoor Air Pollution – Lowering Emissions of Chemicals Released From Final Products. Proc. of *HazMat2003 Hazardous Materials Conf. 2003*, Fire Protection Association Australia, Sydney, April 29-30.

Brundage, J., Scott, R., Lednar, W., Smith, D. & Miller, R. (1988), Building Associated Risk of Febrile Acute Respiratory Diseases in Army Trainees, *JAMA*, 259, 2108-2112.

Bushby, S. T. (1997), BACnet: A Standard Communications Infrastructure for Intelligent Buildings, *Automation in Construction*, 6, 529-540.

CBE. (1999), Office Tenant Needs Study, Center for the Built Environment, University of California, Berkeley.

CRC for Microtechnology (2002), Annual Report 2002, Cooperative Research Centre for Microtechnology, Hawthorn, VIC, Australia.

Evans, P.S.A., Harrey, P.M., Ramsey, B.J., & Harrison, D.J. (2001) Circuit World:(Journal of the Institute of Circuit Technology), *"Lithographic Film Circuit- A Review".* 27(3): 31-34.

Federspiel, C. C. (1998), Statistical Analysis of Unsolicited Thermal Sensation Complaints in Commercial Buildings, *ASHRAE Transactions,* 104(1):912-923.

Feeney, A., North, F., Head, J., Canner, R., and Marmot, M. (1998), Socioeconomic and Sex Differentials in Reason for Sickness Absence from the Whitehall II Study, *Occ Environ Med,* 55, 91-98.

Fisk, W. J. (2000), Health and Productivity Gains From Better Indoor Environments and Their Relationship With Building Energy Efficiency, *Annual Review Energy Environment*, 25, 537-66.

Fisk, W. J. and Rosenfeld, A. H. (1997), Estimates of Improved Productivity and Health From Better Indoor Environments, *Indoor Air*, 7(3), 158-172.

Fisk, W. J., Faulkner, D., Palonen, J. and Seppanen, O. (2002), Performance and Costs of Particle Air Filtration Technologies, *Indoor Air*, 12, 223-234.

Gassman, O., Meixner, H. Hesse, J., Gardner, J. W. and Gopel, W. (2001), Sensors in Intelligent Buildings, Series: *Sensors Applications*, Volume 2, Wiley.

Gratia, E. and De Herde, A. (2003), Design of Low Energy Office Buildings, *Energy and Buildings,* 35, 473-491.

Hartkopf, V., Loftness, V., Mahdavi, A., Lee, S. and Shankavaram, J. (1997), An Integrated Approach to Design and Engineering of Intelligent Buildings–The Intelligent Workplace at Carnegie Mellon University, *Automation in Construction,* 6, 401-415.

Hoge, C., Reichler, M., Dominguez, E., Bremer, J., Mastro, T. (1994), An Epidemic of Pneumococcal Disease in an Overcrowded, Inadequately Ventilated Jail, *New England Journal of Medicine,* 331, 643-648.

Katzev, R. (1992), The Impact of Energy-efficient Office Lighting Strategies on Employee Satisfaction and Productivity, *Environment and Behaviour,* 24(6), 759-77.

Kischkoweit-Lopin, M. (2002), An Overview of Daylighting Systems, *Solar Energy*, 73(2), 77-82.

Kolkosta, D., Tsiavos, D., Stavrakakis, G.S., Kalaitzakis, K. and Antonidakis, E. (2001), Advanced Fuzzy Logic Controllers Design and Evaluation for Buildings' Occupants Thermal-Visual Comfort and Indoor Air Quality Satisfaction, *Energy and Buildings,* 33, 531-543.

Koomey, J., Webber, C., Atkinson, C. and Nicholls, A. (2001), Addressing Energy-related Challenges for the US Buildings Sector: Results From the Clean Energy Futures Study, *Energy Policy,* 29, 1209-1221.

Kroner, W. M. (1997), An Intelligent and Responsive Architecture, *Automation in Construction,* 6,381-393.

Lahtinen, M., Huuhtanen, P., Kahkonen, E. and Reijula, K. (2002), Psychosocial Dimensions of Solving Indoor Air Problems, *Indoor Air*, 12, 33-46.

Leclair, J., Zaia, J., Levin, M., Congdon, R. and Goldmann, D. (1980), Airborne Transmission of Chickenpox in a Hospital, *New England Journal of Medicine,* 302, 450-453.

Leslie, R. P. (2003), Capturing the Daylight Dividend in Buildings: Why and How?, *Building and Environment*, 38, 381-385.

Li, D. H. W. and Lam, J. C. (2001), Evaluation of Lighting Performance in Office Buildings with Daylighting Controls, *Energy and Buildings,* 33, 793-803.

Loe, E. (1996), Proving the Benefits – Justifying the Costs of Intelligent Systems, Facilities, 14, (1/2), (source: Internet database).

Loftness, V., Brahme, R., Mondazzi, M., Vineyard, E. and MacDonald, M. (2002), Energy Savings Potential of Flexible and Adaptive HVAC Distribution Systems for Office Buildings, Air Conditioning and Refrigeration Technology Institute.

Matthews, E. H., Botha, C. P., Arndt, D. C. and Malan, A. (2001), HVAC Control Strategies to Enhance Comfort and Minimise Energy Usage, *Energy and Buildings,* 33, 853-863.

Milton, D., Glencross, P. and Walters, M. (2000), Risk of Sick Leave Associated With Outdoor Air Supply Rate, Humidification and Occupant Complaints, *Indoor Air,* 10, 212-221.

MIT. (2002). Technology Review Magazine, Massachusetts Institute of Technology, Cambridge, MA, July/August, 74-78.

Myatt, T., Staudenmayer, J., Adams, K., Walters, M., Rudnick, S. and Milton, D. (2002), A Study of Indoor Carbon Dioxide Levels and Sick Leave Among Office Workers, *Environ Health Glob Access Sci Source,* 1(1), P3.

Mysen, M., Rydock, J.P. and Tjelflaat, P.O. (2003), Demand Controlled Ventilation for Office Cubicles – Can it be Profitable?, *Energy and Buildings,* 35, 657-662.

Nichol, K., Lind, A., Margolis, K., Murdoch, M., McFadden, R., Hauge, M. (1995), The Effectiveness of Vaccination Against Influenza in Healthy Working Adults, *New England Journal of Medicine,* 333, 889-893.

Niemela, R., Hannula, M., Rautio, S., Reijula, K. and Railio, J. (2002), The Effect of Air Temperature on Labour Productivity in Call Centres – A Case Study. *Energy and Buildings*, 34, 759-764.

Richards, A., Hyams, K., Watts, D., Rozmajzl, P., Woody, J. and Merrell, B. (1993), Respiratory Disease Among Military Personnel in Saudi Arabia During Operation Desert Shield, *American Journal of Public Health,* 83, 1326-1329.

Romm, J.J. and Browning, W. D. 1(994), Greening the Building and the Bottom Line, Rocky Mountain Institute, Old Snowmass, USA.

Seppanen, O., Fisk, W. and Mendell, M. (1999), Association of Ventilation Rates and CO2 Concentrations With Health and Other Responses in Commercial and Institutional Buildings, *Indoor Air*, 9, 226-252.

US Department of Energy (2002), International Performance Measurement and Verification Protocol, Vol II – Concepts and Practices for Improved Indoor Environmental Quality, www.ipmvp.org, US Department of Energy, Oak Ridge, TN.

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Dr Greg Foliente is Team Leader and Principal Research Scientist at the CSIRO Division of Manufacturing and Infrastructure Technology (CMIT). He is also Technical Director of the CSIRO Structures Laboratory and Whole Building Test Facility in Melbourne (Highett).

Greg undertakes research and development work on topics related to construction innovation, sustainable buildings, performance based building, smart building technologies, infrastructure and building asset management, risk and reliability analysis, material and component service life prediction, structural mechanics and timber engineering, whole structure modelling, nonlinear random vibration and structural dynamics, wind and earthquake engineering and condition assessment. Greg has also led CSIRO's Evergen collaborative program, to facilitate innovation and excellence in the Australian building and construction industry through collaboration and practical demonstration in actual projects.

Greg has received numerous international research awards, including the 2003 James Croes Medal from the American Society of Civil Engineers (ASCE), the 2003 Best Paper Award (in an international conference) from the American Society of Mechanical Engineers (ASME), the 1998 L.J. Markwardt Wood Engineering Award from the Forest Products Society (North America), the 1997 STA Research Fellowship from the Japan Science and Technology Agency (STA), and the 1997 George Marra Award from the international Society of Wood Science and Technology.

He has written and co-written more than 130 technical papers and reports, has edited and co-edited three specialty publications in the USA and has contributed an article in the *Encyclopaedia of Materials: Science and Technology* (Elsevier London, 2001).

Greg received a BSc in Civil Engineering in the Philippines, two MSc degrees and a PhD at Virginia Tech, USA. He has previously worked in the Philippines and the USA - at Virginia Tech and at the University of California in Berkeley.

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Dr. Phillip Paevere is a Research Scientist and Project Leader with CSIRO Manufacturing and Infrastructure Technology. He has a Bachelors Degree and a PhD in Civil Engineering, both from The University of Melbourne. He has fifteen years experience working on a diverse range of construction industry related research projects. These include: smart building technologies; full scale testing, monitoring, and modelling of houses, buildings and communications towers; system Identification and optimisation; expert systems; wind and earthquake engineering; stochastic processes modelling; and timber construction. Phillip's work has been published widely, and has been rewarded with numerous scholarships and international research awards.

APPENDIX A – INDUSTRY WORKSHOP

A1 – Overview

The primary objectives of the workshop were to:

- Present to project participants and stakeholder representatives the project objectives and progress to date, including outcomes of the state-of-the-art and state-of-the-practice reviews; and

- Brainstorm Australian industry needs and challenges, and capture practical inputs and contributions of project participants and stakeholder representatives on the scope and nature of a possible follow-up research (Phase 2) focusing on prototyping and field testing.

The workshop was held in Sydney:

NSW Trade and Investment Centre

Business Centre, Level 44, Grosvenor Place

225 George Street Sydney NSW 2000

23 May 2003, 10:00 AM

The meeting/workshop followed this agenda:

10:00 - 10:30 Introduction & Overview

10:30 - 13:00 Facilitated Session

13:00 - 14:00 Lunch

14:00 - 15:30 Discussion of Outcomes (key project members)

This report presents the process used in the facilitated session and the outcomes in the form of mind maps. It also includes the presentation by Dr Greg Foliente, and the list of attendees/participants.

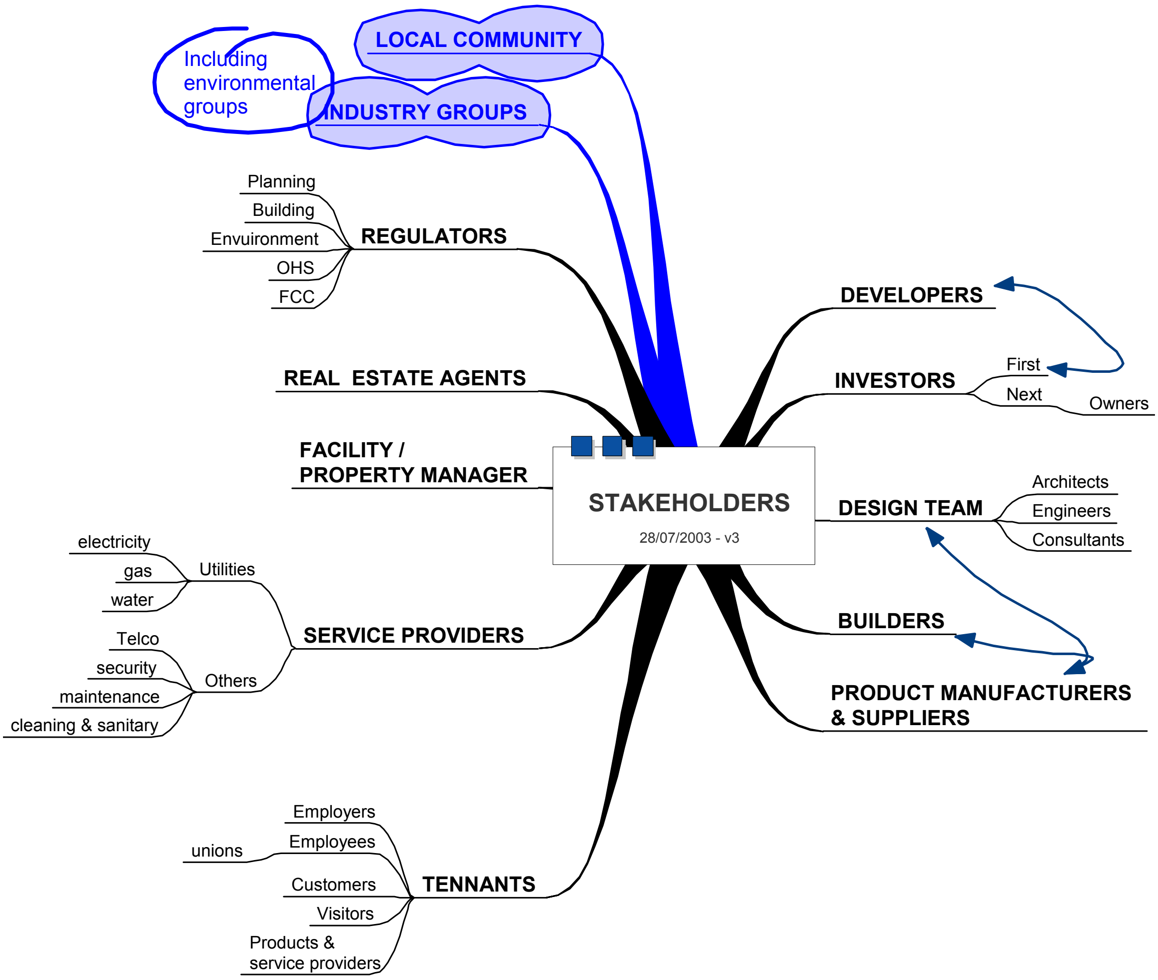
A2 – Processes and Outcomes

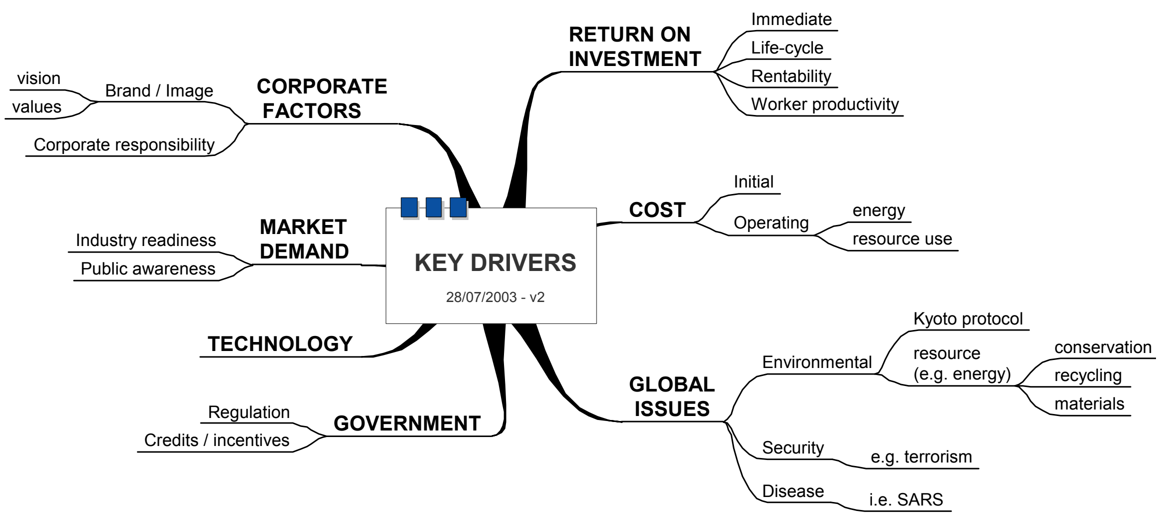
The facilitated brainstorming session was directed by a series of questions:

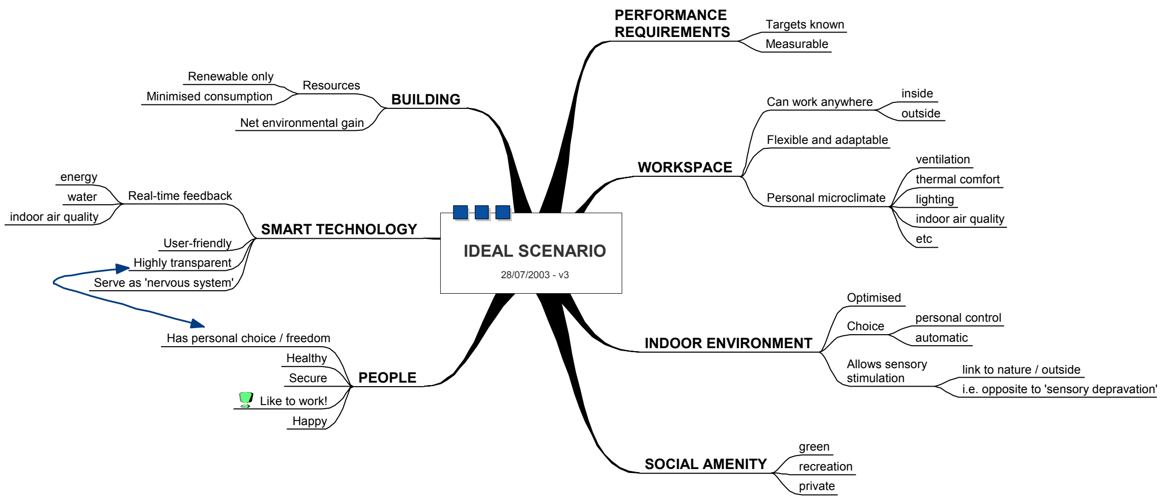
- Who are the key stakeholder groups in the delivery, use/operations and management of office buildings?

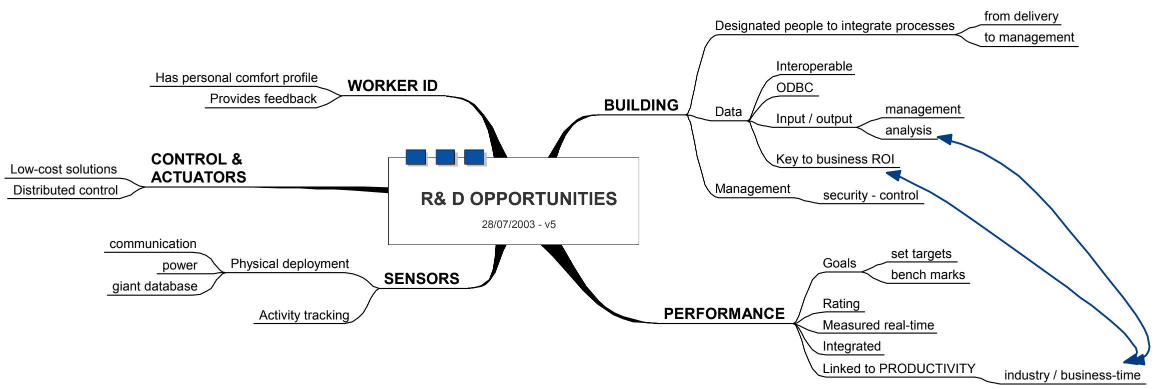
- What are the primary drivers in the delivery, use/operations and management of sustainable and healthy workplaces?
- What are the characteristics of an ideal scenario where sustainable and healthy workplaces are a reality?
- What are the present R&D opportunities that will contribute towards the fulfilment of this scenario?

The contributions and ideas of the participants are summarised in the following mind maps (presented in the order of the above questions).




KEY DRIVERS
28/07/2003 - v2
RETURN ON INVESTMENT
Immediate
Life-cycle
Rentability
Worker productivity
COST
Initial
Operating
energy
resource use
GLOBAL ISSUES
Environmental
Kyoto protocol
resource (e.g. energy)
conservation
recycling
materials
Security
e.g. terrorism
Disease
i.e. SARS
CORPORATE FACTORS
Brand / Image
vision
values
Corporate responsibility
MARKET DEMAND
Industry readiness
Public awareness
TECHNOLOGY
GOVERNMENT
Regulation
Credits / incentives


IDEAL SCENARIO
28/07/2003 - v3
PERFORMANCE REQUIREMENTS
Targets known
Measurable
WORKSPACE
Can work anywhere
inside
outside
Flexible and adaptable
Personal microclimate
ventilation
thermal comfort
lighting
indoor air quality
etc
INDOOR ENVIRONMENT
Optimised
Choice
personal control
automatic
Allows sensory stimulation
link to nature / outside
i.e. opposite to 'sensory depravation'
SOCIAL AMENITY
green
recreation
private
BUILDING
Resources
Renewable only
Minimised consumption
Net environmental gain
SMART TECHNOLOGY
Real-time feedback
energy
water
indoor air quality
User-friendly
Highly transparent
Serve as 'nervous system'
PEOPLE
Has personal choice / freedom
Healthy
Secure
Like to work!
Happy


R& D OPPORTUNITIES
28/07/2003 - v5
WORKER ID
Has personal comfort profile
Provides feedback
CONTROL & ACTUATORS
Low-cost solutions
Distributed control
SENSORS
Physical deployment
communication
power
giant database
Activity tracking
BUILDING
Designated people to integrate processes
from delivery
to management
Data
Interoperable
ODBC
Input / output
management
analysis
Key to business ROI
Management
security - control
PERFORMANCE
Goals
set targets
bench marks
Rating
Measured real-time
Integrated
Linked to PRODUCTIVITY
industry / business-time

A3 – Workshop Presentation

WORKSHOP ON

SMART BUILDING FOR HEALTHY & SUSTAINABLE WORKPLACES

Greg Foliente
CSIRO Manufacturing & Infrastructure Technology
Melbourne, Australia

Kindly supported by

First for Business
Department of State and Regional Development

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TODAY'S AGENDA

- Project overview → workshop objective
- Q & A
- Facilitated session → R&D opportunities
- Lunch

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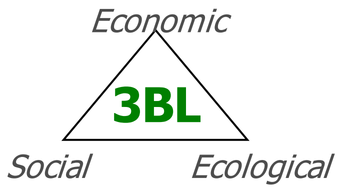
OVERALL PROJECT GOAL

- Develop and implement sensor, control system and other technologies to support the design, construction & management of people-friendly (i.e., healthy), eco-friendly and commercially viable buildings and facilities



SCOPING STUDY OBJECTIVES

- Review and assess technologies that could measure & control factors important for healthy & sustainable workplaces → Scoping study report
- Establish research framework & develop a research program to implement & demonstrate 1st set of promising technologies → CRC follow-up proposal

PROJECT PARTICIPANTS

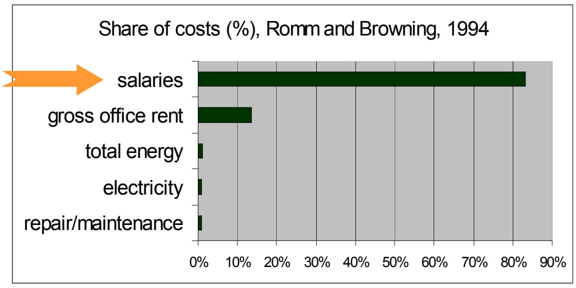
PROGRESS TO DATE

- Literature Review
- Consultants
- MIT Visit
- Interviews
- Sensors
- Workshop – Important Input

EXPECTED PROJECT OUTPUTS

- Scoping study report → 30 June 2003
- CRC follow-up proposal (Stage 3) → 15 June 2003 (earliest) - 15 July 2003 (latest)

FOCUS ON HUMAN WELL-BEING



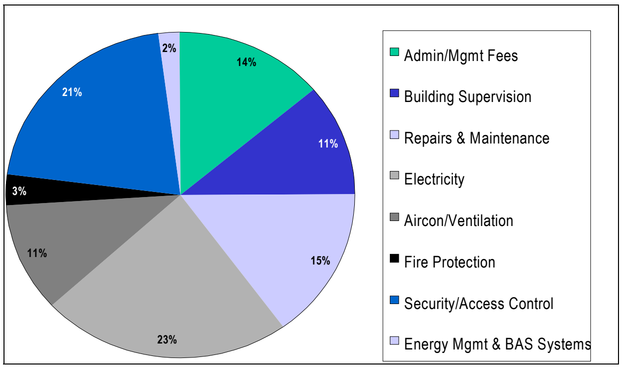
- Explicit attention to human well-being will improve worker's health & productivity & business bottom line

DRIVERS – SUSTAINABLE DEVELOPMENT

- Regulation / government requirements
- 3BL reporting
  - Greenhouse gas emissions,biodiversity, conservation and recycling
- All buildings to be '5 Star' energy rating in future

DRIVERS – BUSINESS

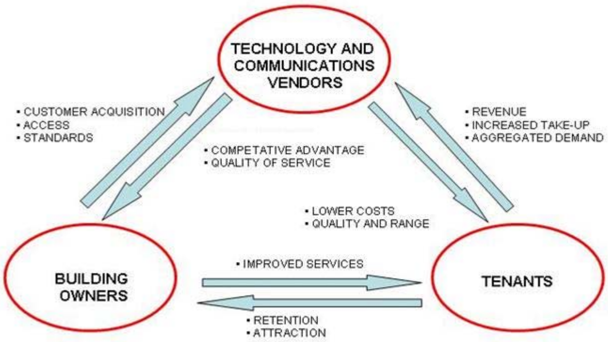
- Green incentives – tax/carbon credits
- Improved worker & workplace productivity, with reduced costs
- Increased need for business flexibility and rapid adaptation to changing times
- Distributed office locations and business networks
- Telecommuting / hot-desking



Breakdown of operating expenses p.a for Premium and A Grade office buildings

DRIVERS – OTHERS

- Security more of an issue now
- Image / branding
- Technically savvy society – Client demand?
- Global competitiveness
- Energy market de-regulation – price spikes!
- Communications de-regulation – expanded services (3G – video – broadband at home) – pricing flexibility



TECHNOLOGY AND PROPERTY RELATIONSHIP FLOW CHART

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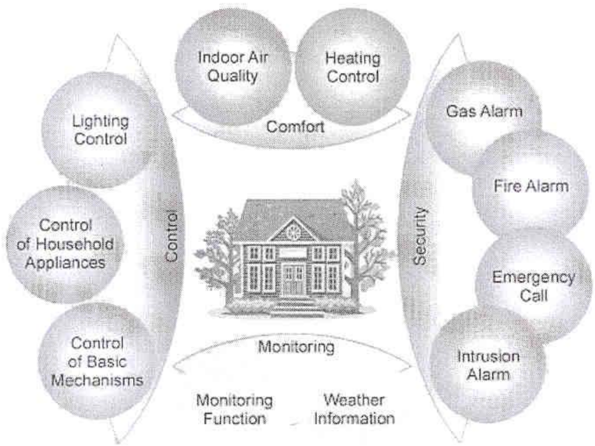
Potential applications for 'smart buildings'

(from Gassman et al. 2001)



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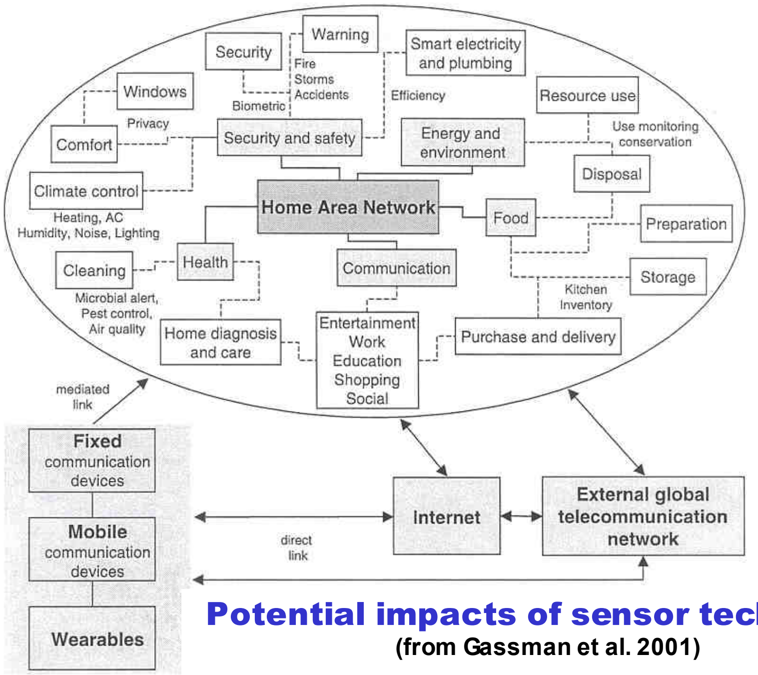

Potential impacts of sensor technology
(from Gassman et al. 2001)

APPLICABLE TECHNOLOGIES

- **SENSORS**
  - Assume we can measure almost anything for very little cost ($1 - $50 per sensor)
  - e.g. MEMS multi-sensor measures the following on a single (tiny, 3mm x 3mm) chip
    - Temperature: 0 to +40 deg. Celsius
    - Relative Humidity: 1 - 100%
    - Light: illuminance level
    - Air Speed: 0 - 40m/s (resolution 0.1 m/s)
    - Air flow Direction (in one plane only)
  - Smart dust (UC Berkeley)

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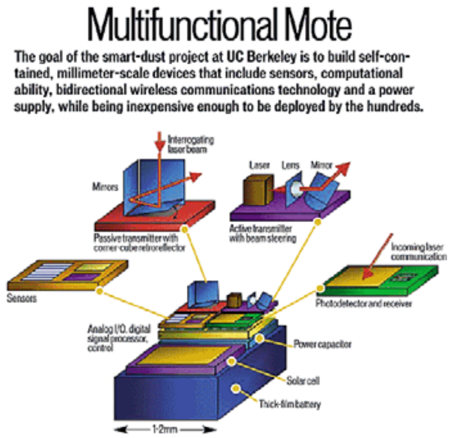
APPLICABLE TECHNOLOGIES

- Wireless platform for sensors
  - Mote
  - PAWNS
  - Proprietary

size of 'Mote' compared to 1c piece



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APPLICABLE TECHNOLOGIES

- **NEW MATERIALS**
  - Intelligent Polymers
    - surface coating → TV screen
    - self repairing gap sealers
  - Nano-materials
    - panels can act as sensors or active building elements
  - Electro-chromic glass
  - Phase change materials (PCM)

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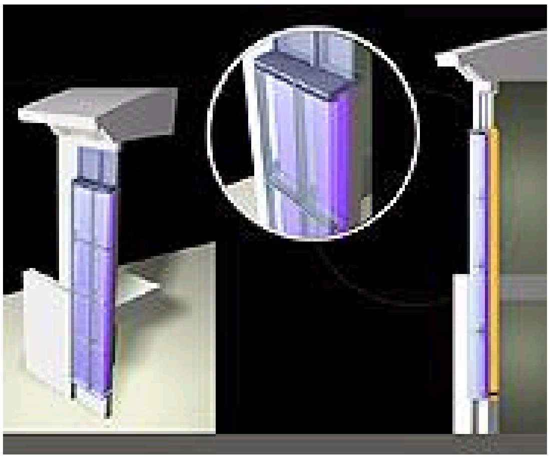

Using AutoCAD 14 and 3D Studio Max, MIT graduate student Kevin Settlemyre depicted prototypical Energy Producing Wall component made of layers of new materials, including thin-film photovoltaics and clear acrylic insulation.

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APPLICABLE TECHNOLOGIES

- **INFORMATION AND COMMUNICATIONS**
  - Wireless technologies
    - 3G
    - Self organising networks
  - Web-based control
    - IP addressable everything
    - High speed networks
  - Voice and image processing
  - Voice control

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OPPORTUNITIES

Indoor Environment I – THERMAL COMFORT

- Dissatisfaction with thermal comfort is most common source of complaints in offices
- Function of temperature (& gradient), humidity, air velocity - preferences vary among people and depend on clothing, activity & stress level, sex (M/F)
- Individual user control could be beneficial to productivity if granularity of HVAC system permits (e.g. controllable workstation – micro zoned system)
- Improved HVAC performance possible through deployment of multiple sensors (cheap) throughout system

OPPORTUNITIES

Indoor Environment II – AIR QUALITY

- Presence of 'Indoor pollutants' can influence occupant health and productivity (e.g. no. sick days taken)
- 'Air Quality' depends on levels of CO_2, CO, VOC'S, moisture, fine particles, pollen, mould, airborne bacteria and viruses (e.g. Legionella, Influenza)
- Pollutant levels can be controlled by increasing ventilation rate, filters, zoned HVAC design or eliminating source of pollutants
- Possible opportunity in sensor development or improved ventilation control

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OPPORTUNITIES

Indoor Environment III – LIGHTING

- Lighting quality dramatically influences productivity of visually-intensive tasks (kind of obvious – plenty of data to support this)
- Lighting characteristics drastically alter mood of occupants (possibly health) and 'feel' of environment
- Opportunities for reduced energy costs through automated switching and dimming –
  - daylight harvesting, time scheduling, load scheduling, occupancy control, pattern harvesting

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OPPORTUNITIES

ENERGY MANAGEMENT

- Break down real-time energy usage in building to zones and even individual occupants
  - HVAC, Lighting, Power, Water
- Analysis of energy breakdown is key to instigating energy use reduction strategies (responsive real-time or long-term strategic)
- High-granularity energy data opens up opportunities for automation algorithms (lighting, heating)
- How does reporting influence energy usage?

OPPORTUNITIES

SECURITY & OHS

- People tracking and Biometrics can be used to create '100% safe' working environment
- OH&S – Activity tracking, working alone
- Preventative health
  - Data-mining activities to look for health 'abnormalities'
  - Contentious but on the drawing board for people's homes
  - Subtle prompts to take medication &/or exercise

OPPORTUNITIES

OFFICE PRODUCTIVITY

- People and activity tracking can be used to collect data on how each workplace ‘works’ – this can then harvested to improve work practices and office design and layout
- Flexible ICT, HVAC, Lighting, Power can enable instant floor-plan reconfiguration, maximum possible usage of existing space
- AudioVisiual + ICT can enable spontaneous or continuous local and remote collaboration (between workstations or offices)

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OPPORTUNITIES

INTEGRATED SYSTEMS

- Programmable building – every switch, outlet, sensor and actuator is on the internet – (IP addressable)
  - wired/wireless combo implementation
  - Provides platform for myriad of options for control, measurement and configuration of building

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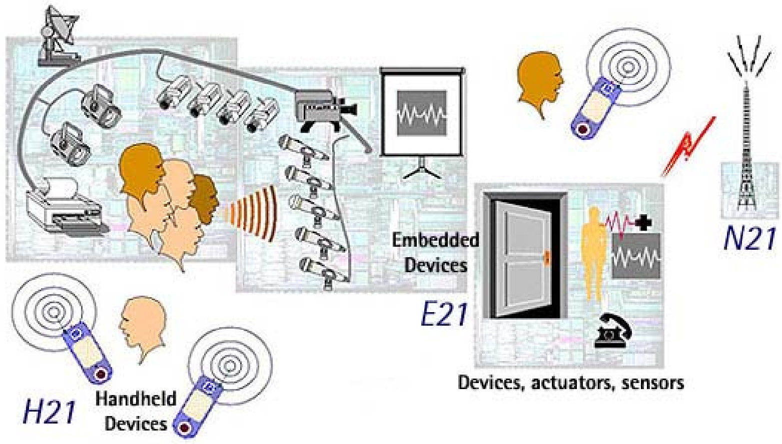
CURRENT RESEARCH

- Intelligent Workplace @ CMU Pittsburgh

CURRENT RESEARCH

- MIT Centre for Bits and Atoms – Programmable Building
- MIT Oxygen 'Intelligent Room' - Human centred pervasive computing – allows a building to interact with its occupants in their everyday activities
- MIT Changing Places – Technologies for healthy living
- UC Berkeley – Smart dust, Motes & effects of work environment on worker productivity

MIT'S PROJECT OXYGEN



http://oxygen.lcs.mit.edu/Overview.html

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FUTURISTIC SCENARIO

- Wireless automatic control of HVAC, lighting and communications based on occupant location, activity and preferences. All systems are voice controllable and can re-configure automatically to optimise comfort and efficiency
- Office layout can be changed instantly to suit daily activities – all systems optimally re-configure for comfort and efficiency – sound-proofing and visual privacy can be switched, open and private zones can be created
- Energy is collected from renewable sources by building, and energy use is tracked and reported down to individual zones/ types / user level
- Occupants are tracked and monitored for security, health and safety
- All new technology for all systems is 'plug and play' onto backbone buildings communications network, everything is web-
- Property owners and managers perspective?

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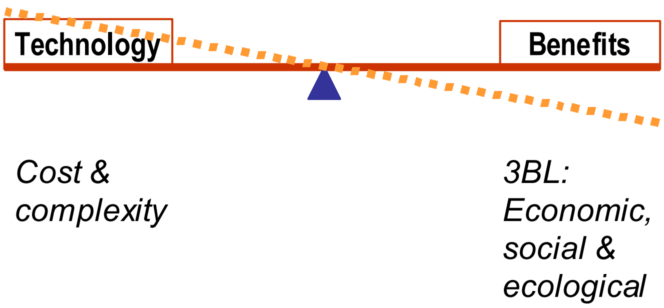
CONSIDERATIONS

- Cost-Benefit Analysis
- Good building design can often achieve substantially more than a considered application of technology can – look for opportunities where intelligent use of technology and good design will complement OR where technology can make good design even better
- Many trade-offs
  - Comfort / sustainability
  - Flexibility / security
  - Conflicting performance requirements

PRIORITISATION/SELECTION



WORKSHOP OBJECTIVES

- Brainstorm technical challenges & opportunities in the delivery & management of healthy & sustainable workplaces in Australia
- Identify R&D priorities

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FACILITATED SESSION

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APPENDIX B – PROTOTYPE PROPOSAL