Seminar on

INDOOR ENVIRONMENTAL QUALITY FOR ACHIEVING TOTAL BUILDING PERFORMANCE

Integrative Paradigm:
Quality, Performance, Value

Organised by:

BCA-NUS Centre for Total Building Performance

Building and Construction Authority

NUS National University of Singapore

In Partnership with:

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Friday, 21 February 2003

Capital Tower, Singapore

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SEMINAR ON INDOOR ENVIRONMENTAL QUALITY FOR ACHIEVING TOTAL BUILDING PERFORMANCE

Friday, 21 February 2003

PROGRAMME

8:30 a.m.	**Seminar Registration**
9:00 a.m.	**Welcome Address by Head of Department, NUS** Professor George Ofori
9:05 a.m.	**Address by Guest-of-Honour** Mr Edmund Cheng Chairman, Construction Working Group for the ERC Sub-Committee on Domestic Enterprises
9:20 a.m.	**Launch of CPD Workshops** Dr Lee Siew Eang Director, Centre for Total Building Performance
9:30 a.m.	**Design and Evaluation Processes for Achieving Total Building Performance** Dr Lam Khee Poh Associate Professor, Departments of Architecture & Building, NUS
10:20 a.m.	**Tea-break**
10:35 a.m.	**Designing Effective Ventilation for Indoor Environmental Quality** Dr Risto Kosonen Director of R&D Asia, Oy Halton Group Ltd
11:30 a.m.	**Energy Efficient Technologies for Good Indoor Environmental Quality** Dr S.C. Sekhar Associate Professor, Department of Building, NUS
12:30 p.m.	**Lunch**
1:45 p.m.	**Effective IAQ Audit for Total Building Performance** Dr Tham Kwok Wai Associate Professor, Department of Building, NUS Deputy Director, BCA-NUS CTBP
2:45 p.m.	**Cost Benefits of IAQ through Effective Facilities Management** Mr Jeffrey Budimulia Deputy Director, PREMAS Environ Pte Ltd
3:45 p.m.	**Tea-break**
4:00 p.m.	**Total Building Performance for Managing Innovation and Change** Dr Lee Siew Eang Associate Professor, Department of Building, NUS Director, BCA-NUS CTBP
5:00 p.m.	**Panel Discussion**
5:30 p.m.	**End of Seminar**

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Design and Evaluation Processes for Achieving Total Building Performance

Dr Lam Khee Poh

Associate Professor

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DESIGN AND EVALUATION PROCESSES FOR ACHIEVING TOTAL BUILDING PERFORMANCE

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Abstract

In the 21st Century, the Asia Pacific will be the world's fastest growing region, and it is anticipated that over half of the world's mega cities will be in Asia. Singapore is well poised to play a significant role in these major developments within the highly competitive construction and real estate sector.

To ensure business success, companies must avoid obsolescence and stay ahead of their competitors by accurately identifying future trends and adopting innovative design and management techniques and advanced technologies for establishing best practices. The "Total Building Performance" concept is one which can contribute to best practices and position us in the fore-front of a knowledge-based approach to the entire building delivery process.

Total Building Performance (TBP) is an integrated and holistic framework for conceptualizing, specifying, designing, analyzing and commissioning a building project. TBP is not just about the application of "hi-tech" building systems and/or materials. TBP seeks to rationally and systematically exploit the synergy of the various relevant technologies as well as design and management know-how to bring about desirable building performance at a reasonable and affordable price tag. It will also facilitate optimization of design for avoidance of conflicts, elimination of omissions and abortive work, and wastage of resources.

Key Words

Total Building Performance, Knowledge-based Design and Evaluation

Industry Motivation

It has been said that "how we are paid and who pays us determine all our attitudes" (Duffy, 1990). The building industry is no exception. Every member of the building delivery team is enraptured by his/her end product. This is evidenced by the fact that the entire vocabulary of the industry revolves around floor areas, structures, facades, "intelligent" M&E systems, etc. These are then quantified as elemental or unit cost of construction by the contractor and ultimately as rental rate by the owner or leasing agent. This is all about the building object and not about what buildings are for and how they function or perform.

Driven by potential economic gains, the industry is obsessed with finishing the job fast, using whatever methods or technologies available at that time. The team disperses and moves on to the next job, hoping never to return, as though it is a "crime scene", as some have unkindly suggested. Records are utterly synchronic and rarely extend to building-in-use. Sadly, diagnostic procedures are only called for when problems arise and litigation is imminent. Understandably, under such circumstances, the publication of information derived is restricted and hence does not benefit the general education of the industry members.

Our materialistic drive can also influence our value judgment in the way we treat the building and its occupants and artifacts. For example, organizations are quite willing to continuously invest in expanding and upgrading their IT systems, resulting in a proliferation of computing equipment in their premises, to meet operational demands. Yet, when it comes to investment in providing a responsive environment and building infrastructure to suitably accommodate these systems and their users, management is often reluctant. It is perceived to be "unnecessary cost" and these features get omitted from the building specifications.

The cost of a project may roughly be categorized as follows – one-third for a fifty-year building shell, one-third for service items which typically last for fifteen years, and one-third for the finishes and decorations, which will possibly change every five years. Therefore, over the lifespan of the building, we will be spending three to four times of the original investment on service items and ten times on decorations. Given this perspective, is it not prudent to invest marginally more on the initial design process and derive an integrated and responsive solution to the building shell and systems? If we factor in people cost over the occupancy period and the potential benefits to be gained, the numbers will even be more persuasive. There are numerous reports of success stories in the literature where owners have adopted such an attitude and approach to holistic design. But, unfortunately, these still represent "a drop in the ocean of ignorance and indifference" (Duffy, 1990).

The existing nature of inter-organisational interactions in the building industry is based on contractual relationships which are not conducive to collaborative working relationships. It tends to develop adversarial attitudes that offset responsibilities and liability to parties further down the supply chain (Peat 2002). This modus operandi will not support a performance-based design and building delivery process. In a sense, it goes beyond contractual agreements. Without a change in the collective mindset, even alternative approaches such as "design and build" will not necessarily achieve the desired outcomes.

As Singapore competes in the global arena for top talents to sustain its economic activities and growth, ensuring a certain quality of life is of paramount importance. This will include providing a conducive and healthy working environment that will support creative and productive work. The building industry has a direct role to play in this matter.

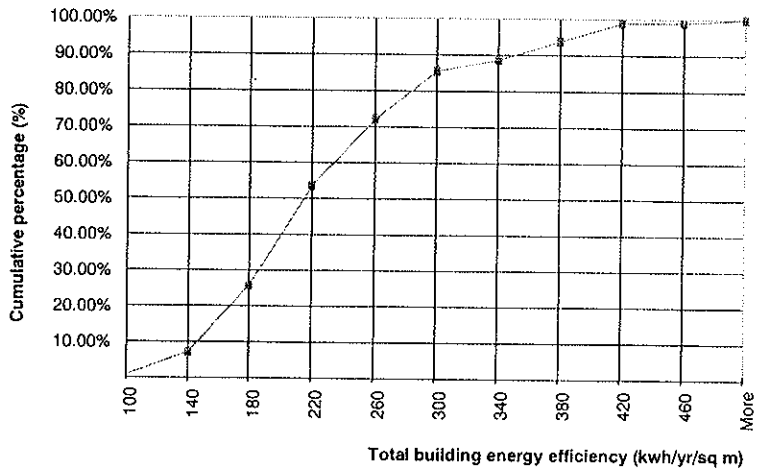
Prescriptive Versus Performance-Based Design

Every building project starts with a brief. This is a very important document as it sets the framework and performance benchmark for the entire process. The quality of the end result will be affected by the comprehensiveness and clarity of the brief. We are more likely to get what we want if we know what we want. Therefore it is worthwhile spending some time and resource in formulating this upfront.

The current approach in brief formulation tends to be prescriptive in nature. It defines requirements in terms of static quantities – floor areas, accommodation schedule and regulatory requirements (e.g., plot ratios, height control, Overall Thermal Transmittance Value (OTTV), fire compartmentalisation and travel distances, and most recently, buildability score). In the environmental design domain, we often take the given numbers for granted and hardly ever stop to question their continued relevance in the present day context. For example, in daylighting design, the codes have been established three to four decades ago (and in a foreign context for that matter). The various indices, such as utilisation factors were derived in very different environmental conditions than today. Research is needed to re-define

a new set of factors in our modern urban habitat [1]. Another obvious example is the OTTV. It only deals primarily with controlling the thermal performance of the building envelope (and its impact on energy use for space conditioning), but energy use in other aspects of the building function is completely ignored. Figure 1 shows the total building energy efficiency based on 104 office buildings in Singapore. While all these buildings have complied with the OTTV requirements, the overall energy efficiency can still vary significantly.

Figure 1. Ogive curve : Total building energy efficiency data based on survey of 104 office buildings in Singapore



Today, we begin to talk about energy design budget in terms of Watts per square metre of floor area per year. Even this may be inaccurate as the same floor area with different ceiling heights (i.e., different spatial volumes) will inevitably require different energy input for environmental conditioning. We should perhaps be considering watts per cubic metre per year as an index.

In the past, we accept rule-of-thumb solutions with "static" singular indices within each domain that purportedly represent the "common average" conditions because it was not possible to perform in-depth dynamic design analysis, due to the lack of local data and knowledge, technically prohibitive and costly in time. With rapid advances in computer technology and reduction in cost, coupled with ongoing data acquisition on local climatic and environmental conditions, we are in a better position to embark on relatively more detailed and accurate computational design analyses based on a performance approach. This will help in refining our decision making process, giving designers certain flexibility in meeting performance requirements and to create an environmentally responsive building.

The performance-based approach to design is gaining some recognition in the building industry[2] in Singapore. We can find many different models in the literature but they share certain common aspirations. For example, questions are raised on the traditional theories concerning the relationship between building design and productivity of occupants. As a result, many long accepted standards pertaining to interior environmental conditions (e.g.,

[1] A collaborative research project between the Department of Building, NUS and the School of Architecture, Sheffield University on this subject matter has been completed recently. In general, research is still grossly lacking in our local building industry, as compared to some other countries.

[2] Some examples of adopting such an approach include the new generation stack-up/drive-up factories by JTC, the URA Building and the New National Library Board Building.

lighting, acoustics, thermal, etc.) are no longer of sufficient quality for occupants. The aspired design objectives should be to seek solutions which give high priority to human needs (in terms of an appropriate and stimulating environment) and job performance while obtaining minimal overall costs with the greatest possible energy savings (Ruck, 1989). Undoubtedly, any specification of "optimal" conditions for human health, comfort and productivity will remain somewhat controversial, but we should nonetheless proceed to grapple with the issues and let rigorous and persistent research yield its insight to educate all of us.

Total Building Performance

To illustrate the performance-based approach, there is an established model known as the Total Building Performance (TBP) concept. This concept was originally advocated by a team at Carnegie Mellon University, USA in the early 1980's (Hartkopf, et al, 1986). It has been adapted and contextualized for the tropics by the Total Building Performance team in the Department of Building at the National University of Singapore.

TBP is an integrated and holistic framework for conceptualizing, specifying, designing, analyzing and commissioning a building project. It can provide a comprehensive brief for a client as well as the project team who are committed to quality and high performance throughout the project duration, from inception to completion, and can even extend to post-occupancy management and maintenance. TBP is not just about the application of "hi-tech" building systems and/or materials. TBP seeks to rationally and systematically exploit the synergy of the various relevant technologies and management know-how to bring about desirable building performance at a reasonable cost.

Performance Mandates

The TBP concept embraces six principal performance mandates, namely, spatial, acoustical, thermal, visual, indoor air quality, and building integrity (Table 1). Each mandate comprises a set of performance targets which are occupant-oriented deliverables that pertain to the environmental or physical attributes of the building which impact the physiological, psychological, social and economic well-being of the occupants.

Table 1. Building performance mandates.

Mandates	Environmental Indices
Thermal	air temperature, humidity, air velocity, radiant temperature.
Visual	lighting levels, contrast, colour rendition, glare index.
Acoustical	reverberation time, sound pressure level, audibility.
Air Quality	ventilation rate, pollutant types and levels.
Spatial	adjacencies, accessibility, way-finding, efficiency, ergonomics.
Building Integrity	degradation, movement, chemical and biological attack, fire safety.

These mandates encapsulate the comprehensive range of environmental factors which we should consider in the design process. Associated with these mandates are diagnostic methodologies developed for the appraisal of the building design in terms of the various performance indices.

Limits of Acceptability

Instead of a singular target figure often found in the prescriptive approach, the performance concept requires the definition of a 'comfort zone' for each performance mandate. Limits of acceptability should be established depending on occupancy type and requirements for four major human and societal conditions, viz., their physiological, psychological, sociological and economical (resource management) needs. There are close inter-relationships between the design mandates and the limits of acceptability. The performance indices in this regard can be both quantitative and qualitative.

Table 2. Inter-relationships of design mandates and limits of acceptability.

	Physiological	Psychological	Sociological	Economical
Spatial	ergonomic, access	habitability, beauty	wayfinding, adjacency	space conservation
Thermal	cool, refreshing	adaptable, control	flexible dress code	energy conservation
Air Quality	no health hazard	openness, not stuffy	no irritant from neighbours	energy conservation
Acoustical	speech clarity	quiet, soothing	privacy, communication	first cost conservation
Visual	good illumination, no glare	orientation, spacious	occupant status, territoriality	energy conservation
Building Integrity	fire safety, weather-tightness	durability, image	status, aesthetics	material/labour conservation

Building Delivery Process

Having established the conceptual framework, we need to review the building delivery process to see how the concept can be feasibly implemented. The building industry has often been characterised as being a fragmented industry. The process commonly consists of a series of discreet and sequential phases of work. Discontinuities in the process from inception to commissioning exist. Gaps in professional and trade responsibilities are prevalent, resulting in operational islands with ineffective coordination and poor communication.

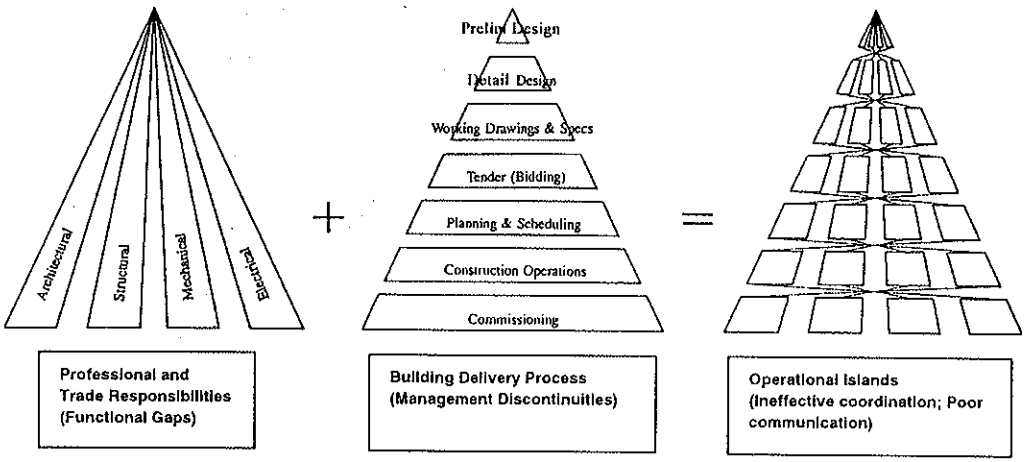


Figure 2. Building delivery process and professional responsibilities (cp. Attar, S.G., Public Works, Canada).

The desired features should include the following:

i. Knowledge-based approach;
ii. Predictive evaluation of proposals for trans-disciplinary performance throughout the collaborative design process for feedback and improvement;
iii. Integrative design and construction process.

Knowledge-Based Approach

Every building that is designed and built is a unique creation in many respects. The design context varies in terms of the external factors (e.g., geographical location with different macro and micro climate, siting and orientation) and internal factors (e.g., spatial functions and utilization schedule, occupancy requirement for human beings and artifacts, etc.). Perhaps the least considered phenomenon is the dynamic interaction between internal and external conditions.

As mentioned earlier, records of buildings are synchronic and rarely extend to cover post-occupancy conditions. Dissemination of such information, if available, is at best sporadic. The design and construction team could thus be unknowingly repeating "standard solutions" which might not have been performing satisfactorily in the previous projects. Furthermore, if we seriously consider the fact that each project is unique, it calls for special attention to every aspect of the design context in every instance. Past experiences are useful starting points but deriving "partial" knowledge from them can be misleading and detrimental to future progress.

A knowledge-based approach is first and foremost about asking "intelligent questions" in formulating the brief. Deciding on what we want is not a trivial matter. Often when the concept of an environmentally responsive design is proposed, it is immediately associated with the plethora of advanced technologies, and naturally to the issue of additional cost. It is assumed that these technologies will somehow meet the design requirements, even though the requirements may be ambiguous or undefined, particularly in the environmental sense. But the very thought of extra first cost would have stopped any further exploration of the idea in majority of project proposals. This need not be the case. We should fully explore the possibilities of the passive mode or a mix of passive and active modes of environmental conditioning in a design before we commit to deploying full active systems.

Adopting a framework such as the Total Building Performance model will facilitate a holistic approach to mapping the environmental performance requirements to the occupant requirements. The same model can be consistently applied in the brief development stage as well as the design evaluation stage. It can also be incorporated into the tender specifications to ensure the objectives are clearly transmitted to the bidders and tender submissions can be objectively evaluated. In Singapore, there are already some cases whereby tender evaluations are conducted concurrently for meeting performance requirements and for price. This practice should be encouraged as it explicitly recognizes that the lowest price may not be the single best criterion for awarding a contract if it compromises on fulfilling stated performance requirements.

Predictive Evaluation of Design Proposals

Predictive evaluation of design options is another important feature in the knowledge-based approach to design. Continuous research efforts have yielded a significant body of environmental information (e.g., detailed local climatic data such as solar radiation, sky luminance, wind velocity, etc.) that is available for use. Various techniques and tools have

also been developed to support the evaluation process. These can be broadly categorized as (1) physical modeling, (2) field testing, and (3) computational simulation studies. The first two techniques are well established for certain building performance domains but have not been widely employed. They tend to be time consuming and expensive, with limited parametric exploration opportunities.

Recent advances in computer technology and perhaps more importantly, the affordability of such powerful technology, has made it feasible and cost effective to use computational design support tools for building performance evaluation. It offers the opportunity to designers to conduct parametric performance studies of various design options, even at the preliminary design phase (Mahdavi and Lam, 1991). Yet the building industry has not begun to tap into this resource seriously. A recent survey of architectural and engineering professionals on the use of computer tools for building performance evaluation showed very limited activity in this aspect (Lam, et. al, 1999). Other than input from environmental research, manufacturers of building materials and systems have an important role to support computational performance simulation by providing detailed scientific/technical data of their products, which are "relevant and applicable" to the local context.

A wide repertoire of domain-specific performance evaluation tools has been available for almost four decades. Some have become increasingly sophisticated in providing detailed analyses of design performance. While they may remain useful in themselves, it is increasingly apparent that a new generation of tools must be developed to cater for the important requirement of integrated building performance evaluation, given the increasing complexity of modern building design. An example of such research work currently in progress at NUS is the development of "SEMPER-II", an internet-based collaborative design computing environment (Lam, et. al., 2002). The modeling environment aims to facilitate concurrent multi-domain building performance evaluation by a design team whose members may be geographically distributed. It is expected to enhance the multi-disciplinary collaborative design decision-making process to achieve high performance buildings.

Integrative Design and Construction Process

The ultimate success in delivering environmentally responsive buildings depends as much on the construction process as on the design specifications. It is crucial therefore to effectively communicate the design intentions behind the system selection (viz., structures, enclosure, M&E and interior) to the prospective contractor, particularly under the normal design-bid-build process. These systems do impact the delivery of one or more building performance mandates. Examples of such implications are shown in Tables 3 and 4.

Table 3. Implication of envelope system on delivery of performance mandates (cp. Hartkopf, et al, 1986).

		spatial	thermal	air quality	acoustical	visual	building integrity
ENVELOPE							
Wall/Roof/Exterior Floor							
	Exterior Surface Material		o				x
	Composite Material Layers	x	o	o	o		x
	Interior Surface Material	o	o	o	x	x	o
	Form: Planar, Curved	x	o		x	o	o
	Slope, Orientation	x	o		x	x	o
	Module Size, Shape	x	o				x
	Connection to Other Envelope Comp.	o	x	o	o		x

x	: Critical implications for the delivery of this performance mandate.
o	: Some implications for the delivery of this performance mandate.

Table 4. Implication of ventilation and air-conditioning system on delivery of performance mandates (cp. Hartkopf, et al, 1986).

VENTILATION AND AIR CONDITIONING	spatial	thermal	air quality	acoustical	visual	building integrity
Service Generators						
Size, Volume	X	X	X	O		
Form, Configuration	X	X	X	O		
Expansion Capability	X	X	X			
Material, Ornament	O					O
Service Conduits						
Thickness, Volume of Service	X	X	X	O		
Form, Shape	O	O		O	O	
Configuration, Distance, rise/run	O	X	O	O		
Interface/Expansion Capability	X	X	X	O		
Material, Ornament	O				O	O
Connection to Other Mechanical	X		O	O	O	O
Access		X	X	O		X
Service Terminals						
Planning Module	X	X	X	X	X	X
Number, Size, Capacity	X	X	X	X	O	X
Form, Material, Ornament	O			X	X	X
Interface/Expansion Capability	X	X	X	O		
Relocation Capability	X	X	X	O	O	
Connection to Other Mechanical	O		O		X	O
Control Systems						
Central Management Systems	X	X	X	O	O	X
Local Management, Automatic/Manual	X	X	X	O	O	X

These matrices, when translated into project-specific specifications and incorporated into the contractual documentation, can serve as checklists for evaluating appropriateness of system implementation in delivering the performance mandates, particular in instances where the contractor may recommend certain variations or alternative proposals to the design during the construction phase.

There are of course other project procurement methods, such as "design and build", which can potentially facilitate an integrated approach to design and construction. If all the team members share the same aspiration, it can be a great opportunity to expand the scope beyond immediate construction productivity gains to encompass the longer term issues of environmental sustainability as well as enhancing the well-being,(and consequently the productivity),of the people who inhabit the buildings we produced.

Concluding Remarks

To compete successfully in the new global economy, providing world-class infrastructures and high performance buildings to accommodate and support the various economic activities is no longer an option. In the face of rapid changes and advances in technology, sustainability is a key issue to contend with. Buildings must be adaptable to changing requirements and consideration of life cycle cost competitiveness will become more important than mere concerns of first cost.

Performance-based design can only achieve its maximum benefit when it is deployed right from the project inception stage, with dedicated support from the multi-disciplinary professional team. It must first establish a clear set of performance targets. This will facilitate optimization of the design for performance, avoidance of conflicts, elimination of omissions and abortive work, and wastage of resources. Specification of the building elements and systems are only means to mediate between the external "uncontrollable" environment and the internal "controllable" environment to achieve the desired conditions and functionality in a building. Proposed design solutions should be evaluated using the most appropriate techniques or tools that will take into account the specific macro and micro climatic and environmental conditions on site. This will at least help to surface any potential problem

before it becomes a costly remedial exercise (if it is at all possible) after the building is constructed.

The Construction 21 report released recently has articulated a vision for the construction industry in Singapore – "To be a World Class Builder in the Knowledge Age" (MOM and MND, 1999). To realise this vision, it recognises the need for a paradigm shift in the image, processes and purpose of the construction industry. Knowledge and integrated teamwork are clearly essential ingredients within the strategic framework for success in developing future high performance buildings.

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Designing Effective Ventilation for Indoor Environmental Quality

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DESIGNING EFFECTIVE VENTILATION FOR INDOOR ENVIRONMENTAL QUALITY

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Abstract

The building industry continues to see a growing interest in creating solutions that consider the priorities of indoor air quality and energy conservation. The majority of air-conditioning systems installed in Singapore are designed to mix the air within the space. These systems can offer high standards of comfort and air quality. It may however be at the expense of high running costs. Thermal displacement systems or swirl diffusers could be other attractive approaches to improving energy and ventilation efficiency. In addition to improve efficiency, it is important to ensure that pollutants are not brought into the space by the system. The system and products will therefore need to be selected and designed with cleanliness in mind. Finally, the seamless function of the building services, such as lighting and various detectors, can be guaranteed by integrating them in a unitary room unit. These room units give the required flexibility of the system for future changes in business activities.

Key Words

Air Quality, Energy Conservation, Quality Control, Room Unit, Design

Introduction

The building industry continues to see a growing interest in creating solutions that consider the priorities of indoor air quality and energy conservation. Additionally, there is an obvious link with indoor climate and productivity. Recent studies have shown the link between indoor air quality to thermal comfort, productivity and health issues (Wargocki 1999 and Wyon 1996). Thus, it was possible to demonstrate that an investment to a better ventilation system is profitable already with very modest productivity improvements (Hagström 2000).

Rapid changes in business activities and loads on spaces due to 'IT' will mean that future systems will need to be designed and selected with flexibility in mind. This may result in a move towards unitary systems where at the moment separate subsystems are integrated together. One example is service beam where ventilation, cooling, heating, lighting, sprinkler, various detectors and PA systems could be integrated in the same prefabricated unit.

The majority of air-conditioning systems installed in Singapore are designed to mix the air within the space – that is, variable and constant volume all-air systems. Correctly designed, these systems can offer high standards of comfort and air quality. It may be however that they do this at the expense of high running costs. Thermal displacement systems or swirl diffusers could be other attractive approaches for improving energy and ventilation efficiency. These systems minimise the quantity of air handled and also have the ability to provide a high quality indoor environment.

This paper presents new concepts for office buildings by taking into account the challenges of tropical climate conditions. In the future, flexibility, life-cycle cost, indoor air quality and environment issues are becoming more important. This means that new types of systems are needed to fulfil these requirements.

Basis for Concept Selection

The need to consider the 'quality' of the space is encompassed within the publication "Ventilation for Buildings – Performance requirements for ventilation and air-conditioning systems" (CEN 1998). This sets a range of target technical values that need to be agreed between the designer and the client. Thus, the end-user will become much more aware of what can be expected.

Space temperature and air quality control are only two of many issues associated with the selection of the most appropriate air-conditioning system. Other issues could be:

- Flexibility,
- Capital cost,
- Environmental impact,
- Life-cycle cost.

Future building regulations can be expected to require an assessment of the environmental impact of the building. This can take several forms, from primary energy consumption to embodied energy. In practice, by far the most significant is the energy used by the systems and equipment within the building. Therefore the designer will need to look to the most energy efficient system. There are tools to enable the designer to compare systems, and supporting design data in a universal format are provided by manufacturers.

Methods to Guarantee Good Indoor Climate

The acceptable air quality is achieved by providing ventilation air of specified quality and quantity into the occupied space. Prescriptive methodologies are available in which a specific amount of ventilation air is recommended in order to dilute the pollutant levels to acceptable concentrations. Tables are provided for specifying the amount of ventilation air required for various types of occupancies calculated either per person or per area. This method assumes implicitly a certain level of indoor pollution loads, air cleaning, supply air quality and ventilation efficiency. This approach is therefore subject to potentially large inaccuracies.

It should be noted that it is not easy to determine the accurate amount of the outdoor airflow rate and adjust the airflow rate in Singapore buildings. Measurement and balancing is usually fraught with technical constraints; this sometimes affects the capability to reach the requested indoor targets in the room spaces.

Besides the dilution of pollutants within the space, it is important to ensure that pollutants are not introduced into the space by the system. This means effective filtration and clean ducts, voids and plenums. The system will therefore need to be selected and designed with cleanliness in mind.

Selection of Air-Conditioning Strategy

The aim of a room's air conditioning is to maintain the target indoor air quality and thermal conditions during different operating conditions in the most economical way (energy, cost efficiency). The room air-conditioning strategy is a fundamental scheme that describes the targeted temperature, humidity and contaminant distributions as well as air-flow patterns within the air-conditioned room. The ideal room air-conditioning strategies are shown in Figure 1 (Hagström 2000). This shows that there are more possibilities for designers to adopt than the normally used mixing ventilation strategy. For example, with stratification strategy (displacement), it is possible to create a temperature and humidity gradient in the room space and so improve thermal comfort and energy economy under tropical conditions.

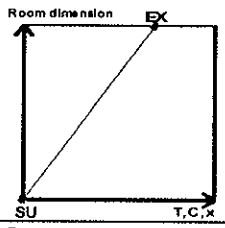
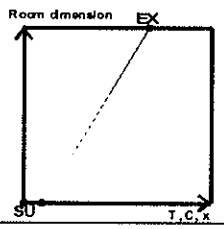
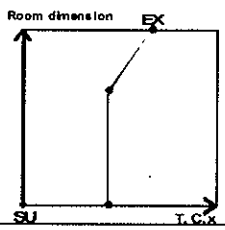
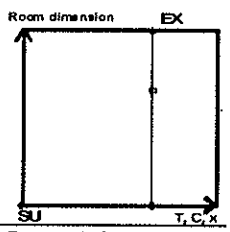
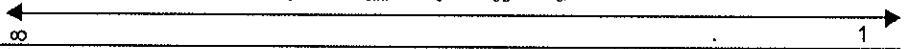
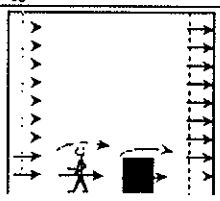
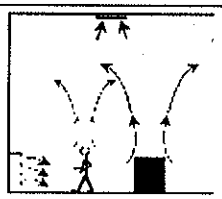
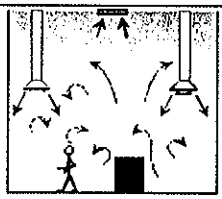
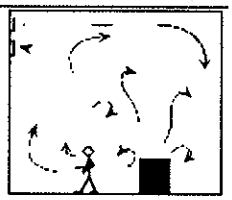
AIR CONDITIONING STRATEGY:	PISTON	STRATIFICATION	ZONING	MIXING
DESCRIPTION	To create unidirectional air flow field over the room area by supply air.	To support flow field created by density differences by replacing the airflow out from the room area with supply air	To control air conditions within the selected zone in the room by the supply air and allow stratification of heat and contaminants in the other room areas	To provide uniform conditions throughout the ventilated space
HEAT, HUMIDITY AND CONTAMINANT DISTRIBUTION (Pictures) X-axis: °C, mg/m^3, g/kg Y:axis: Room dim. (e.g. height) SU=supply, EX=exhaust				
MAIN CHARACTERISTICS:	Room air flow patterns controlled by low momentum unidirectional supply air flow, strong enough to overcome disturbances	Room air flow patterns controlled mainly by boyancy. Supply air distribution with low momentum.	Room air flow patterns controlled partly by supply and partly by boyancy.	Room air flow patterns controlled typically by high momentum supply air flow.
IDEAL EFFICIENCY	$\varepsilon_t = (t_{ex} - t_0)/(t_{oz} - t_0)$ $\varepsilon_c = (C_{exh} - C_0)/(C_{oz} - C_0)$ 			
TYPICAL APPLICATION (An example of a general room air distribution method)				

Figure 1. Summary of the air-conditioning strategies.

Cleanliness of Air-Conditioning Systems

Recent research studies have shown that indoor climate quality is affected by ventilation equipment, building materials and the purity of the supply air. According to studies (Björkroth 2000), only a third of the supply air impurities was derived from human activities; the rest came from building materials and ventilation systems.

Care must be taken at the building site to make sure that dirt does not get into the system during installation. The ductwork should be cleaned of dust after installation and efforts must

be made thereafter to keep it clean by means of filtering and regular cleaning. In connection with air terminal devices and ductwork, to keep the system clean it is necessary to equip the products with protective plugs to prevent dust and dirt from getting into the ducts during construction.

Cleanliness depends on the proper use of the ventilation system when the system is operational. User and maintenance instructions are useful in this respect. Even when the ventilation system has been planned and built with care and is serviced regularly, it will have to be cleaned from time to time. For this reason, the ventilation ductwork and its components must be designed and manufactured in such a way that they can be cleaned easily. Measurement, control equipment and their probes installed in the ductwork must not hinder cleaning. To assist cleaning, air terminal devices should be designed in such a way that they can be opened.

Novel Concepts for the Tropics

Indoor climate requirements and energy economy have to be taken into account when ventilation for commercial buildings is considered. In Figures 2, 3 and 4, some ventilation concepts are presented, which could be considered when good indoor air quality and energy economy are required.

Concept I: Displacement Ventilation

Displacement ventilation (DV) systems have been used in Northern Europe for more than three decades and have proved to be successful, especially where energy efficiency and indoor air quality are of primary importance for building inhabitants. In a displacement ventilated room, the ventilation efficiency is higher (60%-70%) than a room ventilated by mixing ventilation (less than 50%). The supply airflow rate can also be lowered normally by 30%, compared with mixing ventilation (REHVA 2002). Figure 2 shows an example of a DV system.

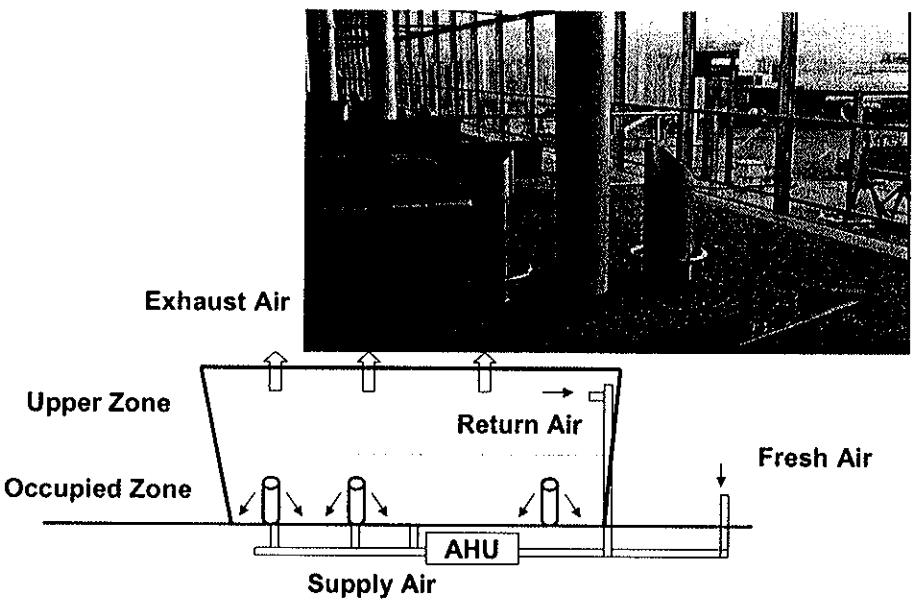


Figure 2. Principle of a displacement ventilation system in a lobby.

However, applications in the hot and humid climate are still limited. Field measurements carried out show that with DV, it is possible to create a humidity gradient (Kosonen 2002). The results indicate that the humidity gradient is as significant as the temperature gradient. The combination of the temperature and humidity gradient improves the energy efficiency of a displacement system in a hot and humid climate. The annual energy consumption could be 33% and cooling capacity 10% lower, compared to the mixing system (Livchak 2001).

Concept II: Zoning Strategy

Concept II presents examples of zoning strategies (Fig. 3). Using the zoning strategy, it is possible to achieve good ventilation efficiency and energy saving compared to the mixing system. However, the temperature gradient is smaller than using the DV system and therefore the energy saving effect is not so significant.

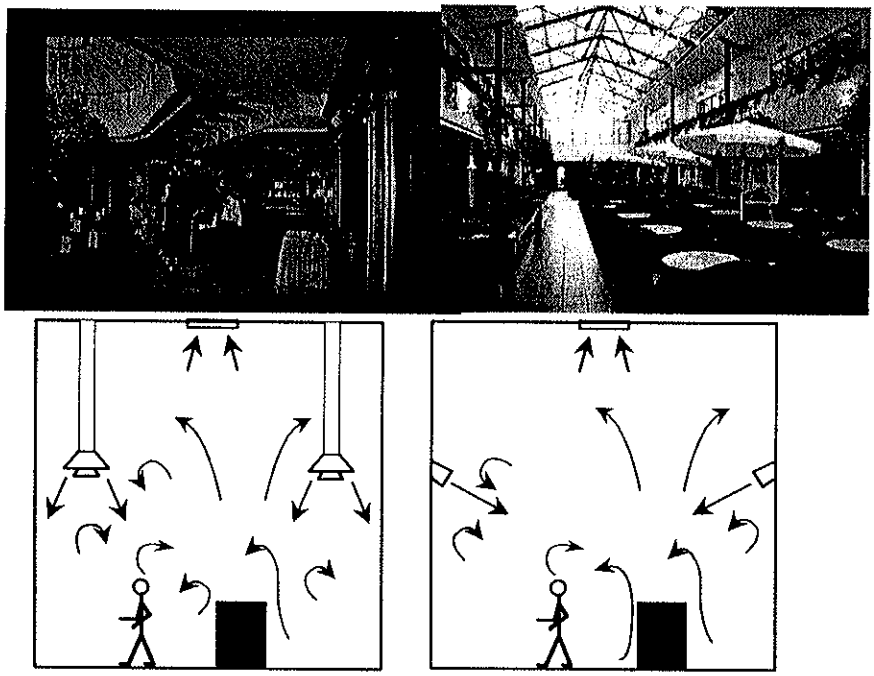


Figure 3. Examples of zoning strategies.

Concept III: Ventilated Beams

Ventilation beams have been commonly used in high-class office buildings. The 'active beam' type, which combines cooling and ventilation, is the most often used beam solution. Active beams can be divided into two groups: freely installable beams and beams for installation in suspended ceilings (Fig. 4).



Figure 4. Ventilated beam concept where building services could be integrated.

In a closed beam solution installed in a suspended ceiling, air circulates only inside the device itself, so no air comes into it through the suspended ceiling. In both types of beam, the lower cover can be opened without tools to permit fast and convenient cleaning of the cooling coil. In the ventilated beam, it is possible to integrate all requested building services like lighting and various detectors in a prefabricated room unit. Avoidance of condensation during the operation phase is necessary in the hot and humid tropical climate. Prevention of condensation is possible, by adjusting the set points and the supply airflow rate for the actual sensible and latent loads.

Discussion and Conclusion

Zoning and displacement ventilation could help to enhance energy efficiency compared to mixing ventilation. Displacement ventilation creates a humidity gradient that is as significant as the temperature gradient and thus improves thermal conditions in the room space. The seamless function of the building services, such as lighting and various detectors, can be guaranteed by integrating them in a unitary room unit. This system also gives the flexibility for future layout changes.

The acceptable air quality is achieved by providing ventilation air of specified quality and quantity into the occupied space. This means that a specific amount of ventilation air is requested in order to dilute the pollutants to an acceptable level. Airflow balancing and cleanliness of the air-handling system are key elements to fulfilling the design targets. The ventilation ductwork and its components must be designed and manufactured in such a way that they can be cleaned easily. Measurement and control equipment and their probes installed in the ductwork must not hinder cleaning.

Acknowledgements

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Energy Efficient Technologies for Good Indoor Environmental Quality

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ENERGY EFFICIENT TECHNOLOGIES FOR GOOD INDOOR ENVIRONMENTAL QUALITY

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Abstract

Energy consumption in Singapore can be attributed to three main sectors: industries (about 29%), residential and commercial buildings (about 34%), and transport (about 37%). Owing to our tropical climate, much of the electricity consumed in buildings (in particular, commercial and institutional buildings) is used for air-conditioning and refrigeration. It should then come as no surprise that commercial and office buildings ought to be targeted as one of the top priorities in implementing energy efficient designs. Simultaneously, the quality of the indoor environment created by such designs should not be compromised as it ultimately has a bearing on the health, comfort and productivity of the workforce occupying these buildings. This paper describes the key features of a typical commercial air-conditioning system in Singapore from both energy and IAQ perspectives. Based on current design practice, the paper then explores the use of emerging energy efficient technologies that are particularly ideal for a tropical climate and have the potential to be applied in both existing and new buildings in Singapore.

Key Words

Energy Efficiency, IAQ, Air-conditioning, Tropical Building, Cooling Coil, Personalised Ventilation

Introduction

According to the International Energy Outlook 2002, the world energy consumption is projected to increase by 60 percent from 382 quadrillion British thermal units (Btu) in 1999 to 612 quadrillion Btu in 2020 and much of this growth in worldwide energy use is expected to occur in Asia and Central and South America (EIA, 2001). Singapore's energy needs have also grown in tandem with its economic growth and the three main sectors of energy consumption include: industries (about 29%), residential and commercial buildings (about 34%) and transport (about 37%), (IACEE, 2000). Due to the hot and humid climatic conditions experienced throughout the year, much of the energy consumed in commercial and office buildings is for air-conditioning. It is also important to consider the quality of air in the indoor environment, as it affects the comfort, health and productivity of the occupants in buildings. The issues of Sick Building Syndrome arising out of poor indoor air quality have often been attributed to inadequate air-conditioning and mechanical ventilation system designs. Using a typical commercial air-conditioning system design as a framework, this paper highlights some of the key issues that need to be considered in addressing both the energy efficiency as well as the indoor air quality (IAQ) of a building. Specific technologies that aim to reduce energy as well as significantly improve thermal comfort and indoor air quality in the tropics are emphasized.

Typical Commercial Air-Conditioning System in Singapore

A typical air-conditioning system used for commercial and office buildings in Singapore is presented in Figure 1. Floor-by-floor air handling units (AHUs) are generally employed with a centralized chiller plant that distributes chilled water to these AHUs. The key energy consuming components are, as indicated in Figure 1, the chiller, the cooling coil and the AHU fan. There are obviously other components, such as the pumps and cooling tower fans that also consume energy but proportionally the consumption of energy is lower than the chiller and the AHU fan. Whilst the technological development in chillers has progressed quite rapidly in terms of chiller efficiency, similar developments in cooling and dehumidifying coil efficiency have been rather slow. The chiller performance is inextricably linked to the cooling coil performance and any optimization or improvement in the efficiency of the coil will inevitably lead to a direct benefit on the chiller energy consumption. It is, therefore, the intent of this paper to focus on the cooling coil performance as well as the mode of distributing conditioned air to the occupied zones, which has a direct bearing on the issues of indoor air quality (IAQ) in the building.

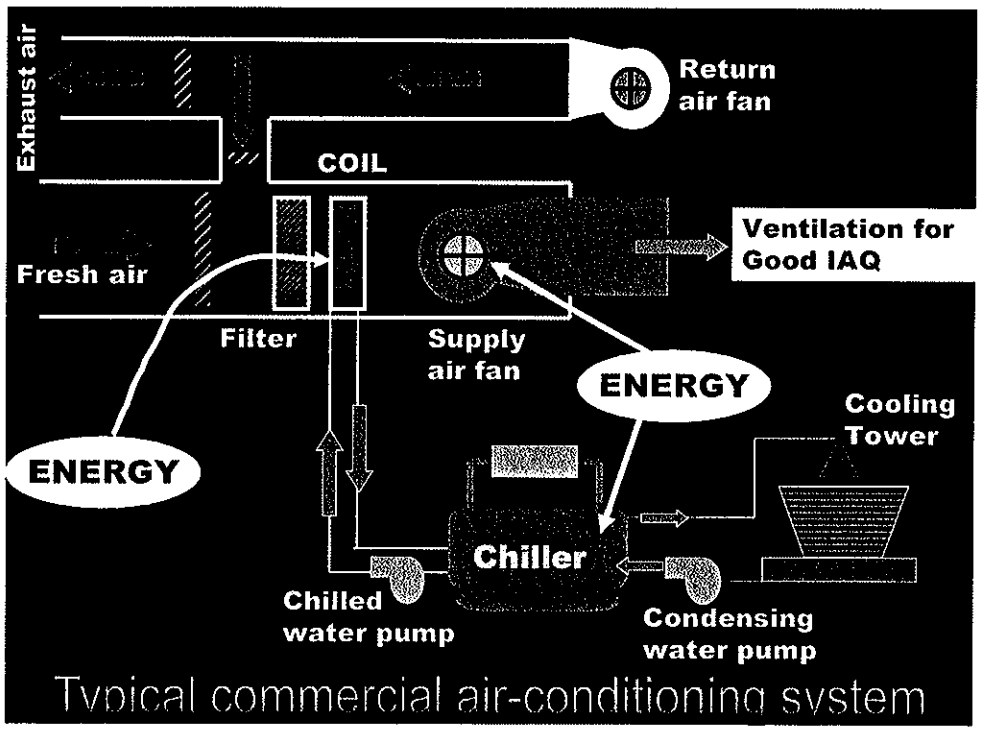

Figure 1. Typical commercial air-conditioning system.

Among the commonly employed air-conditioning systems for large commercial buildings in Singapore, the constant air volume (CAV) and the variable air volume (VAV) systems are more popular. Whilst primary fresh air fan coil units are generally employed for hotel applications with intermittent occupancy, refrigeration modulation systems are increasingly being used for small to medium office buildings. One of the crucial design objectives in all air-conditioning systems is to address the issue of total cooling capacity. It is logical to design for maximum capacity to address the simultaneous maximum cooling loads but it is equally important to consider the part load performance of such system components, such as the cooling coil and the fan. Studies have shown that optimization of part load performance of

various components of the heating, ventilating and air-conditioning (HVAC) system can save as much as 40% of the energy consumption (Karalus, 1997; Lenarduzzi, 1998; Mathews et al, 2001 and Sekhar and Phua, 2003). The psychrometric performance of the cooling coil in a CAV system is illustrated in Figure 2. It is seen that the normal control strategy employed with the operation of the CAV system leads to the indoor humidity being outside the thermal comfort range during part load conditions. This would then lead to the normal practice of overcooling to achieve more dehumidification and thus avoid complaints related to elevated humidity levels. It is apparent that such practices of overcooling imply higher energy consumption.

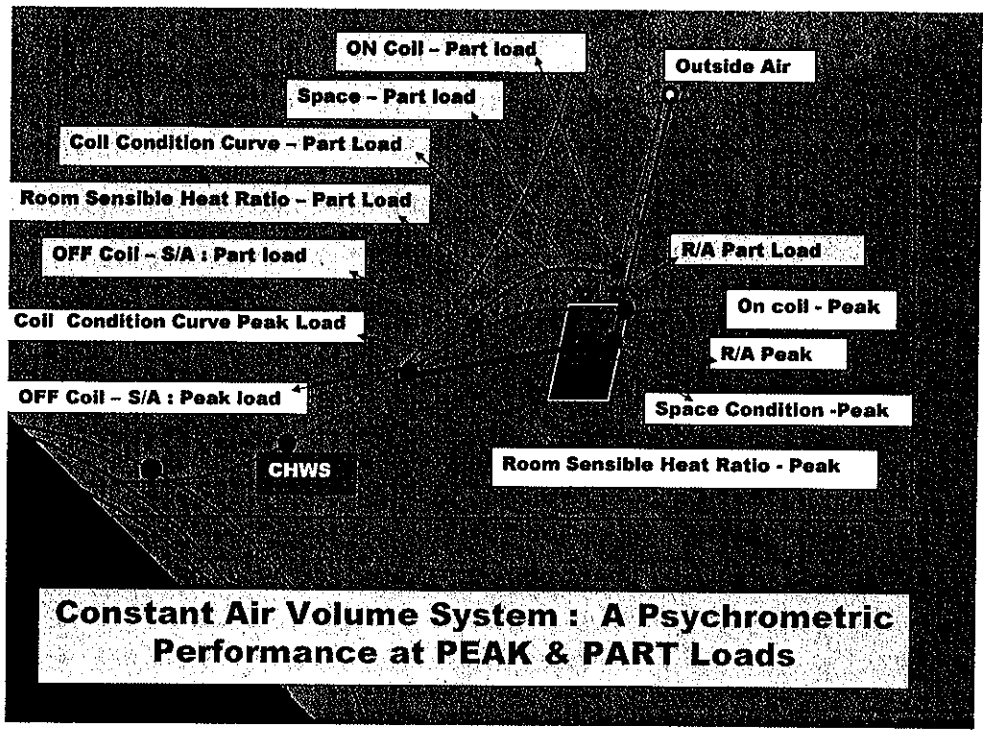

Figure 2. Psychrometric performance of a CAV system.

Energy Efficient Technologies for Good IAQ

In the context of indoor environmental quality in the tropics, the interaction of the cooling coil and the ventilation air (fresh air) quantity is challenging. The inability of conventional cooling coils to address the problems associated with inadequate dehumidification often leads to poor IAQ such as stuffiness. The mitigation of ventilation provision to overcome humidity concerns is a further exacerbation of the problem of poor IAQ, as effective fresh air supply at the occupied zones is essential to dilute the indoor pollutants. Humidity is thus seen as an "indoor pollutant" and the challenge, therefore, is to design an energy-efficient air-conditioning system and air-distribution system for improved IAQ. The following are some of the emerging technologies that aim to achieve energy efficiency as well as provide good IAQ:

- Low Face Velocity – High Coolant Velocity (LFV/HCV) system
- High Driving Potential (HDP) system

- Single Coil Twin Fan (SCTF) system
- Energy efficient VAV system with zonal ventilation control
- Personalised Ventilation (PV) system

Low Face Velocity – High Coolant Velocity (LFV/HCV) system

The combination of low face velocity, giving a low air-side heat transfer coefficient, and a high coolant velocity, giving a high coolant-side heat transfer coefficient, minimises the effective temperature of the coil surface, thus increasing the driving force for dehumidification. The air-side requirements thus translate to low face velocity, low fin density and reduced rows of depth of tubes, all of which are contrary to conventional practice. The LFV-HCV method, presented in Figure 3, is a practical, disciplined, overall strategy derived from fundamental thermodynamics and the physics of heat and mass transfer. It is described in detail in Shaw and Luxton (1988) and Sekhar et al (1989) and is the subject of patents in most countries.

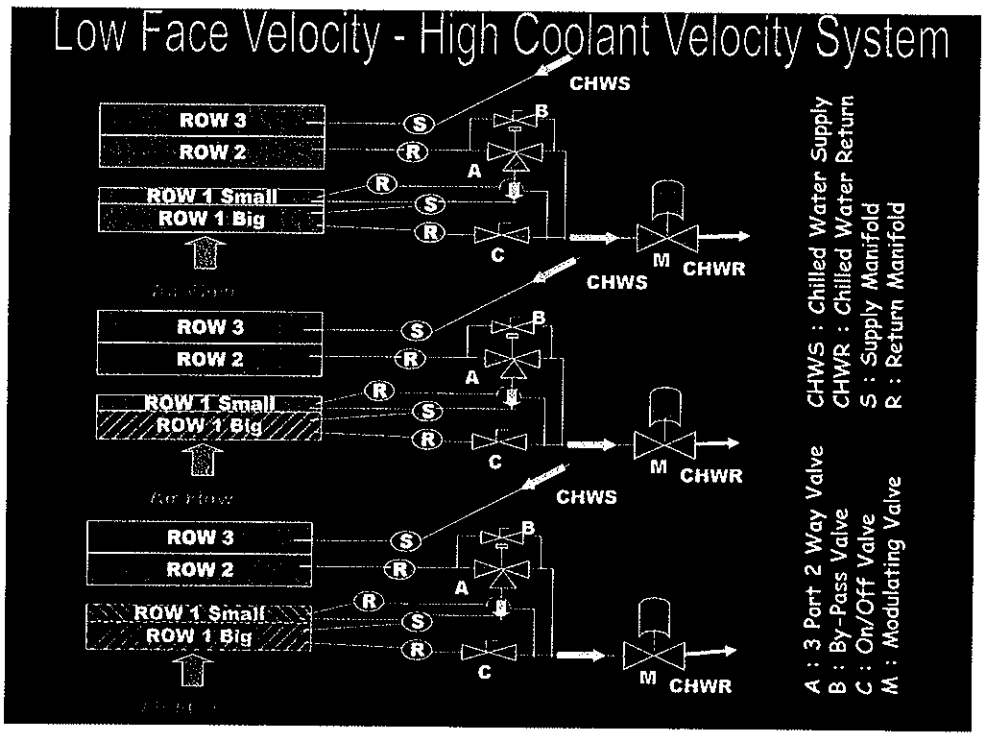

Figure 3. The LFV-HCV system.

By using the methodology, the designer can satisfy all dehumidification loads irrespective of the sensible load, where this is thermodynamically possible. A significant difference between conventional and LFV-HCV designs is that the systematic design procedure of the LFV-HCV method of air-conditioning includes design for all definable operating conditions likely to be imposed on the system during its life. Thus, part load operation of the cooling and dehumidifying coil is a key consideration in the design process. Extensive model tests on a range of air handling unit designs have been undertaken, resulting in the development of LFV-HCV units which occupy substantially the same floor area as conventional units, have a high uniformity of flow distribution, use less fan power, are almost 20 dBA quieter and achieve significantly higher fan efficiencies. Moreover, filters do not need to be of the deep bed variety, as the velocity through the filters is significantly lower than with a conventional system.

High Driving Potential (HDP) system

The High Driving Potential (HDP) system, presented in Figure 4, fundamentally addresses the problem of dehumidification and aims to provide the right balance of sensible and latent cooling requirements in the space (Luxton and Marshallsay, 1998). This is achieved by

- Separate treatment of the outdoor air first by a Primary coil (in which the highest potential for dehumidification exists between the humid outdoor air and the coldest chilled water)
- Separate treatment of the secondary air (return air) by a Secondary coil that re-uses the chilled water returned from the Primary coil, thereby maximising the use of available potential differences and so realising energy savings).

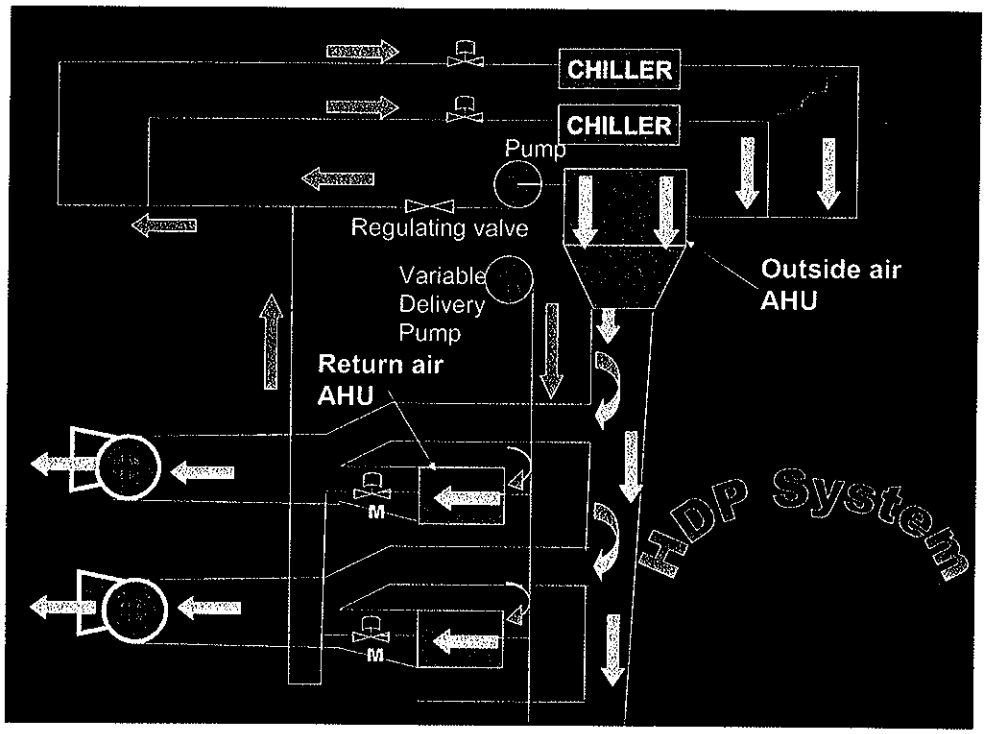

Figure 4. The HDP system.

The primary air and the secondary air may then be mixed or delivered separately to the occupants in the conditioned space (for example, via an induction air terminal unit).

Single Coil Twin Fan (SCTF) system

The National University of Singapore has developed a heating, ventilation and air-conditioning (HVAC) system with two variable air volume (VAV) systems for moving fresh air and recycled air respectively (Sekhar et al, 2002a). Both fresh and recycled air are cooled and dehumidified by a single heat-exchanging coil.

The SCTF system is presented in Figure 5, in which the fresh and recycled air streams travel independently in separate ducts and are conditioned separately by a single cooling and dehumidifying coil before they are mixed and ventilated into a room. This achieves optimal cooling and dehumidifying performance. At the same time, the single coil is energy-efficient and easy to operate. The single-coil system also saves floor space and costs as there is no

need for intermediate return and supply manifolds between separate coils as is the case in conventional systems.

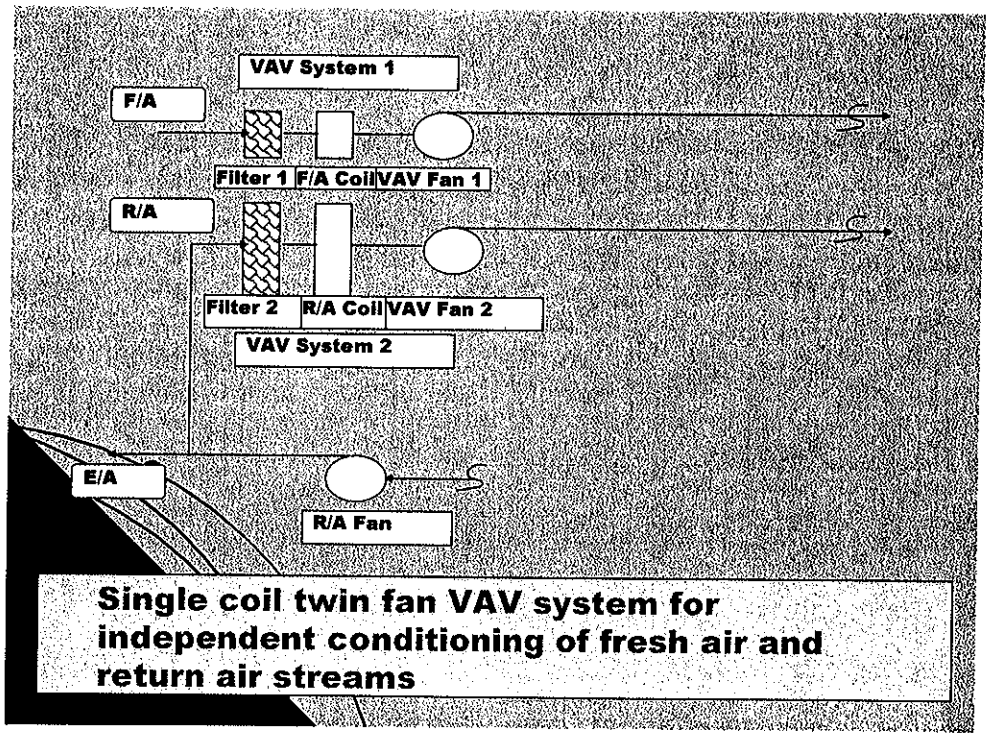

Figure 5. The SCTF system with improved coil performance.

Energy-efficient VAV system with zonal ventilation control

A new method of conditioning and distributing air through the multiple zones of an air-conditioned building is developed such that adequate ventilation, and consequently, acceptable Indoor Air Quality (IAQ) is ensured throughout the operating range of a Variable Air Volume (VAV) air-conditioning system (Sekhar et al, 2002b). It also provides the necessary ventilation while optimising energy consumption, realising the complete energy saving potential of a VAV system. The two air streams are mixed in a mixing box prior to ventilation into a room of a building. A carbon dioxide sensor and a temperature sensor provide feedback signals to a control system to regulate fan speeds and damper openings in the fresh air and recycled air systems. This provides optimal cooling and ventilation, and helps to conserve energy when cooling and ventilation requirements are low. Adequate ventilation and acceptable indoor air quality are thus maintained in each ventilation zone of a building.

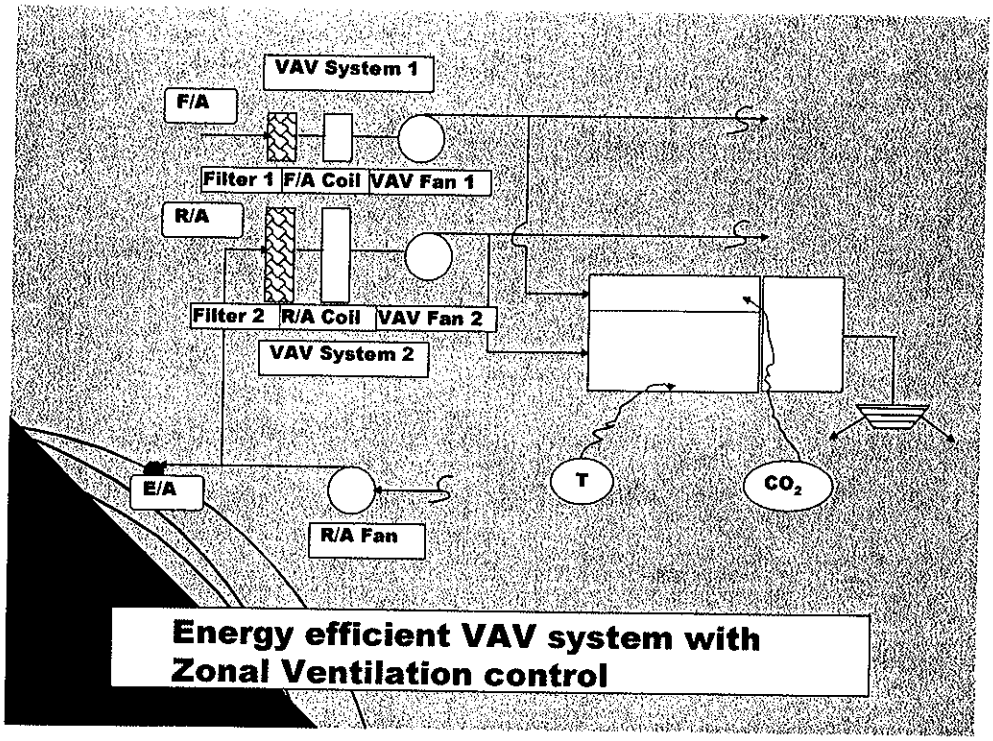

Figure 6. Energy efficient VAV system with zonal ventilation control.

Personalised Ventilation (PV) system

The concept of personalised ventilation (PV) is at the cutting edge of technological developments in the area of air-conditioning and is fundamentally based on improving ventilation to every individual in the built environment (Kaczmarczyk et al, 2002a and 2002b; Melikov et al, 2002). The notion of better ventilation and, thereby, improved Indoor Air Quality (IAQ) underpins the method of supplying conditioned air to the occupants and is essentially aimed at improving the health, comfort and productivity of the workforce. The PV concept has tremendous potential in enhancing the acceptability of ventilation, indoor air quality and thermal comfort in air-conditioned buildings by supplying clean fresh air directly to the occupant's breathing zone without mixing with recirculated air, which is usually contaminated with indoor pollutants. The inability of conventional air-conditioning systems to do so often leads to occupant dissatisfaction. The PV concept is also envisaged to lead to flexibility in the form of individual control of the microenvironment at the occupant level as well as significant energy saving potential through reduction of absolute fresh air quantities in the light of an efficient and effective air distribution system. Preliminary findings from a pilot study conducted at the National University of Singapore suggest that the use of the PV system in conjunction with a secondary air-conditioning system significantly enhances thermal comfort and IAQ acceptability as well as the perception of freshness in the air. The pilot study has also indicated that the PV system has a potential to save energy in tropical designs.

Conclusions

In the tropics, energy consumed by air-conditioning systems constitutes a significant proportion of the overall energy consumption. Following a brief description of the common air-conditioning systems employed for large commercial and office buildings in Singapore,

some emerging technologies addressing energy efficiency and enhanced IAQ have been presented in this paper. The importance of part load operating characteristics of HVAC system components, such as the cooling coil and the fan, is the basis of these technologies.

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Effective IAQ Audit for Total Building Performance

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BCA-NUS CTBP

EFFECTIVE INDOOR AIR QUALITY AUDIT FOR TOTAL BUILDING PERFORMANCE

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Abstract

Indoor Air Quality is a key performance mandate of Total Building Performance which affects occupants in a diverse number of ways – physiologically, perception and productivity. It is perhaps the least understood among the TBP mandates, and its complex nature requires knowledge-based expertise and a systematic methodology for effective evaluation and interpretation. A comprehensive understanding of the plausible causes of indoor air quality problems in the context of the building or premises being measured is necessary in the structuring of a measurement and monitoring plan. The execution of the monitoring and measurement must take into account the specific factors such as operation schedules, occupant density, material used, processes, equipment and so forth. Different types of measurement provides different information, and the relevant "IAQ signature" of the premises being audited must be determined right at the beginning to ensure an efficient and effective IAQ audit. The analysis and interpretation of the audit results and the subsequent recommendations should be made on a case-specific basis. This talk presents the principles for good practice in IAQ monitoring and measurement, and would be of interest to practitioners involved in IAQ auditing and the building management / owner in their consideration of calling for IAQ audits, with the eventual aim of achieving *total building performance.*

Key Words

IAQ Parameters, Monitoring, Measurement, Trends, Patterns, Causal Analysis

Introduction

Among the performance mandates, indoor air quality (IAQ) is perhaps the least noticeable and understood. The understanding and recognition of its importance vis-à-vis the other performance mandates have only recently been occurring. The effects of IAQ, however, are widespread, affecting occupants in a diverse number of ways. These may be described as the 3 'Ps':

1. Physiologically – as the human body reacts and responds to the chemical, physical and biological elements, the sense of well-being or the manifestation of sick building syndrome symptoms defines the range of possible experience.
2. Perception – research have begun to surface the linkages between the way an occupant perceives the indoor environment and the indoor environmental factors themselves.

3. Productivity – field and laboratory studies conducted in different parts of the world have shown convincing evidence of the positive relations between good indoor air quality and increased work performance, and economic analysis has indicated a staggering amount of money is lost through such loss in work performance or even absenteeism.

These 3 'Ps' are significant considerations in today's facilities where human resource and the potential issues arising from the effect of inadequate IAQ on humans can no longer be ignored.

Indoor air quality (IAQ) is a multi-dimensional issue and requires a systematic methodology for its effective evaluation. The end purpose of creating, delivering and sustaining good IAQ needs a total approach, and various processes are involved. IAQ audits are essential parts of a total approach to achieving good IAQ, and the measurement and monitoring of IAQ parameters are just 2 of such processes, but these are important and should be executed carefully in order to achieve as true an assessment of the IAQ of the building being audited.

This brief paper describes essential points to be considered in the effective measurement and monitoring of IAQ.

Measuring IAQ Parameters

A simple meaning of "measurement " is the process of finding out the extent of some quantity or quality. In measuring IAQ it is fundamental that we know *what* to measure, *how, when and where* to measure, and *why* the measurement is conducted.

What IAQ parameters to measure?

Undoubtedly, the measurement should include sufficient parameters to provide sufficient information to answer the questions related to the exercise. Every problem or audit has its defined scope determined by technical considerations and constrained by budgetary provisions.

The dimensions of IAQ must first be established before the scope of what to measure is decided upon. These dimensions include:

- Chemical
- Microbial
- Physical

Chemicals

The chemistry of indoor air is a very complex and dynamic phenomenon. There are constant interactions between sources, sinks and media of transmission, as well as catalysts and inhibitors to chemical reactions. There are emissions from building materials, fabrics, carpets, office machinery and stationery, even humans. There are sinks which absorb some of these emissions and subsequently release them into the air under suitable conditions. For example, fabrics smell of perfume when the wearer has long left the room. There are even dynamic reactions such as photo-oxidation of the volatile organic compounds within the room itself.

There is such a long list of chemicals, particularly the volatile organic compounds (VOCs) that it is both expensive and impractical to attempt to measure them. Instead, a surrogate indicator, called Total Volatile Organic Compounds (TVOC), is advocated to be measured by many health authorities. Formaldehyde is a specific VOC of concern because of its common occurrence in buildings and its known carcinogenic effects. At low levels, it is an irritant to the eyes, nose and throat.

Carbon Dioxide is another chemical commonly measured as it provides a good indicator of the adequacy of the provision of fresh air for the dilution of contaminants. By itself, carbon dioxide is non-toxic at commonly encountered levels in buildings; indeed the harmful levels are a few orders of magnitude higher than what is usually experienced. Its value is that it acts as a surrogate indicator of other pollution when the scope or budget of the IAQ audit does not provide for a thorough measurement of the other contaminants.

Indoor air is constantly replenished by outdoor air. In our urban environment, particularly in areas bounded by heavy traffic or close to carparks, the induction of unwanted products of combustion (or incomplete combustion) may be of concern. Hydrocarbons, especially benzene from petrol, form one target group of concern, though it is expensive to identify and quantify the concentration levels. Carbon monoxide is often measured, as it is relatively inexpensive to do so, and it also provides a good surrogate indicator of such contaminants.

Other chemicals to be measured is determined largely by what is suspected to be of concern – either related to the processes occurring within the building, the types of materials used, or the sources of pollution from the immediate environment.

Microbial

Microbials are micro-organisms that exist in symbiotic relationship with the environment. We are constantly exposed to them, and indeed, ourselves are generators of microbial contamination. Indeed, the basis of ventilation, when it was first introduced, was to deal with the bio-effluent contamination from the occupants. When we speak of body odour in occupied spaces, we refer to the inadequacy of the ventilation system in dealing with the microbial contamination generated by the occupants. Other common sources are food, deterioration of discarded food, insects and animal discharges, and so forth.

Again, there are so many strains and species of microbials, not all of them having adverse impact on the human immunological system, that it is exhorbitantly expensive and impractical to identify and measure them. Two broad indicators are commonly measured : Total Viable Bacteria Counts and Total Viable Yeasts and Molds counts. The former provides an indication of the bacterial exposure, while the latter provides indication of the plant and fungi related exposures.

Physical

These are dimensions that we are more familiar with: dust which our breathing system has to deal with; thermal comfort parameters such as temperature, relative humidity and air movement; electro-magnetic radiation levels.

Many studies have provided very strong evidence that the perception of IAQ is dominated by thermal and draught sensations. Cold, dry air is perceived to be better than warm, humid air

though the pollution levels are similar. High humidity fosters the growth of microbials and molds and commonly produces a musky smell, such as experienced in a carpeted room after the ventilation (or air conditioning) system has shut down.

Subjective Responses

The human being is an extremely good synthesizer of IAQ parameters from all these 3 dimensions of chemical, microbial and physical. The olfactory sense is fairly acute and chemicals and microbials are usually detected even though the recommended threshold levels are not exceeded. Perceptions of stuffiness and stillness are frequently good indications of poor IAQ. For these reasons, the human response and perception provides a very important assessment of IAQ.

Questionnaire survey techniques and forms have been developed for the measurement of sick building symptoms, perceptions and satisfaction with the indoor environmental quality. These are essential in the measurement of IAQ as it has been demonstrated by many studies, including those conducted in the European Union as well as in Singapore, that 30% of the occupants report SBS symptoms although the measured values of the basic IAQ parameters are within recommended threshold values.

How to measure IAQ parameters?

Following from the above discussion, IAQ parameters need to be measured by *objective* as well as *subjective* means. It is here that the issues of level of precision, reliability and completeness of information need be considered.

Generally, the more precise the measurement, the more expensive and time-consuming it becomes. The level of precision must be justified by the purpose of the measurement. While it is sufficient to have an approximate measure of the level of TVOC level to determine if the exposure to VOCs is acceptable, it is important that the concentration level of a toxic compound be measured as precisely as possible.

The measurement method should also be reliable so that the repeatability and validity of the measurement is not compromised. The error incurred should be within acceptable limits, otherwise misjudgment may arise from instrument unreliability rather than actual variation in the contaminant levels.

The importance of completeness of information is perhaps most under-estimated in practice. As IAQ varies dynamically, it is essential that the sampling strategy provides adequate information that captures the dynamics of the space being measured. These variations may be due to operation schedules, occupancy schedules, and even random occurrences of events or activities. A good example is the carbon dioxide profile. A typical profile exhibits an "M"-shaped graph: rising from ambient levels in the morning with the arrival of occupants to a peak just before lunch, then falling to the valley as occupants break (and leave the building) during lunch, and then building up to another peak before the occupants leave at the end of the day. It is obvious that if "spot" measurements were conducted, then the level measured depends on the part of the "M" curve during which the reading is executed.

This raises the consideration of "continuous" versus "spot" measurements. Ideally, the continuous measurement is preferred over a reasonable cycle determined by building,

occupancy, process and activity characteristics. However, this may be expensive. But continuous measurement should not be dismissed from the economic consideration. Many important characteristics are captured by such continuous measurement, such as:

- Emission and de-sorption profiles of materials and fabric
- Ventilation characteristics
- Infiltration characteristics
- Exposure levels, particularly due to build-up overnight
- Trend recognition in cause-relationship analysis

In situations where one does not expect much variation, or that some degree of variation is acceptable, or indeed desirable, cheaper "spot" measurement techniques are suitable. These include temperature, humidity, air movement and dust measurements.

Whatever method is adopted, it is important to recognize the merits and limitations of the method so that qualified conclusions are arrived at with confidence. One should never attempt to extrapolate prognosis beyond the validity of the method used, and this must be made clear to the consumer of the report.

Where to measure IAQ parameters?

Determining the locations for measurements is a very practical issue which must be guided at least by the following considerations:

- How representative of the IAQ entire space would measurements at these locations be?
- Do the measurements provide an accurate and reliable assessment of the exposure of the occupants?
- Do the measurements capture the strength and effects of suspected contaminant sources?
- Are there sufficient reference measurements of the immediate environment with which the audited space interacts with?

Representation in space and IAQ is difficult to ascertain accurately, but may be achieved satisfactorily by some preliminary observations and investigation. Air is invisible, and it is almost impossible to determine the actual patterns of air movement and the resultant contaminant movement in space. Factors which determine this include:

- Office partitions and configuration
- Furniture
- Supply and return diffusers
- Thermal sources
- Contaminant sources and sinks
- Human presence and movement
- Processes and activities

The greater the understanding of how these factors may interfere or determine the air flow and contaminant flow patterns, the better the choice of locations would reflect the IAQ of the space audited. It comes with technical expertise and experience, and is largely a knowledge-based judgment call.

A major purpose in the measurement of IAQ parameters is to ascertain the exposure of the occupants to these contaminants. A logical location of measurement would be where the occupant is, and indeed should be within the "breathing" zone and as close to the occupant as practically possible. It should also take into account the micro-environment of the occupant so that the "windward" space is assessed instead of the "leeward" space.

There are numerous readily identifiable sources of contaminants in the space, such as carpets, photocopiers, computers, shelves, etc. The workflow processes and dynamic process-activated or human-activated emissions must be considered. Taking or replacing documents in densely packed shelves, for example, generates instantaneous release of particulates. A computer placed on carpets encourages the emission of VOCs from the carpet into the thermal plume generated from its heat. If there are suspected sources and the strength of the emission, or the effects of its emissions created as a result of interaction with the air flow patterns are of concern, then the locations of the measurements must be selected to provide measurements of these effects.

Obviously, the IAQ of a space is influenced very much by the adjoining spaces with which they interact, as well as by the ambient environment from which it draws its fresh air and the HVAC system through which the air is treated and distributed. The technique of indicative subtraction may be applied to identify the extent to which the IAQ is affected by such interactions. Sometimes the problem lies not within the space being audited but in the adjoining or ambient locations.

When to measure IAQ parameters?

This indeed is a question of timing! A good analogy is to ask "How much of a day must one see of a place to get an accurate impression of what goes on throughout the day in that place?" Or attempting to decide when and how many times must one observe the traffic along a road to provide an answer to a question on the daily traffic conditions on that road.

Would a static assessment suffice, or does it need to be continuous? There are resource and therefore cost implications. One must therefore reflect on the purpose and then decide what frequency of information is required for the measurement. Events and schedules which affect the IAQ must be considered, such as:

- Occupancy patterns
- Ventilation and air-conditioning schedules
- Operation and maintenance schedules and materials used
- External contaminant profiles
- Infiltration characteristics
- Air change

I offer some considerations for thought:

- Optimize the frequency of measurement to capture the essential dynamic characteristics
- Plan for a "time-series" measurement to provide trends associated with occupancy, equipment and processes
- Plan for intervals of measurement that is necessary to capture important "transients" generated by relevant events such as the decay of chemical contaminants from introduction of fresh air in the first hour of HVAC operation.

Why measure IAQ parameters?

I have intentionally left this issue to be discussed last, simply because the reasons are pretty much obvious. These include:

- Establishing the status quo of IAQ for conformity to statutory requirements
- Establishing the presence or absence of a suspected problem raised voluntarily or involuntarily
- Identifying areas and extent of improvement
- Evaluating the impact of changes arising from changes in occupancy, processes, materials, renovation, etc.

It should be pointed out that IAQ measurements are sometimes commissioned from a biased intention. It may be scoped artificially to prove an *a-priori* assumption, or even to rationalize the existing status quo.

One must be aware of the intention of the measurement when evaluating an IAQ audit report, or an IAQ investigation report. What is left uninvestigated is often more telling than what has been investigated.

Independent, unbiased expertise is recommended in dealing with IAQ measurements.

Monitoring Indoor Air Quality

Measurement provides a snapshot of the status of IAQ of a building. Monitoring provides medium to long term information of its IAQ. The importance of monitoring lies in its value in:

- Identifying trends
- Identifying patterns
- Causal analysis

Identifying trends

This addresses the *temporal* perspective, taking into account the fluctuations and drifts that occur over time. These are determined by the many changes, whether human-initiated or naturally occurring. The question raised is: "What trends in IAQ are detected?" with follow up questions of "Do these trends need be addressed?" and "To what extent are actions necessary?".

Just like a medical record through time provides salient information on the health trends of a person, the monitoring information through a series of planned measurements provides information of the trends of change in the IAQ for a building. The following characteristics of the trends are important in determining the answers to these questions:

- Nature of the trend – is it benign or is it showing improvement / deterioration?
- Magnitude of change in the trend – are changes occurring slowly over time or are they happening rapidly?

- Cyclical – do changes occur in a cycle which may then be related to factors of a cyclic nature, e.g. seasons?

An example would be rising carbon dioxide levels over subsequent measurements due to increased occupant density. Another example would be the rising levels of humidity and temperature in the space due to increased fresh air intake from an air-conditioning system that has exceeded its initial load handling capacity.

Knowing the characteristics of the trends constitutes a basis for determining the type of actions, remedial or otherwise, that may be necessary. This is essential information for the professional management of the IAQ of a building.

Identifying patterns

While trends provide information of temporal variations, patterns provide information of a *spatial* nature. It identifies areas of a building which exhibit patterns that are:

- Commonly occurring
- Localized phenomenon

Such patterns provide succinct information on the nature of IAQ problems. Clustering of high contamination give clues as to:

- common sources of contamination (computers, high occupant densities, etc)
- undesirable leakages (from controlled equipment)
- undesirable build-up of contaminants (e.g. ductworks, filters, etc)

An example would be high levels of carbon dioxide and total viable bacteria counts occurring within zones served by a pre-treatment fresh air AHU providing insufficient quantity of fresh air.

Another example would be high humidity levels consistently measured along a poorly detailed façade, or a basement wall abutting moist soil conditions.

These provide powerful problem-identification and facilitate problem-solving capability. Again, the ability to discern patterns and to associate it with building characteristics, O&M strategies, possible building defects, etc is a highly skilled expertise that requires excellent knowledge of building physics and facilities management.

Causal analysis

Causal analysis identifies the chain of effects from sources of IAQ contamination to the impacts along the paths of the causal chain. It is indeed one of the highest value addition that should be derived from IAQ monitoring.

Through a series of measurements, the occurrences of discrete manifestations can be firstly identified, and then pieced together through a knowledge-driven analysis. The effects of a causation may be mapped onto known consequences, and in the process, the weakness of the system are identified.

Increased levels of dust and bacterial contamination in a conditioned space over a series of measurement may be traced to inadequate filtration system, for example.

Beyond IAQ Measurement and Monitoring

Measurement and monitoring are two important elements in the total process of creating and sustaining good IAQ. The management of IAQ is equally essential for:

- the optimization of resources in a cost-effective manner
- the achievement and sustenance of a high image of pro-active, progressive and occupant satisfaction focus
- improved working conditions for occupant satisfaction and enhanced occupant performance
- mitigation of building and system or operational and maintenance inadequacies

There is the scientific and technical perspective to effective measurement and monitoring of IAQ for healthy buildings, but the perfection of its application into an art remains the treasure of a few.

Achieving good IAQ is a significant contribution to achieving total building performance. The considerations and strategies involved in achieving good IAQ are aligned with the protocols and practice of attaining TBP.

Cost Benefits of IAQ through Effective Facilities Management

Mr Jeffrey J Budimulia

Deputy Director

PREMAS Environ Pte Ltd

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A Leading Total Real Estate Manager

COST BENEFITS OF IAQ THROUGH EFFECTIVE FACILITIES MANAGEMENT

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AGENDA

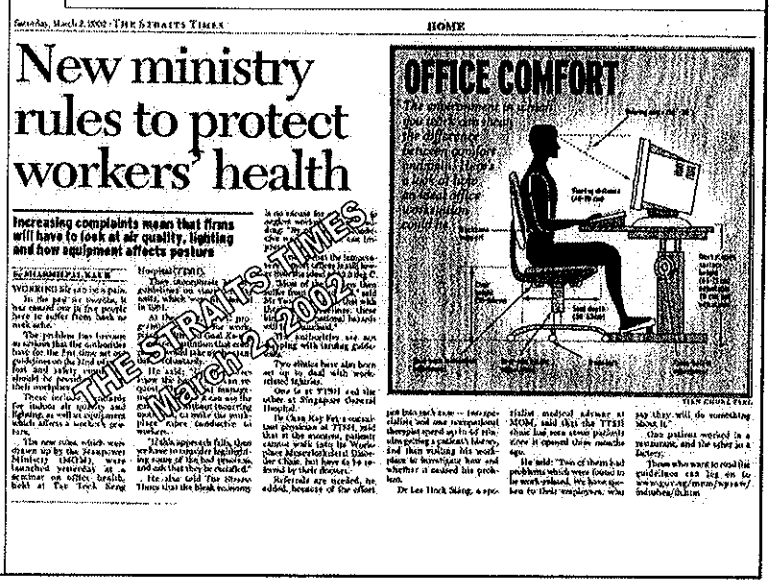
PREMAS INTERNATIONAL

1. INTRODUCTION
2. IAQ AWARENESS
3. EFFECTIVE FM
4. CASE STUDIES
5. COST BENEFITS
6. CONCLUSION

Agenda

AWARENESS

PREMAS INTERNATIONAL


Saturday, March 2, 2002 · THE STRAITS TIMES

HOME

New ministry rules to protect workers' health

Increasing complaints mean that firms will have to look at air quality, lighting and how equipment affects posture

THE STRAITS TIMES March 2, 2002

Agenda

AWARENESS

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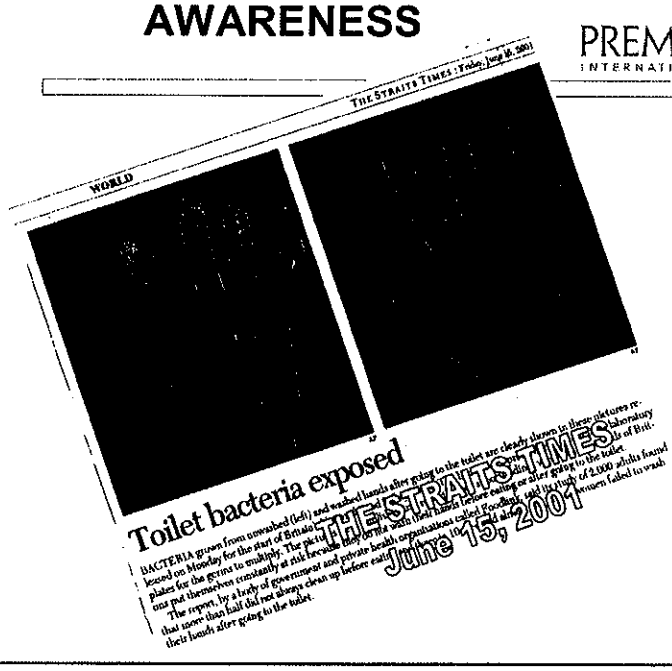
THE STRAITS TIMES : Friday, June 15, 2001

WORLD

Toilet bacteria exposed

THE STRAITS TIMES June 15, 2001

AWARENESS

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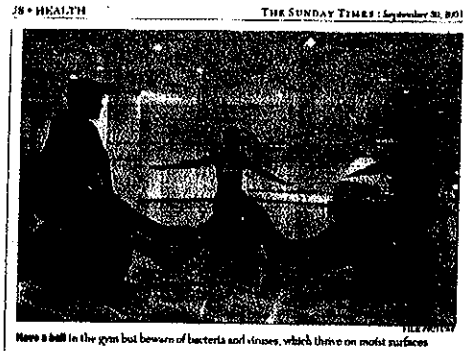

Have a ball in the gym but beware of bacteria and viruses, which thrive on moist surfaces

GYM DANGER

Get fit or get sick in workout?

GYM DANGER

Get fit or get sick in workout?

While working out a sweat at the gym may be healthy, the equipment [illegible] also breeding ground [illegible]

THE STRAITS TIMES September 30, 2001

NEW YORK — Pangi, folliculitis and the flu are just a few of the nasty ailments you can catch at your health club.

Mr Julie McNeney, vice-president of marketing at the Health and Fitness Group in Vancouver, says: "The gym is an ideal breeding ground for bacteria, not to mention viruses and other micro-organisms.

"You're not going to get sick from sweat, but from the invisible-to-the-naked-eye viruses and bacteria that can multiply in moisture."

With that in mind, experts suggest that gym-goers be wary of all shared gym equipment — even fitness balls, yoga mats and free weights.

"These bacteria can cause all kinds of infection and skin ailments," says Mr Adam Urquin, manager of Equinox Fitness Training Institute in New York.

He suggests carrying a towel to [illegible]

And that includes stationary bike seats, too.

"The your own seat or seat cover to your spinning class. People work up so much sweat in these classes and, if the rooms are too hot, bacteria can be all over the equipment," he says. "And that can get nasty."

Steamy showers, poolside puddles and wet bathroom floors are microbial hot spots, as they offer the perfect climate for the spread of skin-irritating fungi.

"Athlete's foot is the most common fungal infection you can pick up," says Dr Bruce Katz, a clinical professor of dermatology at The College of Physicians and Surgeons of Columbia University and director of The Cosmetic Surgery & Laser Clinic at Columbia Presbyterian [illegible]

[illegible] dry skin can be [illegible] foot," [illegible] says.

The best prevention? Wear a pair of cheap flumps to keep your feet off these surfaces.

Dirty hot tubs are another hazard. "If a gym doesn't use enough chlorine or germicidal chemicals, you can get hot tub dermatitis."

Otherwise known as folliculitis, this infection of the hair follicles is marked by itchy red bumps or white pustules.

So, watch where you stop and take care when you take a seat in the sauna or shower areas as "you can get jock itch, an infection of the groin area", warns Dr Katz.

— FASHION WIRE DAILY

Agenda

AWARENESS

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Cooling towers [illegible] cleaned regularly under new [illegible] aimed at preventing Legionnaire's disease

Legionnaire's laws won't cure 'sick' buildings

Legionnaire's laws won't cure 'sick' buildings

THE STRAITS TIMES August 14, 2001

[illegible]

Agenda

AWARENESS

PREMAS INTERNATIONAL

ST 17/12/2001

Bad air harmful to unborn babies

THE STRAITS TIMES

December 17, 2001

Scientists say the [illegible] by air pollution

LOS ANGELES — A growing body of research from around the world is [illegible] unborn babies.

Scientists have long known that the extreme levels of smog in the developing world can harm babies, but the latest research shows that the harmful effects of dirty air can extend even into the world.

More than a dozen studies in the United States, Brazil, Europe, Mexico, South Korea and Taiwan have [illegible] to low birthrates [illegible] the [illegible].

In the United States, the research has documented ill effects on infants even in cities with modern pollution controls.

"Smog can harm the health of babies," said Dr Beate Ritz, an epidemiologist at the University of California, Los Angeles (UCLA) Centre for Occupational and Environmental Health.

"This should make us pause. Air pollution doesn't [illegible] the [illegible] of their life, and that can disadvantage people throughout their life."

[illegible] conducted [illegible] for the first time links air pollution and birth defects in Southern California.

The researchers found that women exposed to high levels of ozone and carbon monoxide were three times more likely to have babies with left lips and palates and defective heart valves.

The study covered thousands of pregnant women in the Los Angeles area from 1987 to 1993 and compared those living in areas with relatively dirty air to those living in cleaner areas.

Virtually the entire study area met federal standards for carbon monoxide, and much of the region complies with ozone requirements.

The study, to be published in the American Journal of Epidemiology, found that the greatest risk occurs during the second month of pregnancy, when a foetus gains most of its organs and much of its facial structure.

Another study by scientists from the Harvard School of Public Health and the University of Basel in Switzerland concluded that as much as 15 per cent of infant deaths in the US — some 3,000 per year — might be a result of microscopic particles in the air.

In a separate study, scientists from the US and Switzerland found that pregnant women in five US cities who were exposed to elevated levels of carbon monoxide during their third trimester were 31 per cent more likely to give birth to underweight babies.

Research done on pregnant women in Sao Paulo, Brazil, also found that women exposed to high levels of nitrogen and sulphur oxides were 16 per cent more likely to have their pregnancies end in stillbirths. Nitrogen and sulphur oxides are produced by fuel combustion in vehicles and factories.

— Los Angeles Times

'AIR POLLUTION DOESN'T JUST HAVE AN IMPACT ON ASTHMATICS AND OLD PEOPLE AT THE END OF LIFE, IT CAN ALSO AFFECT PEOPLE AT THE BEGINNING OF THEIR LIFE, AND THAT CAN DISADVANTAGE PEOPLE THROUGHOUT THEIR LIFE.'

— Dr Beate Ritz, an epidemiologist at UCLA's Centre for Occupational and Environmental Health

Agenda

AWARENESS

PREMAS INTERNATIONAL

Half of 57 offices studied unhealthy, say NUS and ENV

The Straits Times

50%

60%

ABOUT half of the 57 commercial offices studied by the National University of Singapore and Ministry of the Environment had unhealthy levels of carbon dioxide and cancer-causing formaldehyde from furniture glue.

This was one of the findings presented at the [illegible] research [illegible] Cheng, leader of the research team and senior lecturer in NUS' Department of Community, Occupational and Family Medicine, said that the problem could be solved by improving ventilation.

He said that the concentration of formaldehyde in about 50 per cent of the offices exceeded the American Conference of Governmental Industrial Hygienists' limit for industrial use.

The formaldehyde in new furniture takes a few years to vapourise, and affects the atmosphere during this period.

Meanwhile, about 60 per cent of the offices exceeded the healthy limit of [illegible] per million of carbon dioxide. The levels ranged from [illegible] per million in the [illegible] tect the health of workers.

Poor ventilation was often due to attempts to cut electricity costs, he said.

By keeping cooled air in the building and preventing warm air from entering, less energy would be needed to air-condition the offices.

He said that as 42 per cent of the 770 office workers interviewed thought that their offices were too cold, increased ventilation would not only keep the air clean, but also increase temperature to a more comfortable level.

of the offices had formaldehyde which exceeded the American Conference of Governmental Industrial Hygienists' limit for industrial use. The formaldehyde [illegible] furniture takes a few years [illegible], and affects the [illegible] during this period.

of the offices exceeded the healthy limit of 800 parts per million of carbon dioxide.

The carbon dioxide levels ranged from 470 to 1,560 parts per million in the buildings which were studied by the NUS and ENV.

tween the ministry and universities could pave the way to make Singapore a leading centre on environmental science and technology.

He said some of the studies had already yielded tangible benefits. For instance, a private company has adopted the method developed by NTU and ENV to use fine ash from burnt garbage as a substitute for 20 per cent of the cement in concrete.

He said the next step could be joint research on environmental policies. Another possi-

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AWARENESS

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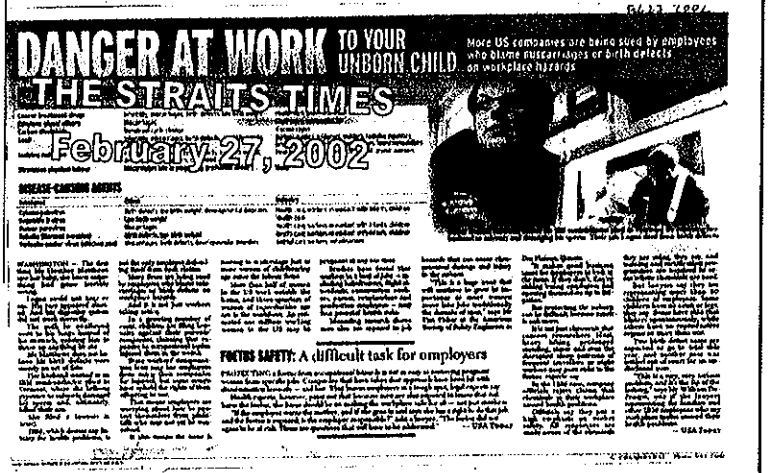
DANGER AT WORK TO YOUR UNBORN CHILD

More US companies are being sued by employees who blame miscarriages or birth defects on workplace hazards

THE STRAITS TIMES

February 27, 2002

FOCUS SAFETY: A difficult task for employers

Agenda

AWARENESS

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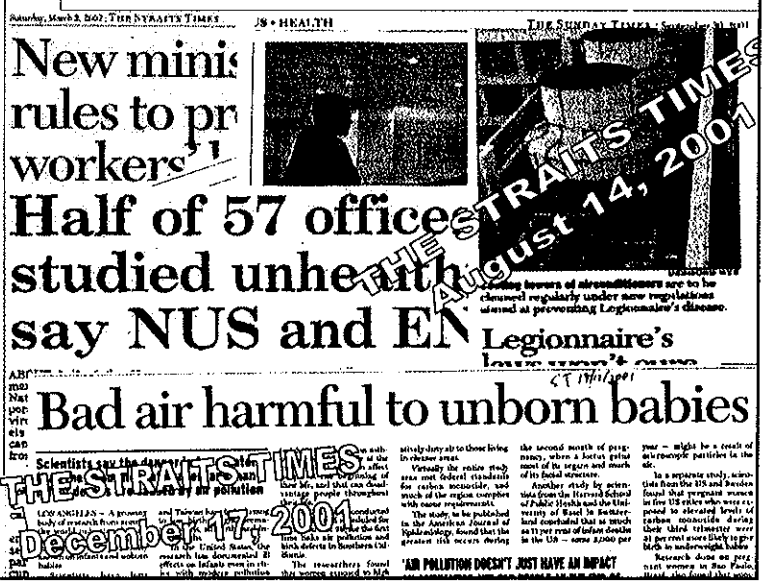
New minis rules to pr workers'

Half of 57 office studied unhealth say NUS and EN

THE STRAITS TIMES August 14, 2001

Legionnaire's

Bad air harmful to unborn babies

THE STRAITS TIMES December 17, 2001

'AIR POLLUTION DOESN'T JUST HAVE AN IMPACT

Agenda

CAUSES OF POOR IAQ

PREMAS INTERNATIONAL

National Institute for Occupational Safety & Health (NIOSH) :

- Inadequate ventilation 53%
- Inside Contaminants 15%
- Outside contaminants 10%
- Microbial Contaminants 5%
- Bldg Material contaminants 4%
- Unknown 13%

For humid environment, microbial contaminant could be much higher.

Agenda

WHY THE IAQ ISSUES?

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- Conflict of interest between income and expense with not much concern on outcome.
- Interesting to note that the air outside is in better shape than indoor air.

Agenda

WHY IAQ COMPLAINTS ARE INCREASING ?

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- Bldg are air tight - codes are dominated by energy consideration
- Health issues : asthma, allergies, new strains of bacteria, virus (drug resistance)
- People better informed thru the media, internet
- Mixed use of space
- High Tech Manufacturing
- External Factors:
  - Haze
  - Global warming

Agenda

INTERNAL CONTAMINATION

PREMAS INTERNATIONAL

- Commercial Buildings :
  - Rental Cost : Increased building population per floor
  - 24 Hr operation : No rest for equipment
  - Change of use : e.g. Car park to food court
  - Frequency of tenancy changes : Fitting out
  - Office equipment : copier, printers, computers.
  - Air freshener and cleaning compound
  - Construction materials : glues, particle board, paints
  - Water infiltration : Fungi, mold, bacteria

Agenda

IAQ IS A CONCERN

PREMAS INTERNATIONAL

- Increased incidence of asthma, respiratory illnesses, lung cancer
- Focus has been on outdoor pollution (car emission, Clean Air Act), complacent on indoor air although we spend 90% of our time indoor
- Frog in warm water analogy

Agenda

EFFECTIVE FM

PREMAS INTERNATIONAL

- Maintenance
- Design
  - Have a say to what goes in
  - Change of use
  - Design of Facilities
- Maintenance
  - Handing/Taking Over
  - Predictive Preventive Maintenance
- New Technologies
  - Be Aware of what's new and what works!
  - Net Work

Agenda

DESIGN – HAVE A SAY!

PREMAS INTERNATIONAL

- Fresh Air Fan – The NOSE
  - Source of air
  - Near by gaseous contaminants
  - Near solid contaminants
  - Wind direction
  - Terrorist Threat
- Change of Use
  - Work in Progress contamination
  - Type of Exhaust e.g. food
  - Sufficient treated and Fresh air
  - Existing capacities of Facilities Equipment
  - Cross Contamination of air

Agenda

HANDING/TAKING OVER

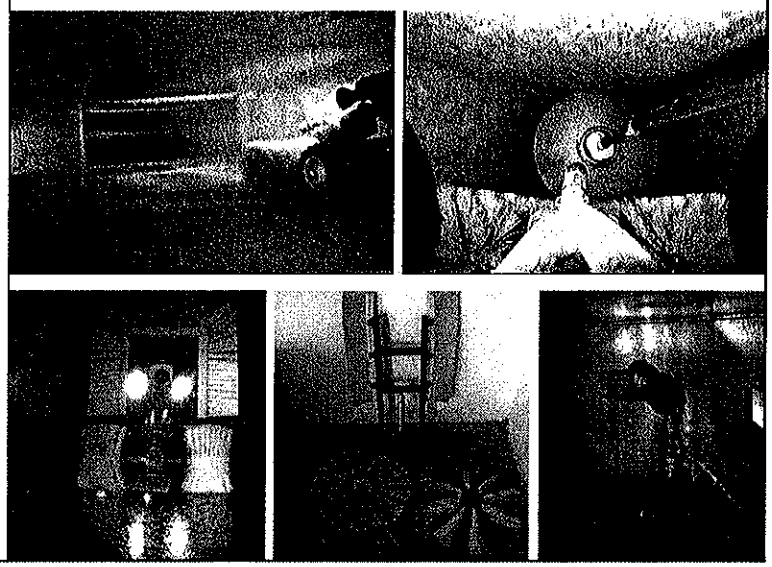
PREMAS INTERNATIONAL

- Surprising number of things one can find at a "completed"job site.
  - Leftover food packaging
  - Dead animals
  - Debris
- Surprising locations these can be found.
  - Room
  - Air Duct Work
  - Site

Agenda

MAINTENANCE DUCT CLEANING

PREMAS INTERNATIONAL



Agenda

MAINTENANCE & IAQ

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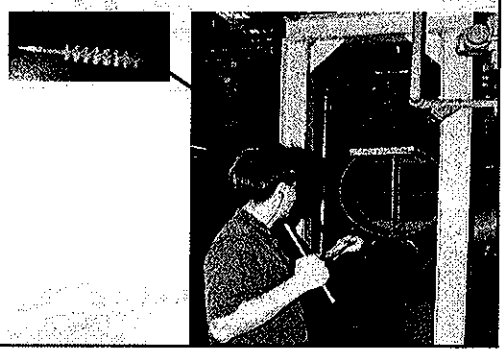
- Cooling towers
  - Legionella bacteria : moisture + oxygen + warm water + food supply
  - Spray mist entering air distribution system
- Fan coil Units/AHUs
  - Cleanliness of filters
  - Fan working
  - Chill water/refrigerant input

Agenda

CHILLER MAINTENANCE

PREMAS INTERNATIONAL

- **Ensure efficiency of chiller**
- **Ensure system integrity**



Agenda

NEW TECHNOLOGIES

PREMAS INTERNATIONAL

- Do you know that .....
  - There is a static device that can neutralize cigarette smoke up to the smell of a sewage plant.
  - There is a cloth duct work that allows ease of cleaning, application and improves aesthethics



Agenda

COST BENEFITS

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- New Set Up w/o Issues
  - Get what you pay for
  - Cost Avoidance
- Equipment/System greater efficiency
  - Savings in Operational cost
  - Greater Reliability
  - Cost Avoidance

Agenda

COST BENEFITS- EMPLOYEES

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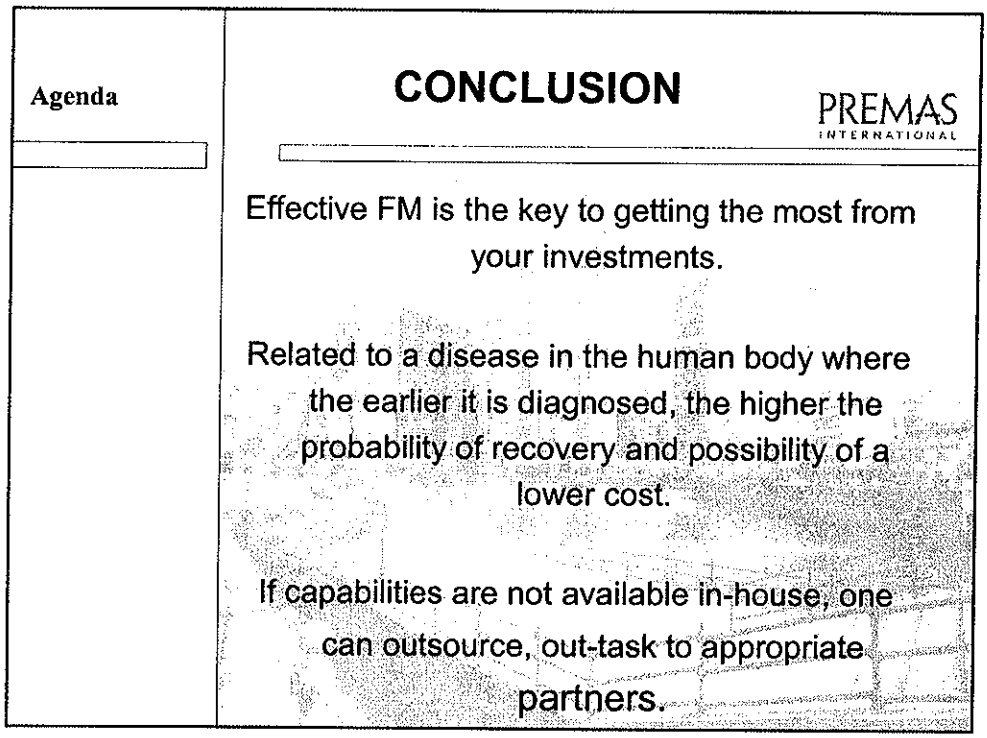
All these benefits are indirect;

- Reduced IAQ related illness
- Better Morale
  - Reduced turnover
  - Increased Productivity
- Less Likely of Litigation


Agenda
CONCLUSION
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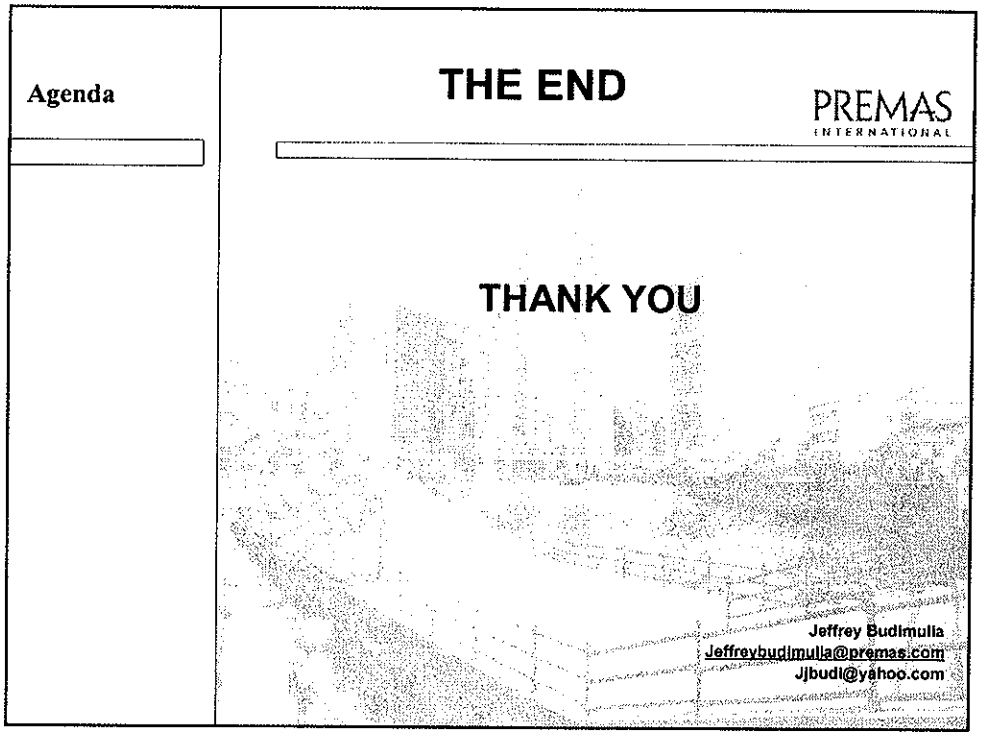
Effective FM is the key to getting the most from your investments.
Related to a disease in the human body where the earlier it is diagnosed, the higher the probability of recovery and possibility of a lower cost.
If capabilities are not available in-house, one can outsource, out-task to appropriate partners.


Agenda
THE END
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TOTAL BUILDING PERFORMANCE FOR MANAGING INNOVATION AND CHANGE

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Abstract

Like many other countries, Singapore's construction industry is undergoing a significant stage of adjustment, re-structuring and re-invention. It is a widely accepted idea that the construction industry should move away from minimum cost mindset, and move towards a maximum value add or quality mindset. The obstacles for the development of a performance oriented industry have been identified. They include the needs for the development of a performance measurement and verification system, and a performance and/or quality valuation system. The methods towards achieving such a system have been discussed.

It has been justified that the Total Building Performance framework is ideally suited for the development of the various tool kits required. The usefulness of TBP as an engine for the innovations and their management has been explained. The various innovation niches within the total construction value chain have also been identified and discussed. The role and function of the Centre for Total Building Performance in the development of a performance oriented construction industry has been explained. The CTBP has successfully generated a conducive environment for performance services development and innovations. It pivotal role in bringing about synergistic development among industry players, academicians and authorities has been emphasised.

Key Words

Total Building Performance, Performance oriented industry, Innovation.

Changing Operating Environment → Opportunities

All sectors of the economy suffer from the effects of economic cycle. The Construction Industry suffers its fair share of ups and downs. Many blame it for the uncertain operating environment, and hence the inability of companies to invest in R&D and long-term development. The current downturn, however, has been a much prolonged one for the construction industry. This has sparked many speculations that this is not an ordinary downturn, and that the route of recovery to healthy growth will not be the same as what it used to be. There are the following effects:

- Hollowing out effect caused by the emergence of China
- Re-structuring of the local economy to meet the challenges of the region

- Global re-structuring towards knowledge-based economy
- The accelerated impact of Information Technology
- The maturity of Singapore's economy.

Of course, within the construction sector, it has its own set of business issues. These are:

- Slow uptake of technology in a rapidly changing world
- A largely traditional labour intensive industry
- A fragmented industry
- Lacking in quality differentiation—a minimum-cost motivated industry structure.

The above listed national and regional economic development trends, and the industry issues represent some of the key threats and weaknesses facing the industry. At the same time, these are the opportunities where innovative development in processes and products may emerge. It is useful to examine these threats and weaknesses carefully and explore strategies and products for mitigating these impacts and closing the technology gaps.

It is also noteworthy that, in many ways, Singapore is not alone. Early this February, a meeting was held in Manchester, UK, for Construction Authorities and National Centres from all over the world to compare their national strategic plan derived during the turn of the century (2000), including Singapore and its C21. One of the findings was that many countries are facing the same set of problems. There is therefore significant scope for international cooperation. This is perhaps an effective and strategic means to address some of the issues.

For example, Finland is in the process of re-inventing its construction industry through multi-disciplinary synergy. They have created real estate and construction clusters to deal with the problems holistically, impacting the entire value chain of a building life cycle. The process is guided by one logo:

"From Minimum Cost to Maximum Value Add"

This shows that the "Minimum Cost Syndrome" is not unique to Singapore.

Towards a Quality/Performance Oriented Industry

It is important to establish the relationship between "Quality" and "Performance". Quality of any kind or class must be able to measure in terms of performance, objective or otherwise. If a quality specifier or descriptor cannot be translated into a performance standard, then its need should be questioned. Hence, the movement towards a quality-based industry is underpinned by performance-based instruments. The need for moving towards a "Quality Oriented Construction Industry" is well established and internationally recognised. The question is how and on what platform. It is recognised that the barriers for a quality-based system are:

a. The lack of a recognised quality differentiation system
b. The lack of a measurement and verification system
c. The lack of a valuation system for different classification of quality
d. The long life-span of major building products and systems.

It is important that major institutional frameworks such as those mentioned above are put in place urgently if the industry is serious about moving forward to a "Quality-based Industry". The way ahead is in overcoming the various barriers. The platform is of course the performance-based approach.

A quality differentiation system must be able to clearly benchmark and classify different levels of quality with respect to different stages of work and different stake holders. For example, the standard of design input must be differentiated and classified. One cannot expect a one-man-show small architecture firm to levy the same fee as a major international firm such as Foster and Associates. Similarly, one cannot expect the same unit rates from a small renovation contractor as those of a major general contractor.

The entire value chain of a construction project must be subjected to the same level of evaluation, differentiation and classification. This is to ensure that a quality-based procurement system may be consistently implemented. Hence such a system must embrace design brief, design, project management, construction, and facility management. The system should be clearly defined and transparent. It should be recognised and accepted.

Where possible, quality indicators should be measurable. The ability to objectively measure and verify that a specified quality has been delivered is important. It reduces the doubts and suspicions at the procurement stage. While it is understandable that not all quality indicators are measurable, this is particularly obvious when it comes to design quality concerning aesthetics; it is however possible to optimise on the quantifiable indicators and develop performance measurement and verification protocol. This would make the quality factor of a construction project a measurable quantum. Currently, the practice of quality control at the design and procurement stage is through a set of specifications and standard testing methods. In most cases, they are so generic and cover such a wide scope that most contractors who are tendering do not bother to read them. They are not usually strictly implemented, and to the contractors they are also usually not a cost issue unless they have been particularly notified and cautioned. In many situations, those quality specifiers indicate the minimum acceptable standards rather than a particular standard consistent with the needs of the project.

The ability to value quality standards puts in place the basis for quality differentiation. Once there is a price tag for quality, and different prices for different qualities, then quality is a serious business. This also means that a rationalised approach for the selection of a quality system and benchmark is required. It enables developers to clearly differentiate and measure the value-add offered by a designer, contractor or system supplier. The companies that champion it will be properly rewarded.

The long life-span of building products may complicate the valuation process. This may be managed using different valuation instruments and concepts to meet different needs. For example, the life-cycle cost and/or assets management approaches may be applied under different circumstances.

Figure 1 shows the importance of the measurement and verification protocol. It underpins the entire decision process across the entire construction value chain in the project. This is rightly so if the industry is to move towards a quality-based industry.

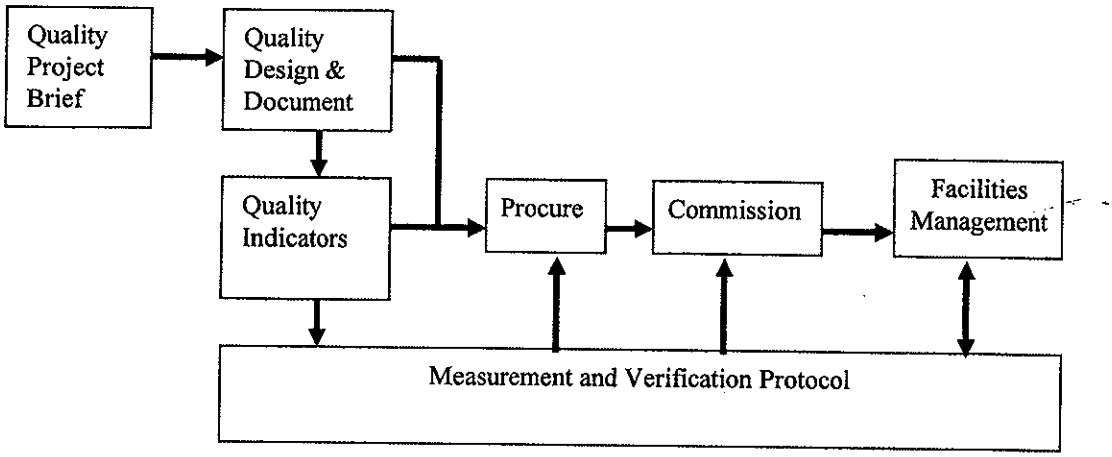

Figure 1. Quality performance relationship with the entire construction value chain.

This quality system may be translated into performance-based processes throughout the various stages of work, as shown in Figure 2 below.

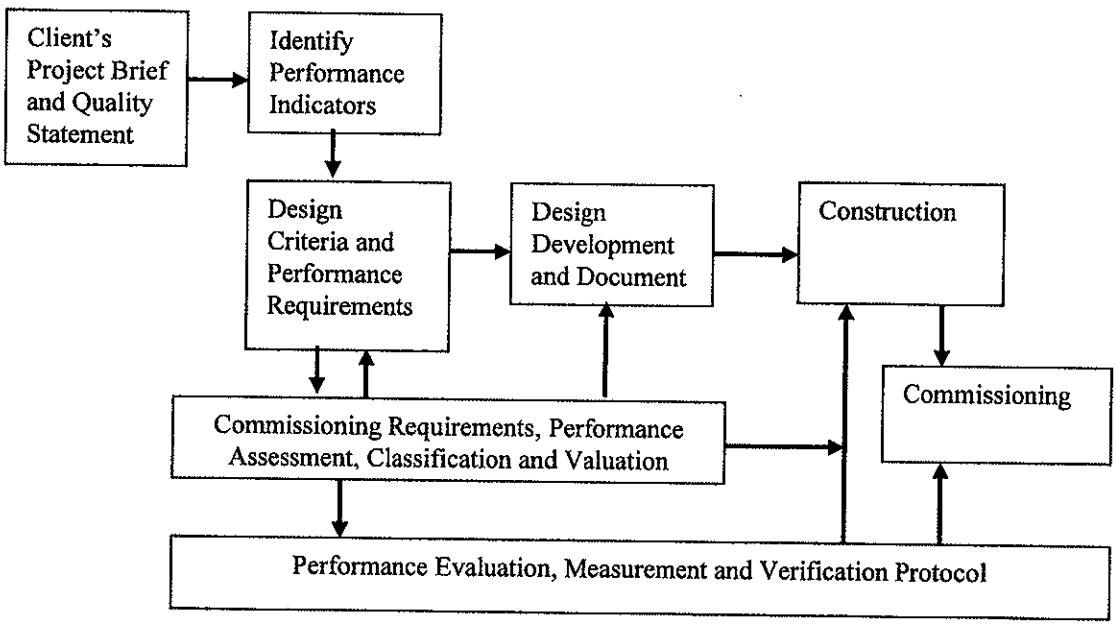

Figure 2. Performance-based platform for achieving quality-oriented industry.

Figure 2 provides the basis for developing the various tool kits required for the drive towards a quality-based construction industry, and frees itself from the stranglehold of a minimum cost procurement system.

Total Building Performance

The Total Building Performance (TBP) framework is an ideal platform upon which to build the performance-based-approach evaluation, measurement and verification system.

The TBP approach adopts a simple matrix of performance mandates. They are:

- Acoustics Performance
- Building Integrity Performance
- Indoor Air Quality Performance
- Spatial Performance
- Thermal Comfort Performance
- Visual Performance

While one may at first instance consider this to be an over simplification, the fact is that they embrace all the basic needs and perceptions of a building user. To deliver a building with a good set of performance criteria developed using this approach requires the careful integrated inputs from all design consultants. This culminates in a documentation which must be carefully transmitted to the contractor, detailing all the measurement and verification requirements. The TBP approach is therefore conducive for:

- The promotion of an integrated holistic approach for consistent performance
- Closing the gaps caused by fragmentation
- Deviation from the prescriptive approach which encourages technology uptake
- Performance evaluation and measurement may be undertaken objectively.

The particular strengths of TBP are:

a. It addresses the fundamental needs of a building in a structured manner. This is particularly useful in coping with change. In the process of a project development, change is a constant. Owing to the complexity of projects, it is important to have a reference frame spelling out the basic needs of a building. In this way, there will not be any mismatch and inconsistency in performance.
b. A holistic integrated approach ensures that priorities are clearly established and observed throughout the project.

With these attributes, the TBP framework will be the ideal platform for constructing a performance/quality-based industry. Indoor Environmental Quality (IEQ) is one area where work has begun at the Centre for Total Building Performance, which involves looking into a comprehensive performance-based approach for the specification, design, simulation and measurement of IEQ.

Innovations and TBP

The emergence of China, the challenges of the region, and the maturity of Singapore's own economy mean that the construction industry's growth will stabilise and the margin will remain small. To strengthen and stabilise growth, the Singapore construction sector must look abroad and develop a competitive edge. It has to synergistically innovate by working in teams.

Innovations may be achieved in a number of ways.

1. Creation of new market space:
   Instead of competing with competitors directly in the same directions and platforms, create a new market space. This can be done by:

   - Looking across substitute industries
   - Creating a new value curve
   - Looking across strategic groups within industries
   - Looking across complementary product and service offerings

2. Creating breakthroughs in services and new products:

   - Learning from lead users
   - Opening new avenues
   - Step by step through the process

3. Developing the innovation factory--The knowledge-brokering cycle

   - Capturing good ideas
   - Keeping ideas alive
   - Imagining new uses for old ideas
   - Putting promising concepts to the test

The TBP framework is particularly suited for some of these innovation processes. This is because while it is a developmental tool and framework, it lends itself comfortably as a diagnostic and evaluation matrix. It also deals with inter-disciplinary interfaces and integration gaps. Hence, the TBP framework is useful for the following developments:

a. Examining the step-by-step development process and facilitating enhancement.
b. Identification of technology gaps for tool-kit developments.
c. Identification of users' needs.
d. Identifying the synergistic strengths of two or more disciplines for inter-disciplinary developments.

TBP is therefore a platform for construction process and product innovations. Such innovations may stand alone, or they may be managed carefully to pave the way towards a performance and/or quality-oriented industry.

It is particularly useful in Singapore's context as the Department of Building at NUS has been working in this area for over 10 years. A number of real building projects have adopted this approach in their projects procurement and development successfully. It is now ready to re-engineer TBP into a framework process for the wider development of the construction industry. As a small well-knitted industry, Singapore has particular advantage for synergistic developments.

Synergistic Innovation Environment

The Centre for Total Building Performance (CTBP) was launched in November 2000 to spearhead R&D development in building performance. Its two main strategic thrusts are to advance:

- Integrated process development within Singapore's Construction Industry.
- Professionalism in construction services development.

Over the last two years, the CTBP has succeeded in attracting projects and creating an environment for R&D and innovative development. The industry funded projects are particularly fruitful in bringing about synergistic development among industry practitioners, academic researchers, and authorities. It is particularly noted that interactions between industry members, local and international enterprises are especially encouraging. It has resulted in new projects, real development projects and inter-disciplinary innovations.

Conclusion

This paper addresses the needs of the Singapore's construction industry, to rethink and re-engineer processes, and work towards a quality-oriented industry. This latter need is not peculiar to Singapore; it is the mission of many construction industries and authorities world wide. A breakthrough in this area will put Singapore in the forefront of construction development and innovation.

TBP has been identified as the ideal platform for developing a quality-oriented industry and innovations. Its advantages and strengths have been identified and explained. The role and function of CTBP in spearheading this developmental work is described. The CTBP has successfully created an environment conducive for such synergistic R&D work.