CRC Construction Innovation

BUILDING OUR FUTURE

Final Report
Task 3: Occupant Health, Wellbeing and Productivity

Research Project No: 2003-028-B-T3-01

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Research Program: B
Sustainable Built Assets

Project: 2003-028-B
Regenerating Construction to Enhance Sustainability

Date: March 2008

Leaders in Construction and Property Research

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Acknowledgements

This report draws on a range of coordinated studies commissioned by City of Melbourne and CSIRO as follows:

- Occupant Surveys of CH1 and CH2: Conducted by Adrian Leaman of Building Use Studies Ltd. in association with Leena Thomas, University of Technology, Sydney, and Monica Vandenberg, Encompass Sustainability.
- Indoor Environment Quality Monitoring of CH1 and CH2: Conducted by Mark Luther and the MABEL team (Mobile Architecture & Built Environment Laboratory), Deakin University.
- Indoor Air Quality Monitoring of CH1 and CH2: Conducted by Stephen Brown of CSIRO.
- Focus Group Interviews of CH2 Occupants: Conducted by Monica Vandenberg, Encompass Sustainability and Leena Thomas, University of Technology, Sydney in association with Adrian Leaman, Building Use Studies Ltd.

The authors, project team and partners also wish to acknowledge the following people and organisations for their valuable contributions to this study:

- Shane Power from City of Melbourne and Adam Leggett (ex city of Melbourne) for their support and assistance in arranging all of the data collection.
- Rob Adams and Austin Ley (City of Melbourne) and Peter Newton (Swinburne University of Technology) for their assistance in the initial establishment of the project.
- Diana Snape Photography for the CH2 photographs in the report
- Finally and most importantly, a big thanks to all of the staff from City of Melbourne who willingly and enthusiastically participated in the study, and tolerated a host of measurements and questionnaires.

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Executive Summary

Introduction

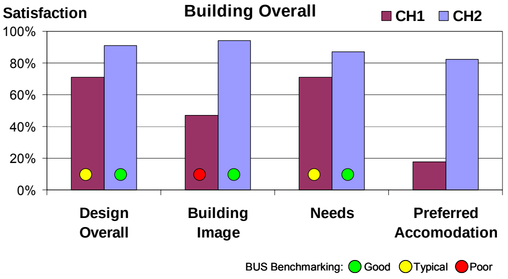
This report presents the results of a study on indoor environment quality (IEQ) and occupant productivity in two buildings that are owned and Occupied by City of Melbourne, and located next to each other in Central Melbourne, Council House 1 (CH1) and Council House 2 (CH2). The impact of a range of relevant IEQ and other parameters on health, wellbeing and productivity of occupants is assessed. The before-and-after case study has demonstrated that the productivity of office building occupants can potentially be enhanced through good building design, and provision of a high quality, healthy, comfortable and functional interior environment, that takes account of basic occupant needs. It has shown that good indoor environment quality is a necessary pre-requisite for enhanced productivity in office buildings, but that broader aspects of overall building and interior design are also important.

Methodology

Evaluation of IEQ and productivity is based on a program of physical IEQ measurements, occupant questionnaires, focus group interviews, and sick leave and staff turnover data. A three page modified 'Building Use Studies' (BUS) occupant questionnaire was conducted in both CH2 and in a 'baseline' City of Melbourne building located next door (CH1). More than 260 responses were received in each building. Assessments for CH2 are compared against Australian and international benchmarks, and the CH1 baseline . Physical measurements and spot health-symptom questionnaires were also conducted in summer and winter seasons. Measurements and occupant responses are averaged over spatial and organisational boundaries to allow overall assessments to be made.

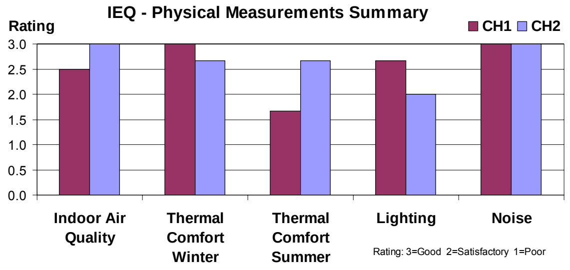
Productivity assessment in the BUS questionnaire is based on occupant assessment of the impact of the environmental conditions in the building on productivity. Although this may not necessarily translate directly to an equivalent increase in work output, it is the most appropriate way to measure the building's impact on productivity in a diverse organisation like City of Melbourne, which encompasses a wide range of job-types that have context-specific productivity dependencies that cannot be clearly defined or measured. The BUS self-assessment methodology has been widely used in Australia and internationally as it provides a consistent measure which enables comparison and benchmarking of productivity effects within and between buildings.

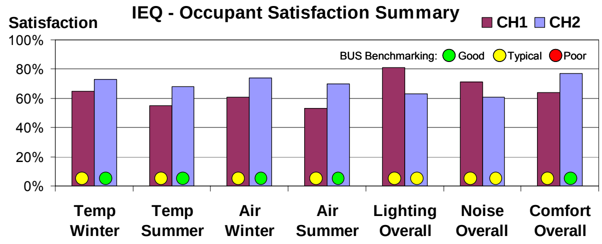
Key Conclusions



CH2 occupants are highly satisfied with the **building overall**, and it's facilities, furnishings and fit-out, with generally higher satisfaction ratings than for previous accommodation in CH1 and BUS benchmarks. More than 80% of occupants prefer CH2 to their previous accommodation.

Thermal comfort measurements in CH2 are generally very good and are better overall than for the CH1 baseline. Measurements indicate that thermal dissatisfaction levels should be below 10% in most locations in the building. Occupant perceptions of overall thermal comfort are also good in CH2, and are generally better than CH1 and benchmarks, except for the airflow which is perceived to be too still.

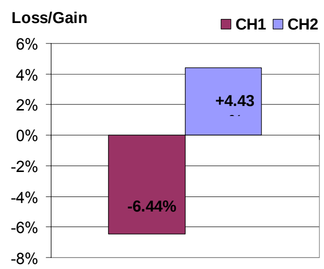


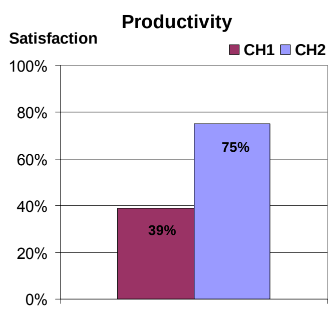


Air quality in CH2 is excellent in terms of measured pollutant levels, and also good based on occupant perceptions, and is better than in CH1. Formaldehyde concentrations in CH2 were much lower than normally found in office buildings. This result can be primarily attributed to the use of 100% fresh air ventilation, and low emission furnishings and finishes throughout the building. Air quality was identified by many occupants as having a positive effect on their productivity.

Measurements of ambient **noise levels** and reverberation times were considered ideal in CH2. However occupant satisfaction ratings for noise in CH2 are average to poor and are worse than for CH1and benchmarks. This is primarily due to unwanted interruptions and distractions from other people in the building. The hindrance of noise from interruptions must be contrasted against the productivity enhancement due to open plan layout as improved communication has been observed by many occupants and managers. Satisfaction with speech privacy in CH2 may be improved through tuning of the white noise system installed in the building. Trials in which white noise levels were increased on one Level in the building resulted in better satisfaction scores for noise when compared to the rest of the building (10-18% better for relevant noise variables), however this result is not conclusive, given that satisfaction ratings for most other variables were also higher on this Level. Careful consideration of workgroup layout, circulation routes, and the separation of quiet and noisy activities may also lead to improvements in occupant satisfaction with noise.

Lighting measurements in CH2 indicated that background lighting levels were sufficient, and that recommended task illuminances could be achieved if personal task lighting was switched on. However, occupant satisfaction with lighting levels is average to poor in CH2 and is worse than for the CH1 baseline and benchmark dataset. Significant improvements and adjustments were made to the lighting systems in CH2 during the study period and further assessment of the CH2 lighting is warranted.





Perceived productivity ratings show that CH2 represents a significant productivity improvement when compared to the CH1 baseline, despite the problems with lighting and increased noise levels due to the open plan layout. Three quarters of CH2 occupants rate the building as having a positive or neutral effect on productivity, compared with just 39% in CH1. CH2 is rated in the top 20% of Australian buildings for perceived productivity when compared against the BUS benchmark dataset. This can be expressed as a 10% perceived productivity enhancement compared to CH1, based on the scale and assessment method used in the BUS questionnaire.

In this case study it appears that the significant improvement in perceived productivity achieved in CH2 can be best correlated to variables relating to the 'building overall' such as Image, Design, Healthiness, Meeting Occupant Needs, and Comfort Overall. It was shown that other factors, such as experiences in previous accommodation may also influence the results. In terms of IEQ impacts on productivity, it is concluded that improved thermal comfort and air quality are likely to have had an enhancing effect on productivity perceptions while noise from interruptions and perhaps some aspects of the lighting may be perceived by occupants as a productivity hindrance.

CH2 is rated very highly by it's occupants for perceived **healthiness**, and is better than CH1 and benchmark, Both buildings are considered to have low levels of occupant-reported rates for building-related **health symptoms**, when compared to levels in the general population. **Absenteeism**, and **staff turnover** have not changed significantly during the first 12 months of occupation of CH2, compared to previous years, however given the year-to-year variability, and the possibility that organisational restructuring during the study period may have had some impact, a longer period of monitoring is required before any solid conclusions can be made about the effects of the building on absenteeism and staff turnover.

Recommendations

It is important that CH2 performance continues to be monitored, as the results presented herein are based on one year of occupation only. During this time, the building was still being fine-tuned, and performance may not have been at the maximum achievable level during this time. However the tuning process also resulted in a vigilant approach by CH2 management in seeking and acting on occupant feedback, and this is likely to have had a positive effect on occupant perceptions of the building, and aided forgiveness of any problems. It is highly recommended that this approach be continued into the future, to ensure ongoing high levels of building performance and occupant satisfaction.

Introduction

Background and Purpose

This study forms a part of the research project, 'Regenerating Construction to Enhance Sustainability', which is run under the CRC for Construction Innovation, Program B – Sustainable Built Assets. The broad aim of Regenerating Construction is to demonstrate the benefits of sustainable construction, and to assist industry in delivering these benefits now and into the future.

This report relates specifically to Task 3 of Regenerating Construction, which aims to examine IEQ and its effect on occupant health, wellbeing and productivity via a before-and-after case-study. The study brings together and summarises data from several source studies and consultancies related to IEQ and occupant productivity [1-9], that have been commissioned by City of Melbourne and CSIRO on two of their office buildings, Council House 1 (CH1) and Council House 2 (CH2), which are located next door to each other in Melbourne.

The specific aims of the study presented herein are to:

- Evaluate the IEQ over the first 12 months of occupation of CH2, and compare against previous 'baseline' accommodation next door, CH1. The evaluation is based on extensive physical measurements and occupant questionnaire data.
- Evaluate the occupant health, wellbeing and productivity in CH2 and compare against CH1 baseline. The evaluation is based on occupant questionnaire data, and other information such as sick leave and staff turnover.
- Assess the impact of a range of relevant IEQ and other parameters on the health, wellbeing and productivity of occupants in the buildings studied.

CH2 Building

Council House 2 (CH2) is a 10-storey office building which houses around 500 City of Melbourne staff, and some ground-floor retail space. CH2 was officially opened in August 2006 and occupied by staff in October 2006.

CH2's gross floor area of 12,536m² comprises:

- Nine floors of office space (9,373m² total; 1,064m² per floor typically)
- 1,995m² of basement areas
- 500m² of ground floor retail

CH2 was conceived, designed and built with a substantial focus on setting a new standard for ecologically sustainable office buildings. It has a raft of sustainable technologies and design philosophies incorporated throughout the entire building, services and fit-out. Key sustainability-related features of CH2 include:

- Low energy, passive cooling systems
- Low energy, integrated electric lighting and daylighting systems
- Co-generation, photo-voltaic cells, and wind-driven turbines
- Active louvres on West facade and vertical garden on North facade
- Sewer mining, water recycling, rainwater collection
- Use of recycled materials
- Extensive facilities for cyclists

A key element of the business case for CH2 was that provision of high levels of IEQ, along with other design features, would result in significant benefits to City of Melbourne through improved health, wellbeing and productivity of staff in the building. Key IEQ features of CH2 include:

- 100% fresh air ventilation is introduced at floor level, and is then exhausted at ceiling height using natural convection.
- Radiant cooling is provided by the thermal mass of concrete ceiling panels, and also through chilled panels which use a mechanical chiller in combination with phase change material stored in the basement, to charge the coolant. Night purging of the building is used to store the night 'coolth' in the concrete ceiling which is then released during the day. Evaporative cooling through shower towers on south face is used to cool the retail areas on the ground floor, and to remove some heat from the coolant used in the chilled ceiling panels.
- Lighting is provided through a mix of high-efficiency recessed luminaries in the ceiling, suspended strip lighting, daylight penetration, and extensive task lighting.
- Low toxicity materials used for all furnishings and finishes
- Extensive use of indoor plants

The Interior design was also intended to produce productivity benefits through increased communication and collaboration between staff. The fit-out of CH2 is based on a modern open-plan philosophy, with no enclosed offices and low adjustable partitions between workstations. There are relatively unobstructed lines of sight throughout each floor, with the only enclosed spaces being the formal meeting rooms. Informal meeting and social spaces are provided throughout the building. Occupants also have access to external balconies, a winter garden, a summer terrace and a rooftop garden. An external view of the CH2 building is shown in Figure 1, and some interior views are shown in Figure 2.

Figure 1: Exterior views of CH2 [1]

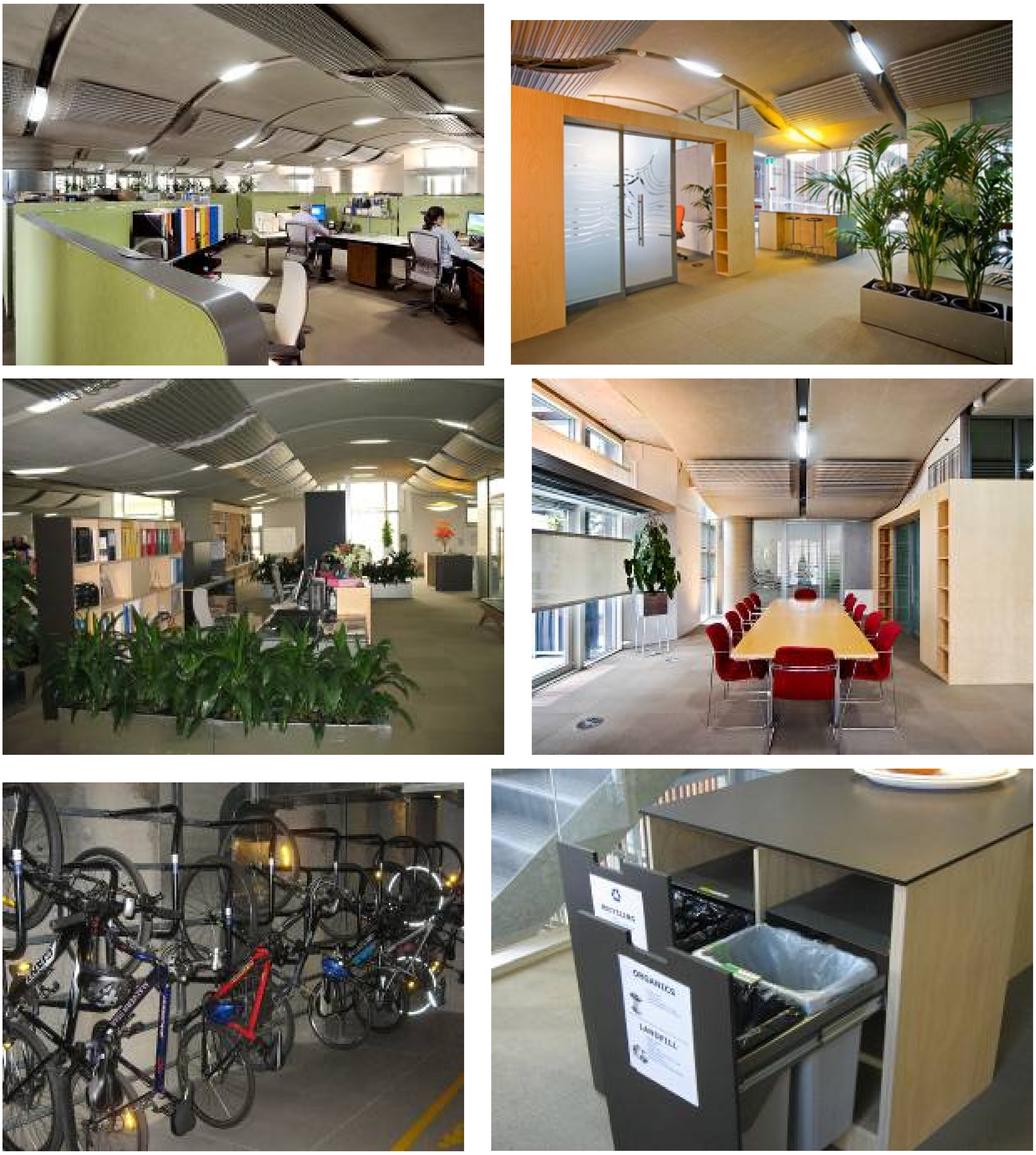


Figure 2: Interior views of CH2 [1]

CH1 Building

Council House 1 (CH1) is used as a baseline comparison for IEQ and occupant health, wellbeing and productivity in this study. The building is ideal for this, as it is of similar size, is located next door to CH2 and is also owned and occupied by City of Melbourne. CH1 was built in the 1970s, and up until August 2006, it housed the majority of City of Melbourne staff, although staff were also located in other nearby buildings.

CH1 comprises:

- Seven floors of office space (7,490m² total, 1,070m² per floor typically)
- Three floors of car park for 230 cars
- 400m² retail area

Mechanical air-conditioning is used in a dilution ventilation system (with fresh and recirculated air), and the windows are non-operable. Overhead lighting from recessed fluorescent luminaries as well as daylight penetration serve as the major light sources. Few occupants have their own task lighting while there are adjustable interior blinds to allow for glare control. External views of the building are shown in Figure 3 and some views of the interior are shown in Figure 4.

Figure 3: Exterior views of CH1

Figure 4: Interior views of CH1

The interior space layout of the CH1 building is typical of 1970s to early 1990s open plan office accommodation. This interior is fitted out with conventional open office partitioning and furniture. The concept of office clusters or pods are the typical arrangement, and these are also used for the partitioning. There are generally one or two conference rooms and a few fully enclosed offices on each of the floors. Common zones such as conference rooms, lounge and printer / copier areas are located in the central core. In the near-future, it is planned to upgrade the fit-out and services for CH1.

Methodology

Evaluation of IEQ is based on:

- Physical IEQ measurements
- Occupant questionnaires (Building Use Studies)

Evaluation of occupant health, wellbeing and productivity is based on:

- Occupant questionnaires (Building Use Studies + additional questions)
- Spot health symptoms questionnaires
- Focus group interviews
- Sick leave and staff turnover data

A summary of the different data streams used for the evaluations is given in Table 1, and further details are given in the following paragraphs.

Table 1: Summary of data sources

Data Source	Location / Time		Brief Description
	CH1	CH2	
IEQ: physical measurements	Summer 2006	Summer 2007	Extensive physical measurements of air quality, thermal comfort, acoustics and lighting at three different floors in each building
	Winter 2005	Winter 2007	
Occupant questionnaire on IEQ, productivity & building evaluation	Spring 2005	Spring 2007	A 3-page modified BUS questionnaire. More than 260 responses received in each building
Focus group interviews on IEQ, productivity & building evaluation	Spring 2005	Spring 2007	Three focus group sessions in each building
Spot health symptoms questionnaire	Summer 2006	Summer 2007	Short simple questionnaire distributed to approx 25 people at each of 3 floors where air quality measurements were made
	Winter 2005	Winter 2007	
Sick leave and staff turnover data	12 mths	12 mths	One year of data before and after CH2 occupation

Physical IEQ Measurements

Physical IEQ measurements were conducted in summer and winter in both CH2 and CH1 [2,3]. Measurements for air quality, thermal comfort, acoustics and lighting were taken throughout three floors in both buildings (lower, middle, upper). Measurements were analysed against specific performance criteria and condensed into simplified three-point ratings to represent physical performance levels for each aspect of IEQ measured (air quality, thermal comfort, lighting, noise). Full details of the measurements, and the criteria used for evaluating the data are given in a separate report [4].

BUS Occupant Questionnaire

A modified 'Building Use Studies' (BUS) occupant questionnaire was conducted in CH2 approximately one year after occupation. The questionnaire was also conducted 2 years prior to this in the CH1 building to provide baseline data. The three-page questionnaire was distributed to all staff working in both buildings and generally was collected on the same day. 260 responses were obtained for the CH2 questionnaire and 266 for CH1. The standard BUS questionnaire covers a wide range of variables related to IEQ and the building design, facilities, fit-out and furnishings. Questions are framed as discrete, quantitative satisfaction scales and also as requests for open-ended comments for key issues. Responses to all quantitative variables in the base questionnaire are able to be benchmarked against Australian or international datasets, depending on the context.

Occupant Productivity

The impact of the IEQ on occupant productivity is included in the standard questionnaire using a single question and a discrete nine-point scale, which asks the respondent to estimate how productivity at work is decreased or increased by the environmental conditions in the building. Although this may not necessarily translate directly to an equivalent increase in work output, it is the most appropriate way to measure the building's impact on productivity in a diverse organisation like City of Melbourne, which encompasses a wide range of job-types which have context-specific productivity dependencies that cannot be clearly defined or measured. The BUS self-assessment methodology has been widely used in Australia and internationally as it provides a consistent measure which enables comparison and benchmarking of productivity effects within and between buildings.

Additional questions were added to the standard BUS questionnaire to obtain extra data on wellbeing, indoor plants, and other contextual factors which may impact on productivity assessments. Full details of the questionnaire and results are given in separate reports for CH1 [5] and CH2 [6].

Focus Group Interviews

A series of focus group interviews were conducted in parallel with the BUS questionnaires. The interviews were designed to obtain extra anecdotal insights and occupant opinions on what does and does not work in the buildings, and how this may impact on people's ability to work effectively. A summary of the findings from the focus groups is given in a separate report [7].

Spot Health Symptom Questionnaire

Spot health symptom questionnaires were conducted in summer and winter in both CH1 and CH2. Approximately 25 people were surveyed at the same time and location in the buildings where air quality measurements were taken (lower middle and upper floors in both buildings). Staff were asked to report their health symptoms and complaints that occurred while at work. These questionnaires were very short and simple, and were intended to identify, quantify and compare health symptoms which may be related to the buildings. Full details of the health symptoms questionnaire and results are given in a separate reports [8,9].

Sick Leave and Staff Turnover Data

Sick Leave and voluntary staff turnover data were provided by City of Melbourne for this study. Twelve months of data since the initial CH2 occupancy was compared against the previous years data for the same Organisational Units within city of Melbourne that occupy CH2.

Satisfaction Ratings

Wherever possible, questionnaire results have been presented as 'satisfaction' ratings. Satisfaction is defined as the proportion of responses that are neutral or better, or in other words, the proportion of occupants who are not dissatisfied. Although this does not give an indication of the shape of the distribution of responses, results are presented this way so that different types of data can be compared directly in a concise manner.

Three different types of seven-point satisfaction scales are used in the BUS questionnaire: right-handed scales with the 'best' on the right, left-handed scales with the best on the left, and centered scales with the best at the centre of the scale. For right- and left-handed scales, satisfaction is assumed for all responses marked at the middle (i.e. neutral) or better. For centered scales, satisfaction is assumed for all responses marked at the middle, and for half of the responses that are marked immediately either side of the middle. Satisfaction for centered scales is calculated this way in order to achieve consistent statistical proportionality for the purposes of comparison of satisfaction ratings with the right- and left-handed scales (note that centered scales effectively contain two variables in one question, e.g. too hot / too cold) and to be consistent with the concept that not all respondents who mark the box adjacent to 'best' can be considered to be dissatisfied.

BUS Traffic Light Benchmarks

Wherever available, BUS traffic light benchmarks [5,6] for the standard set of questions in the BUS questionnaire have been superimposed onto summary graphics throughout this report (note that these are available only for 'core' variables in the BUS questionnaire, and not for the additional variables specific to this study). These benchmarks can be used to compare occupant responses from CH1 and CH2 with results for other Australian and international buildings in the BUS benchmark datasets. Green traffic lights represent a 'good' score, with average scores significantly better than both benchmark and scale midpoint. Amber represent a 'typical' score with average scores no different from benchmark and scale midpoint. Red traffic lights represent a 'poor' score, with average scores worse or lower than benchmark and scale midpoint. It should be noted that for some cases, especially for two-sided variables which use the centered scales, the significance tests used for the traffic light benchmark can be quite sensitive [6], such that only a few 'unsatisfactory' responses can trigger a 'red' rating, even although there may be a reasonably high satisfaction rating overall.

Assessment of Building Overall

In order to properly assess individual aspects of CH2 building performance such as IEQ, it is important to put this in a broader context of the occupants perceptions of the building as a whole. As shown in Figure 5, occupants of CH2 rate the building very highly in it's overall design, image, and ability to meet their needs, with satisfaction scores for these variables all at around 90%, and all better than benchmarks, and significantly higher than the CH1 baseline. More than 80% of CH2 occupants prefer CH2 to their previous accommodation.

This positive result is reinforced by comparing CH2 and CH1 with other buildings as shown in Figure 6, with CH2 falling in the top 25% of Australian buildings in the BUS dataset, well ahead of the CH1 baseline. This result is based on the BUS Summary Index [6], which is derived from a selection of key variables in the occupant questionnaire data.

Assessment of Indoor Environment Quality

IEQ Summary

Based on the questionnaire results, as shown in Figure 7, air quality, thermal comfort, and overall comfort are rated highly in CH2, with satisfaction ratings for relevant variables of around 70%. These are all better than benchmark and the CH1 baseline. Lighting Overall and Noise Overall are rated lower at around 60% satisfaction in CH2, and are worse than the CH1 baseline.

Perceived control over IEQ was rated poorly in CH2 and also for CH1 [6], but only a small portion of occupants indicated this as important to them this and hence for this study, this is not considered as a major factor in assessment of the IEQ. It should be noted that the Building User Guide for CH2, which includes a section ‘How to Use and Work in CH2’ had not been issued to staff at the time of the questionnaire, and will be available to occupants in the near future.

Overall summary assessments of the physical IEQ measurements, based on a simplified three-point scale, are presented in Table 2 and averaged values for each building are shown in Figure 8. The physical measurements partially align with the occupant perceptions, and show that air quality and thermal comfort are rated as very good in CH2, and are better than in CH1. Lighting is rated as satisfactory in CH2, although slightly below the CH1 rating. Noise was rated as very good in both buildings based on measurements, which does not align with the occupant perceptions. This is because the noise measurements are based on ambient noise levels for speech intelligibility and reverberation time, whereas the occupant satisfaction results include consideration of interruptions and speech privacy.

To summarise the IEQ, air quality and thermal comfort are very good in CH2, based on both measurements and occupant perceptions, and are better than the CH1 baseline. Lighting and noise in CH2 are considered satisfactory only due to the relatively lower occupant satisfaction scores for these aspects.

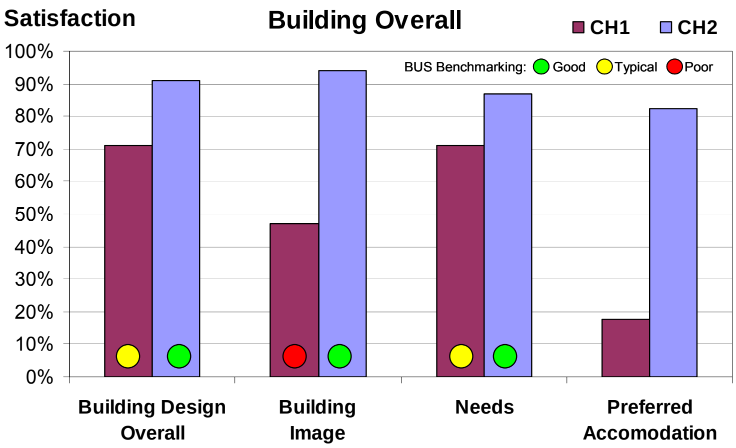


Figure 5: Occupant satisfaction ratings for variables related to overall building

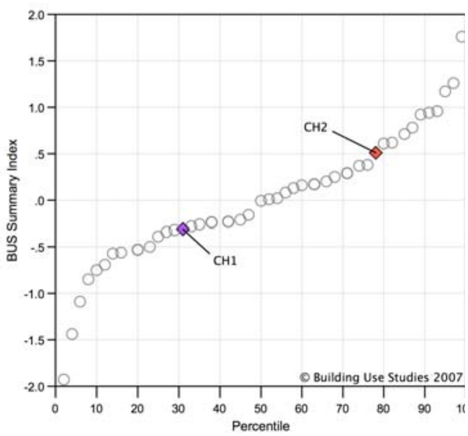


Figure 6: Comparison of BUS Summary Index for CH1 and CH2 with Australian building dataset

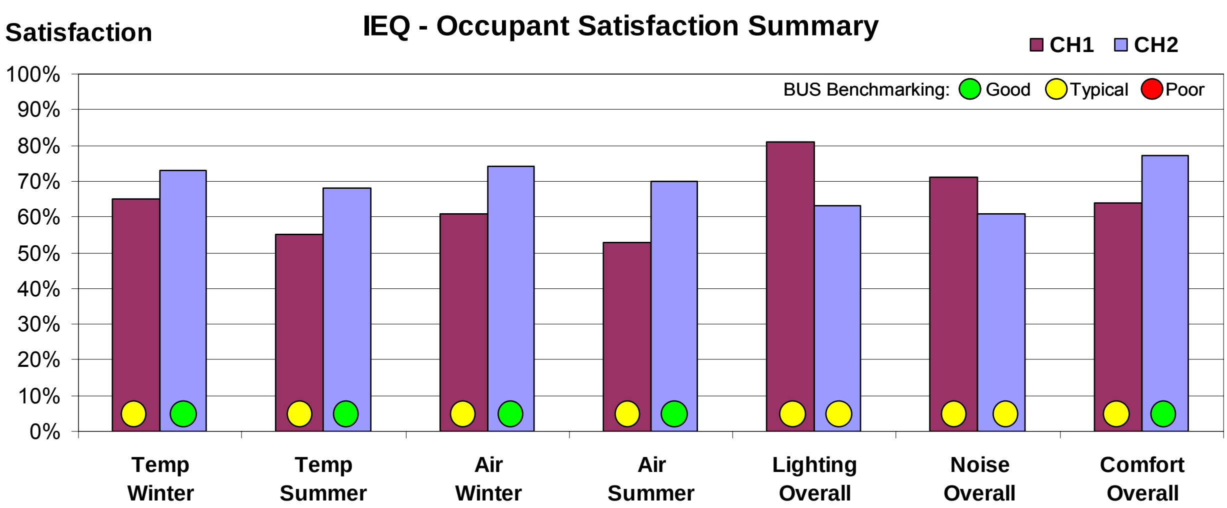


Figure 7: Summary of occupant satisfaction with key aspects of IEQ

Table 2: Summary of IEQ ratings based on physical measurements

Building	Season	Floor	Indoor Air Quality	Thermal Comfort	Lighting	Noise
CH2	Winter	Low	3	3	2	3
		Mid	3	2	2	3
		High	3	3	2	3
	Summer	Low	3	3	2	3
		Mid	3	3	2	3
		High	3	2	2	3
CH1	Winter	Low	3	3	2	3
		Mid	3	3	2.5	3
		High	2	3	3	3
	Summer	Low	3	3	3	3
		Mid	3	1	3	3
		High	1	1	3	3

Rating: 3= Good 2=Satisfactory 1 = Poor

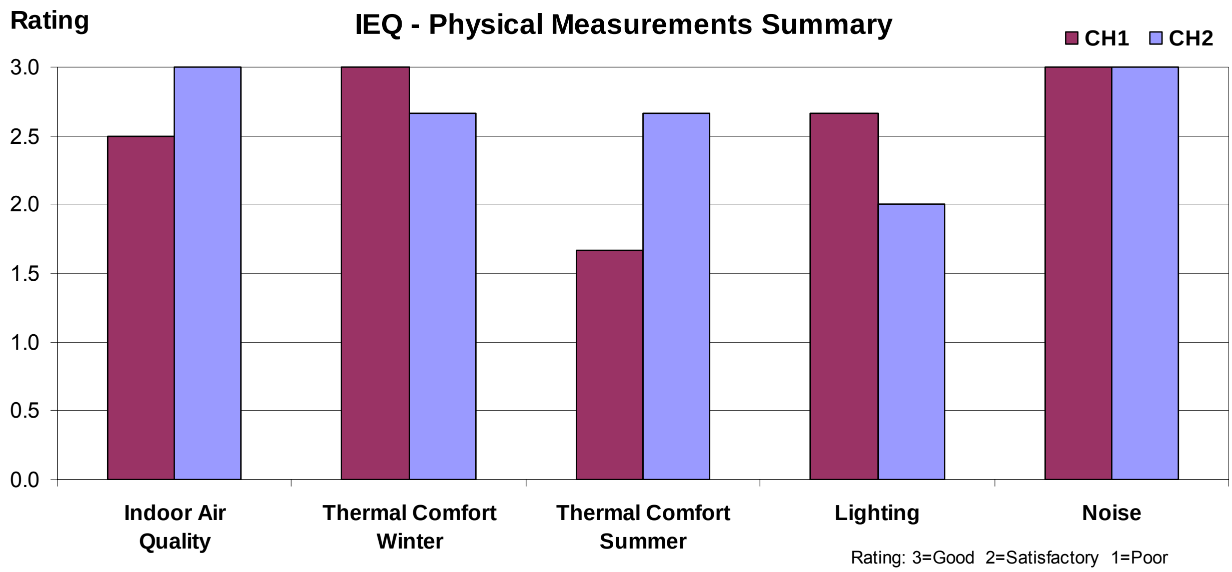


Figure 8: Summary of averaged IEQ ratings based on physical measurements

Thermal Comfort

Occupant Satisfaction

Occupant satisfaction with overall thermal conditions is good in CH2 in both summer and winter, and is better than the CH1 baseline for all variables except for ventilation, as the airflow is perceived to be too still in CH2 for both winter and summer conditions. The perceived ‘stillness’ in CH2 should be contrasted with the conversely good satisfaction with ‘draughtiness’, which is known to have a significant impact on thermal comfort, especially in winter A summary of indoor climate satisfaction scores for winter and summer is given in Figures 9 and 10 respectively. Some concerns were raised during CH2 focus group interviews [7] about temperature variation within and between floors and a tendency to be too hot on summer afternoons. These anecdotal observations are supported by the relatively lower satisfaction scores in CH2 for Temperature Stability and Ventilation. It was also noted during the focus groups that air flow can be improved when the adjustable workstation partitions are set to their lowest level.

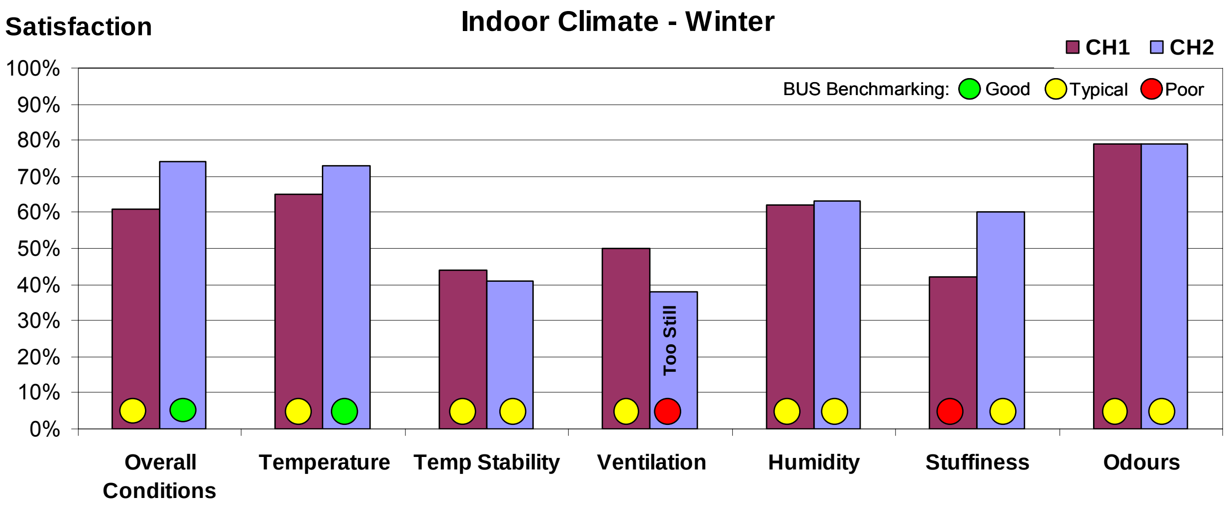


Figure 9: Summary of occupant satisfaction with winter thermal comfort and air quality

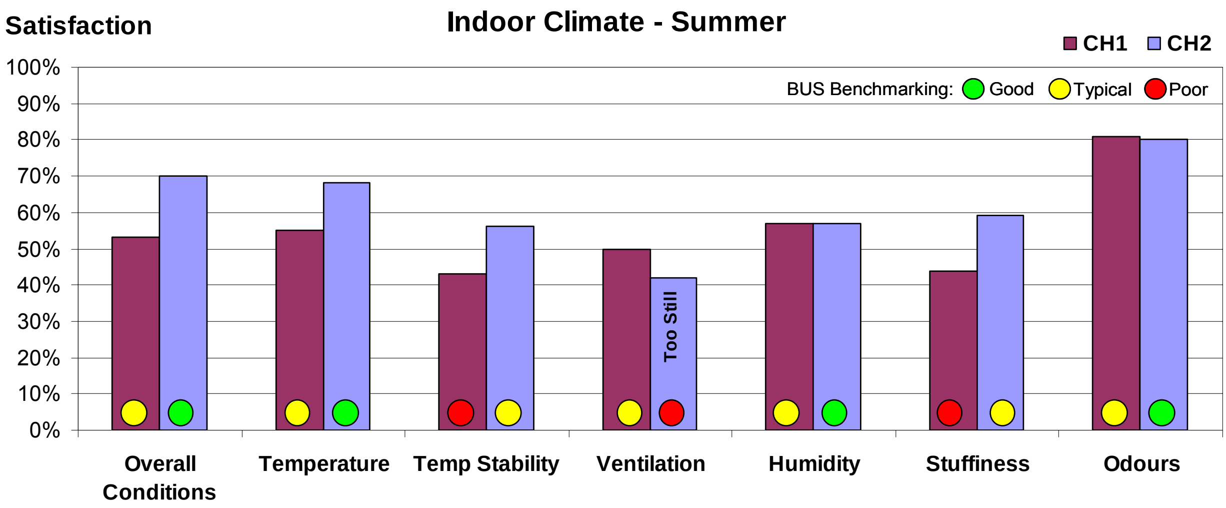


Figure 10: Summary of occupant satisfaction with summer thermal comfort and air quality

Physical Measurements

Physical measurements of thermal comfort parameters were carried out on each of three floors of CH1 (floors 1, 4 and 6) and CH2 (floors 2, 6 and 8). Continuous measurements over 24 hours were made at a central location on each floor, while 15-minute measurements were taken at 6 other locations on each floor, each location being sampled 3 times over the workday. The following thermal factors were measured:

- air temperature at 3 heights (0.1, 0.6 and 1.1m)
- globe temperatures at same 3 heights
- air velocities at same 3 heights
- relative humidity (RH) at one height.

These were used to estimate the Predicted Percentage Dissatisfaction (PPD%) values at 3 heights (as above), assuming ISO7730 default values for occupant activity and clothing [10].

Table 3: Criteria for three categories of thermal environment quality

Category	Whole Body PPD%	Drafts DR%[a]	Vertical Air Temperature Difference[b]		Floor Temperature		Radiant Asymmetry[c]	
			PPD%	°C	PPD%	°C	PPD%	°C
A	<6	<10	<3	<2	<10	19-29	<5	<14
B	<10	<20	<5	<3	<10	19-29	<5	<14
C	<15	<30	<10	<4	<15	17-31	<10	<18

[a] maximum mean air velocities (m/sec): A 0.10-0.12; B 0.16-0.19; C 0.21-0.24
[b] height 0.1m to 1.1m
[c] T shown for cool ceiling

ISO7730 recommends classification of thermal environments within 3 categories, as given in Table 3. The measured air velocities in both buildings were generally in the range 0.05-0.10 m/sec and horizontal radiant temperature asymmetry was <14°C. Similarly, the vertical temperature difference was always below 2°C. Hence, the Draft Rating, Radiant Asymmetry and Vertical Temperature Difference factors were always within the high quality Category A for both buildings. The measurements in CH1 and CH2 did not include floor temperature measurements, but it is considered likely the Category A criterion was achieved. So given that all other metrics fall into Category A, the key metric used for thermal comfort in CH1 and CH2 is the whole body PPD%, and this is presented in Table 4. These results show that the thermal comfort mostly achieved Category A in CH2 in both seasons, slipping slightly to Category B for the middle floor in winter and upper floor in summer. In comparison, the CH1 baseline achieved Category A in winter but not in summer. The higher PPD% values for CH1 summer (some worse than Category C) resulted from operative temperatures that were cool at several locations on middle and upper floors of the building.

In order to quantitatively rate the thermal comfort of these buildings for comparison with occupants' perceptions, a 3-point scale was assumed where:

- 3 = Grade A whole body PPD = good thermal comfort
- 2 = Grade B whole body PPD = satisfactory thermal comfort
- 1 = Grade C whole body PPD. = poor thermal comfort

Note that the approach here is to consider the thermal comfort factor exhibiting significant variations, and to base the rating on this factor alone, rather than on an average of all thermal comfort factors in Table 3. This is consistent with ISO 7730 guidance that the PPDs in Table 3 are not additive, i.e. any single factor could affect the grading of the thermal environment. On this basis, the analysed data was condensed and simplified into the three point ratings given in Table 2.

Comments on Thermal Comfort

Thermal comfort is generally good in CH2 based on both occupant perceptions and physical measurements, and is better than the CH1 baseline. This is a good outcome given the relatively complex and inter-connected nature of the various cooling and ventilation systems, and the fact that the systems were being tuned during the period of the study. Further tuning may result in better performance in the future, but diligent management of the systems must be continued.

Table 4: Whole body Predicted Percent Dissatisfaction for CH1 and CH2

			CH1 (PPD% at 3 heights)				CH2 (PPD% at 3 heights)			
Building Floor	**Season**	**Measure Location**	**PPD high**	**PPD mid**	**PPD low**	**PPD (avg)**	**PPD high**	**PPD mid**	**PPD low**	**PPD (avg)**
Lower	Winter	Core	6	5	5	5	7	6	6	6
		A	7	6	5	6	7	7	6	7
		B	7	6	5	6	7	6	6	6
		C	6	5	5	5	6	5	5	5
		D	6	5	5	6	6	5	5	5
		E	7	5	5	6	7	6	6	6
		F	5	5	5	5	7	7	6	6
Middle	Winter	Core	10	9	8	9	6	7	5	6
		A	6	5	5	5	11	11	10	11
		B	5	6	5	5	11	10	10	11
		C	7	7	6	7	10	10	9	9
		D	7	7	7	7	9	8	8	8
		E	8	7	6	7	10	9	9	9
		F	-	-	-	-	10	10	9	10
Upper	Winter	Core	5	5	5	5	11	5	9	9
		A	8	7	6	7	6	5	5	5
		B	5	5	6	5	6	6	6	6
		C	5	5	5	5	7	7	7	7
		D	6	5	5	5	7	7	6	6
		E	6	6	5	6	6	6	6	6
		F	-	-	-	-	6	6	6	6
Lower	Summer	Core	7	6	6	6	5	6	15	9
		A	7	6	5	6	5	5	5	5
		B	5	5	5	5	5	6	5	5
		C	6	6	6	6	5	6	7	6
		D	5	5	5	5	5	5	6	5
		E	6	5	6	6	5	5	5	5
		F	5	5	5	5	5	5	5	5
Middle	Summer	Core	5	5	5	5	5	6	17	9
		A	12	10	9	10	5	7	6	6
		B	25	22	27	25	5	6	6	6
		C	17	15	17	16	5	8	6	6
		D	11	10	10	10	6	6	6	6
		E	14	11	10	12	6	6	6	6
		F	-	-	-	-	6	6	6	6
Upper	Summer	Core	5	6	5	5	9	10	28	16
		A	10	11	15	12	8	11	10	10
		B	14	17	24	18	9	9	9	9
		C	22	19	22	21	7	8	8	8
		D	9	7	7	8	8	9	8	8
		E	13	16	19	16	9	10	8	9
		F	-	-	-	-	8	8	8	8

Air Quality

Occupant Satisfaction

Figures 9 and 10 show two indicators which can be used to assess satisfaction with air quality: Freshness (i.e. Stuffiness) and Odour. Based on the BUS questionnaires, occupant satisfaction with air quality is average to good in CH2 for both summer and winter conditions, with around 60% of occupants satisfied with perceived Freshness, and 80% satisfied with Odour. The theme of good air quality was raised by many of the CH2 focus group participants as having a positive effect on their ability to work well in CH2 [7]. Satisfaction with Freshness is better in CH2 than CH1, and satisfaction with Odour is the same for both buildings.

Physical Measurements

Physical measurements of a range of indoor air pollutants were carried out for CH1 and CH2, and these were compared to criteria for occupant health and comfort as given in Table 5.

Table 5: Maximum pollutant levels for high indoor air quality

Pollutant	Criterion (avg period)
TVOC	500 µg/m^3 (1h)
Benzene	10 µg/m^3 (1h)
Toluene	4100 µg/m^3 (1h)
Formaldehyde	100 µg/m^3 (0.5h)
PM2.5	25 µg/m^3 (8h)
CO	9 ppm (8h), 25ppm (1h)
CO_2	800 ppm (1h)
Microbial	none visible/no moisture

In general, none of these criteria were exceeded except for formaldehyde in CH1, which is discussed in more detail in a separate report [8]. Specific observations on the indoor pollutant levels are:

- All IAQ measures were within the recommended criteria, with the exception of formaldehyde concentrations in CH1, in particular on floor 6.
- Formaldehyde concentrations on floor 6 of CH1 exceeded the IAQ criterion, especially in summer, but no specific source for the formaldehyde could be identified and it was concluded that there were dispersed formaldehyde sources (e.g. office furniture, wall partitions) on this floor.
- Formaldehyde concentrations in CH2 were much lower than normally found in office buildings probably due to the low-emission office furniture used
- There was a high level of consistency found from season to season in the levels of indoor air pollutants (i.e. a seasonal effect on pollutant levels was not found).
- CO2 levels ranged from 500-710 ppm, below the criterion 800 ppm, indicating that ventilation was adequate in both buildings to remove occupant odours.
- VOCs, formaldehyde, fungi/bacteria and fine particles ($PM_{2.5}$) were present in CH1 and CH2, while ozone from office equipment and carbon monoxide were not detected. Indoor air concentrations of VOCs and formaldehyde exceeded those outdoors, showing there were indoor sources for these pollutants. Fungi and $PM_{2.5}$ were much lower indoors than outdoors, by a factor of 10- to 20-fold, showing there to be no indoor sources and significant cleaning of intake air due to filtration by the ventilation systems of both buildings.

Based on the above findings, simplified three-point IAQ ratings were derived, as presented in Table 2. CH2 was rated very highly, with a best possible rating of 3 on all floors and for both seasons. The IAQ rating for CH1 was lower, due to the formaldehyde pollution observed for this building [8]. Indoor formaldehyde concentrations in CH1 showed a higher formaldehyde levels in summer on some floors, especially floor 6. This effect could be related to the higher indoor temperature/humidity in summer compared to winter since this factor is known to increase formaldehyde emissions from wood-based panels.

Comments on Air Quality

Air quality in CH2 is excellent in terms of measured pollutant levels and occupant perceptions, and is better than in CH1. This result can be primarily attributed to the use of 100% fresh air ventilation, and low emission furnishings and finishes throughout the building. Air quality was identified by many occupants as having a positive effect on their productivity [7].

Noise

Occupant Satisfaction

Satisfaction ratings with noise in CH2 are average to poor, and are generally worse than BUS benchmarks and CH1, as indicated by the questionnaire results shown in Figure 11. Comments from occupants on the questionnaires, and raised during focus group discussions also highlight that noise, primarily in the form of interruptions and distractions from other people in the building, is a cause of some concern [7].

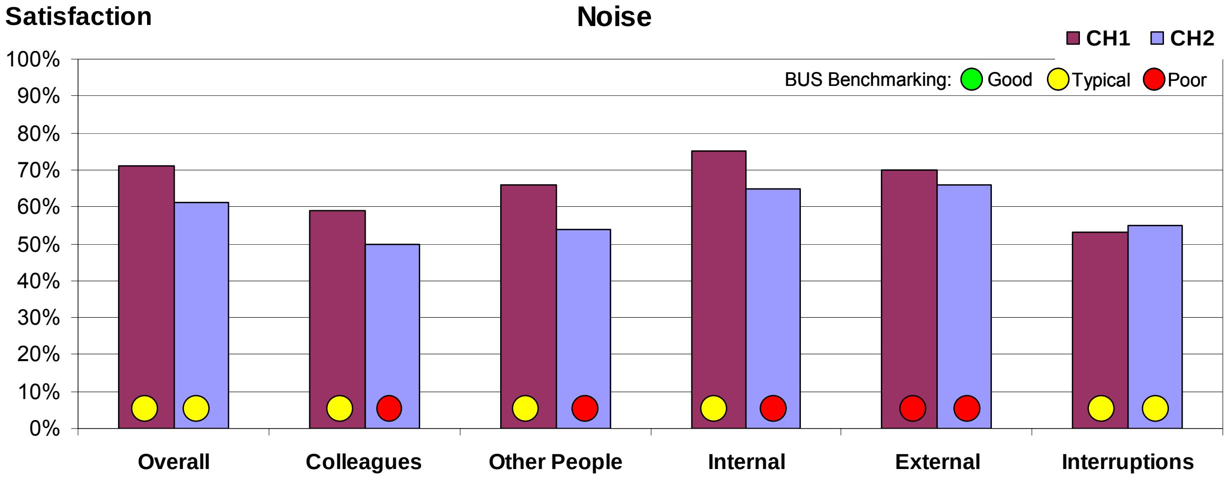


Figure 11: Summary of occupant satisfaction with noise

Physical Measurements

Physical assessment of acoustic properties is based on measured ambient noise levels and reverberation times. Ambient noise levels were measured within both CH1 and CH2 during work hours to assess the level of background noise and speech intelligibility. Criteria for ambient noise measurements are recommended at 40-45 dBA for office environments. However, these are required to be measured with the building unoccupied and with services operational, which was not possible. Since the buildings have a central-city location, it was considered that measurements out of work hours would be biased against external traffic noise, and hence, the ambient noise measurements were made at several floors and locations within floors across the work day. The effect of background noise on the ability to carry out a conversation is well understood, whereby the highest noise level that permits relaxed conversation with 100% sentence intelligibility throughout a room is 45 dBA, but that 99% intelligibility occurs at approximately 55 dBA [11].

Ambient noise measurements for both CH1 and CH2 were very good. Noise measurements in CH1 ranged from 42-55 dBA (ave±SD = 50.0±3.2 dBA) with no trend according to building floor or season. Similarly, measurements in CH2 ranged from 43-57 dBA (ave±SD = 50.5±3.4 dBA). It is concluded that based on these measurements, the background noise levels for both buildings were in the range that should result in very high levels of speech intelligibility (99%).

Reverberation measurements were taken for both buildings while unoccupied and not operating. These assessments showed that reverberation times for CH2 (as measured on floors 2 and 6) were very good as they fell within the 'ideal' range of 0.4-0.6 seconds, as recommended in AS2107:2000 [12]. The frequency-time decay behaviour of the sound was also observed to be good, where longer decay occurred for lower sound frequencies, which in theory should provide a balance between speech intelligibility and speech privacy in the open-plan spaces.

In CH1 the reverberation times were generally in the range 0.3-0.4 seconds, which is slightly on the 'dead' side of ideal range resulting in very little echo or travelling of sound within the building.

Comments on Noise

Lower satisfaction with noise from interruptions in CH2 is not a surprising result as previous studies have shown this type of noise to be one of the biggest sources of dissatisfaction in open plan office spaces [13]. This presents a conflict for designers, because any productivity benefits from increased communication and interaction in more open plan spaces must be traded off against the potential for increased noise levels, and associated distractions and interruptions. This tension between noise and staff interaction exists in CH2, and can be observed when the many positive comments by survey respondents and focus group participants on the benefits of the open plan layout are contrasted against the lower satisfaction ratings and negative occupant comments on noise levels [7].

The high level of speech intelligibility measured in CH2 is due to the relatively quiet operation of the building (note that the air-conditioning system is silent in CH2), but this must be balanced against the occupants desire for speech privacy, which was rated poorly. It may well be the case that the low ambient noise levels have contributed to the sensitivity to speech privacy, and distractions and interruptions from other people in the building, as has been picked up in the questionnaires and focus groups. Careful consideration of workgroup layout, circulation routes, and the separation of quiet and noisy activities are likely to lead to improved satisfaction.

It is important to note that a white noise system is installed in CH2 to enhance speech privacy, and that this was adjusted upwards by 5dB on Level 6 in early 2007 as a trial, and was considered successful by the building management. Analysis of the CH2 questionnaire data for staff on Level 6 indicates overall higher satisfaction ratings for noise when compared to the rest of the building (10-18% better for relevant noise variables), but the result is not conclusive, given that there were higher satisfaction ratings across the board from occupants on Level 6 (average 13% higher satisfaction across key comfort variables). Regardless, tuning of the white noise system on other floors will potentially improve speech privacy, and may well lead to improved satisfaction ratings for noise.

Lighting

Occupant Satisfaction

Results from the BUS questionnaires for lighting-related variables are given in Figure 12, which shows that occupant satisfaction with lighting levels is average to poor in CH2 and is worse than for the CH1 baseline and some of the benchmarks. Although satisfaction with lighting overall in CH2 is more than 60%, Daylight and Artificial Light satisfaction ratings are down around 50%. Conversely, satisfaction with Glare from both interior and external sources is good in CH2 - this may be a consequence of the perceived deficit of natural and artificial light.

Physical Measurements

Physical assessment of lighting in CH1 and CH2 was based on general illuminance and task illuminance levels, which were estimated using horizontal and vertical illuminances measured at several locations across three floors in both buildings in summer and winter.

Criteria for illuminance levels were recommended as follows:

- General Illuminance:160 lx minimum
- Task illuminance: 320 lx minimum (for general office work)

A summary of illuminance measurements is given in Table 6. In CH2, general illuminance of 160 lx was achieved and is considered satisfactory overall. Initial task lighting measurements were less satisfactory with a large proportion of task illuminances measured below the 320lx criteria. However it should be noted that personal task lighting is used extensively in CH2 and is an integral part of the lighting design, but it is not clear whether task lighting was switched on at the time of measurements, so these results may be misleading. Supplementary measurements of task illuminance taken during the summer indicated that locations with personal task lights switched on are likely to achieve the criteria of 320 lx.

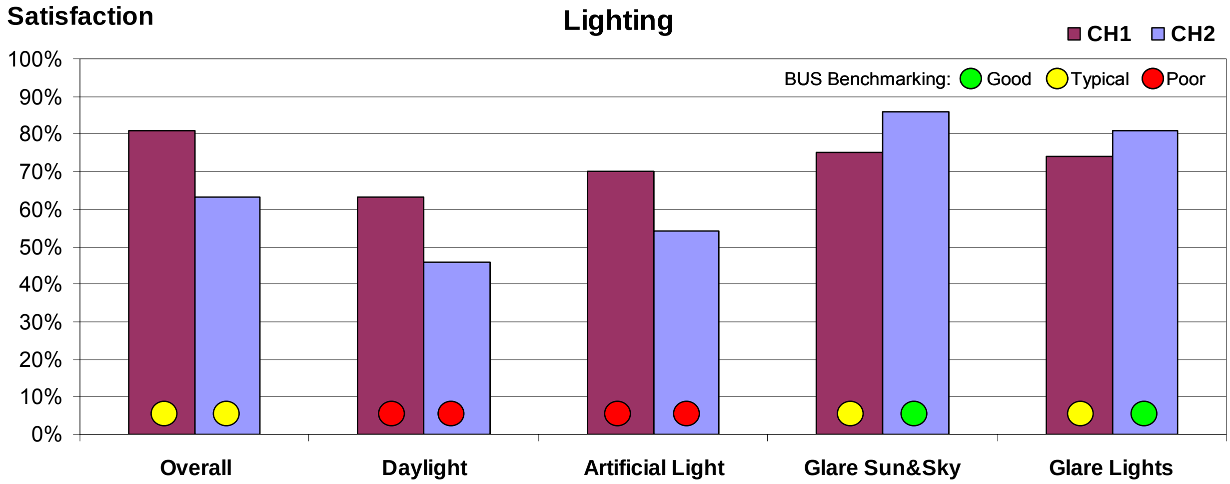


Figure 12: Summary of occupant satisfaction with lighting

Table 6: Summary of measured illuminance levels in CH1 and CH2

Building	Floor	General Illuminance		Task Illuminance: % Measurements > 320 lx	
		Winter	Summer	Winter	Summer
CH2	2	160 lx achieved		5*	33*
	6			33*	33*
	8			17*	11*
CH1	1	160 lx achieved		42	86
	4			67	86
	6			87	100

* Criteria likely to be achieved when personal task lighting switched on

In CH1, general illuminance was also satisfactory, with 160 lx achieved. Task lighting levels were variable, with a significant portion of measurements falling below the 320 lx criteria, at lower floors in winter, but generally achieving this criteria in summer. As the use of personal task lights was not prevalent in CH1, these results are considered to be a reasonable measure of the task illuminance.

Note that glare was also measured using CCD cameral luminance mapping, but no quantitative assessment of the maps has been undertaken and so this is not discussed.

Given that both buildings achieved the criteria for general illuminance, differences in the simplified ratings presented in Table 2 are based on the task lighting only. This is difficult to assess in CH2 because of the possibility that many of the low task light measurements may have been a result of user preference, or the fact that occupants were away from their desks with their lamps turned off. As a result of these uncertainties, a mid-point rating of ‘2’ is assigned to CH2 for all levels and seasons, based on the measurements alone.

Comments on Lighting

Lighting is considered to be satisfactory in both CH1 and CH2 overall with some question marks against task lighting and satisfaction with daylight levels in CH2. Despite the satisfactory spot-measurements for general illuminance reported herein for CH2 (for both summer and winter), the initial configuration of the CH2 lighting resulted in complaints about the building being too dark at various locations across the floor-plate. As a result of this, a decision was taken by CH2 management to amend the lighting and replace some of the existing surface-mounted 'glow worm' fittings with new suspended strip lights that included an up-lighting component (utilising reflected light from the ceiling to help achieve more uniform general illuminance levels). Once the added lighting was linked into the control system, each fitting was adjusted in consultation with the staff at the affected workstations. In this process the lighting intensity in the majority of fittings was lowered, with some fittings running at an intensity as low as 10%.

Occupant comments on the questionnaire and in focus group interviews raised the issue of inadequate natural light and a softly lit interior. Grey concrete ceilings and darker-toned furnishings and plants are a part of the interior design of CH2 and these may have an impact on occupant perceptions of lighting. As described above, an attempt was made to address these issues during the study period by incorporation of additional lights, although the effect of the changes on occupant satisfaction are not conclusive from the questionnaire results.

The integration of task lighting and daylight into the overall lighting strategy, with lower general illuminance levels, as is the philosophy in CH2, is considered good practice from both a sustainability and user control perspective. Given the improvements and adjustments made to the lighting systems in CH2 during the study, further assessment of the CH2 lighting is warranted.

Facilities, Furnishings and Fit-Out

As shown in Figure 13, CH2 occupants are highly satisfied with the building facilities, furnishings and fit-out. Usability of workstations, the effectiveness of space use in the building, storage facilities, IT systems, availability of meeting rooms, and building facilities overall are all rated at more than 80% satisfaction and are better than BUS benchmarks. All of these variables are rated higher than for CH1. Satisfaction with the space layout of the building is above 70%, but is slightly lower than for CH1. Focus groups and occupant comments were very positive about the cycling and changing facilities. In contrast to the high satisfaction rating for meeting room availability, detailed comments by occupants indicated that access to private spaces for confidential meetings can an issue at times [7].

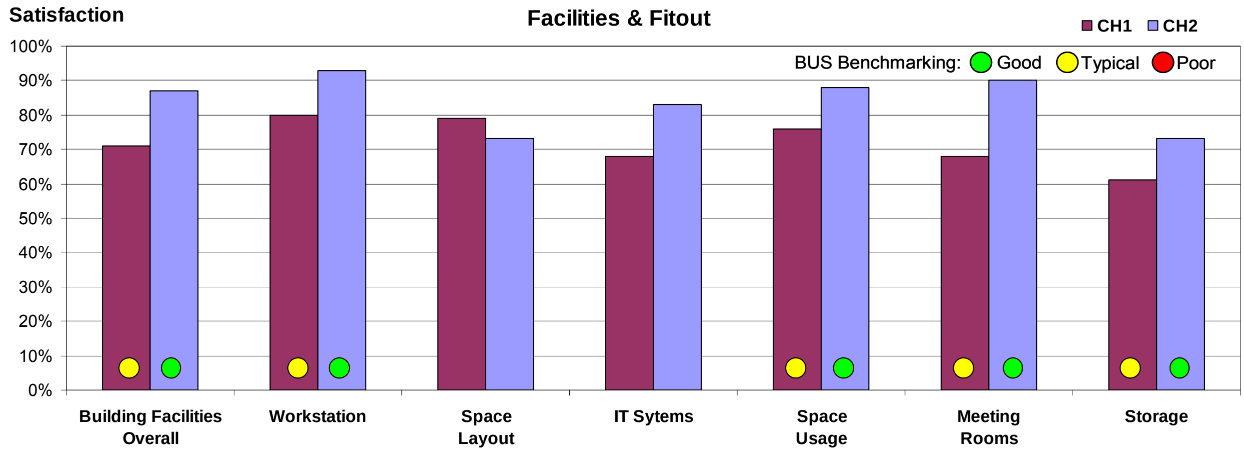


Figure 13: Summary of occupant satisfaction with building facilities, furniture and fit-out

Assessment of Productivity, Health and Wellbeing

Productivity

A key element of the business case for CH2 was that provision of high levels of IEQ, along with other aspects of good building and fit-out design, would result in significant benefits to City of Melbourne through improved health, wellbeing and productivity of staff in the building.

Based on occupants perceptions of the building's impact on their productivity, it is clear that CH2 represents a significant productivity improvement when compared to the CH1 baseline. As shown in Figure 14, three quarters of CH2 occupants rate the building as having a positive or neutral effect on productivity, compared with just 39% in CH1. When the data is converted to productivity loss or gain, as shown in Figure 15, it is estimated that this could represent a greater than 10% productivity improvement, based on the nine-point scale used in the perceived productivity question. This significant improvement is reinforced by comparing CH2 and CH1 with other buildings as shown in Figure 16, with CH2 falling in the top 20% of Australian buildings for perceived productivity in the BUS dataset.

Studies by BUS have shown that there is a strong relationship between the Overall Comfort and Perceived Productivity variables used in the questionnaire. Figure 17 shows the relationship between these variables for CH1, CH2 and the entire BUS Australian building dataset. Given that both buildings fall nearby the line of best fit through the dataset, this indicates that the Perceived Productivity scores for CH1 and CH2 are not too far off what might be expected. This gives added confidence in the reliability of the perceived productivity results.

Focus group interviews highlighted that that some occupants found it difficult to distinguish between building-related impacts on productivity from other effects such as workplace re-structuring which took place during the study period however some managers in the focus groups identified that the open plan office layout has enhanced teamwork and communication. Other comments from occupants indicate that air quality and building image were important for productivity and that the stairways had enhanced communication within the building. Comments on productivity hindrances mainly relate to issues around noise (interruptions), lack of privacy, and some dissatisfaction with the lighting.

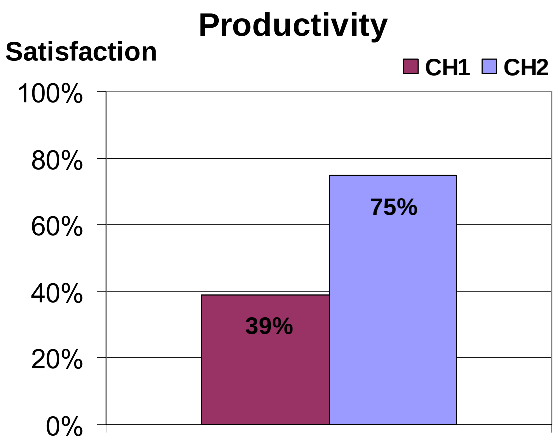


Figure 14: Proportion of occupants rating the building as positive or neutral for their perceived productivity

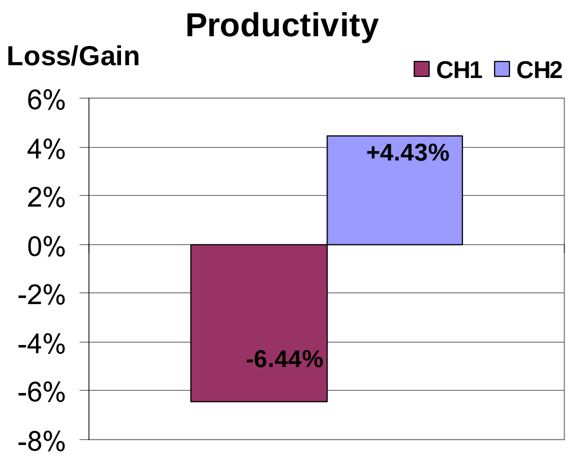


Figure 15: Estimated perceived productivity loss or gain for CH1 and CH2

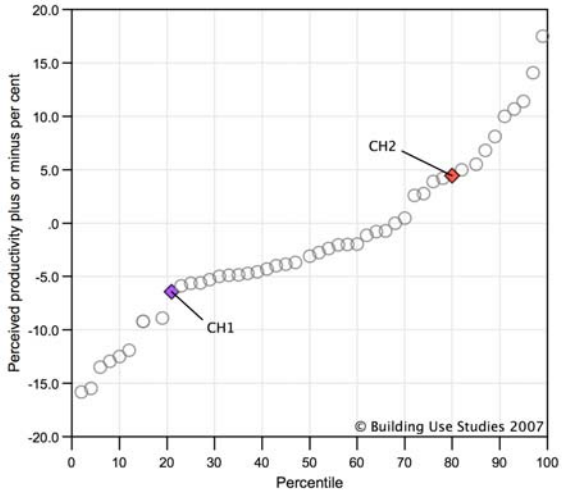


Figure 16: Comparison of perceived productivity loss or gain, for CH1 and CH2 against BUS Australian building dataset

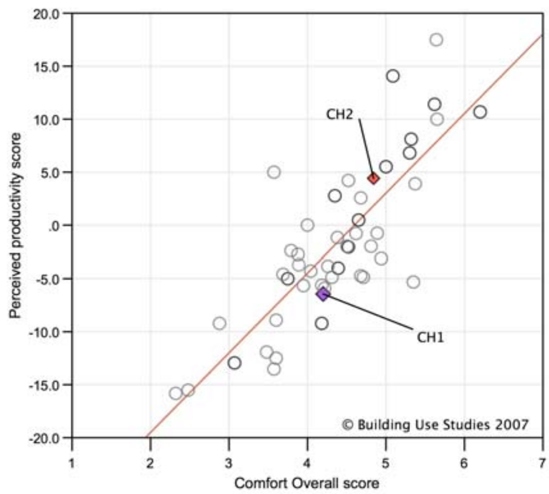


Figure 17: Perceived productivity loss or gain versus Overall Comfort: CH1 and CH2 compared to entire BUS Australian building dataset

Whichever way the results are interpreted, the perceived productivity results in CH2 are impressive. However It should be made clear that productivity assessment from the BUS questionnaire results is based on self-assessed perception of the impact of the environmental conditions in the building on productivity, and does not necessarily translate directly to an equivalent increase in work output.

Health and Wellbeing

Office workers can spend more than 90% of their time indoors, or in enclosed spaces while commuting [14]. It is therefore important that the basic human need for health and wellbeing is considered when designing buildings and interior spaces. Figure 18 and Table 7 show that CH2 is rated very highly for perceived healthiness, and is generally good on occupant-reported rates for various health symptoms, when compared to levels in the general population.

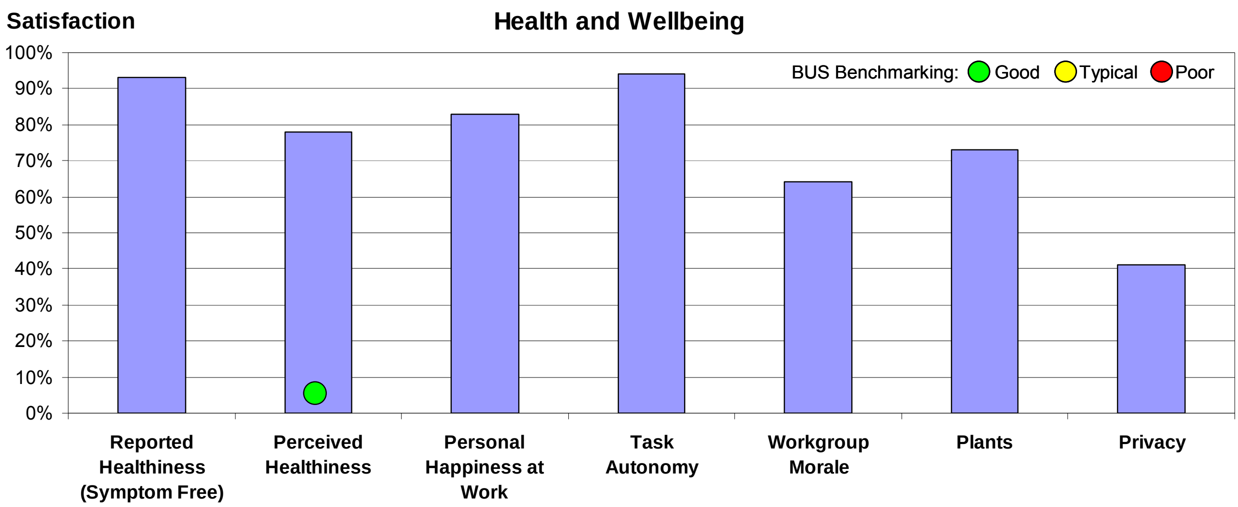


Figure 18: Summary of health and wellbeing indicators

Table 7: Reported healthiness at work for a range of symptoms

Health Symptom	Winter	Summer
Irritation/watering of eyes	85%	80%
Dry eyes	87%	88%
Irritation/running of nose	93%	96%
Blocked or stuffy nose	93%	97%
Hoarse, dry or sore throat	100%	100%
Chest tightness/breathing difficulty	98%	100%
flu symptoms (aches in limbs/fever)	98%	100%
Rash or irritated skin	98%	100%
Dry skin	95%	97%
Headache	77%	86%
Felling lethargic or very tired	87%	93%
ALL SYMPTOMS (average)	92%	94%

Note that values refer to proportion of occupants that are symptom-free

Figure 18 also presents satisfaction scores for some other general wellbeing indicators such as happiness, autonomy, morale and privacy. Happiness at work, and autonomy in use of time to carry out work tasks is rated very highly in CH2 but workgroup morale is rated lower (64%). This result is not surprising, given the uncertainties about workplace restructuring during the study period. Focus group interviews and staff comments on the questionnaires confirmed that the workplace restructuring is the primary reason behind the reduced morale. Satisfaction with privacy levels are also relatively low in CH2 (41%), however this is to be expected given the open plan philosophy of the interior design.

Indoor plants are used extensively in CH2, and so occupants were asked whether the plants have any effect on their satisfaction with the environment, and the majority of occupants responded positively.

Sick Leave and Staff Turnover

Sick Leave and voluntary staff turnover data were provided by City of Melbourne for this study. Twelve months of data since the initial CH2 occupancy was compared against the previous two years data for the same Organisational Units within City of Melbourne that occupy CH2, and against available historical organisation-wide absenteeism and turnover statistics. The normalised results showed that there has been a slight increase in both sick leave and turnover when the first twelve months of CH2 is compared to the previous years, but the change is not statistically significant, and is well within the range of normal year-to-year variation. Given the year-to-year variability in absenteeism and turnover, and the possibility that organisational restructuring may have had some impact, a longer period of monitoring is required before any solid conclusions can be made about the effects of the building on sick leave and staff turnover.

Impact of IEQ and Other Factors on Productivity, Health and Wellbeing

Introduction

Based on the first 12 months of CH2 occupation, there has been a significant improvement in perceived health and productivity when compared against the CH1 baseline. Given the importance of health and productivity in the business case for sustainable buildings, it is useful to examine the differences between CH2 and CH1, as perceived by the occupants, to try and gain some insights into the impact that different aspects of the building have had on the positive productivity ratings for CH2. It must be noted however that it is not possible to make quantitative conclusions about the impact that any particular aspect of building design will have on health and productivity based on a study of only two buildings, in which many variables have been changed simultaneously. The results and analysis presented herein apply only to the context of CH2 compared to CH1.

The following categories have been adopted to represent the broad range of factors which could potentially have an impact on occupant productivity:

- Building Overall
- Furnishings, Facilities, Fit-out & Equipment
- IEQ: Thermal Comfort; Air Quality; Lighting; Noise;
- Health Symptoms
- Other Factors

When the major variables from the occupant questionnaires are categorised in this manner, we can see which aspects of CH2 stand out as the biggest perceived improvement, relative to the CH1 baseline. Figure 19 shows the averaged difference in satisfaction ratings between CH2 and CH1 for these different categories of variables. Table 8 outlines the variables that are assigned to the different categories, the satisfaction differences between CH2 and CH1, and the correlation coefficient of each variable with Perceived Productivity in CH2.

The main conclusion that can be drawn from this analysis, is that in the case of CH2 compared to CH1, the 'Building Overall' category of variables is likely to be the most significant, in terms of impact on Perceived Productivity. All of the variables under this category correlate better with Perceived Productivity, in relative terms, than all of the other variables in all of the other categories (although it should be noted that the correlations are not very strong in absolute terms, with R in the range 0.5 to 0.6). This category also exhibits the largest difference in satisfaction ratings between CH2 and CH1. Other variables and categories in Table 7 which show a relatively stronger correlation with Perceived Productivity are Thermal Comfort (summer more than winter), Noise Overall, Air Quality, Space Layout, Workstation Usability and Privacy, although none of these are as strongly related to the Perceived Productivity rating as the 'Building Overall' variables.

Interestingly, if the averaged satisfaction differences for each category are summed together (they add to 36.5%), this value is very close to the difference in the Perceived Productivity satisfaction rating (which is 36%). Although this is most likely a coincidence, it demonstrates conceptually how different aspects of the building and it's design may either enhance or hinder productivity depending on whether they are perceived as satisfactory, or not by occupants.

Table 8: Difference in satisfaction ratings between CH2 and CH1, and correlations with Perceived Productivity in CH2 for different categories of variables

Category *(Avge % Diff; Avge R_{prod})*	**Variable**	**% Difference Satisfaction CH2-CH1**	**Correlation With Productivity in CH2 R_{prod}**
Productivity *(36% Better)*	Perceived Productivity	36%	1.00
Building Overall *(23.8% Better; R=0.56)*	Comfort Overall	13%	0.61
	Design	20%	0.53
	Image	47%	0.54
	Facilities Meet Needs	16%	0.53
	Perceived Healthiness	35%	0.59
	Space use in the building	12%	0.47
	Comparison with Previous Accommodation	NA	0.65
Furniture & Fit out *(6.5% Better R=0.32)*	Furniture / Workstation	13%	0.42
	Meeting Room Availability	22%	0.32
	Plants	8%	0.19
	Space at Desk	-10%	0.30
	Space Layout	-6%	0.42
	Storage	12%	0.25
Health Symptoms *(1.9% Better)*	Health Symptoms: Summer	4%	NA
	Health Symptoms: Winter	0%	NA
IEQ: Air Quality *(16.5% Better; R= 0.38)*	Air Freshness: Summer	15%	0.36
	Air Freshness: Winter	18%	0.40
IEQ: Lighting *(17% Worse; R=0.28)*	Lighting: Artificial	-16%	0.15
	Lighting: Overall	-18%	0.32
	Lighting: Natural	-17%	0.38
IEQ: Noise *(10% Worse; R=0.4)*	Noise: Overall	-10%	0.40
IEQ: Thermal Comfort *(12.8% Better; R=0.44)*	Thermal Conditions Overall: Summer	17%	0.48
	Thermal Conditions Overall: Winter	13%	0.42
	Temperature: Summer	13%	0.47
	Temperature: Winter	8%	0.39
Other *(2% Better; R=0.29)*	Cleaning	13%	0.40
	Communication	6%	0.18
	Happiness	-6%	0.31
	IT	15%	0.25
	Privacy	-12%	0.42
	Autonomy	-2%	0.23
	Morale	0%	0.24

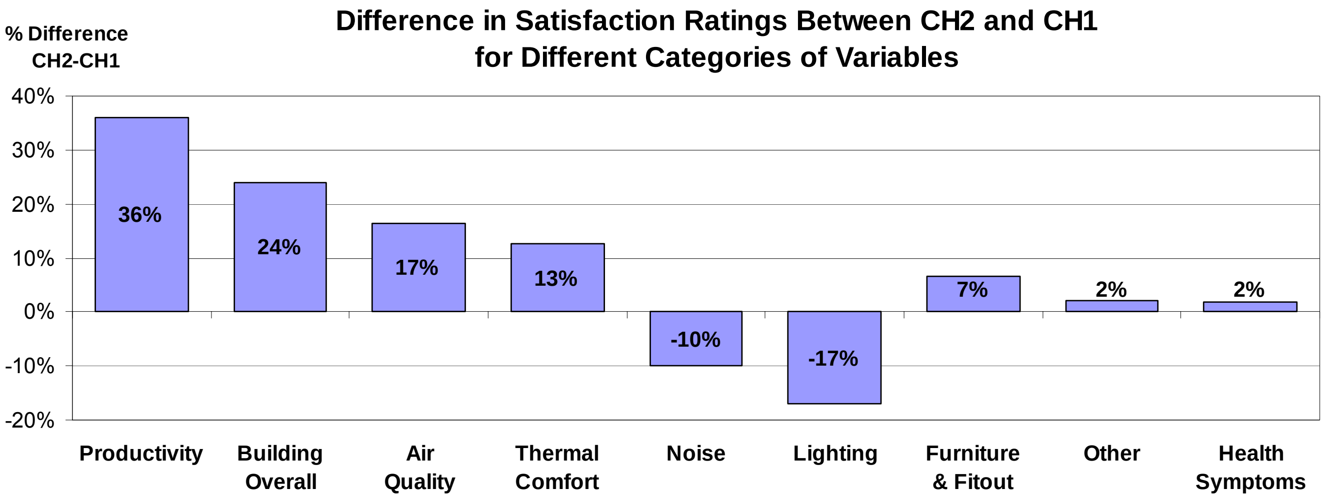


Figure 19: Averaged difference in satisfaction ratings between CH2 and CH1 for different categories of variables

Previous Accommodation

One of the variables which showed the strongest correlation with productivity in Table 8 is the comparison of CH2 with previous accommodation. This variable has been examined in more detail, and a summary of this analysis is shown in Figure 20 and Table 9. The analysis shows that CH2 occupants who were previously NOT in City of Melbourne accommodation, scored Perceived Productivity significantly higher than those previously from City of Melbourne Buildings (CH1, Commonwealth Bank, Town Hall or Elizabeth Street). However it should be noted that all of the perceived productivity ratings are significantly higher than for the CH1 baseline rating which was -6.44%.

Table 9: Breakdown of Perceived Productivity and proportion of occupants who prefer CH2 to their previous accommodation

Previous Accommodation	**N**	**% Prefer CH2**	**Perceived Productivity**	
			% Los/Gain	**%Satisfaction**
CH1	85	81%	0.6%	64%
Commonwealth Bank	58	89%	6.2%	72%
Town Hall	33	87%	6.7%	73%
Elizabeth Street	24	67%	0.5%	42%
Other	35	82%	10.0%	77%
Not Specified	25	80%	6.1%	76%
Total / Average	260	82%	4.4%	68%

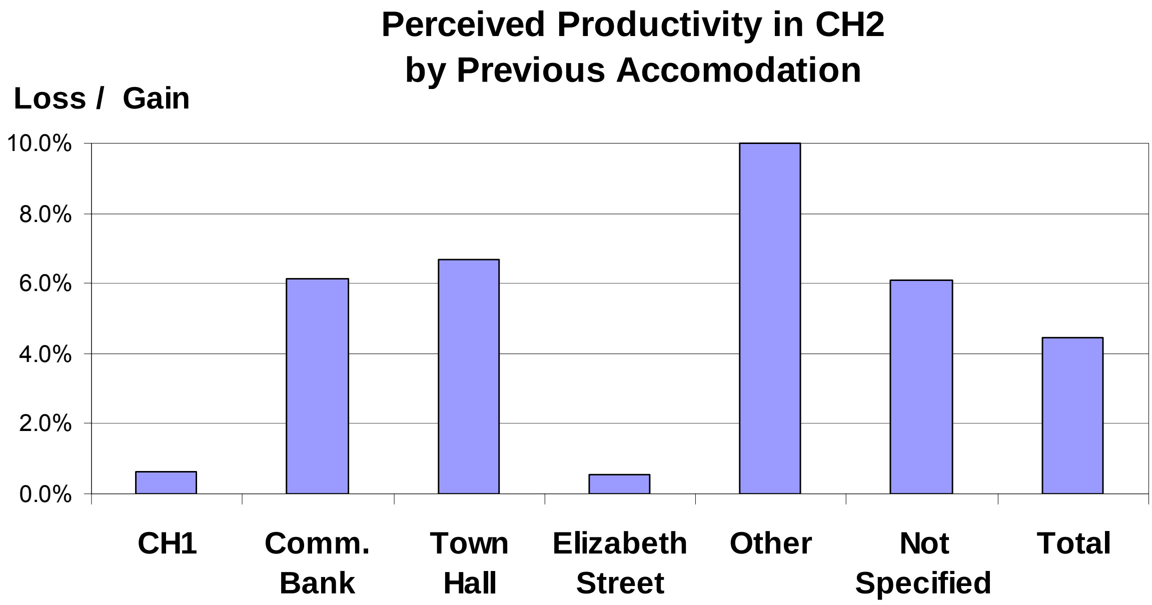


Figure 20: Breakdown of Perceived Productivity in CH2 by previous accommodation

Density

A key variable which is widely thought to have an impact on productivity is occupant density. The assumption is that higher density may lead to lower productivity due to increased noise and interruptions and reduced comfort levels. Table 10 shows the difference in satisfaction ratings for selected variables for 'Low' density floors in CH2 and 'High' density floors. High density floors are defined as those with more than 60 occupants, and low density floors those with less than 60. As can be seen from Table 10, Perceived Productivity shows no significant difference when expressed in terms of satisfaction, but when expressed as a Loss/Gain (as given in brackets in the first row of the table), there is a slightly worse productivity rating on the higher density floors. Also, productivity-related factors such as desk space, furniture/workstation usability, storage, thermal comfort and perceived healthiness all show a tendency to be less satisfactory on the high density floors. Many of these results are intuitive, as things like desk space and storage become more scarce in higher density spaces, and cooling systems need to work harder.

Table 10: Comparison of satisfaction ratings in CH2 for low and high density floors

Variable	% Satisfied		
	Low Density	High Density	Difference
Perceived Productivity	86% (+7.3%)	88% (+3.6%)	-2% (+3.7%)
Cleaning	87%	72%	15%
Space at Desk	80%	65%	15%
Storage	84%	70%	14%
Thermal Conditions Overall: Summer	79%	67%	12%
Temperature: Summer	77%	65%	11%
Perceived Healthiness	87%	76%	11%
Thermal Conditions Overall Winter	82%	72%	10%
Facilities Meet Needs	94%	85%	10%
Furniture / Workstation	100%	92%	8%
Comfort Overall	83%	76%	7%
Design	96%	90%	6%
Image	98%	93%	5%
Space Layout of Building	77%	72%	5%
Happiness	84%	82%	2%
Temperature: Winter	73%	73%	1%
Noise Overall	62%	62%	0%
Lighting Overall	62%	63%	-1%
Privacy	37%	42%	-5%
Morale	57%	66%	-10%

Contextual Factors

Although a detailed organisational study of City of Melbourne is far beyond the scope of this study, some basic ‘contextual’ indicators were collected as a check to see if any major change had occurred in the non-building related factors during the study period. The indicators used were Collaboration, Organisational Communication, IT Systems, Time Autonomy, Happiness at Work and Workgroup Morale.

If it assumed that these non-building related factors can significantly influence productivity, it is important to have some before and after indicators, to be sure that the perceived productivity improvement is not ‘swamped’ by any significant contextual shifts. As shown conceptually in Figure 21, it is quite feasible to obtain misleading results (i.e. ‘false positive’ or ‘false negative’) if these factors are ignored when assessing productivity when using previous accommodation as a baseline.

Satisfaction ratings for six contextual variables which were added to the BUS questionnaires are compared in Table 11. These results show that IT systems are considered better in CH2 than for CH1 baseline, and that workgroup morale is lower, however the other variables are relatively unchanged between the two buildings. Occupant responses on the questionnaires, and discussions in the focus groups identified that workgroup morale issues were related to the organisational restructuring which took place during the study period. Given that other related contextual indicators such as collaboration, happiness and organisational communication are relatively unchanged, it is concluded that contextual changes are unlikely to have resulted in any ‘false-positive’ effect on perceived productivity ratings.

Table 11: Comparison of satisfaction ratings for contextual variables in CH2

Variable	CH1	CH2	Difference CH2-CH1
Collaboration	79%	73%	-6%
Communication	71%	77%	6%
IT	68%	83%	15%
Autonomy	96%	94%	-2%
Happiness	89%	83%	-6%
Morale	81%	64%	-17%

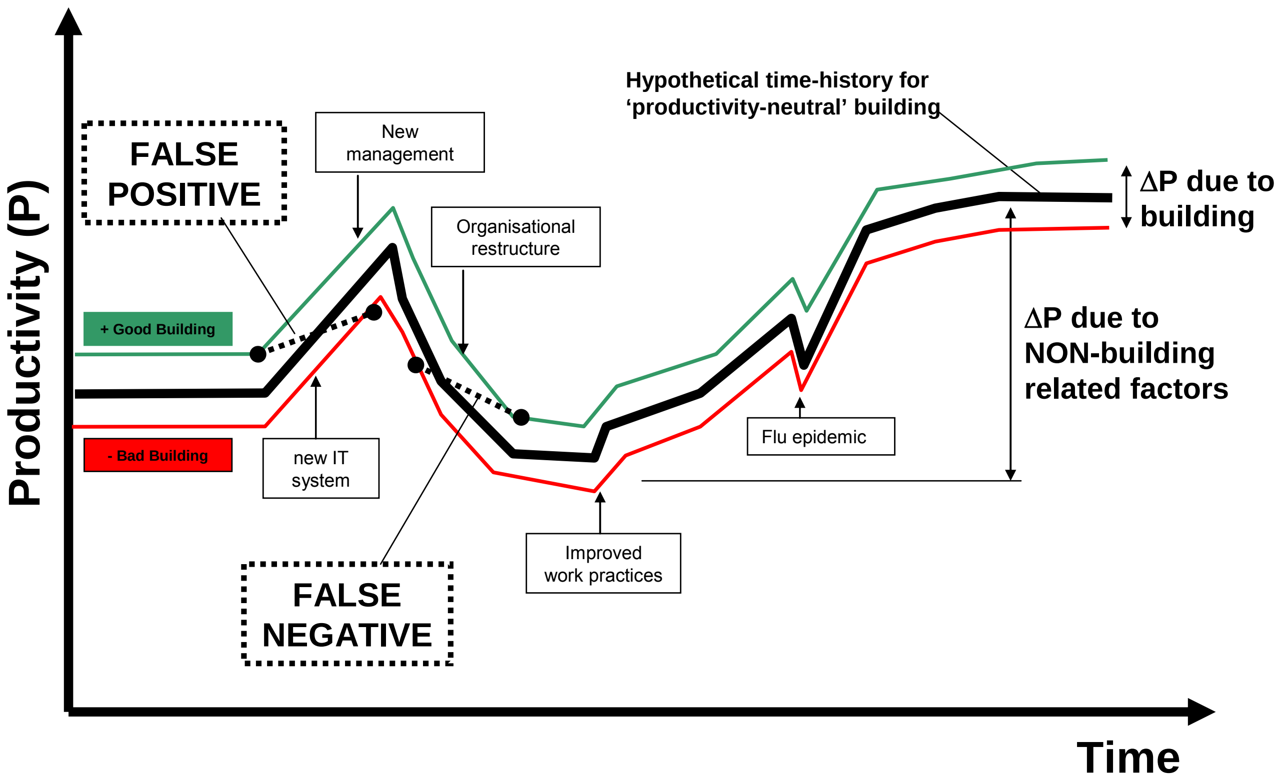


Figure 22: Conceptual diagram showing possible misleading effect of contextual factors on before-and-after productivity assessments

Summary

The analyses presented herein cannot be used to prescribe quantitative relative importance or weightings for the impact of individual variables (or categories of variables) on perceived productivity. However, they reinforce the notion that occupant productivity is likely to be dependant on a range of factors related to the overall building and it's fit-out, the different aspects of IEQ, and possibly other contextual factors which may not be related to the building itself, such as experiences in previous accommodation, and IT systems. In the case of CH2, it would seem that satisfaction with the 'building overall' is likely to have had a greater impact on occupants perceived productivity than any specific aspects of the IEQ. As far as the IEQ impact on perceived productivity is concerned, when the data is considered in light of occupant comments, it is likely that air quality and thermal comfort have enhanced productivity, whereas some issues with lighting and noise due to interruptions may have had a hindering effect.

Assumptions and Limitations

The major assumptions and limitations of the analysis and results presented are as follows:

- Findings are based on only one year of occupation of CH2, during which time the building was still being fine-tuned, and may not have been performing at the maximum level achievable.
- Most of the values presented herein are derived by averaging occupant responses and physical measurements over spatial and organisational boundaries. Naturally, this may result in some 'pockets' of positive or negative occupant responses or measurements to be hidden within the bigger picture.
- Productivity comparisons are made with respect to a CH1 baseline, however only 85 of the 260 people who responded to the occupant questionnaire in CH2 were based in CH1 previously. Although the comparative perceived productivity results are not derived from the exact same set of occupants, it is assumed that large enough samples were obtained in both buildings to provide adequately representative occupant perceptions.

Summary of Conclusions

CH2 occupants are highly satisfied with the **building overall**, and it's **facilities, furnishings and fit-out**, with generally higher satisfaction ratings than for CH1. More than 80% of occupants prefer CH2 to their previous accommodation.

Thermal comfort measurements in CH2 are generally very good, and are rated better overall than for CH1. Occupant perceptions of thermal comfort are also good in CH2, and are better than CH1, for all variables except ventilation, as a result of the airflow being perceived by some to be too still in CH2. This is a good outcome given the relatively complex and inter-connected nature of the various cooling and ventilation systems, and the fact that the systems were being tuned during the period of the study.

Air quality in CH2 is excellent in terms of measured pollutant levels, and is good based on occupant perceptions, and is better than in CH1. Formaldehyde concentrations in CH2 were much lower than normally found in office buildings. This result can be primarily attributed to the use of 100% fresh air ventilation, and low emission furnishings and finishes throughout the building. Air quality was identified by many occupants as having a positive effect on their productivity

Measurements of ambient **noise levels** and reverberation times were considered ideal in CH2. However occupant satisfaction ratings for noise in CH2 are average to poor and are worse than for CH1, primarily due to unwanted interruptions and distractions from other people in the building. The hindrance of noise from interruptions must be contrasted against the productivity enhancement due to open plan layout as observed by many occupants. Satisfaction with speech privacy in CH2 may be improved through tuning of the white noise system installed in the building. Trials in which white noise levels were increased on one Level in the building resulted in better satisfaction scores for noise when compared to the rest of the building (10-18% better for relevant noise variables), however this result is not conclusive, given that satisfaction ratings for most other variables were also higher on this Level. Careful consideration of workgroup layout, circulation routes, and the separation of quiet and noisy activities may also lead to improvements in occupant satisfaction with noise.

Lighting measurements in CH2 indicated that background lighting levels were sufficient, and that recommended task illuminances could be achieved if personal task lighting was switched on. However, occupant satisfaction with lighting levels is average to poor in CH2 and is worse than for the CH1 baseline.

The integration of task lighting into the overall lighting strategy, with lower general illuminance levels, as is the philosophy in CH2, is considered good practice from both a sustainability and user control perspective, however the initial configuration for the CH2 lighting resulted in some complaints about the building being too dark. These issues were addressed by building management during the study period by incorporation of additional lights, and improvements were observed in measured light levels, although the effect of the changes on occupant satisfaction are not clear. Occupant comments indicate that darker-toned furnishings and finishes may have had an impact on perceptions of lighting. The difference in the office layout between CH1 and CH2 may also contribute to the difference in satisfaction with natural light, as In CH1, the majority of staff were placed around the perimeter of the building, closer to the windows, whilst in CH2, the majority of staff are placed closer to the centre of the floor plate. Given the improvements and adjustments made to the CH2 lighting systems during the study, further assessment of the CH2 lighting is warranted.

Perceived **user control** over IEQ was rated poorly by occupants in CH2 and also for CH1, but only a small portion of occupants indicated this as important to them this and hence for this study, this is not considered as a major factor in assessment of the IEQ.

Perceived Productivity ratings show that CH2 represents a significant productivity improvement when compared to the CH1 baseline, despite poor satisfaction with lighting and increased noise levels due to the open plan layout. Three quarters of CH2 occupants rate the building as having a positive or neutral effect on productivity, compared with just 39% in CH1. CH2 is rated in the top 20% of Australian buildings for perceived productivity when compared against the BUS benchmark dataset. This can be expressed as a 10% perceived productivity enhancement compared to CH1, based on the scale and assessment method in the BUS questionnaire. Although this may not necessarily translate directly to an equivalent increase in work output, it is the most appropriate way to measure the building's impact on productivity in a diverse organisation which encompasses a wide range of job-types that have context-specific productivity dependencies that cannot be clearly defined or measured.

In the case of CH2, it would seem that satisfaction with the 'building overall' is likely to have had a greater impact on occupants perceived productivity than any specific aspects of the IEQ. It was shown that other factors, such as experiences in previous accommodation may also influence the results. As far as the IEQ impact on perceived productivity is concerned, when the data is considered in light of occupant comments, it is likely that air quality and thermal comfort are perceived to have enhanced productivity, whereas poor satisfaction with lighting and noise due to interruptions may have had a hindering effect.

Assessment of various **contextual indicators** shows that there has been a reduction in perceived workgroup morale due to workplace restructuring, but there have not been any major contextual shifts in terms of happiness, autonomy and communication during the study period. It is therefore concluded that contextual changes are unlikely to have resulted in any 'false-positive' effect on perceived productivity ratings.

CH2 is rated very highly by it's occupants for perceived **healthiness**, and is significantly better than CH1 in this regard. Both CH2 and CH1 were considered to have low levels of occupant-reported rates for building-related **health symptoms**, when compared to levels in the general population. **Absenteeism** and **staff turnover** have not changed significantly during the first 12 months of occupation of CH2, compared to previous years, however given the year-to-year variability, and the possibility that organisational restructuring may have had some impact, a longer period of monitoring is required before any solid conclusions can be made about the effects of the building on absenteeism and staff turnover.

Recommendations

It is important that CH2 performance continues to be monitored, as the results presented herein are based on one year of occupation only. It is recommended that the occupant questionnaires, and some form of physical IEQ measurements be repeated in 12-24 months, as the building was being fine-tuned during the study period, and the performance may not have been at the maximum achievable level during this time.

Due to the commissioning and tuning of the building, a vigilant approach was used by CH2 management in seeking and acting on occupant feedback. This is likely to have had a positive effect on occupant perceptions of the building, and aided forgiveness of any problems. It is highly recommended that this approach be continued into the future, to ensure ongoing high levels of building performance and occupant satisfaction.

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Established and supported under the Australian Government's Cooperative Research Centres Program