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Nuno Alexandre Faria Da Silva

DTU Civil Engineering Report R335 (UK)
September 2015

DTU Civil Engineering
Department of Civil Engineering

Technical University of Denmark DTU

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Nuno Alexandre Faria da Silva

Ph.D Thesis

Technical University of Denmark - Department of Civil Engineering

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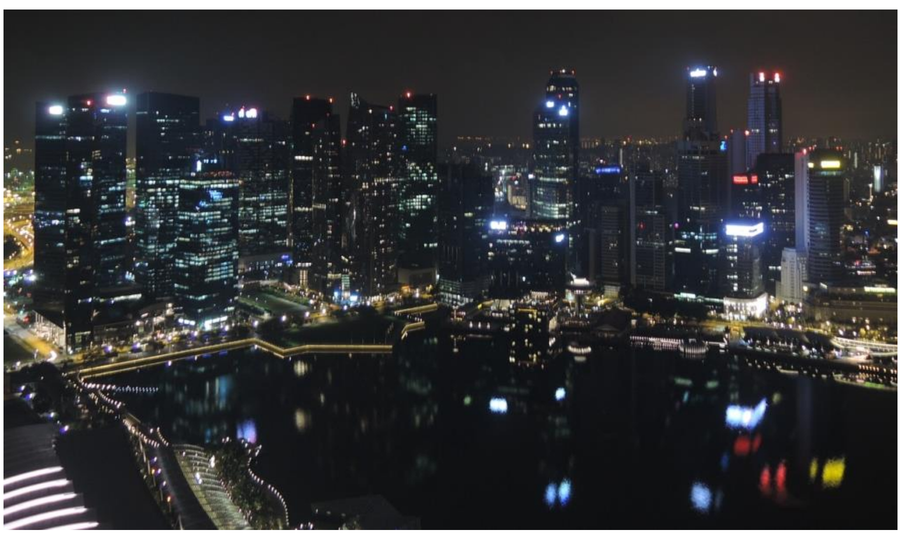

DTU Civil Engineering
Department of Civil Engineering

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Nuno Alexandre Faria da Silva

Ph.D Thesis
BYG – DTU – Department of Civil Engineering
Technical University of Denmark
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# Preface

The work presented on this PhD thesis was carried out at the International Centre for Indoor Environment and Energy (ICIEE), Department of Civil Engineering at the Technical University of Denmark (DTU) and National University of Singapore in the period between January 2012 and June 2015 under the supervision of Associate Professor Pawel Wargocki and Associate Professor Kwok Wai Tham.

The thesis was done as part using data gathered from the project "Indoor Environmental Quality and Productivity in Green Mark Certified Non-Residential Buildings" from Building and Construction Authority of Singapore and National University of Singapore.

First of all, I would like to express my sincere gratitude to my two supervisors Associate Professor Pawel Wargocki and Associate Professor Kwok Wai Tham for their guidance, advice and encouragement throughout my Ph.D. My sincere thanks to Lee Jang Young and Kok Wee Ng from Building and Construction Authority of Singapore, Ron Tan, Joanna Shen, Gayatri Sankaran and Jennifer Yap from National Environmental Agency of Singapore for their help and cooperation. Many thanks to Building and Construction Authority of Singapore for their support trough my project. Also I would like to thank all the staff at the International Centre for Indoor Environment and Energy, for their support and teaching during my PhD, and all the time we spent together. Special thanks to my family, for their constant support.

Kongens Lyngby, Denmark, July 2015

Nuno Alexandre Faria da Silva

## Abstract

**Building certification schemes and the quality of indoor environment**

Building certification schemes create a new standard for the built environment reflecting the growing environmental consciousness and the need for "green buildings". They are expected to signify an outstanding quality and excellence. Buildings, which receive a high degree of certification, are consequently presumed to guarantee the outstanding indoor environmental quality (IEQ). There still exists, however, scarcity of data supporting this postulation, especially as regards the ratings and perceptions of occupants of certified buildings.

This PhD attempts to shed a light on this topic and supplement with new measuring data. It attempts additionally to formulate recommendations regarding future revisions of building certifications, so that the IEQ requirements, human needs and expectations are sufficiently addressed.

These objectives were attained initially by reviewing the scientific literature, providing information on the performance of building certification schemes in relation to IEQ and ratings of building occupants. Then, information was collected on IEQ in existing office buildings certified as green buildings with particular focus on the work performance indicators, acute health symptoms, and perceptions and comfort.

Information on IEQ in the existing buildings was collected through field campaigns. They comprised measurements in 6 office buildings in Singapore certified using the Green Mark (GM) Certification Scheme. The measurements were additionally carried out in 6 office buildings that are not certified, and do not qualify for GM certification. The study looked into seven dimensions in a holistic and longitudinal approach. A special on-line software was developed for collecting responses from building occupants. It integrates the questions regarding satisfaction, acute health symptoms, information on the conditions and parameters supporting and distracting from the efficient work, as well as the self-estimated performance and objectively measured performance using different tasks examining various cognitive skills. The data on absence rates was collected, too, and the range of environmental measurements performed.

Literature review showed that holistic and transversal IEQ studies comparing Green and Non-Green buildings are rare, with most of the evidence over-represented by post-occupancy surveys. Generally results show that green buildings outperform non-green for most of the IEQ parameters, with exception of acoustic, lighting, and glare.

Results of measurements were modeled with statistical methods. They were then correlated with the measurements of IEQ parameters in the buildings. The results and analyses were specifically aiming in examining the differences between Green Mark and Non-Green Mark buildings. Physical measurements did not differ significantly between Green Mark and Non-Green Mark. Occupants´ satisfaction, importance and perceptions of IEQ parameters were observed to be better in GM buildings compared with the NGM buildings and the difference could be caused both by actual exposures and psychosocial factors. Air quality is the most important IEQ parameter for occupants in Green Mark buildings. Acoustical and visual privacy is problematic in Green Mark buildings. The odds of SBS symptoms in Green Mark are half of the odds in Non-Green Mark. Occupant self-assessment performance is better in GM buildings but no significant differences were observed for objective performance between occupants in both types of buildings. Annual sick-leave was lower in the Green Mark buildings; the difference was one day per year. In conclusion, Green Mark buildings have generally a positive impact on occupants, compared with Non-Green Mark buildings.

Improvements and future modifications of the building certification schemes are discussed. O.C.E.A.N (Organization, commitment, environment, aesthetics and natural) approach and a metric to integrate human satisfaction responses in certification schemes are recommended. Additionally, experiences collected during the fieldwork are used to upgrade the software for collection of subjective responses with an intent to use it for developing a common standard that can be used for gauging and benchmarking IEQ in buildings, as well as for examining the performance of buildings.

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# Resumé


**Bygningscertificering og indeklima**

Bygningscertificering har sat nye standarder for det byggede miljø, som et resultat af voksende miljøbevidsthed og et ønske om grønnere bygninger. Certificeringsordningerne forventes at resultere i bygninger af særdeles høj kvalitet. Bygninger der opnår den højeste certificering antages derfor også at have et særdeles godt indeklima. Imidlertid er der endnu kun få studier, der underbygger denne antagelse og især mangler viden om brugernes vurderinger og oplevelser af indeklimaet i certificerede bygninger.

Dette Ph.d.-studium har tilstræbt at imødekomme behovet for viden ved at analysere nye måledata. Studiet udmøntes i anbefalinger til revision af certificeringsordninger, der i højere grad inddrager krav til indeklima samt menneskers behov og forventninger.

Studiet indledtes med en gennemgang af den videnskablige litteratur omkring bygningscertificering og certificeringsordningernes betydning for indeklima og brugeroplevelser. Dernæst blev eksisterende viden om indeklima i certificerede grønne kontorbygninger gennemgået med fokus på præstationer, akutte helbredssymptomer, brugeroplevelser og komfort.

Information om indeklima i eksisterende certificerede bygninger blev indsamlet i målekampagner i seks kontorbygninger i Singapore. Bygningerne var certificeret efter Green Mark Certification Scheme. Endvidere blev der udført målinger i seks ikke-certificerede kontorbygninger, der ikke imødekommer ordningens krav. Kampagnerne betragtede syv dimensioner i et holistisk og longitudinalt perspektiv. Et online værktøj blev udviklet til registrering af brugernes respons. Værktøjet kombinerer subjektive spørgsmål om tilfredshed, akutte helbredssymptomer, information om indeklimaet og beskrivelse af parametre, der fremmer eller reducerer effektiviteten af det udførte arbejde og selvvurderet præstation med objektive målinger af præstation via opgaver, der kvantificerer forskellige kognitive egenskaber. Data om fravær fra arbejdet blev ligeledes indsamlet og der blev gennemført målinger af indeklimaet i bygningerne.

Litteraturstudiet viste, at tværsnitsundersøgelser der sammenligner indeklima i certificerede og ikke-certificerede bygninger er sjældne og at undersøgelserne typisk er gennemført som post-occupancy studier. Generelt viste resultaterne, at certificerede grønne bygninger scorer højere på de fleste parametre end ikke-certificerede bygninger, bortset fra akustik, lys og blænding.

Resultaterne af målingerne blev modelleret med statistiske metoder. Resultaterne blev sammenholdt med målinger af indeklimaparametre i bygningerne. Analyserne var særligt rettet mod at undersøge forskelle mellem Green Mark bygninger og bygninger uden Green Mark. Der var ingen forskel på de fysiske målinger i de to bygningskategorier. Brugertilfredshed og oplevelsen af indeklimaet var signifikant bedre i de certificerede bygninger og forskellen kunne tilskrives både de fysiske eksponeringer og psykosociale faktorer. Luftkvaliteten var den vigtigste indeklimafaktor for brugerne i de certificerede bygninger. Akustisk og visuel privathed var et problem i de certificerede bygninger. Odds for SBS symptomer i certificerede bygninger var lavere end i ikke-certificerede bygninger. Brugernes selvvurderede præstationsevne var bedre i de certificerede bygninger, men der var ingen forskel i objektivt målte præstationer. Det årlige sygefravær var lavere i de certificerede bygninger; forskellen var på én dag om året. I konklusion, havde de certificerede bygninger generelt en postiv betydning for brugerne.

Forbedringer og fremtidige ændringer af bygningscertificering diskuteres. Anvendelse af O.C.E.A.N. (Organization, Commitment, Environment, Aesthetics and Natural) som en ramme og måleenhed for integration af brugertilfredshed i certificeringsordninger anbefales. Ud fra de opsamlede erfaringer fra målekampagnerne er det udviklede værktøj til indsamling af brugeroplevelser blevet opgraderet og det er hensigten, at værktøjet skal udgøre en fælles standard til at måle og certificere indeklima i bygninger i Singapore og til at vurdere bygningernes effektivitet.

## Contents

## List of abbreviations

AC = Air conditioning

ACH = Air change rate per hour

AHU = Air handling unit

ASHRAE = American Society of Heating, Refrigerating, and Air-Conditioning Engineers

BCA = Building Construction Authority

BREEAM = Building Research Establishment Environmental Assessment Methodology

CAV = Constant air volume

CEN = European Committee for Standardization

CO= Carbon monoxide

DGNB = Deutsche Gütesiegel Nachhaltiges Bauen

DTU = Technical University of Denmark

EB = Existing buildings

EPD = Environmental product declaration

FCU = Fan coil unit

GLMM = General linear mixed model

GM = Green Mark

GSA = General Services Administration

HPD = Health Product Declaration

IAQ = Indoor Air Quality

ICEII = International Centre for *Indoor* Environment and Energy

IEQ = Indoor environmental quality

ISO = International Organization for Standardization

LCA = Life cycle assessment

LEED = Leadership in Energy and Environmental Design

LSD = Least Significant Difference

MNC = Multinational corporation

MV = Mechanical Ventilation

NC = New construction

NC = New construction

NEA = National Environment Agency

NGM = Non green mark

NUS = National University of Singapore

OI = Office interior

OR = Odds ratio

PCA = Principal component analysis

POE = Post occupancy evaluation

PPM = parts per million

PSI = Pollutant Standards Index

RH = Relative humidity

SBS = Sick building syndrome

Sqm = square meter

SS = Singapore Standards

TWA = Time weighted average

UGR = Unified glare ratio

VAV = Variable air volume

# 1 Introduction

## 1.1 Background

In recent years with the increase of environmental consciousness the awareness of stakeholders for sustainable buildings has increased. When observing the frequency of which the words “green buildings” and “sustainability” are present in the literature (Figure 1) in the 21st century, compared for example with the decline of references to IEQ and sick building syndrome, gives an idea on how sustainability issues have taken off. As a result of sustainability concerns, the concept of green buildings appeared as a consequence, and several voluntary environmental rating systems for buildings have been created as guidelines and certification tools awarding buildings designed in a more environmental conscious way. These rating systems have focused mainly on energy conservation. While a low-energy building is by definition a building with low energy consumption, a green building is more difficult to define, and maybe there will never be a precise definition, as they are constantly being updated in their definition (Berardi 2013). But all advocate to introduce innovations and sustainability into buildings, focusing on the environment and occupants.

Certification schemes are voluntary schemes, and unlike national codes they are not advocated as code requirements, but as a signature of prestige and sustainability. Building certification schemes initially appear as a natural response to the environmental consciousness of the generation X in the nineties, emphasizing and introducing the state-of-the-art concepts and technology, being advocated as tools to help achieving outstanding standards in buildings. While building codes are established to assure minimum healthy conditions for occupants, certification schemes supposedly are for exceptional conditions. Also most of the certification schemes are managed by private organizations, so there would be a conflict of interests if it were to be adopted at a governmental level. Certifications are not building codes. Codes putt their weight heavily on health, safety and hazard before sustainability. Despite this several public organizations worldwide have adopted green certification has a mandatory add-on on top of building regulations for their buildings. Providing owners and occupiers with a certificate of the building’s performance is also becoming highly valued by tenants and is increasingly viewed as selling and leasing factor.

Recent studies on the asset value of green office buildings, have shown that generally green buildings have a higher market value, by sale and leasing value, compared with conventional buildings (Harrison & Seiler 2011; Chegut et al. 2013; Eichholtz et al. 2013). There is evidence of leasing premiums up to 17% in green buildings compared to conventional buildings(Wiley et al. 2008).

Evidence in selling prices, also showed a premium of up to 30% for green buildings compared with conventional buildings (Eichholtz et al. 2013; Newell et al. 2011). There is supporting evidence of lower sale yields (Sayce et al. 2010) , higher occupancy rates and lower operation expenses in green buildings compared with conventional buildings (Wiley et al. 2008; Eichholtz et al. 2013).

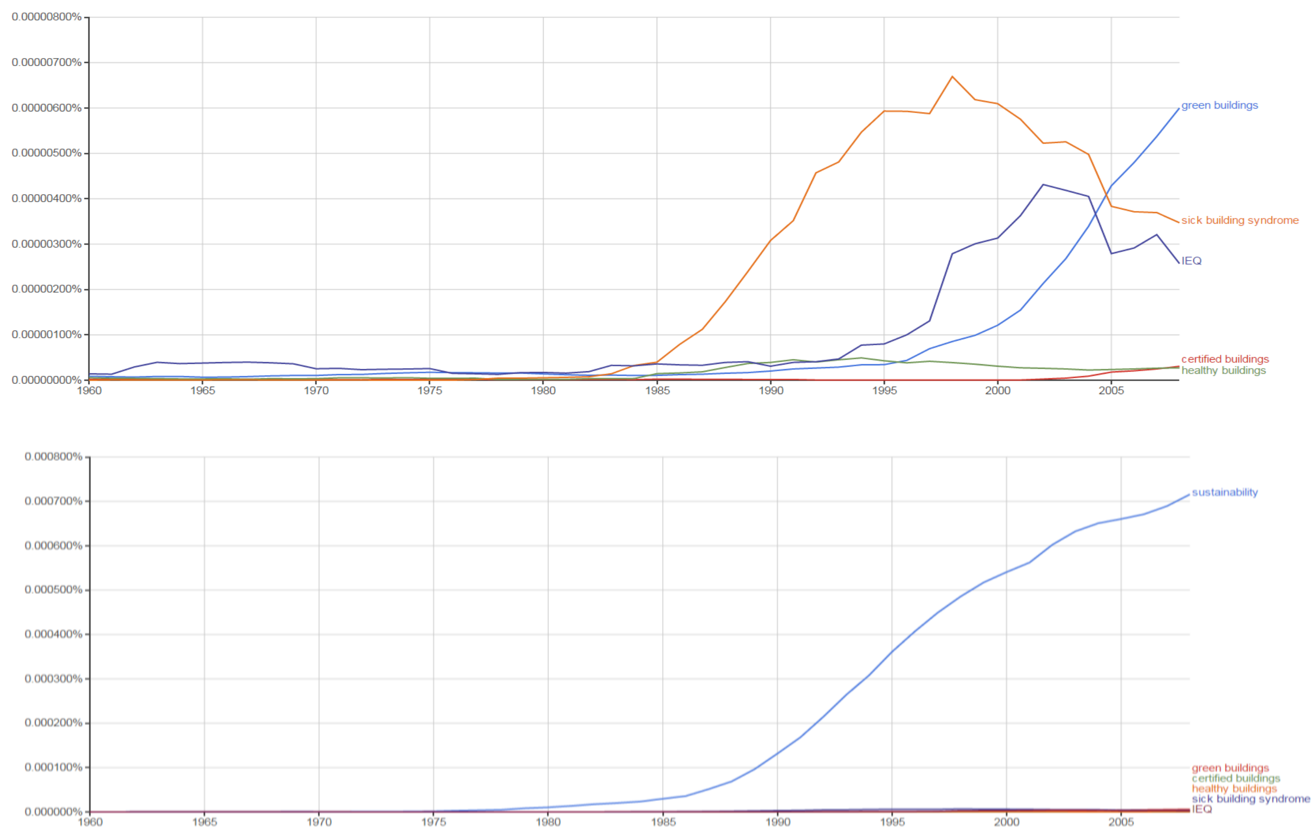


**Figure 1- Sustainability and green building frequency on literature from 1950 until 2008 using Google ngram viewer**

Several building certification schemes have been created around the world, e.g. LEED, GREEN MARK, BREEAM, GREEN STAR, DGNG etc. From United Nations Brundtland Commission, buildings can only be termed sustainable if they safeguard the interests of future generations. So certification schemes should thus also strongly emphasize IEQ, which besides reducing environmental impacts the schemes are also expected to create conditions of health and comfort by advancing indoor environmental quality and as a consequence also improving productivity and reduce sick-leave. These benefits if confirmed contribute directly to a company's profits and can further promote and incentivize the use of certification schemes and improved IEQ. In the last WorldGBC strategy plan (WorldGBC 2014), human health and productivity is placed as a centricity on the role of IEQ in green buildings. This is of course under the assumption that certified buildings do improve human health, comfort and productivity. Conventional metrics as carbon footprint, LCA, operating costs and social impacts with marketing and social responsibility are well-established, while IEQ and occupants benefits is more undeterminated, and is not necessarily and ad-hoc condition of green buildings.

Much less attention is paid to indoor environmental quality (IEQ) than other areas in certification schemes. A recent review of the main certification schemes used worldwide concluded that the average weight of IAQ is only 7.5% (Wei et al. 2015). For example in the new version of LEED V4 N+C, a well known certification scheme for new office buildings, only 16 points out of the total 110 is given for IEQ requirements; consequently a building can be certified in the highest class (LEED Platinum) without even paying much respect to IEQ because only 80 points are needed to reach this level and there is only a mandatory requirement of minimum indoor air quality. As illustrated, there is only modest incentive to promote high IEQ. Building certification schemes are usually voluntary sets of standards and in some cases can be earned for energy solutions without paying much attention to IEQ, as credits in the scheme can be traded across different categories to achieve as high a certification as possible without paying much attention to IEQ, jeopardizing IEQ improvements in relation to conventional buildings (Lee 2011a). A recent industry survey, found that energy cost still is the most important sustainability parameter for stakeholders (LaSalle 2010). In addition certification schemes work on an ascending order and point trade-off, so ultimately the differentiation might be in the amount of money the stakeholders are willing to spend, as mandatory pre-requisites are low. Also many certification schemes place relatively little emphasis on indoor air quality and have no requirement for post-occupancy IEQ monitoring. In some certification schemes one can even achieve the highest category without IAQ points. A sick building may even get certification, even if the building has problems, as there are no penalty criteria. Buildings can mostly upgrade on primary resources side.

There is a general perception by stakeholders that green buildings in recent years have contributed to step up sustainability in the building industry (Heerwagen 2010a), but while most literature tells what green buildings do and might do, few show it. It is not shown or studied to which extent green buildings may actually improve occupants' perceptions, satisfaction and productivity. IEQ data supporting claims is difficult to prove, as there is basically little systematic data benchmarking the benefits of green vs. conventional buildings so far, especially in relation to indoor environmental quality (IEQ) criteria used in the certification schemes, including the Green Mark scheme (Green Mark 2015) in Singapore, which is the subject of study in this dissertation, to support claims. As a consequence very little is known regards the responses of occupants in these buildings. It is thus difficult to judge how schemes, including Green Mark, are performing with regards IEQ and whether any modifications to the scheme would be required. When direct evidence is absent, conclusions are only assumptions. With average employee costs being 10 times higher or more than cost of space, which can be lower than 5% of the total operational expenses compared with numbers of 85% for workforce expenses (Morrell 2005)(Persram et al. 2007), it seems that there is inadequate promotion and evaluation of human related factors in green buildings. Productivity and reduced sick-leave in green buildings should not be ignored, as previous evidence has shown that employees perceived health and productivity improvements on green buildings (Armitage et al. 2011). Still in a recent survey of Canadian practitioners who were asked about important benefits of green buildings, only 25% replied human productivity while operation costs got 80%. Also only less than half have any measures to gauge the impact on green buildings on health, satisfaction and productivity. These metrics are rarely reported, unlike value, image, energy or sustainability (McGraw Hill Construction 2014).

Little is known about the actual IEQ performance differences between green buildings and conventional buildings. Usually expected and causal differences are more a belief than proven. Extensive peer-review literature has looked into IEQ design features, and the possible positive relation they have with occupant productivity and satisfaction (Loftness et al. 2003). However no evidence is shown directly linking these performance benefits with green buildings, although they are commonly and wrongly included as an attachment to the common attributes of green buildings, and so, highlighting the positive IEQ factors of green buildings. But this is mostly indirect speculation, as one cannot say that these attributes are common in green buildings and extrapolate conclusions. What we gather from these studies is the impact of the IEQ parameters on occupants, not the IEQ added value of achieving a green rating level, unless it is showed to be regulated by them in that way. While studies on IEQ parameters influencing comfort and performance are widely reported, the impact of IEQ in green buildings, standalone or in comparison with non green buildings is still very unclear and limited (Srebric 2010; National Academy of Sciences 2011). An additional problem is that the schemes are heavily weighted towards the environment and less to occupants' satisfaction and health.

Despite productivity in offices being influenced by several factors beyond IEQ (e.g. social environment and workplace relations) (Haynes 2008) green buildings are still expected to improve productivity because of their advocated better IEQ, which is featured in all major certification schemes (Yu 2011). Studies have also shown that higher satisfaction lead to higher commitment and extra work effort and retention of employees (Carlopio 1996; Podsakoff et al. 2000), but there are no criteria for assessing and rewarding labour productivity in green buildings.

Human performance is a function of the three factors: ability, motivation and opportunity and all must be supported by the work environment (Heerwagen 1998), so there is an importance for evidence-based results. Most evidence has been energy or cost based over human performance, despite the schemes having guidelines for some IEQ factors. Design and IEQ human relations should be tested and documented independently. This is the rational in energy evidence, so there is no reason not to be also on IEQ and human performance.

The research evidence to date does suggest that IEQ parameters such as temperature, emissions, ventilation (Seppänen et al. 2006; Malmqvist 2008) have a measurable effect on occupants. People are inhabitants of buildings, and so buildings must adapt to people, as they create the environment. For this reason, buildings should deliver a high performance in IEQ parameters. Perceived satisfaction with a good indoor environment in the office among employees is important for success and good productivity in companies. Previous studies have shown that a good indoor environment can result in higher satisfaction and better performance (Hummelgaard et al. 2007; Frontczak et al. 2012; Wyon 2004)

Poor indoor air quality can also affect health. The most common acute health symptoms experienced in modern offices are better known as Sick Building Syndrome (SBS) symptoms (Burge 2004). Suboptimal health will lead to reduced productivity and increased sick leave.

If these risks happened in buildings that are certified but have lesser emphasis on IEQ, this will compromise the sustainability concept promoted by the certification schemes. There is an urgent need to investigate whether the certification schemes, do provide good IEQ conditions in buildings and improvements in relation to conventional buildings. Whether they do not compromise good productivity and health. If this is the case, it must be defined which quick actions for modifying the schemes, are needed and which new policies must be formulated. This is why this study was performed, to address not only the understanding of sustainability but also comfort, health and well-being of occupants. The focus of the work is based on examining the achievement of sustainability certification scheme and identifying its possible enhancements.

The field work of this study was performed in Singapore, where Green Mark (GM) Certification Scheme has been used since 2005. Its aim is to reduce the environmental impacts and promote a reasonable use of resources, energy savings and healthy working environments in Singapore. Green Mark, unlike the other certification schemes was developed by the Singaporean government.

Green Mark´s role in promoting indoor environmental quality in buildings and productivity has not yet been clearly documented, so there is a need to document its current effects, and whether the scope and weightage for credits should be modified in next versions to achieve sustainable healthy living and work environments for occupants. In Green Mark certification schemes 8 out of 190 points are given to air quality in the non-residential buildings version (BCA Green Mark for New Non-Residential Buildings, Version NRB/4.0), while 18 out of 180 in the existing non-residential buildings; for the office interior 28 out 115 points are given for indoor environmental quality (BCA Green Mark for Office Interior, Version 1.1).

This Ph.D. study intends to shed light on the above issues by critically reviewing and examining IEQ criteria used in building certification schemes, in particular Green Mark, by suggesting possible modifications to these criteria and validating them against the intended goals including human performance, health and comfort, as well as by assessing the importance of IEQ criteria in the overall grading of the built environment, promoting safe, healthy and productive IEQ in certified buildings.

## 1.2 Motivation

Mixed reviews on benefits and measuring IEQ protocols, create a cloudy output (Issa et al. 2010a; Meir et al. 2009), making it difficult to make a case to owners and regulators of the benefits and where to invest or improve the IEQ in certified buildings. Longitudinal integration of objective and subjective measurements complemented with the on-site observations and interviews in green buildings are also scarce. Until now, when comparing green buildings with conventional buildings, subjective post occupancy evaluation (POE) surveys of occupants responses are commonly chosen over holistic measuring protocols. Do certified office buildings provide differentiated benefits? To which extent is there a need for improvements, or if there is any need at all?

Most results only look into some IEQ parameters, subjectively (e.g. survey) or/and objectively (e.g. absenteeism) but holistic occupant centric IEQ studies are very uncommon. An holistic approach should measure quantitative data (e.g. IEQ, human performance and sick-leave) and qualitative data (e.g. IEQ, Health, performance and sustainability)

So far building certification is mainly focused on energy and environmental impacts. This motivated the need for this project to focus on people, trying to understand how the indoor conditions should be assessed in offices for maximising occupants' comfort and performance and how these concepts can be developed to be incorporated in certification schemes in a way that will be possible to assure people a high quality indoor environment. Additionally, the motivation behind the project is also to see if it is possible to insert human response conditions into certification.

Also from the few studies available, mostly are from temperate climates, with a lack of results from tropical climates.

### 1.2.1 Research questions

The following are the research questions that were attempted to address in the present work:

- Are the criteria concerning IEQ in the Green Mark certification scheme set sufficiently high to promote satisfaction, health, comfort and performance?
- Is IEQ in Green Mark buildings better compared with Non-Green Mark buildings?
- Are there any other parameters related to IEQ which are not addressed in the Green Mark scheme which can compromise IEQ performance or would be beneficial if presented in the Green Mark scheme?
- Are the IEQ benefits on employees' satisfaction and productivity higher if an office has received higher Green Mark certification credits?
- Are there beneficial IEQ parameters in Green Mark buildings that are not accounted to, in the scheme?
- Can human related criteria be included in the Green Mark scheme?

## 1.3 Objective

The main objective of this Ph.D. study is to study the IEQ differences in GM and NGM buildings, and suggest what improvements are needed in the future indoor environmental requirements for building certification schemes that will pay attention to the satisfaction, comfort, health and productivity of the occupant. The PhD project aims to define and identify the key indicators of indoor environmental quality in office buildings for satisfaction, comfort, health and performance, through revision of available research methods and evidence and cross sectional measurements in office buildings. The project has explored which human-related indicators can be used in the green building certification schemes along with other indoor environmental quality criteria in the schemes. Justification of the potential modifications will have been performed along with the discussion of implications of the revisions.

### 1.3.1 Specific objectives

The specific objectives were:

- Provide evidence which will benchmark the differences in IEQ and its benefits on occupants in Green Mark and Non-Green Mark buildings, which will also facilitate and allow to recommend possible modifications of Green Mark certification scheme in Singapore enhancing IEQ towards higher comfort and health, if necessary. The objectives are:
- Review the current Literature of IEQ, and casual effects as productivity and absenteeism on green buildings and their comparison with conventional buildings.
- Compare IEQ in Green Mark Platinum certified buildings with buildings without Green Mark certification.
- Compare the effects of IEQ and non IEQ-related factors on the satisfaction, comfort, health and performance of occupants in Green Mark Platinum certified buildings with buildings without Green Mark certification.
- Make recommendations for enhancing IEQ within the Green Mark certification scheme.

## 1.4 Contribution of the PhD

The current PhD thesis is expected to contribute to the following information:

- Provide a review of published studies on the contribution of IEQ and its benefits on occupants in green office buildings.
- Benchmark of IEQ conditions and satisfaction of occupants in Green buildings in Singapore with reference to the Singapore Green Mark scheme.
- Identify factors affecting well-being of office occupants, and if they are improved in certified buildings.
- Make recommendations for enhancing IEQ within the Green Mark certification scheme

## 1.5 PhD Scope - Project Stages and Hypothesis

The project is divided in three main stages (as illustrated in Figure 2 below) with each stage having its particular objectives and with clearly defined hypotheses and deliverables.

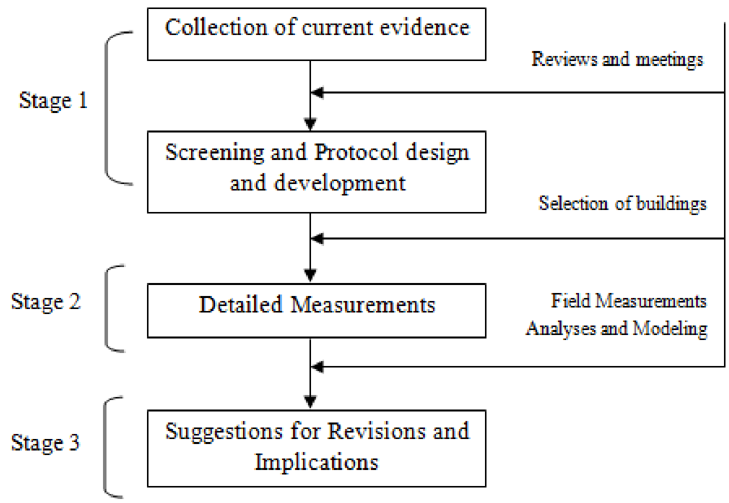


Figure 2 – Project stages

### 1.5.1 Stage 1 - Collection of information on building certification, users needs of indoor environments and productivity assessment

The development of measuring protocols for indoor environment in certified and non-certified buildings requires knowledge on: (1) Background info on the current certification schemes and which IEQ criteria are used in these schemes. What is their structure and weightage; (2) Methodologies in green building certification schemes, a knowledge-driven outcome (3) What is comfort, performance and human health?; (4) How are IEQ parameters understood by building occupants?; (5) How human response relate to indoor environment?; (6) Do parameters other than related to indoor climate (such as surrounding views, nationality, location, etc) and sociological factors affect productivity and satisfaction?; (7) How productivity can be assessed? (8) How current IEQ benchmark and comparisons studies are performed when comparing green buildings with non-green buildings, or only green buildings standalone.

To address the above questions a comprehensive literature review related to building certification schemes was carried out as well as screening of type of studies and measurements were done. The review establishes the present knowledge cap, motivating this project and development of an improved methodology for evaluating the impact of IEQ on people.

### 1.5.2 Stage 2 - Benchmarking and comparison of the performance of Green Mark and Non-Green Mark office buildings with regards indoor environmental quality and productivity

Future certification schemes are likely to accord a higher weightage to human responses in the certification / re-certification process. Therefore, the knowledge on previous studies on IEQ and its effect on occupants, gathered in Stage 1 together with the field work performed on stage 2 will be used for benchmarking and formulating criteria for enhancing IEQ holistically taking into consideration the combined effect of different human factors in office buildings. The sufficiency / inadequacies of the Green Mark scheme in relation to indoor environmental quality, addressing questions such as what they are, their impact on perception, satisfaction, health and performance, and what can be done to avoid them, was studied. IEQ quantitative and qualitative measurements methods were discussed and prioritized based on their feasibility and available timeframe.

Green Mark (GM) and Non-Green Mark (NGM) buildings were selected among a pool of buildings. Analyses were made of IEQ in buildings with certification schemes against the IEQ criteria used in Green Mark and the IEQ in buildings without certification schemes. Other criteria examined the impact of IEQ on human health, comfort and performance. The work was carried out under the umbrella of a research collaboration between the National University of Singapore and the Building and Construction Authority of Singapore. The sampling design includes six Green Mark certified and six Non-Green Mark buildings. A literature analysis and evaluation of the twelve selected buildings yielded knowledge about current situation on constructed certified buildings and select the most important criteria for indoor environmental quality based on the review of studies done to the present. Risks were assessed as regards performing measuring campaigns, insufficient number of occupants, etc.

In this stage, the following hypotheses were tested:

- Measured physical IEQ parameters are better in Green Mark buildings compared with Non-Green Mark buildings.
- Green Mark certified buildings perform better as regards human perceptions of IEQ
- Green Mark certified buildings perform better as regards satisfaction with IEQ.
- Occupants in Green Mark certified buildings have higher regard for IEQ Importance
- Prevalence of building related health symptoms in Green Mark certified buildings is lower compared with Non-Green Mark buildings.

- Occupants in Green Mark certified buildings perform better as regards self-assessment performance
- Occupants in Green Mark certified buildings perform better as regards work performance
- Occupants in Green Mark certified buildings perform better as regards occupant sick-leave.
- Occupants in Green Mark have higher sustainability consciousness
- Occupants in Green Mark buildings will accept compromise IEQ for energy savings

### 1.5.3 Stage 3 - Development of recommendations concepts for modifying Green Mark scheme and certification schemes in general which will promote IEQ, productivity, health and comfort in future.

Discussion of actual benchmarked IEQ conditions on green mark buildings and also their comparison and benefits in relation to conventional buildings.

Recommendations include modifications to the requirements regarding IEQ conditions and assessment of Green Mark buildings within a range that promotes productive and healthy indoor environments. Implications are also discussed.

IEQ criteria used in certification schemes are evaluated and recommendations for their modification made. Integration of human Satisfaction in Green Mark is presented. Assessment and recommendations that may improve the IEQ / non IEQ aspects based on the evidence from human performance results is made. This argues for the satisfaction and comfort value of such recommendations, so that the quality of life indoors and people performance in working spaces can be promoted.

One problem observed on the building industry is the lack of consistency and confusion between schemes (European Commission 2014), but importantly, a universally applicable IEQ rating concepts system for indoor environment was not devised. Results are based on Singaporean conditions and occupants. The work in stage 3 is specific and based on Green Mark results, but may to some extent be carefully extrapolated across different types of rating systems.

Not only the results of this study report the current IEQ difference between Green Mark and Non-Green Mark, the results from the project also try to suggest the future steps on which human index should evolve in Green Mark. Moreover, the study suggests what IEQ improvements can be devised in future Green Mark certification scheme and what are the missing important IEQ elements.

## 1.6 Location

This PhD project took place in two Universities during three years. Half in Technical University of Denmark, under the main supervisor Assoc. Professor Pawel Wargocki, and the other half was carried in Singapore on the Department of Building, National University of Singapore (NUS) under supervision of Assoc. Professor Kwok-Wai Tham.

## 1.7 Format

This thesis is presented on a monograph format.

# 2 Chapter - Literature Review

## 2.1 Introduction

Buildings are increasingly recognized to influence health and psychological well-being of occupants, and this is becoming more important for companies, so green buildings may create an opportunity to raise awareness about good environment associated with buildings and their employees.

Green building is the practice of creating environmentally responsible buildings that conserve natural resources throughout design, construction, operation and maintenance, providing healthier spaces for occupants. Green buildings are expected to optimize building performance attributes, like energy, productivity, sustainability and functionality.(EPA n.d.; USGBC n.d.; Fischer 2010)

| **IEQ Parameters** | LEED | BREEAM | DGNB | GREEN STAR | GREEN MARK – BCA |
|---|---|---|---|---|---|
| Country origin | USA | UK | Germany | Australia | Singapore |
| Prevalent location | Worldwide | Worldwide | Central Europe | South Hemisphere | South-East Asia |
| Started | 2000 | 1990 | 2007 | 2003 | 2005 |
| Regulator | Associative | Associative | Associative | Associative | Governmental |
| System | Points/Weighted | Credits/Weighted | Points/Weighted | Points/Weighted | Points |
| Enforcement | Voluntary | Voluntary | Voluntary | Voluntary | *Mandatory for new buildings with more than 2000 sqm |
| For all schemes there are several versions (e.g. new construction, renovation, interiors, etc) | | | | | |

**Table 1 – Selected certification schemes worldwide.**

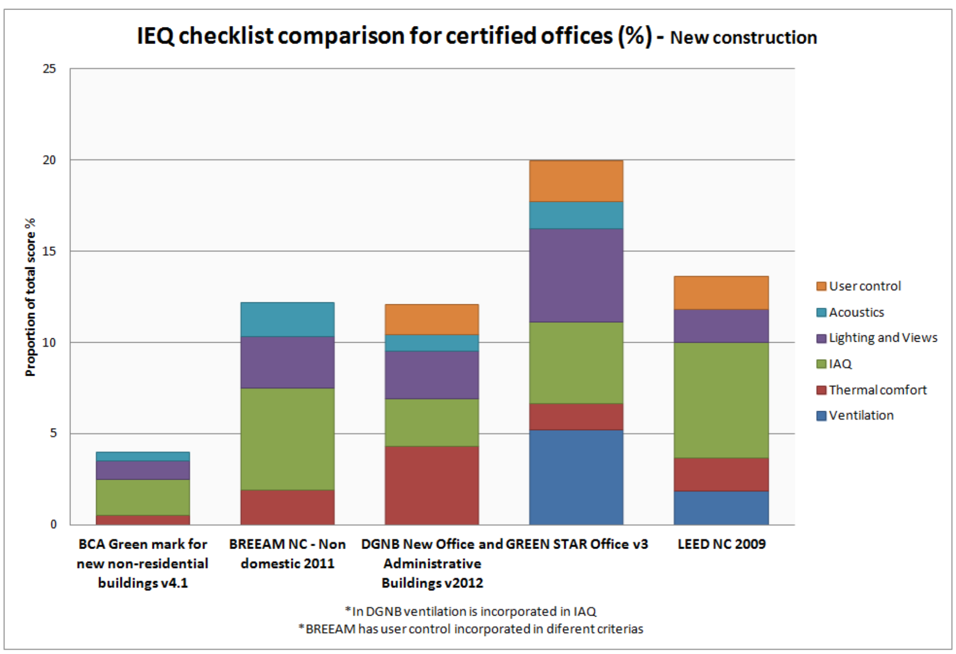


**Figure 3 – Comparison of IEQ checklist comparison among 5 of the main building certification schemes, for their new construction versions. No weigh factors included.**

To promote and help the design and implementation of green buildings, certification schemes have been created. Currently there are more than 50 green building certification schemes worldwide (Wei et al. 2015). Certification schemes are tools to assess sustainability of buildings. There are many voluntary green building rating systems, some of the most well known (Table 1) are LEED, BREEAM, GREEN MARK, GREEN STAR and DGNB, but until now there is no uniform certification process around the world. The schemes use different credit distribution for different variables, such as energy efficiency, location, materials, water efficiency, etc (European Commission 2014), and different importance/weightage to rate indoor environmental quality (IEQ) (Figure 3). IEQ tends to be lower than 20% of the scheme total scores (Figure 3). Most importantly, most schemes work mostly on a voluntary basis (Table 1), where developers can freely choose between different schemes and define their goals and objectives. Also they do have low mandatory IEQ pre-requisites (Table 2).

**Green building certification schemes– Offices New Construction**

| IEQ Conditional Requirements | | Recertification | Indoor Particle Control | IAQ Post Measurements |
|---|---|---|---|---|
| Green mark - New non-residential buildings v4.1 | None | YES | No | Yes - Optional on recertification |
| BREEAM NC - Non domestic 2011 | Visual comfort – Use of high frequency ballasts | PARTIAL | No | Yes - Optional |
| DGNB New Office and Administrative Buildings v2012 | Partial – Uniformity criteria between rating levels | NO | No | Yes - Partial optional |
| GREEN STAR Office v3 | None | NO | No | No |
| LEED NC 2009 | -Minimum Indoor Air Quality<br>-Environmental Tobacco Smoke (ETS) Control | NO | Yes - Optional | Yes - Optional |

**Table 2 – IEQ conditional requirements comparison among 5 of the main building certification schemes, for their new construction versions**

The adoption of schemes has been slow. In 2006 Hepner enquired dozens of architects (Hepner & Boser 2006) and they indicated that still less than 25% of their projects implemented LEED principles at that time. Today numbers have increased, a recent barometer collecting response from executives revealed that 63% were keen to seek certification on new projects (Turner 2014), but is still seen as a premium. Several research projects that have looked also into the costs of green buildings, a factor that could also be a restriction of their wide application (Kats 2003a; Miller et al. 2009a; Miller & Pogue 2009) showed that occupancy rates and rents showed to be higher in green buildings.

Certification schemes are a symbol of prestige and good marketing. It seems however that there is inadequate promotion of human related factors (Figure 3). Employee costs can be more than 10 times higher than the rental operation and maintenance costs (Morrell, 2005; Persramet al., 2007) so even 1% increase in productivity can provide more savings than any other building resource, like energy or materials. It is interesting to examine, whether human related factors are properly addressed in the schemes, as any productivity increase that is attributable to a green building compared to a conventional building should be somehow recognized and evaluated in a certification scheme. Productivity is affected by many factors including not only indoor environment but also social and economical stress. It may be therefore difficult to quantify the effects in real practice. Several studies have shown the relation of IEQ with employee productivity (Seppänen et al. 2006; Wargocki et al. 2002) but used simple mental tasks which may not always replicate the complex work requiring often  creativity and decision making.

IEQ should not be underestimated on long-term benefits as the most important asset in every company are their employees. So it is logical that their performance is the most vital metric. Ultimately office buildings are made to accommodate people. Establishing the link between green buildings and productivity would provide an incentive to seek certification. There seem however to be quite limited empirical evidence, which could substantiate the existence of such link even though it is widely believed that green buildings are more comfortable than conventional buildings, and thereby expected to be more healthy and productive (Heerwagen 2005; Persram et al. 2007). Green buildings potential can and do make broader use of IEQ factors (e.g., increased daylight, fresh air) that have been linked with improved performance and are perceived by occupants to improve workplace satisfaction and productivity (Heerwagen 2010b) however most scientific data commonly marked and linked to the IEQ benefits of green buildings usually stem from conventional buildings (Loftness et al. 2006) and no evidence is usually show directly linking these improvements with green buildings

A 2006 U.S General Services Administration (GSA) report describes that employees which intended to leave an organization were 25% less satisfied with their physical workplace than those who did not plan to change the workplace (GSA 2006). In another study it was found that recruitment and retention of employees in green buildings is perceived by tenants to be easier (Miller & Pogue 2009; Eggers & Widener 2011). Although the cost of productivity reductions from unsatisfactory IEQ can be as much as 100 times energy cost, health, comfort and work performance outcomes are more difficult to quantify than the effects on energy. Consequently, many stakeholders still tend to focus on the conservation of material resources, which are easily measurable and can get many credits in the certification schemes. Although claimed to have an outstanding IEQ, recent studies comparing IEQ in conventional vs. green buildings have shown that IEQ in green buildings may not necessarily be better, if developers are only interested in achieving the certification, and make trade-offs. This is because credits can be almost freely chosen, and the pre-requirements are low (Lee 2011b). Also occupants needs may not always be correctly addressed mainly because schemes are mostly based on building engineering technologies (Lee & Guerin 2009a). A limited numbers of credits for enhancing IEQ offered by the schemes will not certainly help very much that the high IEQ is guaranteed in certified office buildings.

The question on whether green buildings do increase well-being, comfort and productivity compared with the conventional buildings still remains unsolved and confused as there is a lack of consistent and systematic data benchmarking benefits of green building, in particular as regards IEQ and the effects on occupants. This review tries to enlighten this issue by surveying the available literature on this topic and summarizing the current published knowledge on the effects of green office buildings on employees. It attempts to answer the question on how IEQ and related outcomes on occupants in green buildings compare with non-green buildings, and which methodologies are currently used.

## 2.2 Methodology

Published peer–reviewed papers and reports, governmental and corporate, related to the topic were explored and those meeting the criteria for selection in the present survey were identified and carefully examined. The literature was collected using the on-line databases Web of Science and ScienceDirect. Findit database at the Technical University of Denmark was also used. Corporate reports were gathered through companies or associations websites. Their reference lists were screened as well to search for potentially missed publications. Besides the information on the type and level of the certification schemes, general data regarding the protocols and study size, and the procedures for selection of buildings, the following information was extracted: (i) self-estimated performance, perceptions of comfort and health symptoms, if measured; (ii) absenteeism, self-estimated motivation to work and objectively measured performance, if available; and (iii) measured IEQ parameters, if accessible. Peer review papers and reports that did not provide information on any of the above data were discarded. From a sample of around hundred fifty papers, only thirty seven peer-reviewed were selected.

## 2.3 Results

Thirty-seven peer-reviewed papers (Table 4 plus 5 papers in Table 8) and twelve white papers, or corporate studies/reports or governmental reports were included in the present review. These were selected, from a list of around 150 papers that was being constantly updated in the last 3 years, i.e. since 2012.

The data in the collected literature stem from cross-sectional studies performed either in green buildings alone (n=15) or by comparing conventional and green buildings (n=24). The post occupancy surveys were the main source of information on IEQ and human responses; very few studies included also the pre-occupancy evaluations. Physical measurements of IEQ parameters were very limited. The data collected were mainly the subjectively assessed IEQ satisfaction, acute health symptoms, comfort, and self-estimated productivity. In few cases, sick leave was registered. Most data were not adjusted for confounding factors such as, social relations, culture, etc. when comparing green vs conventional buildings. Main individual results are summarized in (Table 5)(Table 6)(Table 7)(Table 8) and conclusions for the literature review are summarized in (Table 3). In the tables colors indicate the direction of overall effect on a specific outcome: green positive effect (improved outcome), yellow no effect and red negative effect (reduced outcome) as a result of exposure in green building; grey shows the type of measurements performed to collect data on the specific outcomes. The text below summarizes main conclusions without cross-referencing the postulates/observations with particular report or the paper. The detailed information is provided in the Tables.

The literature surveyed shows generally that improved self-reported well being and performances are associated with green buildings, as indicated by better overall satisfaction and comfort, air quality, work performance and absenteeism. Health outcomes are better in green building compared with conventional ones, with lower SBS symptoms. Self-assessed performance is higher in green buildings compared with conventional building.

Occupants in green buildings generally report to be more forgiving and tolerant of indoor conditions, and more satisfied with natural aspects like view to the outside and fresh air, compared with conventional buildings. The sense of pride working for an organization that is committed to be green may lead to more tolerance. Occupants in green buildings showed to be more tolerant to suboptimal IEQ conditions. Sustainability beliefs were associated with higher tolerance observed in green buildings (e.g. natural ventilation through windows). Studies also show in several cases that green buildings will work better, if occupants are environmentally conscious. Personal control and thermal comfort do not generally shown improvements in green buildings compared with conventional buildings. Light, glare and acoustics in green buildings perceptions and satisfaction are usually comparable or worse than in conventional buildings.

## 2.4 Discussion

Green office buildings are commonly publicized as having better IEQ and improved occupant productivity (Charles et al. 2004). Comparisons among certification schemes are widely available (Liu et al. 2010; Xiaoping et al. 2009; Yu & Kim 2011). Indoor environment quality is usually featured in building certification schemes, ranging in weight and scope through the different schemes (Wei et al. 2015) but it is mostly prescriptive and actual improved characteristics, benefits and effects on occupants in green buildings compared with conventional buildings are mixed. This is due to the lack of studies on post-certified buildings, with poor methodologies on the studies performed.

As observed in this review most studies on productivity and satisfaction between green buildings and conventional buildings are based on post-occupancy surveys, except few cases when pre-occupancy studies were also made (Agha-Hossein et al. 2013; Brown et al. 2010; Singh et al. 2011; Singh et al. 2010; Thatcher & Milner 2012; Sustainability Victoria et al. 2006). Usually studies lack good comparison groups, with comparison with different types of buildings, in different seasons. They often do not control for different confounding effects and it is uncertain whether the reported benefits in green building will diminish with time as no study have adopted a long timeframe in a prospective design. Individual objective performance, organizational performance and absenteeism analyses are seldom done or reported, as well as physical measurements.

Building sample size in cross-sectional studies is usually small, being common comparisons of only two buildings (Thatcher & Milner 2012; Brown et al. 2010; Brown & Cole 2009; Tham et al. 2015; Agha-Hossein et al. 2013), which barely can represent two populations of buildings. Most of the studies are subjective post occupancy evaluation using questionnaires. Self-assessed productivity is a commonly adopted metric for productivity, as productivity is a holistic phenomenon which is not easy to measure, and it has been shown that the perceptions that occupants have from the IEQ on their workplace significantly influence their perceived productivity (Roelofsen 2002; Vischer 2008). However although objective performance measurements are important, nonetheless they are seldom done, and usually when done only absenteeism is collected. Few studies of cohorts include objective performance results after the move from a conventional building to a new green mark building, but objective performance measurements in cross-sectional studies are few. Post occupancy questionnaires dominate in studies, and their results may over represent IEQ conclusions in green buildings.

While Post Occupancy Evaluation can identify problems that can be unnoticed and in future projects reduce the gap between occupants' expectations and actual performance, they still have a subjective side and standardization problem. In 2009 Meir reviewed POE practices and found that the lack of agreed protocols and procedures, makes comparisons and benchmarks difficult (Meir et al. 2009). POES are also expensive and lengthy to perform (Hewitt & Higgins 2005; Bordass & Leaman 2005; Hadjri & Crozier 2009)

Most of the corporate reports and communications, although widely available to the public, lack the proper scientific rigor as regards the protocols and methodologies. Also these are mostly done in iconic buildings (Paevere & Brown 2088; Heerwagen 2005; Olmstead & Neely 2005; Sustainability Victoria et al. 2006), so only few were selected to be showed here, when their methodologies and description of results were acceptable and relevant. Their observations are usually merely anecdotal.

Another problem comes from the lack of control groups to compare with the new non-certified buildings (Turner 2006; Monfared & Sharples 2011; Mccunn & Gifford 2012; Hwang 2010a; Edwards 2006), making it difficult to know the source and dimension of problems and benefits. Unless systematic benchmarking with the proper control for bias is implemented, green buildings cannot be regarded to provide regular and measurable benefits for health, comfort and work performance. Intervention and long-term follow–up studies after moving to the green buildings could be one approach to provide more scientifically valid information.

The psychosocial workplace effects and connection with nature seemed to be strongly related with perceptions and satisfaction in green buildings. These effects have been observed before. A previous study in 39 offices showed how psychosocial effects related to IEQ are importantly related to occupant performance (Brauer & Mikkelsen 2010) another study have shown how occupant productivity will benefit from greenery in offices (Chau et al. 2006).

There are often no specific mandatory requirements in certification schemes to promote outstanding IEQ that are much different from the current building codes or common referenced standards in conventional buildings (e.g. ASHRAE 62.1 (ASHRAE 2010), EN15251 (CEN 2007), SS554 (Singapore Standards 2009), etc). These codes need to be followed by the new conventional and certified buildings in many countries. This is probably one of the reasons why it is hard to observe, whether green buildings perform systematically better than the conventional buildings. Certification criteria providing credits only for outstanding IEQ are required.

## 2.5 Conclusions

- Although for some parameters green buildings seem to perform better than the conventional buildings, and in comparison studies, the best green buildings usually outperform conventional buildings, there is no firm, consistent and systematic data showing that by default green buildings will perform better compared to conventional buildings as regards IEQ.

- A distinction between what benefits in green buildings are attributed to IEQ or merely to occupants´ expectation is not clear. The credit system in the certification schemes giving too little emphasis on IEQ with low mandatory requirements may be one of the reasons.

- Longitudinal holistic studies comparing the IEQ in green and conventional buildings are missing.

- Most of the information on performance of green building is from over-represented subjective evaluations with large diversity in scope, as well as with low control of confounding. Consequently, the conclusions of improved subjective responses in green buildings may merely mirror the expectations, and even pride of working in such a green building rather than the true tangible effects.

⊕ = Data from green buildings; θ = Data from green buildings compared with conventional buildings

| | | |
|---|---|---|
| Subjective assessments by building occupants (n=6) studies have pre-occupancy measurements. The results show that the best green buildings outperform conventional ones in benchmarking studies. (n=4 benchmarking studies showed no improvements on green) | Overall IEQ | ⊕ High satisfaction with greenery, design, views and openness of the space. Daylight improved (n = 10)<br>θ On average green superior to conventional buildings. After a move or retrofit, overall IEQ rated higher in green buildings (n=20). |
| | IAQ | θ In most cases IAQ rated high in green buildings compared with the conventional buildings (n=20). |
| | Comfort | θ On average green buildings rated better in questions related to the overall comfort scores (n=21). |
| | Health | ⊕θGenerally improved self-reported acute health symptoms (n=15). No studies where green buildings scored low on health. |
| | Self-estimated productivity | ⊕θ Generally improved in green buildings (n=14) (n=3 reverse effect). Self-estimated productivity strongly correlated with subjectively assessed health and comfort. Effects estimate between 2% and 16%. |
| | Tolerance | θ Collected data suggest that occupants are more tolerant, engaged and forgiving to inadequate IEQ (e.g. temp.) in green buildings compared to conventional buildings (n=8), at least after moving to such building. Whether this "affection" remains longer or is temporary is unclear. |
| | Satisfaction | ⊕θ Green buildings achieve better satisfaction scores when occupants are committed with sustainability, and proud of their workplace. Premium location and outside views may also influence perceptions. |
| | Personal Control | ⊕ Lack of controls is one of the main causes for discomfort. There is no tendency in the results when compared with conventional buildings. |
| | Thermal | ⊕ Overheating, overcooling and draft are reported (n=8) but in (n=15) of studies, occupants have been satisfied. Results suggest that complaints are mostly the result of preferences and the facility management. |
| | Lighting<br>Glare<br>Acoustics | ⊕ θ Acoustic and lighting environment are frequently characterized as comparable as or worse than conventional buildings, especially in case of the open-plan offices where excessive noise and lack of privacy affecting concentration. Dissatisfaction with glare, bad layout design, and low light controls is also reported in green buildings (n=17). Users are commonly more dissatisfied with these parameters above compared with conventional buildings. |
| Objective Data n=8 | Productivity<br>Absenteeism | Mostly cohort studies (Pre/Post-Occupancy). θ Values are the same or better, in most of the case studies. Sick leave reduction estimated to be between 5%- 39% (n=1 increase of absenteeism). No information whether effects remain after years of working or are temporary. |
| Phyc. Data n=10 | Measured IEQ | ⊕θ Overall measured IEQ parameters in green building are in the range recommended by building codes/standards, less departures than in conventional buildings. Sporadic cases of temperature departures. |
| Stakeholders valuation | Appraisal | Online surveys, interviews, and annual barometers show that green buildings are perceived by tenants to help improving productivity, recruitment and retention of employees. Practitioners draw attention to the uncertainty about the size of productivity and health benefits. Stakeholders perceive the lack of documentation on IEQ payback values and long-term benefits are still a barrier. |

**Table 3- Main results provided in the literature collected through this survey * Green positive effect (improved outcome), yellow no effect and red negative effect (reduced outcome)**

| Peer review Papers (Pre and Post-Occupancy) | | | | | | | |
|---|---|---|---|---|---|---|---|
| Author (Type of paper) (Methods) | Type of study | Popula tion | Focus | No of buildings (Green/Conventional) | Country | Construction/Renovation Year | Certification type |
| (Leaman 2007) | ***Post-occupancy Surveys*** | >250 High | IEQ/Comfort/ Productivity/Health | 22 Green / 23 Conventional | Australia | 1998-2002 | N.A |
| (Paul & Taylor 2008) | ****Post-occupancy Surveys*** | N.A | IEQ/Comfort | 1 Green / 2 Conventional | Australia | N.A | N.A |
| (Abbaszadeh et al. 2006) | ****Post-occupancy Surveys*** | >250 High | Comfort | 21 Green / 160 Conventional | USA/Canada/Finland | N.A | LEED |
| (Leaman & Bordass 2007) | ****Post-occupancy Surveys*** | >250 High | IEQ/Comfort /Health | 177 (Green+Conventional) | UK | N.A | Several |
| (Thatcher & Milner 2012) | ****Pre and Post-occupancy Surveys*** | <250 Moderate | IEQ/Comfort /Health/Productivity | 1 Green / Several Conventional | South Africa | N.A | GreenStar |
| (Baird 2010) | ****Post-occupancy Surveys*** | >250 High | IEQ/Comfort /Health/Productivity | 30 Green | Worldwide | N.A | Several |
| (Turner 2006) | ****Post-occupancy Surveys*** | N.A | IEQ/Comfort | 7 Green | USA | N.A | LEED |
| (Singh et al. 2010) | ****Pre and Post-occupancy Surveys*** | <250 Moderate | Health/Productivity | 2 Green/ 2 Conventional | USA | N.A | LEED |
| (Singh et al. 2011) | ****Pre and Post-occupancy Surveys*** | <250 Moderate | IEQ/Comfort/ Productivity | 2 Green/ 2 Conventional | USA | N.A | LEED |
| (Monfared & Sharples 2011) | ****Post-occupancy Surveys*** | >250 High | IEQ/Comfort | 2 Green | UK | N.A | BREEAM |
| (Miller et al. 2009b) | ****Post-occupancy Surveys*** | >250 High | Productivity | 154 Green | USA | N.A | LEED + Energy star |
| (Mccunn & Gifford 2012) | ****Post-occupancy Surveys*** | <250 Moderate | IEQ/Comfort/ Productivity | 15 Green | Canada | Several | LEED |
| (Lee & Kim 2008) | ****Post-occupancy Surveys*** | >250 High | IEQ/Comfort | Secondary data from CBE database Green/Conventional | USA | Several | LEED |
| (Lee & Guerin 2010) | ****Post-occupancy Surveys*** | >250 High | IEQ/Comfort in workstation Layout | Secondary data from CBE database Green/Conventional | USA | Several | LEED |
| (Lee 2010) | ****Post-occupancy Surveys*** | >250 High | IEQ/Comfort in workstation Layout | Secondary data from CBE database Green/Conventional | USA | Several | LEED |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| (Lee & Guerin 2009b) | ***Post-occupancy Surveys*** | >250 High | IEQ/Comfort | 15 green from Secondary data from CBE database | USA | Several | LEED |
| (Lee 2011a) | ***Post-occupancy Surveys*** | >250 High | IEQ/Comfort | 15 green from Secondary data from CBE database | USA | Several | LEED |
| (Hwang 2010a) | ***Post-occupancy Surveys *Physical Measurements*** | >250 High | IEQ/Comfort /Health | 1 Green Building | Korea | NA | KGBC |
| (Gou et al. 2011) | ***Post-occupancy Surveys*** | <250 Moderate | IEQ/Comfort | 2 Green building/ 117 employees working in conventional office buildings in Hong Kong. | Hong Kong | 2008/2009 | LEED |
| (Edwards 2006) | ***Case-study **Physical Measurements*** | >250 High | IEQ/Productivity | 1 Green Building | UK | 1996 | BREEAM |
| (Deuble & de Dear 2012) | ***Post-occupancy Surveys *Physical Measurements*** | >250 High | IEQ/Comfort/ Productivity/Health | 2 Building considered green | Australia | 2006/60´s | NA |
| (Brown et al. 2010) | ***Pre and Post-occupancy Surveys Reviews*** | >250 Moderate | IEQ/Comfort/ Health/Productivity | 1 Green / 1 Conventional | Canada | 2008 | LEED |
| (Brown & Cole 2009) | ***Post-occupancy Surveys*** | <250 Moderate | IEQ/Comfort | 1 Green / 1 Conventional | Canada | 2005/1968 | LEED |
| (Newsham et al. 2013a) | ***Post-occupancy Surveys *Physical Measurements*** | >250 High | IEQ/Comfort/ Health | 12 Green / 12 Conventional | USA/CANADA | Several | LEED and LEED CANADA |
| (Gou et al. 2013) | ***Post-occupancy Surveys*** | >250 High | IEQ/Comfort/ Health/Productivity | 9 Green / 5 Conventional | China | 2007-2010 | LEED and GBL |
| (Liang et al. 2014) | ***Post-occupancy Surveys *Physical Measurements*** | <250 Moderate | IEQ/Comfort | 3 Green / 2 Conventional | Taiwan | NA | EEWH |
| (Altomonte & Schiavon 2013a) | ***Post-occupancy Surveys*** | >250 High | IEQ/Comfort/ Health/Productivity | Data from CBE database Green/Conventional | USA | NA | LEED |
| (Hedge et al. 2014) | ***Post-occupancy Surveys*** | >250 High | IEQ/Comfort/ Productivity/Health | 2 Green/1 Conventional | Canada | 2005/2008 | LEED Canada |
| (Menadue et al. 2013) | ***Post-occupancy Surveys*** | >250 High | IEQ/Comfort/ Productivity/Health | 4 Green/4 Conventional | Australia | 1970s - 2009 | Green Star |
| (Pei et al. 2015) | ***Post-occupancy Surveys *Physical Measurements*** | >250 High | IEQ/Comfort | 10 Green/42 Conventional | China | Green - after 2008 Conventional - NA | GBL |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| (Tham et al. 2015) | ***Post-occupancy Surveys *Physical Measurements** | <250 Moderate | IEQ/Comfort/ Productivity/Health | 1 Green/1 Conventional | Singapore | -/1970 | Green Mark |
| (Agha-Hossein et al. 2013) | ***Pre and Post-occupancy Surveys *Physical Measurements** | <250 Moderate | IEQ/Comfort/ Productivity/Health | 1 Green/1 Conventional | UK | 1962/2010 | BREEAM |

**Table 4 – Peer review papers selected for the literature review**

| Peer review Post-Occupancy studies - (with(out) Comparison with Conventional Buildings) | | | | | | |
|---|---|---|---|---|---|---|
| First Author (Type of paper) (Methods) | Sick Leave Data | Quality of the Results | Remarks | Human-Relation (Productivity) | Comments | Main Results |
| (Leaman 2007) | No | (+) | Several green buildings are not certified, just considered "green". | ⊕ Occupants in green buildings have on average worst self-assessed productivity, but the best green buildings surpass conventional ones | Lower productivity is mainly driven by poor thermal comfort.<br><br>Occupants in Green buildings showed more tolerance to IEQ | ⊕ Scores on design, image, health were on average better in green buildings<br>⊕ Only the best Green buildings outperforming conventional buildings, for thermal comfort and forgiveness.<br>⊕Temperature, ventilation, noise and lighting rated lower in green buildings than conventional buildings. |
| (Paul & Taylor 2008) | No | (-) | The study shown that thermal comfort highly influences overall satisfaction<br><br>University buildings | Not available | Anecdotal conclusions has there were malfunctions in the green building systems which can distort the conclusions | ⊕ Results do not support the hypothesis that green buildings outperform conventional buildings. Thermal complaint in green building. |
| (Abbaszadeh et al. 2006) | No | **(++)** | Comparison between green and conventional buildings using CBE database<br><br>*6 buildings are 'only' identified as green | Not available | In Green buildings is reported that the problems observed with daylighting and artificial lighting, could be due to inadequate provision of personal control.<br><br>Reported that occupants are more tolerant to IEQ if they have some personal control over the IEQ. | ⊕ Occupants of green buildings were more satisfied with the building overall, IAQ and thermal comfort. Overall, IEQ variables in green buildings showed improvement or stayed the same.<br>⊕Lighting and acoustics did not show any improvements.<br>⊕ For both types there were complains about lack of daylight and light and glare. Acoustics and lack of privacy complaints on both types. |
| (Leaman & Bordass 2007) | No | (+) | Positive responses in individual IEQ parameters are more unclear and diluted than for overall IEQ questions | ⊕ Self-assessed productivity better in green buildings. | In this study is pointed out that smaller green buildings are often more successful than larger buildings.<br><br>Occupants in Green buildings showed more tolerance to sub-optimal IEQ conditions. | ⊕Ratings scores for green buildings tend to be better than conventional buildings for 'comfort overall' and 'lighting overall'. Design, image, and health are rated better in green buildings compared to conventional.<br>⊕Temperature, IAQ and noise no significant differences. |
| (Baird 2010) | No | **(++)** | Employee surveyed on 45 aspects of building performance | ⊕ Self-assessed productivity have been increased by | Occupants showed high thermal tolerance in sustainable buildings. | ⊕Design, overall lighting, daylighting, overall comfort and health reported positive scores. |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | 4 % on average as a result of IEQ | Occupants like to have the possibility of personal control (e.g. Natural ventilation) | ⊕Noise was the commonest source of complaint. Complaints about daylight glare. Temperatures showed cases of summer overheating and overcooling. |
| (Turner 2006) | No | (+) | Results gathered by a Post-Occupant survey to office buildings | ⊕ Light and IAQ were perceived by employees as being helpful in getting work done | Temperature had the lowest score of all positive ratings<br><br>Some complaints include drafts, heat gradients in the office, and lack of temperature control. | ⊕ Occupants were generally satisfied with IEQ overall and personal workspace. Satisfaction ratings for most IEQ categories were positive<br>⊕ The exception was noise level and sound privacy, which typically had a negative satisfaction |
| (Monfared & Sharples 2011) | No | (+) | Survey was done twice in the two buildings (1 year gap)<br><br>Interviews were also performed | Not available | 32% of the staff used either fans or heaters for personal comfort.<br>Green attitudes from occupants lead to more tolerance and better overall satisfaction and self-reported productivity, even for abnormal IEQ conditions. | ⊕High overall IEQ satisfaction in the green building<br><br>⊕ The Lack of control caused dissatisfaction, being override by individual actions. Is unknown if it is a design problem or a FM problem. |
| (Miller et al. 2009b) | Yes | **(+++)** | Multi-Large Survey | ⊕ Survey to tenants. sick days and self-assessed productivity improved after moving into a green building. | A substantially part of the sample are energy-star buildings, which more focus on energy efficiency | ⊕ Results from tenants: 12% strongly agree that employees are more productive, 42.5% agree that employees are more productive, and 45% suggest no change. When moving to a green building 45% agree that sick leave decreased, 45% find it is the same, while 10% find more sick leaves. 19% of occupants reported better productivity |
| (Mccunn & Gifford 2012) | No | **(++)** | All employees have worked in the buildings for at least 4 years. Relation between green attributes and employees outcome | ⊕ No improvements in self-assessed productivity | Pro-environmental employees are more engaged at work | ⊕No relations between green design attributes with job satisfaction, productivity and organizational commitment.<br>⊕Complaints about the lack of access to windows and decoration of workspace. |
| (Lee & Kim 2008) | No | **(++)** | Data analysis from CBE Database | Not available | Acoustic problems are considered by occupants to disturb their performance | ⊕Green buildings are better in office furnishings quality, thermal comfort, IAQ, and cleanliness and rated lower in office layout, lighting and acoustic quality<br>⊕Complaints about lack of privacy and personal space. |
| (Lee & Guerin 2010) | No | (-) | Data analysis from CBE Database – Layout | Not relevant | Study more focused on different workspace layout outcomes in green buildings. | People in high cubicles showed lower performance satisfaction in connection with lighting. Private offices show the best IAQ effect on self-reported improvements on performance |
| (Lee 2010) | No | (-) | Data analysis from CBE Database - Layout | Not relevant | Study more focus on different workspace layout outcomes | High cubicle type had the lowest satisfaction and perceived performance. |

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| | | | | | in green buildings. Conclusions of this study oppose results from most studies on open-plan offices. | Bullpen offices achieve better acoustic and privacy results than partition cubicles. Private offices have the best overall scores |
| (Lee & Guerin 2009b) | No | **(++)** | Data analysis from CBE Database | ⊕ Overall IEQ enchants self-assessed productivity | Complaints about lack of IEQ control | ⊕ IEQ elements that have a positive impact include ergonomics, cleanliness and IAQ.<br>⊕Acoustic and temperature had a self-reported negative impact in performance. Light and office layout was poorly rated. |
| (Lee 2011a) | No | (+) | Data analysis from CBE Database | ⊕ Overall IEQ is perceived by occupants to enchants productivity | IAQ was showed to be d strongly associated with self-reported productivity and health. | ⊕ The certification level in LEED is related to IEQ satisfaction levels. Positive relation between performance, IAQ and overall satisfaction was showed. Building overall and IAQ have positive satisfaction.<br>⊕ Temperature has a neutral satisfaction |
| (Hwang 2010a) | No | (+) | Results related to lighting in a green building | Not available | Is reported that daylighting can improve psychological health and productivity. | ⊕ Lighting was overall poor. Glare cause dissatisfaction. Significant correlation between occupants' visual comfort and satisfaction and lighting conditions and luminance was found. |
| (Gou et al. 2011) | No | **(++)** | Post-occupancy Survey in 2 green building | Not available | Daylight levels were perceived higher compared to artificial light in the green offices.<br><br>Open-plan offices increased interruptions compared with conventional offices. | ⊕ Overall IEQ satisfaction positive in green buildings. Overall occupants in green buildings perceive to have more daylight<br>⊕No significant satisfaction differences between green and conventional for IEQ perceptions and satisfaction. In green buildings the temperatures tend to vary more.<br>⊕ Complaints about glare and lighting and odors in green buildings. Open plan office configuration lead to acoustics and privacy complaints in green buildings |
| (Edwards 2006) | No | (-) | Case study of an office bank | ⊕2–3% potential improvement in productivity | Iconic building with several "green" technologies | ⊕ Occupants reported more satisfaction the higher the floor they work. |
| (Deuble & de Dear 2012) | No | (+) | Post-occupancy Survey in 2 academic buildings.<br><br>The buildings are just 2 conventional buildings that are assumed to be green | ⊕ Self-assessed productivity was negative | Occupant perceptions and satisfaction were positively associated with environmental beliefs.<br><br>Green attitudes from occupants lead to more tolerance towards sub-optimal IEQ conditions. | ⊕ Design, needs, health and productivity had positive scores<br>⊕Temperature, ventilation, noise, lighting and overall comfort satisfaction had mixed scores |
| (Brown & Cole 2009) | No | (+) | Relation between expectation and control in | Not available | Occupants in the green building are more tolerant to | ⊕ Green building have higher |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | green buildings.<br><br>Academic buildings | | IEQ conditions and engaged IEQ issues<br><br>Lack of control can cause higher dissatisfaction and lead to use of personal devices on the office. | satisfaction for Image, design, ergonomics, comfort overall, lighting overall. Personal control is higher in green buildings<br><br>⊕ Some problems with temperature and IAQ no both types |
| (Newsham et al. 2013a) | No | **(+++)** | Post-occupancy Survey and physical measurements in 12 “green” and 12 conventional buildings matched | Not available | Recommendation to give more attention to acoustic performance and airborne particles in green buildings. | ⊕Green buildings have better overall IEQ performance and satisfaction. Better Satisfaction with temperature, views, aesthetics, personal space, IAQ. Better health outcomes<br>⊕ Acoustics are comparable in both type of buildings |
| (Gou et al. 2013) | No | **(++)** | Post-occupancy Survey base on BUS questionnaire | ⊕ Self-assessed productivity improvements | Green buildings have the best but also the lowest scores.<br><br>Occupants in Green buildings are more tolerant to suboptimal IEQ<br><br>More personal control is present in Green buildings | ⊕Better overall comfort, design and health in green buildings.<br>⊕ Temperature and IAQ better in summer but worst in winter in green buildings. Lighting no showed no differences<br>⊕Noise worst in green buildings. |
| (Liang et al. 2014) | No | **(+++)** | Conventional buildings considerably older than green buildings. | Not available | Occupants concerned about energy efficiency are more tolerant to suboptimal IEQ | ⊕ Comfort ratings for overall IEQ, Noise, lighting, CO2, temperature, IAQ, were better in green buildings.<br>⊕Measurements of physical parameters complied with Taiwan standards for both types of buildings. |
| (Altomonte & Schiavon 2013a) | No | **(++)** | Data analysis from CBE Database | Not available | No significant satisfaction difference between green and non-green buildings for IEQ parameters. | ⊕ Occupants in green buildings tend to be slightly more satisfied with IAQ, and slightly more dissatisfied with lighting |
| (Hedge et al. 2014) | No | (+) | Survey and measurements in 2 green building and 1 conventional. Occupants were asked to recall prior workplace | ⊕ Self-assessed producitivty improvements in green buildings | Problems with office ergonomics are highlighted. | ⊕ On overall results for health, IEQ perceptions and satisfaction are better in green buildings. Green buildings had better perceived daylight.<br><br>⊕ Temperature, workstation and lighting had mixed scores<br><br>⊕Problems with noise on both types of buildings |
| (Menadue et al. 2013) | No | **(++)** | Conventional buildings considerably older than green buildings. | ⊕ Self-assessed productivity was lower in green | Despite general positive results, improvements in green buildings are not high | ⊕ Green buildings provide better satisfaction with health, overall comfort, |

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| | | | | buildings | On both types of buildings IEQ was perceived has having a negative impact in productivity | daylight, glare, aesthetics and design<br>⊕No significant improvements on thermal comfort<br>⊕Lower satisfaction with lighting and noise in green buildings |
| (Pei et al. 2015) | No | (+) | More relevance on the physical IEQ measurements | Not available | PMV-PPD more suited for cold winter areas | ⊕Green buildings have significantly higher satisfaction with thermal environment, indoor air quality, visual, acoustic environment and overall environment.<br>⊕IEQ physical measurements are on the expected range. |
| (Tham et al. 2015) | Yes | **(+++)** | Conventional building was very leaky with high ACH | Not available | No visible differences between green and conventional on physical IEQ parameters. Both in recommended ranges | ⊕Green building has better IAQ and ergonomics.<br>⊕ No significant differences in health or absenteeism |

**Table 5 – Peer review post-occupancy studies with(out) comparison with conventional buildings. Results/paper quality: (+++) Very good / (++) Good / (+) Moderate / (-) Poor. The quality of the results is a subjective observation based on the methodology, scope and analyses. Indication of the main results ⊕ = Good/Better ⊕=Neutral/No ⊕=Bad/Worst**

| Peer review Pre and Post-Occupancy in Green Buildings | | | | | | |
|---|---|---|---|---|---|---|
| First Author (Type of paper) (Methods) | Absenteeism Data | Results Quality | Remarks | Human-Relation (Productivity) | Comments | Main Results |
| (Thatcher & Milner 2012) | Yes | **(++)** | Comparison of a cohort moving into a GreenStar building and a cohort group that did not move.<br><br>Measurements were taken before the move and six months after the move<br><br>All employees belong to the same company | ⊕ No self-assessed improvements | No significant differences in self-reported absenteeism | ⊕Noise levels, thermal comfort, ventilation, were significantly better in the Green Building<br>⊕The move to a green building did not produce significantly better physical or psychological wellbeing.<br><br>⊕ Green Building occupants reported that the lighting, IAQ, draftiness, and odours had worsened. |
| (Singh et al. 2010) | Yes | **(+++)** | Cohort results from a group that moved from conventional to green | ⊕ self-assessed Improvements | Perceived health improvements after the move to green buildings, including | ⊕ Reduced self-reported absenteeism and perceived lower affected working |

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| | | | buildings | | lower stress and depression | hours because of health problems, as result of improved IEQ |
| (Singh et al. 2011) | Yes | (+++) | Cohort results from a group that moved from conventional to green buildings | ⊕ Self-assessed Improvements 2% | Outside views scores improved substantially. | ⊕ Most of the IEQ parameters rated overall higher. Perceived health improvements after the move. Reduced self-reported absenteeism, as result of improved IEQ.<br><br>⊕Privacy, glare, and noise, were the lowest rated and did not show improvements compared to the old building. |
| (Brown et al. 2010) | No | (+++) | Move from an old headquarter to a new green building headquarter | ⊕73% of employees report the building as having a neutral or positive effect on their productivity compared to 39% before the move There was a 12% gain in self-assessed productivity after the move | Occupants are more tolerant in the new green building to IEQ conditions<br><br>Personal control showed to be not relevant has was not available and people were used to it. | ⊕ Occupants in the green building were highly satisfied with the facilities: design, Image, aesthetics, brightness, openness and outside views after the move. Overall, the comfort scores were on average 36% higher after the move. Lighting and IAQ were the best. Occupants perceived 41 percent healthier on average.<br>⊕Temperature scores didn't show significant improvements |
| (Agha-Hossein et al. 2013) | Yes | (+++) | Move from an old headquarter to a new refurbished green building headquarter | ⊕ Self-assessed Improvements | Image, design and layout better in the green buildings.<br><br>Reported that satisfaction with personal space and IEQ are a good predictor for self-assessement productivity<br><br>Enjoyment at work increased 22% | ⊕Occupants more satisfied with the IEQ after the move. Satisfaction for all parameter, with exception for personal control, higher in the green building. Daylight and IAQ rated the best. Green building perceived healthier<br>⊕Personal control did not show improvements<br>⊕ Privacy and noise rated poorly before and after the move<br><br>Absenteeism decreased almost 20% |

**Table 6 - Peer review studies with pre and post-occupancy in green buildings. Results/paper quality: (+++) Very good / (++) Good / (+) Moderate / (-) Poor. The quality of the results is a subjective observation based on the methodology, scope and analyses. Indication of the main results ⊕ = Good/Better ⊕=Neutral/No ⊕=Bad/Worst**

| **Published Reports/White Papers<br>(Weak in methodology descriptions)** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| First Author | Nº of buildings (Green/Conventional) | Country | Construction /Renovation Year | Certification type | Population | Remarks | Main Results (including Human-Related Productivity) | Comments |
| (Fowler & Rauch 2008) | 12 green buildings (8 LEED) | USA | 2001-2005 | LEED, Green Star, California Energy Standard Title 24, GBC | >250 High | A modified version of CBE survey was used | ⊕ In comparison to all non-LEED buildings in the CBE database, the 12 GSA buildings in this study reported higher than average satisfaction scores for general building, general workspace, thermal comfort, air quality, lighting, acoustic, cleanliness and maintenance.<br>⊕Lighting and acoustics satisfaction was just slightly higher in green buildings | Highlighted how commitment is fundamental for a good performance in green buildings. |
| (Sustainability Victoria et al. 2006) | 1 Green – Refurbished<br><br>2 firms: Only 1 firm with pre-assessment | Australia | 2002 | Green Star | <250 Moderate | Surveys in two firm´s after moving to a new refurbished green building (in one firm there was also a survey before the move).<br><br>Organizational (sick leave) and individual performances (only one firm) presented | ⊕ In the firm with pre/post assessment there was a 11% gain in typing speed, 7% increase in billings ratio and 39% reduction in average sick leave days was observed. Self-reported satisfaction increased in both companies, with improved perceived fresh air and thermal comfort. In the firm with only post-assessment 64% found the old office ambience tiring compared to only 9% in the new office; 40% of staff found the new office 'invigorating' compared to 0% in the old office. 12% increase in self-reported productivity.<br>⊕Perceptions of lighting quality in both companies improved.<br>⊕ Significant improvements in health perceptions | Physical Measurements on recommended range<br><br>Good report lacking better methodology and details.<br><br>The move had an overall very positive impact. Being the same building and cohort the conclusions are even more relevant |
| (GSA Public Buildings Service 2011) | 16 Green and 6 energy-star | USA | 2000-2008 | LEED | High >250 | Self-assessment results only | ⊕ Green buildings showed 27% higher occupant satisfaction than the national average (CBE database). IAQ, cleanliness and general building satisfaction have the highest satisfaction<br>⊕Mix results for thermal comfort<br>⊕ Lighting in acoustics had scores comparable or below the national average.<br>⊕ Privacy complaints especially in open-space offices | Lack of methodology information |
| (Olmstead & Neely 2005) | 1 Green - Genzyme center | USA | 2003 | LEED | High >250 | Personal control over windows and temperature. | ⊕58 % of the occupants in the Genzyme Center believed that they are more productive in the new headquarters compared to their old building. | Extensive use of daylight and glare technologies. Application of Low- |

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|---|---|---|---|---|---|---|---|---|
| | | | | | | Improved Biophilia with the use of interior gardens and terraces<br><br>Poor methodology information | ⊕Sick leave was 5% lower than the average in other Genzyme facilities in the same U.S State.<br>⊕ Improved employee attraction and retention is also reported. | emission materials, temperature and humidity monitors. |
| (Eggers & Widener 2011) | 51 LEED buildings | USA | Unknown – Buildings certified between 2005 and 2010 | LEED | High >250 | Poor methodology information | ⊕Occupant surveys in 11 buildings, revealed generally a positive comfort score among occupants for IEQ parameters. Lighting was rated the highest while privacy the lowest. Overall satisfaction and overall comfort had positives scores.<br>⊕4 tenants indicated that number of complaints has decreased after moving to a LEED building and 15 tenants reported no change. One tenant reported a decrease in sick leave after the move to a LEED building and 11 reported no changes. | The highest levels of satisfaction were observed on the buildings with lower occupant density |
| (Heerwagen 2005) | 1 Green – Philip Merrill Center building | USA | 2000 | LEED | <250 Moder ate | Good case-study<br><br>Web-survey and interviews<br><br>IAQ and lighting reported to enchanted productivity | ⊕ Overall the IEQ results are positive. Occupants were highly satisfied with the workplace, IAQ, daylighting, openness, greenery and views. High levels of well being. Sustainability pride was also reported.<br>⊕Complaints about temperature, acoustic, lack of privacy, and glare.<br>⊕Open plan environment reported by occupants to negatively affect productivity with constants distractions | Overall IEQ scores better the individual. Its postulated the reason is the pride of working in a green building |
| (Paevere & Brown 2088) | 1 Green (**CH2 building** )/ 1 conventional for comparison | Australia | 2006 | NA | >250 High | Good report | ⊕In the green building there was high building overall satisfaction. IEQ measurements were good. Health scores were also good.<br>⊕75% of the green building occupants rate the building as having a positive or neutral effect on their productivity<br>In the green building there was 10% enhancement in self-assessed productivity compared with conventional one<br><br>⊕ Absenteeism and institutional productivity did not showed significant differences<br><br>⊕Satisfaction with light and noise was poor in the green building | Complaints about distractions and interruptions because of open-plan offices and lack of privacy.<br><br>IEQ measurements in recommended ranges |

**Table 7 - Reports and white papers without peer-review. Indication of the main results ⊕ = Good/Better ⊕=Neutral/No ⊕=Bad/Worst**

| Reviews/Inquires/Surveys | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| First Author | Year | Building Type | Country | Certification type | Remarks | Main Results | Human-Relation (Productivity) | Comments |
| (Beard 2009) *Peer-Review | 2009 | Green | USA | LEED | None | Despite LEED awarding credits for low-VOCs, more consideration could be focused on the VOCs arising from occupants and their office activities | Not available | Linking of LEED with different air quality parameters, without references. |
| (Turner 2010) | 2010 | Green | USA | LEED | Barometer survey to practitioners | Energy-efficiency was rated more likelihood for green investments than indoor climate - 87% vs 59% | Productivity was rated as one of the less important factors when evaluating costs and benefits | Reputation is rated as the top reason to commit with sustainable practices. |
| (Smith & Pitt 2011) *Peer-review | 2011 | Green | USA | NA | Literature review on sustainable workplaces | The review shown that occupants perceive green buildings to be healthier, and improve their productivity. It is also shown that that IEQ tolerance is higher in green buildings. | Not available | Review is confuse and in some parts misleading. More focus on IEQ elements and strategies, than Green buildings themselves. |
| (Romm & Browning 1998) *Peer-review | 1998 | Energy-efficient | USA | NA | Review of several case studies. Results based on *Post-occupancy Surveys And *Physical Measurements | Both retrofitted and new “energy-efficient” buildings show gains in productivity and lower absenteeism rates. No individual IEQ elements are directly linked to these gains. | 6% to 16% increase | The paper reported that the gains in productivity can be considered as permanent gains and not just a placebo effect |
| (Persram et al. 2007) | 2007 | GREEN | Global | Global | Review of cases studies and surveys | Better employee retention in green buildings base on stakeholders´ opinions. | Not relevant | Review using secondary mainly sources on possible IEQ elements benefits |
| (Lockwood 2008) | 2008 | GREEN | USA | LEED | Survey to owners of 15 retrofitted buildings | Employee comfort, well-being, health, productivity showed positive scores, being comfort improvements the highest rated Green buildings perceived to improve employee retention | 87% of the owners think there was improvements | Lack of information on methodologies |
| (Lafarge 2006) | 2006 | GREEN | USA | SEVERAL | Survey to 872 architects and developers | Practitioners know the importance of work in a healthier environment and know that occupants enjoy working in green buildings, but still 57% indicated that cost is still a barrier to build green buildings. 75% also indicated that studies on costs and benefits of green buildings vs. conventional buildings are missing | Not relevant | Barometer |
| (Kats 2003b) | 2003 | Green | USA | Several | Report/review | Kats review several worldwide research linking IEQ studies and health and productivity performance. Main core is the results from Vivian Loftness team in Carnegie Mellon | Broad conclusions based on several types of studies | Widely cited report. The report review studies around the world, but not necessarily in green buildings. Studies linking IEQ requirements and their connection with performance |

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|---|---|---|---|---|---|---|---|---|
| | | | | | | | | and health are presented and a direct conclusion for green buildings benefits. |
| (Issa et al. 2010b)<br><br>*Peer-review | 2010 | GREEN | CANADA | LEED | Survey to practitioners | Practitioners were uncertain about the size of productivity and health benefits and also about how to measure and benchmark them especially for long-term savings. Energy was reported as the most important element in green buildings while health and productivity one of the lowest | Productivity and health benefits tend to be ignored by practitioners | Good Survey on perceptions |
| (Hepner & Boser 2006)<br><br>*Peer-review | 2006 | Green | USA | LEED | Survey of 55 architects | Indoor Environmental Quality is ranked as the second most important area. Daylight, views, user control and thermal comfort are percept as the most associated with productivity | Not available | In Architects opinion Daylight/Views and Controllability of systems, are the most related to occupant performance |

**Table 8 – Reviews, inquires and surveys related to green buildings. Peer-review papers are indicated**

# 3 Chapter – Methodology

## 3.1 Measuring methodology

Measurements in certified Green Mark (GM) office buildings and conventional Non-Green Mark (NGM) buildings were conducted in Singapore. The measurements were carried to examine whether receiving certification would have the positive impact on IEQ, employees' satisfaction and symptoms as well as performance; these effects were compared against the same variables measured in conventional office buildings.

The study was performed as a cross-sectional monitoring (benchmarking of buildings in use). Combined responses were collected from occupants through survey and physical measurements of IEQ in 6 GM platinum office buildings (with office interior certification) and 6 conventional buildings with no certification (NGM).

Other building indicators were examined as well including absenteeism rates, sustainability, interior design, occupant density, building system. The credits for IEQ related parameters in GM buildings were collected as well as hypothetical credits that could be given in NGM if they had applied for certification.

### 3.1.1 Introduction

Objective and subjective measurements in certified GM office buildings and conventional (NGM) buildings were conducted in Singapore. The focus was on IEQ. The field measurements were carried in the last 4 months of 2014. The following section describes the study protocol in THE 12 buildings selected for measurements. This includes the selection of the buildings, IEQ measurements, and post-measurement phase details. The different phases of the field study are as follows and presented in the flow chart (Figure 4).

1. Analysis of the requirements for IEQ in other building certification schemes, in the published guidelines and codes, and IEQ measurements methodologies.
2. Selection of buildings.
3. Development of the protocols and tools for IEQ and productivity assessment. Similar measurements, if reported in the scientific and grey literature (e.g. white papers, corporate reports, etc), were identified and used as a reference for the measured IEQ parameters, perceptions, symptoms and performance.
4. Measurements and surveys in buildings.
5. Analyses and reporting.

All data obtained in this study was treated anonymously.

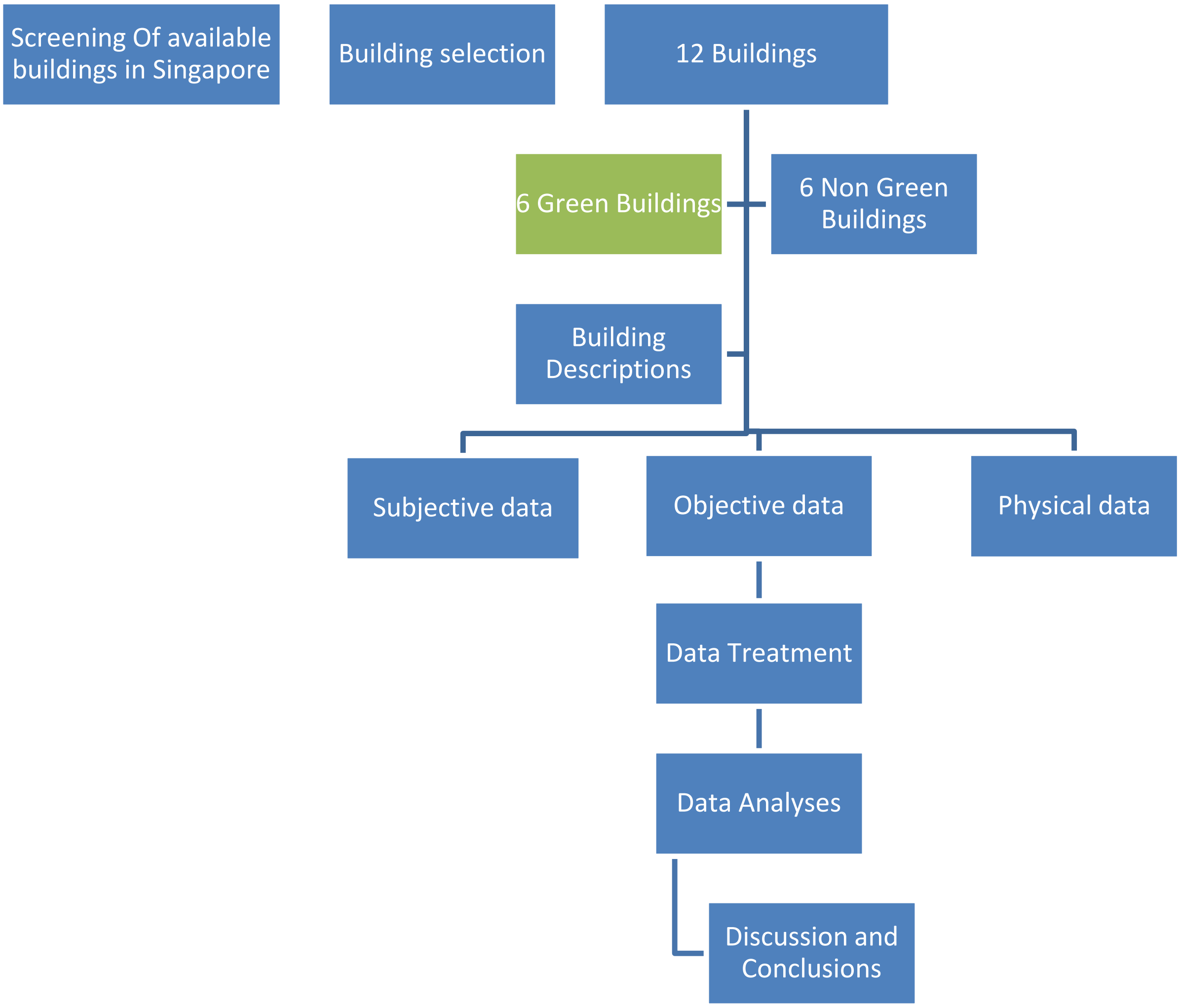



Figure 4- Methodology flow chart

### 3.1.2 Building Selection Protocol

Conventional buildings can be considered as buildings without certification. It is difficult to define what a conventional building is, how good it is and how it should be selected. A conventional building can have even better IEQ than a GM building, so it was important (to create contrast and variability) that the selected conventional buildings, even if not certified, did not fulfill the majority of Green Mark IEQ requirements, so it can be better observed whether fulfilling them makes the expected difference and positive change. It is also important not to force only conventional buildings that would not qualify for any GM criteria, as it would create an increased bias, as likely these buildings would have the risk of poor IEQ. All buildings have been occupied for at least 3 years, to avoid expectation effects or temporary Hawthorne effects from moving to a new office (Romm & Browning 1998).

The non-green mark buildings underwent a virtual green mark assessment to see how many credits they would have received if they had applied to be certified, and which special features they might have. This was done to ensure a distinction between the two categories. This also avoids the cases where the criteria for Green Mark certification were met by the building, but the building did not go through the certification procedure because of e.g. economic reasons. Meeting national IEQ regulations and codes were not considered, assuming by default that they should be implemented and met for all building categories included in the study. Still, in Singapore there are no statutory requirement by law on IEQ related performance (Green Mark 2015). It is noted that all buildings a have different ages, so the buildings codes might have change through years, but that information was not accessible. Green Mark buildings were analyzed for their individual IEQ scores.

It would have been preferred that the selected GM and NGM buildings were matched according to the company, work/culture, etc. to eliminate some organizational and social confounders. Unfortunately that was not possible.

A total of 12 buildings (Table 9) were selected for 6 x 6 comparison and monitoring. None of the buildings can be considered an iconic architectural building in Singapore. The selected GM offices were categorized as being GM building and GM office interior. The classification and number of offices in different categories is shown in Table 9.

| | Green Mark Platinum Office Buildings | Non-Green Mark Office Buildings |
|---|---|---|
| Green Mark Office Interiors | 5 | 0 |
| Non-Green Mark Office Interiors | 1 (soon to be OI) | 6 |

Table 9- The four categories of office interiors for IEQ measurement

The 6 NGM buildings will be termed NGM1-6 and 6 Green Mark as GM7-12:

| Non-Green Mark (NGM) | | | | | | Green Mark (GM) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| NGM1 | NGM2 | NHM3 | NGM4 | NGM5 | NGM6 | GM7 | GM8 | GM9 | GM10 | GM11 | GM12 |

#### 3.1.2.1 Selection of Office Premises

In order to categorize the offices into the two groups described above, a number of sources were consulted and analyzed:

- A database of Green Mark office interiors and Green Mark office buildings was obtained from the Building and Construction Authority (BCA). As of March 2014 there were more than 140 Green Mark office buildings and approximately 90 Green Mark office interiors in Singapore
- For conventional buildings, as of March 2014, a search through CommercialGuru.com.sg, a website developed by PropertyGuru Pte. Ltd., yields roughly 700 registered office buildings in Singapore.(*Also Includes Green Mark buildings)

The data gathered from these sources provided information such as the addresses, names of buildings and the Green Mark certifications awarded when applied. Using these data it was possible to gather:

Green Mark office interiors located in Green Mark office buildings:

> By matching both the lists of the Green Mark office interiors with the Green Mark office buildings, as of March 2014. This yielded 59 Green Mark office interiors located in 33 Green Mark office buildings: 11 Platinum, 23 Gold Plus, 21 Gold and 4 Certified.

Non-Green Mark office interiors located in non-Green Mark office buildings:

> All of the office buildings that are listed in CommercialGuru.com.sg were compared with the Green Mark list to identify office buildings that are not Green Mark-certified. As of March 2014, there were registered approximately 580 non-Green Mark office buildings in Singapore.

#### 3.1.2.2 Selection of Office Premises

Building selection and consent from tenants was very arduous, taking several months and meetings. To be selected, the office space had to meet the following criteria:

- Located in buildings with total gross floor area (GFA) greater than 2,000 $m^2$
- Occupied by more than 30 employees per floor (based on statistical considerations and previous studies on air quality and productivity (Wargocki et al. 1999)).
- Served by centralized air-conditioning and air handling unit (AHU) with outdoor air intake (i.e. no split units)

After building selection, the building's directory was consulted for the list of offices inside that building, and one office interior in each building was chosen for monitoring using the criteria described above. The selected office interiors belong to two categories: Green Mark office interiors located in Green Mark office buildings and Non-Green Mark office interiors located in non-Green Mark office buildings. Owners/tenants of the office premises and the building management office were then contacted to determine if the office premise met the selection criteria as mentioned above and also to seek their permission and approval to participate in the study.

A site visit to meet with the office and building owners/managers and occupants was also performed to obtain background information on the study, such as the study's objectives, details of monitoring activities, schedules and locations in every building and collect information on the premises: office and building floor plans, air conditioning (ACMV) system, location of AHU room, location of outdoor air intake for the AHU, number of occupants, low and high occupancy areas, locations of common areas such as pantries, printing/photocopying rooms, and conference/meeting rooms, use of blinds, light type, air cleaners, plants, flooring, areas with open shelves, outside views, sky gardens, greenery, resting places, leisure areas etc.

In the site visits, potential IEQ measurement locations (AHU room, indoor monitoring points, and outdoor monitoring points) and storage room/area for the safekeeping of equipment were also identified. Office occupants were notified and briefed about the study, especially those seated near monitoring locations and one liaising person from the office premise and one liaising person from the building management office were appointed.

### 3.1.3 Definition of the measuring protocol

Several types of measurements were performed in the selected buildings including quantitative and qualitative data collections as indicated in Table 10. Seven dimensions are measured:

<table>
<tr><th>Outcomes (variables)</th><th>Measurement Method</th></tr>
<tr><td>IEQ: Physical parameters</td><td rowspan="3">Quantitative: Data and results collection</td></tr>
<tr><td>Absenteeism</td></tr>
<tr><td>Productivity - Concentration<br>Speed<br>Memory</td></tr>
<tr><td>IEQ: Perceptions<br>Satisfaction<br>Importance<br>Ranking</td><td rowspan="4">Qualitative: Survey; Self-Assessment; Observations; Interviews;</td></tr>
<tr><td>Health</td></tr>
<tr><td>Performance</td></tr>
<tr><td>Sustainability</td></tr>
</table>

Table 10 – Type of measurements

Non invasive physical measurements included objective measurements of IEQ: continuous measurements of temperature, RH, $CO_2$; semi-continuous measurements of illuminance, air velocity, $PM_{2.5}$, outdoor air exchange rate, gaseous air pollutants: HCHO, CO, $CO_2$, biological matter: total bacteria and total fungi.

Subjective Measurements with an individual online survey included subjective assessments by the occupants in these buildings using web-based survey collecting information on satisfaction and importance with IEQ and building features, perceptions of IEQ, health symptoms as well as demographical information about the study cohort including health status; self-estimated work performance integrated in the web-based survey.

Quantitative performance using quantitative indicators included absence rates and short tests of ability to perform work, also integrated in the survey (*indicators presented later on this chapter).

Unstructured interviews with the building managers and some employees about IEQ and comfort were made during and after the measurements.

### 3.1.4 Measuring Protocol of Physical Measurements

The following section describes the protocol for IEQ measurements in the offices. This includes pre-monitoring activities and details of the actual monitoring.

All measurements were non intrusive to occupants. Climatic seasonal changes are not critical in Singapore, as weather conditions are fairly constant throughout the entire year. Therefore there should not be climate confounding between measurements, as they are representative for the entire year. In parts of buildings that are not occupied most of the day the physical measurements were avoided (e.g. management offices). The measuring protocol was as follows:

1. Continuous Measurements were performed for 96 hours (4 days) from Monday to Thursday. Equipment was set up outside working hours prior to the measurements period. Measurements were performed with non invasive data loggers and Innova.
2. Spot measurements of physical parameters were performed for 2 days in each building (Tuesday and Wednesday). Only 2 days of spot measurements were performed as there is always some occupant disturbance associated when performing on-site measurements. Spot measurements were done in all zones (5 or 4 depending of the building)

During all activities, disturbance and disruption to normal daily office activities was kept to a minimum. Before measurements a protocol was drafted and given to tenants for prior approval.

#### 3.1.4.1 Physical Measurements Location

For each office, five or four zones were selected, and for each of them one indoor IEQ measurement location was set. Also one outdoor location was selected for measurements. The measurement locations satisfied the following for the Indoor measurement locations:

All measurements were made in the same floor, in the most representative zone/area where most of the occupants were working. Indoor measurements were done in the following locations:

a. Open plan area that represents the highest overall occupant density (1 to 5 location depending on the size of the open plan area) When five locations were selected in the open plan they were as evenly distributed by area and density as possible.
b. Enclosed private/shared office room (e.g. HR office) (1 location)

All indoor IEQ measurement locations also had to satisfy the following requirements:

a. Located at least 1 m from corners, doors, windows, walls, partition and other vertical surfaces (e.g. file cabinets, cupboards, etc.)
b. Located at least 1 m from occupants
c. Located at least 2 m from localized pollutant sources (e.g. photocopiers, printers, etc.)
d. Not located directly in front of air supply diffusers, induction units, floor fans or heaters
e. Not located under direct sunlight glare
f. Not located in hallways or corridors

The locations where monitoring was performed were determined beforehand with five or four locations indoors selected. For each zone, during indoor IEQ measurement, the sampling equipment was positioned between 75 cm and 170 cm from the floor at the occupied zone, as close as possible to the office occupants (without entering their breathing zone), depending on accessibility. The heights recommended by the thermal comfort standard (ASHRAE 2004; ISO 1998) are 0.1, 0.6, 1.1. and 1.7 m. Every time possible we used 0.75m (desk level) or 1.1 m (seated person)

One outdoor air quality measurement was selected at the building location. The outdoor location had to be sheltered from direct sunlight and rain, and be located at least 2 m from an entrance when possible.

Continuous weather data and pollutant standards index (PSI) data was also gathered from NEA (NEA 2014)

#### 3.1.4.2 Physical measurements parameters

There were a total of 12 parameters measured during monitoring. These parameters are listed in Table 11, along with the measurement method and any additional remarks. Noise, ozone and TVOC were measured but unfortunately technical problems in the equipment led to an incomplete set of the data, and so they were discarded. For noise unfortunately only on-site subjective observations are available.

| SCIENTIFIC PARAMETER | MEASUREMENT METHOD | INSTRUMENT USED | ACCURACY |
|---|---|---|---|
| **Air temperature** | Continuous | Measured using a temperature/humidity/light sensor HOBO U12 x 5 | ±0.35 ℃ |
| **Globe temperature** | Continuous | Measured using a globe thermometer (grey ping-pong ball); Globe thermometer x 5 | ±0.3°C |
| **Relative humidity** | Continuous | HOBO U12 x 5 | ±2.5% RH |
| **Air velocity** | 2x2 times (10am, 3pm) | Lutron Am-4214Sd | ± ( 5% + 0.1m/s ) Range (0.2 to 5.0 m/s) Resolution(0.01 m/s) |
| **Particulate matter ($PM_{2.5}$)** | 2x2 times (10am, 3pm) | DustTrak 8530 | Range: 0.001 to 400mg/m3 Resolution: ±0.1% |
| **Carbon dioxide ($CO_2$)** | Continuous | VAISALA GM20D coupled with HOBO U12 | 0-5000 ppm ±(30 ppm+2% of the readings) |
| **Carbon monoxide (CO)** | 2x2 times (10am, 3pm) | PPM monitor | PPM Resolution: 0.1 ppm |
| **Formaldehyde (HCHO)** | 2x2 times (10am, 3pm) | PPM monitor | PPM Resolution: 0.01 ppm |
| **Total viable bacteria count** | 2x2 times (10am, 3pm) | Air Ideal | Visually counted and converted to CFU/$m^3$ |
| **Total viable fungal count** | 2x2 times (10am, 3pm) | Air Ideal | Visually counted and converted to CFU/$m^3$ |
| **Light** | 2x2 times (10am, 3pm) | Yokowaga Model 51001 | ±4% reading ±1 digit |
| **Air exchange rate** | Measured by injecting tracer gas at AHU/Room and calculating gas concentration decay using a INNOVA (photo-acoustic gas monitor) | | |
| *** The equipment was calibrated prior to measurements** | | | |

Table 11- Measuring equipment and parameters

Figure 5- Equipment used on physical measurements

### 3.1.4.3 Pre-Monitoring Activities

In the week before the day of the scheduled monitoring, the office occupants were notified about the upcoming activities by management through email. The liaison person from the premise appointed during the office selection process, disseminated this information to the office occupants, especially those seated around the monitoring locations.

Innova system (Photo-acoustic infrared multi-gas monitoring system) and HOBO loggers were installed prior to the measurements. Setting up the photo-acoustic infrared multi-gas monitoring system (Innova) involved the laying of sampling tubes from the multi-gas monitor (located in the storage room/area) to all the measurement locations in the office premise. Also the HOBO loggers needed locations to be fixed. All this was discussed and decided beforehand in talks with the liaison person in every building.

A rehearsal and testing period for the software and physical measurements was done in a building (NUS) for testing. The objective of making some pre-measurements was to test and get familiarized with the equipment before the actual measurements start. Also to do some data treatment to get familiarized with the type of data.

### 3.1.4.4 Actual Monitoring Activities of IEQ

There were two methods of conducting IEQ measurements: continuous measurement, which includes 4 days, and “spot” measurements done for shorter periods (10 minutes) in morning and afternoon for 2 days.

#### 3.1.4.4.1 Continuous measurements

In the Friday before the measuring week, data-logging devices for continuous measurements were installed on all monitoring locations and started recording. The sequence, location, identification and exact times of the data-loggers were registered. All data-logging devices were set to take readings at five minute intervals.

For temperature, relative humidity and $CO_2$, in each indoor measuring zone (5 or 4 zones) a Hobo U12 sensor together with a Vaisala $CO_2$ sensor was installed for 96 hours measurements usually in the desk partitions (Figure 6) between 1.1 and 1.7 meters above the floor. The sensors were not distracting to the employees.

Globe temperature was measured by a characteristic grey sphere, between 1.1 and 1.7 meters above the floor. Mean radiant temperature (through globe temperature) together with air temperature and air speed allowed the calculation of operative temperature.

Operative temperature was calculated following ASHRAE guidelines (ASHRAE 2004). As the activity level is between 1 -1.3 met and velocities were below 0.2 m/s, the operative temperature was the average of air temperature and radiant temperature.

Figure 6-Data-logging equipment set-up and spot measuring equipment

#### 3.1.4.4.2 Spot measurement

Spot measurements were performed when it was not practical to perform continuous measurement, because of manpower limitations and/or shortage of equipment.

Spot measurement involved carrying instruments (Figure 6) to each measurement location (5 or 4 indoor and one outdoor) to record one-minute readings for ten minutes at two different time-slots during the two days of the monitoring: once in the morning and once at noon, so four measurements in total.

For luminance and noise levels, spot measurements were performed, but only luminance data was valid. Because of this, was important that these two parameters were coupled with observations and informal comments from occupants in the measured offices. These two parameters can have a relative assessment but are considered as some of the most important factors for indoor comfort. Noise only has a relative observational assessment, as measured values were incomplete due to technical problems.

Illuminance levels were measured manually in every zone placing the meter the surface of the workstation (0,75 m) in front of the chair, also around (left, back, right) in a total of 4 different locations, to cover a office task area. Methodology adapted from EN 12464-1 (CEN 2003).

Carbon monoxide and formaldehyde were recorded using a PPM monitor, which uses electro-chemical sensors to measure IEQ parameters.

Particulate concentrations were measured using an aerosol monitor DusttrakTMII 8530. Measurements were performed for 10 min in each location and $PM_{2.5}$ mass concentrations reported.

The measurement and analyses of bacteria and fungi were adapted from SS554:2009 (Singapore Standards 2009). An Air IDEAL® 3P was used for the detection of viable organisms through active air sampling. It operated according to the impaction principle (ISO/DIS 14698-1), with air intake of 100 L/min and impact speed of <20 m/sec (Biomerieux 2006). Between samplings, the equipment was always cleaned with alcohol swabs. The sampling for biological parameters was done in every measuring zone for the breathing zone and air inlet (Figure 7) twice a day for two days. Trypticase Soy Agar (TSA) plates were used for the cultivation of bacteria, and Malt Extract Agar (MEA) plates for the cultivation of fungi. These agar plates were prepared beforehand in the laboratory two or three days before the day of the sampling or bought from a supplier.

After sampling, the agar plates for bacteria and fungi were stored in a cooler box and transported to the laboratory in the day of the measurements for incubation and analysis. The bacteria plates were incubated at 38°C for a period of 2 days before the counting of bacteria colonies. The fungi plates were incubated at room temperature for a period of 5 days before the counting of fungi colonies.

Figure 7- Example of bacteria/fungi measurement

3.1.4.4.3 Air change rate

Outdoor air change rates in the studied offices provided by the ventilation system and through infiltration or exfiltration, were obtained using tracer gas measurements with decay method.

Small (3 mm diameter) sampling tubes (Figure 8) were laid from the selected zones (Table 12) to the monitoring station, and either run along the ceiling or the floor (Figure 8). After that the tracer gas $SF_6$ (colorless, odorless and harmless to occupants) was injected into the AHU or released through the office when was not possible to access the AHU (Table 12) to make a uniform concentration in the office and the concentration of $SF_6$ was monitored with the photoacoustic multi-gas monitor Innova 1312 and multipoint sampler Innova 1309.

The Innova monitor was started before the release of the gas. Recordings were taken for the five or four internal zones and one outdoor location when possible. After the five zones reached similar mixing level, i.e. the decay of the gas concentration in all zones was similar, the first set of readings was taken (C1). Concentrations were taken at each measuring point once every 10 minutes. Measurements were taken for at least two hours in the morning.

The air change per hour (ACH) was defined as the slope (*best-fit plot lines in log scale) of the tracer gas concentration decay curve and is given by the equation (ASTM 1995; Sekhar et al. 2002):

$$ACH = \frac{Q}{V(m^3)} = \frac{\ln\left[\frac{C_1(t_1)}{C_2(t_2)}\right]}{t_2 - t_1}$$

Where: $C_1(t_1)$ = tracer gas concentration at the start of the test (ppm)

$C_2(t_2)$ = tracer gas concentration at end of the test (ppm)

$t_2$-$t_1$= time in hours

Q= Average flow rate between $t_1$ and $t_2$; V = ventilated volume ($m^3$)

The ACH was calculated for single zones. The calculations were done for all zones, considering every zone a single zone. It is considered that all zones have a good mixing of the gas, as the gas was released either on the AHU or uniformly in the room for a higher amount of time. Analysis of decay segments for the decay method were only taken when the $SF_6$ concentration and decay reached uniformity.

| Building | Release of the SF6 gas | Tubing layout | Number of indoor zones | Outside sampling |
|---|---|---|---|---|
| **NGM1** | AHU | Ceiling | 5 | Window staircase |
| **NGM2** | AHU | Ceiling | 5 | Window conference room |
| **NGM3** | AHU | Ceiling | 4 | Building entrance |
| **NGM4** | Room | Ceiling | 5 | Building entrance |
| **NGM5** | Room | Ceiling | 4 | Building entrance |
| **NGM6** | Room | Floor | 4 | Outdoor carpark |
| **GM7** | AHU | Ceiling | 5 | Terrace |
| **GM8** | AHU | Floor | 4 | Terrace |
| **GM9** | AHU | Ceiling | 5 | Terrace |
| **GM10** | AHU | Ceiling | 5 | Outdoor Garden |
| **GM11** | Room | Ceiling | 4 | Building entrance |
| **GM12** | AHU | Floor | 5 | Terrace |

Table 12-Layout characteristics for ACH calculations


Figure 8- Tube configuration used on the study of ACH

### 3.1.4.5 Measurements schedule

Typical the physical measurements followed the schedule in Table 13.

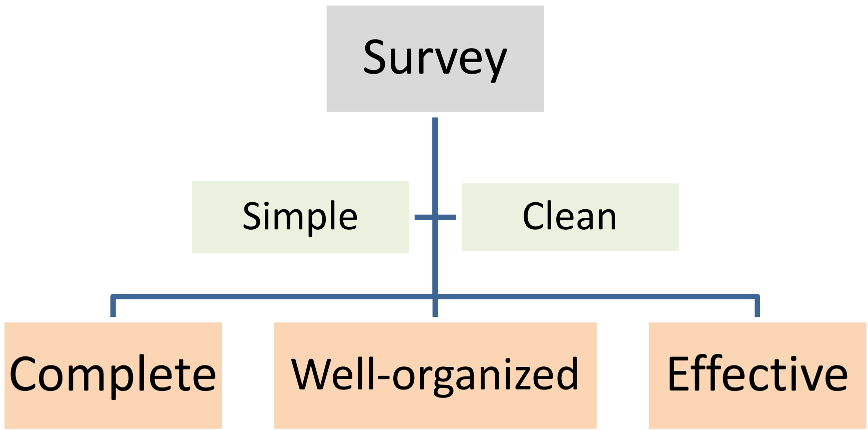
| Date | Activity |
| --- | --- |
| Friday afternoon | Equipment was taken to the office and deployed<br>Tubes were laid via ceiling or floor for all measuring locations for the ventilation study and continuous measurements if pollutants<br>HOBO loggers were installed for continuous measurements |
| Monday to Thursday | Continuous non-invasive measurement of temperature, RH $CO_2$, and globe temperature<br>Continuous measurement of CO, Formaldehyde |
| Tuesday and Wednesday | Sampling Locations:<br>Sampling point 1<br>Sampling point 2<br>Sampling point 3<br>Sampling point 4<br>Sampling point 5<br>Outdoor sampling point<br><br>Spot measurement to measure when office is occupied<br>4 time slots for CO2, CO, air temperature, Relative humidity, formaldehyde, air velocity, lighting.<br>4 time slots for total viable bacterial count, Total viable fungal count<br><br>Tuesday: 10 pm and 3 pm (1 hour each)<br>Wednesday: 10 pm and 3 pm (1 hour each) |
| Tuesday to Friday | Occupant filled up the questionnaire on perception of indoor air quality<br>The hyperlink of the questionnaire was sent to tenant and tablets were also used.<br><br>Obtained absenteeism rates from Aug 13-Aug 14 |
| Friday | In the morning ventilation rate study to measure how much air is being exchanged<br>Dosing of $SF_6$<br><br>Afternoon system dismantling and moving of the equipment to another building |

**Table 13 – Measuring schedule**

### 3.1.5 Survey - Subjective Measurements

For the subjective part of the cross-sectional study in the 12 buildings, an online survey was designed to obtain the responses of occupants working in GM and NGM buildings. The responses were automatically registered immediately after occupants have completed the online survey. No incentive was provided to encourage occupants to complete the survey. The construction of the survey was outsourced based on design, aesthetics and contents specifications. All answers were collected automatically on rented servers.

Questions in the survey were selected to avoid much technical terms or complexity as possible as it is important that occupants clearly understand the questions (Lai & Yik 2007). The design of the survey followed the following principles:




It must be complete and effective, as was aimed for a maximum of 20 minutes, clean and simple so respondents do not get visually tired, and well organized so respondents clearly understand what is being asked.

The survey was made of a questionnaire part and a performance section, made of games. Several questionnaires that have already been used in the past were analyzed prior to the development of the new questionnaire. Though the survey developed contains classic elements that are commonly asked on “popular” and validated questionnaires such as DTU IEQ survey (Wargocki et al. 1999; L Lan et al. 2011; Wargocki, Wyon, Sundell, et al. 2000), CBE satisfaction questionnaire (Altomonte & Schiavon 2013b; Schiavon & Altomonte 2014; Huizenga et al. 2003; Frontczak et al. 2012) or Glostrup questionnaire (for SBS symptoms) (Brauer & Mikkelsen 2003; Brauer et al. 2006), a new designed questionnaire with new elements was done. A rehearsal and improvement period for the survey was undertaken. Testing through different researchers on the IEQ field in

Denmark, Singapore and USA was carried for feedback before a final version was designed. After feedback through IEQ experts' comments the survey final structure was agreed, and the survey finalized.

The survey was presented on-line via an Internet link send to the building occupants by the building management or through a tablet (also connected to internet). In the latter case employees were approached at their workstation. In the former they themselves decide when to launch the survey. Participation of the occupants was solicited through management and encouraged to provide information as accurate as possible. Occupants were asked to respond to the questionnaire on Tuesday or Wednesday. An additional email from management was sent on the day when the survey was supposed to be taken; this email included the web link to where the survey resides. The number of respondents was continuously observed. Emails were sent with reminders to increase the response rate. No incentive was given.

The online survey was anonymous, where each occupant was assigned with an anonymous ID, and included the features as follows:

- Introduction of the survey and the productivity tests
- Questionnaire
- Three performance tests - One practice game for each productivity test

The survey is presented in the (Appendix A), with selected screenshots of the software.

#### 3.1.5.1 Questionnaire

The first part of the survey was a questionnaire. Through this questionnaire the occupants working in both GM and NGM buildings were asked to rate IEQ, comfort, their health symptoms and psychological perceptions, and how well they performed their work. Demographics and working premises/conditions were also asked.
The questionnaire was designed to take no more than 10 minutes to complete.

The survey was designed thinking on specific associations of special interest and the ways they will be analyzed; to gather all the data we need for the study without oversize it. For example in the U.S. BASE study (Mendell & Mirer 2009), the environmental assessments were selected for inclusion in the study with no specific hypotheses, thus resulting in a very large amount of data that has been very useful undoubtedly, but in this study we try to have specific hypotheses that focused attention on environmental factors of specific interest for extra attention or detail in data gathering.

The questionnaire is divided in 7 sections as described in Table 14.

| Questionnaire categories | Sub-categories |
|---|---|
| Description of the Demographics and Workplace of a Respondent | Age; Gender; Seniority; Job; Workplace; Health Status and Chronic Diseases; Company appointment; Layout of the workplace; Routine |
| Rating of Indoor Environmental Quality | Workstation; Window view; Personal control; Temperature; Air movement; humidity; Lighting; Daylight; Visual Comfort; Visual Privacy; IAQ; Noise; Sound Privacy; Overall IEQ; Relation between IEQ and performance |
| Description of Awareness of Sustainability | Sustainability knowledge; IEQ Tolerance; Sustainable practice |
| Rating of Health Symptoms | SBS symptoms; Apathy; Odors |
| Self-Assessment of performance and working conditions | Job Difficulty; Effort; Stress; Job satisfaction; Performance |
| IEQ Ranking | Ranking of IEQ in relation to performance; Ranking of non-IEQ conditions in relation to performance |
| Open-ended questions (Personal opinions) | Personal open comments |

**Table 14 – Questionnaire sections**

Questions were presented to respondents using different scales as illustrated in Appendix A and in Table 15.

| **Questionnaire Part** | **Type of scale** | **Type** |
|---|---|---|
| Demographics and Workplace | Checkbox<br>Multiple Choice | Nominal/Ordinal |
| Indoor Environmental Quality (IEQ) | Continuous Scale | Scale |
| Sustainability | Continuous Scale<br>Multiple Choice<br>Dichotomous scale | Scale/Nominal |
| Health | Dichotomous scale | Nominal |
| Self-Assessment performance/Social | Continuous Scale | Scale |
| IEQ Ranking | Multiple Choice – Ranking grid | Nominal |
| Open-ended question | Textbox | Text |

**Table 15 – Types of scales**

The continuous scales ranged from -100 to 100. On this type of scale occupants were asked to move two different sliders in the same scale corresponding to the IEQ conditions at the moment they were responding to the questionnaire (called "Now") and the conditions experienced on average (called "Average") (Figure 9). It was surmised that the latter response would describe typical conditions and would put the responses in the retrospective context while the former in the "here and now context". The idea behind two different questions was to see whether any differences exist between the responses collected when the measurements were performed and the typical conditions at workplace.

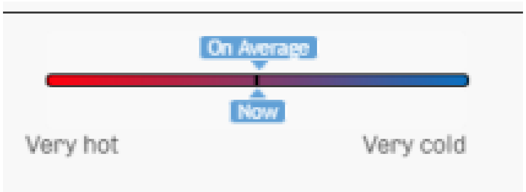



Figure 9- Continuous scale example

### IEQ

For IEQ questions every question is tri-divided: perception, satisfaction and importance (Figure 10).

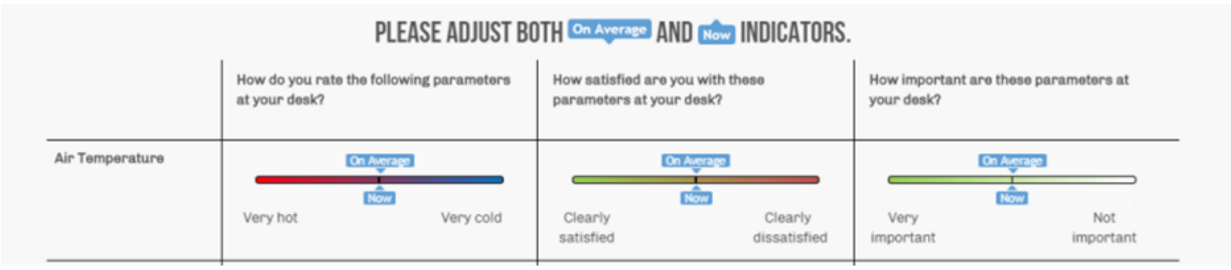



Figure 10 – Example IEQ question

Occupants were also asked to rate overall environment and how IEQ affects their performance (negatively or positively) and by how much. This will make a connection to the studies, in which the respondents are asked to rate the magnitude by which their performance is affected by the IEQ.

### Sustainability

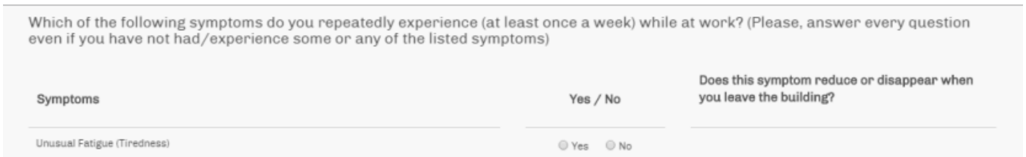
Sustainability has different meanings for different people and many might simply respond with what they think they ought to, but still is important to know the perception, as the study is related to sustainability. Including four questions allowed to learn about the attitudes of respondents towards sustainability and energy saving:

- I attempt to save energy at my workplace?
- Has my office received a certification for sustainability?
- I would approve energy saving measures even though indoor environmental conditions at work (e.g. higher temperatures, poorer air quality) would be consequently reduced?
- How important is it to work in a sustainable building?

**Health**

Symptoms as defined in the World Health Organization (WHO 1982) on the definition of SBS were asked. In addition, odor annoyance and apathy were also added.

On SBS symptoms a dichotomous scale was used. When the user selected the option "Yes" another dichotomous scale appeared (Figure 11).


Which of the following symptoms do you repeatedly experience (at least once a week) while at work? (Please, answer every question even if you have not had/experience some or any of the listed symptoms)

| Symptoms | Yes / No | Does this symptom reduce or disappear when you leave the building? |
| --- | --- | --- |
| Unusual Fatigue (Tiredness) | Yes No | |

Figure 11- Example SBS symptom question

Odor annoyance and apathy are not really symptoms; but was decided to be included in the group of symptoms.

**Self-Assessment performance and Job**

Self-estimated performance is measured in different ways so it is difficult to select one method of measurement that will embrace all methods that have been potentially used in the past, but considering this, was decide to add 5 scales for job difficulty, effort, stress, job satisfaction and self-assessment performance (Figure 12).

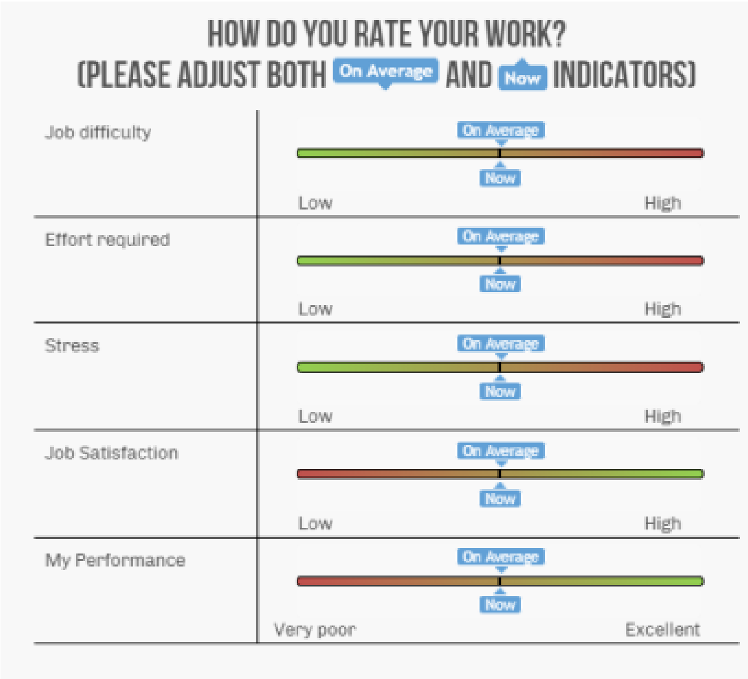



Figure 12- Self-Assessment performance and social questions

Scale 5 is more neutral and only qualitatively assesses the performance. It does not examine the absolute level of performance simply indicating whether the performance is poor or excellent. It is expected that all scales are strongly correlated.

Including questions requiring respondents to rate their self-estimated performance and even the subjectively assessed level of performance is done to later verify whether these ratings match the performance of games

**IEQ Ranking**

Two different lists of IEQ components (one of them related to workplace layout), were presented and asked on their possible negatively impact on their work performance. The respondent selected as many components as wished and at the end they were was asked to select the relative importance of each parameters (ranking method) by selecting the most important.

As the questionnaire is electronic a rule was implemented that did not allow blank/skipped questions. In a case of empty questions a pop up warning was prompt to the occupant (Figure 13). A blank/skipped question in the questionnaire, if that question was to be later included in a statistical analysis, would most likely require omitting that occupant from the analyses entirely, so it was decided to avoid it. When one or more questions are missed, a yellow pop up would warn the occupant and the occupant cannot advance to the next screen until completion.

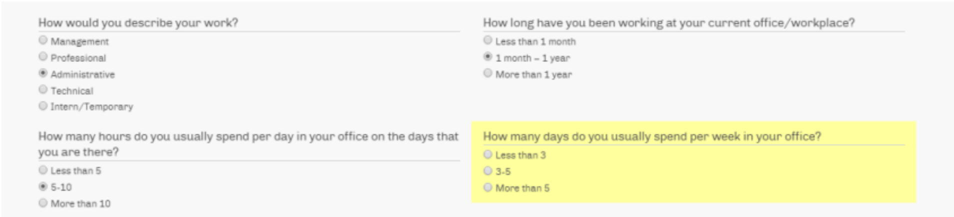



Figure 13 – Warning example

Despite this must be noted that the survey is anonymous and occupants can withdraw from it at any time, simply closing the browser mid-way, and this person will not be used in any analysis.

The questionnaire is divided through several screens. The respondents move between screens manually after replying all questions and click the button next (Figure 14). Also the progress is illustrated showed to the user through all screens (Figure 14)


Figure 14 – Progress bar

### 3.1.5.2 Measurements of performance: Games

The purpose was to evaluate whether the work performance is affected by GM certification status and their IEQ. The tests had to be short and easy to understand by the occupants as well as sensitive to IEQ conditions. This may not always be the case as shown by (Wargocki et al. 1999). Other tests more typical of office work would be useful but too long. Three tests were consequently built into survey, one examining concentration, one providing information on stress/arousal of occupants and the last one on short term memory. These were D2, connecting the nodes (Tsai-Partington test) and working memory (serial recall task).

These tests were referred to in the survey as games, respectively, D2-game, connecting the nodes game and the working memory game. The D2 game was based on the work of Brickenkamp (1981) as a cancellation task test (Bates & Lemay 2004), and consists on the selection of the correct characters for a controlled period of time. Tsai Partington is an executive functioning test, which requires the respondents to connect numbered dots (0 to 99) as quickly as possible in ascending order without making errors. It is adapted from the Tsai-Partington test described by Ammons (Ammons 1955) and a previous work introduce by (Wyon 1969). This test measures speed, accuracy, visual processing and is performed less well when respondents are stressed. Serial recall task is a visual recall memory for testing memory. It was created based on the knowledge of several studies published before on working memory (Martini & Maljkovic 2009; Zimmer 1998; Potter 1975; Gathercole 1999; Klatte et al. 2002; Lan et al. 2009). Other tests could be selected as well but it was decided during the development of the survey to use these tests also because, the intention, was to make short tests that can be understood by the respondents and affected by the conditions in the office. Initially another approach was entertained: the intention was to find the tests that are used by HR departments during employment procedures when they look for personnel with the specific skills matching the job task and demands at the workplace. The intention was to adapt these tests and include in the survey. But the task appeared to be difficult and would take more time than expected

The three games were taken by respondents without practice sessions so that potential confounding through learning would be eliminated. Only a trial session was offered after the game was introduced. This was also one of the reasons why the tasks had to be simple and self-explanatory. The three games took approximately 10 minutes to complete and results were also reported anonymously. Some confounders like corporate culture and workforce IQ were not normalized as it is not feasible to do it. Also it was not the objective of the games to test personal skills.

**D2 Game (D2 test)**

In this game, 5 screens with 10 different symbols of the noncapital letters "p" and "d" were presented to respondents; there were 6 series with the five screens; these five screens constitute one series. The “p” and “d” characters had one or two dots above and/or below. The task of the respondents was to identify “d” characters with 2 dots (1 above and 1 below or 2 above or 2 below). The other characters are distracting characters. In each screen ten symbols were shown (Figure 16). Each series thus contained 50 characters, 10 characters per screen (fig 12) (in the original test there are 14 lines (series) each containing 47 characters of which about 21-22 are d2-characters). In the tests included in the survey similar proportions were used between d2 and distracting characters.

Respondents proceeded to the next screens by pressing the “next button”. They were supposed to complete the task as quickly as possible without making errors within the allocated maximum 25 second per one series (5 screens each with 10 characters). After 25 seconds, the new series began independently of where the respondents completed the preceding series.

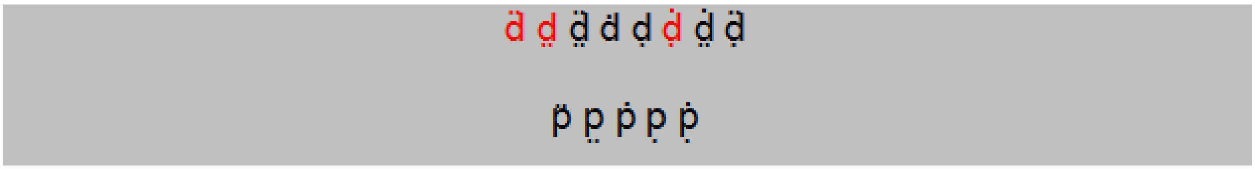


Figure 15 – Characters in D2 game

There are 3 different correct d (with two dots – red color) and distracting characters: d (with one, three, four dots) and p (with one and two dots) (Figure 15)

Thus in short, the game comprised six (6) similar series with a time limit of 25 seconds for each of the 6 series. The total time for 6 series was thus 2.5 minutes. The respondent had to identify and click on the characters shown below:

d̈ → two dots above,

d̤ → two dots below, and

ḍ̇ → one dot above and below.

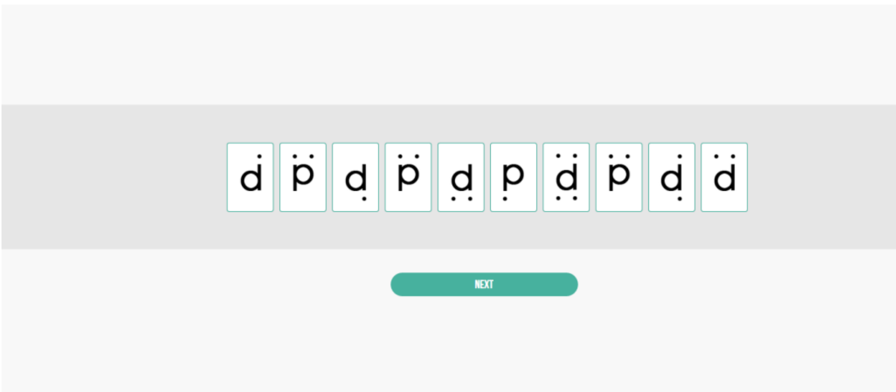



Figure 16 – Example of one screen in D2 game

Before the starting of the game there was a trial with unlimited time (Figure 17). The trial had two lines of characters and respondents received feedback whether they clicked the correct or incorrect character, or missed clicking any correct character. No feedback was provided during the actual games.

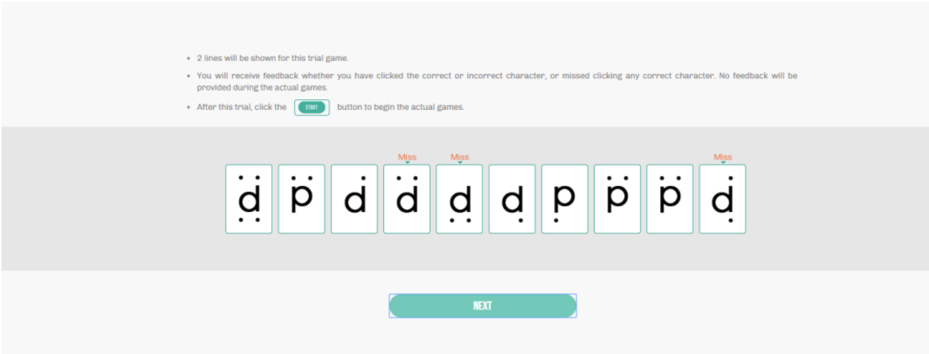



Figure 17-D2 game trial example

Performance indicators described on games analysis section.

### Connecting the nodes game (Tsai-Partington test)

This game comprised one (1) series. The respondent had to connect the 25 randomly arranged numbered nodes (e.g. 1, 2, 7, 23) in an ascending (increasing) order (Figure 18). The numbers incremented irregularly on the screen. The connections between nodes were made when the user clicked on the node (Figure 18). There was a time limit of forty (40) seconds for the respondent to complete this game and the respondent could only proceed when the maximum time had elapsed or has clicked all nodes.  Also the selections could not be undone. As in D2 game before the starting of the test there was a trial with unlimited time.

In connecting the nodes game corrections were not allowed, when the respondents missed a number when constructing the pathway. A clear statement was given in instructions that the omissions should be ignored if noticed as it would help to avoid very long delays, as some respondents think about this, which would increase variance between respondents, while other respondents may not delay, either because they did not spot the omission or because they just assume they can ignore it. The software derives an average rate of working from the links that were made and tabulates errors separately, so ignoring errors would be appropriate because estimates of the rate of searching and finding will be less affected.

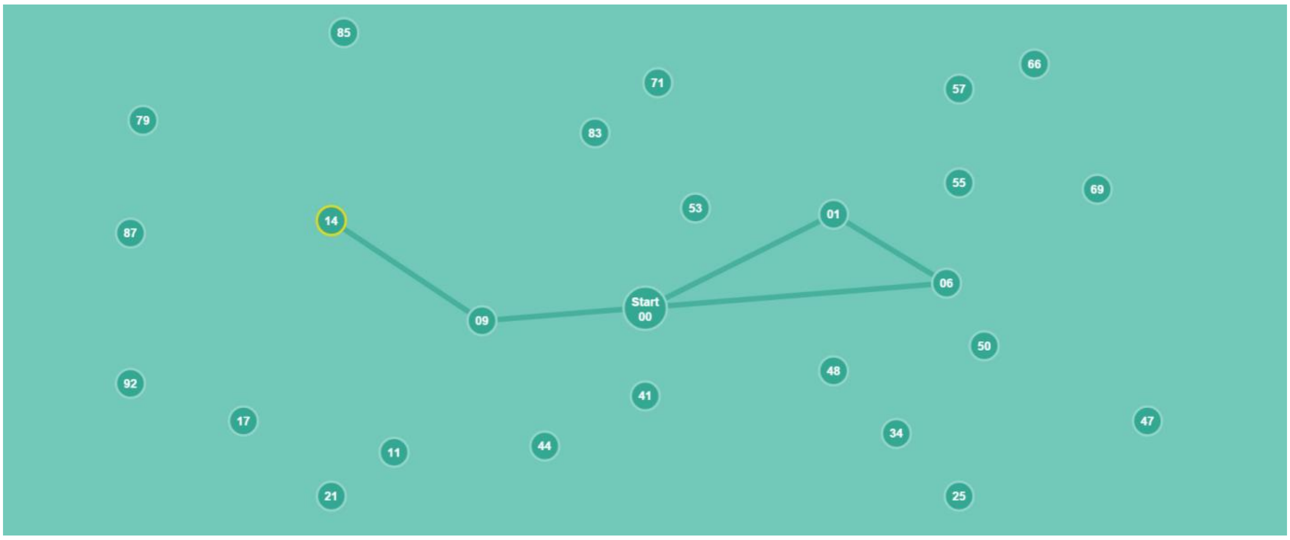



Figure 18 –Example of connecting the nodes game

Performance indicators described on games analysis section.

**Working memory game**

This game comprised six (6) similar series. The respondents had to memorize the sequence in which five images appeared and put them in the same order. The six series of images comprised images of: Cats; Flowers; Birds; Food; Hats; Wild animals. Each image was flashed for one second, one after another. There was one second inter image interval.

After the images were flashed, they were displayed in a random order, with another numbered row below from 1 to 5 (Figure 19).The responded had then to click to select from this display and the image was placed in the next available order in the numbered row.

There was a time limit of ten (10) seconds to complete the selection. If finished before, the respondent could click the next button to the next series, and time would be recorded. Errors could be edited by clicking on the image, which undone the selection. In this game there was also an unlimited time trial before the starting of the game


**Figure 19- Working memory game example**

Performance indicators described on games analysis section.

Between all three games there was three (3) seconds waiting time (Figure 20).

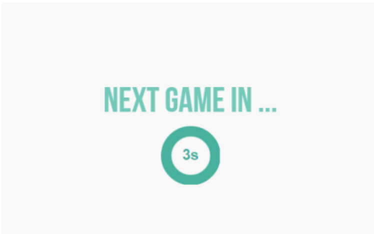



**Figure 20 – Indication between games**

Actual performance tests are unusual in studies comparing green buildings with conventional buildings, so they were incorporated for their added value and novelty. These games (tests), were also intended to make the questions about occupants' self-performance (on whether aspects of the IAQ decrease or increase their performance) more valuable, if they correlate well. Having parallel sets of measurements like this, one typically more difficult to collect and which typically is done in experimental control studies, and one easier to collect, can be valuable if the games can validate the self-assessment measurement for future use and reference.

### 3.1.6 Other Performance Indicators

It was intended to collect any available institutional performance measurements collected by the companies participating in the study. However the companies were either non-receptive or did not have measures of performance that could be used in the context of the present work.

Absenteeism/sick leave days were obtained for one working year preceding the experiment. Historical absence rates of the years prior to the study were not collected, as companies were non-receptive to give this information.

Absenteeism data were obtained (Table 16) in the format of monthly sick-leave days for each individual employee, in an anonymous format. Data was only provided for the employees on the floor were the measurements were performed. Buildings NGM4 and GM8 could not provide sick leave data. The obtained data on absenteeism was carefully checked and the monthly data was excluded if an occupant had more than five days of leave in one month or if sick leave data was related to hospitalization or child medical care.

One or two day absence rates taken back-to-back with public holidays, which may have nothing to do with that actual sick leave were not verified. This was done before in Singapore by (Tham et al. 2015) but in this study it was not possible as the data was provided as monthly accumulated absence rates, so it was decided to use these data as is.

| | | Absenteeism Data | | |
|---|---|---|---|---|
| | | Number of employee data received | Period | |
| Building | NGM1 | 50 | Sep_13 | Aug_14 |
| | NGM2 | 126 | Jan_14 | Dec_14 |
| | NGM3 | 26 | Jan_14 | Dec_14 |
| | NGM4 | ---------------------------- | | |
| | NGM5 | 38 | Jan_14 | Dec_14 |
| | NGM6 | 26 | Sep_13 | Aug_14 |
| | GM7 | 39 | Sep_13 | Aug_14 |
| | GM8 | -------------------------- | | |
| | GM9 | 126 | Nov_13 | Oct_14 |
| | GM10 | 50 | Sep_13 | Aug_14 |
| | GM11 | 19 | Jan_14 | Dec_14 |
| | GM12 | 158 | Sep_13 | Aug_14 |

**Table 16 – Number of employees data received and for which period**

### 3.1.7 Interviews

Qualitative, unstructured casual talks with occupants on both NGM and GM buildings were done. Instead of asking very specific questions, casual talks were done to assess the IEQ in the offices, gather peoples´ opinions, (dis)comfort from indoor climate, symptoms or health complaints, psychological effects. Also to learn their wishes and complaints. Colors, textures, art, beauty and aesthetics are relative and difficult to measure by occupants on a survey, so was also important to discuss observation with occupants.

### 3.1.8 Data confidentiality

All hard data is confidential so only selected results are showed as the work presented here will be public available.

## 3.2 Methodology for data analyses

Comparisons of IEQ performance and occupant perceptions and productivity in the GM certified buildings and buildings without GM certification were carried. IEQ performance (Subjective and objective) in Green Mark certified buildings and in the buildings without certification were compared against the guidelines and codes implemented in Singapore, as well as recognized authorities worldwide.

All statistical analyses were performed using SPSS version 22.0 (SPSS Inc., Chicago, IL, USA). The sample included a total of 12 offices in 12 different buildings in Singapore aggregated in different types, Green Mark and Non Green Mark, which were statistical analyzed.

Statistical analyses were performed to remove the chance effect on how Green Mark offices differ from Non-Green Mark.

There are four main types of analyses in this study; Descriptive, Parametric (e.g GLMM) correlative (e.g. Pearson correlation) and regressive (e.g. Binary logistic regression), using different combinations of objective and subjective data.

**Physical Measurements**

The measurement data are compared to Singaporean Standards (SS) (Singapore Standards 2009), ASHRAE (ASHRAE 2004; ASHRAE 2010), EN (CEN 2003; CEN 2007) and ISO(ISO 2005) standards to understand whether the results are within (good IEQ) or outside the recommended IEQ guidelines.

**Questionnaire**

Only 100% of completed questionnaires were used to avoid potential bias and changes on the results of the analyses.

**Health**

As only 100% complete surveys were used, the numbers of responses on health (N) follow the number complete questionnaires.

Only building related symptoms are of interest, as it is not of this study objective to focus on the number of symptoms that do not disappear when occupants leave the buildings, as is a chronic symptom. This is not to say that there would not be any causality with the results observed, but is out of the scope. First it was observed how many occupants indicated that they do experience each symptom. After, from this group of occupants, it was calculated how many people indicated that they do experience a symptom that is building related, so disappears when they leave the building. If this is n1 then:

% of people who reported building related symptom = n1/N*100%.

The analysis was performed on these outcomes (n1/N*100%) This is the most important outcome and the one which tells about building related symptoms. Note that in the results the sum of yes and no is 100% because the negative responses are coupled together with a negative response when occupants leave the building, so adding the "No" frequencies for symptoms and building related symptoms plus the "Yes" frequencies for building related symptoms produce 100% (Figure 21).

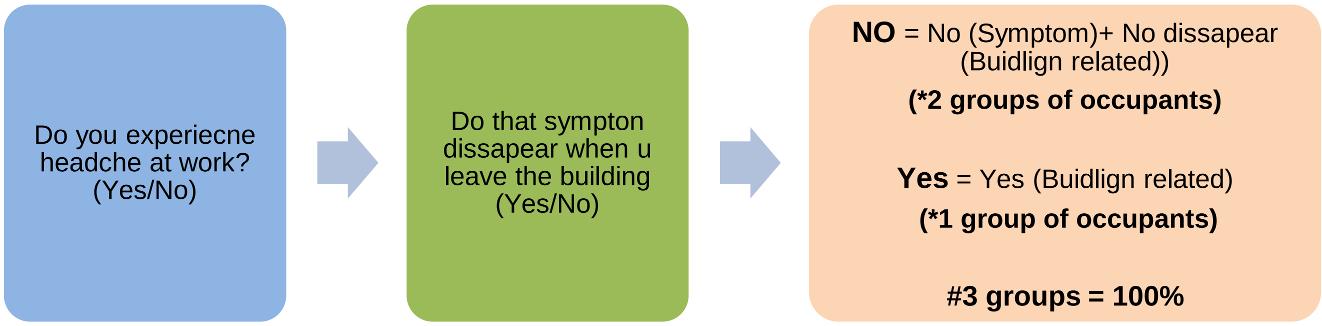



Figure 21 – SBS symptom prevalence outcome

### 3.2.1 Statistical analyses

Associations are more important, the statistical power is more indicative. Confounding variables were to some extent controlled already on the design of the experiment, through randomness both from buildings and occupants

Relevant results of the survey were visually presented for better comprehension using:

- Averages/standard error,
- Median/Interquartile ranges
- Percentages
- Confidence intervals
- Standard deviation

Only the relevant results of the survey were visually presented for better comprehension

**Normality of continuous variables**

A rule of thumb for normal distribution is that skewness and kurtosis have values between –1.0 and +1.0. Most continuous data variables (-100 to 100) fulfilled these criteria. For the few variables that were outside they were still in the limit normality case of skewness -3 and +3 and kurtosis -8 and +8 (Kline 1997)

**General linear mixed model (Parametric)**

In the survey, continuous scaled questions for perceptions, satisfaction and importance, job and performance both subjective and objective, general linear mixed model using buildings as random variables nested under fixed variables, i.e Green Mark and Non-green Mark, were used. Using a multilevel hierarchical model, which in this case will be a more conservative model, improves the validity of the statistical power on this case, as the sample on both types of buildings are intended to represent a Green and Non-Green Mark population of buildings. Building type is specified as the fixed main factor, while buildings are nested under each fixed category (GM or NGM) as random. The statistical model is the main effect of the fixed factor, which in this case is the type of buildings, plus the effect of the random nested factor (selected buildings) for each main fixed factor.

As there are many parameters in the survey using manova would have the advantage of taking the correlations between outcomes into account and controlling type I error. However, manova would fail to observe the significance since the joint distribution of multiple outcomes may conceal the variations of single outcomes, and manova usually need very large samples to have robust and valid results. Manova would also be problematic if random effects are included in the model as is intended, and data normality assumption becomes even more important in this case, as there are many outcomes. In our case, the individual analyses for each outcome are valid even though some outcomes might be correlated – meaning that conclusions for individual outcomes are valid.

Results were not adjusted using Bonferroni correction. It is difficult to know how many outcomes are correlated and whether the correlation is accidental or there is a underlying mechanism. In a study of this type the correction can create more problems than benefits, being unnecessary (Perneger 1998). Also would increase the risk of committing Error II by having a rigorous correction of p (0.05) divided number of all the outcomes (Perneger 1998).

F ratios, P values and Partial eta-square values are represented.

Homogeneity of variance was tested using Levene test. Significance was not observed.

Fishers Least Significant Difference (LSD) test was also performed for each parameter. In this case means are compared between Green Mark and Non-Green Mark with no hierarchical assumptions. LSD test are essentially individual t-tests (Zar 2010). This is a less conservative model.

**Pearson Chi-Square**

Chi-square tests were used to analyze the strength of association between two categorical variables (e.g. prevalence SBS symptoms, IEQ ranking, Demographics). P-values are shown through several charts for the statistically significance difference between Green Mark and Non-Green Mark.

**Principal components analyses (PCA)**

PCA was done to see any natural reduction of data in factor groups (Dunteman 1989) in IEQ satisfaction and importance. To analyze the importance of different factors (variables) in explaining the difference between Green Mark and Non-Green Mark and how they group themselves together. Reliability of the PCA is strongly correlated with the sample size. In the literature is reported that 300 observations are needed (Field 2005). In the present study if we separate the buildings in green mark and non-green mark the sample size will be lower than 300, but still was decided to perform a PCA on the data. No pre-defined number of factors were input and the Kaiser stopping criterion was used (factors with eigenvalues > 1) (Field 2005). The rotation method choosed was orthogonal "varimax" as we did not know if the factors would be highly correlated or not and assumed independence. PCA was done for perceptions and satisfaction parameters. No multicollinearity and singularity are expected from the tested variables. Factor loading in the rotated matrix were set to a minimum of 0.4 instead of 0.3 because of the sample size

**Binomial Logistic Regression**

When the testing parameter was a dichotomous variable and the independent variable the type of building, binomial logistic regression was used (Siegel 1956). This technique was used to calculate the odds-ratio on health symptoms. The Wald test was used to calculate the significance of the independent variable, the type of building. The method used was “enter”. Did not violate logistic regression assumptions.

**Multiple Linear Regression**

Multiple regression, using two methods, one were all the variables are always forced into the regression model and other (stepwise), where variables with low explanatory power are removed interactively, were performed when the objective was to observe how well one or a set of continuous independent variables can fit and predict a continuous dependent variable (Freedman 2009). E.g. individual satisfaction parameters vs overall IEQ satisfaction. Prevalence of multicollinearity was analyzed. VIF values are represented. Linearity between variables and homoscedasticity was observed through scatter plots.

**Pearson Product-Moment Correlation**

To analyze the strength of association between two continuous variables Pearson coefficients were also calculated for some of the results. The correlation can be either positive or negative. Linearity was observed through scatterplots. The data showed no violation of homoscedasticity. E.g. IEQ satisfaction association with self-reported performance.

**Point-biserial correlation**

Point-biseral correlation was used also in building related SBS symptoms. Point-biserial correlations are a special case of the Pearson product moment correlation when applied to a dichotomous variable (SBS) and a continuous variable (e.g. satisfaction). In our case in SPSS, the coefficients from Pearson correlations will be point-biserial associations. The strength of association has the same format as Pearson product-moment correlations. Variables also follow normal distribution for the continuous variables and homoscedasticity.

### 3.2.2 Games analyses

As in the survey only 100% complete game data are used. In case of the games, the dubious data was cleaned to avoid using results that are expect to be either incomplete or suggestive that the occupant taking the game did not take the task seriously. The exclusion criterions are described below:

A classification and validation algorithm was done, so pattern of answers can be analyzed and cleaned and proper data used. In the D2 game a series was excluded when the total number of characters selected was equal to 0 or less than 11(*It means the respondent did not pass the first screen) or the correct number of selected characters bellow 6 AND the total time below 11 seconds.

Following the D2 game cleaning, for the other two games, the occupant was only excluded if for both games did not have any correct answer, and follow a null case (i.e. 0)

For the D2 and memory game an average of the best 3 series were used for the performance indicators analyses

The games were treated separately from questionnaire data so there can be different number of responses/individuals completing the game from surveys.

#### 3.2.2.1 D2 game

For the D2 game three results are represented in the result section, the concentration performance, accuracy, and fluctuation rate.

The software provided the following output: number of characters processed until the last indicated d2 character (TS), number of d2-characters that are identified correctly (d2-cor) and number of characters crossed other than d2-characters, false positives (FP), d2 characters that were missed until last crossed d2-character or the total number of d2-characters (d2-tot) until last crossed d2 character.

The following outcomes were used to examine the performance of building occupants on D2-game. These outcomes were calculated separately for each of the 6 series of D2-games and then only the average of the best 3 were used.

> TS = a total number of characters processed until the last marked d2 character in the series; F1=number of d2 characters missed. F2= number of false positives (FP) for false positive there are 3 types of error:

Wrongly identified character (ie. p instead of d) with two correctly identified dashes
Wrongly identified character (ie. p instead of d) with two dots
d character with wrong number of dots (i.e d with more/less than two dots).

- Accuracy = % of total errors: (F1+F2)*100/TS. Accuracy measures the qualitative aspects of performance, the proportion of errors made across all characters processed. The smaller the percentage of errors, the better the accuracy.
- Concentration performance (CP): TS-(F1+F2). CP is the number of correctly processed items minus errors of commission. This score cannot be distorted by such tendencies as skipping over characters or crossing out all characters without discriminating among them. CP represents attention an inhibitory control.

The above performance outcomes were supplemented with the following performance indicators calculated based on performance on all 6 series:

- Fluctuation rate (FR) = Maximum difference between all TS in all 6 series: Max TS – Min TS. FR is indicated by the discrepancy between the series with the maximum number of items processed and the series with the minimum of items processed. A high FR can indicate distractions during the game.

#### 3.2.2.2 Connecting-the-nodes game (Tsai-Partington test)

For the game connecting the nodes two results are presented, accuracy and performance (arousal/speed) when connecting the nodes

The following output was provided by the software: response time (RT) i.e. the time used by the user to complete the game (maximum time possible was 40 seconds), number of correct links, termed correct numbers, i.e. number of links that are done correctly i.e. following the ascending order of the numbers (L-cor), and number of mistakes i.e. wrongly made links, termed wrong numbers i.e. the links that do not follow the ascending order of numbers (L-err). The following outcomes were used to examine the performance of building occupants on this game:

Connecting the nodes accuracy = performance indicating number of correct links normalized by the response time and total number of links made (L-cor/(L-cor + L-err))*(40/RT), where 40 is the total allowable time to perform the task

Speed performance = number of correctly made links adjusted by response time (time used to perform the task): L-cor/RT

#### 3.2.2.3 Working memory Game (Serial recall task)

For the memory game, working memory performance is presented, which represents speed and memory accuracy.

The following output were provided by the software: response time (RT) i.e. the time used by an individual to complete the game, % of correctly recalled pictures (R-cor), and % of wrongly recalled pictures (R-err), separately for each series and each respondent.

The following outcomes were used to examine the performance of building occupants on the memory game:

Working memory performance indicator = % of correctly recalled pictures adjusted by response time: r-cor/RT

These outcomes were calculated separately for each of the 6 series of the memory game and then only the average of the best 3 was represented.

Performance on each series allowed observing whether if there were any trends in performance.

All performance indicators were calculated separately for each respondent and means are represented for GM and NGM respondents. A hierarchical mixed model was also used to observe the differences between GM and NGM buildings are significant. Individual building medians are also represented.

## 3.3 Green Mark IEQ scheme credits

Individual building analyses based on IEQ credits on Green mark schemes for all buildings were performed and also analysis of the GM certified buildings on relative emphasis accorded to IEQ section in comparison with the other sections. This provided a useful insight on the strategies adopted by the industry in achieving GM certification.

# 4 Chapter – Results

The following sections show the results. Green is understood as GM buildings while dark blue as NGM buildings.

## 4.1 Buildings

The main description of the buildings is shown from Table 17 to Table 20. Extra additional observations and descriptions can be found in appendix B. All buildings are located in Singapore. Three NGM buildings and two GM buildings are located on the business district. GM buildings construction years vary from 1995 to 2011. NGM buildings construction years vary from 1969 to 2011. Two GM buildings are high rise buildings. Four GM buildings achieved GM Platinum and two GM Gold Buildings. Approximate occupant density varies between 6 and 14 sqm per occupant in NGM buildings and 7 to 26 sqm per occupant in GM buildings.

| | Building Information | | | | | |
|---|---|---|---|---|---|---|
| | Measuring week (2014) | District in Singapore | District area in Singapore | Building Certification | Building Floors | Construction Year |
| NGM1 | 15-09 (week) | 2 | Business District | None | 14 | 1971 |
| NGM2 | 29-09 (week) | 1 | Business District | None | 22 | 1969 |
| NGM3 | 20-10 (week) | 1 | Business District | None | 22 | 1969 |
| NGM4 | 13-10 (week) | 11 | Central North | None | 20 | 1985 |
| NGM5 | 24-11 (week) | 13 | Central South | None | 3 | 1994 |
| NGM6 | 08-12 (week) | 22 | Far East | None | 11 | 2011 |
| GM7 | 06-10 (week) | 7 | East Coast | GM Platinum | 15 | 1995 |
| GM8 | 27-10 (week) | 2 | Business District | GM Platinum | 19 | 2009 |
| GM9 | 03-11 (week) | 1 | Business District | GM Gold | 50 | 2011 |
| GM10 | 10-11 (week) | 22 | Far East | GM Platinum | 32 | 2000 |
| GM11 | 17-11 (week) | 20 | Central North | GM Platinum | 3 | 2009 |
| GM12 | 01-12 (week) | 14 | Central East | GM Gold | 14 | 1999 |

Table 17 – Building info observations

| | Tenant floor Information | | | | | | |
|---|---|---|---|---|---|---|---|
| | Occupants (estimated) | Occupant density sqm/Person | Gross Floor Area (sqm) | Office Certification | Office floor | Height - Floor to Ceiling (m) | Office Type |
| NGM1 | 50 | 8 | <500 | None | 12 | 2,5 - 2,7 | Commercial |
| NGM2 | 120 | 13 | >1500 | None | 17 | 2,5 - 2,7 | Governmental |
| NGM3 | 30 | 13 | <1000 | None | 12 | 2,5 - 2,7 | Governmental |
| NGM4 | 50 | 10 | <1000 | None | 8 | 2,5 - 2,7 | Commercial |
| NGM5 | 40 | 6 | <500 | None | 2 | 2,5 - 2,7 | Governmental |
| NGM6 | 30 | 14 | <500 | None | 7 | 5 | Industrial(Adapted) |
| GM7 | 40 | 12 | <1000 | None (*soon OI gold+) | 14 | 2,5 - 2,7 | Commercial |
| GM8 | 140 | 14 | >1500 | GM OI Platinum | 17 | 3 | Commercial |
| GM9 | 120 | 14 | >1500 | GM OI Platinum | 49 | 2,5 - 2,7 | Commercial |
| GM10 | 120 | 11 | >1000 | GM OI Platinum | 8 | 2,5 - 2,7 | Commercial |
| GM11 | 35 | 26 | <1000 | GM OI Platinum | 3 | 2,5 - 2,7 | Governmental |
| GM12 | 120 | 7 | >3000 | GM OI Platinum | 11 | 2,5 - 2,7 | Commercial |

Table 18 – Individual tenant info observations

Floor plan drawings and air conditioning plan layout were given by the tenants and used for the volume calculations and selection of measuring zones in the buildings. Because of anonymity they are not presented here.

All buildings have open plan offices (Table 19). All measurements were taken on open plan sections, as most occupants were seating there. In NGM4 there were 3 private offices were measurements were also performed, but as they have a big area and were well connected to the main open plan, that can be considered as one open plan office also. Most buildings have a few small offices for management, usually in corner or perimeter, but during measurements was observed that they are mostly unoccupied during the day, which was the reason why measurements were not performed there.

NGM buildings have CAV ventilation systems or FCUs. All GM buildings have VAV systems (Table 20). Only two NGM and two GM buildings have temperature control provided to occupants. Only three GM buildings have ducted air return to the mixing room. All GM buildings have monitoring of $CO_2$ levels to control intake of outdoor air. NGM buildings have MERV4 filters on the AHU. On the NGM building with FCUs the filter type is unknown, but likely is low efficiency.  GM buildings have MERV 13, MERV14, electrostatic and HEPA filters (Table 20).

| | Workplace | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Type | Partitions | Green IEQ initiatives | Green Products | Cleaning | Lounge | Greenery | Ceiling Light |
| NGM1 | Open Plan – High Density | Low (1 m from the floor) | No | No | Unknown (-) | Small kitchen | No | Magnetic Ballast T8 |
| NGM2 | Open Plan – High Density | High (1.4 m from the floor) | Eco office certification | No | Daily (-) | Small kitchen | No | Magnetic Ballast T8 |
| NGM3 | Open Plan – High Density | High(1.4 m from the floor) | Eco office certification | No | Daily (-) | Small kitchen | No | Magnetic Ballast T8 |
| NGM4 | Open Plan – High Density | Medium (1.2 m from the floor) | No | No | Unknown (-) | Small kitchen | No | Magnetic Ballast T8 |
| NGM5 | Open Plan – High Density | Medium (1.2 m from the floor) | No | No | Unknown (-) | No | No | Magnetic Ballast T8 |
| NGM6 | Open Plan – Low Density | Medium (1.2 m from the floor) | Off lights during lunch and in zones not in use. | Certified washing products | Weekly (+) | kitchenette | No | High bay PLC |
| GM7 | Open Plan – High Density | Medium (1.2 m from the floor) | -Recycling Program | - Sustainable purchasing policy | Daily (++) | Large Lounge and kitchenette Outdoor terrace | Plotted Plants | Magnetic Ballast T8 |
| GM8 | Open Plan – Low Density * Partial Hot-desk | Medium (1.2 m from the floor) *Only Front | -Green corner | -Certified recycled furniture/ carpets | Daily (++) | 1 Large exchange | Potted Plants/Green wall | HF Magnetic Ballast T5/LED |
| GM9 | Open Plan – Low Density | Low (1 m from the floor) *Only Front | - Implementation of indoor green wall. | -Recycled furniture/Carpets made. | Daily (++) | 2 Large Exchanges | Planter boxes at workstation areas/ Green Wall | LED |
| GM10 | Open Plan – High Density | Medium (1.2 m from the floor) | -Light timer switches - Extensive use of environmentally sustainable materials | -98% of office equipment is Energy Star rated -SGLS certified and high recycled products | Daily | Kitchenette | Potted Plants | LED |
| GM11 | Open Plan – Low Density | Medium (1.2 m from the floor) | Daylight pipes light shelves sun-shading devices Mirror ducts | Unknown | Unknown (+) | No | Potted Plants | HF Magnetic Ballast T5/LED |
| GM12 | Open Plan – High Density * Partial Hot-desk | High (1.4 m from the floor) | Recycling bins in utility room | No | Daily (++) | -Outdoor garden -1 Large exchange | Potted Plants/ Green Wall | T8 Magnetic ballast |

**Table 19 – Individual workplace observations* (++) Very good cleaning / (+) Good cleaning / (-) Bad cleaning**

| | Ventilation | | | | | |
|---|---|---|---|---|---|---|
| | Ventilation Type | Control | AHUType | Air Return | Outdoor Air | Filter Type |
| NGM1 | CAV | No (FM control) | Mixing Room | Ceiling Plenum | Opening to Mixing room | Merv 4 |
| NGM2 | CAV | No (FM control) | Mixing room | Ceiling Plenum | Opening to Mixing room | Merv 4 |
| NGM3 | CAV | No (FM control) | Mixing room | Ceiling Plenum | Opening to Mixing room | Merv 4 |
| NGM4 | FCUs | No (FM control) | FCUs with AHU | --- | Unknown | Unknown |
| NGM5 | FCUs | Temperature | Individual FCUs | --- | Unknown (-) | Unknown |
| NGM6 | Passive displacement cooling/ FCU | Temperature/Ceiling fans | Passive displacement cooling/ FCU | --- | No (-) | --- |
| GM7 | VAV | No (FM control) | Mixing room | Ceiling Plenum | Automatic – CO2 sensors | Electrostatic |
| GM8 | VAV | No (FM control) | Mixing room | Ceiling Plenum | Automatic – CO2 sensors | Merv 13 |
| GM9 | VAV | No (FM control) | Mixing room | Ducted | Automatic – CO2 sensors | Merv 13 |
| GM10 | VAV | Temperature | Mixing room | - Ceiling Plenum | Automatic – CO2 sensors | Merv 13 |
| GM11 | (Personalized and under floor air ventilation)VAV | Temperature | Single-coil twin-fan | Ducted | Automatic – CO2 sensors | HEPA |
| GM12 | VAV | No (FM control) | Mixing room | Ducted | Automatic – CO2 sensors | Merv 14 |

**Table 20 – Individual tenant ventilation info**

## 4.2 Physical data

Physical data results were averaged for the different zones within the open plan offices. Unlike data from the survey, which are weighted by occupants, all physical data presented results are weighted by buildings, i.e. averages of individual building data. Due to failure of some measuring equipment some measuring data were lost and could not be recovered. This pertains to the following: Noise levels, and Ozone. $PM_4$, $PM_{10}$ and TVOC were judged to have low quality being not reliable results. Also the equipment measuring these rejected parameters was tested after the measuring campaign against other sets of equipment confirming the initial suspicion of inaccurate measurements, and for that reason these results were discarded form analysis. Thermal and atmospheric measurements are presented in this chapter.

### 4.2.1 Continuous measurements of Temperature, Relative humidity and CO2

Continuous measurements of temperature and relative humidity were extracted from HOBO loggers, for the period from Monday to Thursday, and for the period representing working hours from 9 am to 5 pm. Measurements from all measuring zones (4 or 5 zones) were merged, as described above.

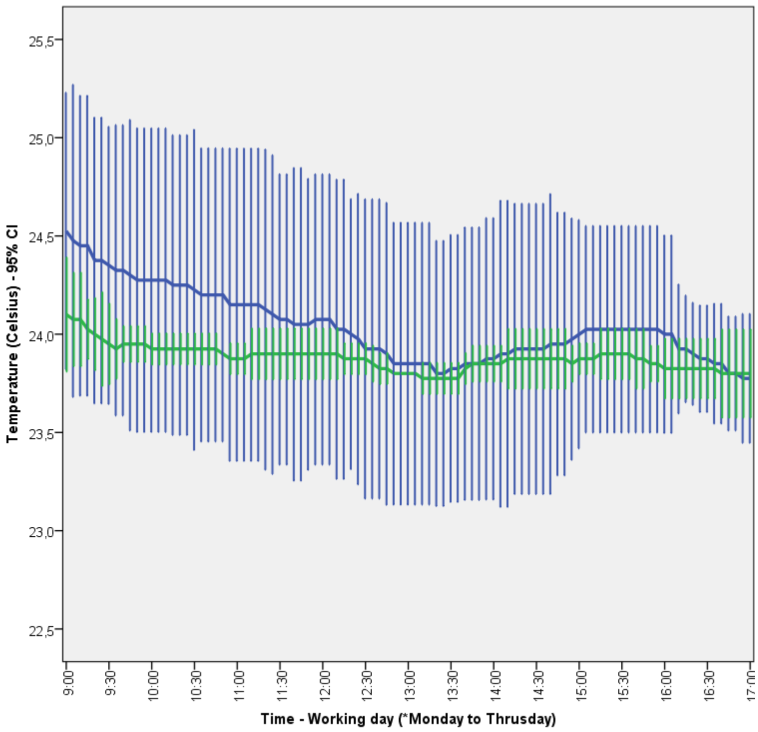



**Figure 22- Time weighted average of indoor temperatures for a working day in GM and NGM buildings; lines show average values for the 6 NGM (Blue) and 6 GM buildings (Green) with all zones merged and bars show the 95% confidence interval**

Time weighted averages (TWA) are presented. Figure 22 and Table 21 show that the variation in temperature in NGM buildings is much higher than in GM buildings. Temperature is more constant in GM buildings (green line) compared with NGM (blue line); it is maintained fairly constant around 24 ºC across all GM buildings while in NGM buildings it ranges from 23 ºC to 25 ºC. GM buildings make use of newer VAV systems with zone thermostats compared with the CAV and FCU systems in NGM, which may explain the better temperature control. Temperatures in NGM building are on average higher in the morning.

In Singapore to secure thermal comfort, Green Mark certification adopts the recommendations of SS554:2009 (Singapore Standards 2009). ASHRAE 55-2004 (ASHRAE 2004), ISO 7730: 2005 (ISO 2005) and EN 15251: 2007 (CEN 2007) are also commonly used as regards the thermal comfort requirements in certification schemes. Temperature interval which is set in the Green Mark office interior, is set for the indoor operative temperature. The range is between 24ºC to 26ºC. The values in Figure 22 are for the air temperature. They are anticipated to be on the lower side of the recommendation in Green Mark, as in Singapore sporadically operative temperature will likely be slightly lower in air conditioned offices than air temperatures in periods of outdoor rain.

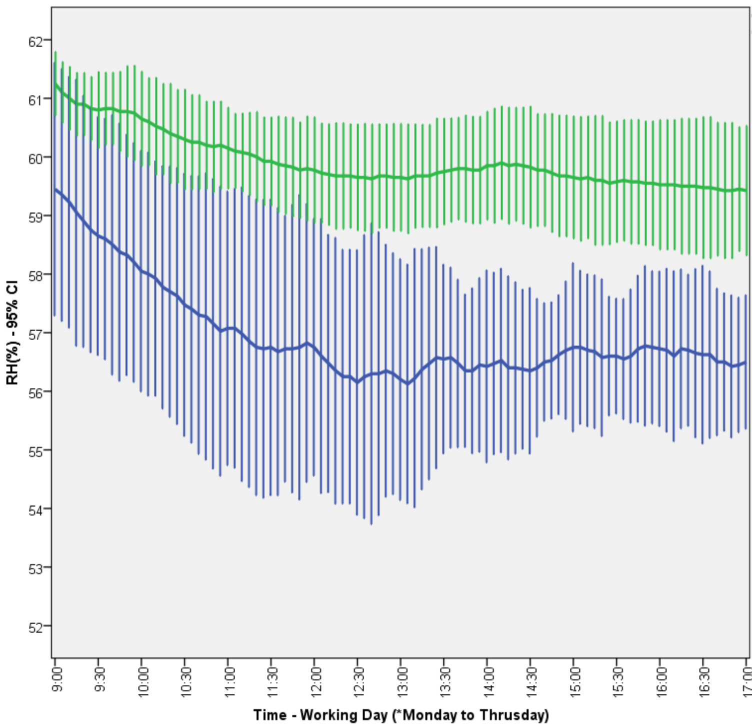



**Figure 23 – Time weighted average of relative humidity for a working day in GM and NGM buildings; lines show average values for the 6 NGM(Blue) and 6 GM buildings(Green) with all zones merged and bars the 95% confidence interval**

Figure 23 shows the time weighted average relative humidity in GM and NGM buildings. RH is lower in NGM buildings. Relative humidity recommended values are included in Green Mark Office interior v1.1: relative humidity should be less than 65% (Green Mark 2015). ISO (ISO 2005) recommends the levels of relative humidity in offices to be between 30% to 70%. It can be seen in (Figure 23) and (Table 21) that both GM and NGM buildings meet the Green Mark and ISO requirements.

Lower RH fluctuations were observed in GM buildings. GM buildings have higher RH compared with NGM buildings. RH falls in NGM buildings during the day and remains constant in the afternoon. RH in the GM buildings also follows this pattern but with a smaller variation between buildings and the average value which is fairly constant during the day. RH increases inside the offices during the night (data not shown) as the ventilation systems are not working after 6 pm, this may explain higher RH in the beginning of the day. Lower RH in the NGM buildings is probably due to the higher ventilation rate or instable AHU temperature control. During measurements in the buildings it was not possible to gather design set points for the AHUs.

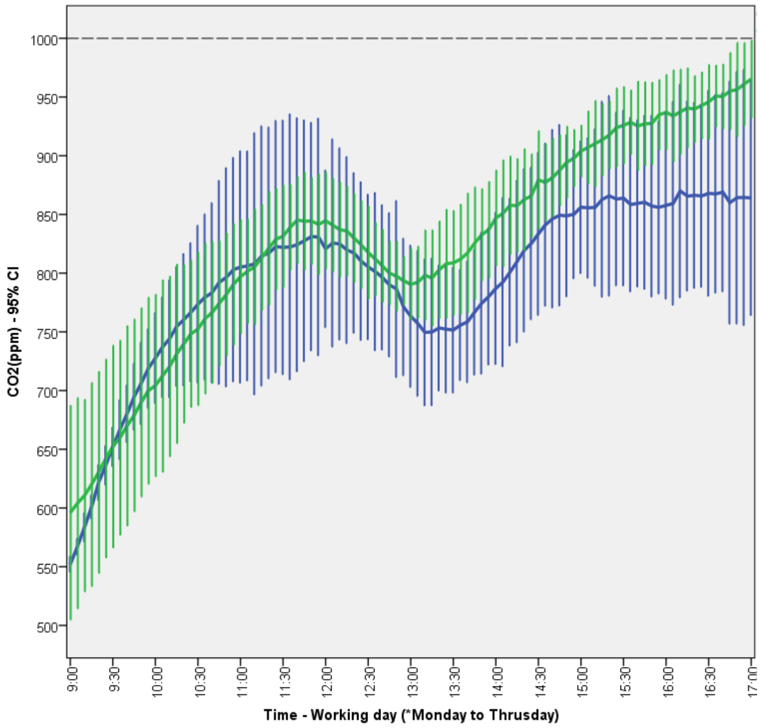



**Figure 24- Time weighted average of absolute $CO_2$ (PPM) for a working day in GM and NGM buildings; lines show average values for the 6 NGM(Blue) and 6 GM buildings(Green) with all zones merged and bars 95% confidence interval**

Figure 24 shows $CO_2$ concentrations both in the GM and NGM buildings. It can be seen that $CO_2$ concentration follows the expected pattern during a working day. The concentration increases during the day until lunch time, when it starts to decrease. After lunch it starts to increase again stabilizing for NGM buildings around 3 pm, which is not observed in GM buildings, in which case the concentration continues to increase until 5 pm. Variation between buildings in $CO_2$ concentration is higher in NGM buildings. For both types of buildings the concentrations are below 1,000 ppm (Figure 24)(Table 21). This complies with recommendations of ASHRAE 62.1 (ASHRAE 2010) and OSHA (OSHA 1999). According to SS554:2009 (Singapore Standards 2009), which is adopted by the Green Mark scheme, the concentrations should not be more than 700 ppm above outdoor values. As the outdoor $CO_2$ values in Singapore are below 500 ppm, both the GM and NGM buildings fulfill the requirements as regards $CO_2$ concentration as set by Green Mark requirements. $CO_2$ concentrations are higher in the afternoon.

In the GM buildings the time-weighted average concentration was still increasing towards the end of the day because two GM buildings continue to show an increase of the $CO_2$ concentration, as seen in (Figure 27) did not reach a steady state indoor concentration of $CO_2$.

#### 4.2.1.1 Individual building values for temperature, relative humidity and $CO_2$

Figure 25, Figure 26 and Figure 27 show temperatures, relative humidity and CO2 in each of the building where the measurements were performed.

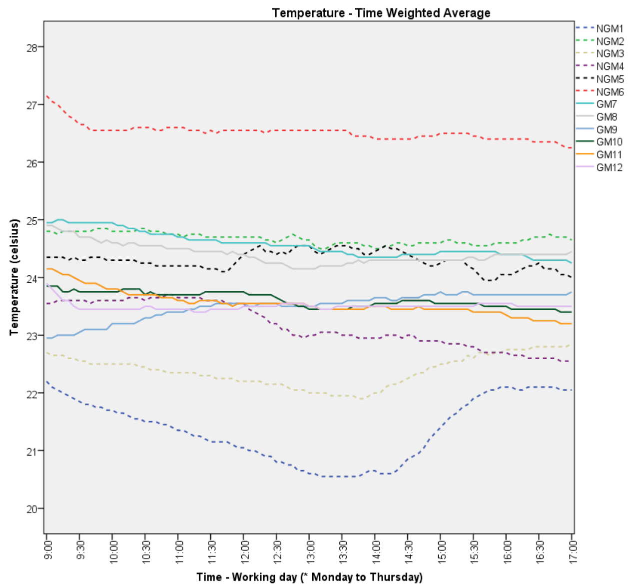



Figure 25- Time weighted average of temperature (ºC) for a working day in each of the 6 GM and 6 NGM buildings; lines show average temperatures for each building

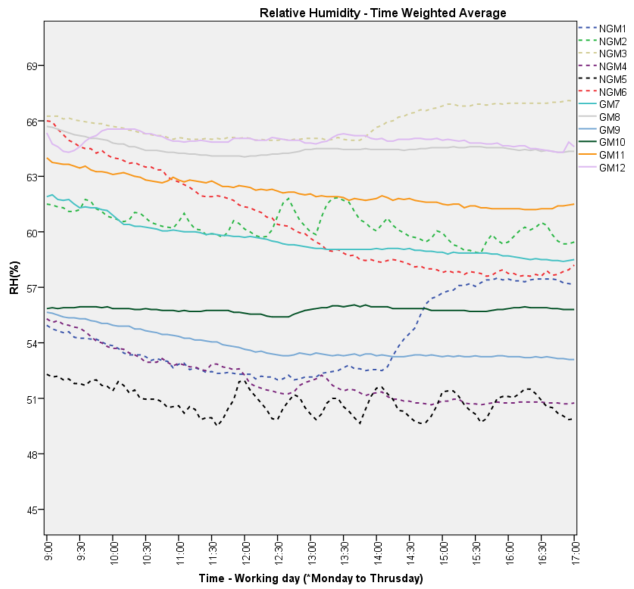



Figure 26- Time weighted average of RH (%) for a working day in each of the 6 GM and 6 NGM buildings; lines show average RH in each building

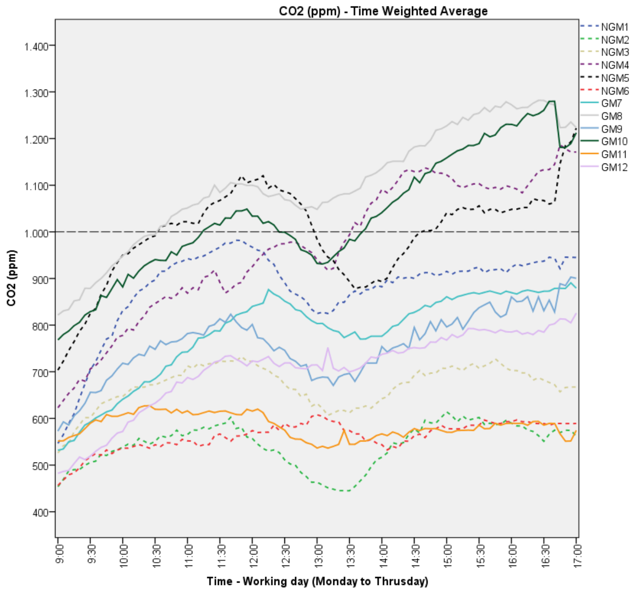



**Figure 27 – Time weighted average of CO2 (PPM) for a working day in each of the 6 GM and 6 NGM buildings; lines show average values in each building**

Temperatures in NGM buildings showed a much higher disparity between buildings compared with GM buildings (Figure 25). The same is observed for RH (Figure 26). All GM buildings have $CO_2$ monitoring sensors for fresh air, but GM8 and GM10 have $CO_2$ concentrations above 1200 ppm (Figure 27) which never reach steady state concentrations. These two buildings have $CO_2$ sensors for control outdoor air intake, so likely there is a calibration problem or control problem in the AHU system. Regular calibration and testing of $CO_2$ sensors should be implemented to avoid among situations like in these two buildings.

| Temperature (Celsius) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | NGM1 | NGM2 | NGM3 | NGM4 | NGM5 | NGM6 | GM7 | GM8 | GM9 | GM10 | GM11 | GM12 |
| Mean | 21,5 | 24,8 | 22,5 | 23,5 | 24,3 | 26,5 | 24,5 | 24,4 | 23,6 | 23,6 | 23,8 | 23,5 |
| Std.Deviation | 0,6 | 0,3 | 0,4 | 0,6 | 0,3 | 0,2 | 0,4 | 0,2 | 0,5 | 0,2 | 0,4 | 0,2 |
| Variance | 0,4 | 0,1 | 0,1 | 0,4 | 0,1 | 0,1 | 0,1 | 0,0 | 0,3 | 0,1 | 0,2 | 0,1 |
| Range | 2,4 | 1,5 | 1,6 | 2,3 | 1,6 | 1,5 | 1,6 | 0,9 | 2,5 | 1,0 | 2,0 | 1,3 |
| Minimum | 20,3 | 24,3 | 21,8 | 22,4 | 23,5 | 26,2 | 24,0 | 24,1 | 22,5 | 23,1 | 23,1 | 23,0 |
| Maximum | 22,7 | 25,8 | 23,4 | 24,7 | 25,1 | 27,7 | 25,6 | 25,0 | 25,0 | 24,1 | 25,1 | 24,3 |
| **RH(%)** | | | | | | | | | | | | |
| | NGM1 | NGM2 | NGM3 | NGM4 | NGM5 | NGM6 | GM7 | GM8 | GM9 | GM10 | GM11 | GM12 |
| Mean | 54 | 60 | 65 | 52 | 51 | 61 | 59 | 65 | 53 | 56 | 62 | 64 |
| Std.Deviation | 2 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 2 |
| Variance | 4 | 2 | 2 | 2 | 2 | 6 | 1 | 0 | 1 | 1 | 1 | 3 |
| Range | 7 | 7 | 6 | 6 | 6 | 10 | 5 | 3 | 5 | 4 | 4 | 6 |
| Minimum | 51 | 58 | 64 | 50 | 48 | 57 | 58 | 64 | 51 | 54 | 61 | 62 |
| Maximum | 58 | 65 | 70 | 56 | 54 | 67 | 63 | 67 | 56 | 58 | 65 | 68 |
| **CO2 (ppm)** | | | | | | | | | | | | |
| | NGM1 | NGM2 | NGM3 | NGM4 | NGM5 | NGM6 | GM7 | GM8 | GM9 | GM10 | GM11 | GM12 |
| Mean | 921 | 546 | 677 | 1033 | 1002 | 573 | 811 | 1053 | 768 | 1020 | 579 | 722 |
| Std.Deviation | 126 | 49 | 51 | 179 | 120 | 44 | 121 | 166 | 86 | 157 | 42 | 103 |
| Range | 649 | 218 | 262 | 764 | 622 | 272 | 502 | 817 | 421 | 841 | 189 | 498 |
| Minimum | 535 | 423 | 516 | 619 | 640 | 430 | 505 | 535 | 504 | 561 | 484 | 427 |
| Maximum | 1184 | 642 | 778 | 1383 | 1261 | 702 | 1006 | 1351 | 925 | 1401 | 673 | 925 |

**Table 21 –Temperature, RH and CO2 in each of the investigated 12 buildings**

### 4.2.2 Air Velocity and Operative temperature

Continuous measurements of globe temperature were extracted from HOBO loggers, for the period of Monday to Thursday, and for the period representing working hours from 9 am to 12 pm (accounting for mornings) and 1 pm to 5 pm (accounting for the afternoon); data between 12 am and 1 pm were not included due to lunch break. Air velocities were not continuously measured, but measured through spot measurements, so there were four sets of measurements. Average values of radiant temperatures are 23,6 ºC for both NGM and GM buildings, but variance in operative temperatures was much higher in the NGM buildings (Table 22). Average globe temperatures in NGM buildings range from 21,5 ºC to 26,6 ºC and in GM buildings from 23,2ºC to 24,5 ºC. Measured air velocity (Table 22) is close to 0 m/s in all buildings.

ASHRAE Standard 55 (ASHRAE 2004) for thermal comfort recommends that the air velocity should be below 0.2 m/s. Green Mark buildings follow SS554:2009 (Singapore Standards 2009) which recommends acceptable upper limit for velocity between 0.1 – 0.3m/s. All measurements (Table 22) were below 0.2 m/s, and as such within recommended values, but still, as shown later in the results, there were occupant complaining of occasional episodes of draft.

| | | RADIANT TEMPERATURE (Celsius) | AIR VELOCITY (m/s) | OPERATIVE TEMPRATURE (Celsius) |
|---|---|---|---|---|
| NGM1 | MEAN + SD *Radiant temperature was continuously measured | 21,4±0,9 | 0,04±0,02 | 21,6±0,8 |
| NGM2 | | 24,1±0,4 | 0±0,1 | 24,2±0,8 |
| NGM3 | | 22,3±0,3 | 0,01±0,01 | 22,3±0,3 |
| NGM4 | | 23,3±0,9 | 0,00±0 | 23,3±0,9 |
| NGM5 | | 23,9±0,8 | 0,00±0,01 | 24,1±0,9 |
| NGM6 | | 26,6±1,2 | 0,00±0 | 26,5±0,9 |
| GM7 | | 24,5±0,6 | 0,00±0,04 | 24,6±0,6 |
| GM8 | | 23,8±0,6 | 0,00±0,00 | 24,1±0,4 |
| GM9 | | 23,5±1,1 | 0,00±0,00 | 23,7±0,8 |
| GM10 | | 23,2±0,9 | 0,00±0,00 | 23,4±0,9 |
| GM11 | | 23,2±0,5 | 0,00±0,00 | 23,4±0,6 |
| GM12 | | 23,4±0,7 | 0,01±0,01 | 23,4±0,6 |

**Table 22 – Average radiant temperature (ºC) and air velocity (m/s) and calculated operative temperature (ºC) in each individual building included in the measurement.**

In Singapore, operative temperature in Green Mark buildings follow the recommendations of SS554:2009 (Singapore Standards 2009), and the recommended values are between 24 to 26 °C. It is not a mandatory requirement unless it is an existing buildings version, where IAQ audit is mandatory. Operative temperature requirements specified on ASHRAE 55-2004, ISO 7730: 2005 and EN 15251: 2007 are also commonly in certification schemes around the world, but in Singapore comments from BCA GM assessors in Singapore often express problems to measure operative temperature in offices during audits and use air temperature instead. (it is now considered to change the requirement of measuring operative temperature into measurement of air temperature).

### 4.2.3 Air change rate (ACH)

For outdoor air change rate, results are presented in Table 23. The average ACH in NGM building is 1,1 with a variance between 0,6 and 1,7. In GM building the average ACH is 0,9 with a variance between 0,3 and 1,8. No trend is conclusive on the differences between NGM and GM buildings. Observing values of litters per second per occupant and per square meter is possible to observe fours buildings fours building in NGM buildings and 2 buildings in GM buildings are over ventilating. NGM6 is an industrial building that was adapted to an office layout and GM11 an energy-efficient building with low occupant densities which explain the high values of fresh air per occupant, of 33 l/s and 26 l/s respectively. NGM4 and GM10 have overestimated ACH, which is explained in the discussion chapter. The ACH values on this study are similar to previous results done in Singaporean office buildings (Sekhar et al. 2002)

| Building | ZONE 1 | ZONE 2 | ZONE 3 | ZONE 4 | ZONE 5 | Average ACH | *L/S per person | *L/S per SQM |
|---|---|---|---|---|---|---|---|---|
| NGM1 | 0,60 | 0,64 | 0,63 | 0,60 | 0,62 | 0,6 | 3,2 | 0,4 |
| NGM2 | 1,23 | 1,23 | 1,19 | 1,27 | 1,38 | 1,3 | 12,0 | 0,9 |
| NGM3 | 1,15 | 1,11 | 1,05 | 1,14 | | 1,1 | 10,1 | 0,7 |
| NGM4 | 0,93 | 0,95 | 1,13 | 1,23 | 1,65 | 1,2 | 9,4 | 0,8 |
| NGM5 | 0,70 | 0,80 | 1,02 | 1,18 | | 0,9 | 3,8 | 0,6 |
| NGM6 | 1,40 | 1,42 | 2,05 | 2,10 | | 1,7 | 32,7 | 2,3 |
| GM7 | 0,60 | 0,58 | 0,68 | | | 0,6 | 5,1 | 0,4 |
| GM8 | 0,30 | 0,32 | 0,35 | 0,34 | 0,31 | 0,3 | 3,5 | 0,2 |
| GM9 | 0,52 | 0,52 | 0,51 | 0,56 | 0,52 | 0,5 | 5,0 | 0,3 |
| GM10 | | | 0,59 | 0,72 | 0,72 | 0,7 | 5,3 | 0,5 |
| GM11 | 1,47 | 1,46 | 1,35 | 1,24 | | 1,4 | 25,6 | 0,9 |
| GM12 | 1,83 | 1,69 | 1,74 | | | 1,8 | 9,2 | 1,2 |

Table 23 – Air change rates for the 6 NGM and 6 GM buildings * Approximately estimated

Singapore has a tropical climate so high air change rates might also increase moisture levels or the energy demands to dehumidify the air.

### 4.2.4 Bacteria and Fungi

A high count of bacteria might be a sign of a very high occupant density, poor ventilation or cleaning. SS554:2009 (Singapore Standards 2009) recommends bacteria and fungi levels below 500 CFU/$m^3$. The American Conference of Governmental Industrial Hygienists (ACGIH) also recommends 500 CFU /$m^3$ as a limit (Jensen & Schafer 1998). Bacteria and fungi measurements in this study were performed four times in each location in each building. On average measured bacteria counts in the both NGM and GM buildings are below recommended limits of 500 CFU /$m^3$ (Figure 28), with GM buildings having on average lower counts. The World Health Organization recommends bacteria and fungi counts in offices to be lower than 300 CFU/$m^3$ (WHO 1988). If compared with these stricter criteria, bacteria and fungi count in 50% of GM buildings meets these criteria but only 34% of NGM buildings meet them. As shown in (Table 24) bacteria counts in all GM buildings were below the recommended limits of CFU/m3 (Table 24). In case of NGM buildings two buildings had bacteria counts above the limit of 500 CFU/$m^3$. The highest count observed for bacteria was 658±453 CFU/$m^3$ in NGM buildings and 412±399 CFU/$m^3$ for the GM buildings. For fungi, it was 273±91 CFU/$m^3$ and 88±62 CFU/$m^3$ as measured respectively in the NGM and GM buildings. Figure 28 shows that bacteria and fungi measured in the breathing zone were higher than in the air vent.

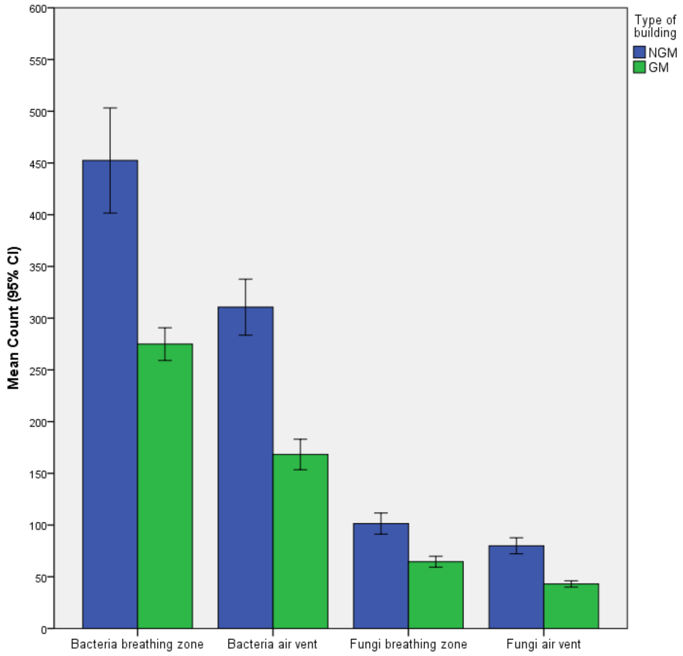



**Figure 28- Average counts of bacteria and fungi in GM and NGM buildings**

| | | Bacteria breathing zone | Bacteria air vent | Fungi breathing zone | Fungi air vent |
|---|---|---|---|---|---|
| **NGM1** | MEAN + SD (cfu/m³) | 658±453 | 381±199 | 137±86 | 110±65 |
| **NGM2** | | 272±146 | 246±187 | 46±21 | 38±27 |
| **NGM3** | | 191±77 | 187±177 | 85±52 | 72±69 |
| **NGM4** | | 543±351 | 408±213 | 110±106 | 85±55 |
| **NGM5** | | 391±231 | 247±189 | 107±55 | 77±34 |
| **NGM6** | | 370±222 | 148±40 | 273±91 | 199±188 |
| **GM7** | | 293±201 | 133±23 | 37±23 | 40±42 |
| **GM8** | | 161±113 | 169±30 | 60±30 | 53±34 |
| **GM9** | | 371±188 | 137±62 | 88±62 | 64±55 |
| **GM10** | | 229±132 | 134±23 | 43±23 | 34±31 |
| **GM11** | | 412±399 | 115±30 | 81±30 | 22±18 |
| **GM12** | | 329±129 | 97±49 | 85±49 | 46±36 |

**Table 24 – Average bacteria and fungi count measured in each of the 12 investigated buildings**

### 4.2.5 CO and formaldehyde

According to WHO 0,1 mg/m$^3$ is the recommended upper limit for the short-term (30 minutes) indoor formaldehyde concentrations (WHO 2010). The value represented as the upper limit in SS554:2009 (Singapore Standards 2009) adopted by the Green Mark Scheme is 0,120 mg/m$^3$ (0,1 ppm) (8 hours). Carbon monoxide has a recommended upper limit of 9 ppm in SS554:2009 (Singapore Standards 2009).

| | | CO (ppm) | HCHO (ppm) |
|---|---|---|---|
| NGM1 | MEAN + SD | 1,8±0,2 | 0,02±0,00 |
| NGM2 | | 1,8±0,2 | 0,01±0,01 |
| NGM3 | | 1,9±0,1 | 0,04±0,01 |
| NGM4 | | 2,0±0,2 | 0,03±0,00 |
| NGM5 | | 1,8±0,2 | 0,03±0,01 |
| NGM6 | | 1,9±0,2 | 0,02±0,01 |
| GM7 | | 2,1±0,1 | 0,06±0,01 |
| GM8 | | 2,3±0,3 | 0,03±0,01 |
| GM9 | | 2,0±0,1 | 0,03±0,01 |
| GM10 | | 2,5±0,2 | 0,02±0,01 |
| GM11 | | 1,7±0,2 | 0,02±0,01 |
| GM12 | | 2,1±0,2 | 0,04±0,01 |

**Table 25 – Average measured concentrations of CO and HCHO in NGM and GM buildings.**

Both CO and formaldehyde have been measured to have concentrations below recommended upper limits; this is the case for both types of buildings (Table 25). NGM buildings had on average CO concentrations of 1,9 ppm, ranging between a minimum of 1,8 ppm and a maximum of 2 ppm. GM buildings had on average CO concentration of 2,1 ppm, ranging between a minimum of 1,9 ppm and a maximum of 2,5 ppm. Concentration of formaldehyde in NGM buildings was on average 0,03 ppm, ranging between a minimum of 0,01 ppm and a maximum of 0,04 ppm ppm. In GM buildings concentration of formaldehyde was on average 0,03 ppm, ranging between a minimum of 0,02 ppm and a maximum of 0,06 ppm.

### 4.2.6 Atmospheric Pollution

#### 4.2.6.1 PSI

The occurrence of outdoor pollution peaks during the week of measurements (e.g. Haze) could overshadow the overall performance, so ambient pollution was observed and monitored during measurements in buildings. Pollutant standard index (PSI) is used in Singapore as a measure of outdoor pollution and it was used for this purpose. It is a weighted result of measurements of ambient concentration of sulphur dioxide, $PM_{10}$, $PM_{2.5}$, nitrogen dioxide, carbon monoxide and ozone (NEA 2014). It is calculated on (24-hour) basis.

PSI data showed no significant differences in ambient pollution during the weeks of measurements (Table 26). The average PSI during the weeks of measurements in NGM buildings was 62 and in the GM buildings it was 64. The total average PSI for all weeks of measurements was 66 (Table 26). This according to qualification of the ambient air quality in Singapore falls into the category of moderate pollution conditions (NEA 2014). However, as mentioned above PSI is an integrated index resulting from measurements of several pollutants and the pollutant with the highest concentration is used to set the PSI. So even if the PSI is same it may be a result of e.g. high level of ozone or PM2.5. Thus PSI data should only be used in the context as indicative but are not able to inform whether composition of pollutants during the measurements was different or the same.

| Building | NGM1 | NGM2 | NGM3 | NGM4 | NGM5 | NGM6 | GM7 | GM8 | GM9 | GM10 | GM11 | GM12 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PSI | 72,6 | 70,6 | 71,7 | 67,8 | 45,1 | 45,2 | 77,4 | 62,9 | 78,3 | 66 | 40,2 | 56,6 | 66,3 |

Table 26-Average PSI indicating the level of ambient pollution during measuring weeks; average is calculated from Monday to Thursday between 9:00-12:00 and13:00 to 17:00)

PSI was on a higher side between 45 to about 80 for all measuring weeks, so the outdoor air quality is considered poor, as by NEA guidelines (NEA 2014) PSI levels should be below 50 to be considered good outdoor air quality.

#### 4.2.6.2 Ultrafine Particles

PM2.5 concentrations are lower in GM buildings compared with NGM buildings. In NGM buildings (Table 27) the average concentration of PM2.5 was 42 μg/m3 with a minimum of 31 μg/m$^3$ and a maximum of 65 μg/m$^3$. In GM buildings (Table 27) the average concentration of PM2.5 was 29 μg/m3 with a minimum of 11 μg/m$^3$ and a maximum of 40 μg/m$^3$.

In SS554:2009 (Singapore Standards 2009), used by the Green Mark Scheme, the recommended concentration for PM2.5 is 35 μg/m$^3$ (8 hours), but for example in LEED V4 (USGBC n.d.) for commercial interior the recommendation is set to 15 μg/m$^3$ (4 hours). In all NGM buildings but one $PM_{2.5}$ was above 35 μg/m$^3$ and in the case of GM buildings 50% of the buildings were above this level (Table 27). All values were obtained by the measurements using light scattering principles, so absolute values and comparisons with the recommended upper limits, should be taken carefully. Unless the measurements are done using gravimetric methods, which are highly costly, there is a high uncertainty. This has been documented before (Morawska et al. 2013). For a relative comparison between buildings, measuring light scattering measurements are acceptable.

| | PM2.5 (MEAN ± SD) (μg/m$^3$) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | NGM 1 | NGM 2 | NGM 3 | NGM 4 | NGM 5 | NGM 6 | GM7 | GM8 | GM9 | GM 10 | GM 11 | GM 12 |
| PM2.5 | 46,5 ±2,4 | 64, 7±2,5 | 44,0 ±1,9 | 44,5 ±3,0 | 42,3 ±4,2 | 30,9 ±0,7 | 39,7 ±1,4 | 27,6 ±4,1 | 40,5 ±6,7 | 38,1 ±7,0 | 19,0 ±6,8 | 11,0 ±0,9 |

**Table 27 – Average PM2.5 concentration in the 6 NGM and 6 GM office buildings measured using light scattering methods**

On average GM buildings fulfill recommendations of SS554:2009 (Singapore Standards 2009) in the Green Mark Scheme which is not the case with the NGM buildings, but as explained values were obtained through light scattering methods. The important result is that the concentrations of PM2.5 are lower in GM buildings.

### 4.2.7 Illuminance

Lighting is commonly rated poorly in green buildings as was observed in the literature review, chapter 2. Lighting as an influence on well-being, satisfaction and productivity of office workers (Veitch et al. 2011; Borisuit et al. 2015; Baron et al. 1992). EN 12464-1 (CEN 2003) standards for interior illuminance recommend for writing, typing, reading, data processing in offices, illuminance levels not inferior to 500 lux on the working plane and the uniformity factor of illuminance not inferior to 0,6 (CEN 2003). In Singapore the SS 531-1 (Singapore Standard 2006) standard recommends also 500 lux but a uniformity of 0,7(Singapore Standard 2006).

In the Green Mark Building Illuminance levels are to be complied with SS531/CP 38 (Singapore Standard 2006). Daylight sensors may give points under Green Mark Scheme: existing buildings and new construction, but as a feature to improve energy use of artificial lighting.

Table 28 shows average measured illuminance levels in the 12 buildings, Table 29 workstation light uniformity while Table 30 the open plane illuminance uniformity. On average NGM buildings have an indoor lighting level of 524 lux and GM buildings 473 lux (Table 28), the latter is slighty lower than the recommended 500 lux. In the NGM buildings (Table 28) 4 buildings had average lighting levels below 500 lux, but none below 300 lux. In GM buildings (Table 28) also four buildings had average lighting levels below 500 lux. One GM building had actually lighting levels below 300 lux. For uniformity factors, the value on average for NGM buildings is 0,6 while in GM buildings is 0,7 (Table 29). Three GM buildings (50%) were below the recommend value of 0,7 but only one below 0,6. In case of NGM buildings four buildings (66%) had values below 0,7 but only two below 0,6. Light uniformity on the open plane is not included in the Green Mark Scheme, but was also calculated and presented in Table 30. On average for the open plan in the NGM buildings the light uniformity factor was 0,65 and for the GM buildings it was 0,67; they were not different from each other.

| | MEAN + SD | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | NG M1 | NG M2 | NG M3 | NG M4 | NG M5 | NG M6 | GM7 | GM8 | GM9 | GM 10 | GM 11 | GM 12 |
| Illuminance (lux) | 413± 73 | 427± 119 | 410± 178 | 748± 197 | 399± 86 | 751± 210 | 624± 139 | 657± 169 | 388± 136 | 452± 92 | 456± 98 | 264 ±83 |

**Table 28 – Average lighting levels measured in the 12 office buildings**

| | Average uniformity factor of illuminance - Workstation area | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | NGM1 | NGM2 | NGM3 | NGM4 | NGM5 | NGM6 | GM7 | GM8 | GM9 | GM10 | GM11 | Gm12 |
| Zone 1 | 0,80 | 0,54 | 0,60 | 0,69 | 0,72 | 0,27 | 0,59 | 0,79 | 0,47 | 0,84 | 0,84 | 0,74 |
| Zone 2 | 0,90 | 0,70 | 0,54 | 0,76 | 0,60 | 0,53 | 0,69 | 0,80 | 0,73 | 0,79 | 0,59 | 0,51 |
| Zone 3 | 0,67 | 0,56 | 0,48 | 0,71 | 0,52 | 0,77 | 0,85 | 0,73 | 0,53 | 0,54 | 0,36 | 0,53 |
| Zone 4 | 0,69 | 0,69 | 0,60 | 0,72 | 0,86 | 0,54 | 0,63 | 0,77 | 0,67 | 0,60 | 0,36 | 0,68 |
| Zone 5 | 0,84 | 0,60 | | 0,73 | | | 0,87 | 0,60 | 0,82 | 0,79 | | 0,78 |
| Average | **0,78** | **0,62** | **0,55** | **0,72** | **0,68** | **0,53** | **0,73** | **0,74** | **0,64** | **0,71** | **0,54** | **0,65** |

**Table 29 - Workstation illuminance uniformity factor measured in the 12 buildings**

| Average uniformity factor of illuminance in the open plan office | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| NGM1 | NGM2 | NGM3 | NGM4 | NGM5 | NGM6 | GM7 | GM8 | GM9 | GM10 | GM11 | Gm12 |
| 0,79 | 0,79 | 0,58 | 0,73 | 0,50 | 0,29 | 0,72 | 0,66 | 0,76 | 0,77 | 0,77 | 0,60 |

**Table 30 - Average open plane illuminance uniformity measured in the 12 buildings**

## 4.3 Survey

The survey in this project was typical of what is considered a post occupancy evaluation (POE). Two of the tenants from the NGM building group (NGM2 and NGM3) moved to a brand new GM building after the survey had been completed and the measurements will also be performed there in the future after the move and will be part of a different report. POEs are common method to measure users' satisfaction, expectations and health within the building, helping improving future regulations and designs (Hadjri & Crozier 2009; Nicol & Roaf 2005). Post-occupancy surveys are featured in the Green Mark Scheme for office interior version and credited for their execution and corrective actions.

In the present work the respondents rated the conditions in the offices, their perceptions and symptoms as experienced “Now” (at the moment of completing the survey) and “Overall” (i.e. how the experienced them in general when in the building not necessarily at the moment of completion of the survey). There were generally no considerable differences in the statistical model results which used responses for “now” and “overall”; the only difference was for temperature and lighting. When comparing mean ratings of perceptions, satisfaction and importance in GM and NGM buildings there were some small differences as seen in Figure 29 but correlation between “Now” and “Overall” responses were highly significant with R square values of 0,98 and 0,99, suggesting that the differences were negligible. Only in case of NGM buildings there were some small differences in the importance for personal space, window view, personal control and temperature as seen in Figure 29; these differences were more in absolute values but not trends in the results. Since there is nearly no seasonality in Singapore and weather conditions are fairly constant, it is likely that what is considered as “Now” responses reflects also “Overall” ratings, or basically this is what can be expected because of fairly constant weather conditions. Furthermore the high correlation between the two can be also caused because the respondent responded to each of them one after another starting first with the “Overall” (Figure 9). Consequently, only responses for “Overall” have been used as the major reference for comparing the buildings and are presented in the result section. Responses and analyses for “Now” are presented in appendix C for reference.

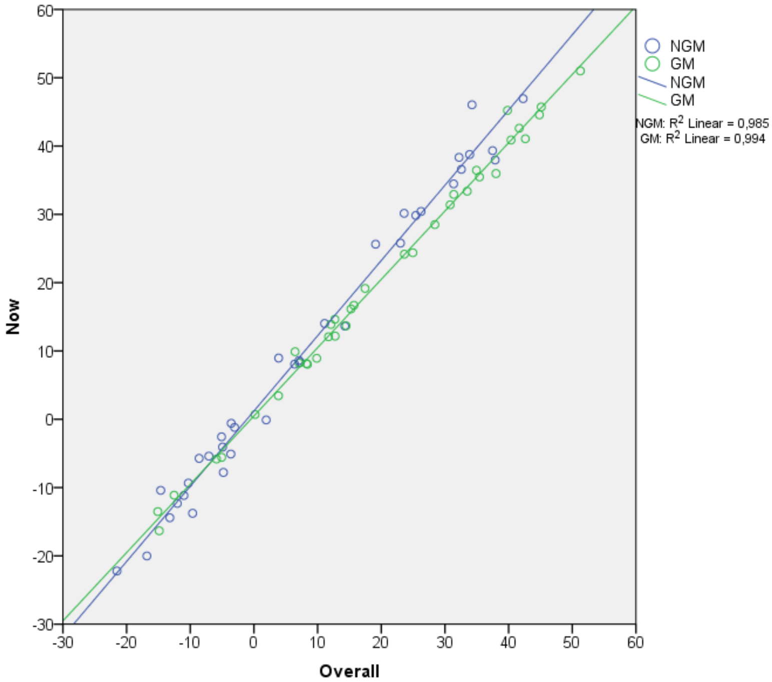



**Figure 29 – Comparison between "Overall" and "Now" mean values for perception, satisfaction and importance. R square represented for NGM and GM buildings**

### 4.3.1 Survey response rate

Initially the objective was to obtain a convenience sample of at least 30 respondents per building. Table 31 shows the response rate to the survey. Last column indicates the total number of participants who have completed 100% of both the questionnaire and the performance games. Only those respondents who fully completed questionnaire or survey are used on the analyses. Those who did not respond to all questions were not used to keep the sample clean of any biases that could be caused by the fact that the questionnaire was not fully completed such as lack of concentration, misunderstanding etc. The rejected survey results is about 30% of the total population. 100% completion was also used for the games, as it is again unknown the reasons for the missing data and may indicate less concentration performing the games. This creates a selection bias because only motivated respondents or respondents that wanted to express their dissatisfaction or satisfaction with the environmental conditions are included in the sample.

From the initial objective of 30 complete responses per building for questionnaire and games, technically there is only one office building (NGM2) that that fulfils this objective (Table 31). In the questionnaire seven buildings can be considered to fulfill the requirement (GM10 and GM12 did not reach 30 but are close to). In case of games fewer responses were received than from the questionnaire. All in all the response rate can be considered as acceptable and typical for this types of studies (>70%).

| | RATING | QUESTIONNAIRE NUMBER STARTED | COMPLETED 100% | Response rate | GAME REPORT (Performance) NUMBER STARTED | D2 | Nodes | Memory | COMPLETED 100% (3 games) | Response rate | TOTAL (100%) Questionnaire & Game completed |
|---|---|---|---|---|---|---|---|---|---|---|---|
| NGM1 | Non-Green Mark | 48 | 34 | 71% | 29 | 24 | 23 | 22 | 20 | 69% | 20 |
| NGM2 | | 57 | 39 | 68% | 35 | 34 | 33 | 30 | 30 | 86% | 30 |
| NGM3 | | 14 | 8 | 57% | 8 | 6 | 8 | 8 | 6 | 75% | 6 |
| NGM4 | | 33 | 23 | 70% | 29 | 21 | 22 | 21 | 20 | 69% | 20 |
| NGM5 | | 21 | 13 | 62% | 18 | 11 | 13 | 12 | 10 | 56% | 10 |
| NGM6 | | 23 | 17 | 74% | 19 | 14 | 14 | 14 | 14 | 74% | 14 |
| GM7 | Green Mark | 47 | 41 | 87% | 38 | 33 | 30 | 29 | 28 | 74% | 28 |
| GM8 | | 53 | 33 | 62% | 33 | 29 | 28 | 28 | 28 | 85% | 28 |
| GM9 | | 50 | 31 | 62% | 24 | 24 | 19 | 19 | 19 | 79% | 19 |
| GM10 | | 33 | 27 | 82% | 32 | 27 | 25 | 25 | 25 | 78% | 25 |
| GM11 | | 27 | 18 | 67% | 24 | 17 | 17 | 17 | 16 | 67% | 16 |
| GM12 | | 39 | 29 | 74% | 24 | 17 | 20 | 19 | 14 | 58% | 14 |
| | | 445 | 134/179 Total = 313 | 70% | 313 | | | | 100/130 Total = 230 | 72% | |

Table 31- Survey response rate

### 4.3.2 Respondent demographics data

Figure 30, Figure 31 and Figure 32 summarize information about the respondents. In NGM buildings there was a younger workforce (age group <30). In GM the main age group was 31-40 years old. The difference is significant as observed by Pearson chi square (P<0,000). Age should then be considered as a potential confounder.

Gender has an equal distribution in both groups with no differences between NGM and GM buildings. Despite it was considered as a potential confounder because many studies show differences in responses of females and males, females responding more critically to environmental conditions and responding with more symptoms (Rasche et al. 2001).

More than 90% of respondents were living in Singapore for more than a year. Professional was the category with the highest percentage of respondents followed by administrative. Around 80% of respondents in the GM buildings and 70% in the NGM buildings were working in the building for more than one year. Around 15% of respondents in the GM buildings and 30% in the NGM buildings were working in their building less than one year. The difference was shown to be significant as seen by Pearson chi square (P<0,016).

Most of the respondents in both types of buildings spent between five and ten hours a day in their offices, and between three to five days a week. Most of respondents in GM and NGM buildings had a sedentary work routine or a mix of seated and standing working positions. Around 10% respondents in NGM buildings and 3% in GM buildings consider themselves to be highly active. The difference is significant as seen by Pearson chi square (P<0,013).

Health demographics of respondents did not show significant differences between respondents working in GM and NGM buildings. Around 12% of respondents in both types of building wear contact lens. Only 5% respondent informed that they smoke.

Respondents in both NGM and GM buildings reported to be more sensitive to air quality (around 30%) and temperature and noise (around 20%) (Figure 31).

Respondents in GM buildings sit farther to the office entrance (25%) then in the NGM buildings (35%) closer to the printing areas (48%) than in the NGM buildings (38%) and closer to the lounge areas (15%) compared with NGM buildings (2%); the differences are significant (P<0.05).

Most respondents in GM and NGM buildings are between 2 to 5 meters from the window to outside. 10% of respondents in the NGM buildings reported that they could operate windows against 0% in GM buildings, both values being very low. 42% of respondents in GM buildings reported that they could operate blinds against only 20% in NGM buildings. 10% of NGM buildings respondents reported that they could modify temperature settings against 1% in GM buildings. All above differences are significant by Pearson chi square with P<0,000.

Only age and gender were tested as confounders for adjustment on the results, as they are commonly addressed as confounders (Mcnamee 2003). In initial crude analyses individual adjustments for the other four significant parameters described above were performed, without any significant influence on the observed results, so was decide not to adjust for these four parameters as there is also a risk of overfitting (Zhang 2014; Hawkins 2004)

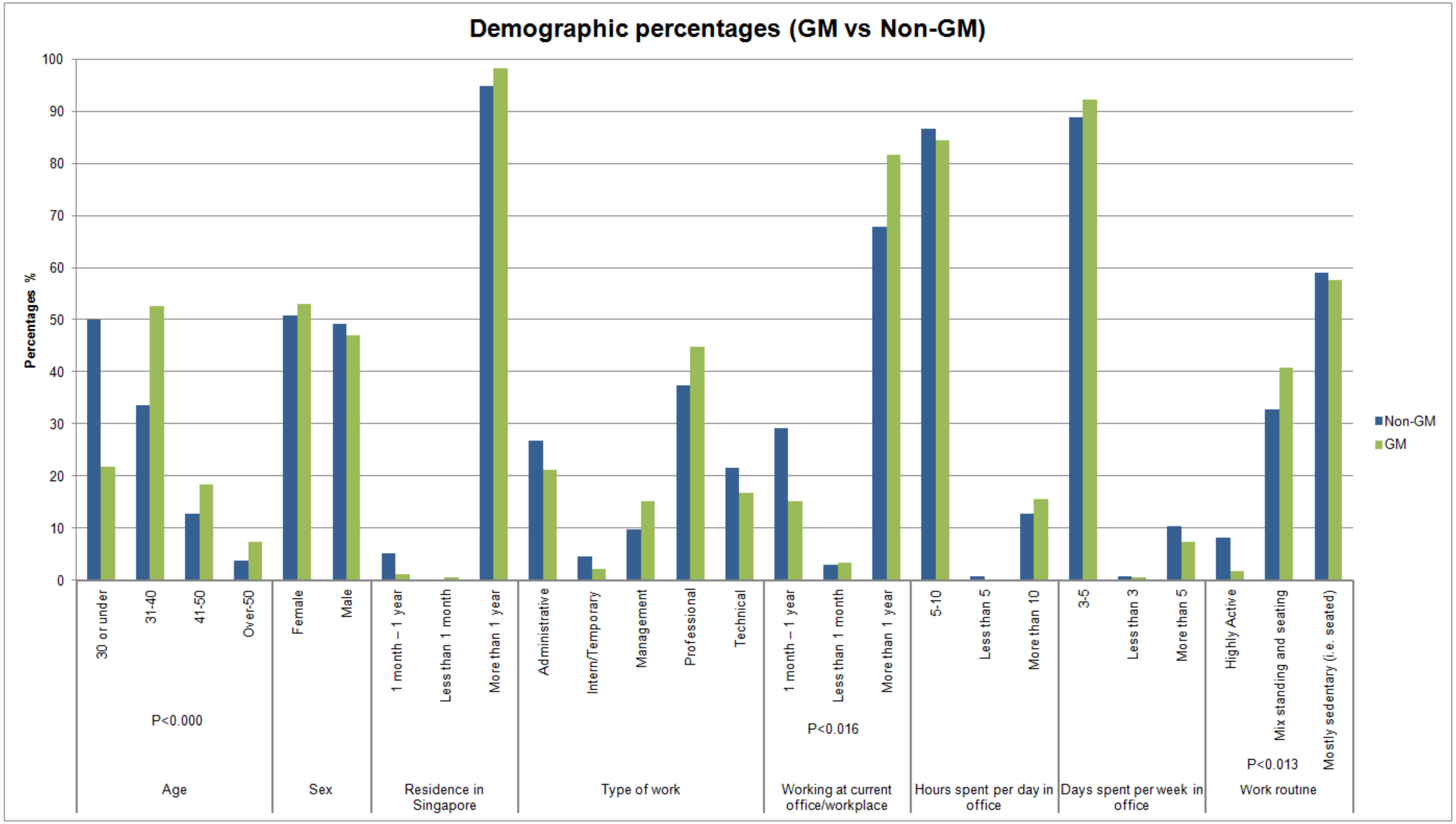



**Figure 30 – Demographics of respondents part 1. P values represented for significant differences (age, workplace seniority and work routine)**

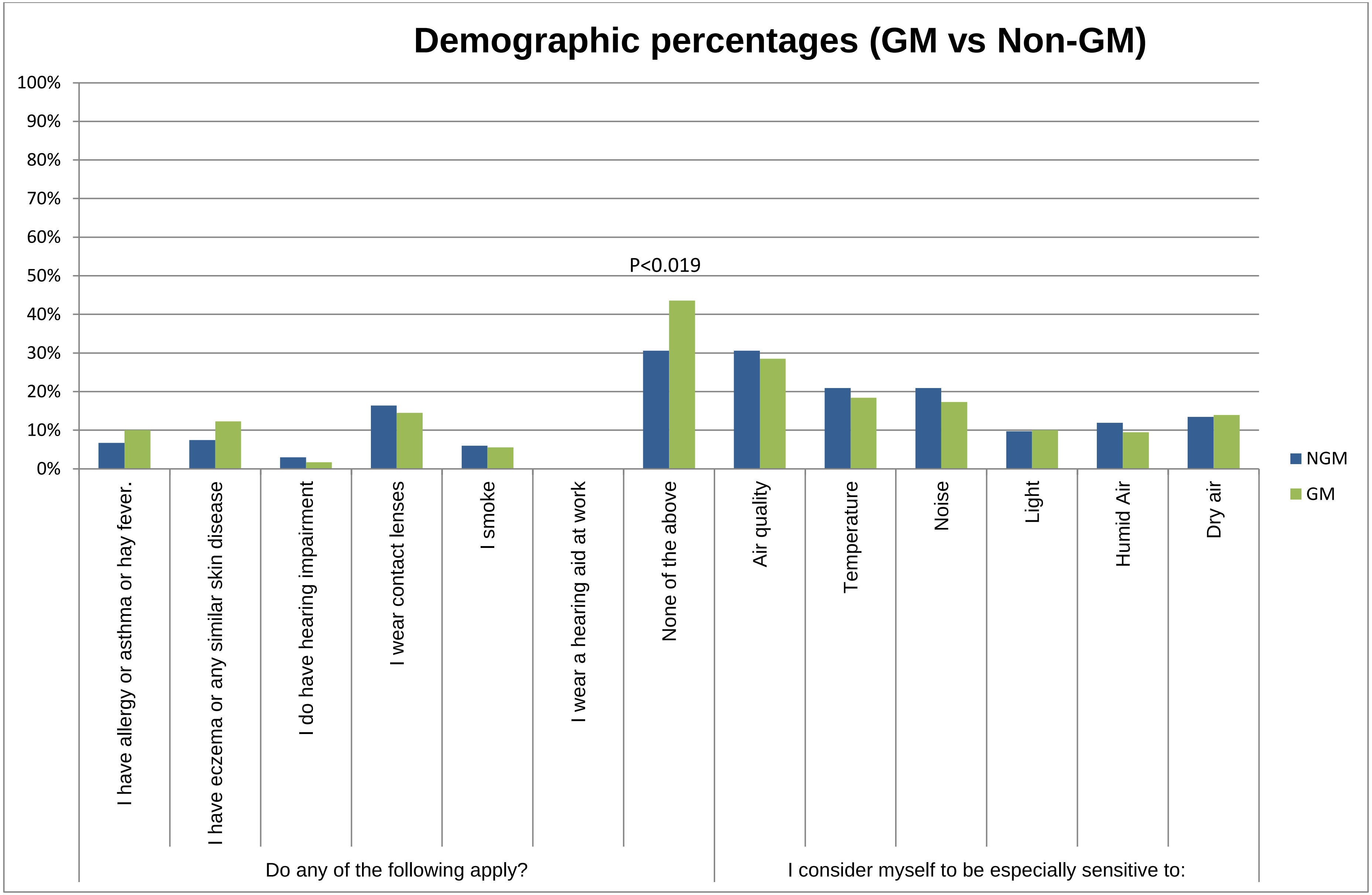



**Figure 31 – Demographics of respondents part 2. P values represented for significant differences**

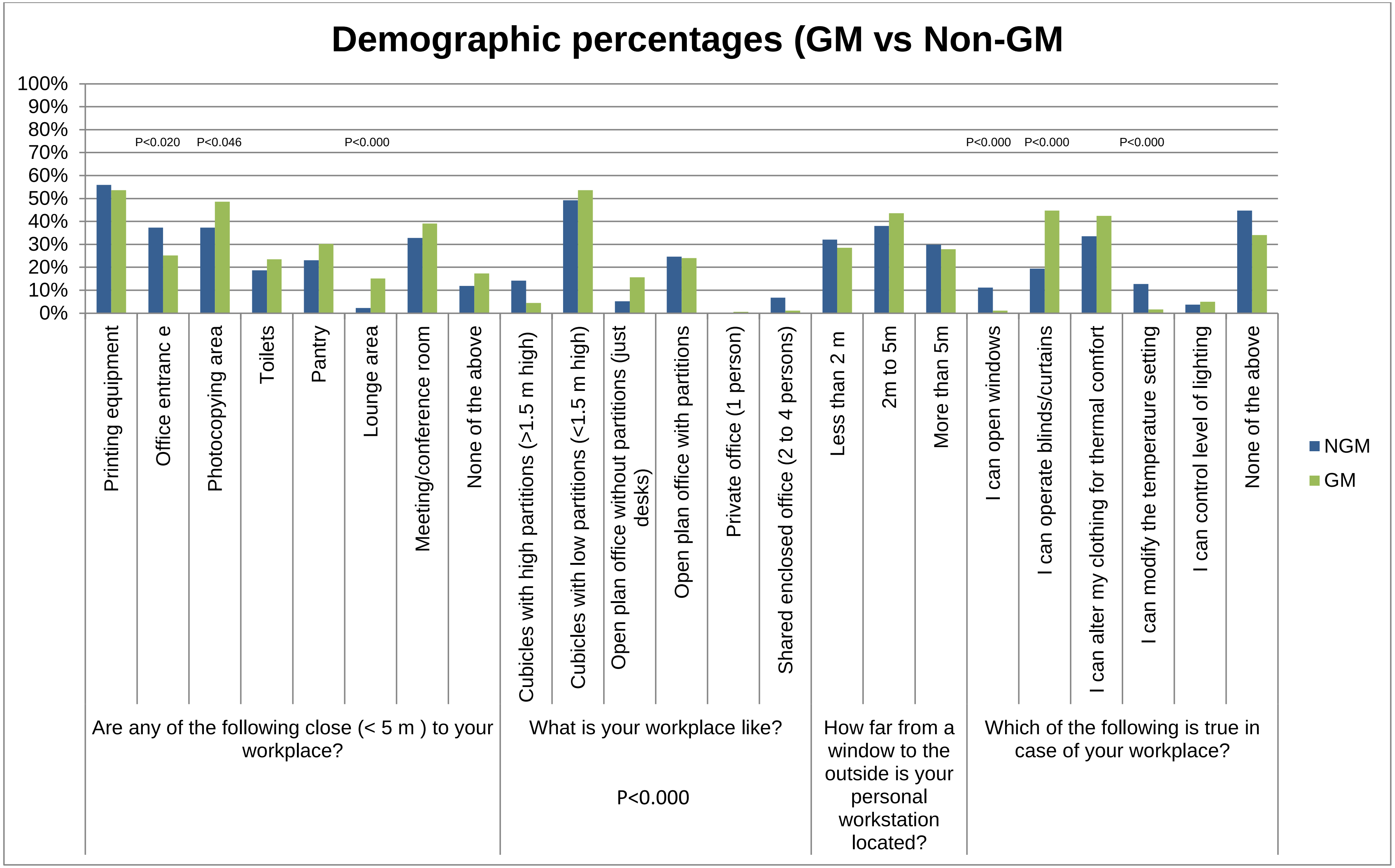



**Figure 32 – Demographics of respondents part 3. P values represented for significant differences (distance to entrance, photocopying area and lounge area; also significant differences workplace type)**

### 4.3.3 Questionnaire results for satisfaction, importance and perception,

Data for GM and NGM buildings was grouped by occupants for both types of buildings unless stated otherwise.

The continuous variables in the survey follow normal distribution, observed by their Skewness and kurtosis values, and so it was decided to show the central tendencies by presenting mean values.

Central tendencies for individual IEQ parameters satisfaction are presented in Figure 33. The results of statistical models are presented in Table 32 and Table 33. All results showed better satisfaction in GM buildings (Figure 33). All IEQ parameters in GM buildings were voted on the positive side of the scale i.e the occupants were satisfied with these parameters; this was except of sound privacy, which was voted to be not positive (they were not satisfied with it) and visual privacy which was voted on average neutral i.e. neither were they satisfied nor dissatisfied with it (Figure 33). Amount of personal space had the highest satisfaction in GM buildings, following by lighting and view while lighting had the highest satisfaction in NGM buildings, followed by visual comfort and daylight. These three ratings in NGM buildings are the only ones with which the occupants in NGM buildings were satisfied with (Figure 33). The occupants in NGM buildings were most dissatisfied with air quality, view and sound privacy.

In Table 32 statistical results are presented for the hierarchical nested model. The hierarchical statistical model applied provides very conservative estimates of the effects, where each category is considered to have a sampling of six building as representative of Singapore GM and NGM buildings; the model takes into account the sampling strategy and the way the data was collected assuming that buildings selected are randomly sampled from the whole population of NGM and GM buildings in Singapore. The model shows that compared with the occupants of buildings that have not received Green Mark certification (NGM buildings) the occupants of buildings which received Green Mark certification (GM buildings) are more significantly satisfied with personal space, personal control, window view, humidity, lighting and air quality. These effects are significant ($P<0,05$) or reaching statistical significance ($P<0,10$) in the hierarchical crude analyses without adjusting for confounders (Table 32). All results presented are unadjusted. The confounders tested were age and gender but were non-significant in the model. Results for adjusted for age and gender for satisfaction, importance and perceptions can be observed in appendix D.

There are large differences within the buildings classified as either having or not having Green Mark certificate (Table 32). These buildings were treated as random variables, as they were intended to represent a family of buildings in the hierarchical model used for analysis and so, these differences should be considered with caution at that macro level analysis, buildings being treated as random sample from the building stock. These analyses showed that there are significant differences between buildings within each category as regards the satisfaction with these parameters, and imply the need for even bigger sample in the future experiments. At the same time this indicates how conservative the hierarchical model is and how strong the results provided by the model are.

Air quality had the worst satisfaction score in NGM buildings (Figure 33) and the difference between GM and NGM buildings showed that this difference was statistically significant (Table 32). On aggregate across all continuous scales for satisfaction coded from -100 to +100, the average satisfaction in GM buildings is 13 while in NGM buildings is -3.

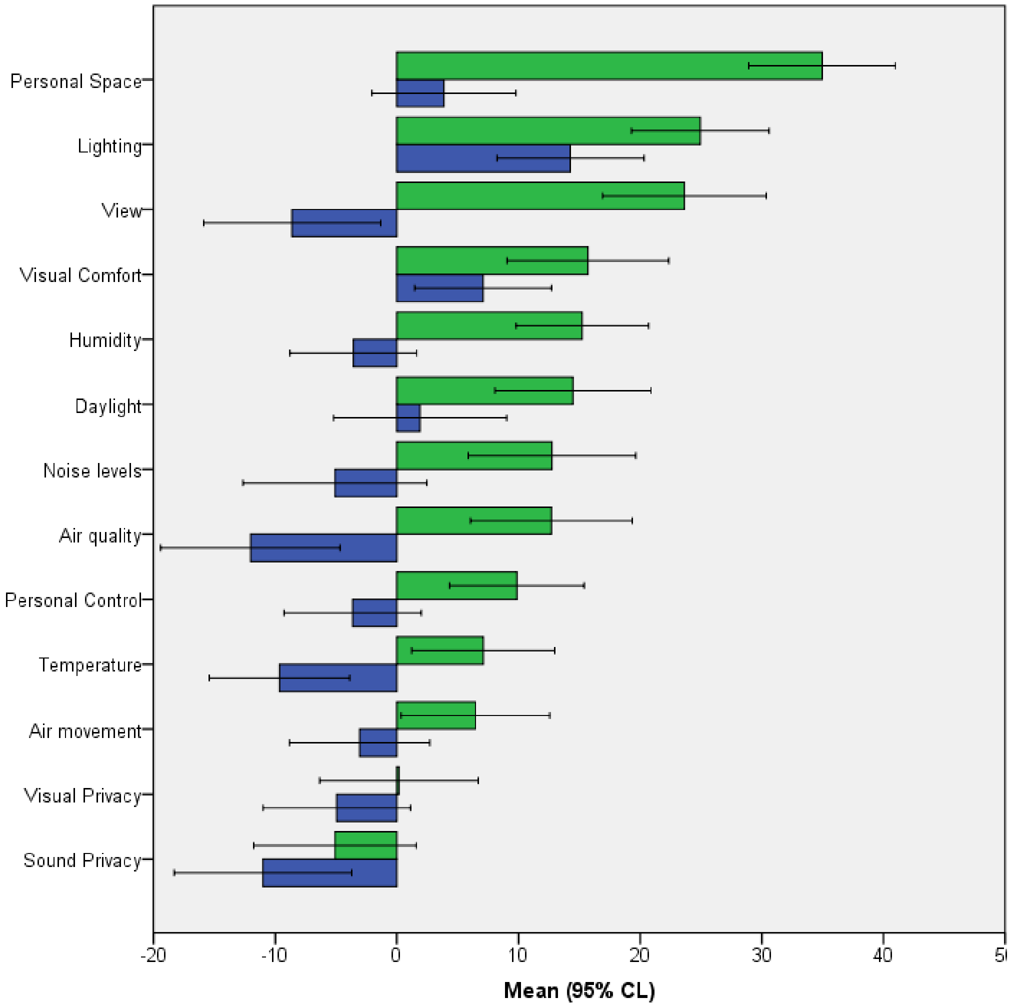



**Figure 33 – Satisfaction with IEQ parameters. Green bars represent mean satisfaction values in GM buildings with 95% confidence intervals. Blue bars represent mean satisfaction values in NGM buildings with 95% confidence intervals**

| Hierarchical model - Mixed Model | Between Green Mark and Non Green Mark (Includes random effect) | | | Between buildings within same category (Nested under Type) | | |
|---|---|---|---|---|---|---|
| **Satisfaction** | F | Sig. | Partial Eta Squared | F | Sig. | Partial Eta Squared |
| Personal space | 15,289 | **,002** | ,569 | 2,765 | **,003** | ,084 |
| Windows view | 5,195 | **,044** | ,329 | 7,075 | **,000** | ,190 |
| Personal control | 4,014 | **,067** | ,243 | 1,799 | ,060 | ,056 |
| Temperature | 2,936 | ,114 | ,208 | 3,694 | **,000** | ,109 |
| Air movement | 1,083 | ,320 | ,089 | 3,887 | **,000** | ,114 |
| Humidity | 8,645 | **,013** | ,427 | 2,728 | **,003** | ,083 |
| Lighting | 3,794 | **,076** | ,245 | 2,640 | **,004** | ,081 |
| Daylight | 2,249 | ,162 | ,169 | 4,068 | **,000** | ,119 |
| Visual comfort | 2,048 | ,178 | ,144 | 2,096 | **,025** | ,065 |
| Visual privacy | ,830 | ,380 | ,063 | 1,880 | **,048** | ,059 |
| Air quality | 5,352 | **,041** | ,328 | 4,541 | **,000** | ,131 |
| Noise levels | 1,606 | ,231 | ,126 | 3,917 | **,000** | ,115 |
| Sound privacy | ,005 | ,944 | ,000 | 4,272 | **,000** | ,124 |

**Table 32 – Results of GLMM for satisfaction with IEQ parameters. Bold numbers are significant (P<0.05) and red reaching significance (P<0.10). The results are unadjusted. The column showing the results for the difference between buildings WITHIN the same category (the last three columns) should be considered with caution as the buildings are random variable in the model. Partial Eta square shows the explanatory power of the model (comparable to R square) and F is the F –statistics from the model.**

Large variations within building type (column 5) in Table 32 where there is significant variation to all parameters except personal control clearly shows that the difference that can be attributed to the building category is only for few dimensions, where although there is a big variance between buildings, satisfaction in green mark as a group still score significantly higher. This represents strong evidence that GM buildings have better perceived satisfaction.

When Fisher's Least Significant Difference, a less conservative model, is performed where buildings are not randomly assigned to each category (GM vs NGM buildings) most of the differences between GM and NGM buildings are significant (P<0,05) (Table 33). Only air movement, visual privacy and sound privacy did not show significant differences (P>0,05) between GM and NGM buildings. The mean differences (GM-NGM) represented in LSD are estimated using marginal means, i.e. adjusted for individual building means. The results are somewhat similar to last three columns of Table 32.

| Satisfaction | (LSD) Pairwise Comparisons (GM - NGM) Weighted by Building | | | | |
|---|---|---|---|---|---|
| | Mean Difference (GM-NGM) | Std. Error | Sig. | 95% Confidence Interval for Difference | |
| | | | | Lower Bound | Upper Bound |
| Personal space | 28,8 | 4,698 | **,000** | 19,5 | 38,0 |
| Windows view | 28,6 | 5,113 | **,000** | 18,5 | 38,6 |
| Personal control | 11, 5 | 4,449 | **,010** | 2,8 | 20,2 |
| Temperature | 13,9 | 4,521 | **,002** | 5,0 | 22,8 |
| Air movement | 8,9 | 4,631 | ,057 | -0,3 | 17,9 |
| Humidity | 19,3 | 4,211 | **,000** | 10,9 | 27,6 |
| Lighting | 13,7 | 4,569 | **,003** | 4,7 | 22,6 |
| Daylight | 14,5 | 5,142 | **,005** | 4,4 | 24,6 |
| Visual comfort | 9,9 | 5,002 | **,049** | 0,0 | 19,7 |
| Visual privacy | 6,1 | 5,067 | ,232 | -3,9 | 16,0 |
| Air quality | 24,2 | 5,292 | **,000** | 13,8 | 34,7 |
| Noise levels | 12,9 | 5,501 | **,020** | 2,0 | 23,7 |
| Sound privacy | 0,7 | 5,298 | ,891 | -9,7 | 11,2 |

**Table 33 – Results of LSD for satisfaction with IEQ parameters. Bold numbers are significant (P<0.05). The results are unadjusted. Mean differences between GM and NGM buildings with 95% confidence interval are presented.**

Central tendencies for individual ratings of importance of IEQ parameters importance are represented in Figure 34. Statistical models results are also represented in Table 34 and Table 35. Importance is related to individual occupants' expectations and relative IEQ weightage. All IEQ parameters were judged by occupants of the buildings to have importance in GM and NGM buildings (Figure 34). All IEQ parameters were still judged to have higher importance for occupants in GM building compared to NGM buildings (Figure 34). Air quality and visual comfort are judged to be most important in GM buildings while in NGM buildings air quality and sound privacy are rated to be the most important. The following ratings of importance reached statistical significant difference (P<0.05) or were close to significant (P<0.10) between GM and NGM buildings: View from the window, Temperature, Humidity, Light, Daylight, Visual comfort and air quality (Table 34). The importance ratings can be interpreted to show that the occupants expect more from GM buildings and that their expectations are higher compared to the occupants in NGM buildings. On aggregate across all ratings of importance the average importance in GM buildings is 38 while in NGM buildings is 31 on the continuous scale from -100 to +100; this suggests also that IEQ parameters are of importance to occupants in NGM buildings which would also be expected as general pattern in the population.

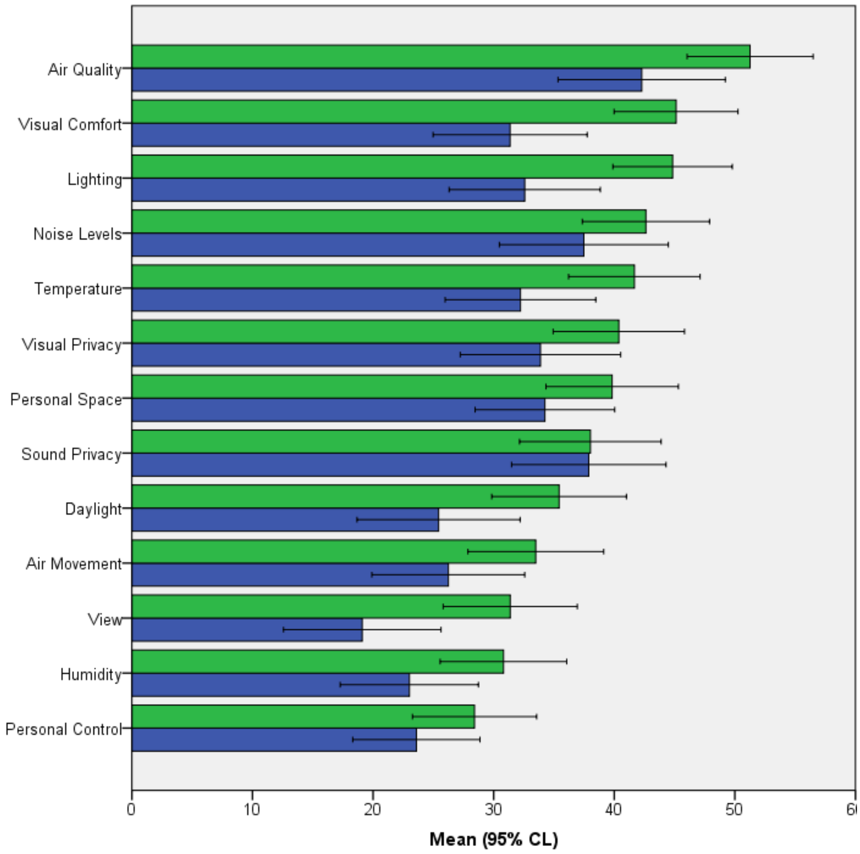



**Figure 34 – Importance of IEQ parameters. Green bars represent mean satisfaction values in GM buildings with 95% confidence intervals. Blue bars represent mean satisfaction values in NGM buildings with 95% confidence intervals**

| **Hierarchical model - Mixed Model** | **Between Green Mark and Non Green Mark (Includes random effect)** | | | **Between buildings within same category (Nested under Type)** | | |
|---|---|---|---|---|---|---|
| **Importance** | F | Sig. | Partial Eta Squared | F | Sig. | Partial Eta Squared |
| Personal space | 2,392 | ,145 | ,152 | 1,359 | ,199 | ,043 |
| Windows view | 6,057 | **,029** | ,322 | 1,637 | ,095 | ,052 |
| Personal control | 1,027 | ,330 | ,078 | 2,013 | **,032** | ,063 |
| Temperature | 4,880 | **,046** | ,278 | 1,696 | ,081 | ,053 |
| Air movement | 2,847 | ,115 | ,177 | 1,399 | ,180 | ,044 |
| Humidity | 4,211 | **,060** | ,236 | 1,273 | ,245 | ,041 |
| Lighting | 8,056 | **,015** | ,397 | 2,008 | **,032** | ,063 |
| Daylight | 4,475 | **,053** | ,243 | 1,174 | ,308 | ,038 |
| Visual comfort | 8,028 | **,015** | ,405 | 2,445 | **,008** | ,075 |
| Visual privacy | 2,803 | ,120 | ,193 | 2,523 | **,006** | ,077 |
| Air quality | 3,441 | **,089** | ,226 | 2,441 | **,008** | ,075 |
| Noise levels | 1,461 | ,249 | ,106 | 1,914 | **,043** | ,060 |
| Sound privacy | ,090 | ,770 | ,007 | 2,179 | **,019** | ,068 |

**Table 34 - Results of GLMM for importance with IEQ parameters. Bold numbers are significant (P<0.05) and red reaching significance (P<0.10). The results are unadjusted. The column showing the results for the difference between buildings WITHIN the same category (the last three columns) should be considered with caution as the buildings are random variable in the model. Partial Eta square shows the explanatory power of the model (comparable to R square) and F is the F –statistics from the model.**

When Fisher's Least Significant Difference, a less conservative statistical analysis, is performed (Table 35) where buildings are not randomly assigned to each category (GM vs NGM buildings), the importance of visual privacy also showed to be rated significantly different in GM buildings compared with the NGM buildings (P<0,05). Compared to the ratings of satisfaction with IEQ there is less variance between NGM and GM buildings, as can be also expected.

| Importance | (LSD) Pairwise Comparisons (GM - NGM) Weighted by Building | | | | |
|---|---|---|---|---|---|
| | Mean Difference (GM-NGM) | Std. Error | Sig. | 95% Confidence Interval for Difference | |
| | | | | Lower Bound | Upper Bound |
| Personal space | 7,9 | 4,499 | ,079 | -0,9 | 16,8 |
| Windows view | 14,4 | 4,736 | **,003** | 5,1 | 23,7 |
| Personal control | 5,7 | 4,130 | ,171 | -2,5 | 13,8 |
| Temperature | 12,7 | 4,594 | **,006** | 3,7 | 21,8 |
| Air movement | 9,2 | 4,727 | ,053 | -0,1 | 18,5 |
| Humidity | 9,9 | 4,364 | **,024** | 1,3 | 18,5 |
| Lighting | 16,7 | 4,341 | **,000** | 8,1 | 25,2 |
| Daylight | 11,0 | 4,858 | **,024** | 1,4 | 20,6 |
| Visual comfort | 18,6 | 4,436 | **,000** | 9,9 | 27,3 |
| Visual privacy | 11,7 | 4,656 | **,012** | 2,5 | 20,9 |
| Air quality | 12,8 | 4,655 | **,006** | 3,6 | 21,9 |
| Noise levels | 7,6 | 4,738 | ,111 | -1,7 | 16,9 |
| Sound privacy | 2,0 | 4,809 | ,674 | -7,4 | 11,5 |

**Table 35 - Results of LSD for importance with IEQ parameters. Bold numbers are significant (P<0.05). The results are unadjusted. Mean differences between Gm and NGM buildings with 95% confidence interval are presented.**

Perceptions of individual IEQ parameters are presented in Figure 35. Results of statistical models are also presented in Table 36 and Table 37. Only air quality was perceived to be statistically significantly different between GM and NGM buildings (p<0,05) in the hierarchical model (Table 36). In GM buildings occupants rated the air fresher compared with NGM buildings where the air was rated to be stuffy (Figure 35). Respondents rated that it was cold in both GM and NGM buildings and that the air was still. Air was rated to be dry in both types of buildings. Respondents rated that it was bright in both types of buildings. GM buildings were rated to have high level of daylight while NGM buildings were rated to have low level of daylight. Visual comfort was rated to be moderately good in both types of buildings. Visual and sound privacy were rated poor in both types of buildings. For noise levels, occupants in GM buildings rated their offices quiet while the occupants of NGM buildings rated their offices to be loud. All results can be seen in Figure 35.

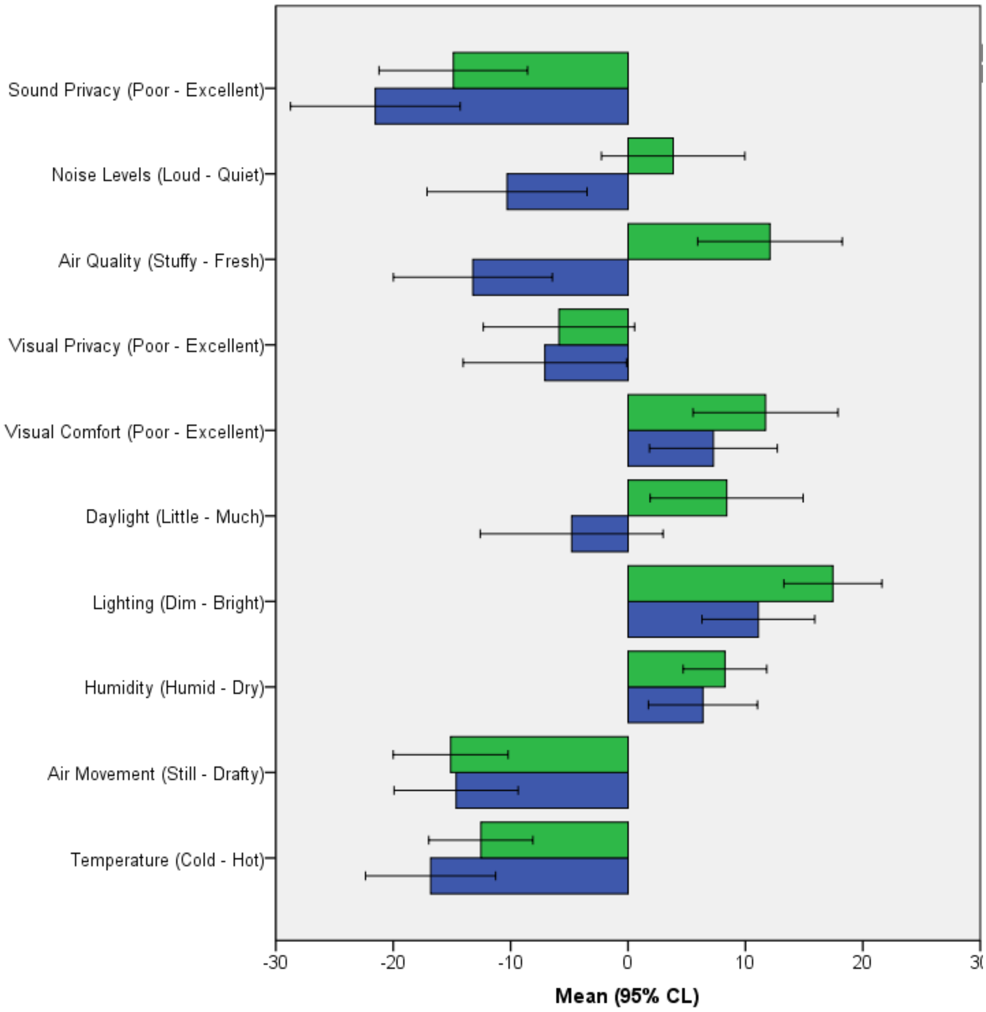



**Figure 35 – Perceptions of IEQ parameters. Green bars represent mean satisfaction values in GM buildings with 95% confidence intervals. Blue bars represent mean satisfaction values in NGM buildings with 95% confidence intervals**

| Hierarchical model - Mixed Model | Between Green Mark and Non Green Mark (Includes random effect) | | | Between buildings within same category (Nested under Type) | | |
|---|---|---|---|---|---|---|
| **Perception** | F | Sig. | Partial Eta Squared | F | Sig. | Partial Eta Squared |
| Temperature? | ,643 | ,439 | ,053 | 2,827 | **,002** | ,086 |
| Air movement | ,000 | ,984 | ,000 | 2,521 | **,006** | ,077 |
| Humidity | ,418 | ,529 | ,031 | 1,505 | ,136 | ,048 |
| Lighting level | 1,785 | ,208 | ,138 | 3,884 | **,000** | ,114 |
| Daylight | 1,014 | ,337 | ,088 | 8,297 | **,000** | ,216 |
| Visual comfort (e.g. glare) | ,600 | ,453 | ,047 | 2,003 | **,033** | ,062 |
| Visual privacy | ,208 | ,656 | ,016 | 1,683 | ,084 | ,053 |
| Air quality | 6,161 | **,031** | ,362 | 4,943 | **,000** | ,141 |
| Noise levels | 1,453 | ,252 | ,111 | 2,777 | **,003** | ,084 |
| Sound privacy | ,005 | ,944 | ,000 | 3,990 | **,000** | ,117 |

**Table 36 - Results of GLMM for perceptions with IEQ parameters. Bold numbers are significant (P<0.05) and red reaching significance (P<0.10). The results are unadjusted. The column showing the results for the difference between buildings WITHIN the same category (the last three columns) should be considered with caution as the buildings are random variable in the model. Partial Eta square shows the explanatory power of the model (comparable to R square) and F is the F –statistics from the model.**

When a less conservative analysis is performed, in which the buildings are not randomly assigned to each category, the ratings of lighting and daylight were additionally significantly different (p<0.05) between GM and NGM buildings (Table 37).

| | (LSD) Pairwise Comparisons (GM - NGM) Weighted by Building | | | | |
|---|---|---|---|---|---|
| | Mean Difference (GM-NGM) | Std. Error | Sig. | 95% Confidence Interval for Difference | |
| **Perception** | | | | Lower Bound | Upper Bound |
| Temperature | 4,8 | 3,817 | 0,205 | -2,7 | 12,4 |
| Air movement | -0,1 | 3,971 | 0,975 | -7,9 | 7,7 |
| Humidity | 2,5 | 3,192 | 0,442 | -3,8 | 8,7 |
| Lighting level | 8,4 | 3,41 | **0,015** | 1,7 | 15,1 |
| Daylight | 13,6 | 5,084 | **0,008** | 3,6 | 23,6 |
| Visual comfort (e.g. glare) | 4,9 | 4,709 | 0,296 | -4,3 | 14,2 |
| Visual privacy | 3,0 | 5,295 | 0,569 | -7,4 | 13,4 |
| Air quality | 24,9 | 4,857 | **0,000** | 15,3 | 34,4 |
| Noise levels | 9,5 | 5,002 | 0,059 | -0,4 | 19,3 |
| Sound privacy | 0,7 | 5,14 | 0,893 | -9,4 | 10,8 |

**Table 37 - Results of LSD for perceptions with IEQ parameters. Bold numbers are significant (P<0.05). The results are unadjusted. Mean differences between Gm and NGM buildings with 95% confidence interval are presented.**

Perceptions of the environment are most likely associated with satisfaction and importance of the IEQ parameters. This issue will be discussed later. For example, occupants were satisfied with the temperature in GM buildings but at the same time indicated that it was on a cold side which may be considered to be not acceptable, but for air quality there is a good match between satisfaction and perception where the respondents in GM building indicate higher satisfaction with fresher air whereas in NGM buildings they show low satisfaction with stuffy air.

#### *4.3.3.1 Overall IEQ and Sustainability*

Table 38 shows the results from the analyses concerning importance of working in sustainable building, overall satisfaction with IEQ and impact of IEQ on work performance. Occupants in Green Mark buildings indicated that it is more important for them to work in a sustainable office than those in NGM buildings have a higher interest in sustainability and higher overall satisfaction with IEQ and compared with the ratings of occupants in NGM building (Figure 36 and Figure 37). These differences were statistically significant (P<0,05) in the nested hierarchical model (Table 38).

| | Between Green Mark and Non Green Mark (Includes random effect) | | | Between buildings within same category (Nested under Type) | | |
|---|---|---|---|---|---|---|
| **Hierarchical model - Mixed Model (Overall)** | F | Sig. | Partial Eta Squared | F | Sig. | Partial Eta Squared |
| Importance to work in a sustainable office | 6,565 | **,023** | ,323 | 1,230 | ,271 | ,039 |
| Satisfaction with Indoor Environment | 13,305 | **,004** | ,537 | 2,977 | **,001** | ,090 |
| How Indoor Environment influences productivity (Positive – Negative) | 2,707 | ,126 | ,184 | 2,203 | **,018** | ,068 |

**Table 38 - Results of GLMM for for sustainability, overall IEQ and IEQ influence on productivity. Bold numbers are significant (P<0.05) and red reaching significance (P<0.10). The results are unadjusted. The column showing the results for the difference between buildings WITHIN the same category (the last three columns) should be considered with caution as the buildings are random variable in the model. Partial Eta square shows the explanatory power of the model (comparable to R square) and F is the F –statistics from the model.**

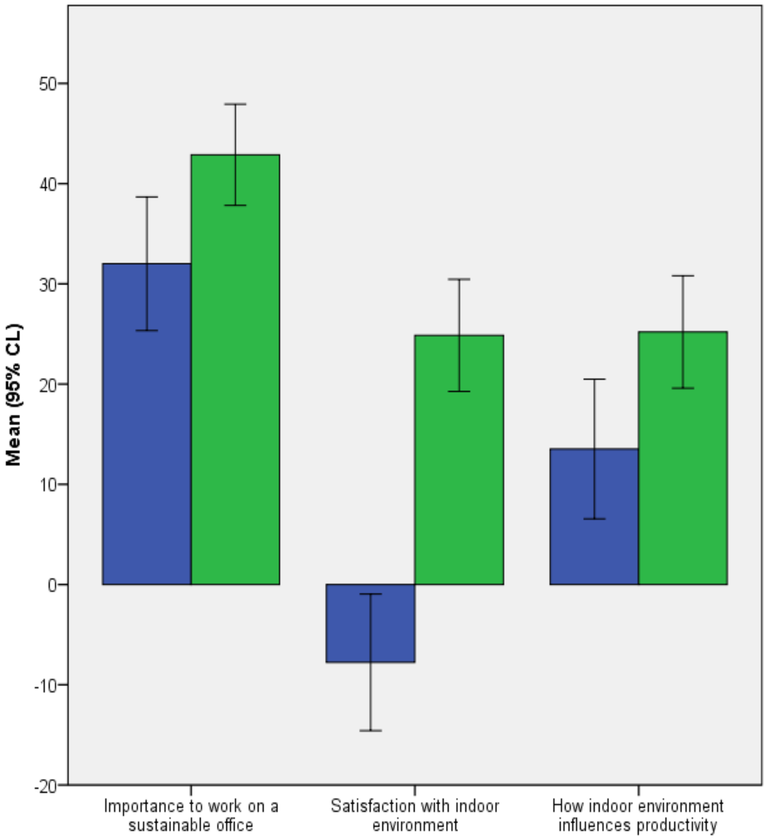



**Figure 36 – Mean values for sustainability, overall IEQ and IEQ influence on productivity. Green bars represent mean values in GM buildings with 95% confidence interval. Blue bars represent mean values in NGM buildings with 95% confidence interval**

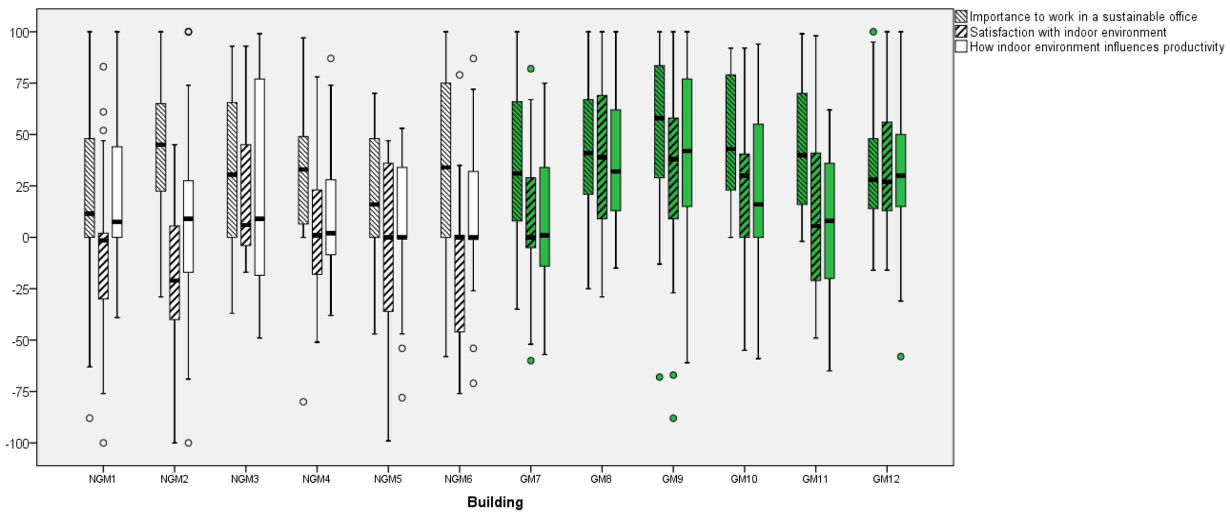



**Figure 37 – Box plots of awareness of sustainability, overall satisfaction with IEQ and influence of IEQ on performance of work in each building selected for the study**

Occupants in GM buildings showed that they were satisfied with overall satisfaction with IEQ while the occupants in NGM buildings were dissatisfied with IEQ (Figure 36). It is a significant indication that on overall level GM buildings perform better as to securing satisfaction with IEQ compared with NGM buildings. Additionally Figure 38 shows that there is a strong relationship between satisfaction with IEQ and the ratings on whether IEQ affects work performance both in NGM and GM buildings, as shown by fit curves with R squares of 0,1 and 0,4, respectively. The higher satisfaction the higher the perception that IEQ affects the performance.

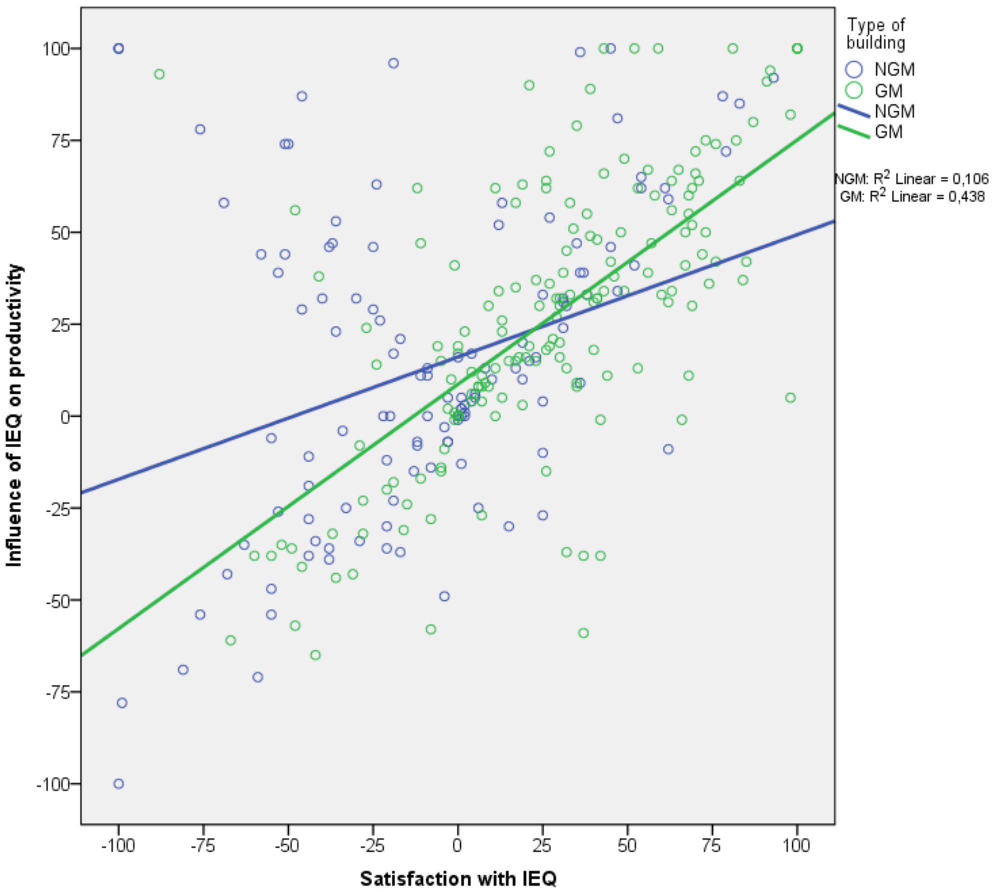



**Figure 38 – Ratings of the level of influence of IEQ on work performance as a function of overall satisfaction with IEQ**

Figure 39 shows that occupants working in GM buildings who are more sustainably conscious are more satisfied with overall IEQ; this is not the case with the occupants of NGM buildings, where there is no discernible relation. The R-square is only 0,1 for GM occupants, so the explanatory power is weak, and the relation more indicative of a trend, in which some occupants in GM buildings may potentially have a positive psychosocial effect on their responses for IEQ satisfaction.

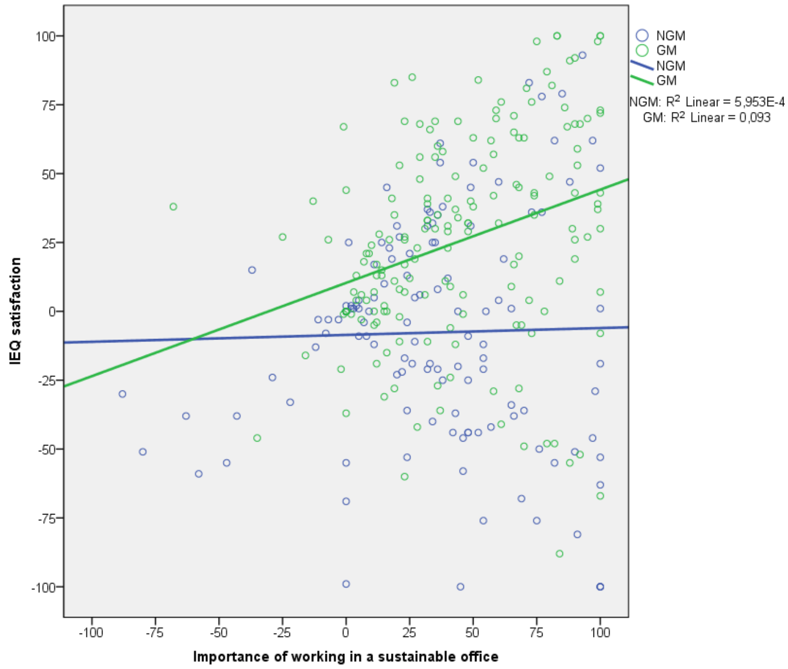



**Figure 39 – Overall satisfaction with IEQ as a function of importance of working in a sustainable office.**

In (Table 39) it is possible to observe the strength of association between satisfaction with individual IEQ parameters and with the overall IEQ satisfaction separately for GM and NGM buildings. Except satisfaction with humidity in NGM buildings (P>0,05), satisfaction with all other parameters is strongly and significantly correlated with overall satisfaction with IEQ. Visual comfort, air quality and daylight have the strongest correlation with the overall IEQ satisfaction (P<0,01) (Table 39) in GM buildings. While in NGM buildings air quality, visual privacy and noise levels have the strongest correlation.

| | | Pearson Correlation Overall IEQ Satisfaction | |
|---|---|---|---|
| | | NGM | GM |
| Satisfaction | **Personal Space** | **,339**** | **,440**** |
| | **Window view** | **,240**** | **,300**** |
| | **Personal Control** | **,325**** | **,448**** |
| | **Temperature** | **,291**** | **,391**** |
| | **Air movement** | **,371**** | **,471**** |
| | **Humidity** | -0,059 | **-,201**** |
| | **Light levels** | **,281**** | **,426**** |
| | **Daylight** | **,300**** | **,530**** |
| | **Visual comfort** | **,349**** | **,581**** |
| | **Visual Privacy** | **,476**** | **,361**** |
| | **Air quality** | **,557**** | **,557**** |
| | **Noise levels** | **,471**** | **,481**** |
| | **Sound Privacy** | **,454**** | **,461**** |

**Table 39 – Pearson correlation between overall IEQ satisfaction and IEQ parameters satisfaction (**P<0,01)**

Multiple stepwise linear regressions between physical parameters and overall satisfaction with IEQ and the results are presented in Table 40 and Table 41. These were made to examine which of the ratings of satisfaction with individual parameters have the highest impact on overall satisfaction with IEQ. Satisfaction with visual comfort, noise levels, daylight, air movement and personal control had a significant relationship predicting rated IEQ satisfaction in GM buildings (Table 40). In NGM buildings air quality, visual and sound privacy had a significant relationship predicting overall IEQ satisfaction (Table 41).

| | | Stepwise linear regression - **Satisfaction with IEQ in GM Bldgs.** | | | | | |
|---|---|---|---|---|---|---|---|
| | | **R Square = 0,589** | | | | | |
| | | Unstandardized Coefficients | | Standardized Coefficients | | Collinearity Statistics | |
| | | B | Std. Error | Beta | Sig. | Tolerance | VIF |
| **Satisfaction** | **Constant** | 12,363 | 2,023 | | ,000 | | |
| | **Visual comfort** | ,299 | ,046 | ,355 | ,000 | ,791 | 1,264 |
| | **Noise levels** | ,211 | ,044 | ,260 | ,000 | ,798 | 1,253 |
| | **Daylight** | ,199 | ,050 | ,229 | ,000 | ,709 | 1,410 |
| | **Air movement** | ,165 | ,051 | ,181 | ,001 | ,776 | 1,289 |
| | **Personal Control** | ,117 | ,057 | ,116 | ,042 | ,748 | 1,337 |

**Table 40 – Stepwise linear regression between satisfaction with IEQ and individual IEQ satisfaction in GM buildings**

| | | Stepwise linear regression - **Satisfaction with IEQ in NGM Bldgs.** | | | | | |
|---|---|---|---|---|---|---|---|
| | | **R Square = 0,448** | | | | | |
| | | Unstandardized Coefficients | | Standardized Coefficients | | Collinearity Statistics | |
| | | B | Std. Error | Beta | Sig. | Tolerance | VIF |
| **Satisfaction** | **Constant** | ,628 | 2,733 | | ,819 | | |
| | **Air quality** | ,352 | ,068 | ,381 | ,000 | ,787 | 1,270 |
| | **Sound Privacy** | ,264 | ,065 | ,283 | ,000 | ,885 | 1,130 |
| | **Visual Privacy** | ,254 | ,083 | ,226 | ,003 | ,776 | 1,289 |

**Table 41 - Stepwise linear regression between satisfaction with IEQ and individual IEQ satisfaction in NGM buildings**

#### *4.3.3.2 Percentages satisfied/dissatisfied with the conditions in buildings*

The ratings of satisfaction were analyzed differently by calculating the % dissatisfied with different IEQ parameters in GM and NGM buildings. Basically the number of votes that fell below neutral point on satisfaction scale were counted and divided by number of votes to calculate the % dissatisfied, and the reverse was done to calculate the % satisfied; those that voted on neutral were considered as undecided and their % was also calculated. The results are presented in Table 42. Same was done for the ratings of importance and the results are shown in Table 43. Generally more than 50% of occupants in GM buildings are satisfied with IEQ parameters (Table 42) with the exception of visual and sound privacy. In NGM buildings on average 30%-40% are satisfied with IEQ parameters. A higher percentage of occupants in NGM buildings are undecided as regards satisfaction with IEQ.

Importantly it is observed that in GM buildings:

- 30% were not satisfied with the amount of daylight.
- 33% were not satisfied with the levels of noise.
- 33% were not satisfied with the air quality.
- 37% were not satisfied with temperature.
- 38% were not satisfied with the air movement
- 48% were not satisfied with visual privacy
- 51% were not satisfied with sound privacy

| | Percentage (%) – Satisfaction | | | | | |
|---|---|---|---|---|---|---|
| | DISSATISFIED | | UNDECIDED | | SATISFIED | |
| | NGM | GM | NGM | GM | NGM | GM |
| Personal Space | 41,8 | 15,1 | 14,2 | 8,4 | 44,0 | **76,5** |
| Window view | 50,0 | 25,1 | 14,9 | 8,9 | 35,1 | 65,9 |
| Personal control | 44,8 | 31,8 | 20,1 | 11,7 | 35,1 | 56,4 |
| Temperature | 50,0 | 36,9 | 17,9 | 6,7 | 32,1 | 56,4 |
| Air movement | 41,0 | 38,0 | 16,4 | 9,5 | 42,5 | 52,5 |
| Humidity | 42,5 | 25,1 | 17,9 | 9,5 | 39,6 | 64,8 |
| Lighting level | 19,4 | 20,7 | 18,7 | 8,9 | **61,9** | 69,8 |
| Daylight | 38,8 | 29,6 | 14,9 | 8,9 | 46,3 | 61,5 |
| Visual comfort | 30,6 | 29,6 | 18,7 | 8,4 | 50,7 | 62,0 |
| Visual privacy | 44,8 | **47,5** | 17,9 | 7,8 | 37,3 | 44,1 |
| Air quality | **53,0** | 33,0 | 17,2 | 6,7 | 29,9 | 59,8 |
| Noise levels | 47,8 | 33,0 | 17,2 | 7,8 | 35,1 | 59,2 |
| Sound Privacy | 50,7 | 50,8 | 16,4 | 6,7 | 32,8 | 41,9 |
| Overall IEQ | 49,3 | 21,2 | 11,9 | 8,4 | 38,8 | 70,4 |

**Table 42 – Percentages of satisfied, undecided and satisfied with individual parameters of IEQ and overal IEQ in GM and NGM buildings**

On average 75% of occupants in NGM buildings and 85% of occupants in GM buildings considered IEQ parameters important (Table 43). Air quality is considered in GM buildings as important by the highest number of occupants (91%) while in NGM buildings noise had the highest percentage of occupants who considered it important (80%) (Table 43). A higher percentage of occupants in NGM buildings are undecided as regards importance of IEQ. Window view was considered unimportant by 22% of occupants in NGM buildings and 16% in GM buildings, being the highest percentage of people for whom IEQ parameters were not important.

| | Percentage (%) – Importance | | | | | |
|---|---|---|---|---|---|---|
| | NOT IMPORTANT | | UNDECIDED | | IMPORTANT | |
| | NGM | GM | NGM | GM | NGM | GM |
| Personal Space | 10,4 | 9,5 | 14,9 | 6,2 | 74,6 | 84,4 |
| Window view | **21,6** | **15,6** | 17,9 | 5,6 | 60,4 | 78,8 |
| Personal control | 16,4 | 15,1 | 14,2 | 6,7 | 69,4 | 78,2 |
| Temperature | 9,0 | 9,5 | 12,7 | 3,4 | 78,4 | 87,2 |
| Air movement | 12,7 | 12,8 | 13,4 | 4,5 | 73,9 | 82,7 |
| Humidity | 11,9 | 12,8 | 15,7 | 6,7 | 72,4 | 80,4 |
| Lighting level | 8,2 | 7,3 | 12,7 | 5,0 | 79,1 | 87,7 |
| Daylight | 14,2 | **15,6** | 14,2 | 5,0 | 71,6 | 79,3 |
| Visual comfort | 8,2 | 6,1 | 16,4 | 5,6 | 75,4 | 88,3 |
| Visual privacy | 11,2 | 8,9 | 12,7 | 5,0 | 76,1 | 86,0 |
| Air quality | 7,5 | 5,0 | 13,4 | 3,9 | 79,1 | **91,1** |
| Noise levels | 6,0 | 8,4 | 14,2 | 5,0 | **79,9** | 86,6 |
| Sound Privacy | 6 | 13,4 | 15,7 | 5,0 | 78,3 | 81,6 |
| Sustainability | 11,2 | 5,6 | 11,9 | 6,7 | 76,9 | 87,7 |

**Table 43 – Percentages of occupants for whom different IEQ parameters were important, not important or who were undecided as regards their importance in GM and NGM buildings**

### 4.3.4 Awareness of sustainability and energy-wise behavior

Figure 40 shows whether occupants were aware that they worked in the certified building. Only 63% of occupants in GM building knew that their offices were certified. 23% of occupants in NGM building thought, unexpectedly, that their offices were also certified (Figure 40).

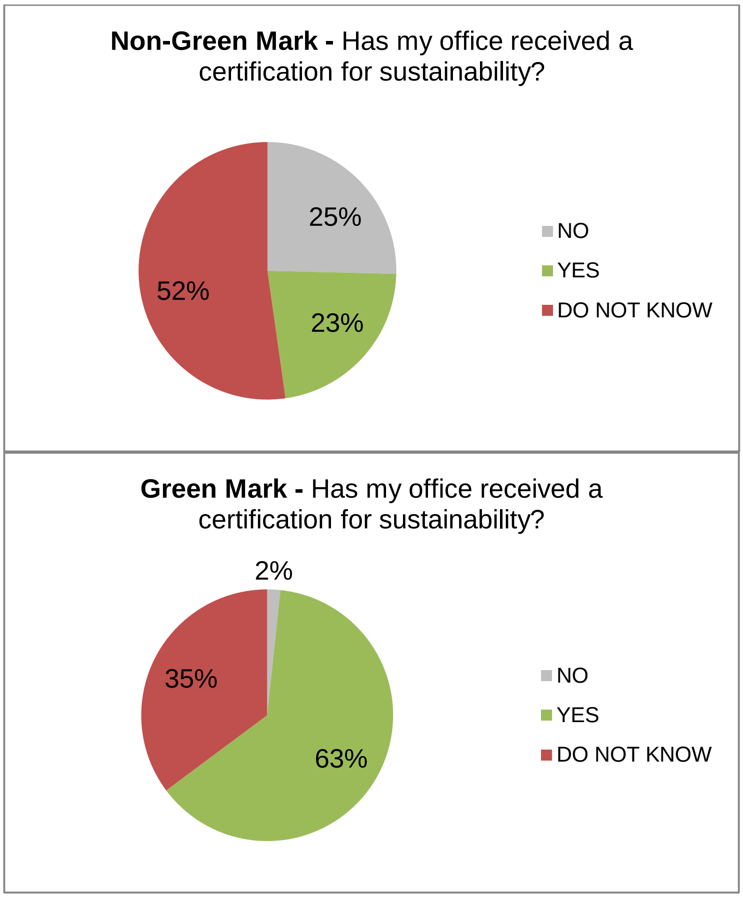



**Figure 40- Awareness of sustainability**

Figure 41 shows the energy behavior of occupants in GM and NGM buildings and Figure 42 whether occupants of these buildings would compromise IEQ to save energy. In GM buildings 93% of occupants compared with 84% in NGM attempt to save energy in their workplace (Figure 41). This difference is small but significant as determined by Pearson chi square ($P<0,05$) (Table 44). Slightly more than half of occupants in GM and NGM buildings would accept reductions in IEQ for energy savings (Figure 42). This value is higher in NGM buildings, which implies that occupants in GM buildings are more demanding as regards IEQ, but the difference does not reach statistical significance ($P>0,05$) (Table 44).

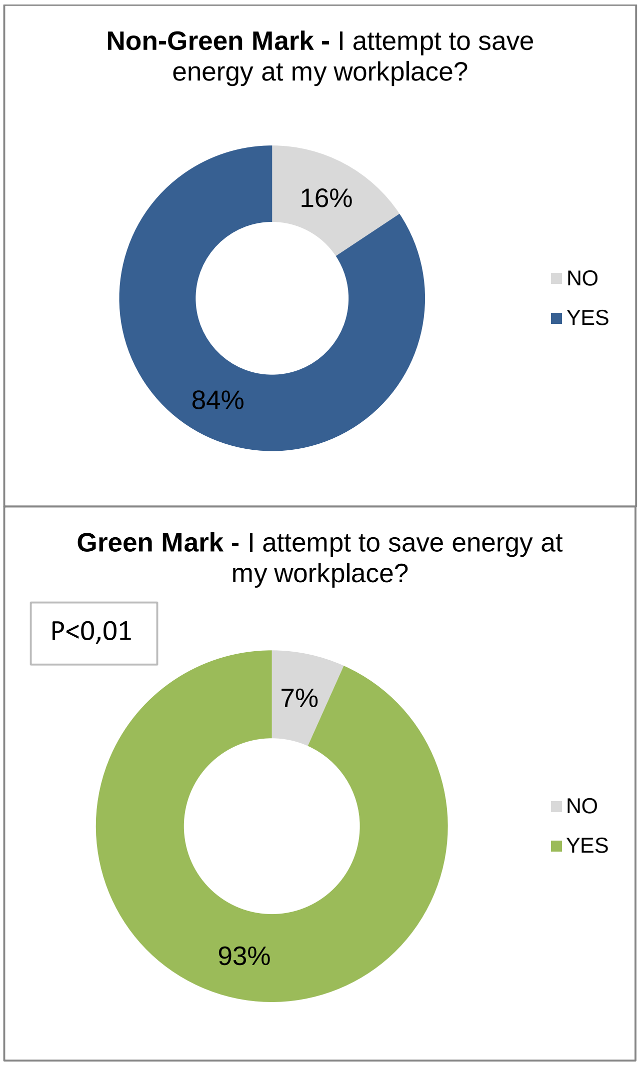



Figure 41 – Energy wise behavior

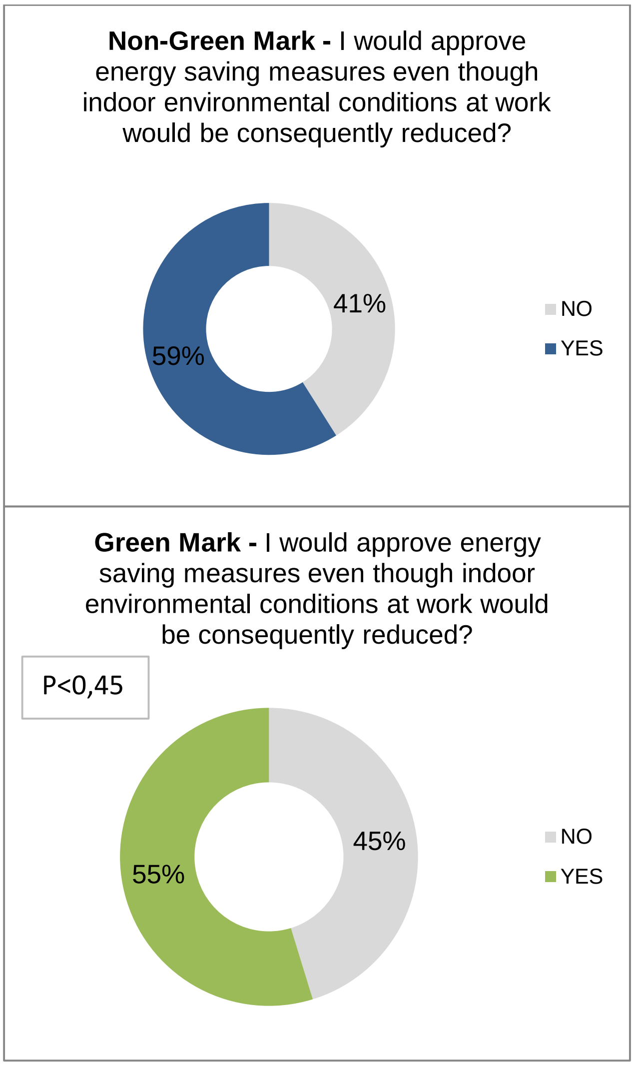



Figure 42 – Tolerance to compromise IEQ to save energy

In the second chapter of this thesis, in the literature review, the psychological effect of green buildings on occupants was observed in some studies, i.e. there is a chance that some occupants which know that they are working in green building may slightly be more tolerant and over report satisfaction and perceptions. In Figure 43 it is possible to observe that in the GM buildings for occupants that know their building is certified and also attempt to save energy there is around 10% more occupants with higher tolerance to compromise IEQ from the total population in GM, while in the case of GM building where the occupants did not know if their building was certified, for the occupants that attempt to save energy there is around 2% more occupants without tolerance to compromise IEQ for energy purposes,  which is a very small indicative difference.

| | Attempt to save energy | | Pearson chi square | Approval of energy saving measures even though IEQ would be reduced | | Pearson chi square |
|---|---|---|---|---|---|---|
| Type | NO | YES | | NO | YES | |
| NGM | 16% | 84% | **P<0,011** | 41% | 59% | P<0,458 |
| GM | 7% | 93% | | 45% | 55% | |

**Table 44 – Pearson chi-square test significance between NGM and GM for sustainability questions: Attempt to save energy and approval of energy savings.**

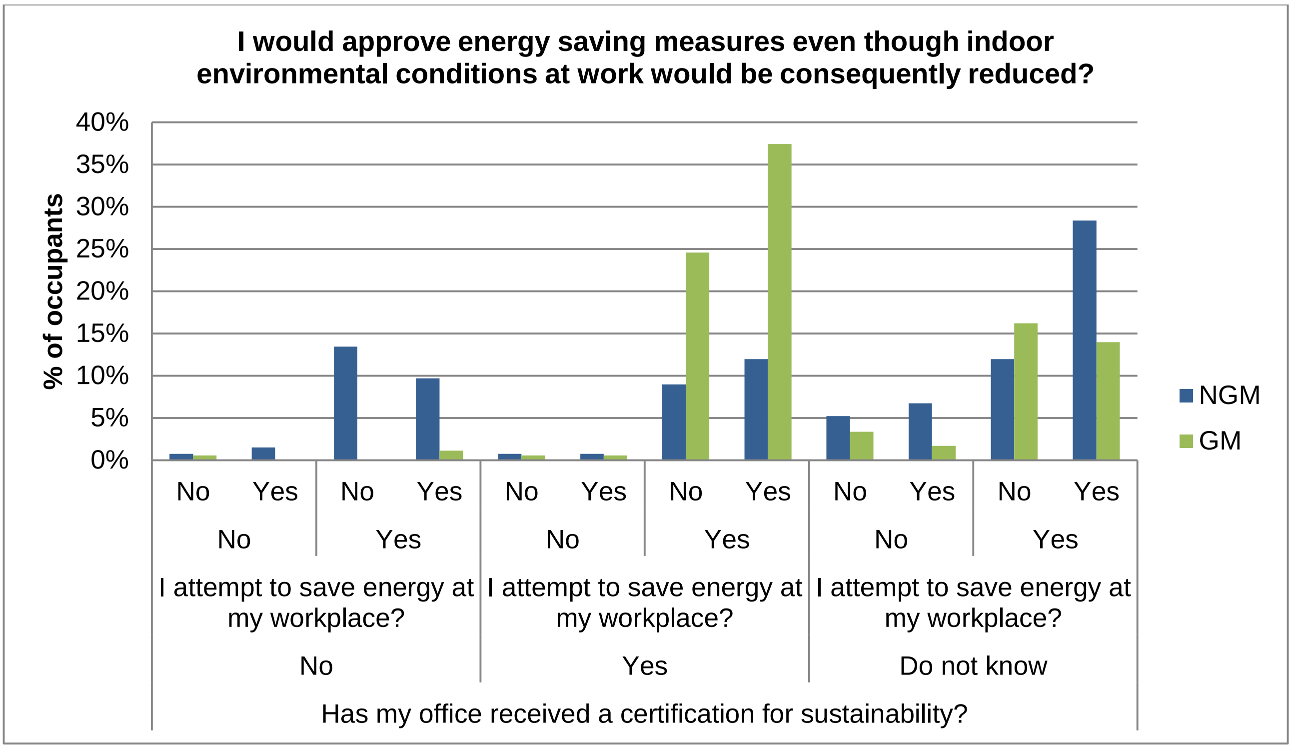



**Figure 43 – Sustainability cross-comparison. Nested chart of the three sustainability questions.**

### 4.3.5 Health – SBS

Sick building symptoms are first presented in descriptive form and subsequently through adjusted odds ratio modeling.

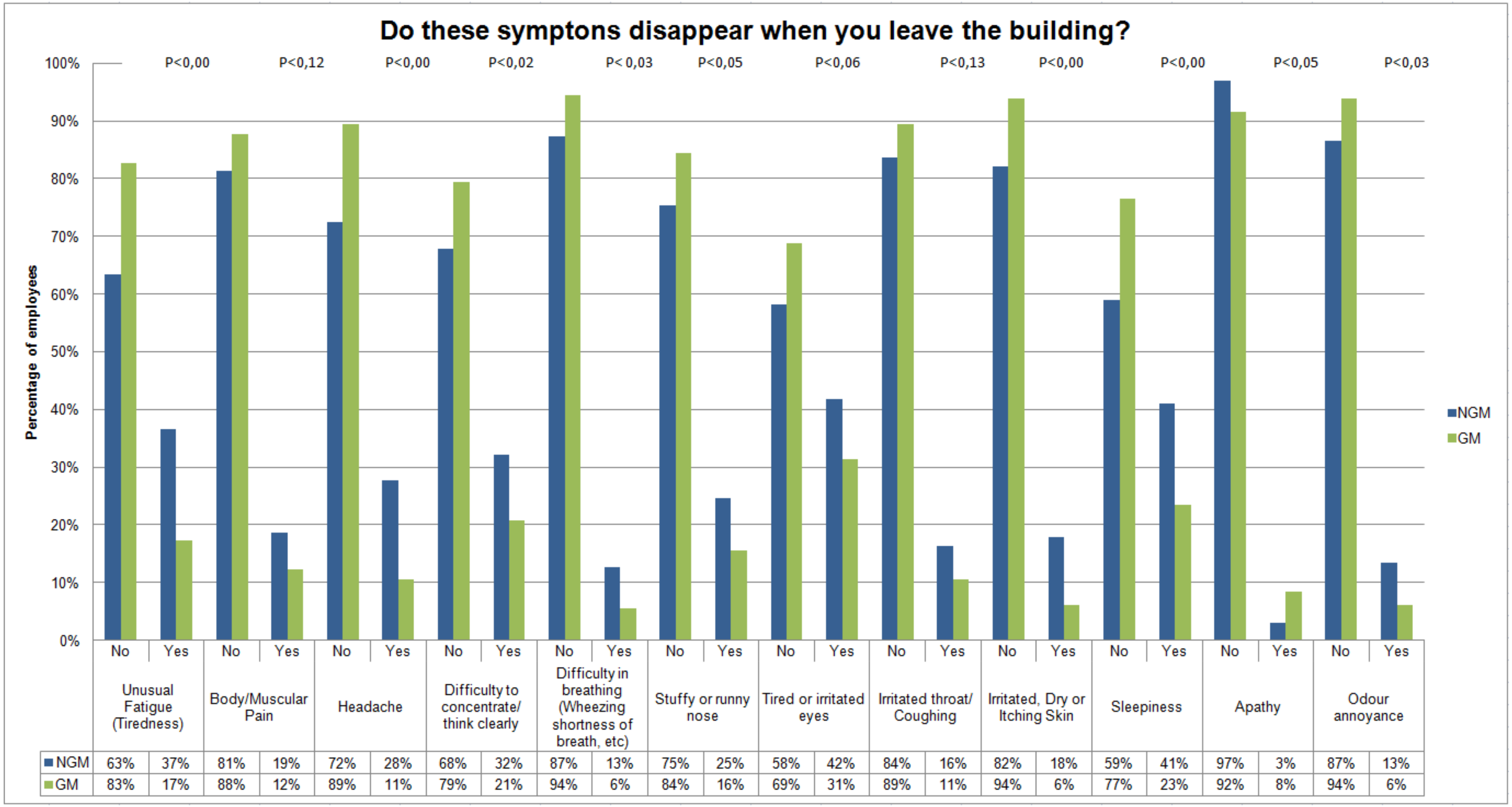
All symptoms, except apathy, have been observed in a crude analysis to have a higher prevalence among occupants of NGM buildings (Table 45) being on average 1,67 times higher compared with occupants in GM buildings. These however are not building related symptoms.

| Symptoms Prevalence | Yes | |
|---|---|---|
| | NGM | GM |
| Unusual Fatigue (Tiredness) | 57% | 29% |
| Body/Muscular Pain | 44% | 28% |
| Headache | 39% | 22% |
| Difficulty to concentrate/ think clearly | 40% | 28% |
| Difficulty in breathing (Wheezing shortness of breath, etc) | 16% | 7% |
| Stuffy or runny nose | 34% | 25% |
| Tired or irritated eyes | 59% | 44% |
| Irritated throat/ Coughing | 27% | 17% |
| Irritated, Dry or Itching Skin | 26% | 11% |
| Sleepiness | 58% | 36% |
| Apathy | 4% | 9% |
| Odour annoyance | 14% | 6% |

**Table 45 – Symptoms prevalence**

First occupants were asked if they had the symptom and in the case of a positive answer they were asked if the symptom disappeared when they leave the building. In Figure 44 the “no” composes the percentage of occupants without the symptom plus the percentage with chronic symptom, i.e. the symptom did not disappear when occupants leave the building. The results of interest in this study are symptom cases that disappear when occupants leave the building, as they are building related.

Figure 44 shows that SBS symptoms are more prevalent in NGM buildings. Among those symptoms prevalence of fatigue, headache, difficulty in concentrate, runny nose, tired eyes, sleepiness and odour annoyance was higher in NGM buildings compared with GM buildings. Crude analyses with Pearson chi square test showed that there was statistical significant difference between these symptoms in NGM and GM buildings ($P<0,05$). Apathy had higher prevalence in GM buildings compared with NGM buildings, the difference also being statistically significant in crude analyses ($P<0,05$). Irritated/tired eyes, sleepiness and difficulty in concentrate had the highest prevalence in GM buildings, slightly above 30% for tired eyes and slightly above 20% for the other two symptoms (Figure 44). In NGM buildings prevalence of fatigue, headache, difficulty to concentrate, runny nose, irritated eyes, sleepiness was above 20% (Figure 44). The lowest prevalence of symptoms in GM buildings was difficulty in breathing, apathy and odour annoyance. In NGM buildings, the lowest prevalence of building related symptoms were also the same (Figure 44).




| Symptom | Answer | NGM | GM |
|---|---|---|---|
| Unusual Fatigue (Tiredness) | No | 63% | 83% |
| | Yes | 37% | 17% |
| Body/Muscular Pain | No | 81% | 88% |
| | Yes | 19% | 12% |
| Headache | No | 72% | 89% |
| | Yes | 28% | 11% |
| Difficulty to concentrate/ think clearly | No | 68% | 79% |
| | Yes | 32% | 21% |
| Difficulty in breathing (Wheezing shortness of breath, etc) | No | 87% | 94% |
| | Yes | 13% | 6% |
| Stuffy or runny nose | No | 75% | 84% |
| | Yes | 25% | 16% |
| Tired or irritated eyes | No | 58% | 69% |
| | Yes | 42% | 31% |
| Irritated throat/ Coughing | No | 84% | 89% |
| | Yes | 16% | 11% |
| Irritated, Dry or Itching Skin | No | 82% | 94% |
| | Yes | 18% | 6% |
| Sleepiness | No | 59% | 77% |
| | Yes | 41% | 23% |
| Apathy | No | 97% | 92% |
| | Yes | 3% | 8% |
| Odour annoyance | No | 87% | 94% |
| | Yes | 13% | 6% |

**Figure 44 – Prevalence of health symptoms and inexistence of symptoms (no-columns in the chart) and building related symptoms (yes columns) in GM and NGM buildings. P values show whether difference in prevalence of building related symptoms (yes columns) between population of respondents working in GM and NGM buildings was statistically significant**

| | Prevalence of building related symptoms | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Building | | | | | | | | | | | |
| | NGM1 | NGM2 | NGM3 | NGM4 | NGM5 | NGM6 | GM7 | GM8 | GM9 | GM10 | GM11 | GM12 |
| Unusual Fatigue (Tiredness) | **26%** | **41%** | 13% | **43%** | **54%** | **35%** | **29%** | 18% | 16% | 19% | 11% | 3% |
| Body/Muscular Pain | 15% | 18% | 13% | 17% | **31%** | **24%** | **20%** | 6% | 6% | 15% | **28%** | 3% |
| Headache | 12% | **26%** | **25%** | **39%** | **31%** | **47%** | 10% | 9% | 6% | **26%** | 11% | 3% |
| Difficulty to concentrate/ think clearly | **21%** | **46%** | **25%** | 13% | **38%** | **47%** | **29%** | **24%** | 13% | **33%** | 11% | 7% |
| Difficulty in breathing (Wheezing shortness of breath, etc) | 9% | **18%** | 0% | 13% | 15% | 12% | 12% | 3% | 3% | 7% | 6% | 0% |
| Stuffy or runny nose | **24%** | **33%** | 0% | 9% | **38%** | **29%** | **29%** | 9% | 10% | **22%** | 17% | 3% |
| Tired or irritated eyes | **32%** | **41%** | **25%** | **39%** | **54%** | **65%** | **34%** | **27%** | **52%** | **44%** | 17% | 7% |
| Irritated throat/ Coughing | 18% | **26%** | 13% | 0% | 15% | 18% | 17% | 3% | 13% | 15% | 17% | 0% |
| Irritated, Dry or Itching Skin | 18% | **21%** | **25%** | 9% | **23%** | 18% | 15% | 3% | 3% | 7% | 6% | 0% |
| Sleepiness | **38%** | **59%** | 13% | **22%** | **23%** | **59%** | **41%** | 18% | **35%** | 11% | 17% | 7% |
| Apathy | 0% | 5% | **13%** | 4% | 0% | 0% | **20%** | 0% | 10% | 7% | 6% | 3% |
| Odour annoyance | 6% | 18% | 0% | 17% | **23%** | 12% | 2% | 0% | 10% | **15%** | 11% | 3% |

**Table 46 – Prevalence of building related symptoms in NGM and GM buildings**

Prevalence of building related "tired/irritated eyes" was the highest both for GM and NGM buildings (Table 46), e.g. GM9 building had more than half of the occupants complaining about "tired/irritated eyes". Prevalence of neurobehavioral symptoms was higher in NGM buildings compared to GM buildings. This higher prevalence of SBS symptoms in NGM buildings compared to GM buildings is similar to what has been observed in a previous study in Singapore (Tham et al. 2015). Another study in Singapore (Sekhar et al. 2003) in air conditioning offices also shown that "tired/irritated eyes" had the highest prevalence of all SBS symptoms.

Odds ratios (ORs) for building related SBS symptoms were calculated with a binary logistic model; crude (Unadjusted) and adjusted ORs were calculated. Adjustment was made for age and gender (Figure 45). Gender and age were not correlated, so there is not collinearity. Adjustment for building sample size was made initially but because some of the buildings had a small sample size it was decided not to adjust for sample size. The reason is that binary logistic regression assumes a parametric distribution, which may become unstable for small samples and lead to unusually high odds ratios.

Crude and adjusted SBS ORs were significant (P<0,05) (Table 47)(Table 48) except "body/muscular pain", "Irritated throat/Coughing" and "apathy". "Stuffy or runny nose" was close to significant in the adjusted model and significant in the crude model. With an exception of apathy the odds ratios of building related symptoms were always lower than 1 in GM buildings compared with NGM buildings (Figure 45).

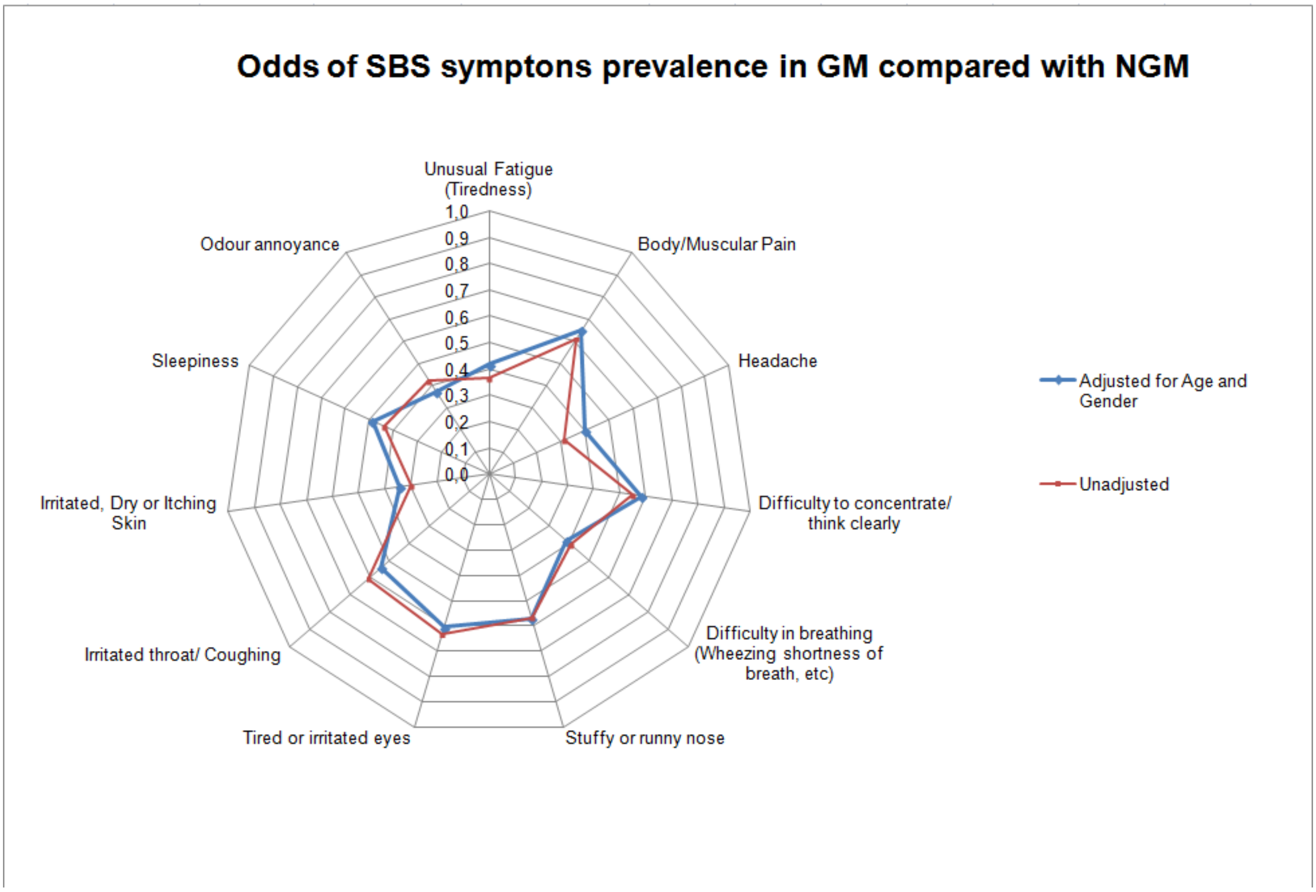



**Figure 45 - Odds for having SBS symptoms in GM buildings compared with NGM buildings. Apathy is not represented for a better visualization but can be observed. The odds of apathy are 2,8 for the adjusted model and 3 for the unadjusted model.**

Adjusted odds suggest that the risk for having SBS symptoms is about half in GM buildings compared with NGM buildings.

| | SBS symptoms odds in NGM compared with GM **Unadjusted** | | | | |
|---|---|---|---|---|---|
| | | | | 95% Confidence Interval for Exp(B) | |
| | Wald | Sig. | Odds | Lower Bound | Upper bound |
| Unusual Fatigue (Tiredness) | 14,398 | **,000** | ,363 | ,215 | ,613 |
| Body/Muscular Pain | 2,404 | ,121 | ,611 | ,328 | 1,139 |
| Headache | 14,153 | **,000** | ,311 | ,169 | ,572 |
| Difficulty to concentrate/ think clearly | 5,187 | **,023** | ,551 | ,330 | ,920 |
| Difficulty in breathing (Wheezing shortness of breath, etc) | 4,657 | **,031** | ,407 | ,180 | ,921 |
| Stuffy or runny nose | 3,888 | **,049** | ,568 | ,323 | ,997 |
| Tired or irritated eyes | 3,661 | **,056** | ,634 | ,398 | 1,011 |
| Irritated throat/Coughing | 2,236 | ,135 | ,605 | ,313 | 1,169 |
| Irritated, Dry or Itching Skin | 9,814 | **,002** | ,300 | ,141 | ,637 |
| Sleepiness | 10,859 | **,001** | ,440 | ,270 | ,717 |
| Apathy | 3,592 | ,058 | 2,973 | ,963 | 9,172 |
| Odour annoyance | 4,623 | **,032** | ,422 | ,192 | ,927 |

**Table 47 –Unadjusted Odds for SBS symptoms prevalence in GM compared with NGM with 95% confidence interval. Significant odds are presented in bold. Significance of odds ratio for crude model is also represented in red**

| | SBS symptoms odds in NGM compared with GM Adjusted for age and gender | | | | |
|---|---|---|---|---|---|
| | | | | 95% Confidence Interval for Exp(B) | |
| | Wald | Sig. | Odds | Lower Bound | Upper bound |
| Unusual Fatigue (Tiredness) | 9,651 | **,002** | ,417 | ,241 | ,724 |
| Body/Muscular Pain | 1,680 | ,195 | ,648 | ,336 | 1,249 |
| Headache | 7,999 | **,005** | ,399 | ,211 | ,754 |
| Difficulty to concentrate/ think clearly | 3,784 | **,052** | ,583 | ,338 | 1,004 |
| Difficulty in breathing (Wheezing shortness of breath, etc) | 4,712 | **,030** | ,388 | ,165 | ,912 |
| Stuffy or runny nose | 3,448 | ,063 | ,569 | ,314 | 1,032 |
| Tired or irritated eyes | 3,951 | **,047** | ,605 | ,369 | ,993 |
| Irritated throat/Coughing | 2,990 | ,084 | ,543 | ,272 | 1,085 |
| Irritated, Dry or Itching Skin | 7,118 | **,008** | ,343 | ,156 | ,753 |
| Sleepiness | 7,566 | **,006** | ,487 | ,292 | ,813 |
| Apathy | 3,029 | ,082 | 2,833 | ,877 | 9,151 |
| Odour annoyance | 5,559 | **,018** | ,372 | ,164 | ,846 |

**Table 48 – Adjusted Odds for SBS symptoms prevalence in GM compared with NGM with 95% confidence interval. Significant odds are presented in bold. Adjusted for Age and Gender**

Odds of SBS symptoms prevalence for Women compared with Men are presented in Figure 46. It can be observed that the odds of SBS symptoms are higher in women than men with apathy being almost 4 times higher.

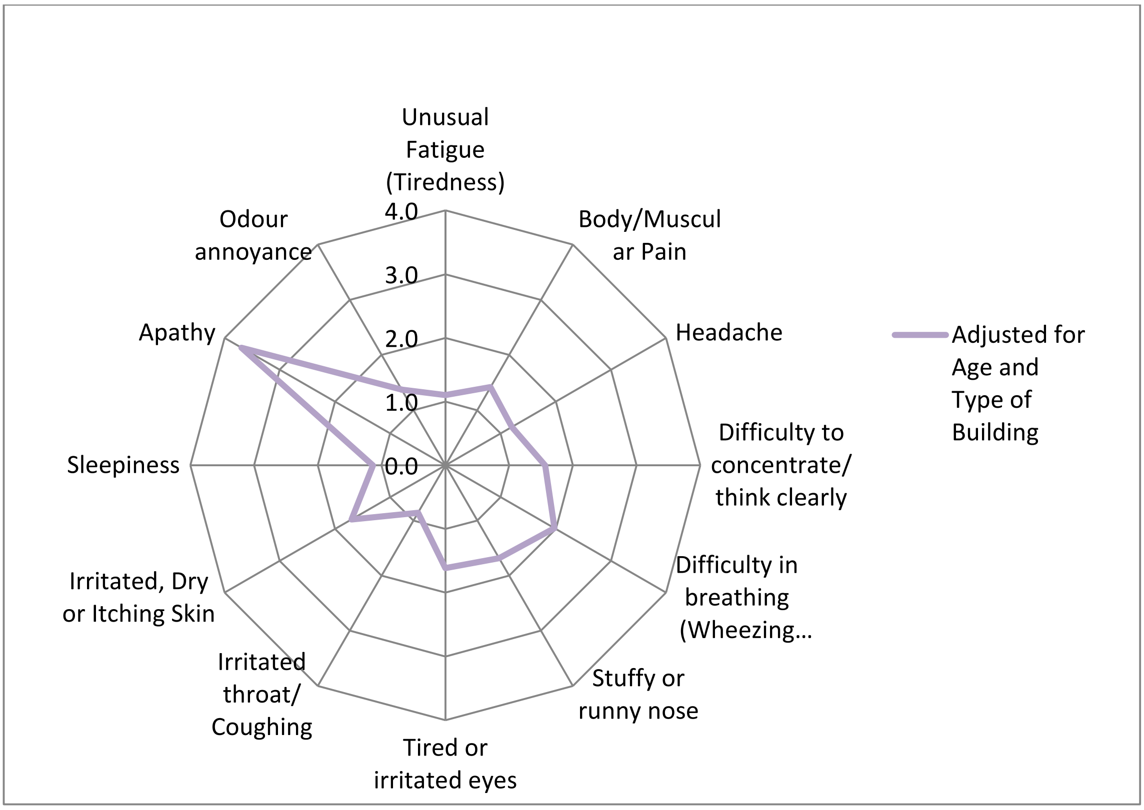
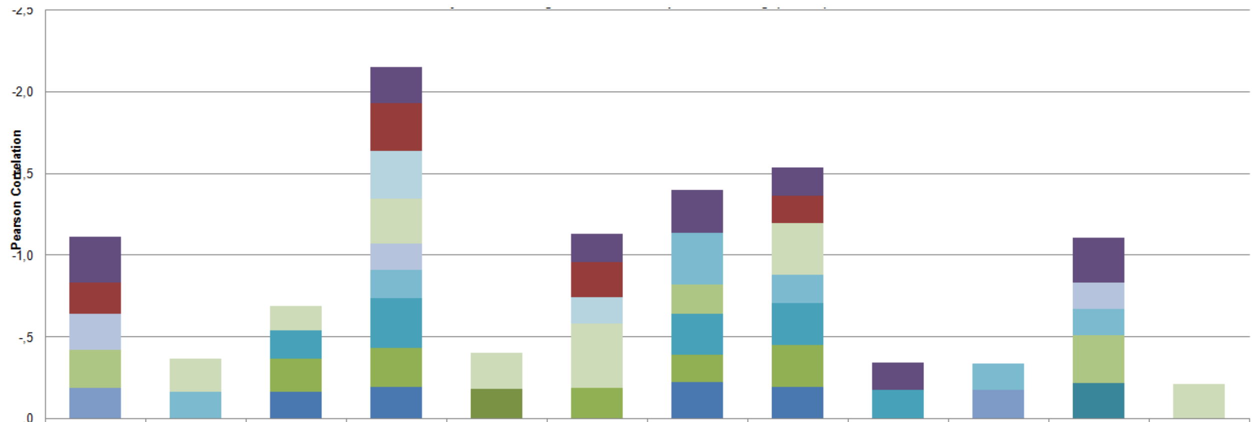



**Figure 46 - Odds for having SBS symptoms in women compared with men. "Tired or irritated eyes" and "apathy" were significant with (p<0,05)**

### *4.3.5.1 Health symptoms and IEQ satisfaction for GM buildings*

Point-biseral correlation coefficients between building related health symptoms and IEQ satisfaction and perceptions in GM buildings are presented in Figure 47 and in Figure 48 to observe which are the associations between SBS symptoms and satisfaction/perceptions with IEQ parameters ;only significant coefficients (p<0,05) are presented. NGM not presented as there was no clear-cut underlying pattern association. Point-biseral correlations are used as SBS symptoms is a dichotomous variable. The Point-biseral correlation coefficients do not estimate the slope of the relation, only the strength of the association and direction of that association. The correlation is considered to be strong with coefficients >0,4, weak with coefficients <0,3 and very weak if <0,2. All correlation coefficients have negative value implying lower symptoms prevalence with higher satisfaction.

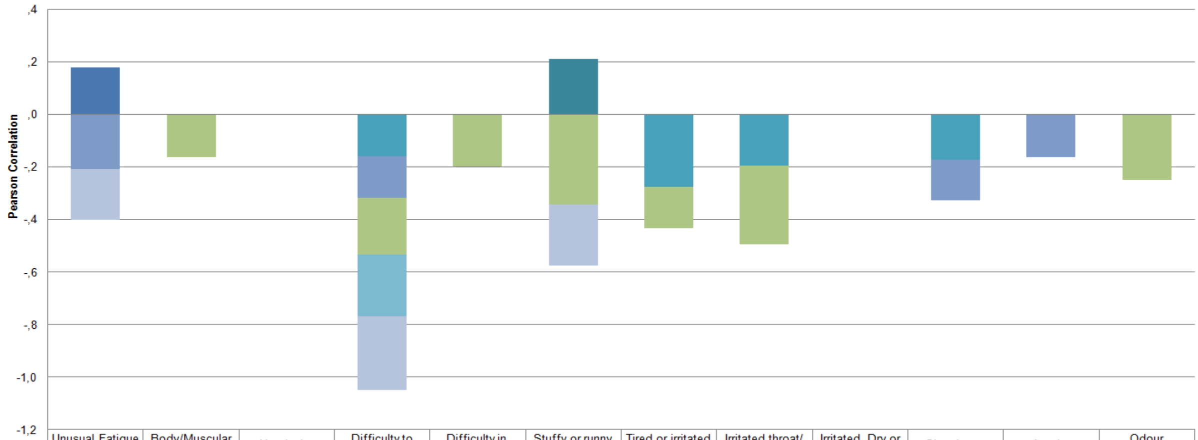



| | Unusual Fatigue (Tiredness) | Body/Muscular Pain | Headache | Difficulty to concentrate | Difficulty in breathing | Stuffy or runny nose | Tired or irritated eyes | Irritated throat/ Coughing | Irritated, Dry or Itching Skin | Sleepiness | Apathy | Odour annoyance |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Overall IEQ | -0,281 | | | -0,223 | | -0,17 | -0,261 | -0,173 | -0,167 | | -0,274 | |
| Sound Privacy | -0,186 | | | -0,289 | | -0,216 | | -0,171 | | | | |
| Noise levels | | | | -0,295 | | -0,163 | | | | | | |
| Air quality | | -0,202 | -0,149 | -0,274 | -0,219 | -0,392 | | -0,313 | | | | -0,21 |
| Visual Privacy | -0,225 | | | -0,161 | | | | | | | -0,163 | |
| Visual comfort | | -0,164 | | -0,173 | | | -0,319 | -0,172 | | -0,161 | -0,159 | |
| Daylight | -0,231 | | | | | | -0,175 | | | | -0,293 | |
| Light levels | -0,187 | | | | | | | | | -0,176 | | |
| Humidity | | | -0,171 | -0,306 | | | -0,253 | -0,257 | -0,173 | | | |
| Air movement | | | -0,205 | -0,235 | | -0,187 | -0,165 | -0,257 | | | | |
| Temperature | | | -0,163 | -0,194 | | | -0,225 | -0,195 | | | | |
| Personal Control | | | | | | | | | | | -0,219 | |
| Window view | | | | | -0,183 | | | | | | | |
| Personal Space | | | | | | | | | | | | |

**Figure 47 – Correlation between building related symptoms and satisfaction with IEQ in GM buildings; only significant correlation coefficients are shown**

Difficulty to concentrate, tired eyes and irritated throat are the symptoms that are correlated with the highest number of IEQ parameters for which satisfaction rating was collected. Overall IEQ, air quality, visual comfort, humidity and air movement are the parameters with more correlation with SBS symptoms. Generally it can be concluded that correlations are reasonable and make sense. For example "Tired/irritated eyes" correlated strongly with visual comfort (i.e. Glare) "difficulty to concentrate" correlated strongly with sound privacy, noise and air quality and humidity and "sleepiness" only correlated lightly with visual comfort and lighting (Figure 47),. "Stuffy/runny nose" and "Irritated throat/coughing" correlated strongly with air quality. Apathy correlated with daylight.

For perceptions "tired/irritated eyes" lightly correlated strongly with air quality and visual comfort (i.e. Glare) , "difficulty to concentrate" correlated lightly with sound privacy, noise and air quality and "sleepiness" only correlated lightly with visual comfort and visual privacy (Figure 48). Air quality was the perception which correlated with more symptoms. These correlations seem also to be reasonable.




| | Unusual Fatigue (Tiredness) | Body/Muscular Pain | Headache | Difficulty to concentrate | Difficulty in breathing | Stuffy or runny nose | Tired or irritated eyes | Irritated throat/ Coughing | Irritated, Dry or Itching Skin | Sleepiness | Apathy | Odour annoyance |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sound privacy | -0,194 | | | -0,28 | | -0,23 | | | | | | |
| Noise levels | | | | -0,234 | | | | | | | | |
| Air quality | | -0,164 | | -0,218 | -0,2 | -0,345 | -0,158 | -0,301 | | | | -0,249 |
| Visual privacy | -0,209 | | | -0,156 | | | | | | -0,152 | -0,162 | |
| Visual comfort | | | | -0,161 | | | -0,276 | -0,194 | | -0,174 | | |
| Daylight | | | | | | | | | | | | |
| Lighting | 0,177 | | | | | | | | | | | |
| Humidity | | | | | | 0,209 | | | | | | |
| Air movement | | | | | | | | | | | | |
| Temperature | | | | | | | | | | | | |

**Figure 48 – Correlations between building related health symptoms and IEQ perceptions in GM buildings**

Point-biseral correlation coefficients were also performed for physical measurements and SBS symptoms but there were no strong associations (Appendix E).

### 4.3.6 Self-Assessed work performance

There were no differences in ratings of self-assessed work performance between GM and NGM buildings (Figure 49). Job difficulty, effort required to perform work, stress and job satisfaction were slightly higher in NGM buildings compared with GM buildings but the difference did not reach statistical significance (P>0.05). Self-assessed work performance was slightly higher in GM buildings compared with NGM buildings (Figure 49) and (Figure 50), but again no statistically significant difference could be documented in the conservative hierarchical statistical model (Table 49).

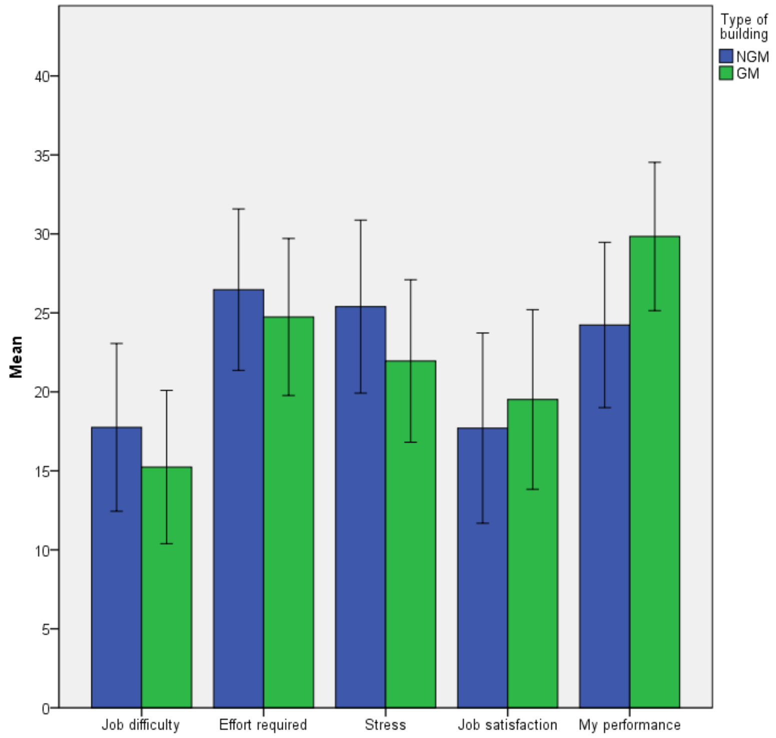



Figure 49 – Different categories describing work as assessed by the occupants in GM and NGM buildings Green bars show means in GM buildings with 95% confidence intervals while blue bars show means in NGM buildings with 95% confidence intervals. The scale is from -100 to +100

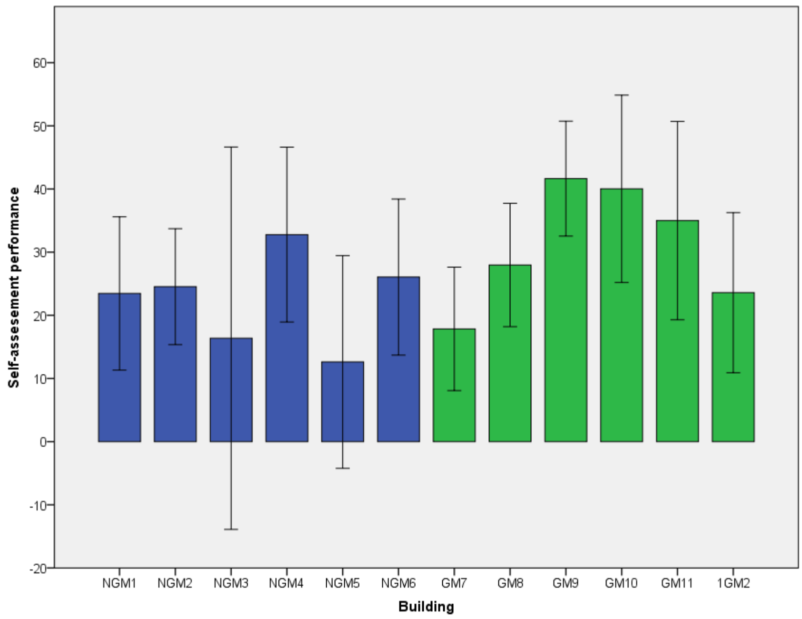



Figure 50 – Self-assessed work performance rated by the occupants of individual buildings. Green bars represent show means in GM buildings mean values with 95% confidence intervals, while blue bars show means in NGM buildings mean values with 95% confidence intervals.* The scale is from -100 to +100. For all except performance (-100/0/100) is equivalent to (Low/neutral/High). For performance the equivalence is (Poor/neutral/Excellent)

| Hierarchical model - Mixed Model | | Between Green Mark and Non Green Mark (Includes random effect) | | | Between buildings within same category (Nested under Type) | | |
|---|---|---|---|---|---|---|---|
| | | F | Sig. | Partial Eta Squared | F | Sig. | Partial Eta Squared |
| How do you rate your work? | Job Difficulty | ,060 | ,811 | ,005 | 3,496 | **,000** | ,104 |
| | Effort required | ,000 | ,992 | ,000 | 3,019 | **,001** | ,091 |
| | Stress | ,243 | ,630 | ,019 | 1,769 | **,066** | ,056 |
| | Job Satisfaction | ,209 | ,655 | ,015 | 1,369 | ,194 | ,043 |
| | My performance | 2,570 | ,134 | ,173 | 1,972 | **,036** | ,061 |

**Table 49 – Results of GLMM for different categories describing work as assessed by the occupants in GM and NGM buildings. Bold numbers are significant (P<0.05). The results are unadjusted. The column showing the results for the difference between buildings WITHIN the same category (the last three columns) should be considered with caution as the buildings are random variable in the model. Partial Eta square shows the explanatory power of the model (comparable to R square) and F is the F –statistics from the model.**

When less conservative statistical analysis are performed (Table 50) where buildings were not randomly assigned to each category (GM vs NGM) self-assessed performance differed significantly between GM and NGM buildings, the absolute difference being small (Figure 49).

| | | (LSD) Pairwise Comparisons (GM - NGM) | | | | |
|---|---|---|---|---|---|---|
| | | Mean Difference (GM-NGM) | Std. Error | Sig. | 95% Confidence Interval for Difference | |
| | | | | | Lower Bound | Upper Bound |
| How do you rate your work? | Job Difficulty | -1,668 | 3,902 | ,669 | -6,011 | 9,346 |
| | Effort required | 0,069 | 3,929 | ,986 | -7,802 | 7,663 |
| | Stress | -2,649 | 4,202 | ,529 | -5,621 | 10,918 |
| | Job Satisfaction | 2,437 | 4,663 | ,602 | -11,613 | 6,740 |
| | My performance | 8,375 | 3,892 | **,032** | -16,034 | -,716 |

**Table 50 – Results of LSD comparisons between GM and NGM building for self-assessment/job parameters. Bold numbers are significant (P<0.05). The results are unadjusted. Marginal mean differences between Gm and NGM buildings with 95% confidence interval are presented.**

Association between overall satisfaction with IEQ and self-assessed performance ("My performance") (Figure 51) and job satisfaction ("Job satisfaction") (Figure 52) were examined; linear regressions and Pearson correlation were performed (Table 51). In GM buildings self-reported performance increased with higher IEQ satisfaction but not in NGM buildings (Figure 51) (Table 51). Job satisfaction was positively correlated with IEQ for both types of buildings (Figure 52) (Table 51).

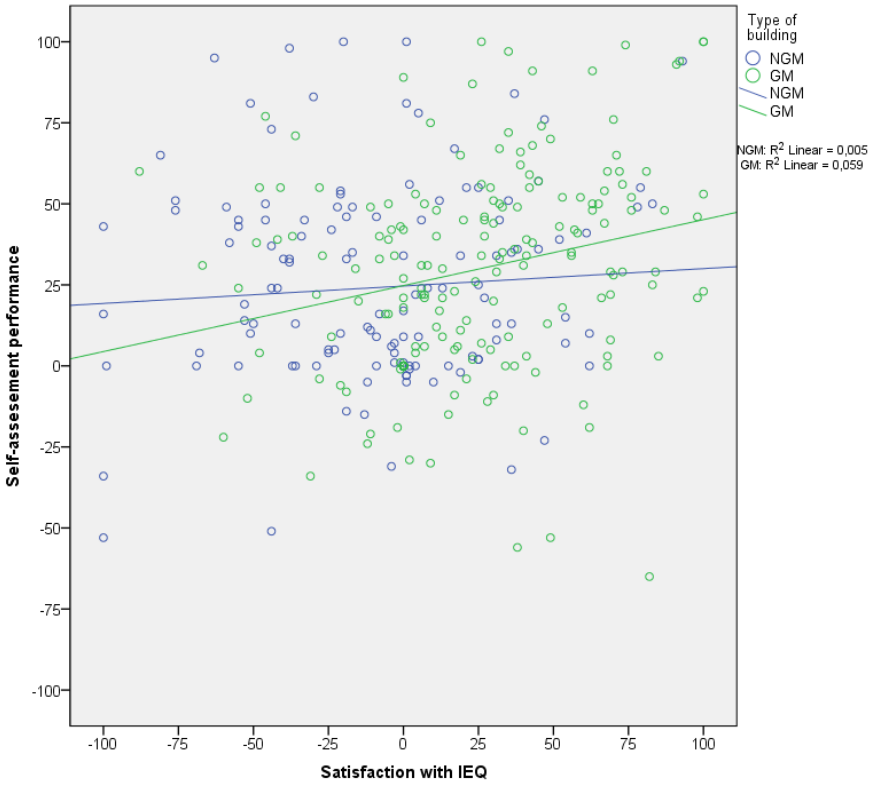



Figure 51- Self-assessed performance of work in GM and NGM buildings as a function of overall satisfaction with IEQ

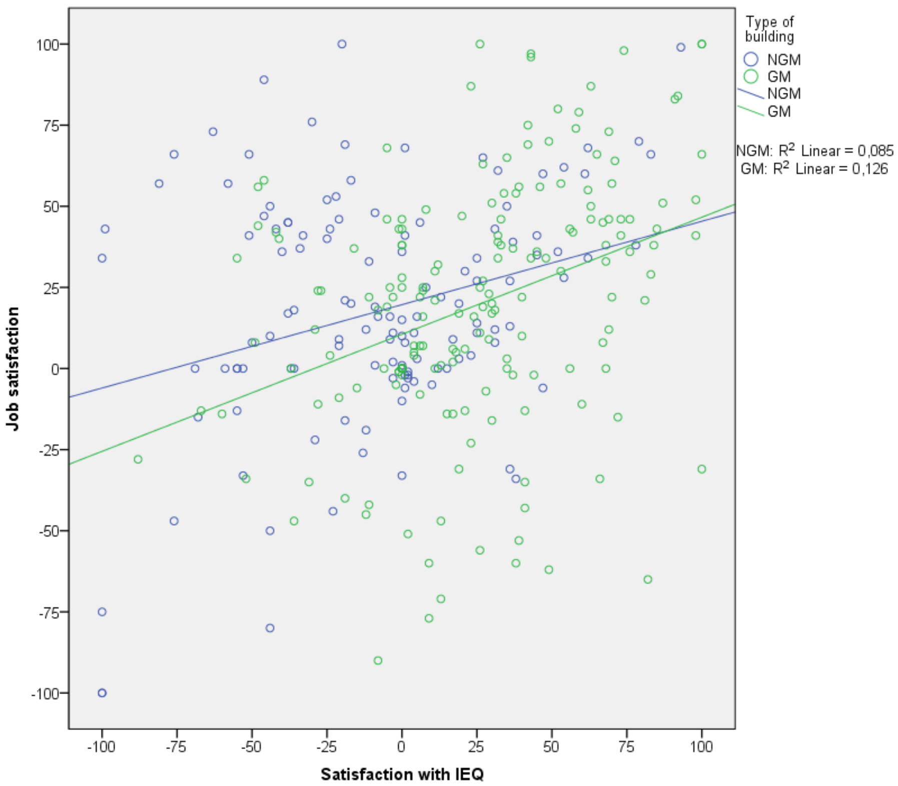



Figure 52 – Self-assesed job satisfaction in GM and NGM buildings as a function of overall satisfaction with IEQ

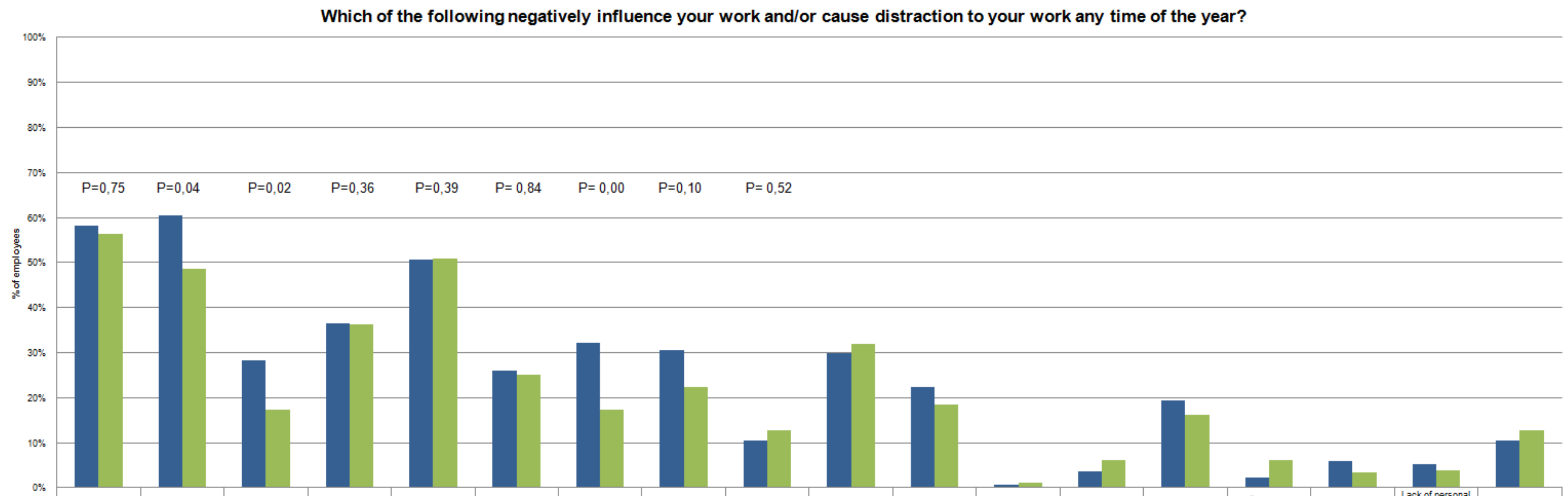
| Satisfaction with IEQ | Correlation | | Job Satisfaction | Self-reported performance |
|---|---|---|---|---|
| | NGM | Pearson Correlation | **0,291** | ,070 |
| | | Sig. (2-tailed) | **0,001** | ,422 |
| | GM | Pearson Correlation | **0,335** | **,242** |
| | | Sig. (2-tailed) | **0,000** | **,001** |

**Table 51 – the strength of correlation between overal satisfaction with IEQ and self-assessed work performance and job satisfaction**

### 4.3.7 Ranking of IEQ important for work performance

This study looked beyond traditional questions and asked occupants to rank a set of preselected IEQ parameters and parameters not related to IEQ regarding impact on work (Figure 53) (Figure 54). Pearson chi square was used to examine which parameters were ranked most frequently in GM and NGM buildings.

Thermal discomfort, poor air quality and noise causing distraction were ranked more frequently in GM and NGM buildings (Figure 53). Poor air quality, insufficient daylight and lack of view to the outside were ranked statistically significantly less frequent to have impact on work in GM buildings compared with NGM buildings ($P<0,05$) (Figure 53). When asked which of the parameters can be ranked as having the highest impact on work among all parameters included in the set, thermal discomfort and air quality were ranked highest (Figure 53).




| | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Most Important | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Thermal discomfort | Poor air quality | Insufficient daylight level | Poor lighting | Noise causing distraction | Constant background/traffic noise | Lack of view to the outside | Lack of personal control of the indoor environment | None of the above are important | Thermal discomfort | Poor air quality | Insufficient daylight level | Poor lighting | Noise causing distraction | Constant background/traffic noise | Lack of view to the outside | Lack of personal control of the indoor environment | None of the above are important |
| NGM | 58,2% | 60,4% | 28,4% | 36,6% | 50,7% | 26,1% | 32,1% | 30,6% | 10,4% | 29,9% | 22,4% | ,7% | 3,7% | 19,4% | 2,2% | 6,0% | 5,2% | 10,4% |
| GM | 56,4% | 48,6% | 17,3% | 36,3% | 50,8% | 25,1% | 17,3% | 22,3% | 12,8% | 31,8% | 18,4% | 1,1% | 6,1% | 16,2% | 6,1% | 3,4% | 3,9% | 12,8% |

**Figure 53 – Ranking of IEQ parameters having impact on work performance for both GM buildings (green columns) and NGM buildings (blue columns)**

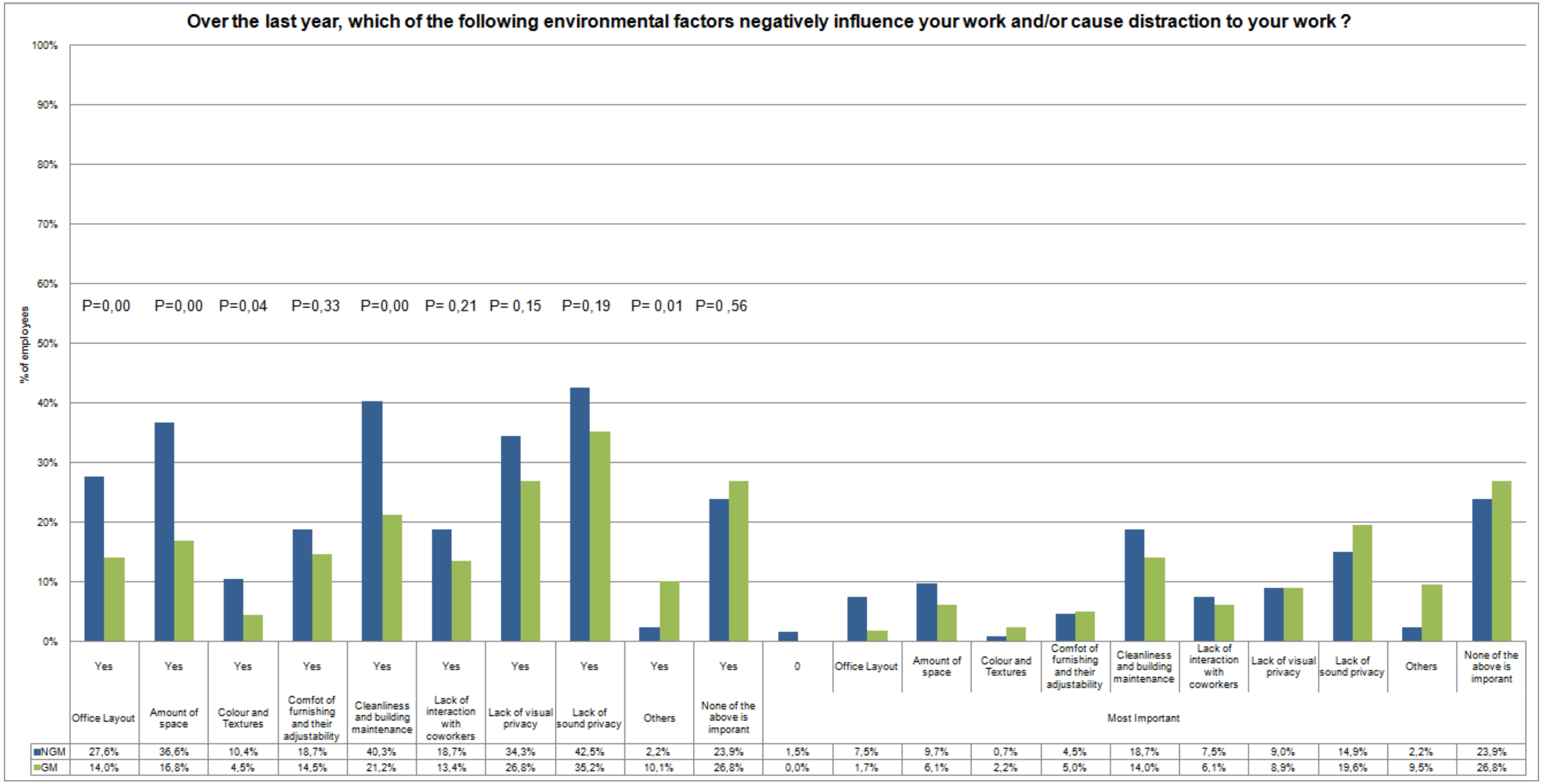



**Figure 54 – Ranking of parameters other than IEQ having impact on work performance**

As regards factors related to workplace, lack of visual privacy, lack of sound privacy and cleanliness were ranked more frequently by occupants in GM buildings to have an impact on work performance (Figure 54). In NGM buildings lack of sound and visual privacy, cleanliness and amount of space were ranked more frequently to have impact on work performance. Office layout, amount of space, colours and textures, cleanliness had a statistically significant lower frequency in GM buildings compared with NGM buildings ($P<0,05$) (Figure 54). When asked directly lack of privacy and cleanliness were selected to have the highest impact on work performance in NGM buildings and GM buildings.

### 4.3.8 Principal components analysis of IEQ satisfaction

It was examined whether satisfaction with IEQ and perceptions of IEQ in NGM and GM buildings can be explained by major components. For this purpose principal component analysis (PCA) was performed for GM and NGM buildings. It was done separately for both types of buildings, as factors may load differently in these two groups. Results are shown in Figure 55, Figure 56, Figure 57, and Figure 58.

The loadings in PCA can vary between -1 and +1 and only loadings with absolute values > 0,4 were included.

The explained variance by the used PCA was between 63% and 65 for perceptions and 69% and 75% for satisfaction (Table 52). For perceptions (Figure 55)(Figure 56) PCA showed that air quality loads always on the first component so it can be interpreted as being a very important factor. Air quality was shown to be significant in hierarchical models too and ranked high by the occupants as having important impact on the work performance.

PCA for perceptions in GM buildings (Figure 56) show that the first component is related to the layout, the second component is related to light, while the third component is also related to the workstation layout and the fourth component to the environment. The variance for each principal component are 25%, 16%, 12% and 11% respectively, with a cumulative explaining power of 63%. PCA for perceptions in NGM buildings show no clear definition for the components (Figure 55). Still the cumulative explanatory power in NGM buildings is high and at 65%.

PCA for satisfaction in GM buildings show the components that can be clearly defined as environmental ($1^{st}$ component), psychosocial ($2^{nd}$ component), lighting ($3^{rd}$ component), and privacy ($4^{th}$ component) (Figure 58). The explanatory power for each principal component are 22%, 16%, 16% and 15% respectively, with a cumulative power of 69% (Table 52). PCA for satisfaction in NGM buildings (Figure 57) show that components cannot be well defined, the first is a mix of light and air quality, the second is environmental, the third relates to privacy, fourth to workspace and fifth connection to outside. The explanatory power for each principal component is 22%, 15%, 15%, 12% and 11% respectively, with a cumulative explanatory power of 75% (Table 52).

The PCA shows that IEQ satisfaction can be judged by a reduced number of variables in GM buildings, explanatory power for each principle component can be used as a guiding parameter to estimate the weightage (importance) of different IEQ parameters when satisfaction is regarded.

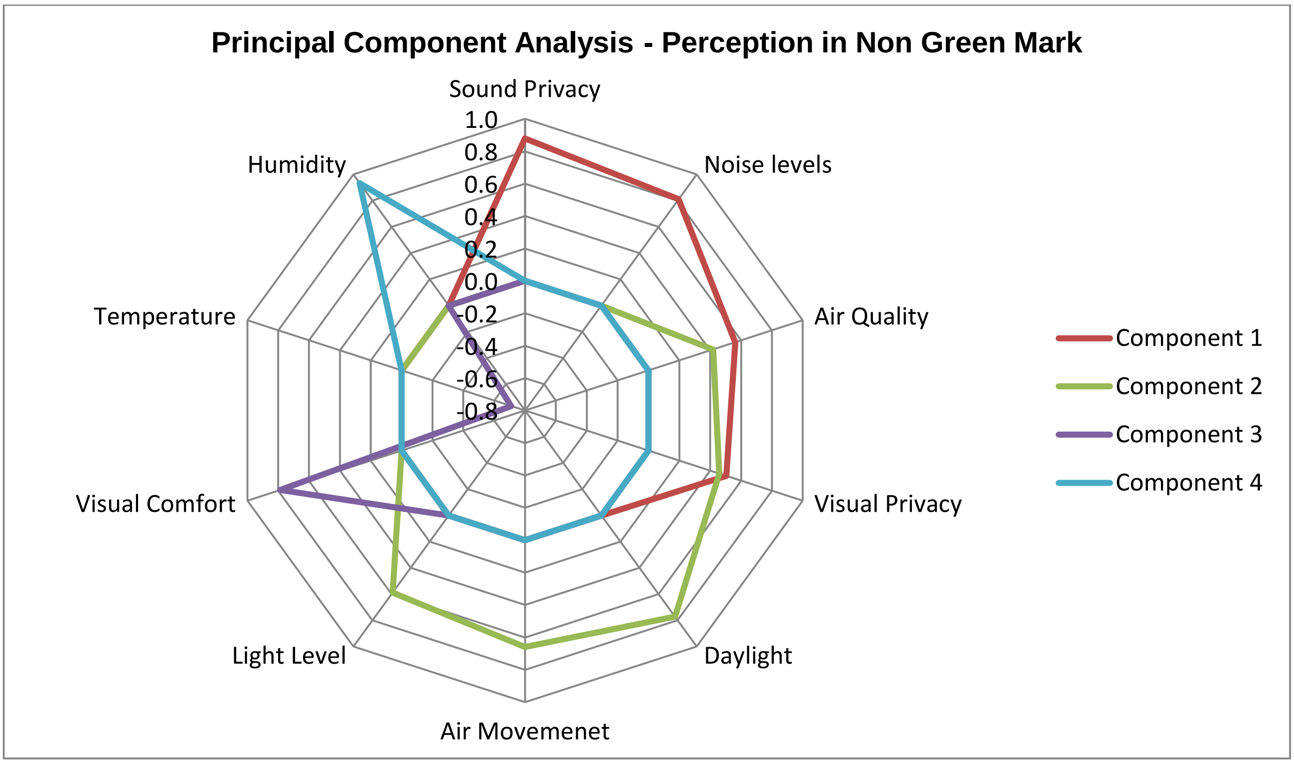



Figure 55 – PCA for perceptions in NGM buildings

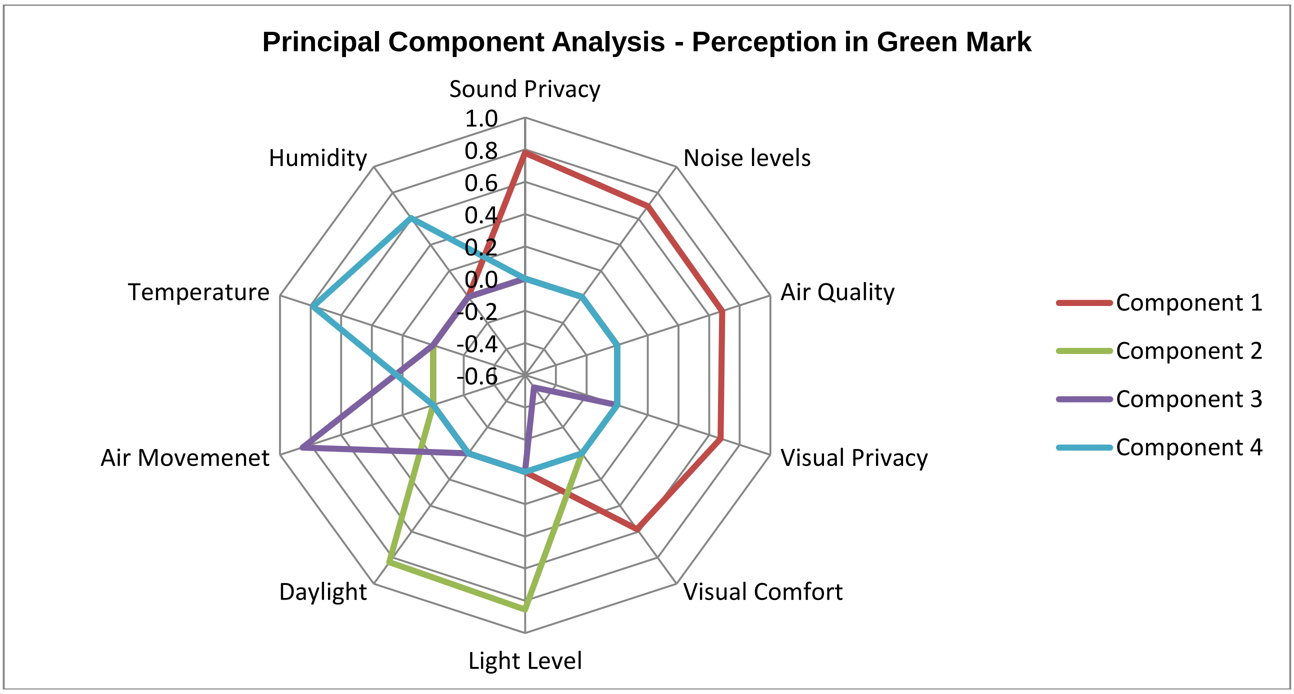



Figure 56- PCA for perceptions in GM buildings

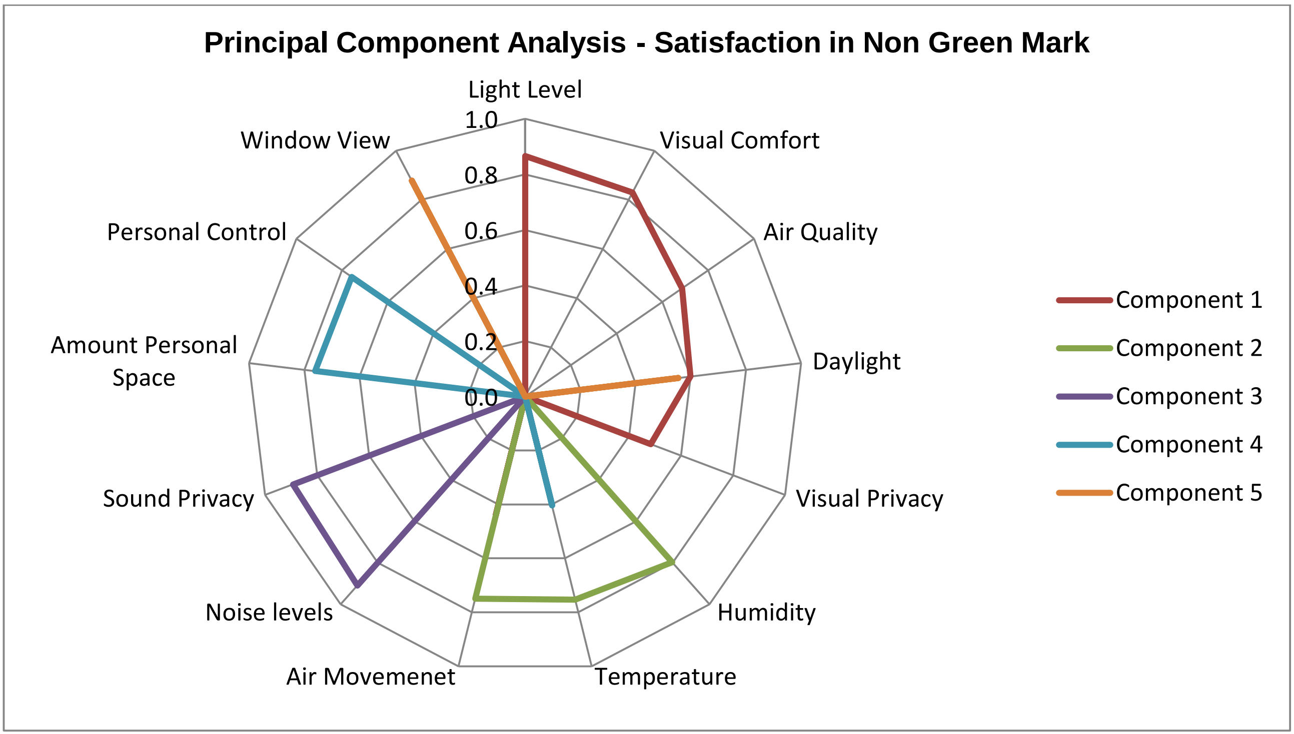



Figure 57 – PCA for satisfaction in NGM buildings

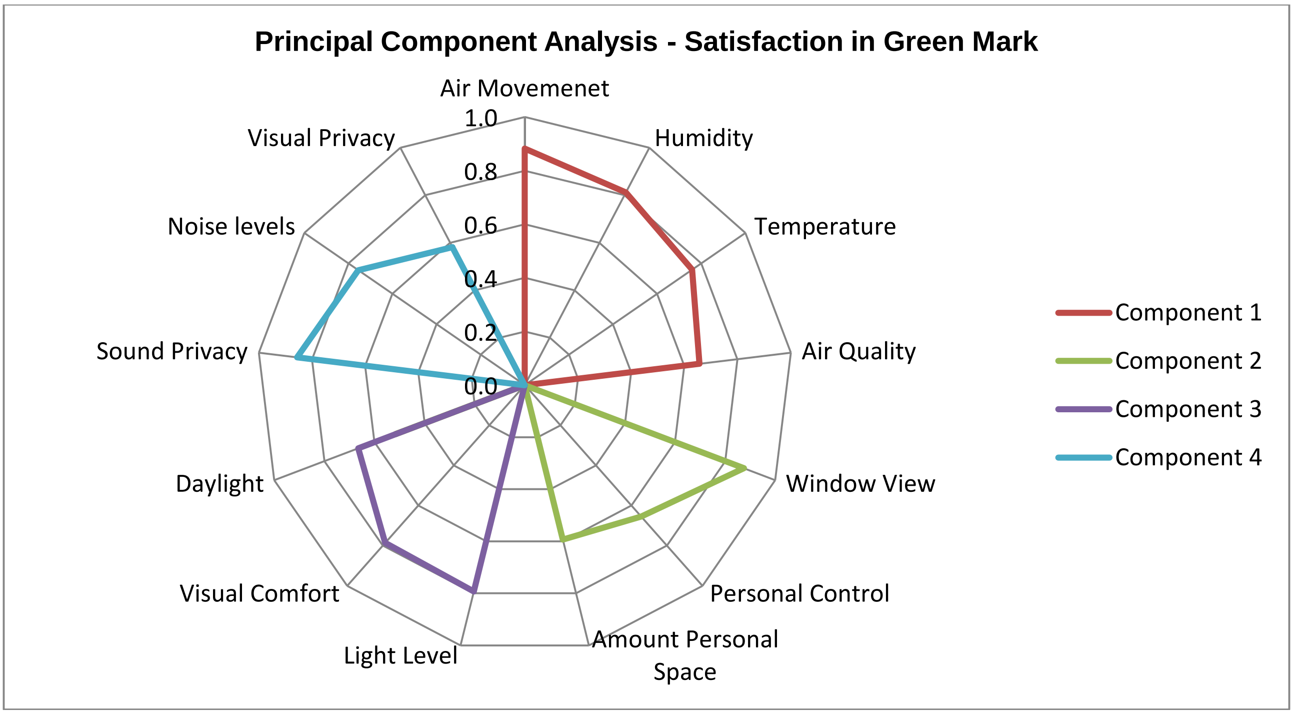



Figure 58 – PCA for satisfaction in GM buildings

| | Principal Component Analysis (PCA) | | | |
|---|---|---|---|---|
| | Rotation Sums of Squared Loadings (% of Variance) | | | |
| Component | Perceptions | | Satisfaction | |
| | NGM | GM | NGM | GM |
| **1** | 21% | 25% | 22% | 22% |
| **2** | 18% | 16% | 15% | 16% |
| **3** | 13% | 12% | 15% | 16% |
| **4** | 12% | 11% | 12% | 15% |
| **5** | | | 11% | |
| **Total** | 65% | 63% | 75% | 69% |

Table 52 –Percentages of variance (explanatory power)for each principal component in NGM and GM buildings

In GM buildings, IEQ parameters follow a more clear distinction, i.e. individual IEQ parameters naturally group together. In NGM buildings less clarity might suggest that many more factors influence perceptions, satisfaction and importance. This may indicate that the GM scheme creates a clearer framework which allow occupants of GM buildings occupants to clear distinct parameters that are important for their perceptions and satisfaction.

### 4.3.9 Performance of mental tasks (games)

Three games were performed to estimate the impact of IEQ on mental performance of occupants in GM and NGM buildings. From all 313 respondents only 230 completed all the three games (Table 53). They were used in the subsequent analyses.

| Game Data | |
|---|---|
| Possible answers for the 3 games | **313** |
| Answered all 3 games | **230** |
| D2 Game | |
| Answered all 6 sets | 238 |
| Answered more than 3 sets but less than 6 sets | 18 |
| Answered less than 3 sets | 57 |
| Total | 313 |
| Connecting the Nodes Game | |
| Answered | 252 |
| Not answered | 61 |
| Total | 313 |
| Memory Game | |
| Answered | 244 |
| Not answered | 69 |
| Total | 313 |

Table 53 – Response rates in different games

The following indices of performance were used: For D2 game three results are represented, concentration performance, which measures a combine effect of accuracy and speed, accuracy, and fluctuation rate. For connecting the nodes game two results are presented, accuracy and speed. For memory game, working memory performance is presented, which measures a combine effect of accuracy and speed

Observing in (Figure 59)(Figure 60) the occupant distribution across all twelve buildings by order (NGM1 to GM12) of games performance indicators with the exception of accuracy and fluctuation rate in D2 game, it can be observed that the distributing of performance shows little differences between all buildings in this study. This was also observed in the analysis of the results, described in the next pages.

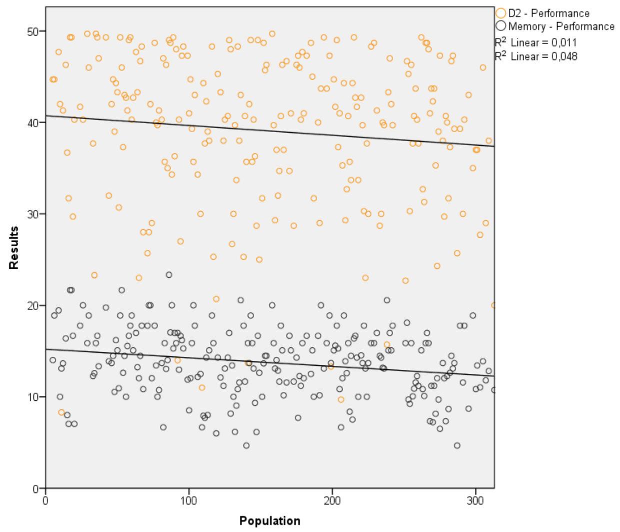



**Figure 59 – Distribution of D2 game CP and memory game working memory performance for all occupants on the twelve buildings (313 occupants)**

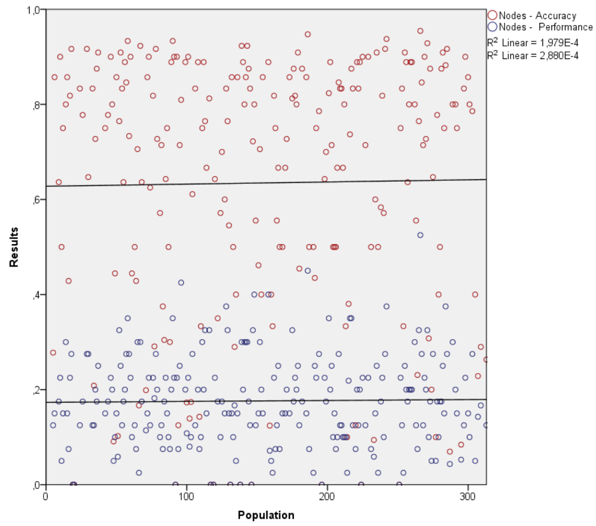



**Figure 60 – Distribution of connecting the nodes accuracy and results for all occupants on the twelve buildings (313 occupants)**

Both the conservative hierarchical model and a less conservative LSD model did not show statistically significant differences in performance of games between GM and NGM buildings (Table 54)(Table 55). Concentration performance and accuracy in the D2 game (Figure 61)(Figure 62)(Figure 63)(Figure 64) was similar between GM and NGM buildings. The fluctuation rate was slightly higher in GM buildings compared with NGM buildings (Figure 65)(Figure 66).

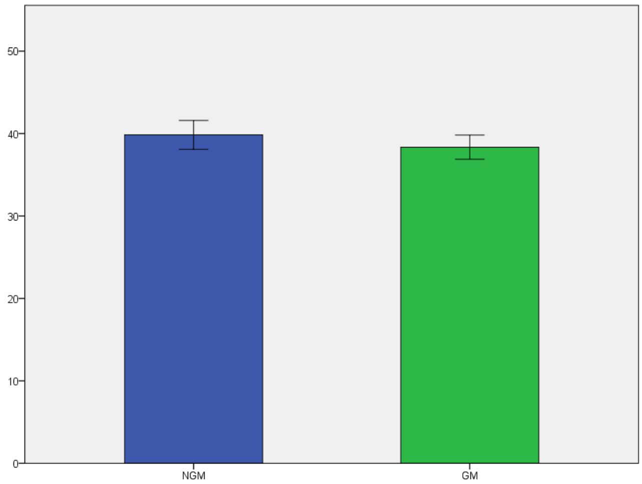



Figure 61 – Concentration performance for D2 game, mean results for GM (Green) and NGM(Blue) buildings with 95% confidence interval

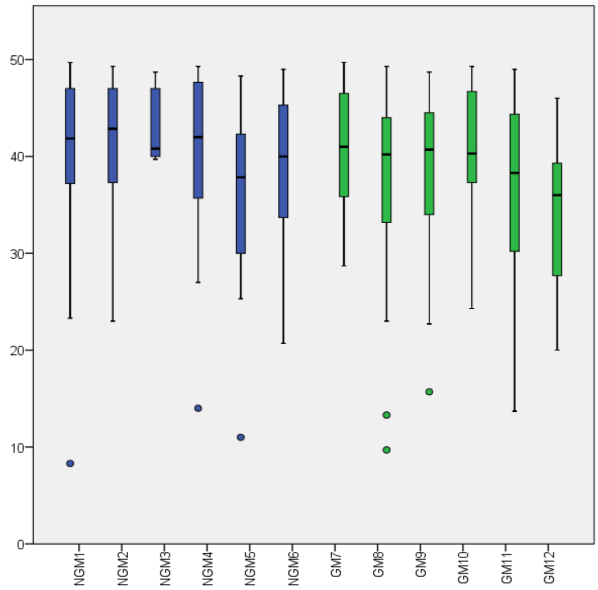



Figure 62 – Box plots for concentration performance in D2 game in each building participated in the study. GM (Green) and NGM(Blue)

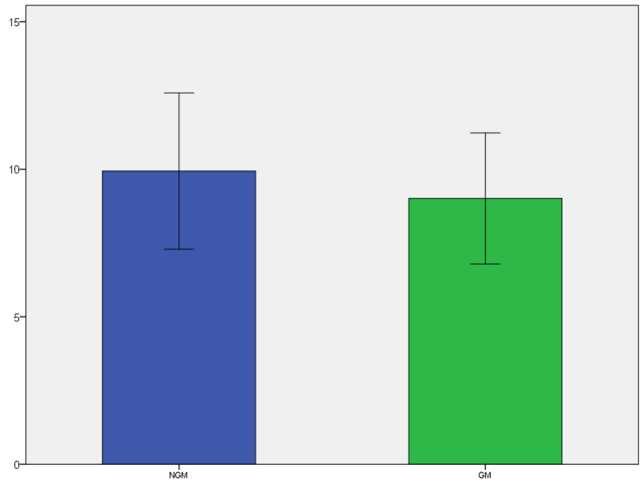



Figure 63 - Accuracy for D2 game, mean results for GM (Green) and NGM (Blue) buildings with 95% confidence interval

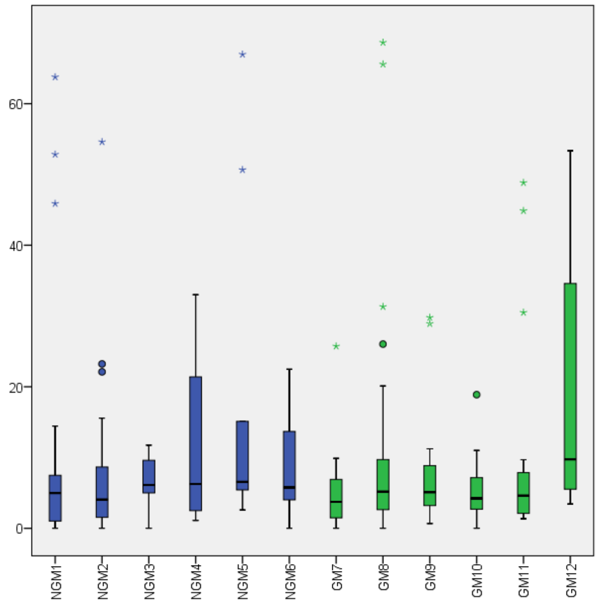



Figure 64 - Box plots for accuracy in D2 game in each building participated in the study. GM (Green) and NGM(Blue)

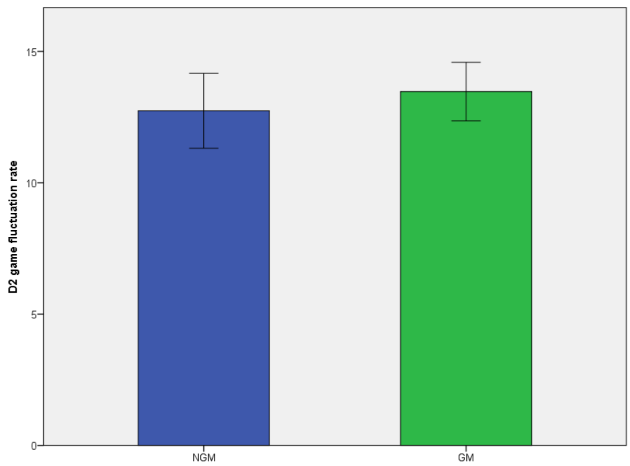



Figure 65 – D2 game fluctuation rate , mean results for GM(Green) and NGM(Blue) buildings with 95% confidence interval

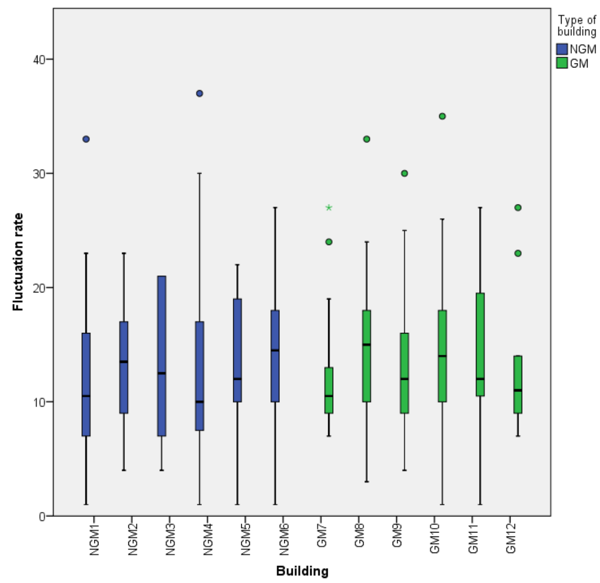



Figure 66 – Box plots for fluctuation rate in D2 game in each building participated in the study. GM (Green) and NGM(Blue)

In connecting the nodes game accuracy was similar in NGM and GM (Figure 67)(Figure 68). In connecting the nodes game, speed, the number of correct links adjusted by time, was also similar for NGM and GM (Figure 69)(Figure 70).

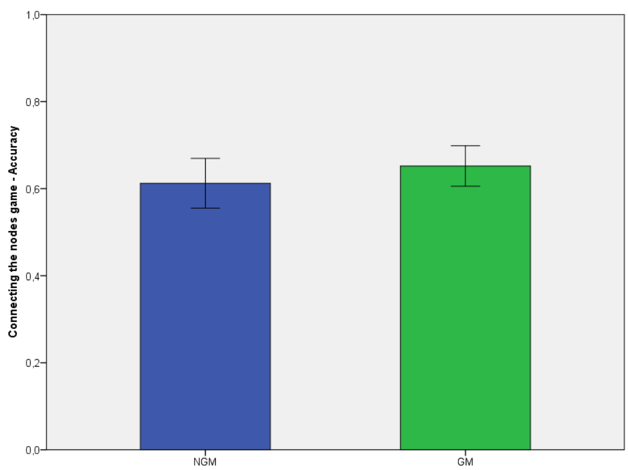



Figure 67 –Connecting the nodes game accuracy adjusted by time mean results for GM (Green) and NGM (Blue) buildings with 95% confidence interval

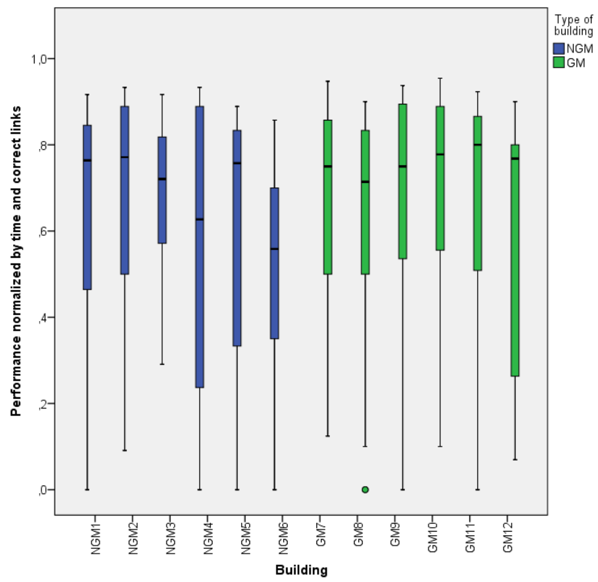



Figure 68 – Box plots for accuracy adjusted by time in connecting the nodes game in each building participated in the study. GM (Green) and NGM(Blue)

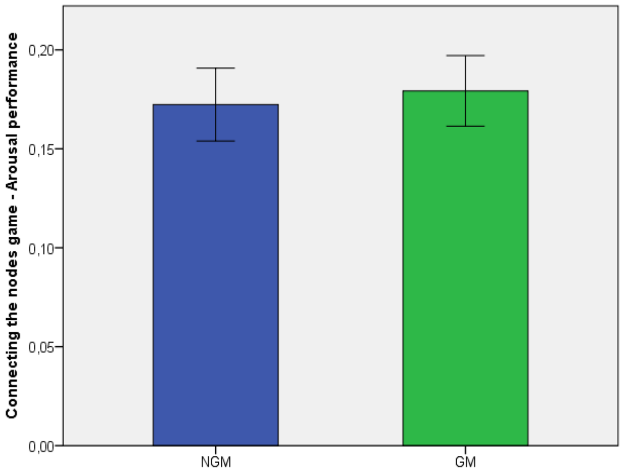



Figure 69 – Connecting the nodes game speed performance mean results for GM and NGM buildings with 95% confidence interval

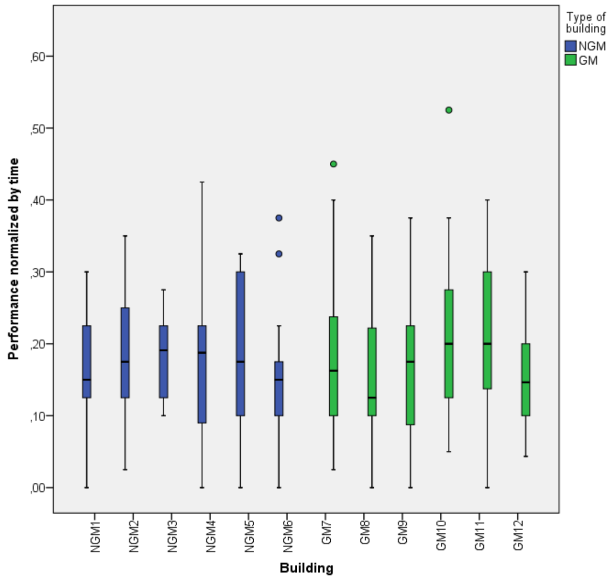



Figure 70 – Box plots for speed performance in connecting the nodes game in each building participated in the study. GM (Green) and NGM(Blue)

For the memory game, working memory performance was similar in NGM and GM buildings (Figure 71)(Figure 72).

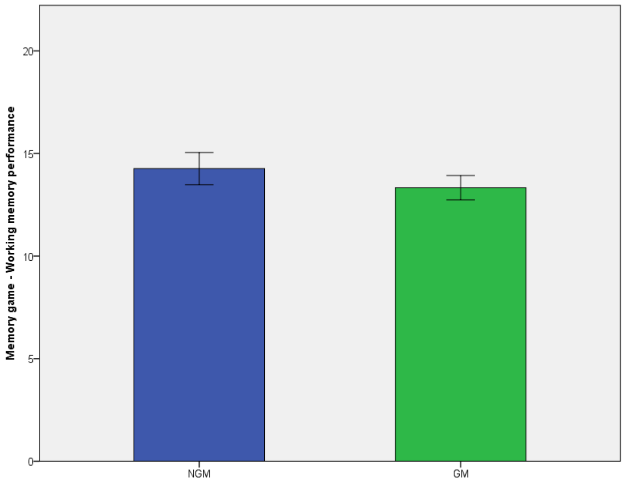



Figure 71 – Memory game working memory performance mean results for GM (Green) and NGM (Blue) buildings with 95% confidence interval

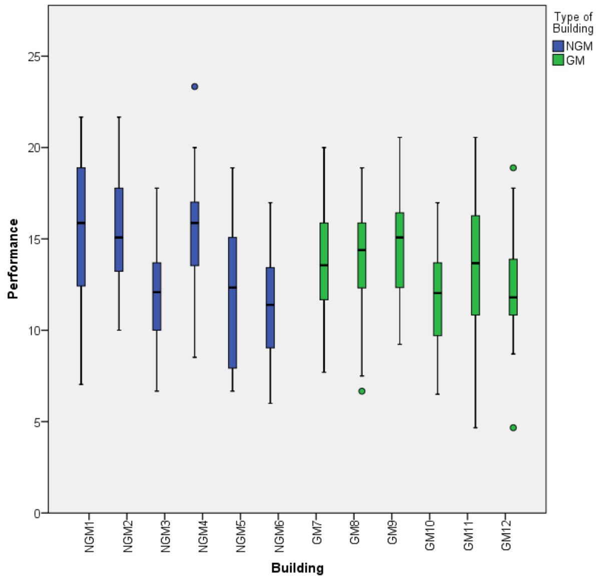



Figure 72 – Box plots for working memory performance in memory game in each building participated in the study. GM (Green) and NGM(Blue)

| Hierarchical model - Mixed Model<br>Objective performance | Between Green Mark and Non Green Mark (Includes random effect) | | | Between buildings within same category (Nested under Type) | | |
|---|---|---|---|---|---|---|
| | F | Sig. | Partial Eta Squared | F | Sig. | Partial Eta Squared |
| D2 concentration performance | 1,5 | ,238 | ,104 | 1,351 | ,205 | ,058 |
| D2 Accuracy | ,04 | ,855 | ,003 | 2,095 | **,026** | ,087 |
| D2 fluctuation rate | ,65 | ,429 | ,029 | ,417 | ,937 | ,019 |
| Connecting the nodes - Accuracy | 1,1 | ,312 | ,065 | ,771 | ,656 | ,034 |
| Connecting the nodes – Speed performance | ,2 | ,645 | ,014 | ,772 | ,656 | ,034 |
| Memory game - Working memory performance | ,08 | ,780 | ,007 | 3,586 | **,000** | ,142 |

**Table 54 – Results of GLMM for GM and NGM buildings differences for games performance. Bold numbers are significant (P<0.05). The results are unadjusted. The column showing the results for the difference between buildings WITHIN the same category (the last three columns) should be considered with caution as the buildings are random variable in the model. Partial Eta square shows the explanatory power of the model (comparable to R square) and F is the F –statistics from the model.**

| | (LSD) Pairwise Comparisons (GM - NGM) | | | | |
|---|---|---|---|---|---|
| | Mean Difference (GM-NGM) | Std. Error | Sig. | 95% Confidence Interval for Difference | |
| | | | | Lower Bound | Upper Bound |
| D2 concentration performance | -1,8 | 1,253 | ,161 | -4,2 | ,71 |
| D2 Accuracy | -0,5 | 1,869 | ,797 | -4,2 | 3,2 |
| D2 fluctuation rate | 0,6 | 1,001 | ,565 | -1,4 | 2,6 |
| Connecting the nodes - Accuracy | 0,04 | ,041 | ,349 | -,04 | ,12 |
| Connecting the nodes – Speed performance | 0,006 | ,014 | ,673 | -,02 | ,04 |
| Memory game - Working memory performance | -0,3 | ,510 | ,611 | -1,3 | ,75 |

**Table 55 – Results of LSD comparisons between GM and NGM buildings for games performance. Bold numbers are significant (P<0.05). The results are unadjusted. Marginal mean differences between Gm and NGM buildings with 95% confidence interval are presented.**

In GM buildings objective and subjective performance were correlated with PCA components for satisfaction (Table 56). Only self-assessment performance correlated with the first 3 components. The correlation is weak.

Job difficulty, effort, stress, job satisfaction and self-assessment performance were also correlated with objective performance (Table 57). Only job difficult revealed a weak correlation with D2 concentration performance.

| | | Pearson correlations for satisfaction PCA components | | | | | |
|---|---|---|---|---|---|---|---|
| | | D2 Concentration performance | D2 Fluctuation rate | Connecting the nodes - Accuracy | Connecting the nodes - Arousal performance normalized by time | Memory Game - Working memory Performance | Self-Assessment performance |
| Satisfaction GM | PCA1 | -,025 | ,046 | ,082 | -,126 | ,011 | **,256****|
| | PCA2 | -,105 | -,119 | ,000 | -,165 | -,084 | **,208**** |
| | PCA3 | -,009 | -,123 | ,067 | -,007 | ,078 | **,226**** |
| | PCA4 | -,117 | ,003 | ,083 | -,037 | ,013 | ,088 |

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

**Table 56 – Pearson correlation for satisfaction PCA components with objective performance indicators and self-assessment performance**

| | | Pearson correlations (NGM + GM) | | | | |
|---|---|---|---|---|---|---|
| | | D2 concentration performance | D2 Fluctuation rate | Connecting the nodes - Accuracy | Connecting the nodes – Arousal Performance | Memory Game – Working memory Performance |
| Self-assessment | Job Difficulty | **,187**** | ,006 | ,046 | ,041 | ,094 |
| | Effort required | ,041 | -,004 | -,072 | -,078 | ,003 |
| | Stress | ,122 | -,055 | ,013 | ,047 | ,000 |
| | Job Satisfaction | ,017 | -,030 | ,078 | ,089 | ,047 |
| | Performance | ,020 | -,081 | ,040 | ,063 | -,006 |

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

**Table 57 – Pearson correlations between objective and subjective performance**

### 4.3.10 Sick leave/Absenteeism

Sick leave data was collected from tenants. It shows accumulated annual sick leave for the respondents working in the area where the measurements were performed (not for all company employees) it only shows sick leave for 12 months. Data on sick leave was only obtained for five NGM buildings and five GM buildings. A Pearson chi-squared test was performed to examine proportion of sick leave in NGM buildings compared with GM buildings. Results are showed individually for each building (Figure 73) or by a building type (Figure 74). When sick leave in building type is compared, building averages are compared and not average across occupants.

Results (Figure 74) revealed that occupants in  GM buildings had on average one day less of sick leave in a year prior to experiments compared with NGM buildings the difference being statistically significant (P<0,001).

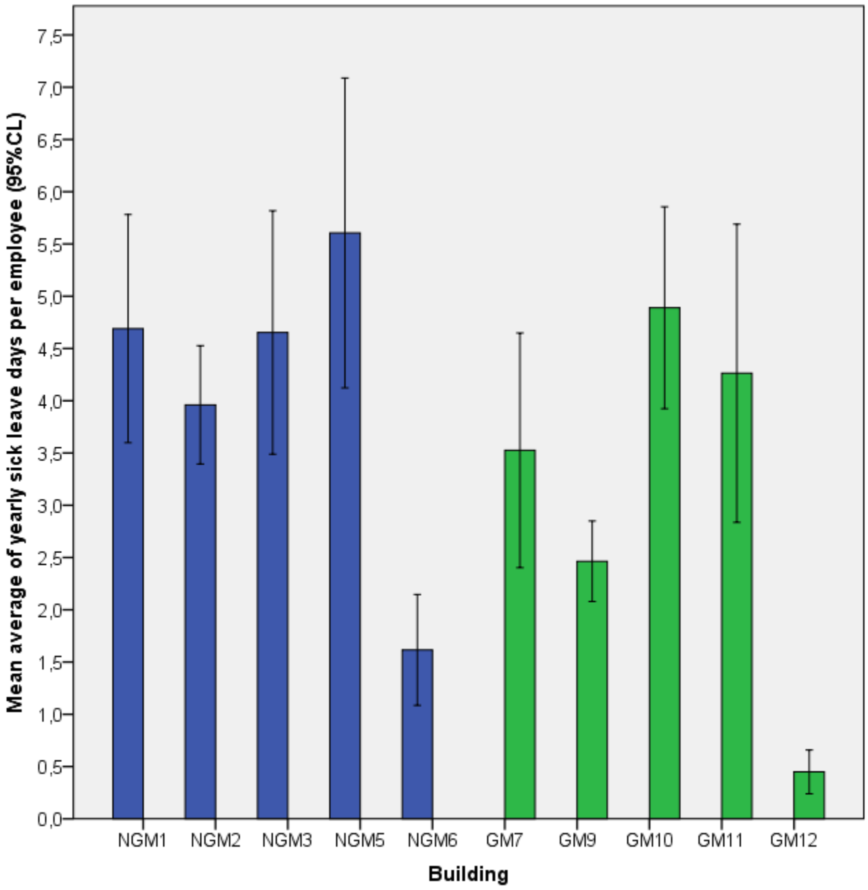



**Figure 73 – Annual sick leave for respondents in GM (Green) and NGM (Blue) buildings with 95% confidence interval.*The average sick leave in Singapore in 2010 was 3 days per year per office worker (Source: Ministry of Manpower, Singapore (2011)**

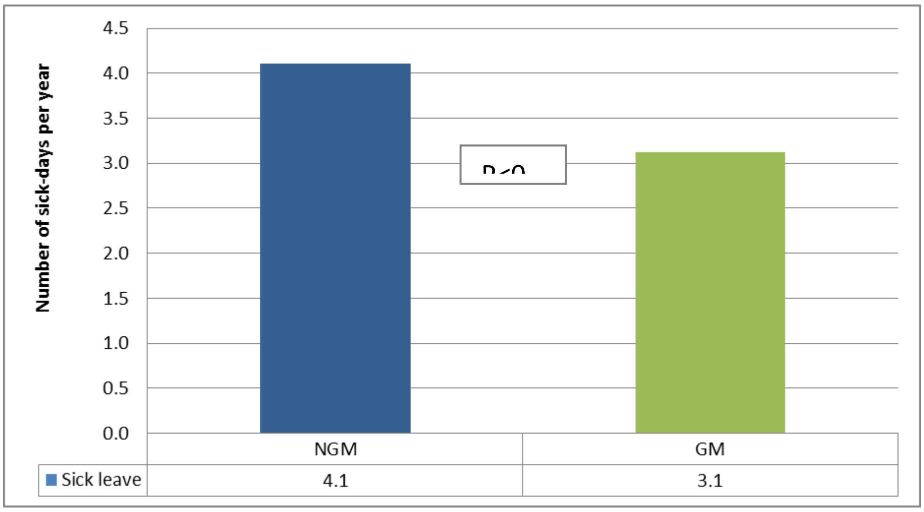



**Figure 74 – Average yearly sick leave for GM (Green) and NGM (Blue) buildings. P<0,001 (value obtained based on monthly data)**

When analysing the distribution of annual sick-leave data can be observed that most occupants take one day of sick leave per month (Figure 75)

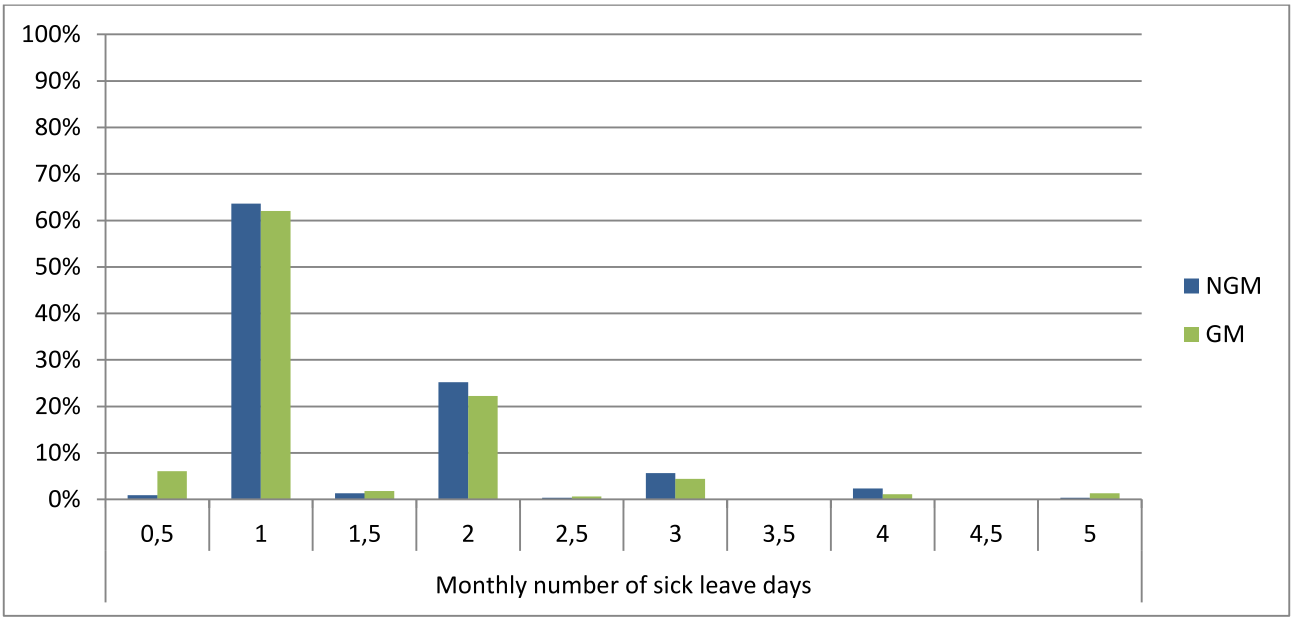



**Figure 75- Distribution of monthly prevalence of sick leave days.**

### 4.3.11 Green Mark assessment criteria

Assessment of the twelve buildings based on Office Interior v1.1 which has the most strict IEQ requirements, can be observed for the IEQ related features in Table 58. Mann-Whitney U tests were performed to compare differences between credits in GM and NGM buildings. It must be remembered that by law there are no statutory performance-based building indoor environment quality requirements in Singapore.

As can be observed in (Table 58) the number of credits for sustainability varies between a total of 7 to 14 in GM buildings (max score is 14). In NGM buildings the hypothetical score was made and the score vary between 0 and 3. This difference in scored credits is statistically significant with (P<0,004). In GM buildings IEQ scored between 21 and 24 points; the maximum possible score is 25 points. The score for NGM buildings varies between 8 and 15 points for IEQ. This difference is also statistically significant with (P<0,003). For the total score of IEQ related features GM buildings vary between 43 and 55, while NGM buildings vary between 16 and 26; the maximum score is 67. The difference between scores in GM and NGM buildings is statistically significant with (P<0,004).

| | | Max Point | GM7 | GM8 | GM9 | GM10 | GM11 | GM12 | NGM1 | NGM2 | NGM3 | NGM4 | NGM5 | NGM6 | Mann-Whitney (NGM/GM) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | OI V1.1 | GM | | | | | | NGM | | | | | | |
| Energy Efficiency | Lighting Power Budget | 12 | 12 | 12 | 12 | 11,7 | 12 | 10,2 | 6 | 6 | 6 | 6 | 6 | 6 | P<0,002 |
| | Lighting Controls | 4 | 3 | 4 | 3 | 4 | 4 | 3 | 2 | 2 | 2 | 2 | 2 | 2 | P<0,002 |
| | Other Features | 7 | | | | | | | | | | | | | NA |
| | Light Sensors | | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | P<0,056 |
| Subtotal | | 23 | 15 | 16 | 16 | 16,7 | 17 | 13,2 | 8 | 8 | 8 | 8 | 8 | 8 | P<0,002 |
| Sustainable Management and Operation | Office renovation conserve existing furnishing an flooring | 2 | 0 | 1 | 2 | 2 | 0 | 0,5 | 0 | 0 | 0 | 0 | 0 | 0 | P<0,022 |
| | Maintain at least 50% of existing furniture | 2 | 0 | 0 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | P<0,138 |
| | Use of sustainable products | 3 | 0 | 3 | 3 | 3 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | P<0,005 |
| | Post occupancy evaluation | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 0 | 2 | 2 | 0 | 2 | 0 | P<0,019 |
| | List of corrective actions | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | P<0,019 |
| | Greenery at common recreation areas | 2 | 2 | 0 | 2 | 2 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | P<0,006 |
| | Planter or potted plants | 2 | 2 | 2 | 1 | 2 | 0 | 2 | 1 | 0 | 0 | 1 | 0 | 0 | P<0,027 |
| Subtotal | | 14 | 7 | 9 | 13 | 14 | 8 | 9,5 | 1 | 3 | 3 | 1 | 3 | 0 | P<0,004 |
| IEQ | Conduct IAQ Audit | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 0 | 5 | 5 | 0 | 5 | 0 | P<0,019 |
| | IAQ management plan | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | P<0,019 |
| | CO2 monitoring | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | P<0,001 |
| | Sustainable and environmental friendly products | 4 | 2 | 3 | 3 | 3 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | P<0,002 |
| | Procurement policy | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | P<0,019 |
| | Lighting Level | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 |
| | Controllability of lighting system | 2 | 0 | 0 | 0 | 2 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | P<0,056 |
| | High frequency ballasts | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | P<0,001 |
| | Thermal Comfort comply with CP 13 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 |
| | Controllability of temperature | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 |
| | Internal Noise Level | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 |
| Subtotal | | 25 | 21 | 22 | 22 | 24 | 24 | 23 | 8 | 15 | 15 | 8 | 15 | 8 | P<0,003 |
| Others | Other Green Feature | 5 | | | | | | | | | | | | | NA |
| | VAV diffuser | | | 0 | 0,5 | | | | | | | | | | NA |
| | Green Wall | | | | | | | 1 | | | | | | | NA |
| Subtotal | | 5 | 0 | 0 | 0,5 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | P<0,140 |
| Total | | 67 | 43 | 47 | 51,5 | 54,7 | 49 | 46,7 | 17 | 26 | 26 | 17 | 26 | 16 | P<0,004 |

Table 58 – Credits according to Green Mark office interior v1.1 scheme in GM buildings and hypothetical score in NGM buildings

IEQ satisfaction is not directly proportional to the green mark score. GM10 has the highest GM score (Table 58), but can observed in (Figure 76) as not having the highest satisfaction scores. GM11 building is an energy-efficient office with several uncommon technologies as under floor air distribution, light pipes, etc, still the HEPA filter in the AHU did not improved air quality satisfaction (Figure 76), being the second lowest from all GM buildings (orange color). GM9 building has beautiful ocean views and evenly daylight, which was observed in the building, but also in this building there was several complaints of glare, causing headaches and eyesight pain and that can be seen in (Figure 76) where visual comfort has the lowest score in GM) building. GM8 and GM9 buildings have low occupant density, and GM8, GM9 and GM12 had the best aesthetics, openness and relaxing environment and satisfaction for these three buildings scored the highest (Figure 76). GM7 building had a good new indoor lounge but the office looked outdated, and that is also reflected on IEQ satisfaction (Figure 76).

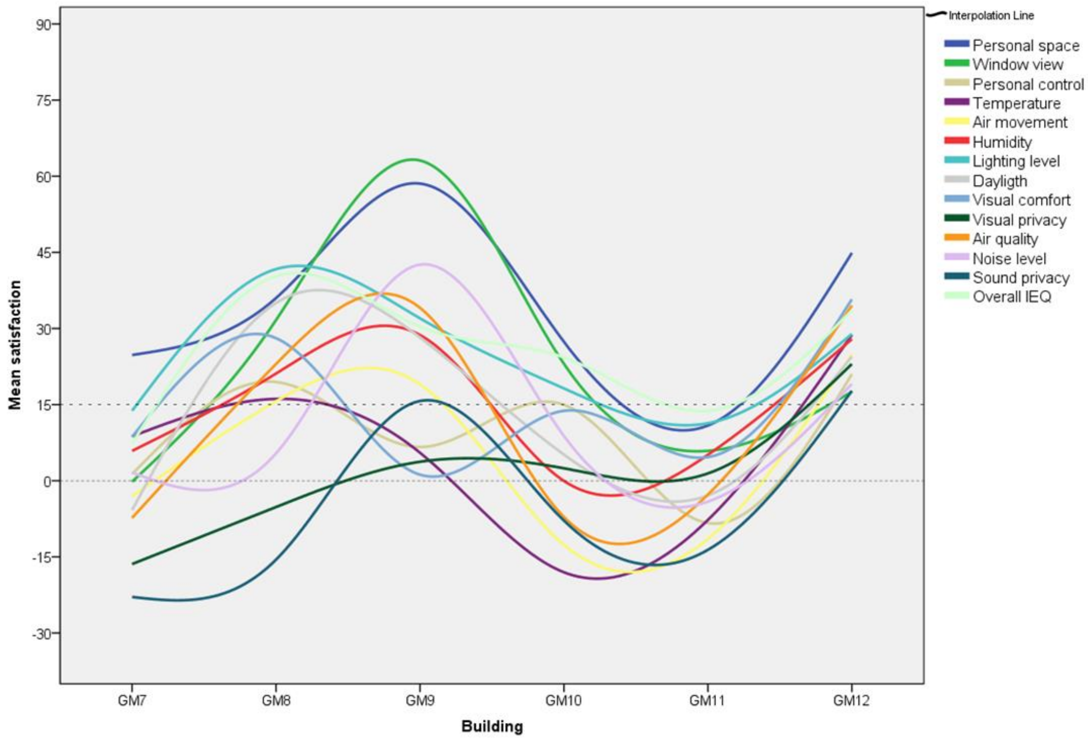



Figure 76 - IEQ parameters interpolation across GM buildings

IEQ parameters in NGM buildings are mostly below an upper limit of 15 (Figure 77).

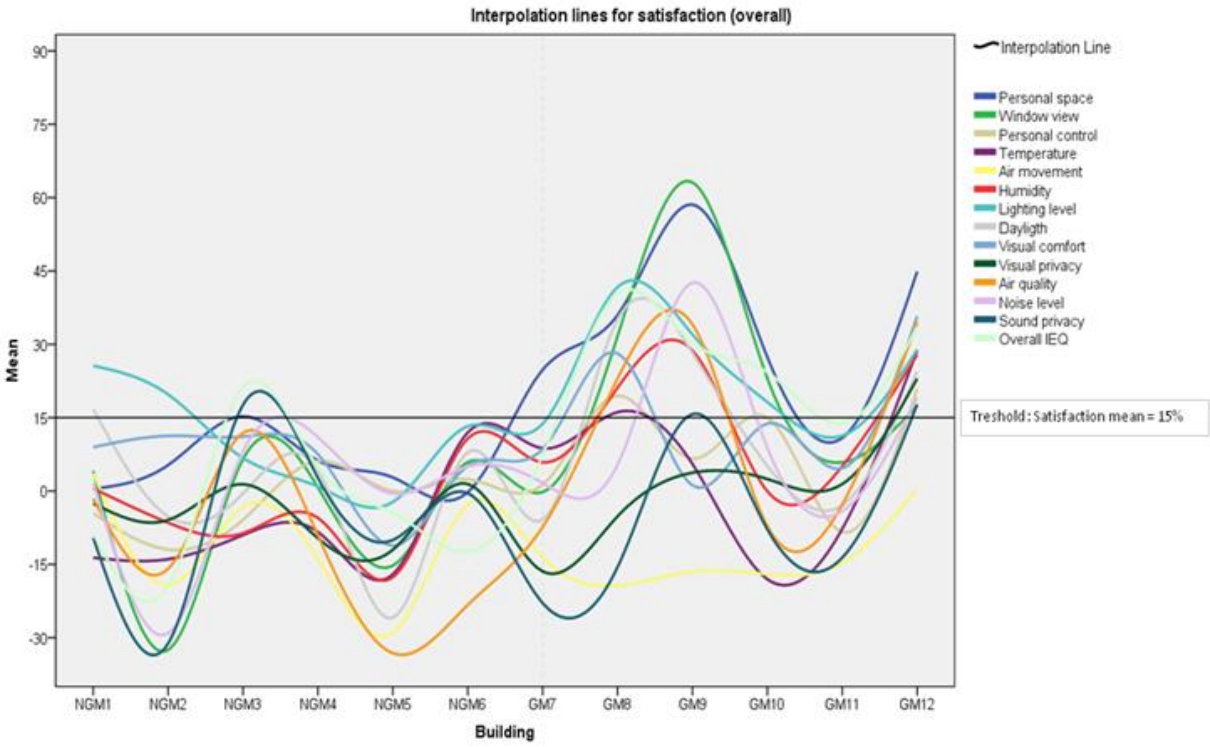



**Figure 77 – IEQ mean satisfaction interpolation across the twelve buildings: Six NGM and Six GM buildings**

### Interviews and open comments

The comments from occupants here are only qualitative, based on unmethodological and unstructured casual talks with occupants on both NGM and GM buildings, and so should be interpreted lightly, being more informative than scientific. The comments are summarized in appendix F.

# 5 Chapter – Discussion, recommendations and conclusions

## 5.1 Discussion

Green buildings are approached nearly as a faith, but there must be a distinction between law, beliefs and performance. With a new generation of millennials (born in the 80s), a generation of urban and young creative employees in offices, becoming the main workforce in companies, sustainability and IEQ becomes even more important for companies. A recent survey revealed that millennials are three times more likely to seek jobs in companies with good sustainability practices (Morgan Stanley 2015). For millenials, importance is shifting to an adaptive and healthy lifestyle. The same way, organic and healthy food has been replacing traditional food, healthy and peaceful offices are likely to offspring from the traditional office space, favoring comfort and satisfaction.

Buildings systems are becoming more complex and sophisticate. However it can be observed that somehow the design and connection with human performance, health and satisfaction in green buildings is not being advanced with the same pace as the pace in advancing building technologies, or not overlooked for economic reasons, even when it is expected to represent more than half of possible long-term savings in offices (Kats 2003a; Issa et al. 2010a). For a really outstanding built environment, occupants must be prioritized, and placed in the center of the design, energy efficiency cannot overshadow occupant well being. Recent schemes as the WELL building standard (Delos Living LLC 2014) are following this human centricity direction.

Green buildings are becoming more common. For example, by 2020 all public office buildings must be certified in Singapore, and by 2030, 80 percent of all buildings in Singapore are expected to receive Green Mark certification. In Singapore there are no statutory requirements for IEQ performance, only recommended codes of practice, which may be followed or not. The only performance based regulations are envelope thermal transfer value (ETTV). Despite that, all new buildings with more than 2000 $m^2$ of working area must achieve the minimum Green Mark category at least. But still this is no guarantee of good IEQ as GM certification of the office interior is not required. Only building level certification, which dedicates less than 10% of the total score to IEQ is required. Also usually codes of practices are not holistic, but individual performance-based standards without IEQ inter-correlations, which may not necessarily lead to a better IEQ perception (Kim et al. 2008).

The present PhD thesis compared IEQ, health, satisfaction and performance in GM and NGM buildings. There is large difference in subjective ratings of occupants between GM and NGM buildings. So it can be concluded that sustainability measures and certification scheme bring benefits to tenants. Even though in the present work credits for IEQ achieve on average only 70% of total possible, and there are no mandatory IEQ requirements in GM OI, GM scheme is still providing benefits as shown in the present work.

However, the relation of measured physical IEQ parameters in GM and NGM buildings in the present study, with subjective perceptions, satisfaction and importance is weak to nonexistent. The fact that physical measurements and subjective measurements revealed such a disparity in this study, may suggest social and psychological effects of IEQ on occupants. The fact that IEQ in GM buildings is rated better by occupants and no differences are seen as regards physical measurements poses the question whether this is because of the certification or because of other variables (e.g. stress, company, etc.).

Another topic when comparing green office buildings with conventional buildings a common topic is the so-called “Halo effect” or expectation effect of working in a green building compared to a conventional building, which is giving biased feedback of actual effect of conditions on response of occupants in a form of more positive response. In this work it was avoided to select buildings that were recently completed to minimize the impact of this effect

In the subsequent sections different aspects related to the conditions measured in GM and NGM buildings will be carefully discussed.

### 5.1.1 Physical measurements

One of the hypotheses of this work was that measured physical IEQ parameters are better in GM buildings compared with NGM. This hypothesis could not be fully verified as discussed below.

Thermal conditions

Temperatures in GM buildings are more constant, compared with NGM buildings. In GM buildings temperature was fairly constant around 24$^{o}$ Celsius, while in NGM buildings both overcooling and undercooling was observed. Previous studies in air conditioned offices in Singapore showed that 24.2 Celsius (*operative temperature) is the thermal neutrality response from occupants in Singapore (de Dear et al. 1991). This matches well the present results. In NGM buildings the temperature was rated not to be satisfactory by occupants, while in GM buildings it was rated to be satisfactory. Occupants perceived the conditions as being cold in all offices. Complaints about cold peaks were also reported.

All buildings in the study lack individual temperature thermostats as working areas are open plan offices. Some buildings have zone thermostats. There are many cold peaks. As reheating of air is not allowed in Singapore, these cold peaks tend to occur when there is high precipitation, and require costly technology to deal with as the typical fan-coil systems used have serious limitations when the relative humidity is very high outside in the Tropical climates. It is likely that in GM buildings the ratings of temperature are influenced by the events of cold peaks.

In a previous study (Seppänen et al. 2003) reviewed data and showed that there is no evidence that temperature variations within the comfort range affect worker performance considerably. When outside this comfort zone a decrement is more evident for high temperatures. This decrement however normally happens when temperature rises above 25 degrees Celsius (Seppänen et al. 2003), which was not observed (with the exception of one NGM building which was adapted from an industrial warehouse), so it can be assumed that the variations observe for both GM and NGM buildings should not significantly affect performance. However all data of (Seppänen et al. 2003) are based on the experiments in moderate climates. Also in previous studies even slightly low temperatures were associated with higher accuracy in simulated cognitive tasks (Witterseh et al. 2004). So the slightly cool temperatures in GM and NGM buildings may have also positive effect on performance of office work.

Thermal comfort in the workplace is derived from a combination of temperature, humidity and air flow. A problem in any one of these three parameters can in itself create discomfort for building occupants. Both humidity and air velocity registered were below the limit values recommended for GM and NGM buildings. Air velocity values were low, and that is reinforced by the perceptions of occupants indicating that the air was generally still both in the NGM and GM buildings. As air velocity was taken as spot measurements, it was not possible to characterize whether there could be periods of elevated air velocity as reported in the open question by some occupants. It is recommended that for assessment of air velocity in the future studies continuous measurements over a long period of time (e.g. one week) are made with fixed stands at desk positions for the heights recommended by the thermal comfort standard (ASHRAE 2004; ISO 1998) which are 0.1, 0.6, 1.1. and 1.7 meters

Ventilation

Outdoor air exchange rate had a high variance between buildings and are actually on the higher side. Some reasons for this are provided below. Building NGM6 is a warehouse with high natural ventilation that was adapted to an office building and ventilation is to a large extent occurring through infiltration as well. GM11 is a building with a very low density of occupants which may explain the high values of ACH and low $CO_2$ there. NGM4 and GM10 buildings have unoccupied sections on the open plan served by different FCU and AHU with likely low supply of outdoor air as the heat load are low due to the reduced occupancy in these zones. This creates an overestimated ACH. NGM2 and NGM3 use CAV systems while GM12 uses a VAV system and do not have a uniform occupant density which might explain the high rate of outdoor air per person.

| | | Mean Values | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | L/S Person | CO2 (ppm) | Formaldehyde (ppm) | Bacteria breathing zone (cfu/m³) | Fungi breathing zone (cfu/m³) | IAQ (Fresh (+) / Stuffy (-)) (-100 to 100) | Satisfaction with IAQ (-100 to 100) |
| Building | NGM1 | 3,2 | 921 | 0,02 | 658 | 137 | 2 | -2 |
| | NGM2 | 12 | 546 | 0,01 | 272 | 46 | -20 | -16 |
| | NGM3 | 10,1 | 677 | 0,04 | 191 | 85 | 1 | 12 |
| | NGM4 | 8,7 | 1033 | 0,03 | 543 | 110 | -12 | -9 |
| | NGM5 | 3,8 | 1002 | 0,03 | 391 | 107 | -34 | -33 |
| | NGM6 | 32,7 | 573 | 0,02 | 370 | 273 | -20 | -23 |
| | GM7 | 5,1 | 811 | 0,06 | 293 | 37 | -3 | -7 |
| | GM8 | 3,5 | 1053 | 0,03 | 161 | 60 | 23 | 23 |
| | GM9 | 5 | 768 | 0,03 | 371 | 88 | 32 | 34 |
| | GM10 | 5,3 | 1020 | 0,02 | 229 | 43 | -6 | -7 |
| | GM11 | 25,6 | 579 | 0,02 | 412 | 81 | -10 | -3 |
| | GM12 | 9,2 | 722 | 0,04 | 329 | 85 | 32 | 35 |

**Table 59 - ACH comparison with IAQ parameters**

$CO_2$ levels are generally below 1000 PPM for both types of buildings (Figure 24). All Green Mark buildings have $CO_2$ monitoring sensors for fresh air, but two buildings had values above 1000 ppm and never reached steady state concentrations, which is indicative of the potential control problems, so likely there is a calibration problem or control problem in the AHU system. Calibration of $CO_2$ sensors and testing should be implemented especially when conditions deviate substantially from design specifications.

Relation between ACH and IAQ satisfaction and perceptions can be considered as inconclusive (Table 59). Table shows that for example GM9 and GM7 have similar ACH but the air feels stuffy and fresh respectively. GG11 have a high ACH compared to GM8, but IAQ satisfaction is positive in GM8 while in GM11 is negative.  GM12 has high ACH and also high IAQ satisfaction. This can be indicative of different loads of pollutants and limitation of using purely ventilation to characterize exposures in the buildings.

Previous reviews have shown that low ventilation rates may increase SBS symptoms (Sundell et al. 2010). This is typically represented by higher $CO_2$ concentrations. In our case $CO_2$ concentrations are low (Table 59). Lower ACH might provide better IAQ if the outdoor air has high pollution. Even if previous studies have shown the benefits of outdoor air on productivity and health (Wargocki, Wyon & Fanger 2000), these studies were performed in temperate climates with good outdoor air quality. In Singapore several considerations must be taken on this issue. First the outdoor air has a very high relative humidity, characteristic of Tropical climates. Also outdoor pollution peaks do episodically reach hazard levels (BBC 2015). Singapore is a Tropical climate so high air change rates may also increase moisture levels or result in high energy demands to dehumidify the air  (Odom et al. 2009). Also for these reasons alone, the air change rate alone may not be the right indicator for acceptable IAQ.

Many schemes make use of codes of practice such as ASHRAE Standard 62.1 or EN15251 for ventilation and air quality criteria. In some it is a pre-requisite to meet standard requirements (e.g. LEED). In Green Mark scheme there is presently no performance requirements for ventilation, with the exception of $CO_2$ monitoring. Also In Green Mark office interior (GM OI) the mandatory IAQ audit based on SS554:2009 (Singapore Standards 2009) is  not a pre-requirement. The tenant does not have incentive to make corrective actions if necessary.

Contaminants levels

Most indoor contaminants originate from human activity, building materials  or contamination of the ventilation systems (Buttner & Stetzenbach 1993; Jankowska et al. 2000) and can cause illness, headache and allergic reactions to building occupants such as allergic rhinitis (Stetzenbach 1998; King & Auger 2002). Requirements for contaminants are presented in the Green Mark scheme through the IAQ audit in the office interior and existing building version following SS554:2009 (Singapore Standards 2009). In the present work bacteria and fungi concentrations are higher in NGM, with cases above recommended values; this is not the case for GM buildings (Table 24). All GM building had counts below 500 cfu/m3, but half still had values above WHO recommendations so a discussion to implementation mandatory lower upper limits on Green Mark office interior version is recommended, as these may affect health. Credits for regular maintenance and cleaning and mandatory enforcement of the IAQ audit results and post-hoc measures is an option. The IAQ audit is only mandatory in existing building version for re-certification and only based on a sampling at a proportion of all floors. At the tenant level compliance with the office interior version is not a pre-requisite.

CO and formaldehyde values were low (Table 25) below recommended limits in all buildings. While GM buildings are likely to use of certified materials which explain the expected low formaldehyde levels, formaldehyde levels in NGM buildings may be low because of the age of the offices.

Haze from neighboring countries has lead to extreme conditions the air quality in Singapore in the recent past, with occurrences of hazardous Pollutant Standards Index (PSI) levels recorded several times. There is no indication that reduced PSI is correlated with worse IAQ satisfaction in the present work (Table 60); it shows generally no relationship with PSI.

| Building | NGM1 | NGM2 | NGM3 | NGM4 | NGM5 | NGM6 | GM7 | GM8 | GM9 | GM10 | GM11 | GM12 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PSI | 72,6 | 70,6 | 71,7 | 67,8 | 45,1 | 45,2 | 77,4 | 62,9 | 78,3 | 66 | 40,2 | 56,6 | 66,3 |
| IAQ mean satisfaction | 2,0 | -20,5 | 1,3 | -11,8 | -33,6 | -20,1 | -3,4 | 22,5 | 32,2 | -6,4 | -10,2 | 31,8 | |

**Table 60-Average outside PSI levels for the every week of measurements (*Average from Monday to Thursday: 9:00-1200 and13:00-17:00)**

Table 60 shows that IAQ rating in more leaky buildings (NGM buildings) was lower as expected in relation to this moderate level of PSI. Green Mark buildings are more sealed and have much higher filtration efficiency of outside air so lower influence of poor IAQ would be expected there.

PSI is not an aggregate (integrative) index but simply the highest PSI among the constituent ambient pollutants that are measured in Singapore by the National Environment Agency. So on some days it may be determined by for example $PM_{2.5}$ and on other days by ozone. Also on some days it may result from high $PM_{2.5}$ and high ozone and on some days high $PM_{2.5}$ and low ozone. In the latter case PSI may be the same as in the former but the potential for the effects on IAQ can be different, so the PSI cannot either confirm or reject the hypotheses of negative effect of ambient air quality on indoor air quality. There would have to be detailed measurements of different pollutants to draw more definitive conclusions as regards ambient air quality and outdoor air. Still these observations suggest that more attention should be given to both the strength of indoor and outdoor pollution sources.

All GM buildings had the recommended AHU filtration. Filtration of ultrafine particles is overall better in GM buildings, as shown by lower $PM_{2.5}$ concentration (Table 27). The GM buildings with higher category AHU filters (Table 20) showed lower concentrations of $PM_{2.5}$. Half of GM buildings are close to recommended values (Table 27). The minimum recommended efficiency for primary AHU filter in the recommended code of ventilation in Singapore SS553:2009 is MERV5. If the PSI is above 100 a secondary filter is also recommended for outside air. For comparison in EN 13779 is recommend that in a polluted city environment for a high IAQ a double-stage filtration with F7 and F9 filter (EN 779:2012) is required and recommend together with a gas filter for molecular pollutants. F9 is equivalent to MERV16 and F7 to MERV13. In the recommend code for IAQ SS554:2009, the recommendations for the ventilation system are higher. A primary filter with minimum MERV6 category and secondary minimum MERV13 for ultrafine particles removal is recommended. Green Mark scheme in the existing building version has also a non-mandatory credit if MERV13 or higher is used. In office interior and new buildings there are no minimal requirements for filter category or filter maintenance.

Schemes do not address extreme sporadic pollution conditions. It has been suggested that a strategy based on reducing outdoor air supply and air cleaning for these peaks might be useful (Mudarri 2010). $PM_{2.5}$ is considered more dangerous to human health than $PM_4$ or $PM_{10}$ as they can enter the human blood stream (Miller et al. 1979). SS 554:2009 recommends a limit of 35 µg/m3 for $PM_{2.5}$ concentration indoors in offices, which was not always observed in GM buildings (Table 27). No statutory law requirements exist in Singapore for $PM_{2.5}$ concentrations indoors. Monitoring of particles inside the office premises is recommended to control for peak changes in outside pollution.

Lighting, Daylight and Glare

Lighting results are mixed in GM and NGM buildings. 66% of GM and NGM building have values below recommended value of 500 lux. Light uniformity is similar between GM and NGM. (Table 28)(Table 29) Most buildings have lighting system that consists of T8 lamps. Two GM building already had LED and other had a mix of LED and T5 lamps. Fluorescent lighting contains less "blue spectrum" wavelength which is highly relevant for human biology and concentration (Mills et al. 2007). Color temperature can regulate humor and the circadian system. It has been shown that higher color temperatures, which are characteristic of daylight, can improve mood and mental performance (Deguchi & Sato 1992). GM9 which had LEDs, had an average lighting level below 400 lux and average lux values were lower than any NGM building, but despite that, was observed during the measurements to have a good lighting distribution, being a very pleasant lighting set up to work on.

The link between natural light and comfort, satisfaction, wellbeing and productivity has been widely studied and published (Hwang 2010b). The absence of daylight can lead to higher stress also. (HMG 2003; Edwards & Torcellini 2002). It is commonly reported that low daylight levels is one of the worst IEQ parameters for satisfaction ratings. Natural light has been reported to be favored to artificial indoor lighting (Roche et al. 2000)**.** Unfortunately it was not possible to calculate daylight contribution, only observational perceptions in every building trhough the days presenetd at each building. Occupants rated daylight levels to be higher in GM buildings comared with NGM buildings. GM occupants also gave more importance to daylight compared to NGM occupants, and satisfation with Daylight was higher in GM (Figure 33)(Figure 34)(Figure 35).

Recommendations on daylight usually, as in SS531:2006 (Singapore Standards 2006) or EN 12464-1:2011(CEN 2003), are informative and advisory for good working conditions. GM requirements for daylight and glare control (new buildings version) are focused on energy savings and not human comfort. No post-construction analyses of daylight in GM are required. Daylight factor and glare unified glare ratio (UGR) (CIE 1995) are presented in Green Mark, but certification is only based on simulations values, and is seldom done. Daylight factor also does not take into account building location and façade orientation (Kota & Haberl 2009). Also UGR is not recommended for natural light but suitable for artificial light.

Daylight factor is used because of its simplicity, and there are no certified standard models for comfort and acceptability in certification schemes, but new holistic daylight calculation methods as Climate Based Daylight modeling (CBDM) (Mardaljevic 2006) can with location and building orientation more accurately predict heat gains, glare and natural illuminance. Another daylight metric also recently published is Useful Daylight Illuminance (UDI) (Nabil & Mardaljevic 2006) that uses a top-down from human factors to objective metrics. UDI uses yearly climate information to predict usefull illumination from natural light, but also predicts possible glare, excessive illuminance, artificial light needs and occupant discomfort. Discussion of daylight methodologies based on human comfort should be considered to be included in GM.

Quality of view is already described in LEED V4 but these are basically a criteria linked to daylight. GM buildings showed better satisfaction with window view, daylight and lighting levels for the same distance to outer windows (Figure 78). For glare, occupants closer to the windows in GM buildings had lower satisfaction (Figure 78), reporting average dissatisfaction with glare. This is consistent with previous results where highly discomfort with glare was reported (Hirning et al. 2014)

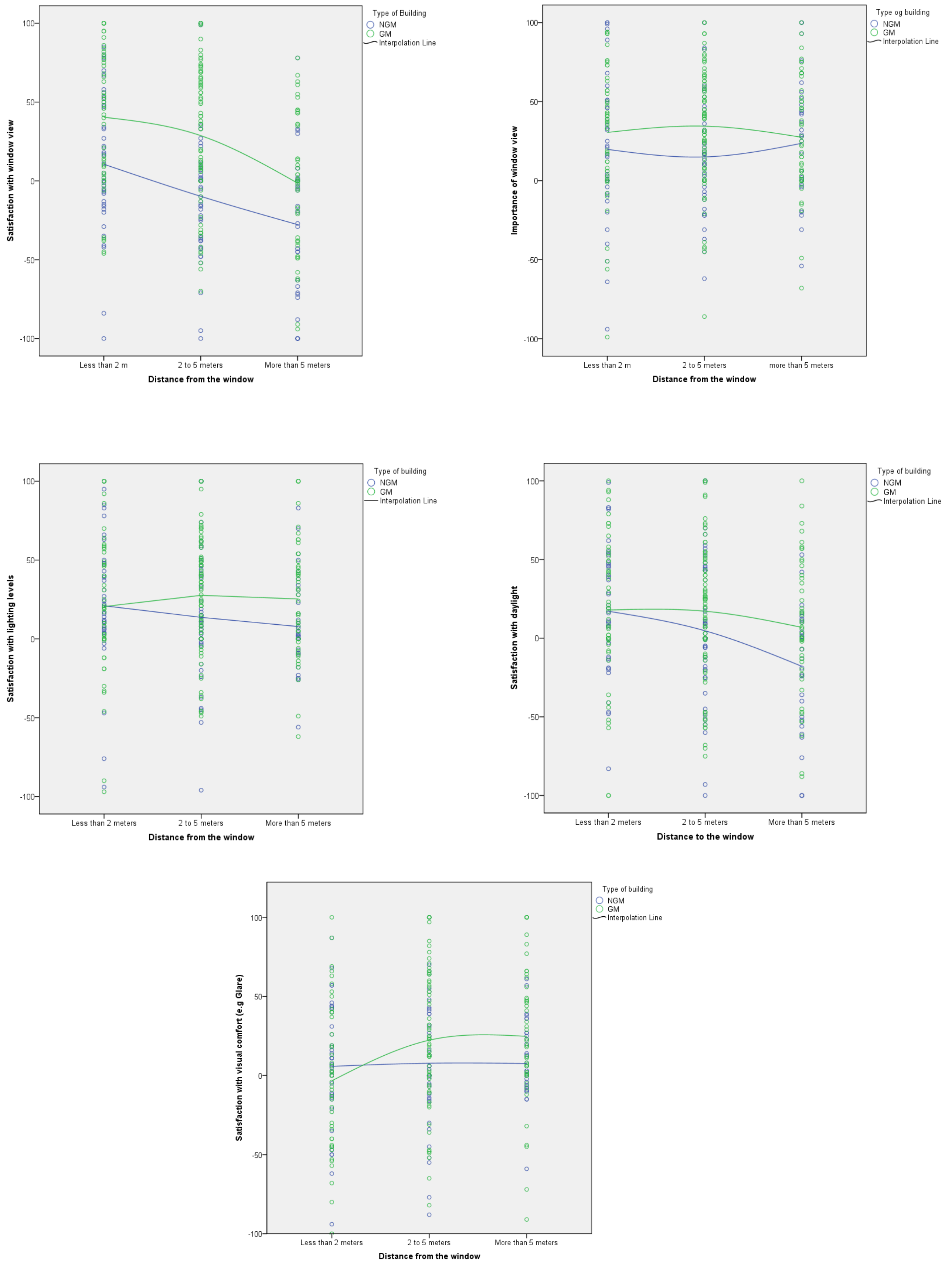



**Figure 78- Distance from window vs daylight satisfaction**

Recommendation in Green Mark for shading devices for visual comfort, might be useful, as has been shown to help reduce glare annoyance (Hwang 2010b).

LED glare, due to its specific intensity, is also a new topic, which in the present study was not examined but might become a issue has adoption of LED will likely become more common, and previous glare studies were mostly done using other light sources, with very different characteristics.

Intermediate conclusion

> It was hypothesized that measured physical IEQ parameters are better in GM buildings compared with NGM. This hypothesis is only partially confirmed. Physical measured parameters between GM and NGM did not differ significantly. Some of the IEQ exposures could ot be properly measured. On average, both types of building meet requirements by recommended Singaporean standards without significant deviations, IEQ parameters seemingly better controlled in GM buildings. Similar finding was also observed in the literature review, when physical measurements were performed in green and conventional buildings comparisons. It should be noted that all physical measurements were performed for a short time (maximum 4 days); It is unknown if the same conclusions would still derived from long term measurements, although since ambient conditions in Singapore are farly constant the 4-day measurements should well represent the actual typical conditions in the GM and NGM buildings.

### 5.1.2 Survey

Although subjective responses from occupants are biased by personal differences in opinions and preferences, they are a good tool to benchmark satisfaction. In this study perception, satisfaction and importance were benchmarked across a random group of NGM buildings and GM buildings. Results showed a normal response distribution with extremes in both the positive and negative responses being quite rare. The usage of tablets proved to be a good method to increase the response rate, but it increases a manpower cost, as ultimately there needs to be a liaison person reaching up to occupants with the tablets asking them to undertake the survey. The articulation of the tablets with the days of physical measurements is a good strategy.

Subjective measurements of IEQ satisfaction, IEQ importance, IEQ perceptions, health and self-assessment performance were significantly better in GM buildings, with several parameters reaching statistical significance. The findings of this study are contrary to the recent studies, where subjective assessment by occupants in a large database of buildings in US revealed no satisfaction differences between Green (LEED) and Non-Green buildings satisfaction (Altomonte & Schiavon 2013b) but are in agreement with the recent study of (Newsham et al. 2013b).

#### 5.1.2.1 Satisfaction, importance and perceptions

Three hypotheses examined in this PhD related to Green Mark certified buildings and their better performance as regards IEQ human perceptions, IEQ Satisfaction and IEQ Importance

Satisfaction ratings for all IEQ parameters were higher in GM buildings (Figure 33). All satisfaction ratings were below 40 when the possible maximum is 100 on a scale from -100 to +100. Overall, IEQ was assessed to have positive satisfaction in GM buildings compared with a negative satisfaction in NGM buildings.

Personal space, lighting and views were rated the highest. Sound and visual privacy had a negative satisfaction votes in both types of buildings. Temperature had a low positive score in GM buildings. In NGM buildings, most parameters had negative satisfaction ratings. On average occupant positive satisfaction prevalence with IEQ parameters in GM buildings is more than 60% compared with 40% on NGM buildings (Table 42). Occupants in GM buildings have a better overall satisfaction with IEQ which may also positively influence their productivity (Table 38). On average half of the occupants in NGM buildings are dissatisfied with overall IEQ (Figure 36).
PCA analyses showed that satisfaction in GM buildings can be grouped in four main components: environmental, social/psychological, lighting, and privacy (Figure 58)(Table 52). This natural grouping was not observed in NGM buildings, which may suggest that GM scheme implements a structure, an underlying construct to the ratings of satisfaction with IEQ.

All offices were open plan. Privacy both visual and acoustic are problematic in both types of buildings. These problems were already reported as far as 1982 (Hedge 1982) and from the evidence collected in the present work they still persist.

Glare (visual comfort) did not show negative satisfaction rating in GM buildings. Perception revealed "much" daylight in GM buildings compared with "little" in NGM buildings. Unlike previous studies where thermal satisfaction was shown to have the highest impact in on overall IEQ satisfaction (Lai & Yik 2007; Cao et al. 2012) in this study glare satisfaction in GM and air quality satisfaction in NGM are shown to have the strongest relationship with overall IEQ satisfaction. Air quality and glare have been shown to be highly proportional to IEQ satisfaction (Kim & de Dear 2012)

More than half of IEQ satisfaction parameters are not statistically significantly different in GM and NGM buildings, when a conservative model is used. If GM buildings are to be the best example, then they need to make sure that they are overall better on all different dimensions describing satisfaction. The results of this analytical approach tell us that something must be immediately done in GM buildings. Particularly satisfaction with visual and sound privacy, air quality and air movement which have negative values in at least two GM buildings (Figure 76) should be prioritized in the future development of the GM scheme.

Building occupants considered all IEQ parameters important in both types of buildings (Figure 34), air quality being the most important for both GM and NGM buildings. Air quality is likely associated by people to their health, and for that reason perhaps rated as the most important. In GM buildings air quality, visual comfort and lighting are the most important, personal control and humidity being the lowest. In NGM buildings views are the least important while air quality also the most important. On average IEQ parameters are around 5% more important for occupants in GM buildings. On average occupant positive prevalence for importance with IEQ parameters in GM buildings is more than 80% compared with 79% in NGM buildings. Neutrality prevalence is on average 14% in NGM buildings compared with 5% in GM buildings (Table 43)

<u>Temperature vs IAQ</u>

One other important issue is the impact of temperature on IAQ. Different relations are represented in Figure 79 and Figure 80 using LOESS (locally weighted scatterplot smoothing) regression curves (99% fit) to examine these relations.

The analysis is suggestive of a very weak relation between temperature and IAQ ratings for GM buildings. For NGM buildings there could be a combined effect of temperature, ambient and indoor sources on IAQ ratings.

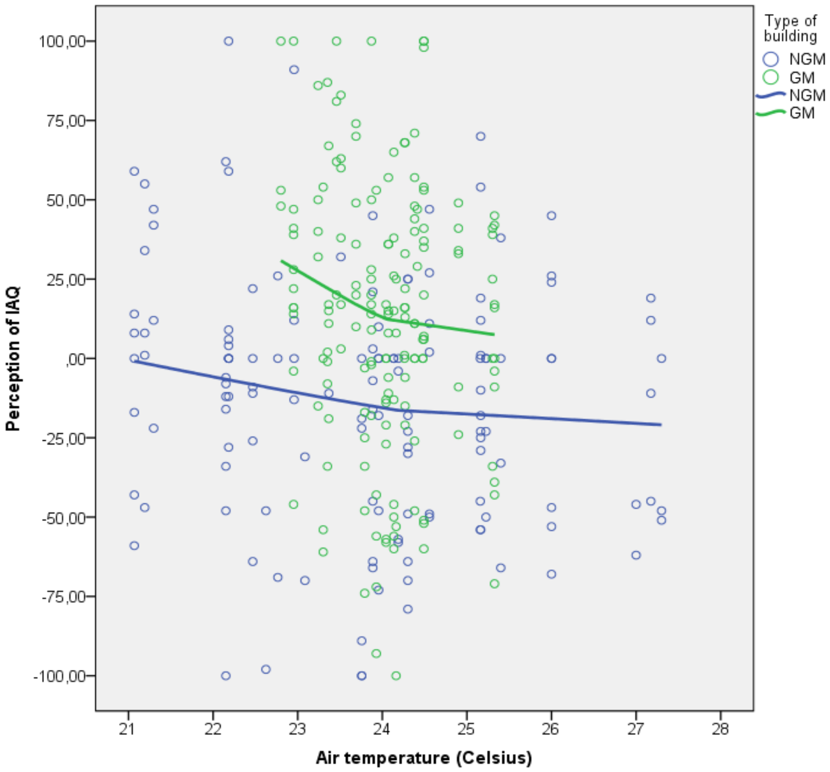



**Figure 79- Relation between air temperature and IAQ perception**

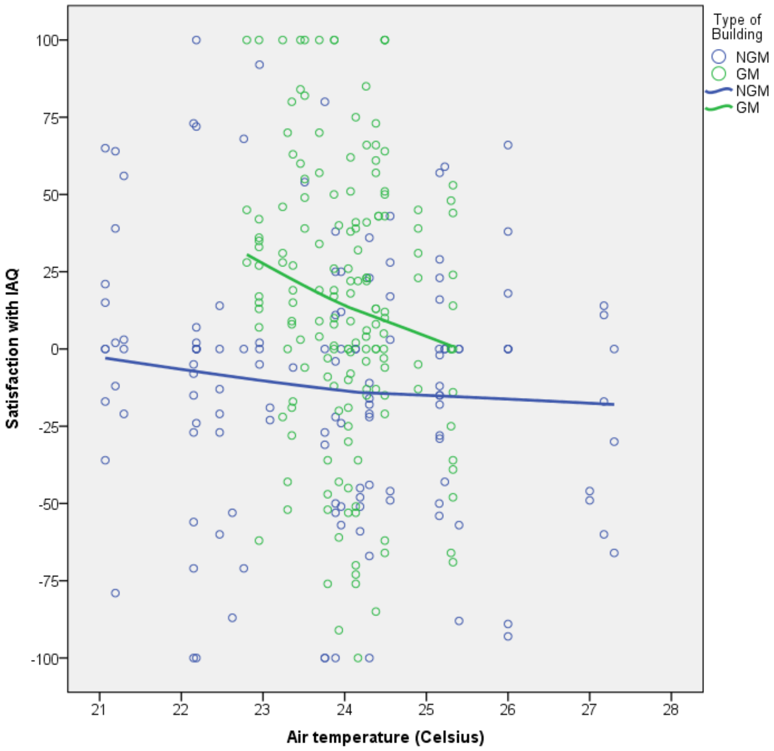



**Figure 80 – Relation between air temperature and IAQ satisfaction**

The influence of measured physical parameters did not show either a strong influence of temperature (Table 61) on IAQ satisfaction.

| | Stepwise linear regression - **Physical parameters with IAQ satisfaction** | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Unstandardized Coefficients | | Standardized Coefficients | | Collinearity Statistics | |
| | | B | Std. Error | Beta | Sig. | Tolerance | VIF |
| **GM** | | **R Square = 0,227** | | | | | |
| | Constant | 265,436 | 157,115 | | 0 | | |
| | Air temperature | -11,891 | 6,424 | -,181 | ,067 | ,877 | 1,141 |
| | Fungi air vent | ,662 | ,212 | ,295 | ,002 | ,941 | 1,063 |
| | Air velocity | 2337,157 | 798,518 | ,285 | ,004 | ,885 | 1,130 |
| **NGM** | | **R Square = 0,06** | | | | | |
| | Constant | -32,833 | 8,697 | | ,000 | | |
| | Bactria air vent | ,069 | ,025 | ,245 | ,007 | 1,000 | 1,000 |

**Table 61 – Stepwise regression between measured physical IEQ parameters and air quality satisfaction**

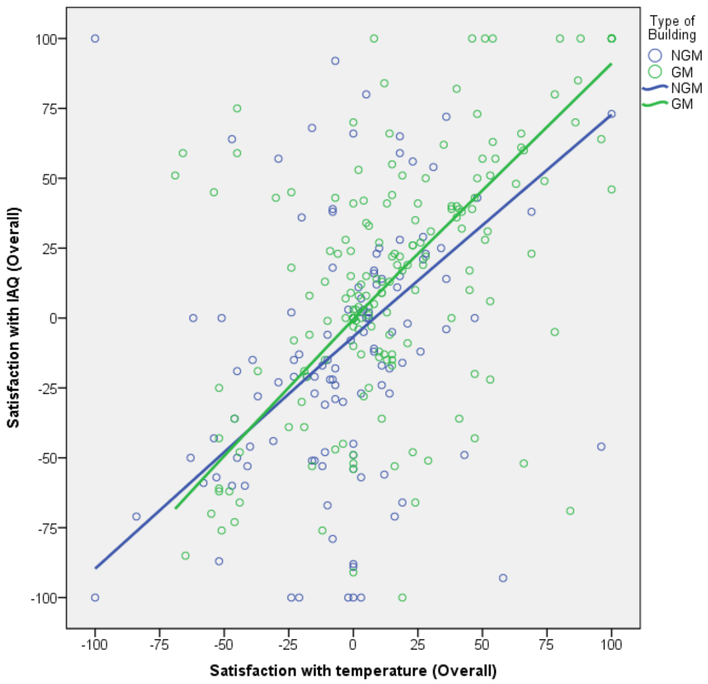



**Figure 81 – Relation between satisfaction with IAQ and satisfaction with temperature**

It is also very instructive to see a very strong correlation between satisfaction with air temperature and satisfaction with air quality in Figure 81. While there is a strong positive correlation between them it is difficult to establish causality. Because of the holistic aspect of IEQ, it is interesting to observe the most satisfied with IAQ are also the most satisfied with temperature.

Importance could help stakeholders to decide where they should invest as regards GM scheme and what is more important for occupants in GM buildings. Importance is a mix of psychosocial factors and local dominant effects. The fundamental is that occupants in GM buildings give more importance to IEQ parameters than occupants in NGM buildings, which is likely an indicator of higher expectations, but in both buildings the importance with IEQ uis still high. Importance can be used also as an underlying structure (based on psycho-social factor) for recommendations for GM buildings. Air quality was considered by occupants in both types of buildings as the most important IEQ parameter, which reinforces its importance in GM buildings.

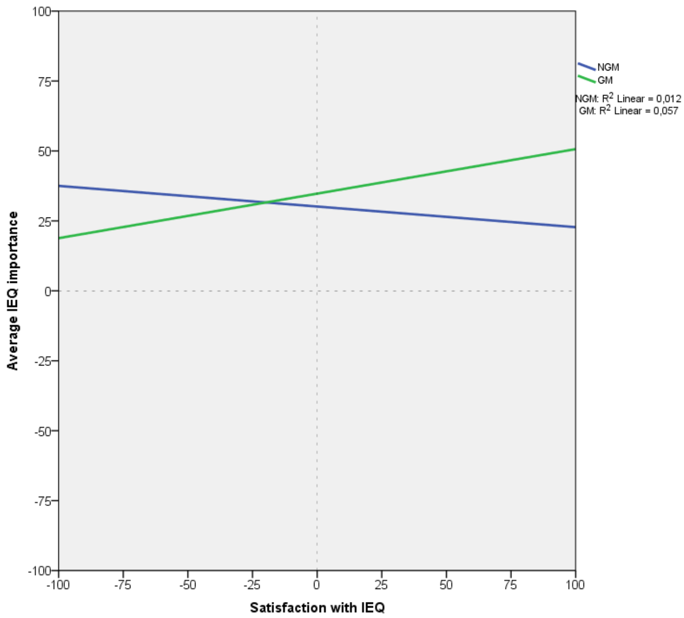



Figure 82 – Relation between IEQ and Satisfaction

A higher percentage of occupants in NGM buildings have neutral responses on satisfaction and importance. This reinforced the indication that occupants in NGM buildings may have lower expectations and pay less attention to it in their workplace. It can be observed in Figure 82 that while in GM buildings higher satisfaction with IEQ is related with higher IEQ importance, the same is not observed in NGM buildings.

Personal control was observed to be poor in both type of buildings, but it seems relatively not important to occupants compared to other IEQ parameters. In GM buildings personal control received the lowest rating of all importance ratings, and in NGM buildings the third lowest.

The social and physiological effect of these might help explain the difference in satisfaction and expectations in GM and NGM buildings. If a space is very crowded, this might lead to stress and dissatisfaction, creating a sensation of no privacy and stuffiness. Open and bright spaces, by natural daylight and interior colors, lounge areas, space between workstations help decreasing visual density and crowdness feeling. Views were also better in GM buildings, which might improve satisfaction and perceptions of IEQ. Previous studies indicated a positive impact of visual access to an outside view and employee satisfaction (Yildirim et al. 2007). GM buildings not only had more satisfaction with views but gave it a higher importance. Views will always be more a real estate decision than a quantifiable metric, but its positive effect should be considered.

The influence of IEQ on productivity was perceived by GM occupants more positively compared to occupants in NGM buildings (Figure 36). Sound and visual privacy were perceived poor in both types (Figure 35), likely as a consequence of occupants being in open plan offices. Temperatures were perceived cold, but still better in GM buildings compared to NGM. Noise, air quality, visual comfort, daylight, lighting have better perceptions in GM buildings, but only air quality is significant (Table 36). Perceptions in both GM and NGM building are in the range of -20 to 20 in a scale of -100 to 100. With the exception of daylight noise and air quality, generally differences in perceptions between GM and NGM buildings are small, compared to the difference in satisfaction, which may suggest an effect of social and psychological factors on occupants IEQ satisfaction, with more space, quieter environment, pleasant and natural feeling in GM buildings. The fact that air quality showed to be the most important IEQ parameter in GM and NGM buildings and the only significant difference in perceptions, strengthen the importance of air quality for occupants in offices. And also indicates that not only psycho-social factors but exposures and their differences between GM and NGM play important role in the causality (Figure 83).

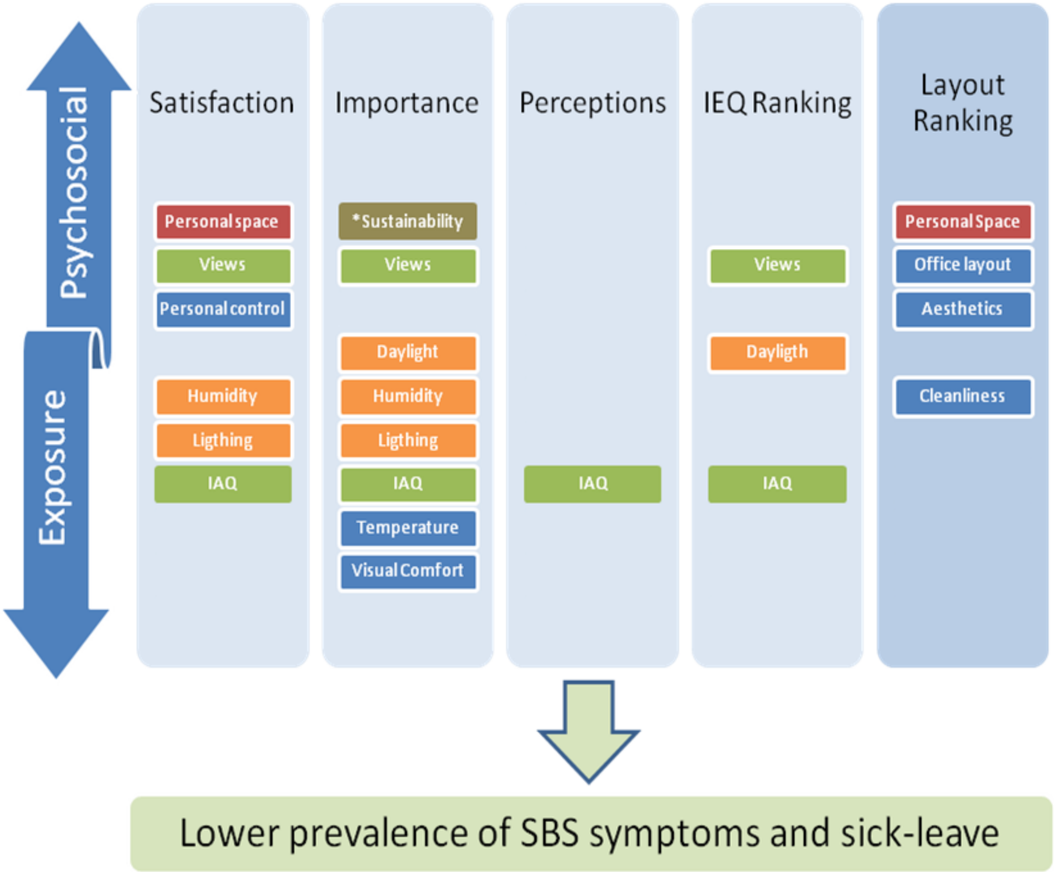



**Figure 83 – Statistically significant positive difference between GM and NGM buildings. Parameters are divided between exposures and psychosocial. Daylight is part of both.**

Through PCA analysis for satisfaction and perceptions, it can be seen that there is a better structure underlying framework that is perceived by the people and represented by their votes. Actually these are their votes that likely show that such a structure has been established using GM scheme on top of occupant mental IEQ organization. The framework established by GM scheme does result in an order – it is better to identify connections, what is not working and what does. This was not the case of NGM buildings. The question remains open, what in the scheme caused that such a framework was established.

Thermal, air quality, noise and privacy were selected by occupants as the most detrimental for their performance on both GM and NGM buildings. These results reinforce again the importance of air quality and temperature control.  Cleaning was also perceived by both occupants on both types of building as detrimental to their performance, but is a requirement difficult to be promoted in certification scheme. Cleanliness has been showed before to be proportional to IEQ satisfaction (Kim & de Dear 2012)

Intermediate conclusion

Occupants´ satisfaction, importance and perceptions of IEQ parameters are better in GM buildings compared with the NGM buildings and the difference can be caused both by the psychosocial factors and also the actual exposures.

#### 5.1.2.2 Sustainability

It was hypothesized that occupants in Green Mark buildings have higher sustainability consciousness and that occupants in Green Mark buildings will also thus accept to compromise IEQ for energy savings.

Sustainability consciousness is higher in GM occupants, has occupant in GM buildings consider working in a sustainability office more important than occupants in NGM buildings (Figure 41)(Table 38). The percentage of occupants tat consider important to work in a sustainable office is also higher in GM buildings (Table 43). More occupants in GM buildings reported that attempt to save energy at the workplace (Figure 41). Interestingly 23% of occupants in NGM buildings thought that they were working in a certified sustainable office while 35% of occupants in GM buildings thought they were not working in a certified sustainable office, which might indicate that the sustainability communication and engagement from tenants is not high.

While occupants in GM buildings revealed to be more energy-conscious, IEQ forgiveness did not revealed differences between NGM and GM buildings (Figure 42). Only approximately half of occupants in GM and NGM buildings indicated that they would accept reductions in IEQ for energy savings. Intervention study would be needed to verify this statement.

Intermediate conclusion

No indication that occupants in GM buildings would be more tolerant to suboptimal IEQ conditions, for energy purposes. Occupants in GM buildings have a significant higher Sustainability consciousness, compared to occupants in NGM buildings.

#### *5.1.2.3 SBS symptoms*

It was hypothesized that prevalence of building related health symptoms in Green Mark certified buildings is lower compared with NGM buildings.

Present results showed that building related SBS symptoms were significantly lower in GM buildings compared with NGM buildings (Figure 44), including fatigue, headache, problems with concentration, runny nose, irritated skin and sleepiness. If we considered the traditional classification of 20% threshold commonly accepted in the literature for SBS, the prevalence of “tired/irritated eyes” is high in GM buildings and also in NGM buildings. While artificial light and the monitor screen may cause this symptom, the effect of glare must be considered too. Glare can be considered a great concern in GM certification schemes, as seen by SBS symptoms. Difficulty to concentrate also showed high prevalence, but in this case the work load might be highly related. Odds of building related SBS symptoms are on average twice for NGM compared to GM (Figure 45). This is an important indicator and differentiator factor of GM buildings, showing superior performance of these buildings.

Intermediate conclusion

The hypothesis is fulfilled. Prevalence of building related SBS symptoms is lower in GM buildings.

#### *5.1.2.4 Performance*

It was hypothesized that Green Mark certified buildings perform better as regards self-assessed and objectively measured performance.

Self-assessed performance is higher in GM buildings in the less conservative model (Figure 49)(Table 50).

In NGM buildings there is no association between overall IEQ and performance while in GM buildings there is a positive trend (Figure 51).
Previous results have reported that self-reported productivity increased with better IEQ satisfaction (Agha-Hossein et al. 2013). This was partially observed for Green Mark buildings.

Objective performance measurements do not support the assumption that IEQ in GM is better than in NGM.
Compared to previous studies using computer-based versions of the D2 test (HELLWIG et al. 2014), the concentration performance results in the twelve buildings are above average. Occupants in all building can be considered to have high concentration performance. Because of time constraints, the D2 game only had 6 series of 50 characters each (6*50=300) when usually the D2 test has 658 characters. This might be one of the reasons for such a high performance across all buildings, together with the already described bias.

While it is true that poor IEQ will be detrimental for occupant health and performance (Li Lan et al. 2011; Wargocki et al. 2002; Seppänen et al. 2006) objective performance results did not showed relevant differences in the present study. This may suggest that the cognitive tests were too easy for the occupants or that there is actual no difference on performance. The games were short and only motivated respondents were selected (only motivated people completed the games. Only 73% of the people that complete the survey also completed the games, which might indicate that only motivated people completed the games, and such the minimal differences observed between buildings). Also motivated people will likely compensate poor IEQ with increasing of commitment and concentration as the test took less than ten minutes. For that reason results are inconclusive, and do not allow strong conclusions relating work performance with IEQ in GM and NGM buildings. This is an important result, as demonstrated that measuring work performance in cross-sectional studies following traditional methods used in intervention studies represents a challenge.

The negligible performance difference between GM and NGM buildings does not show causality for the effect of IEQ on performance between GM and NGM buildings. One complex topic in human performance evaluation in recent office buildings is what constitutes productivity in the modern workforce, and how can quality can be differentiated. Occupants have abilities that can be decremented by the environment to a higher or lower degree, and this is what we wanted initially to observed, whether GM buildings do it to a lower degree. A larger sample size is likely necessary to observe differences between both types of buildings.

Intermediate conclusion

> The hypothesis is not fulfilled. Objective performance did not show difference between GM and NGM.

### 5.1.3 Sick-Leave/Absenteeism

It was hypothesized that Green Mark certified buildings perform better as regards occupant sick-leave.

Absenteeism was lower in Green Mark buildings (Figure 74). IEQ can be considered as an influencing factor, IEQ alone is not the only reason that influences sick leave.

Sick-leave is a good indicator to support the investment in green buildings, as it can be easily quantified. The estimate value of 266 SGD of savings per year (Table 62) was calculated, which might be higher depending on the salaries in each company. Unfortunately was not possible to gathered salary data on the twelve buildings used. The reduction of 25% lower sick-leave in GM buildings observed in his study is consistent with the sick-leave results observed on the literature review on chapter 2.

| Productivity benefits of reduced sick leave | |
|---|---|
| Fewer sick leave days in Green mark | 1 |
| Average working days Singapore | 260 |
| Median monthly salary for a professional in Singapore in 2013 | 5769 SGD |
| Annual Savings per employee | 266 SGD / 176 € / 1310 DKK |
| Source: http://stats.mom.gov.sg/ | |

**Table 62 – Productivity benefits of reduced sick leave. * Management excluded**

Intermediate conclusion

Annual sick leave is one day lower in GM buildings compared with NGM buildings

### 5.1.4 Green Mark Score

Actual IEQ requirements in Green mark OI, which is the most demanding related to IEQ, do not aim for high outstanding IEQ, but a reasonable set of parameters that are typically of codes of practices, which are not difficult to achieve or considered unreasonable, supplemented by some sustainability points. All the six GM buildings have similar total score (Table 58).

GM buildings scored high in IEQ, which revealed a commitment to IEQ. But despite scoring almost the maximum in IEQ, there is still high variation within GM IEQ satisfaction, which suggests that Green Mark score alone will not guarantee a good IEQ satisfaction among occupants. Also GM scheme is very modest in IEQ demands, because they follow a standard for good code of practice which has compromises. It is not set for outstanding requirements.

Design weightage is also much higher than operation (performance based) requirements. The use of sustainable materials in GM buildings will lead to lower emissions, which potentially lead to better IAQ. Sustainability and greenery score is higher in GM, which contribute to the building related social and psychological effect on occupants.

The criteria concerning indoor environment quality in the Green Mark certification scheme should be set sufficiently high to promote satisfaction, health, comfort and performance, if used together with sustainability and commitment.

Visual and acoustic privacy, temperature and glare control should be addressed in the Green Mark scheme. These factors as seen by the results can compromise IEQ performance in GM buildings and would be beneficial if presented in Green Mark

From the results it is not possible to conclude if the IEQ benefits on employees' satisfaction and productivity are higher if an office has higher green mark certification credits, as all GM buildings received a similar score.

## 5.2 Recommendations

Present chapter shows recommendations. It introduces a framework for crediting points based on occupant satisfaction, OCEAN concept and recommendation for changes on the survey.

### 5.2.1 Framework for crediting points based on occupant ratings

The discussion below shows the potential framework for crediting satisfaction and symptoms. It can be called a human related framework for the GM scheme in an office interior version. Crediting points for occupant satisfaction based health symptoms and PCAs analyses over satisfaction results, weighted on the different variance associated with PCA components.

The method is based on a benchmark system. Anonymous surveys, distributed online from the regulator to each building management would create a database, similar to what was doing on this study for 12 buildings. Building tenants would not have access to raw data, but would have access to the results, and the possibility to take corrective actions, similar to what is already present in GM OI. With the data gathered from the surveys on GM OI Platinum buildings, average benchmarks and PCA components would be updated every 2/3 years. An example following the results of this study is presented:

In this study, it was observed that for all IEQ parameters the average satisfaction in GM buildings was 13% and as seen in (Figure 77), 15% is the upper end satisfaction of any IEQ parameter for NGM buildings. So in this case, a satisfaction threshold can be established at the 15% level for good satisfaction. This value is established based on benchmark results, so it can be updated through the years. The distribution of points ($BRHSS$) can give a total of 4 points. One point for completion of the survey, independently of the results, which would incentivize tenants, a maximum of two points for satisfaction and plus or minus one point for building related SBS symptoms. The calculation would follow as:

1. PCA results which is a sum of satisfaction using the PCA components, i.e. for each component each IEQ parameter with an absolute loading higher than 0,4 would be weighted for the final PCA satisfaction score:

$$PCAR_n = \sum_{|\alpha|=0,4}^{|\alpha|=1} IEQ_{n\alpha} \times \frac{loadings\ PCA_{n\alpha}}{\sum loadings\ PCA_{n\alpha}}$$

2. Building related SBS symptom score ($BRSBSS$) would add 1 point if all SBS building related symptom have a prevalence below 20% and subtract 1 point if any symptom has a prevalence above 20%:

$$BRSBSS(Building\ related\ sick\ building\ symptom\ score) = f\left(\sum x_\theta\right)$$
$$= \begin{cases} -1, & \ni\ \exists\ x_\theta > 20\% \\ 1, & \ni\ \forall\ x_\theta \leq 20\% \end{cases} \{x = symptom\}$$

3. The final score would follow an hierarchical model with the sum of participation plus satisfaction plus health. Satisfaction can give a maximum of 2 points. For each PCA component ($PCAR_n$) if the results are above 15%, will then be weighted based on the total explained variance of that component:

$$BRHSS(Building\ related\ human\ satisfaction\ score$$
$$= (1\ Point)_{Complete\ survey}$$
$$+ \sum_{n=1}^{n=total\ components} \left((2\ Poinst) \times \frac{PCA(\%)_n}{\sum PCA(\%)_n} \{PCA(\%)_n = 0\ if\ PCAR_n\ \leq\ 15\}\right)$$
$$+ BRSBSS$$

Based on the results of this study (Figure 84) shows the points each PCA would give in this study, if their satisfaction were above 15%. The necessary response rates are a more subjective pre-requirement. While in this study a sample of 30 respondents was defined, a minimum percentage is more appropriated. A minimum 51% of occupants can be a good choice as would represent more than half of the tenant population.

After the database has maturity a pre-requisite can also be implemented. i.e. GM OI Platinum would only be attributed if a building got at least 1,5 points on this human related framework.

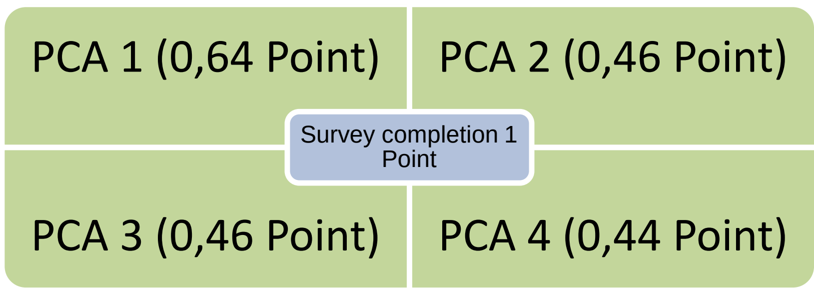



**Figure 84 – POE survey credit scheme* Example of possible credits in the buildings of our study**

### 5.2.2 Ocean

Taking action to increase sustainability in the building without thinking on occupants will most likely lead to failure on the well-being of occupants. Rental and running costs are undoubtedly essential conditions linked to the company wealth, but the primary building condition should always be the responsibility and goal for a healthy environment. Higher management concerns on running costs than occupant comfort will make employees liabilities instead of assets. Good IEQ is tomorrow value and profit. Based on the results of this study, review of GM scheme and critical thinking on the human centricity topic in green buildings, the O.C.E.A.N concept (Figure 85) model was idealized for the future and is recommended. The O.C.E.A.N concept was idealized using the findings observed on this study, such as privacy problems and the importance of social and psychological effects on IEQ perceptions, but must be observed that only some elements discussed on the O.C.E.A.N method were studied. What is suggested in the O.C.E.A.N is and holistic approach to green buildings, and is a recommendation for the future, as the concept is not yet validated. The measurements of this study weigh towards the environment part of O.C.E.A.N. It is also recommended that future cross-sectional and cohort studies try to validate and update the method.


**Figure 85 – O.C.E.A.N concept**

## O as Organization

### Green buildings and human performance

It is common to refer that good IEQ can improve productivity, so organizations should take it into account. This includes everything from good air quality to lounge areas to unwind, places to brainstorm etc. Integration team and strategies are important for the final result since the pre-design phase.

Employees' long term costs and benefits from the possible outstanding IEQ green buildings must somehow be introduced in initial budget figures. Without this information, the influence/weight of IEQ may not grow in the expected pace.

### Innovation and Research

Smart design and innovative solutions that achieved improvements on long-term well-being and comfort of occupants should be considered by tenants and accommodated and credited as optional points in GM. Extra features are already presented in GM OI but it only corresponds to 4% of the total credits. The social-psychological effects of art, lounges and greenery are expected to highly improve IEQ satisfaction; it was observed in this study. Innovation should be a two-fold evaluation: Design phase assessment and post-occupancy observation.

Fundamental research on economics, IEQ and sustainability is difficult for small owners/tenants. Research used and marketed in certification schemes results mostly from the research in universities and research institutes. Because collaboration between universities and tenants on the topic are scarce there is a lack of verifications and uniform conclusions. In real estate there is a lot at stake, as even small changes might have big costs, but surprisingly there is a lack of research comparing the IEQ benefits of green buildings compared to conventional ones, and how and where IEQ strategies can have positive difference. The last WGBC report "Health, Wellbeing & Productivity in Offices" (WorldGBC 2014) is an example, as most of the results presented in this report are summaries of building research, done in the past, but not specifically research comparing the performance of green buildings with non-green. Making POEs both for design and post-occupancy results and benefits available to all in a transparent form, may help tenants on their IEQ organization and goals of renovation and new office space.

**C as Commitment**

**The open office**

While an open plan office can have a positive effect on productivity when there is a friendly atmosphere between coworkers, due to the social behavior of people, improving collaboration and free-flow of ideas, it is also a source of unnecessary distractions and interruptions, and lack of privacy. Open plan offices have extensive list of positive aspects (e.g. communication, flexibility, sense of community, easier interaction, socializing etc) and then same amount of negative aspects (e.g. noise, distractions, privacy, personal space etc) that have been discussed extensively in the past years (Maher & von Hippel 2005; Brennan et al. 2002). In the present work all offices were open plan offices. In Singapore the majority of office space is actually open plan, as the price per sqm makes it prohibitive to attribute single offices to occupants in most companies. This is probably the deciding factor in most companies nowadays, as rentals are very expensive in developed countries/cities.

A well-designed workspace will increase satisfaction and productivity. Although in this study, all offices were open plan, the survey results showed a higher percent of respondents in GM buildings were satisfied with their IEQ and reported that their workplace allowed them to perform better. This is an important argument showing that Green Mark Scheme brings actually benefits also in open plan offices.

Open plan offices are advocated for greater communication and openness in relations, where people can move around to interact with colleagues, which supposedly leads to more teamwork. The problem is when an open plan office becomes oppressive without any privacy. Results of this study showed the privacy both visual and acoustic, and noise are rated and perceived as the worst. Recent studies showed occupants´ frustration with lack of sound and visual privacy (Kim & de Dear 2013). Lack of privacy and noise in the open-plan offices can also reduce concentration of employees. According to a recent research, 50% of employees in open- plan offices cited the lack of sound privacy as the most frustrating IEQ aspect (Kim & de Dear 2013). Also when occupants are exposed to too many inputs simultaneously, will require from them more work to given results (Davis et al. 2011). Open-plan offices may also lead to more superficial discussion because of the sense of lack of privacy (Fayard 2011)

Health can also be an issue in open plan offices. A recent Danish study found that self-estimated sick leave was significantly related to number of occupants in the working space. Compared to single offices, occupants in open-plan offices (>6 persons) had 62% more days of sick leave. (Pejtersen et al. 2011)

But not everything is a downside as open plan offices also bring benefits. Creative workers (e.g marketing, social media) may prefer an open plan layout mixed with private rooms where they can retire sometimes. Natural daylight and views to the outside are easier to provide through all office, and previous studies have shown, that occupants overall prefer daylighting for visual acceptance, and also those working under artificial light become sleepier compared to those in a natural environment (Borisuit et al. 2015). Views to outside nature have also been documented to improve productivity and health (Grinde & Patil 2009)(Mayer et al. 2009).

Open plan offices are unlike to disappear in the foreseen future, not because of the advocated concepts, but because of economical reasons. This ultimately might be the sole reason to keep open plan offices, especially in countries like Singapore. Consequently, alternative workplaces strategies to address noise, visual and acoustic privacy complaints observed in this study as being a general problem of certified buildings should follow four main recommendations addressing Consent, Proximity, Tolerance and balance, and Privacy, as shown in (Figure 86). These four recommendations, were not studied in this project, and are only a result of observational thinking.

**Consent**

- Occupants are submerged in company policy for interactions with colleagues and working etic on the open plan.
- People should feel comfortable for their type of work

**Proximity**

- Ample space between workstations
- Derpartmetn sections semi-segregagtion (i.e. island on the open plan)
- Ample circulation areas within the open plan to avoid unecessary disturbance

**Tolereance and balance**

- Flexibility as the open plan area will likely see changes through the years
- Employers and employees must be supportive and accodomate each other needs as possible.
- Balance open spaces with enclosed areas, as private offices and relaxation areas
- Avoid high occupant density

**Privacy**

- Possibility to work without imterruptions when necessary
- Ability to have private conversations if needed
- Visual Privacy
- Quiet spaces should always be available

**Figure 86 – Alternative workplace strategies**

It should be able to make private conversations, so breakout areas are fundamental. Also public areas for unwind and isolation for complex individual work should be available when possible and when economically feasible. Functional environments with at least some private areas may increase the leasing cost, but if there is an increase of productivity the costs will pay off. Findings from a recent survey in US showed that a mix of alternative working spaces was reported by occupants as to increase the focus and collaboration (Gensler 2013).

Layout system indoors should be based on a dynamic concept with multiple layout design, where employees can choose the level of disturbance as much as possible: The main open plan, where employees are based, small meeting rooms integrated in the open plan, not necessarily enclosed spaces but then securing acoustic privacy, large enclosed meeting rooms, quiet/private spaces for 1/2 persons for highly concentration work, conversation island where a reduced number of employees can move for short discussions and brainstorming with some degree of privacy, short stay VOIP enclaves, and finally lounger areas both indoor and when possible outdoor for relaxation.

Good open plan offices need also good personal space. Findings of this study revealed (Figure 87) that satisfaction with personal space is positively related with IEQ satisfaction, independently of whether the building has got Green Mark certification.

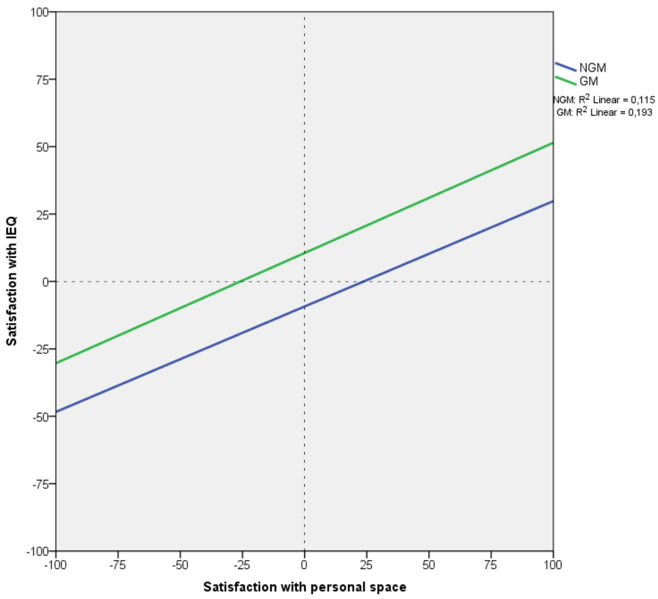



**Figure 87 – Relation between personal space satisfaction and IEQ satisfaction**

**Privacy**

Workers enjoy privacy in order to manage distractions and also to keep work/information confidential both personal and corporative. These both aspects have become more difficult as high density and open office trends have become a norm. This is why a diversity of spaces in the office is even more fundamental, where at least people can retreat when they really have that desire. Workers need for privacy and sharing must work in harmony, they always complement each other so is difficult to define an optimal workspace. Too much concentration or discussion will exhaust the brain so moving and change between different set ups will at least minimize that effect. The office must work as a balance ecosystem where workers can move to different layouts of privacy to fulfill their needs. Even If economic reasons may not allow providing such private spaces for everyone, everyone should be able to find one when really necessary.

Personal space and borders is also important. It was observed during the field measurements in this study that in offices with lower density where there is higher physical distance between workers, there is a more natural and relaxing environment.

Ultimately privacy is contextual to each occupant and that's why is important to provide difference work spaces layouts as described above. Mental privacy might be difficult to achieve for some occupants if they are surrounded by colleagues without the possibility to retreat. A recent survey on more than 10500 workers all over the world showed that privacy is an issue that does not fulfill employees' needs: 95 percent identify work privacy as important but only 41 percent said they can have that opportunity and 31 percent of workers routinely leave the office to get more privacy to work (Steelcase 2014).

If they are requirement regarding privacy they should have a similar weight and number of points as air quality and temperature, if the objective is an outstanding IEQ. Recent technologies like privacy and screen protectors are a good recommendation to improve visual privacy. It might be seen as redundant by the company management but as seen in this study privacy is generally rated unsatisfactory by occupants.

**NOISE**

In this study noise was perceived close to neutral in GM buildings and loud in NGM buildings. It was clear by employees' comments in that noise is a major negative aspect of their workplace. Without effective acoustical solutions, the negative impacts of noise will most likely negatively affect productivity and well-being. All the offices in this research, both GM and NGM are open plan, so the major source of noise will be people's conversations, which is inconstant and so more distracting. Open plan can lead to excessive noise as seen in this study. Constant interruptions because of noise have a negative impact on productivity (Zijlstra et al. 1999). Noise was showed in this study also to cause dissatisfaction between occupants in NGM buildings.

Occupant noise is difficult to legislate as is strongly correlated with design and conscience, so credits must be given as innovation in workplace. Still a weight of quiet collective and individual areas area per office sqm might be effective metrics rewarded in the green standards. Green Mark points for acoustical environment should improve sound privacy and are recommended. Noise reduction can also be through absorption elements as ceilings, panels, sound masking as natural white noise, partition greenery etc. Noise isolation from AHU rooms is also needed. Wireless headsets also might decrease noise. In one GM building was observed that was common for people to move to private and lounge areas when having conversation on the wireless headset.

Greenery might also be used to absorb sound (Asdrubali et al. 2014) and also increase visual satisfaction. Recent research has showed that green walls are very likely to absorb noise and used as acoustic insulation indoors as they showed similar or better acoustic absorption properties than other common building materials (Azkorra et al. 2015). Small greenery separating areas integrated on the partitions in the open plan might be considered. With this last solution air quality, aesthetics and psychological wellbeing will also improve. Maintenance costs will however increase and humidity control will be more critical in countries like Singapore.

**E as Environment**

Design-based codes of good practice and/or standards from US, Europe and Singapore (ASHRAE 2010; CEN 2007; Singapore Standards 2009) are already widely used in green building schemes as they attempt to ensure improved IEQ. However, mandatory compliance with the standards related to IEQ is not always required, as e.g., in the case of Green Mark scheme. A critical discussion should take place involving all stakeholders so as to mandatorily enforce such codes for critical areas for IEQ such as thermal comfort, ventilation, filtration etc. The need to create a minimum set of pre-requirements that must be met to be eligible to get a certification level. Certifications scheme could in this way work in a weighted progressive path: first an initial assurance of minimum good IEQ (mandatory prerequisite), then extra features that improve comfort and increase innovation of solutions for improving IEQ (credited with extra points in the scheme). Pre-occupancy performance evaluation should be mandatory, instead of only design-based requirements. Pre-occupancy indoor air monitoring is already present in some versions of several schemes (DGNB n.d.; USGBC n.d.; BREEAM n.d.)

Certification (at least for the IEQ part of it) should only be awarded for 6 months to 1 year after construction. After this time, an effective independent audit of building parameters (in this case IEQ), satisfaction and comfort, with both subjective and objective measurements should be done Also, energy efficient and design options cannot affect other parameters like IEQ. If office buildings should have outstanding performance and comfort, there must be uniformity, as in the case of DNGB (DGNB n.d.).

Ergonomics were not studied in this project though it is an important aspect.  It is also difficult to regulate. Ergonomics is still a forgotten issue in certification schemes.  There is already a possibility in some schemes, such  as LEED, to earn ergonomic credits, but few projects received them (Lynch 2014). It has been documented that ergonomics design issues and complaints are important in green buildings (Hedge & Dorsey 2013).

Low emission materials are already awarded in most certification schemes including Green Mark. This can be further incentivized. Exposure control is already in Green Mark with accreditation of certified sustainable materials. The discussion over building materials is now in 2015 shifting to the importance of EPD and HPD disclosure for the materials used in buildings. Manufactures usually are mostly looking for material composition not looking for end-user health context, providing this information can help designers on the selection of healthy materials. Research must transform into consumer products that are healthy for occupants. HPD is already included in the recent LEED V4 (USGBC n.d.).

Product and construction transparency and compliance with a  list of banned materials that are known as e.g. endocrine disruptors with human impact as the “red list materials” (ILFL 2011), will set a more outstanding IEQ in schemes as e.g. Green Mark. In the Green Mark buildings studied, IAQ and building related SBS symptoms can be considered good, so adoption of high demand lists as the “red list” can be initially establish as optional and an extra effort, reward as an extra feature. This would allow tenants to set Green Mark buildings apart, if desired. Long-term exposures studies should be performed in new offices, to better document any observable benefits.

**POE and recertification**

Recertification should be enforced as a tool to regularly verify the operation and certification attributed to avoid only the prediction of the environmental performance of buildings before they are occupied and check if the building maintains a high quality IEQ. If not the certification level may be taken away. These follow-up verifications will also provide a learning repository of newly office environments. Currently, buildings are certified in a base of build-and-forget, and most likely there is not much interest of buildings owners to review their certifications, once it is leased.

A set of mandatory pre-requisites must be enforced. The strength of the connection of credits earned and successful outcomes must be required for learning and assurance of a truly outstanding building. For example in the newly announced wellbeing standard WELL V1.0 (Delos Living LLC 2014) the main focus is on occupants with 50% of pre-requisites and 80% field verification compared with 20% on paper. There is also a three year recertification.

A public benchmark would also create preferences benchmarks for different job types. What are IEQ preferences of lawyers compared with IT professionals for example? People working in office building are not built or feel the same. There will never be a best solution, but combination of preferences is possible. There's no office of the future with perfect guidelines, there might be a style and different preferences, but not a certified outfit. Different people working in diverse jobs have different preferences for working spaces, comfort zones and layout in relation to colleagues.

With large scalability and agility, a benchmark would push all stakeholders to use it, as they would be able to benchmark their buildings against public and credible data. This data that would grow during the years as more certified buildings are constructed and inputted in the cloud.

**A as Aesthetics and N as Nature - Well-being, Beauty and Biophilia**

People love colors and nature and feel good about it. Greenery is already present in Green Mark, as a very elementary requirement and in some new voluntary schemes as well. For example WELL v1.0 (Delos Living LLC 2014) already credits beauty and Biophilia.

The term Biophilia introduced by E.O. Wilson in 1984 in his book *Biophilia* points out that humans have an innate connections and attraction to the natural world. Greenery improves the sense of nature inside the office space reducing stress and improving well being. This bond usually has been extensively studied with positive results on well-being of occupants (Lohr et al. 1996). This can be increased by gardens, terraces etc This will also create a sensory change on occupants, increasing their satisfaction (Heerwagen 2010a). In previous studies occupants with views of nature reported higher overall health and patience and less frustration (Kaplan 1993). Natural elements can lower stress in the office. Maintenance of greenery is often a disadvantage, but low maintenance and space options like hydroponic greenery, might eliminate several of the disadvantages of installing natural greenery in offices.  This is an example how technology and innovation can create solutions to integrate and connect nature, buildings and its occupants Small natural elements as potted plants can also be added when monetary conditions do not allow for more and occupants will have a more domestic feeling on their desk.

Beauty is more difficult and subjective to measure. How to develop metrics for parameters like beauty and aesthetics, because of its subjectivity? Beauty and art cannot be quantified on an objective way, but can be recommended and a human-related metric to be included on the certification schemes. This metric will always have to be discussed with the regulator, as perception is mostly qualitative. Quantitative metrics as art/per sqm can be set, but still will always ultimately be a qualitative assessment.

Previous reviews and experimental studies have found that office colors have a significant effect on occupants productivity and mood (Jalil et al. 2012)(Kwallek et al. 2007). Color varies with culture and countries but should be not monotonous. Changing colors through the office gives a sense of circulation and character. Light colors will also reflect more daylight and create a peaceful work environment.

## 5.3 Survey recommended modifications

### 5.3.1 Questionnaire

After review of the current results in the study to see which parts of the survey are important and where it can be modified, which parts are redundant and which are missing, and recommendations for revision to the existing version are described in this section. The survey used in this study can be treated as a pilot survey and based on its results the modifications are here described. The formal structure should be kept unchanged.

As for the continuous scale, it should be maintained, as proved to be successful with occupants with no complaints and positive comments about how different it was from common surveys. Continuous scales will benefit in "immeasurable" responses in physical terms such as satisfaction, preference, acceptance as allow respondents to decide how the scale should be used and what is moderate and what is strong or weak. Also allow uniformity between perceptions, satisfactions and intensity.

It is recommended to remove the two sliders "now" and "overall" and use only one as this is not well understood by occupants and makes the survey rather tedious and potentially confusing, and from respondents feedback seems meaningless for most respondents, causing frustration to them.

Denotation of a neutral/middle mark in the continuous scales might be considered. Questions related to aesthetics, design, art and colours should be inserted on the survey, as was observed on this study that psychosocial factors have influence on occupants' perceptions.

An additional question should be added for IEQ tolerance. When respondents are asked if would accept reduction on IEQ quality for energy savings, a list of IEQ parameters should be provided, for multiple selection.

It is recommend to include three self-assessment questions which will better characterize working conditions and their impact on performance of work. These will provide information on sick absence (which can be compared with actual sick leave reports received from different employers), interruptions to work (on a daily level) and overtime (extra time).

On SBS symptoms section an additional column with pop-ups  "Have you taken sick leave due to this symptom in the last year?" may be added when the answer on SBS symptoms is positive. This would be create a complement information to self-assessment absenteeism.

The specific question on "how would you describe your work?" which has been used in many previous studies, showed to be of limited use, because of the categories used.   Many administrative workers will describe themselves as technical; most people want to consider themselves professionals even if the researchers would not put them in that category; it is not at all clear what someone should say if they are in several categories, such as an administrative or a professional, etc.  Generally, can be concluded these questions are not useful, being difficult to suggest an alternative, unless the study is done in few buildings, were hypothesis can be tailored.

### 5.3.2 Games

Three games can not represent occupant productivity. They do test selected cognitive functions but findings cannot be over generalized. The games in the survey were intended to examine whether from an objective performance endpoint is possible to observe a difference between NGM and GM buildings or rather whether if IEQ conditions do affect them. One important change would be moving the games before the questionnaire, as occupants might be already tired after finishing the questionnaire.

The Tsai Partington (Connecting the nodes) test was observed to be difficult to understand (some occupants though was a "speed" test others and "accuracy" test) and complete by respondents and also difficult to interpret on a building level. It is suggested to replace it by an attention test, using comprehension and understanding. To this end its proposed the Baddeley test (Baddeley 1966), which test for executive functions, comprehension, attention. The new game should not prolong the time required to complete both questionnaire and games. Changes are not to extend the questionnaire and games but to make sure that the games cover/measure the effect on different skills and are easily comprehendible by occupants. This new game measures how well the brain can reason about the relationships among different letters based on deductions from grammatical statements. It is involving the sentences of various syntactic complexity.

Also is recommended to reduce the d2 and memory game test by two sets. From feedback, occupant thought the games were too long, and did not realized they had to spend so much time. If occupants get frustrated with the games there is a risk of rushing to the end of them.
It is recommended to reduce also the presentation time of each image in the memory test game to 0,5 seconds as feedback suggests that 1 second is higher than necessary.

It is also recommended the give respondents the possibility to repeat a game in case of unwanted interruptions in the office, as this would biased the results.

The games with their new recommended changes should follow the new description presented on appendix G.

### 5.3.3 Incentive to complete the survey

The hypothesis of provide an incentive to occupants to increase the response rate to the electronic survey in the buildings where the measurements were made was though. The entire endeavor of a study of this type hinges on the success of the survey as low response rates may not be sufficient to draw strong general conclusions. Potentially low responses rates may also lead to very challenging statistical analysis with very weak power.

It is difficult to motivate and encourage occupants to take the survey. And after considering several reward options it was concluded it is a very difficult option. If it is decided to reward all occupants, the reward cannot be very high as the monetary cost would be too high for large studies. If it is decided for example to award the top performers creates such a risk and may wipe out small differences that we are looking for, as might over motivate occupants and the differences we are looking disappear, and will also risk anonymity.

The best option is employees to be informed two or three times during the days when they are supposed to take the survey, and if response rates are still low, to have the liaison person in each building to walk around and ask people. Using only tablets will most likely increase the response rates, but the use of this method is still uncertain, as in the current study most answers were computer based.

## 5.4 Limitations and implications

There are several limitations of the validity of the results presented in this work. They include:

(1) It was not possible to match GM and NGM building by age and type of company, so an age bias was present. New buildings without ratings would be the best case scenario. In other hand is possible to show occupant satisfaction with older buildings and contribute to Singapore national agenda. Green mark buildings are newer so they use different materials. Also some of the pollutants (e.g. formaldehyde) may have disappeared with time on conventional buildings as they are older.

(2) A detailed characterization of exposures and performance is not practical in a field study of this dimension, unlike chamber studies. A more detailed analyze in a smaller set, with a cohort of employees through time or within a move from conventional to green would reduce the generalization of the results.

(3) Many factors influence performance, where the prediction is a large combined effect, so factors cannot be single outed. As strong control in a field study is almost impossible, so to individualize factors effects, a very large population of buildings is needed. This is a limitation of this study. What we observed in this study was a combined effect and it was difficult to single out individual factors.

(4) Productivity tests should have been done for the same occupants when they move from a conventional building to a green building or vice versa, in a cohort. As seen in this project, on cross-sectional studies objective-based performance will likely be difficult to measure and compare between GM and NGM buildings. Still the survey will be from now constantly updated, and it is possible that in a near future a tailoring of tests which reflect the effect of IEQ on performance is achieved.

(4) Validation of recommendations presented in this work was not possible. In future a validation of the developed recommendations should be made in newly constructed or renovated buildings that can fulfill the requirements for the new protocols. It would to some extent examine how recommendations are applicable and if the new certification indexes would provide improved comfortable conditions to people compared with buildings where the new recommendations were not introduced.

## 5.5 Future work

During this project was observed how arduous is to have access buildings to perform IEQ measurements, still a benchmark is now provided, and even if there is possible methodology improvements in cross-sectional studies (e.g. more exposures measurements), the natural steps now are cohort studies, following groups of occupants moving from a conventional building to a green building. This design will provide string strong evidence, especially on objective performance, as there would not be a respondent bias.  A follow up repetition in the same building in two to three years would also be important, as would strengthened the findings and conclusions of this study.

In both cross-sectional and cohort studies, a better chemical specification indoors should be performed in NGM and GM with long term measurements of IEQ parameters. Longitudinal quantification of long-term exposures would provide a strong metric in green buildings.

An effort and dialoged with companies to obtain corporate key performance indicators (KPI) should take place.

The social and physiological effect must be further studied.

Tailoring of which objective performance indicators can be use to compare the effect of IEQ on occupants performance in office buildings, when intervention studies are not an option.

## 5.6 Conclusions

Literature review show that holistic and transversal IEQ studies comparing Green and Non-Green buildings are rare. Benchmark IEQ and productivity evidence on green building is over-represented by POE surveys. Generally results show that green buildings outperform non-green for most of the IEQ parameters, with exception of acoustic, lighting, and glare. Thermal comfort has mixed results. Psychosocial office elements (e.g. greenery, views, openness, etc) are better perceived and praised in green buildings. Data is not systematic and there are cases of green buildings where improvements were not observed. Is unknown the long-term benefits of green buildings. Quantitative indicators and absenteeism, KPI and objective performance are seldom done. When presented they are by norm better in green building compared to non-green buildings. Sustainability consciousness and pride are frequently reported for occupants in green buildings, and there is an evidence of higher tolerance for suboptimal IEQ.  Widely available corporate reports on case-studies and barometers, lack proper methodologies and design.

This study looked into seven dimensions in a holistic and longitudinal approach, three quantitative: IEQ, human performance and sick-leave and four qualitative: IEQ, Health, performance and sustainability.

Physical measurements did not differ significantly between GM and NGM. Both types of building meet requirements by recommended Singaporean standards without significant deviations, being better controlled in GM buildings.

Occupants´ satisfaction, importance and perceptions of IEQ parameters are better in GM buildings compared with the NGM buildings and the difference can be caused both by the psychosocial factors and actual exposures. Privacy both acoustical and visual is problematic in Green Mark buildings. Temperature, air quality and noise, are considered by occupants on both types of buildings as the most detrimental indoor environment parameters to their performance and in the workstation lack of privacy in GM buildings compared to cleanliness in NGM are also considered by occupants on as the most detrimental to their work.

Occupants in Green Mark buildings reported a higher sustainability consciousness. Prevalence of building related SBS symptoms is lower in GM buildings, with half the odds of prevalence of symptoms, compared with NGM buildings. While occupant self-assessment performance is better in GM buildings, no significant differences were observed for objective performance between occupants on both types of buildings.

Annual sick leave is lower on the population of Green Mark buildings by one day, compared to Non-Green Mark buildings. It is not possible to conclude if the IEQ benefits on employees' satisfaction and productivity are higher if an office has higher green mark certification credits, as no direct association was observed. The differences within GM buildings reflect also the importance of the tenants on the final result.

Being a pioneer longitudinal study on Green vs Non-Green in a tropical climate, the general results of this study are very positive and motivating. While there are improvements which are recommended, it seems that Green Mark buildings are having a positive impact on occupants, compared with Non-Green Mark. O.C.E.A.N approach and human satisfaction metric are recommended based on the knowledge and results gathered on this study.

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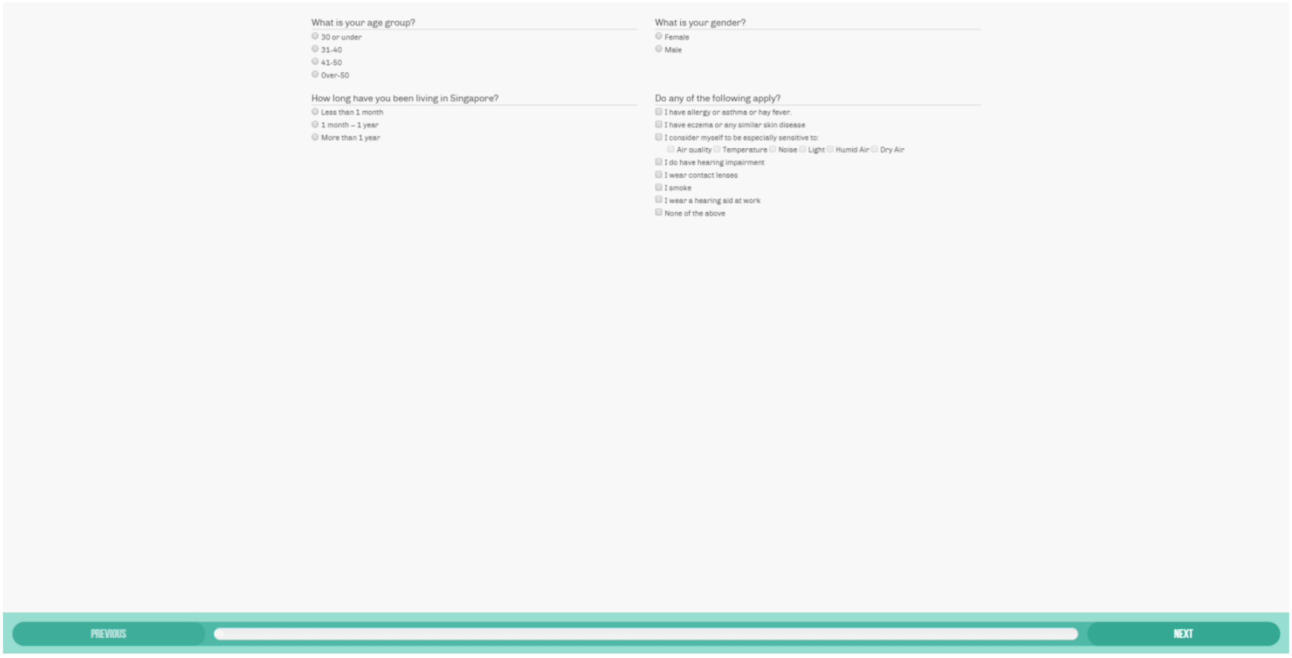
# 7 Appendix

## 7.1 Appendix A – Survey screen shots

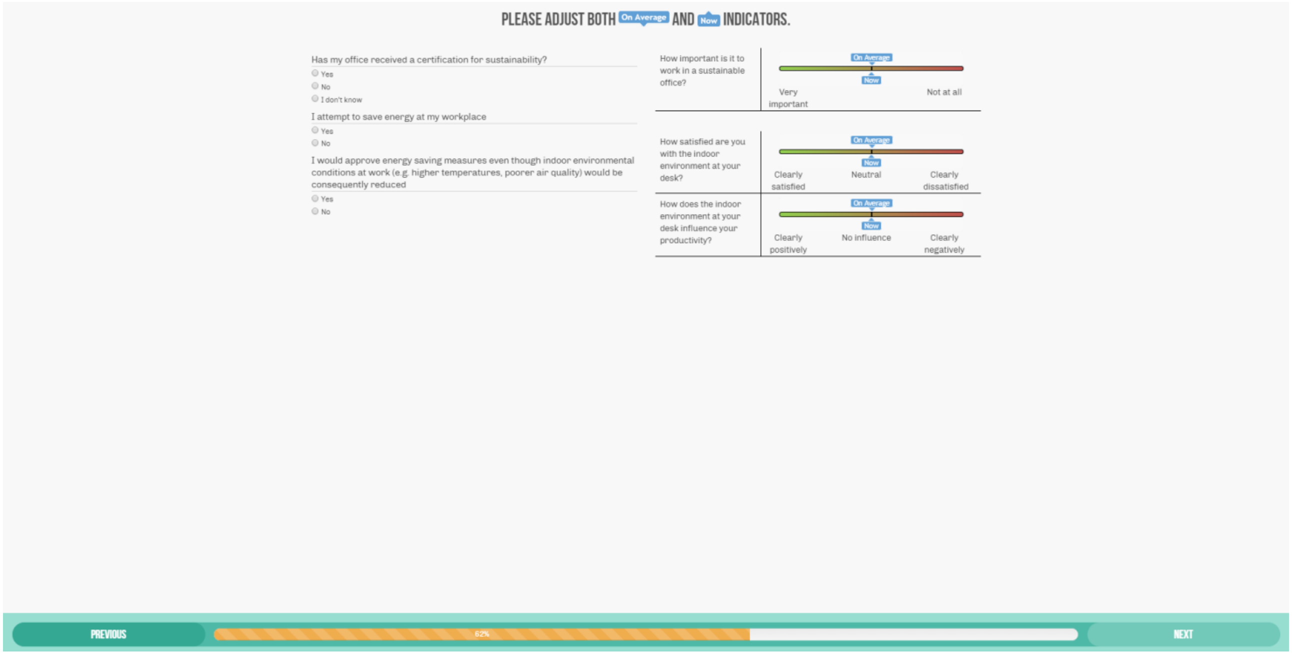
Only some screen shots are presented for each section, as the survey is under intellectual property protection. *This survey should not be used without authorization

Demographics and Workplace




Rating of Indoor Environmental Quality

Description of Awareness of Sustainability

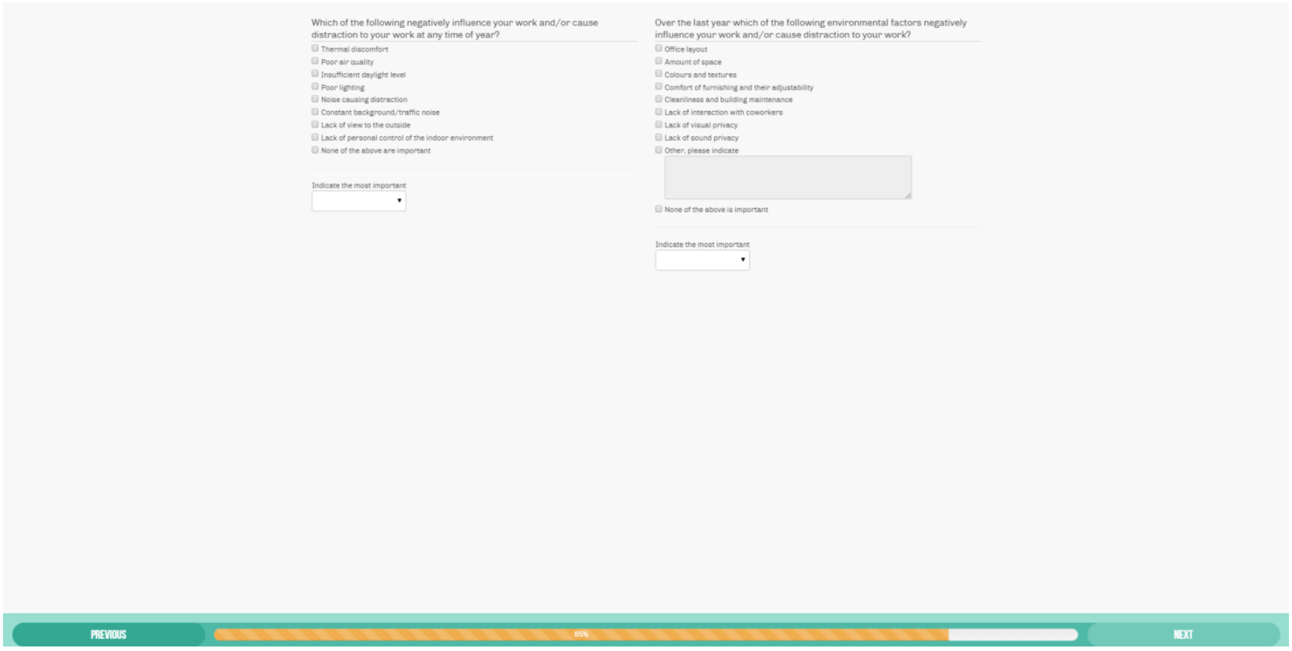



Rating of Health Symptoms


Self-Assessment of performance and working conditions


HOW DO YOU RATE YOUR WORK?
(PLEASE ADJUST BOTH On Average AND Now INDICATORS)
Job difficulty
Effort required
Stress
Job Satisfaction
My Performance
On Average
Now
Low
High
Very poor
Excellent
PREVIOUS
NEXT

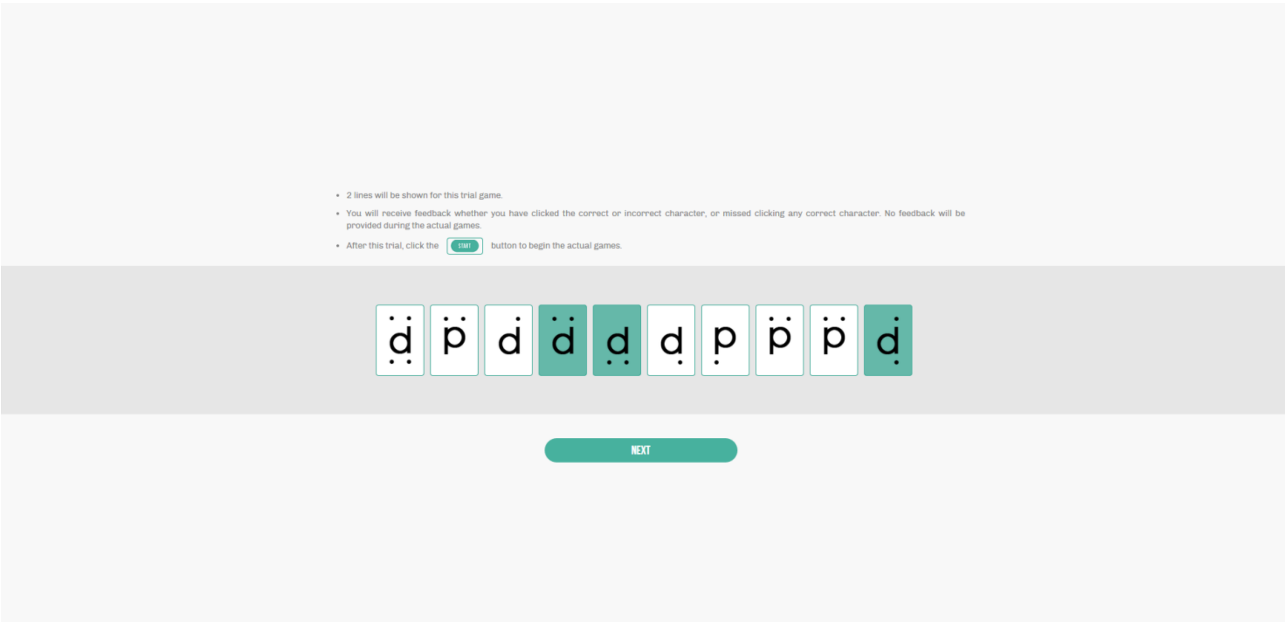
IEQ Ranking


Which of the following negatively influence your work and/or cause distraction to your work at any time of year?
Thermal discomfort
Poor air quality
Insufficient daylight level
Poor lighting
Noise causing distraction
Constant background/traffic noise
Lack of view to the outside
Lack of personal control of the indoor environment
None of the above are important
Indicate the most important
Over the last year which of the following environmental factors negatively influence your work and/or cause distraction to your work?
Office layout
Amount of space
Colours and textures
Comfort of furnishing and their adjustability
Cleanliness and building maintenance
Lack of interaction with coworkers
Lack of visual privacy
Lack of sound privacy
Other, please indicate
None of the above is important
Indicate the most important
PREVIOUS
NEXT

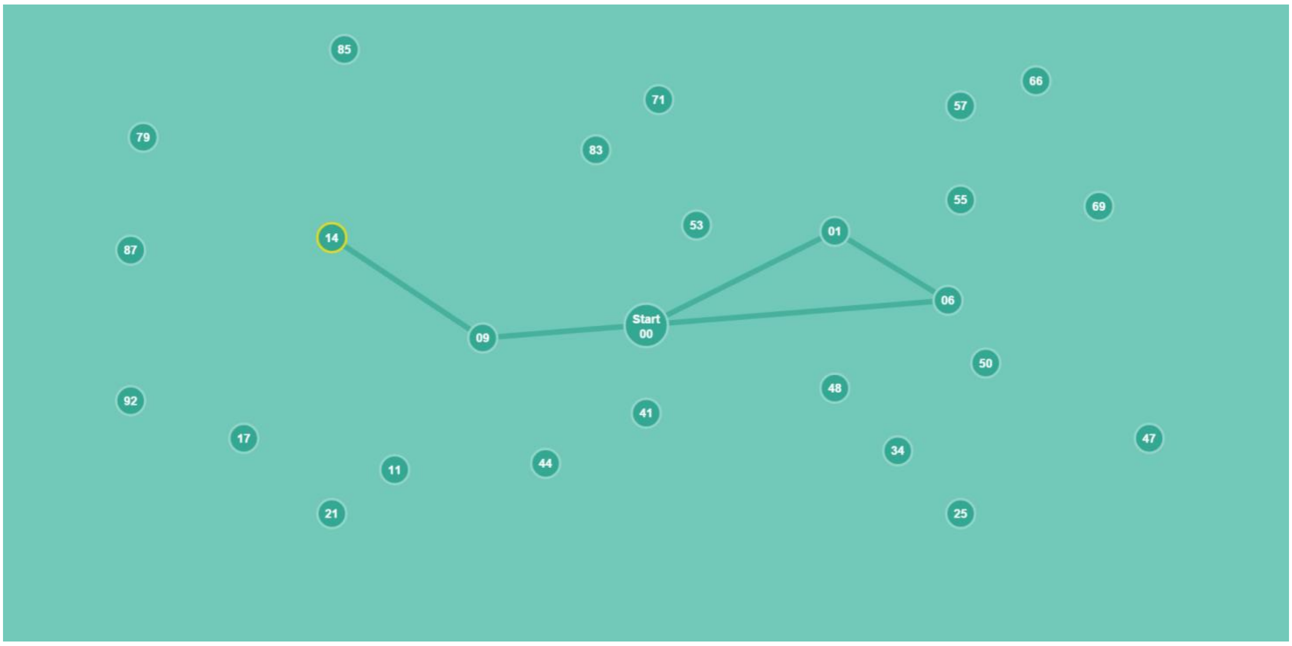
Open-ended questions (Personal opinions


## Games

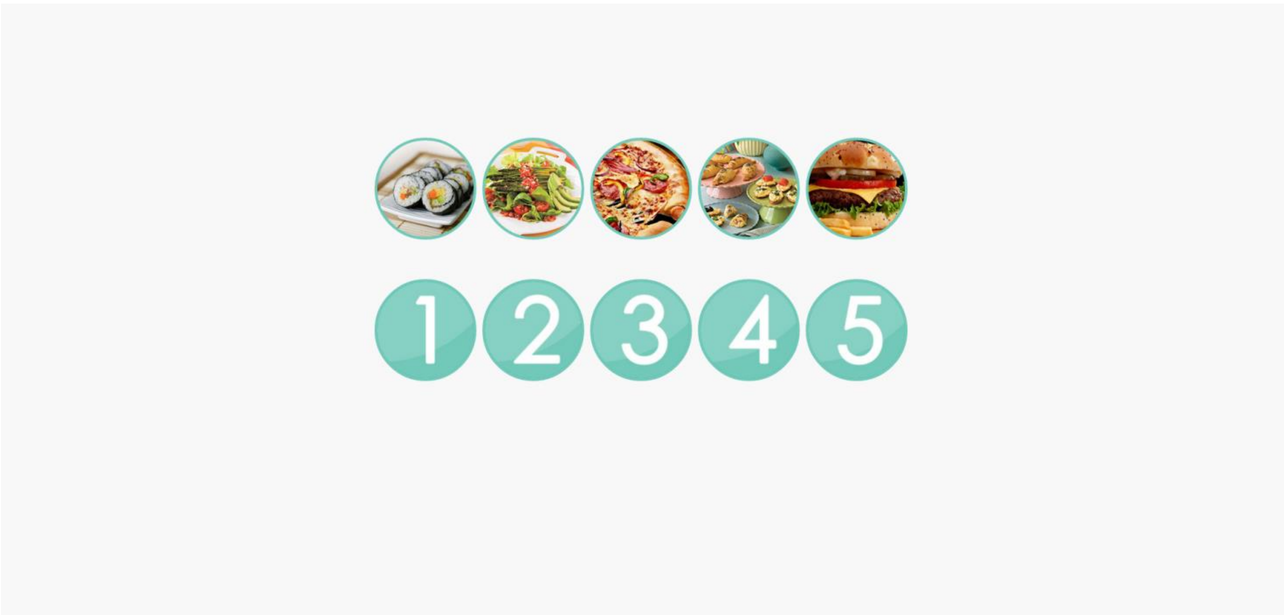
## D2 game



Connecting the nodes game




Memory Game



## 7.2 Appendix B – Building Observations

| | Ventilation | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Temp. Set point | NºAHU | Diffuser | Operating Hours | Purging | Age | Cleaning | Dirt/Mold | Filter Replacement |
| NGM1 | 24 Celsius | 1 | Square (-) | 7:30 am – 5:30 pm | No | > 10 years | Unknown | Yes/No | Unknown |
| NGM2 | 24 Celsius | 2 | Linear (-) | 7:30 am – 6:30 pm | No | > 10 years | Monthly | Yes/No | 6 months |
| NGM3 | 24 Celsius | 1 | Linear (-) | 7:30 am – 6:30 pm | No | > 10 years | Monthly | Yes/No | 6 months |
| NGM4 | Unknown | 1 | Linear (-) | 8 am – 6 pm | Yes | > 10 years | Unknown | Yes/Yes | Unknown |
| NGM5 | FCUs | --- | Square cassette units | 8 am – 6 pm | No | > 10 years | Unknown | Yes/Yes | Unknown |
| NGM6 | 24 Celsius | -- | PDV(++) | Variable | No | <10 Years | Yearly | No/No | NA |
| GM7 | 24 Celsius | 2 | Linear (+) | 8 am – 6 pm | Unknown | > 10 years | Weekly | No/No | *Cleaned every month |
| GM8 | 24-26 Celsius | 1 | Linear (++) | 8 am – 6 pm | Unknown | < 10 years | Unknown | No/No | Unknown |
| GM9 | 24.5 Celsius (23.5 meeting room) | 1 | Swivel (++) | 8 am – 6 pm | Unknown | < 5 years | Monthly | No/No | 6 months |
| GM10 | 24 – 26 degree Celsius | 2 | Linear | 0730 – 1830 | Yes | < 10 years | Monthly | No | Unknown |
| GM11 | 26 Celsius | 1 | Grille(-)/Square (+)* | 7:30 am – 6:30 pm | Unknown | < 10 years | | | Unknown |
| GM12 | 24 Celsius | 2 | Swivel | 8 am – 6 pm | No | > 10 years | Monthly | No/ No | Unknown |

Table 63B – Ventilation data on the 6 GM and 6 NGM buildings

| | Building Materials | | | | | | |
|---|---|---|---|---|---|---|---|
| | Floor | Paint | Ceiling | Windows | Furniture | Meeting room Walls | Outer Walls |
| NGM1 | Dark Grey Carpet (-) | White (-) | Suspended - White (-) | Single Glazed (-) | Compressed wood with plastic finishing (+) | *No meeting rooms | Concrete |
| NGM2 | Dark Grey Carpet (-) | White (-) | Suspended - White (-) | Single Glazed (-) | Compressed wood with plastic finishing (-) | Plaster | Concrete |
| NGM3 | Dark Grey Carpet (+) | White (+) | Suspended - White (-) | Single Glazed (-) | Compressed wood with plastic finishing (+) | Glass | Concrete |
| NGM4 | Light Grey Carpet (-) | White (-) | Suspended - White (-) | Single Glazed (-) | Compressed wood with plastic finishing (-) | Glass | Concrete |
| NGM5 | Dark Brown Carpet (-) | White (-) | Suspended - White (-) | Single Glazed (-) | Compressed wood with plastic finishing (+) | *No meeting rooms | Concrete |
| NGM6 | Grey/Brown Carpet (+) | White (+) | Concrete high ceiling (++) | Single Glazed (+) | Compressed wood with plastic finishing (+) | Plaster | Concrete |
| GM7 | Dark Grey Carpet (+) | White (+) | Suspended - White (-) | Double Glazed (+) | Compressed wood with plastic finishing (+) | Plaster | Concrete |
| GM8 | Light Grey Carpet (++) | White Low-VOC (++) | Suspended - White (++) | Double Glazed (++) | Compressed wood with plastic finishing (++) | Glass | Concrete |
| GM9 | Light Brown Carpet (++) | White Low-VOC (++) | Suspended - White (++) | Double Glazed (++) | Eco friendly bamboo board with linen laminate (++) | Glass | Concrete |
| GM10 | Grey carpet | White | Suspended - White (-) | Single glazed | Wood and plastic finishings | Glass window | Concrete |
| GM11 | Grey Carpet(+) | White | Metallic White (+) | Double Glazed (++) | Compressed wood with plastic finishing (++) | Plaster | Concrete |
| GM12 | Grey carpet (+) | White | Suspended White (+) | Double glazed (++) | Compressed wood with plastic finishing (+) | Glass | Concrete |

**Table 64B – Building materials on the 6 GM and 6 NGM buildings**

| | Workplace 1 | | | | | |
|---|---|---|---|---|---|---|
| | Daylight | Blinds | Desk Light | Light Sensor | Décor Light | Glare |
| NGM1 | Natural lighting (-) | Horizontal sunshades | No | No | No | No (++) |
| NGM2 | Natural lighting (-) | Vertical textile sunshades | No | No | No | No (++) |
| NGM3 | Natural lighting (-) | Vertical textile sunshades | No | No | No | No (++) |
| NGM4 | Natural lighting (-) | Running Textile | No | No | No | No (++) |
| NGM5 | Natural lighting (-) | Running Textile | No | No | No | No (++) |
| NGM6 | Natural lighting (+) | Vertical textile sunshades | No | No | No | No (++) |
| GM7 | Natural lighting (-) | Horizontal sunshades | No | No | No | Artificial Light Glare (-) |
| GM8 | Natural lighting (++) | Running Textile | No | Motion sensors Daylight sensors | No | Yes (-) |
| GM9 | Natural lighting (++) | Horizontal sunshades | No | Motion sensors Daylight sensors | No | Monitor Glare (-) |
| GM10 | Natural lighting (+) | Textile vertical sunshades | Yes | Motion sensors Daylight sensors | No | No (++) |
| GM11 | Natural lighting (+) | Inflector Blinds | Yes | Motion sensors Daylight sensors | No | Unknown |
| GM12 | Natural lighting (-) | Vertical sunshade | Yes | No | No | No (++) |

**Table 65B – Worplace characteristics on the 6 GM and 6 NGM buildings**

| | Workplace 2 | | | |
|---|---|---|---|---|
| | Private Offices | Decoration | Printers | Storage |
| NGM1 | 3 | No | Located at open plan | Personal and local (-) |
| NGM2 | 8 | No | Located at open plan | Personal and local (-) |
| NGM3 | 4 | No | Located at open plan | Personal and local (+) |
| NGM4 | All outer perimeter | No | Located at utility area | Personal and local (-) |
| NGM5 | 2 | No | Located at utility area | Personal and local (-) |
| NGM6 | No | No | Located at open plan | Personal and local (++) |
| GM7 | 8 | Yes | Located at open plan | Personal and local (+) |
| GM8 | No | Yes | Located at utility area | Personal and local (+) |
| GM9 | No | Yes | Located at utility areas | Very Limited |
| GM10 | No | No | Located at utility area | Personal and local (-) |
| GM11 | 2 | No | Located at open plan | Personal and local (-) |
| GM12 | No | Yes | Located at utility area | Personal workspace |

**Table 66 – Workplace characteristics on the 6 GM and 6 NGM buildings**

| | Workplace/workstation | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Dress Code | Additional clothing | Eating | Desk | Desk Space/Storage | Chair | Desk Control | Room Control |
| NGM1 | Casual | On site Jackets | Yes (Hot food) | Non adjustable, longitudinal workstation (-) | Bad (-)/Good (+) | Adjustable Normal (-) | None | - Blinds –Non Operable Windows |
| NGM2 | Light formal | No | Yes (Hot food) | Non adjustable, 90 degrees workstation (-) | Bad (-)/Good (+) | Adjustable Normal (-) | Some Personal Fans | -Blinds –Operable Windows |
| NGM3 | Light formal | No | Yes (Hot food) | Non adjustable, 90 degrees workstation (+) | Good (-)/Good (+) | Adjustable Ergonomic (+) | Some Personal Fans | -Blinds –Operable Windows |
| NGM4 | Light formal/ casual | On site Jackets | Unknown | Non adjustable, 90 degrees workstation (+) | Very Good Bad(-)/Good (+) | Adjustable Normal (-) | Some Personal Fans | - Blinds – Non Operable Windows |
| NGM5 | Casual | On site Jackets | Unknown | Non adjustable, 90 degrees workstation (+) | Good (+)/Good (+) | Adjustable Ergonomic (++) | Some Personal Fans | - Blinds –Operable Windows |
| NGM6 | Casual | No | Yes (Hot food) | Non adjustable, 90 degrees workstation (+) | Good (+)/Good (+) | Adjustable Ergonomic (++) | Some Personal Fans | - Blinds –Operable Windows |
| GM7 | Light formal/ casual | No | Yes (Hot food) | Non adjustable, 90 degrees workstation (+) | Good (+)/Good (+) | Adjustable Normal (-) | None | - Blinds – Non Operable Windows |
| GM8 | Light formal/ casual | On site Jackets | Yes (Hot food) | Non adjustable, longitudinal workstation (-) | Bad (-)/Good(+) | Adjustable Ergonomic (++) | None | - Blinds –Non Operable Windows |
| GM9 | Light formal/ casual | On site Jackets | Hot food not allowed | Non adjustable, 120degrees workstation (++) | Very Good (++)/None (-) | Adjustable Ergonomic (++) | None | - Blinds – Non Operable Windows |
| GM10 | Casual / light formal | On site Jackets | No | Non-adjustable – longitudinal desks | Good (+)/Good (+) | Adjustable, Normal | No | - blinds - non operable windows |
| GM11 | Casual | No | Unknown | Non adjustable, 90 degrees workstation (+) | Good (+)/Good (+) | Adjustable Normal (-) | Some Personal Fans | - Blinds – Non Operable Windows |
| GM12 | Light formal/ casual | No | Unknown | Non adjustable, 90 degrees workstation (++) | Good (+)/Good (+) | Adjustable (+) | No | - Blinds -Desk Light – Non Operable Windows |

**Table 67B – Workplace characteristics on the 6 GM and 6 NGM buildings**

| | Additional | | | | |
|---|---|---|---|---|---|
| | Acoustical absorbers | Noise Perception | Odor Perception | Employees | Additional/ Others |
| NGM1 | Desk partitions | Noisy (-) | Dust and food (-) | Mostly Nationals | No |
| NGM2 | Desk partitions | Noisy (-) | Dust (-) | Mostly Nationals | No |
| NGM3 | Desk partitions | Quiet (+) | None (+) | Mostly Nationals | No |
| NGM4 | Desk partitions | Noisy(-) | Dust(-) | National/International | No |
| NGM5 | Desk partitions | Quiet (+) | Dust and VOC (-) | Mostly Nationals | No |
| NGM6 | Desk partitions | Noisy(-) | Food (-) | National/International | No |
| GM7 | Desk partitions | Quiet (+) | None (+) | Mostly Nationals | No |
| GM8 | No | Quiet (+) | None (++) | National/International | 17 meeting rooms |
| GM9 | No | Quiet (++) | None (++) | National/International | CO2 sensors in meeting rooms |
| GM10 | No | Noisy(-) | Dust(-) | National/International | CO2 sensors in meeting rooms |
| GM11 | Desk partitions | Quiet (++) | None (+) | Mostly Nationals | -CO2 sensors for occupancy<br>-Motion sensors |
| GM12 | Desk partitions/Ceiling | Quiet (+) | None (+) | National/International | No |

**Table 68B – Additional characteristics on the 6 GM and 6 NGM buildings**

(++) = Very Good (Condition/Cleaning/Result/Effect)
(+) = Good (Condition/Cleaning/Result/ Effect)
(-) = Bad (Condition/Cleaning/Result/ Effect)

## 7.3 Appendix C – Central tendencies, GLMM and LSD models results for "now"

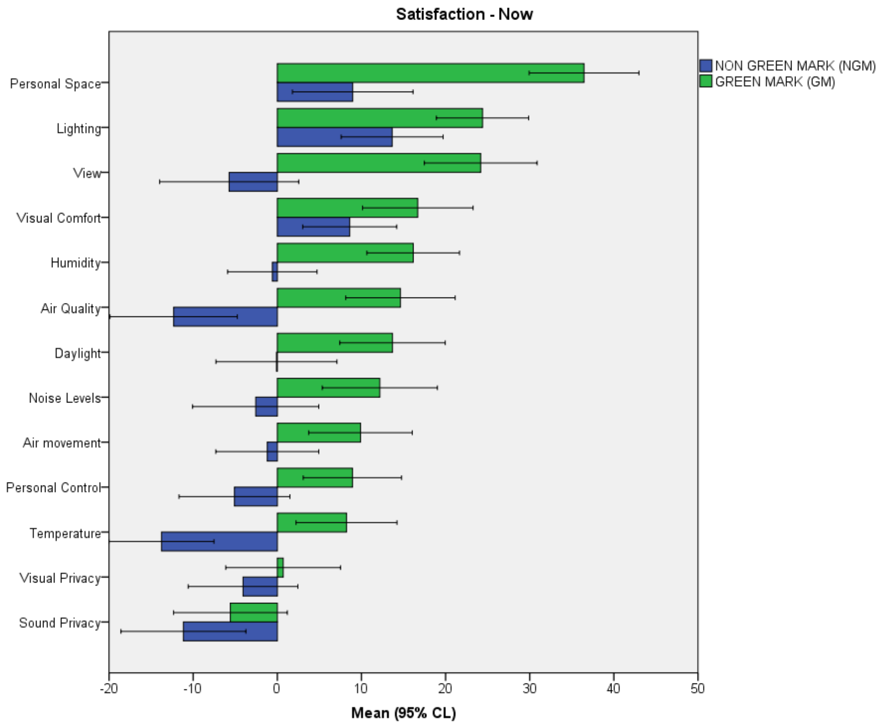



**Figure 88C - Satisfaction with IEQ parameters for "now". Green bars represent mean satisfaction values in GM buildings with 95% confidence intervals. Blue bars represent mean satisfaction values in NGM buildings with 95% confidence intervals**

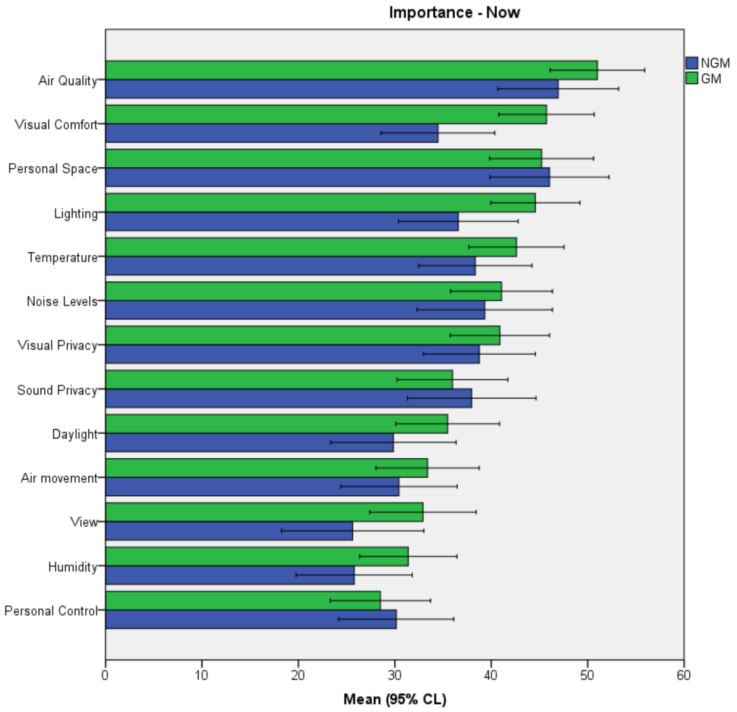



**Figure 89C - Importance of IEQ parameters for "now". Green bars represent mean satisfaction values in GM buildings with 95% confidence intervals. Blue bars represent mean satisfaction values in NGM buildings with 95% confidence intervals**

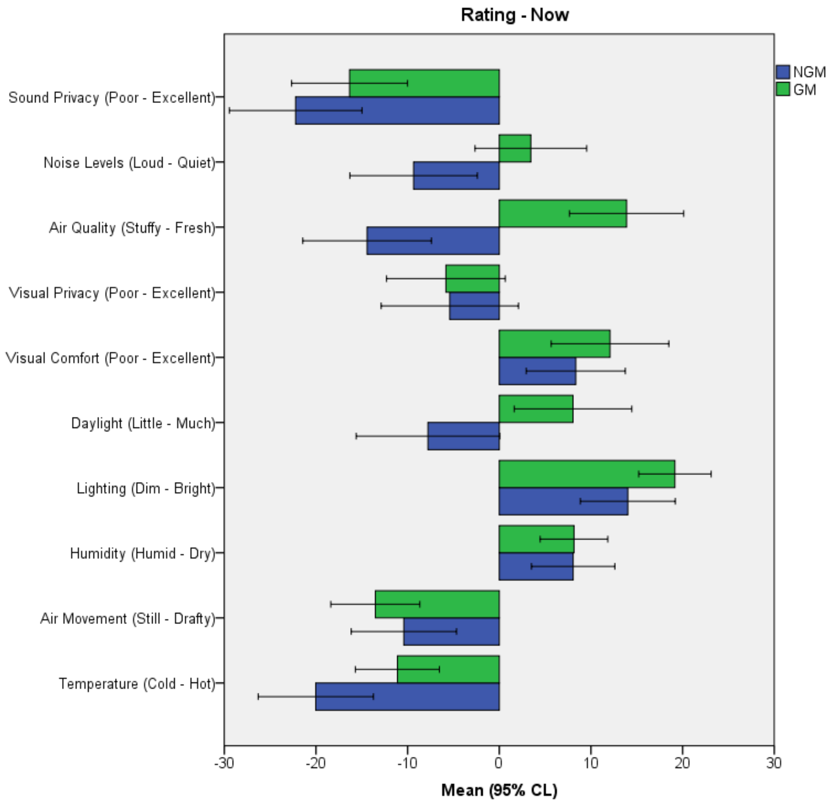



**Figure 90C - Perceptions of IEQ parameters for "now". Green bars represent mean satisfaction values in GM buildings with 95% confidence intervals. Blue bars represent mean satisfaction values in NGM buildings with 95% confidence intervals**

| Hierarchical model - Mixed Model | Between Green Mark and Non Green Mark (Includes random effect) | | | Between buildings within same category (Nested under Type) | | |
|---|---|---|---|---|---|---|
| **Satisfaction** | F | Sig. | Partial Eta Squared | F | Sig. | Partial Eta Squared |
| Personal space | 9,171 | **,011** | ,440 | 2,659 | **,004** | ,081 |
| Windows view | 3,330 | **,097** | ,241 | 8,712 | **,000** | ,224 |
| Personal control | 4,099 | **,063** | ,235 | 1,368 | ,194 | ,043 |
| Temperature | 8,629 | **,013** | ,423 | 2,505 | **,007** | ,077 |
| Air movement | 1,285 | ,281 | ,105 | 4,541 | **,000** | ,131 |
| Humidity | 4,780 | **,051** | ,300 | 3,763 | **,000** | ,111 |
| Lighting | 4,582 | **,054** | ,277 | 2,293 | **,013** | ,071 |
| Daylight | 2,855 | ,119 | ,205 | 4,136 | **,000** | ,121 |
| Visual comfort | 1,669 | ,221 | ,124 | 2,500 | **,007** | ,077 |
| Visual privacy | ,295 | ,597 | ,025 | 2,538 | **,006** | ,078 |
| Air quality | 6,168 | **,031** | ,361 | 4,700 | **,000** | ,135 |
| Noise levels | ,582 | ,462 | ,050 | 4,574 | **,000** | ,132 |
| Sound privacy | ,005 | ,944 | ,000 | 5,159 | **,000** | ,146 |

**Table 69C – Results of GLMM for satisfaction with IEQ parameters for "Now". Bold numbers are significant (P<0.05) and red reaching significance (P<0.10). The results are unadjusted. Partial Eta square shows the explanatory power of the model (comparable to R square) and F is the F –statistics from the model.**

| | (LSD) Pairwise Comparisons (GM - NGM) Weighted by Building | | | | |
|---|---|---|---|---|---|
| | Mean Difference (GM-NGM) | Std. Error | Sig. | 95% Confidence Interval for Difference | |
| **Satisfaction** | | | | Lower Bound | Upper Bound |
| Personal space | 24,8 | 5,320 | **,000** | 14,3 | 35,3 |
| Windows view | 26,1 | 5,279 | **,000** | 15,7 | 36,5 |
| Personal control | 11,4 | 4,916 | **,021** | 1,7 | 21,0 |
| Temperature | 21,1 | 4,801 | **,000** | 11,7 | 30,6 |
| Air movement | 10,6 | 4,700 | **,026** | 1,3 | 19,8 |
| Humidity | 16,7 | 4,207 | **,000** | 8,4 | 24,9 |
| Lighting | 13,9 | 4,506 | **,002** | 5,0 | 22,7 |
| Daylight | 16,3 | 5,087 | **,002** | 6,3 | 26,3 |
| Visual comfort | 9,5 | 4,920 | ,054 | -0,2 | 19,2 |
| Visual privacy | 4,3 | 5,293 | ,414 | -6,1 | 14,7 |
| Air quality | 26,3 | 5,269 | **,000** | 16,0 | 36,7 |
| Noise levels | 8,2 | 5,420 | ,131 | -2,5 | 18,9 |
| Sound privacy | 0,8 | 5,315 | ,879 | -9,7 | 11,3 |

**Table 70C – Results of LSD for satisfaction with IEQ parameters for "now". Bold numbers are significant (P<0.05). The results are unadjusted. Mean differences between GM and NGM buildings with 95% confidence interval are presented.**

| Hierarchical model - Mixed Model | Between Green Mark and Non Green Mark (Includes random effect) | | | Between buildings within same category (Nested under Type) | | |
|---|---|---|---|---|---|---|
| **Importance** | F | Sig. | Partial Eta Squared | F | Sig. | Partial Eta Squared |
| Personal space | ,325 | ,579 | ,024 | 1,495 | ,140 | ,047 |
| Windows view | 3,773 | **,072** | ,209 | 1,076 | ,380 | ,035 |
| Personal control | ,191 | ,669 | ,013 | 1,016 | ,430 | ,033 |
| Temperature | 1,861 | ,192 | ,109 | ,906 | ,528 | ,029 |
| Air movement | 1,144 | ,301 | ,069 | ,866 | ,565 | ,028 |
| Humidity | 1,881 | ,190 | ,109 | ,872 | ,560 | ,028 |
| Lighting | 5,307 | **,038** | ,280 | 1,253 | ,257 | ,040 |
| Daylight | ,826 | ,378 | ,055 | 1,102 | ,360 | ,035 |
| Visual comfort | 7,947 | **,014** | ,375 | 1,413 | ,173 | ,045 |
| Visual privacy | 1,082 | ,318 | ,078 | 1,666 | **,088** | ,052 |
| Air quality | 1,375 | ,262 | ,095 | 1,464 | ,152 | ,046 |
| Noise levels | ,605 | ,451 | ,045 | 1,651 | **,092** | ,052 |
| Sound privacy | ,068 | ,798 | ,005 | 1,676 | **,086** | ,053 |

**Table 71C - Results of GLMM for importance with IEQ parameters for "now". Bold numbers are significant (P<0.05) and red reaching significance (P<0.10). The results are unadjusted. Partial Eta square shows the explanatory power of the model (comparable to R square) and F is the F –statistics from the model.**

| | (LSD) Pairwise Comparisons (GM - NGM) Weighted by Building | | | | |
|---|---|---|---|---|---|
| | Mean Difference (GM-NGM) | Std. Error | Sig. | 95% Confidence Interval for Difference | |
| **Importance** | | | | Lower Bound | Upper Bound |
| Personal space | 3,1 | 4,550 | ,500 | -5,9 | 12,0 |
| Windows view | 10,1 | 5,042 | **,046** | 0,2 | 20,0 |
| Personal control | -2,0 | 4,435 | ,660 | -10,7 | 6,8 |
| Temperature | 5,6 | 4,279 | ,191 | -2,8 | 14,0 |
| Air movement | 4,6 | 4,541 | ,314 | -4,4 | 13,5 |
| Humidity | 5,7 | 4,380 | ,196 | -2,9 | 14,3 |
| Lighting | 10,7 | 4,214 | **,012** | 2,4 | 19,0 |
| Daylight | 4,4 | 4,688 | ,345 | -4,8 | 13,7 |
| Visual comfort | 13,9 | 4,255 | **,001** | 5,5 | 22,3 |
| Visual privacy | 5,6 | 4,311 | ,196 | -2,9 | 14,1 |
| Air quality | 6,0 | 4,350 | ,169 | -2,6 | 14,6 |
| Noise levels | 4,6 | 4,765 | ,336 | -4,8 | 14,0 |
| Sound privacy | 1,6 | 4,865 | ,745 | -8,0 | 11,2 |

**Table 72C - Results of LSD for importance with IEQ parameters for "now". Bold numbers are significant (P<0.05). The results are unadjusted. Mean differences between Gm and NGM buildings with 95% confidence interval are presented.**

| Hierarchical model - Mixed Model | Between Green Mark and Non Green Mark (Includes random effect) | | | Between buildings within same category (Nested under Type) | | |
|---|---|---|---|---|---|---|
| **Perception** | F | Sig. | Partial Eta Squared | F | Sig. | Partial Eta Squared |
| Temperature? | 1,840 | ,202 | ,142 | 3,984 | **,000** | ,117 |
| Air movement | ,221 | ,647 | ,018 | 2,191 | **,018** | ,068 |
| Humidity | ,030 | ,865 | ,002 | 1,702 | ,079 | ,054 |
| Lighting level | 1,285 | ,280 | ,102 | 3,273 | **,000** | ,098 |
| Daylight | 1,812 | ,206 | ,146 | 6,963 | **,000** | ,188 |
| Visual comfort (e.g. glare) | ,412 | ,533 | ,033 | 2,175 | **,019** | ,067 |
| Visual privacy | ,000 | ,985 | ,000 | 2,422 | **,009** | ,074 |
| Air quality | 6,192 | **,031** | ,366 | 6,072 | **,000** | ,168 |
| Noise levels | ,998 | ,338 | ,079 | 2,649 | **,004** | ,081 |
| Sound privacy | ,074 | ,791 | ,007 | 4,139 | **,000** | ,121 |

**Table 73C - Results of GLMM for perceptions with IEQ parameters for "now". Bold numbers are significant (P<0.05) and red reaching significance (P<0.10). The results are unadjusted. Partial Eta square shows the explanatory power of the model (comparable to R square) and F is the F –statistics from the model.**

| | (LSD) Pairwise Comparisons (GM - NGM) Weighted by Building | | | | |
|---|---|---|---|---|---|
| | Mean Difference (GM-NGM) | Std. Error | Sig. | 95% Confidence Interval for Difference | |
| **Perception** | | | | Lower Bound | Upper Bound |
| Temperature | 10,2 | 4,058 | **,012** | 2,3 | 18,2 |
| Air movement | -2,7 | 4,113 | ,509 | -10,8 | 5,4 |
| Humidity | -0,7 | 3,210 | ,827 | -7,0 | 5,6 |
| Lighting level | 6,6 | 3,456 | ,056 | -0,2 | 13,4 |
| Daylight | 16,9 | 5,145 | **,001** | 6,7 | 27,0 |
| Visual comfort (e.g. glare) | 4,3 | 4,815 | ,368 | -5,1 | 13,8 |
| Visual privacy | 0,2 | 5,416 | ,978 | -10,5 | 10,8 |
| Air quality | 27,7 | 4,889 | **,000** | 18,1 | 37,3 |
| Noise levels | 7,7 | 5,045 | ,126 | -2,2 | 17,7 |
| Sound privacy | 2,6 | 5,132 | ,607 | -7,5 | 12,7 |

**Table 74C - Results of LSD for perceptions with IEQ parameters for "now". Bold numbers are significant (P<0.05). The results are unadjusted. Mean differences between Gm and NGM buildings with 95% confidence interval are presented.**

| Hierarchical model - Mixed Model (Overall) | Between Green Mark and Non Green Mark (Includes random effect) | | | Between buildings within same category (Nested under Type) | | |
|---|---|---|---|---|---|---|
| | F | Sig. | Partial Eta Squared | F | Sig. | Partial Eta Squared |
| Importance to work in a sustainable office | 2,898 | ,109 | ,162 | ,940 | ,497 | ,030 |
| Satisfaction with Indoor Environment | 11,873 | **,005** | ,514 | 3,602 | **,000** | ,107 |
| How Indoor Environment influences productivity (Positive – Negative) | 3,793 | ,075 | ,239 | 2,120 | **,023** | ,066 |

**Table 75C - Results of GLMM for for sustainability, overall IEQ and IEQ influence on productivity for "now". Bold numbers are significant (P<0.05) and red reaching significance (P<0.10). The results are unadjusted. Partial Eta square shows the explanatory power of the model (comparable to R square) and F is the F –statistics from the model.**

| Hierarchical model - Mixed Model | | Between Green Mark and Non Green Mark (Includes random effect) | | | Between buildings within same category (Nested under Type) | | |
|---|---|---|---|---|---|---|---|
| | | F | Sig. | Partial Eta Squared | F | Sig. | Partial Eta Squared |
| How do you rate your work? | **Job Difficulty** | ,746 | ,404 | ,058 | 2,168 | **,020** | ,067 |
| | **Effort required** | ,915 | ,358 | ,072 | 2,365 | **,010** | ,073 |
| | **Stress** | 2,659 | ,126 | ,164 | 1,306 | ,227 | ,042 |
| | **Job Satisfaction** | ,526 | ,480 | ,035 | 1,013 | ,432 | ,033 |
| | **My performance** | 3,160 | ,098 | ,191 | 1,337 | ,210 | ,043 |

**Table 76C – Results of GLMM for different categories describing work as assessed by the occupants in GM and NGM buildings for "now". Bold numbers are significant (P<0.05) and red reaching significance (P<0.10). The results are unadjusted. Partial Eta square shows the explanatory power of the model (comparable to R square) and F is the F –statistics from the model.**

| | | (LSD) Pairwise Comparisons (GM - NGM) | | | | |
|---|---|---|---|---|---|---|
| | | Mean Difference (GM-NGM) | Std. Error | Sig. | 95% Confidence Interval for Difference | |
| | | | | | Lower Bound | Upper Bound |
| How do you rate your work? | **Job Difficulty** | -5,1 | 4,227 | ,227 | -3,2 | 13,4 |
| | **Effort required** | -5,9 | 4,225 | ,164 | -2,4 | 14,2 |
| | **Stress** | -8,1 | 4,423 | ,069 | -0,6 | 16,8 |
| | **Job Satisfaction** | 3,7 | 5,005 | ,466 | -13,5 | 6,2 |
| | **My performance** | 8,4 | 4,191 | **,045** | -16,7 | -0,2 |

**Table 77C – Results of LSD comparisons between GM and NGM building for self-assessment/job parameters for "now". Bold numbers are significant (P<0.05). The results are unadjusted. Marginal mean differences between Gm and NGM buildings with 95% confidence interval are presented.**

## 7.4 Appendix D – GLMM and LSD models results for "overall" adjusted for age and gender

| Hierarchical model - Mixed Model | Between Green Mark and Non Green Mark (Includes random effect) | | | Between buildings within same category (Nested under Type) | | |
|---|---|---|---|---|---|---|
| **Satisfaction** | F | Sig. | Partial Eta Squared | F | Sig. | Partial Eta Squared |
| Personal space | 18,211 | **,001** | ,605 | 2,916 | **,002** | ,089 |
| Windows view | 4,727 | **,053** | ,305 | 7,105 | **,000** | ,192 |
| Personal control | 5,045 | **,042** | ,270 | 1,577 | ,113 | ,050 |
| Temperature | 2,994 | ,110 | ,206 | 3,556 | **,000** | ,106 |
| Air movement | 1,620 | ,228 | ,123 | 3,578 | **,000** | ,107 |
| Humidity | 8,510 | **,013** | ,413 | 2,651 | **,004** | ,081 |
| Lighting | 4,148 | **,064** | ,255 | 2,583 | **,005** | ,080 |
| Daylight | 1,887 | ,196 | ,143 | 4,088 | **,000** | ,120 |
| Visual comfort | 2,495 | ,138 | ,160 | 1,836 | ,054 | ,058 |
| Visual privacy | ,606 | ,450 | ,044 | 1,845 | ,053 | ,058 |
| Air quality | 6,282 | **,029** | ,358 | 4,367 | **,000** | ,127 |
| Noise levels | 2,156 | ,169 | ,158 | 3,762 | **,000** | ,112 |
| Sound privacy | ,005 | ,947 | ,000 | 4,204 | **,000** | ,123 |

**Table 78D – Results of GLMM for satisfaction with IEQ parameters for "Overall". Bold numbers are significant (P<0.05) and red reaching significance (P<0.10). The results adjusted for age and gender. Partial Eta square shows the explanatory power of the model (comparable to R square) and F is the F –statistics from the model.**

| | (LSD) Pairwise Comparisons (GM - NGM) Weighted by Building | | | | |
|---|---|---|---|---|---|
| | Mean Difference (GM-NGM) | Std. Error | Sig. | 95% Confidence Interval for Difference | |
| **Satisfaction** | | | | Lower Bound | Upper Bound |
| Personal space | 32,1 | 4,748 | **,000** | 22,8 | 41,5 |
| Windows view | 27,6 | 5,265 | **,000** | 17,3 | 38,0 |
| Personal control | 12,4 | 4,567 | **,007** | 3,4 | 21,4 |
| Temperature | 14,0 | 4,658 | **,003** | 4,8 | 23,2 |
| Air movement | 10,5 | 4,755 | **,027** | 1,2 | 19,9 |
| Humidity | 19,2 | 4,328 | **,000** | 10,7 | 27,7 |
| Lighting | 14,4 | 4,705 | **,002** | 5,1 | 23,6 |
| Daylight | 13,5 | 5,294 | **,011** | 3,1 | 23,9 |
| Visual comfort | 10,4 | 5,121 | **,043** | 0,3 | 20,5 |
| Visual privacy | 5,2 | 5,219 | ,316 | -5,0 | 15,5 |
| Air quality | 26,1 | 5,430 | **,000** | 15,4 | 36,7 |
| Noise levels | 14,8 | 5,631 | **,009** | 3,7 | 25,8 |
| Sound privacy | 0,7 | 5,462 | ,899 | -10,1 | 11,4 |

**Table 79D – Results of LSD for satisfaction with IEQ parameters for "Overall". Bold numbers are significant (P<0.05). The results are adjusted for age and gender. Mean differences between GM and NGM buildings with 95% confidence interval are presented.**

| Hierarchical model - Mixed Model | Between Green Mark and Non Green Mark (Includes random effect) | | | Between buildings within same category (Nested under Type) | | |
|---|---|---|---|---|---|---|
| **Importance** | F | Sig. | Partial Eta Squared | F | Sig. | Partial Eta Squared |
| Personal space | 3,062 | ,102 | ,178 | 1,403 | ,178 | ,045 |
| Windows view | 5,642 | **,033** | ,296 | 1,655 | ,091 | ,052 |
| Personal control | 1,351 | ,266 | ,095 | 1,970 | **,036** | ,062 |
| Temperature | 5,572 | **,034** | ,296 | 1,745 | ,070 | ,055 |
| Air movement | 3,167 | **,097** | ,183 | 1,401 | ,179 | ,045 |
| Humidity | 4,213 | **,059** | ,224 | 1,269 | ,248 | ,041 |
| Lighting | 8,867 | **,011** | ,409 | 2,003 | **,033** | ,063 |
| Daylight | 4,293 | **,056** | ,220 | 1,133 | ,337 | ,037 |
| Visual comfort | 8,229 | **,014** | ,401 | 2,409 | **,009** | ,075 |
| Visual privacy | 3,005 | ,108 | ,198 | 2,567 | **,005** | ,079 |
| Air quality | 3,292 | **,094** | ,211 | 2,376 | **,010** | ,074 |
| Noise levels | 1,319 | ,271 | ,092 | 1,885 | **,047** | ,059 |
| Sound privacy | ,024 | ,880 | ,002 | 2,037 | **,030** | ,064 |

**Table 80D - Results of GLMM for importance with IEQ parameters for "Overall". Bold numbers are significant (P<0.05) and red reaching significance (P<0.10). The results are adjusted for age and gender. Partial Eta square shows the explanatory power of the model (comparable to R square) and F is the F –statistics from the model.**

| | (LSD) Pairwise Comparisons (GM - NGM) Weighted by Building | | | | |
|---|---|---|---|---|---|
| **Importance** | Mean Difference (GM-NGM) | Std. Error | Sig. | 95% Confidence Interval for Difference: Lower Bound | Upper Bound |
| Personal space | 9,3 | 4,611 | **,045** | 0,2 | 18,3 |
| Windows view | 14,3 | 4,878 | **,004** | 4,7 | 23,9 |
| Personal control | 6,6 | 4,252 | ,123 | -1,8 | 14,9 |
| Temperature | 14,1 | 4,724 | **,003** | 4,8 | 23,4 |
| Air movement | 9,9 | 4,865 | **,042** | 0,4 | 19,5 |
| Humidity | 10,2 | 4,499 | **,025** | 1,3 | 19,0 |
| Lighting | 17,8 | 4,463 | **,000** | 9,0 | 26,6 |
| Daylight | 10,9 | 5,003 | **,030** | 1,1 | 20,7 |
| Visual comfort | 19,1 | 4,570 | **,000** | 10,1 | 28,1 |
| Visual privacy | 12,4 | 4,795 | **,010** | 3,0 | 21,9 |
| Air quality | 12,6 | 4,799 | **,009** | 3,1 | 22,0 |
| Noise levels | 7,3 | 4,866 | ,135 | -2,3 | 16,9 |
| Sound privacy | 1,0 | 4,949 | ,836 | -8,7 | 10,8 |

**Table 81D - Results of LSD for importance with IEQ parameters for "Overall". Bold numbers are significant (P<0.05). The results are adjusted for age and gender. Mean differences between Gm and NGM buildings with 95% confidence interval are presented.**

| Hierarchical model - Mixed Model | Between Green Mark and Non Green Mark (Includes random effect) | | | Between buildings within same category (Nested under Type) | | |
|---|---|---|---|---|---|---|
| **Perception** | F | Sig. | Partial Eta Squared | F | Sig. | Partial Eta Squared |
| Temperature | ,179 | ,680 | ,015 | 2,865 | **,002** | ,087 |
| Air movement | ,023 | ,882 | ,002 | 2,903 | **,002** | ,088 |
| Humidity | ,724 | ,409 | ,051 | 1,584 | ,110 | ,050 |
| Lighting level | 2,259 | ,160 | ,165 | 3,789 | **,000** | ,112 |
| Daylight | ,572 | ,466 | ,051 | 8,816 | **,000** | ,228 |
| Visual comfort (e.g. glare) | ,709 | ,415 | ,051 | 1,815 | ,058 | ,057 |
| Visual privacy | ,117 | ,738 | ,009 | 1,637 | ,095 | ,052 |
| Air quality | 6,807 | **,024** | ,379 | 4,686 | **,000** | ,135 |
| Noise levels | 1,678 | ,219 | ,122 | 2,673 | **,004** | ,082 |
| Sound privacy | ,000 | ,995 | ,000 | 3,921 | **,000** | ,116 |

**Table 82D - Results of GLMM for perceptions with IEQ parameters for "Overall". Bold numbers are significant (P<0.05) and red reaching significance (P<0.10). The results are adjusted for age and gender. Partial Eta square shows the explanatory power of the model (comparable to R square) and F is the F –statistics from the model.**

| | (LSD) Pairwise Comparisons (GM - NGM) Weighted by Building | | | | |
|---|---|---|---|---|---|
| | Mean Difference (GM-NGM) | Std. Error | Sig. | 95% Confidence Interval for Difference | |
| **Perception** | | | | Lower Bound | Upper Bound |
| Temperature | 2,6 | 3,893 | ,506 | -5,1 | 10,3 |
| Air movement | -1,0 | 4,064 | ,811 | -9,0 | 7,0 |
| Humidity | 3,4 | 3,276 | ,304 | -3,1 | 9,8 |
| Lighting level | 9,4 | 3,498 | **,008** | 2,5 | 16,3 |
| Daylight | 10,5 | 5,180 | **,044** | 0,3 | 20,7 |
| Visual comfort (e.g. glare) | 5,2 | 4,828 | ,281 | -4,3 | 14,7 |
| Visual privacy | 2,3 | 5,455 | ,675 | -8,4 | 13,0 |
| Air quality | 25,8 | 4,989 | **,000** | 15,9 | 35,6 |
| Noise levels | 10,1 | 5,136 | **,049** | 0,0 | 20,3 |
| Sound privacy | -0,1 | 5,293 | ,991 | -10,5 | 10,4 |

**Table 83D - Results of LSD for perceptions with IEQ parameters for "Overall". Bold numbers are significant (P<0.05). The results are adjusted for age and gender. Mean differences between Gm and NGM buildings with 95% confidence interval are presented.**

| Hierarchical model - Mixed Model (Overall) | Between Green Mark and Non Green Mark (Includes random effect) | | | Between buildings within same category (Nested under Type) | | |
|---|---|---|---|---|---|---|
| | F | Sig. | Partial Eta Squared | F | Sig. | Partial Eta Squared |
| Importance to work in a sustainable office | 5,357 | **,036** | ,271 | 1,320 | ,219 | ,042 |
| Satisfaction with Indoor Environment | 13,254 | **,003** | ,528 | 2,951 | **,001** | ,090 |
| How Indoor Environment influences productivity (Positive – Negative) | 2,679 | ,126 | ,176 | 2,181 | **,019** | ,068 |

**Table 84D - Results of GLMM for for sustainability, overall IEQ and IEQ influence on productivity for "overall". Bold numbers are significant (P<0.05). The results are adjusted for age and gender. Partial Eta square shows the explanatory power of the model (comparable to R square) and F is the F –statistics from the model.**

| Hierarchical model - Mixed Model | | Between Green Mark and Non Green Mark (Includes random effect) | | | Between buildings within same category (Nested under Type) | | |
|---|---|---|---|---|---|---|---|
| | | F | Sig. | Partial Eta Squared | F | Sig. | Partial Eta Squared |
| How do you rate your work? | **Job Difficulty** | ,031 | ,863 | ,003 | 3,450 | **,000** | ,103 |
| | **Effort required** | ,006 | ,939 | ,001 | 2,993 | **,001** | ,091 |
| | **Stress** | ,381 | ,548 | ,028 | 1,742 | ,071 | ,055 |
| | **Job Satisfaction** | ,104 | ,752 | ,007 | 1,474 | ,148 | ,047 |
| | **My performance** | 1,754 | ,209 | ,121 | 2,053 | **,028** | ,064 |

**Table 85D – Results of GLMM for different categories describing work as assessed by the occupants in GM and NGM buildings for "overall". Bold numbers are significant (P<0.05). The results are adjusted for age and gender. Partial Eta square shows the explanatory power of the model (comparable to R square) and F is the F –statistics from the model.**

| | | (LSD) Pairwise Comparisons (GM - NGM) | | | | |
|---|---|---|---|---|---|---|
| | | Mean Difference (GM-NGM) | Std. Error | Sig. | 95% Confidence Interval for Difference: Lower Bound | 95% Confidence Interval for Difference: Upper Bound |
| How do you rate your work? | **Job Difficulty** | -1,2 | 4,021 | ,762 | -9,1 | 6,7 |
| | **Effort required** | -0,5 | 4,047 | ,900 | -8,5 | 7,5 |
| | **Stress** | -3,4 | 4,327 | ,438 | -11,9 | 5,1 |
| | **Job Satisfaction** | 1,8 | 4,783 | ,705 | -7,6 | 11,2 |
| | **My performance** | 7,1 | 3,983 | ,074 | -0,7 | 14,9 |

**Table 86D – Results of LSD comparisons between GM and NGM building for self-assessment/job parameters for "overall". Bold numbers are significant (P<0.05). The results are adjusted for age and gender. Marginal mean differences between Gm and NGM buildings with 95% confidence interval are presented.**

## 7.5 Appendix E - Pearson product-moment Correlation between physical IEQ measured parameters and SBS symptoms prevalence

| | | **$CO_2$** | | CO | | HCHO | | RH% | | Air temperature | | Operative temperature | | Light | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | NGM | GM | NGM | GM | NGM | GM | NGM | GM | NGM | GM | NGM | GM | NGM | GM |
| Unusual Fatigue (Tiredness) | Pearson Correlation | | | | | | | | | | | | | | |
| | Sig. (2-tailed) | | | | | | | | | | | | | | |
| Body/Muscular Pain | Pearson Correlation | | | | | | | | | | | | | | |
| | Sig. (2-tailed) | | | | | | | | | | | | | | |
| Headache | Pearson Correlation | | | | | | | | | | | 0,175 | | | |
| | Sig. (2-tailed) | | | | | | | | | | | ,046 | | | |
| Difficulty to concentrate/ think clearly | Pearson Correlation | -0,199 | | -0,197 | | | | 0,204 | | | 0,2 | | 0,178 | | |
| | Sig. (2-tailed) | ,024 | | ,022 | | | | ,018 | | | ,010 | | ,025 | | |
| Difficulty in breathing (Wheezing shortness of breath, etc) | Pearson Correlation | | | | | | | | | | | | | | |
| | Sig. (2-tailed) | | | | | | | | | | | | | | |
| Stuffy or runny nose | Pearson Correlation | | | -0,227 | | | | | | | | | 0,161 | | |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Sig. (2-tailed) | | | ,008 | | | | | | | | | ,042 | | |
| Tired or irritated eyes | Pearson Correlation | | | | | | | | -0,23 | | | | | | |
| | Sig. (2-tailed) | | | | | | | | ,003 | | | | | | |
| Irritated throat/ Coughing | Pearson Correlation | | -0,18 | | | | | | | | | | | -0,175 | |
| | Sig. (2-tailed) | | ,024 | | | | | | | | | | | ,043 | |
| Irritated, Dry or Itching Skin | Pearson Correlation | | | | | | | | | | | | 0,164 | | |
| | Sig. (2-tailed) | | | | | | | | | | | | ,039 | | |
| Sleepiness | Pearson Correlation | -0,286 | | -0,18 | | -0,28 | 0,173 | | | | | | | | |
| | Sig. (2-tailed) | ,001 | | ,038 | | ,001 | ,024 | | | | | | | | |
| Apathy | Pearson Correlation | | -0,165 | | | | | | | | | | | | |
| | Sig. (2-tailed) | | ,039 | | | | | | | | | | | | |
| Odour annoyance | Pearson Correlation | | | | | | -0,193 | | -0,162 | | | | | | |
| | Sig. (2-tailed) | | | | | | ,012 | | ,038 | | | | | | |

| | | Air Velocity | | Bacteria Breathing Zone | | Bacteria Air Diffuser | | Fungi Breathing Zone | | Fungi Air Diffuser | | Air Change | | PM2.5 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | NGM | GM | NGM | GM | NGM | GM | NGM | GM | NGM | GM | NGM | GM | NGM | GM |
| Unusual Fatigue (Tiredness) | Pearson Correlation | | | | | | | | | | | | | | |
| | Sig. (2-tailed) | | | | | | | | | | | | | | |
| Body/Muscular Pain | Pearson Correlation | | | | | | | | | | | | | | |
| | Sig. (2-tailed) | | | | | | | | | | | | | | |
| Headache | Pearson Correlation | -0,193 | | | | | | | | | | 0,196 | | | |
| | Sig. (2-tailed) | ,026 | | | | | | | | | | ,023 | | | |
| Difficulty to concentrate/ think clearly | Pearson Correlation | | -0,158 | | | | | | -0,153 | | | | | | 0,175 |
| | Sig. (2-tailed) | | ,039 | | | | | | ,046 | | | | | | ,023 |
| Difficulty in breathing (Wheezing shortness of breath, etc) | Pearson Correlation | | | | | | | | | | | | | | |
| | Sig. (2-tailed) | | | | | | | | | | | | | | |
| Stuffy or runny nose | Pearson Correlation | | | | | | | | | | | | | | |
| | Sig. (2-tailed) | | | | | | | | | | | | | | |
| Tired or irritated eyes | Pearson Correlation | | -0,238 | | | | | | | | | | -0,211 | | 0,275 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Sig. (2-tailed) | | ,002 | | | | | | | | | | ,006 | | ,000 |
| Irritated throat/ Coughing | Pearson Correlation | | -0,156 | | | | | | | | -0,154 | | | | 0,152 |
| | Sig. (2-tailed) | | ,043 | | | | | | | | ,045 | | | | ,049 |
| Irritated, Dry or Itching Skin | Pearson Correlation | | | | | | | | | | | | | | 0,157 |
| | Sig. (2-tailed) | | | | | | | | | | | | | | ,042 |
| Sleepiness | Pearson Correlation | | -0,157 | | | | | | | | | | | | 0,226 |
| | Sig. (2-tailed) | | ,040 | | | | | | | | | | | | ,003 |
| Apathy | Pearson Correlation | | | | | | | | | | | | | | |
| | Sig. (2-tailed) | | | | | | | | | | | | | | |
| Odour annoyance | Pearson Correlation | | | | | | | | | -,187* | | | | | |
| | Sig. (2-tailed) | | | | | | | | | ,040 | | | | | |

**Table 87E - Pearson product-moment Correlation between physical IEQ measured parameters and SBS symptoms prevalence**

## 7.6 Appendix F - Interviews and open comments

**Non Green Mark Buildings**

- Sometimes extremely cold
- Bad ergonomics (explain more)
- Noise and privacy (both acoustic and visual) complaints
- Cleaning not good
- No desk lights or desk fan
- Dusty smell
- Lack of desk space and office area very crowded
- More fresh air wanted

**Green Mark**

- Generally, comments of good overall IEQ to work in with soothing interior. Cleanliness is also good.
- Glare from daylighting & thermal transmittance from sun resulting in discomfort and causing eye irritation and headaches. There were complaints of eyesight deterioration because of glare. The exact same complaint was observed in different green mark buildings. Even if it is a minority that complaints about this issue this is a quite serious issue as poses a health hazard. Complaints were more evident on high rise floors.
- Poor ergonomics. No monitor adjustment in height in some cases. Some people wished that workstations allow for standing work. Ergonomics improvements needed.
- Noise and privacy(both acoustic and visual) complaints
- Complaints about cold temperature when it is raining outside. People cannot understand how this cannot be solved even after constant complaints to FM.
- People wish to have locally control over air conditioned instead of centralized control
- People located under the air vents complaint of irregular draft and cold peaks, and they feel powerless as cannot be adjusted.
- People feel that better control over temperature will improve their productivity.
- People rate temperature and air quality as the most important for their well-being and privacy and ergonomics also when thinking on productivity
- Missing more informal meeting and discussion areas.

## 7.7 Appendix G – Games

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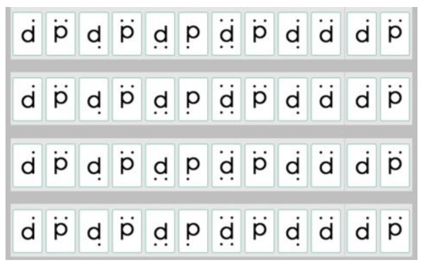
| **D2** | A single page representation for each set will be more compact and most of all participants need only scroll through for the next lines of each set.<br>There are 47 characters in each line in the original task and 21-22 d2 characters in each line; the remaining characters are distracting characters; there are two d2 characters among the last three characters in each line, in the following combinations: last two characters d2 characters, the third last and last characters are d2 characters and the third last and the second last character are d2 characters. The same arrangement should be made in new version of the d2-game in<br><br>Example:<br>Start game (1st set): See all 48 characters; 4 rows to work separately (12chars x 4rows). <br>- Identify all d2s in 1st row then 2nd row will be available. (While working on 1st row, only 1st row highlighted. 2nd to 4th row hidden in background).<br>- Preceding row does not fade out to keep all rows active at the end of d2 game.<br>- 4 seconds/row. Thereafter, next row will be active when:<br>(i) all d2s identified within 4secs, or<br>(ii) Respondents did not identify all d2s but 4secs is used up.<br>- Total response time = 25secs<br>(i) If respondents take <25secs to identify all d2s per set, they are able to check back if they had missed out any d2s as all rows remain active. If users marked all D2 the next screen will appear.<br>(ii) When 25 seconds is up, the game will move on to the next set.<br><br>Imposing a line-by-line approach will accurately determine the important measures of number of characters attempted<br><br>Proposed a reduction to a total of 4 sets. 1st set act as a trial for respondents. Take results based on 2nd to 4th set. Total RT = 25s x4sets =100 seconds<br><br>The version of the game used in the current survey is 6 sets, each has 50 characters on 5 screens and there is 5 seconds per each screen (line) yielding 25 seconds to complete one set. Altogether the test takes at least 3 minutes (6x25s=180s plus time to switch between screens and sets). there is allocated 1 |

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| | second per 2 characters (1 character in 0.5 seconds).The original test had 47 characters in a line and 20 seconds thus 1 second is given for 2.35 characters (or 1 character in 0.43 seconds). This new version will have 1 character per 0.53 seconds. |
| **Memory game** | - Presentation of tasks at a rate of 1 picture per second.<br>(i) Entire sequence of presentation consists of 5 images. Total 5 seconds; half of which allocated to showing the pictures and half to changing from one picture to another (inter-picture interval being thus 0.5 seconds).<br><br>Proposed a reduction to a total of 4 sets. |
| **Baddeley's Test - Reasoning Game** | Using Precede:<br>A precedes B, A does not precede B, B precedes A, B does not precede A,<br>Using Follow:<br>A follows B, A is followed by B, A does not follow B, A is not followed by B, B follows A, B is followed by A, B does not follow A, B is not followed by A and so on.<br><br>Follows and precede have active (follows/precedes) and passive (is followed/is preceded) form and positive (follows/precedes, is followed/is preceded)) and negative form (does not follow/does not precede, is not followed/is not preceded), this makes already 8 combinations for A first B second (in the sentence describing the order) and 16 combinations for B first and A second, and 32 combinations for equal number of false and true sentences.<br><br>In our case we will have the following combinations:<br>A comes before B (in AB or BA)<br>A comes after B<br>A does not come before B<br>A does not come after A<br><br>This will create 8 combinations for AB/BA pairs and 16 combinations if we gave B comes first and A second in the sentence.<br><br>A follows B<br>A is followed by B<br>A does not follow B<br>A is not followed by B<br><br>Makes another 16 combinations.<br><br>A is ahead of B<br>A is behind B |

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| | A is not ahead of B<br>A is not behind  B<br><br>Makes another 16 combinations.<br><br>So we will have altogether 64 combinations that we can use to create the test. The test should include equal number of each possible combination of letter pair AB and the description so it should include a multiple of 64 combinations indicated above.<br><br>Each combination will have a false/true sign next to it were respondents will click to indicate their answers<br><br>A total of 3 minutes response time to complete the test as the original task<br><br>The outcome measures are response time and errors of commission. |

Building certification schemes foster sustainable design and energy efficiency. This PhD study indicates that they also foster indoor environmental quality. This was attested by extensive field measuring campaigns which also included occupant responses in certified and non-certified buildings. Further enhancements to certification schemes were proposed to promote human well-being. The study was anchored at the Technical University of Denmark (DTU) and executed with the National University of Singapore (NUS) within a Joint NUS-DTU PhD Programme established between the two universities.

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