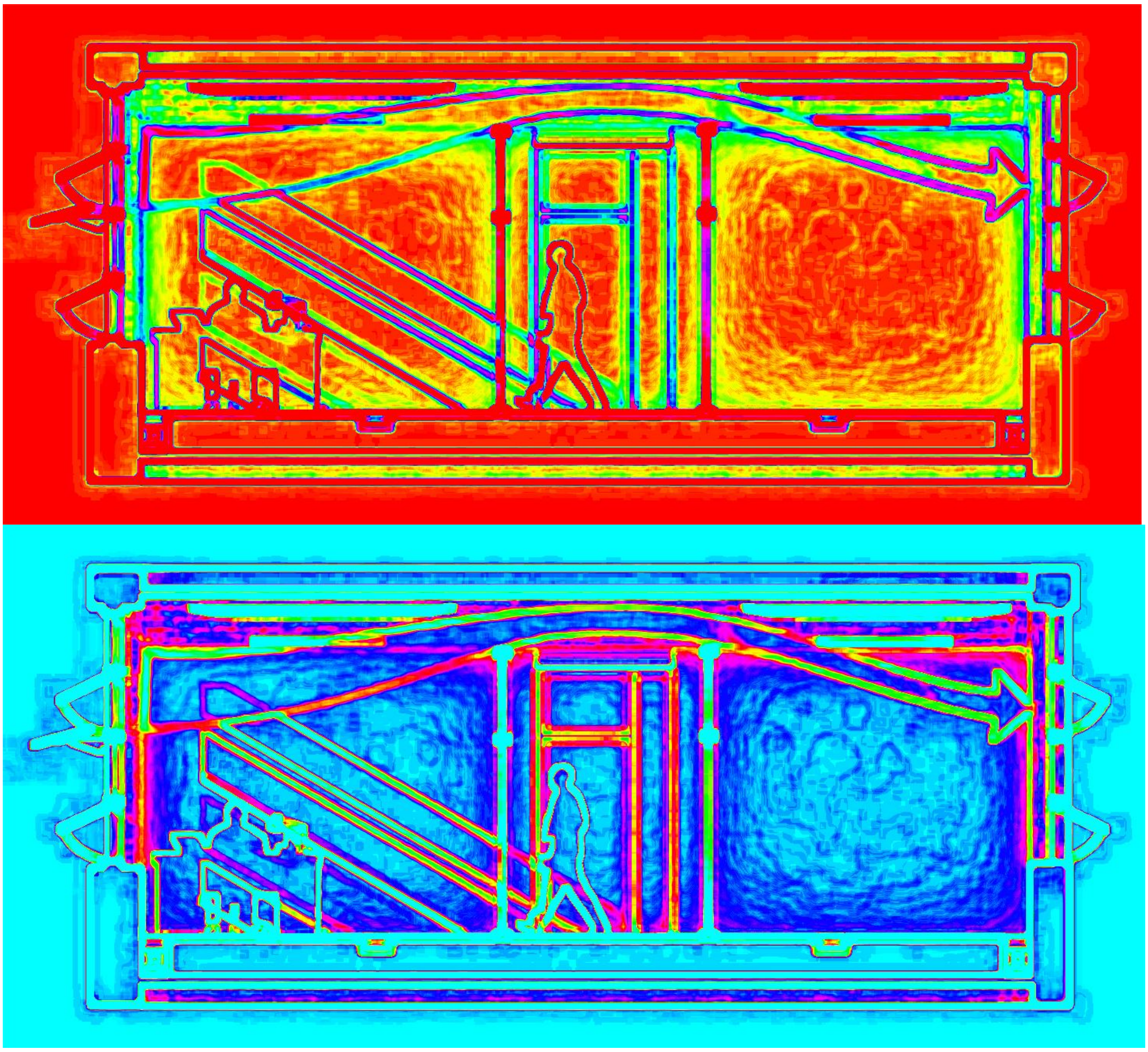
CHALMERS
UNIVERSITY OF TECHNOLOGY



Positive impact on wellbeing and energy related behaviors in office buildings

The Challenge Lab 2015: Sustainable Urban Development

Master's Thesis in the Master's Programme Design & Construction Project Management

EDUARDO NAVARRO BRINGAS
GUILLERMO SIBAJA ENDONIO

Department of Civil and Environmental Engineering
Division of Construction Management
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2015
Master's Thesis 2015:07

REPORT NO. 2015:07

Positive impact on wellbeing and energy related behaviors in office buildings

The Challenge Lab 2015: Sustainable Urban Development

Master's Thesis in the Master's Programme Design & Construction Project Management

EDUARDO NAVARRO BRINGAS

GUILLERMO SIBAJA ENDONIO

Department of Civil and Environmental Engineering
Division of Construction Management
CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden 2015

Positive impact on wellbeing and energy related behaviors in office buildings

The Challenge Lab 2015: Sustainable Urban Development

Master's Thesis in the Master's Programme Design & Construction Project Management

EDUARDO NAVARRO BRINGAS

GUILLERMO SIBAJA ENDONIO

Report no 2015:07
Department of Civil and Environmental Engineering
Division of Construction Management
Chalmers University of Technology
SE-412 96 Göteborg
Sweden
Telephone: + 46 (0)31-772 1000

Cover:

"A section of the Case study CIRS building through an artistic filter exposing the warm and cold colors; still on searching of the right balance between wellbeing and energy efficiency."

Chalmers Reproservice
Gothenburg, Sweden 2015

Positive impact on wellbeing and energy related behaviors in office buildings

The Challenge Lab 2015: Sustainable Urban Development

EDUARDO NAVARRO BRINGAS
GUILLERMO SIBAJA ENDONIO
Department of Civil and Environmental Engineering
Division of Construction Management
Chalmers University of Technology

ABSTRACT

Around 90% of the total costs of commercial buildings´ operations are attributed to the staff in terms of salaries and benefits. Energy-related behaviors of building occupants are directly related to high fluctuations of energy consumption in buildings. Evidently, Green buildings and upcoming sustainable building technologies will need to justify their impact on the occupants´ energy consumption along the whole building´s lifecycle. This MSc Thesis explores the relation between Wellbeing and energy-related behaviors during the operation and maintenance phase of the building. The aim is to find practices applicable to operations management that will have a positive impact on the occupant´s Wellbeing while fostering lower energy consumption. First, through an extensive literature review, this report organizes relevant concepts, theories and frameworks. Afterwards, the Center for Interactive Research on Sustainability (CIRS) is presented as a case study via the operation strategies undertaken to ensure health and comfort of the occupants. Semi-structured interviews with the post-occupancy evaluator and operations director at CIRS were performed. The interviews focused on the implications of applying such strategies and their relations. The results are presented via a 5-step framework highlighting awareness, competence and meaningfulness when operational strategies aim to ensure the wellbeing of occupants. Moreover, the CIRS strategies were organized in two frameworks (CAS & PAS). This, to visualize the processes and roles involved in the assessment of Wellbeing and energy-related behaviors. Finally, the applicability of the learned strategies from CIRS on the Swedish context is presented. A semi-structured interview was conducted with the environmental strategist on a Real Estate company in Gothenburg. The operational strategies and occupant´s practices involving Wellbeing and energy-related behaviors were identified. In order to progressively adapt the overall results in Gothenburg, a set of managerial recommendations and transitional practices is proposed.

Keywords: Sustainable Development, Challenge Lab, Indoor Environmental Quality, Occupants, Behavioral Change, Social Practice, Sustainable Office Buildings, Facilities Management, Wellbeing, Energy

Acknowledgements

We would like to express our gratitude to our friends from the Challenge Lab 2015 who walked the same path with us; it would have not been the same without you. Thanks to our parents and beloved ones for their great support and encouragement throughout this experience in Sweden.

We kindly acknowledge our supervisors Holger Wallbaum and Alexander Wunderlich; for their critical views on our work and guidance on the formulation of the research questions. The valuable information and guidance provided by them has been possible through the Climate-KIC's flagship project Building Technology Accelerator, Smart and Sustainable Offices.

We are grateful to our wise examiner Professor John Holmberg, who´s teachings will always be guide and encouragement to face the challenges of transforming society. Thanks also to the Challenge Lab team; David, Kamilla, Örjan and Daniella for their assistance and support during the activities and events of The Challenge Lab´s 2015. Furthermore, Pernilla Gluch as our Master Programme Director for her support on the early stages and for introducing us to the Challenge Lab, without her we would not have been part of this fantastic group.

Special Thanks to John Robinson (Head of IRES) for facilitating the collaboration among universities towards sustainability transitions and sharing his expertise with us. Thanks to all our interviewees from CIRS and HIGAB who generously gave their time and support us with their knowledge.

Guillermo would like to thank the Vladimir Kaspé fund for the financial support in this venture and to my teachers and friends from Universidad La Salle; Homero Hernández and Rocío Martínez.

On a more personal note, I wish to dedicate this thesis to my dear grandmother Elvia S. who suddenly left this world before her travel to visit me in Sweden. Your perseverance and generosity will always be in my heart.

Guillermo

Definition of terms

ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
BREEAM	BRE Environmental Assessment Method
BRI	Building Related Illnesses
C-Agent	Challenge Lab Change Agent
DPI	Daylight Performance Index
HVAC	Heating, Ventilating and Air Conditioning
IRES	Institute for Resources, Environment and Sustainability
IE	Indoor Environment
IEQ	Indoor Environmental Quality
LEED	Leadership in Energy and Environmental Design
PMV	Predicted mean vote
PPD	Predicted Percentage Dissatisfied
SBS	Sick Building Syndrome
TC	Thermal Comfort
HPB	High Performance Buildings
BMS	Building Management System
BAS	Building Automation System
CIRS	Centre for Interactive Research on Sustainability
O&M	Operation and Maintenance phase of a building
POE	Post Occupancy Evaluation

Table of contents

APPENDIX:

Table Index

Figure Index

Introduction

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

(Brundtland, 1987)

Today, buildings are responsible for more than 40 percent of global energy used and at least a third of global greenhouse gas emissions. During the last years, emerging trends regarding sustainability on the built environment have showed a strong focus on the issues occasioned by the high-energy consumption and large contribution to the CO_2 emissions of buildings (UNEP, 2009). According to the World Green Building Council report (2014) the costs of commercial building operations are 1% energy, 9% rental and around 90% related to staff. Thereby, to justify investments on sustainable offices addressing the higher costs of occupants is of relevant importance. The New Buildings Institute conducted a study in 2007 showing that 30% of LEED buildings perform better than expected, 25% perform worse than expected, and a handful have serious energy consumption problems post-occupancy (Owen et al., 2007).

Theory on sustainable construction has discussed mainly environmental sustainability, especially issues regarding energy efficiency while lessen the attention to the social and human aspects (Cole, 2012; Feige et al., 2013). One of the most important aspects for the health, comfort and perceived productivity of building users is the indoor environment quality (IEQ) (Bluyssen et al, 2011; Agha-Hossein et al., 2013). High performance buildings bring different benefits for employers and employees, e.g., increasing performance, reduction of Sick Building Syndrome (SBS) or higher employee retention and attraction (Day and Gunderson, 2015).

Technologies and solutions are improved over time; however, human behavior in office buildings is still responsible for high fluctuations on energy consumption in those buildings. Thus, the impact of human energy related behaviors are a key factor when analyzing energy performance in office buildings (Hong et al., 2015). Moreover, different approaches and strategies have been applied to reduce the energy consumption of users in office buildings through the integration with information and communication technologies (ICT), users and operation managers. (Gulbinas and Taylor, 2014; Orland et al., 2014)

This MSc thesis seeks to explore the relation between operational strategies of buildings to ensure users well being and positively influence the energy related behaviors of users towards energy savings on the long term. For this purpose, an extensive literature review was conducted to define the framework of wellbeing; its relation to the building systems, and the operations management. Afterwards, a case study of the operational strategies applied at the Center for Interactive Research on Sustainability (CIRS) is presented. CIRS aims to achieve net positive impact on the environment and on the human beings. Finally, the knowledge gathered was analyzed and brought into the Swedish context. The barriers to adopt the synthesized practices were encountered; however, this MSc thesis proposes a series of practices to gradually evolve into sustainability transitions. Backcasting was crucial towards the interaction with stakeholders at an international level through the outside-in perspective. Moreover, it enabled the authors of this thesis to find the intrinsic motivation to challenge the current mindsets towards new sustainability paths.

Why Backcasting?

The issues regarding sustainability show the complex patterns that make the use of Backcasting the ideal tool to find solutions and strategies for change (Holmberg and Robèrt, 2000). The societal, economical and environmental systems are complex, making effective the approach of using Backcasting as a planning tool to prepare for changes. Organizations can use the tool to prepare for future changes on the market such as policy changes or cost increase for ecological or resource limitation. The long term and short-term perspectives are addressed; solutions that will fit in the long-term future and also the steps towards those solutions are aligned with the vision. The methodology has four steps strategic planning for sustainability. (Holmberg, 1998)

Purpose and Goal

The purpose of this master thesis is to explore the operational strategies on buildings in order to provide wellbeing (health and comfort) to occupants and energy saving on office environments. The goal is to identify the factors that support energy saving without compromising (or decreasing) the wellbeing (health and comfort) of the occupants on a long-term perspective. Finally, analyzing opportunities and hinders of those strategies in order to apply them in the Swedish context.

Limitations

In order to narrow the investigation towards the solution of the purpose, limitations were set on top of the time boundaries.

- The report focuses on the operation and maintenance phase; after the occupancy of the building, the brief, design and construction phases were not considered for the purpose of this investigation.

- The report was limited to the building´s operations manager perspective since their responsibilities include applying operational strategies during the longest period of the building´s life cycle.

- The analyzed strategies were limited to those of the Indoor Environmental Quality (IEQ) and the interactions of occupants with the building systems.

Outline of the Thesis

This master thesis includes eight sections after the previously Introduction, Purpose and Limitation statements.

Section 1 includes The Challenge Lab´s description where its theoretical background, the process and the results are presented. The research questions represent the main outcome of this section.

Section 2 includes the Literature Review which encompass (1) Green Buildings & Regenerative Sustainability, (2) IEQ and its impact, (3) Behavioral Change & Social Practice theories and finally building systems and strategies for the provision of IEQ (4).

Section 3 describes the methods used to answer the purpose of the MSc thesis report. Moreover, the steps performed to conduct this research are described.

Section 4 presents a background with the results obtained from the building manual and the semi structure interviews performed with the CIRS team.

Section 5 includes the analysis of the case study.

Section 6 includes the context analysis to explore the applicability of the findings from the case study on a Swedish context.

Section 7 and 8 presents the discussion of the findings regarding the case study, context analysis and the Challenge lab. Finally, concluding remarks followed by further research are presented on section 8.

Section 1: The Challenge Lab

The Challenge Lab forms an integral part of the strategy taken by Chalmers University of Technology towards sustainable development. The aim of the Challenge lab is to become a hub for the triple helix actors (Academia, Industry and Society), where students can challenge the status quo of society on a trust based environment towards a sustainable future (Holmberg, 2014). The lab is physically located at Kuggen in Lindholmen campus in Gothenburg and connected to Lindholmen Science Park. The Challenge Lab serves as a neutral arena where the triple helix actors can meet each other. During the spring semester 2015, thirteen master students became the Change Agents (C-Agent) who formed the core of the Challenge Lab by developing their Master Thesis.

On this section, the theoretical background supporting the Challenge Lab is described. Afterwards, the Challenge Lab 2015 process is explained following the same structure presented in the theoretical background. Finally, the results of applying empirically the theory along the C-Lab´s process are presented.

1 Theoretical Background

The Challenge Lab process is based on a wide theoretical background encompassing perspectives, tools, methodologies, theories and frameworks. The theoretical background is meant to be used by the C-Agents to work on complex problems related to sustainable development. This section describes the theoretical background behind the Challenge Lab process carried out during the spring semester 2015.

1.1 Backcasting

The methodology followed during the Challenge Lab master thesis has backcasting as its base (Robinson, 1990) (Holmberg and Robèrt, 2000). This methodology is suitable for studying problems within a complex system, with dominant trends that lead to the issue, the solutions have a long-term focus and there is need of change of the status quo (Dreborg 1996).

The backcasting process (figure 1) contains four steps:

Step 1: Define a criteria for sustainability
Step 2: Describe the present situation in relation to the criteria
Step 3: Envision future solutions
Step 4: Find strategies towards sustainability

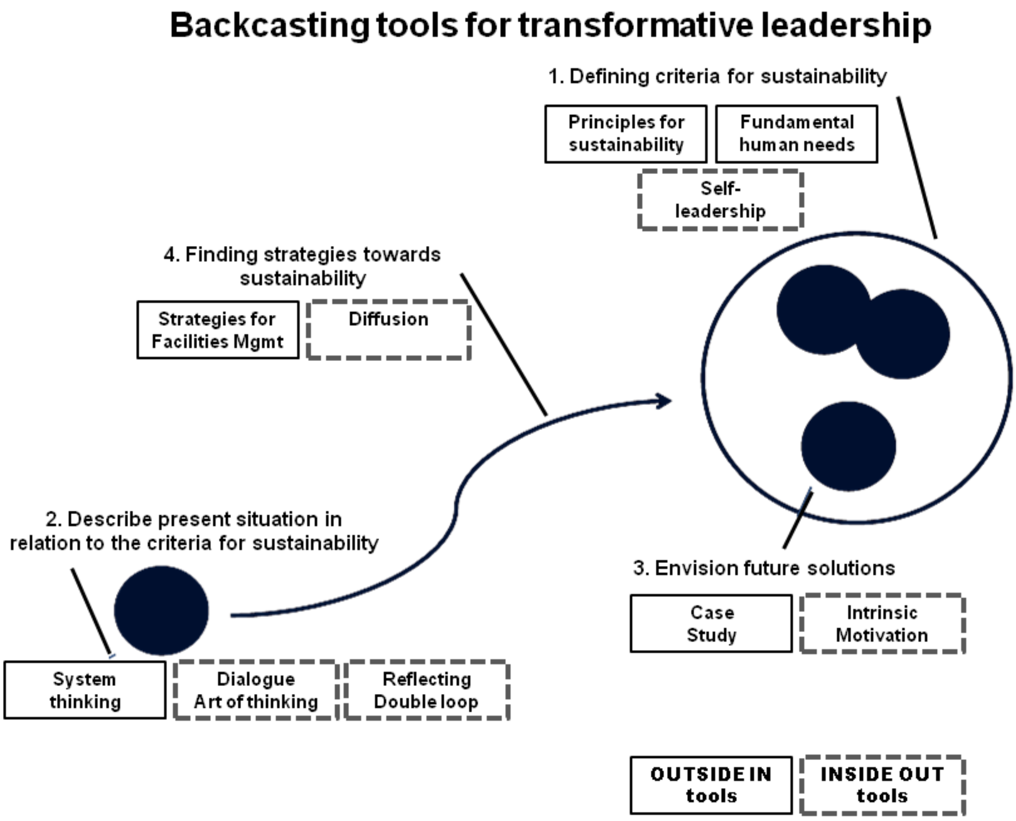


Figure 1 Backcasting tools for transformative leadership. Adapted from Holmberg (2014)

The first step focuses on define a future vision, even though it cannot be predicted the precise outcomes, sustainability principles are used as a foundation for creating the future vision. Second, the present situation is mapped in order to understand the gap between current and desired situation. Furthermore, this mapping allows the identification of leverage points to act upon. The third stage of the backcasting methodology refers to envisaging solutions for the desired future vision. This is done to overcome the gap previously mentioned. The fourth and final step refers to future steps and strategies needed to establish a clear path that will lead towards the desired vision established in the beginning.

1.2 Outside-In Perspective

During the early phases of the Challenge Lab 2015, an overview of the global situation was presented through the Outside-In Perspective. The Outside-In Perspective shows the whole picture regarding spatial scales (global, continental, national, regional and local) and time periods (past, present and future). Through backcasting, the Outside-In Perspective encompasses tools such as Principles for sustainability, The Funnel and The Compass. These tools were used by C-Agents to allocate past trends, present challenges and future plans at different spatial scales.

1.2.1 Sustainability compass:

In order to establish clear, visible and understandable criteria for sustainability "The compass index of sustainability" is applied (Atkisson and Hatcher, 2001). The compass (figure 2) is an answer to the paradox that arises between the complexity of data regarding sustainable development and how to manage and communicate in a simple and effective way. The four clusters in the compass have Daly´s pyramid and its four great areas as a base. Those categories are Nature, Well-being, Economy and Society, although originally Daly (1973) ranked them in different levels, the compass considers all of equal importance.

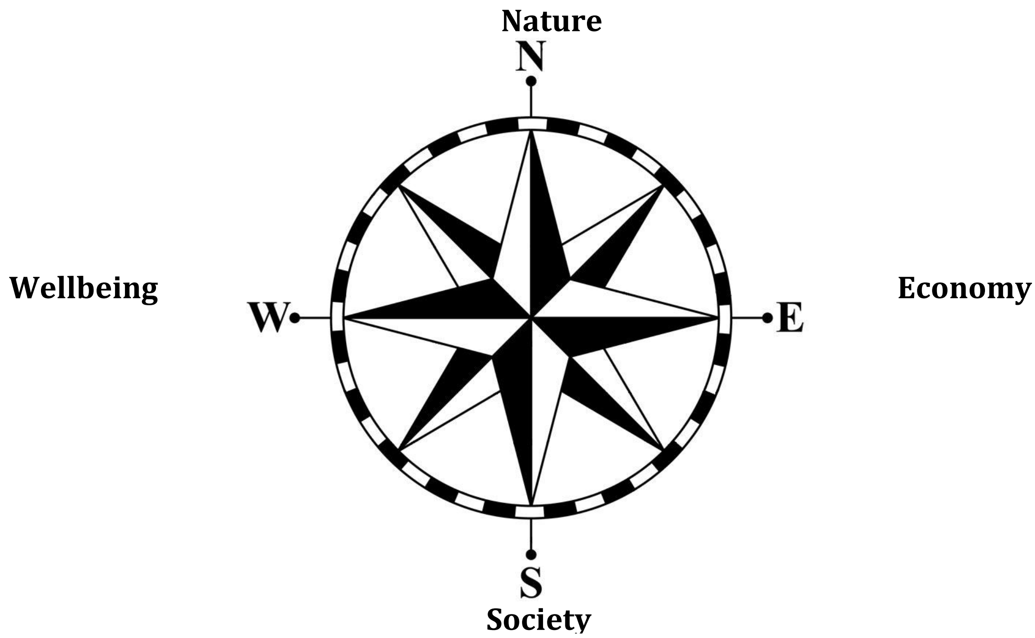


Figure 2 Sustainability Compass. Adapted from Atkisson and Hatcher (2001)

1.2.2 The funnel: Visualization of the Trends

As it has been presented before, the second step of the backcasting consists in understanding the current situation (Holmberg, 1998). The framework for visualizing the trends was introduced by Robért et al. (1997) and it uses a funnel as a metaphor of the current trends. The walls of the funnel represent the boundaries and they symbolize those trends.

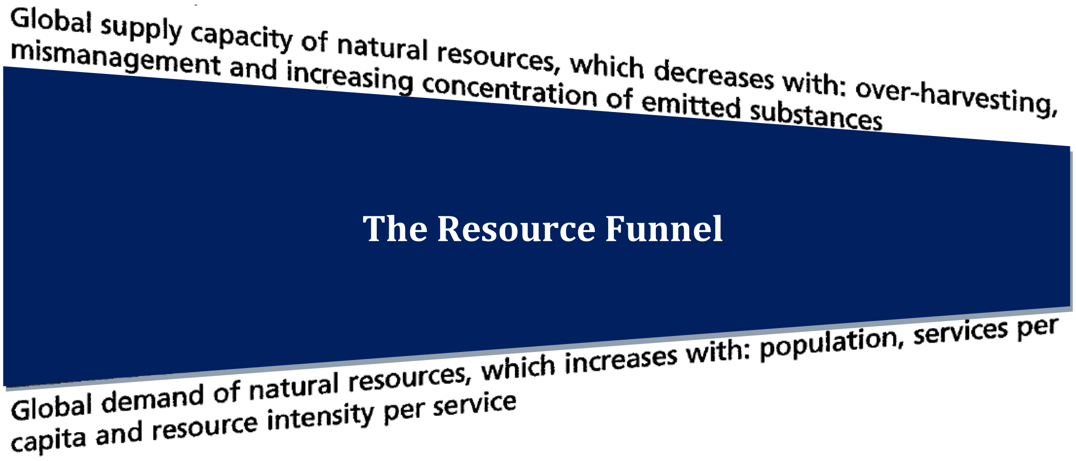


Figure 3 The resource funnel (Holmberg 1998)

The six key trends at global level are represented in the figure 3 by increasing and decreasing trends. (Holmberg, 1998) On one side the increasing trends are shown; (bottom of the figure) *Material and Energy intensity, economy and population* are shown*.* On the other side the decreasing trends compounded by *resources available, assimilation capacity of the planet and land usage* can be found. The funnel serves as a representation of the path that current trends are leading us to. Thereby, the funnel helps on the visualization and understanding of the unsustainable practices.

1.2.3 Socio-Technical Transitions: Systems Thinking

Our current society is characterized for its complexity, which requires understanding it through systems perspective. Co-evolutionary Multi Level Perspective (MLP) theory (Geels, 2005), aims to explain transitions of society in different system levels. The transition is explained through the understanding of the interconnections between technologies and society. Furthermore, with the objective of providing a better system understanding, Haraldsson (2004) proposes the establishment of clear system boundaries for the different levels. Fig.4 show the Multilevel Design Methodology, which allows grasping the different levels of action towards sustainable transitions.

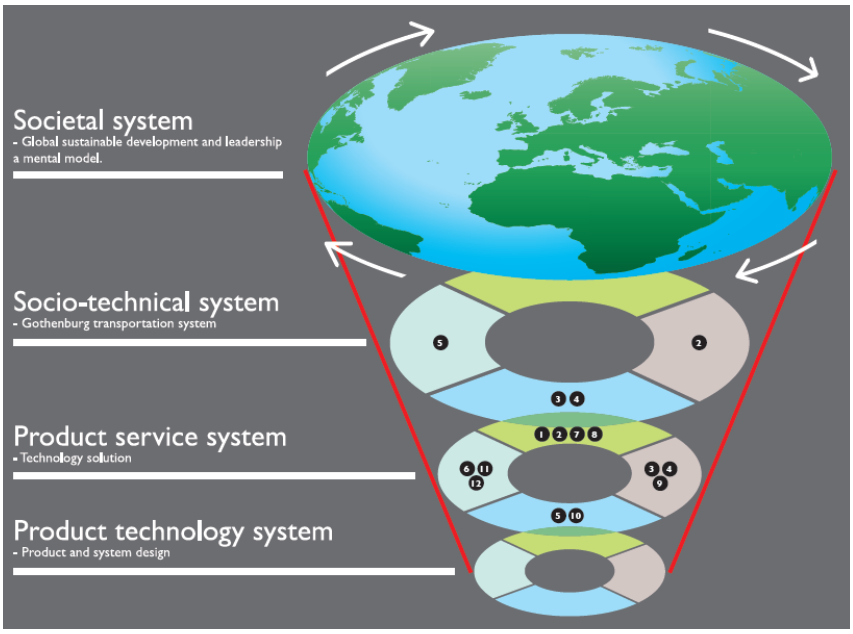


Figure 4 Multilevel Design Methodology (Geels, 2012)

An example of the transitions can be found in the economical systems and the evolution of them over time. The big economical transitions have raised different needs on the users; in our main research this involved mainly comfort of office occupants and IEQ. According to Bluyssen (2009), nowadays we are transitioning from knowledge economy to a creativity-based economy, and this transition is also reflected on users needs. However, Bluyssen (2009) indicates that in the near future the climate change will push society into the direction of prioritizing other type of needs and basic aspects such as belonging and safety. Many of the theories regarding IEQ and comfort re-conceptualization (de Dear and Brager, 1998; Cole et al., 2008; Chappels and Shove, 2005) will play a key role on that climate change economy of the future.

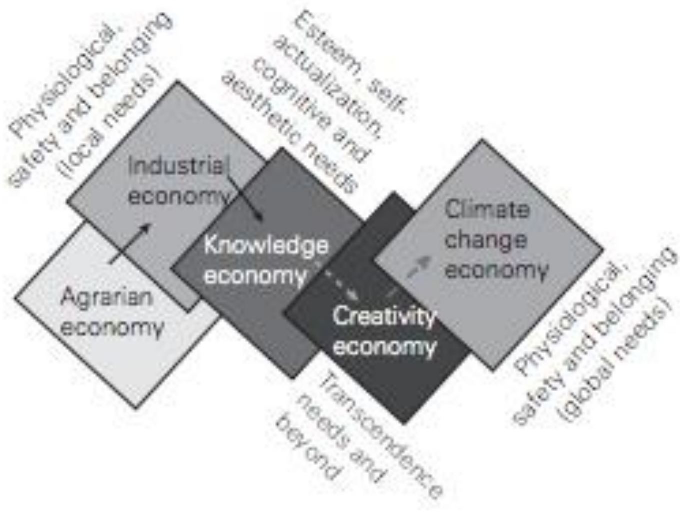


Figure 5 Economic societal transitions and implications on human needs (Bluyssen, 2009)

1.3 Inside-Out Perspective

In order to achieve transformational changes as important as understanding trends and principles is the understanding of own values, motivations and driving forces. In this section self-leadership and self determination will be presented.

1.3.1 Self-Determination (self leadership)

The Self Determination Theory (SDT) by Ryan and Deci (2000) deals with the human nature and the positive potentials that in many cases are hindered by apathetic and alienated behaviors. Thus, is of importance the understanding of values and motivations but also which social environments can arise individual's own personal development. Intrinsic motivation is a core aspect of the SDT, it serves to explain the reasons for the continuous looking for challenges to improve and practice one's abilities and competences. The intrinsic motivation is considered to be a source of happiness throughout individuals' life. The intrinsic motivation is directly related to the need of autonomy and competence of human beings. However, intrinsic motivation requires that the activity being conducting includes genuine interest and also that imposes a challenge for the individual.

On the other hand, the most common type of motivation seen is the extrinsic motivation, which is explained by the social rules and pressures that come with living in society. (Ryan & Deci, 2000). In this case the response to the factors that motivate the action can differ in a various types of attitudes, from rejection to active engagement and internalizing the value or regulation. The ideal situation is to promote social situations where the extrinsic motivations are integrated within individuals internally. In order to achieve this internalization the need of relatedness and belonging of individuals is of key importance. Thus, social environments that promote integration and group relatedness are more likely to success in the self-adoption of individuals of the extrinsic motivations. Furthermore, the adoption is also facilitated when the individual feel competent to develop it and the environment is safe and gives the individual a perceived autonomy to develop the action/task. Thereby, the environment supportive the individual integration of extrinsic motivation is the one that can comply with the three needs of autonomy, competence and relatedness. When, the failure of internalization or intrinsic motivation is not prompted attitudes such as lack of commitment and engagement occur. (Ryan and Deci, 2000)

1.3.2 Dialogue

A key aspect within the Challenge Lab is the dialogue meetings with different stakeholders. The analysis of dialogue shows that the four different roles and their corresponding actions (fig.6) result in effectiveness. Dialogic leaders understand the need of those roles and identify when are required to take the different roles. The actions that a good leader should nurture for developing effective dialogues are listening, suspending, respecting and voicing. (Isaacs 1999) Good dialogues are the base of social collaboration (Sandow and Allen, 2005), which results in a reinforcing circle that potentiates collaboration, understanding, listening and trust among the involved actors. When those four mentioned factors are not present in the relationship the opposite occurs, creating a circle of social separation that results in increase in costs and depletion of resources. (Sandow and Allen 2005)

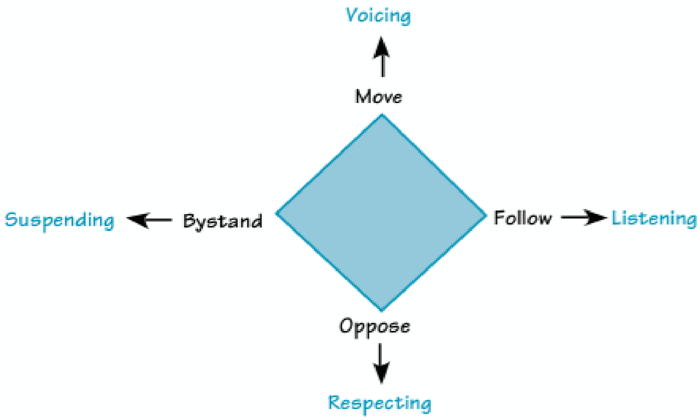


Figure 6 Roles and actions in a dialogue (Isaacs 1999)

2 Backcasting: The Challenge Lab 2015 Process

The C-Lab is a process for developing the Master Thesis where the interaction between Academia, Industry and Government is enhanced. The C-Lab took place in the City of Gothenburg from January 19th to May 26th 2015. In order to deal with the complexity and mixture of theories and practice, the C-Lab process described on this section was structured on the same basis as the previous section Theoretical Background. The four steps of the back casting process represent the main structure for the C-Lab Process. Outside-In and Inside-out perspectives are described as the series of activities and events occurred during the four steps of the C-Lab´s process. Time was a critical factor in order to define the vision, principles of sustainability, the system and the research question. Once these four elements were defined, the aim, purpose, methodology and expected outcomes would be clear in order to develop further the Master Thesis. Therefore, a strict but nonetheless flexible and dynamic work-plan was necessary to understand critical activities and relevant events during the whole process. Fig. 7 shows the weekly events and activities during the first six weeks encompassing Backcasting steps, Outside-in and Inside-out perspectives occurred during the C-Lab´s process. The complete timeline of events and activities of this MSc thesis is shown on Appendix B.

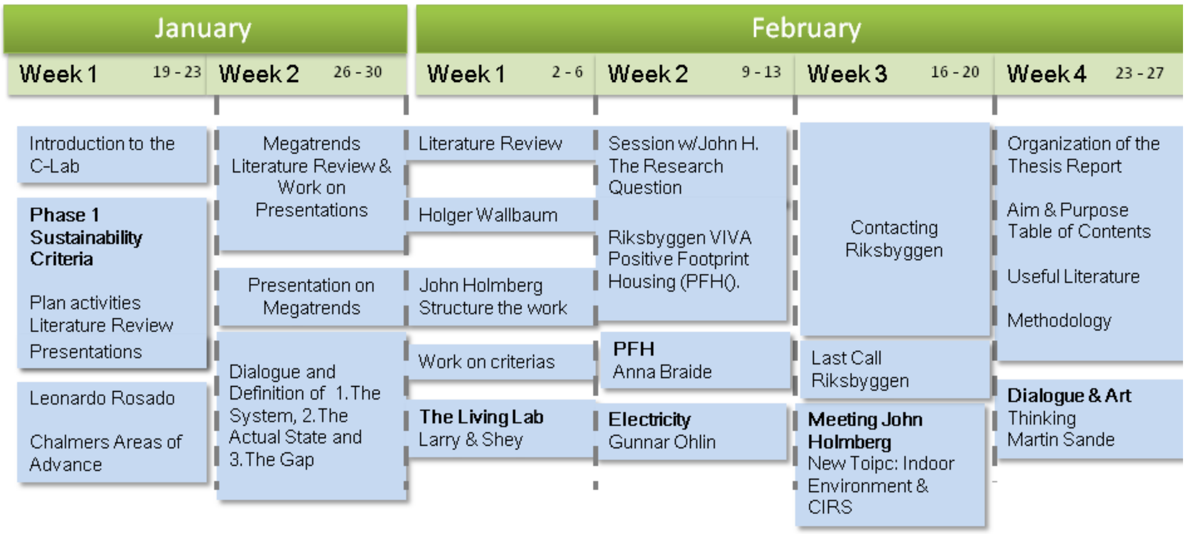


Figure 7 The C-Lab process work schedule during the first six weeks

The physical workspace was mainly composed by the dialogue area, the desk area and a meeting area (Appendix C). Support areas such as kitchen and restrooms were also provided. On January 19th, the introduction to the C-Lab was held at Kuggen in Lindholmen Campus the thirteen change agents met each other. Moreover, the C-Lab´s background, purpose and aim were discussed with the guidance of John Holmberg. Afterwards, a dialogue session among the change agents was held to define the further activities, meetings and to establish rules (see fig. 7 above).

During the first weeks, uncertainty existed on how to develop the C-Lab process in order to define a research question for the Master Thesis. However, the strategy followed to plan and execute the following activities was based on ambiguity as a common frame of action within organizations (McCabe, 2010). Dealing with uncertainty is key for leadership within organizations (Clegg et al., 2010). Eventually the series of events occurred tested the C-agents behaviors and actions towards complexity (Self Determination Theory).

2.1 Step 1: Define the criteria for sustainability

During week 1, as a way of organizing the principles, the sustainability compass (Atkisson and Hatcher, 2001) was used to organize and visualize the existing literature regarding principles in the different areas of the compass. Furthermore, different discussions among the participants had been conducted to establish and define common criteria for sustainable urban development.

2.1.1 Outside-In Perspective

The sustainability criteria were approached through literature review, presentations, discussions for analysis in smaller groups and conclusions altogether. The workspace of the C-Lab played an important role to organize and realize all the activities. On this stage, the challenges faced were the management of a large group of thirteen people in order to review literature, present the results, organize the information, analyze and draw conclusions. The methodology used, was to separate the C-Agents into four sub-groups based on The Sustainability Compass' dimensions. The sub-groups, namely (1) Wellbeing, (2) Society, (3) Economy and (4) Nature would discuss the relevance of the literature review and presentations. The aim of these discussions was to develop a draft version of the sustainability criteria belonging to each of the four dimensions. A challenge was ensuring that every participant could participate on the four discussion subgroups. For this purpose, after 15 minutes of discussion on each subgroup, the rotation to another subgroup was encouraged. Finally, the draft of criteria contained on each of the four dimensions was discussed at the dialogue area and the final Sustainability Criteria was defined.

2.1.2 Inside-Out Perspective

The Self Leadership seminar was the tool used to understand the own values, as well as those of the other C-Agents. The seminar was developed within one day through activities such as Portrait of Personal Strengths, Strength Management and The 7 Motivational Value Systems™. The activities held during the seminar allow the C-Agents to reflect upon themselves and the others, aiming to understand the forces that drive and encourage people to face challenges. A key output from the whole seminar was to understand the balance of all the C-Agents strengths and weaknesses as the best tool to achieve the common goal, i.e. the vision.

2.2 Step 2: Describe the present situation in relation to the framework

For the second step a research on the current megatrends regarding urban development was conducted. This was supported by a more local analysis of the projects and strategies that are currently happening in the city of Gothenburg to create a general background on the current situation. Furthermore, dialogues with multiple stakeholders were conducted, understanding the different perspectives on some of the projects. The dialogues with stakeholders involved the three main groups that form our society; academia, public sector and private sector.

2.2.1 Outside-In Perspective

During week 2, Past Trends, Present Challenges and Future Plans were reviewed. A literature review was undertaken and the results were presented and discussed at the dialogue area. The input from the meetings held at the C-Lab during the whole process was a retroactive feedback that defined the further aim, purpose, methodology and expected outcomes.

Leonardo Rosado research described the cities as key drivers of the economy and introduced the District Factor 10 projects. Riksbyggen VIVA housing project was a highlight regarding energy performance on the built environment. Moreover, it envisioned future solutions regarding energy consumption and sustainable behavior of occupants. Holger Wallbaum described the Built Environment Challenges regarding the office buildings and the related expenditures of staff vs. energy. After this presentation, the built environment was on focus for the purpose of this thesis where the housing and office buildings would be studied more deeply.

3 Results: Sustainability Criteria, System & Research Question

The results of the series of activities and events until week 4 of Challenge Lab process were the development of the sustainability criteria composed by each dimension of the sustainability compass and the vision for sustainability. The understanding and definition of the system where the Master Thesis would focus as well as the research question were defined as well.

3.1 Sustainability Criteria

In order to visualize sustainability principles, fig. 8 shows the abstracted version of the sustainability compass containing the results of the literature review, analysis and discussion of sustainability principles. The vision for sustainability, which generally gathers the essence of the four dimensions for sustainability, is at the center. The four dimensions; Nature, Wellbeing, Society and Economy can be found in detail on Appendix A.

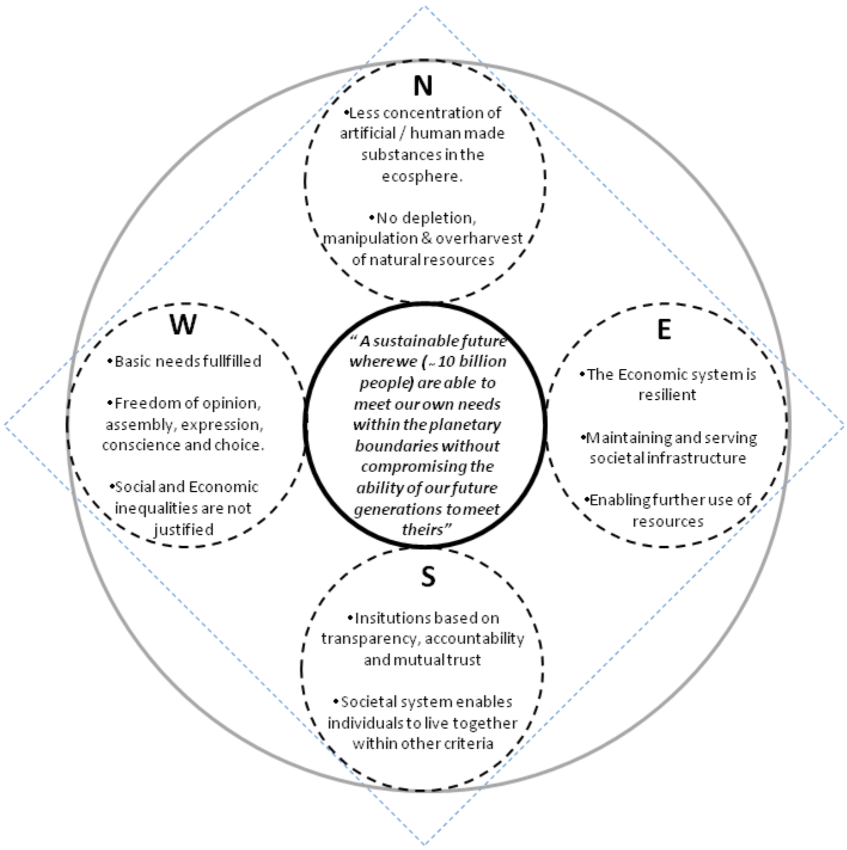


Figure 8 Sustainability Criteria & Vision. Adapted from Atkisson and Hatcher (2001)

3.2 The System

During the seminar held during Week 4, the synthesis of the sustainability criteria and the system were discussed and narrowed to develop the research questions. The built environment was the main resultant subject. The system was decided to remain at a local scale. Find a city where a project undertaken by Academia, Industry and Government towards sustainable development was the main criteria for the development of this thesis report. The city of Gothenburg was already analyzed through the Outside In and Inside Out perspectives, therefore was the most suitable place to develop the further research. A series of projects from the District Factor 10 were reviewed. Riksbyggen Viva project was originally chosen as the case study for this thesis report. After several intents of contacting the main stakeholders, this project was discarded after receiving any positive response or intention to collaborate. On week 5 of the C-lab, the CIRS building on the UBC campus on Vancouver was introduced by Prof. John Holmberg.

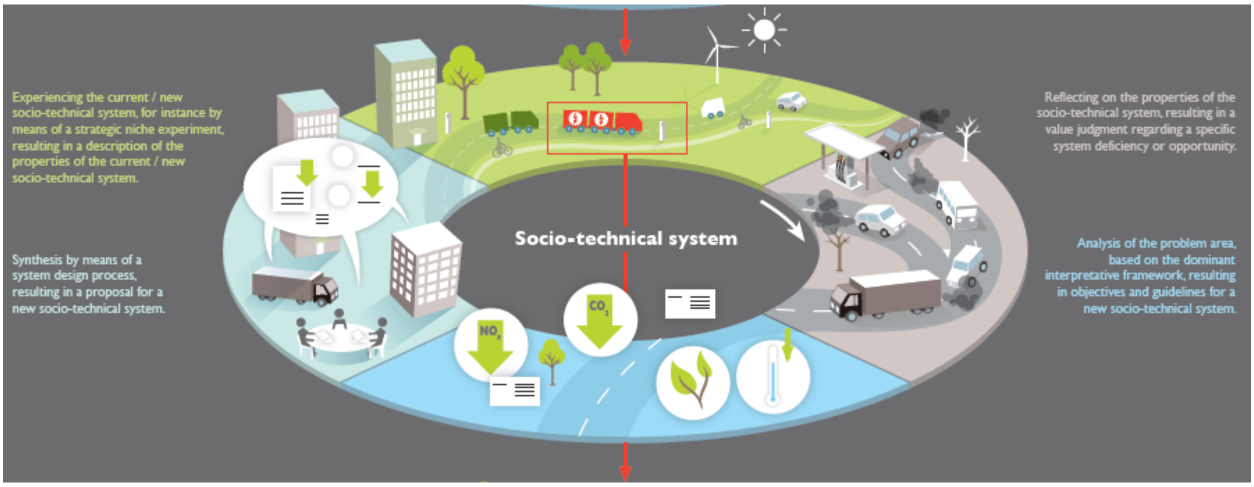


Figure 9 Socio-technical system (Geels, 2012)

3.3 Research Questions

After analyzing the CIRS context, we decided to focus our energy on studying the general success factors and best practices of the building. A surprising set of principles, goals and strategies were found, and it was at this moment that we decided to narrow down to the operational strategies at CIRS. During the operational phase, the most interactions among building users are performed and it is the longer period where the energy related behaviors and energy performance might be studied, evaluated and improved. Finally, we pursued sustainability transitions in Gothenburg and proposed practices to achieve change. As an aim to solve the issue, the topic and the research questions were chosen.

RQ1: What strategies and systems during the OM phase of the building involve occupants' interaction regarding IEQ?

RQ2: Which impact do the strategies have on energy consumption and occupants´ wellbeing?

RQ3 How to apply the strategies from an operations manager perspective positively in order to influence the energy-related behavior of the occupants (habits) during the long term?

RQ4: Which are the implications to apply those strategies in the context of a property manager in the city of Gothenburg?

Section 2 - Literature review

2.1. Green buildings and general definitions

"Green building is a holistic concept that starts with the understanding that the built environment can have profound effects, both positive and negative, on the natural environment as well as the people who inhabit buildings every day. Green building is an effort to amplify the positive and mitigate the negative of these effects throughout the entire lifecycle of a building."

(U.S. Green Building Council, 2015)

2.1.1 Green design of buildings and its issues

Green design is commonly used and associated with buildings that have higher environmental performance compared with typical buildings (Cole, 2012). The focus of green design is to reduce damage on natural, resource consumption, emissions etc., while at the same time minimizing discomfort and the use of pollutant substances for occupants. Recently (Cole, 2012), criticism regarding the approach of reduction of consumption is not enough to achieve a sustainable future as it only serves to decelerate unsustainable practices.

Nowadays, the most used assessment tools for green buildings such as LEED or BREEAM approach green building mainly from a performance perspective. These systems evaluate based on a checklist system the performance of the buildings in aspects such as energy, water use, use of materials.... etc. The technical strategies and solutions required on those assessments for environmental performance are valid, however there is more potential when partnering human and natural systems. (Cole, 2012)

2.1.2 Sustainable offices

Sustainability has been early introduced to the relation of building and user perception. Current research (Feige et al., 2013) intends to find the link between building design, comfort and productivity in order to show the best building solutions towards the social sustainability concept. The results show that building's occupants feel the need to have influence on their work environment than rather work on fully automated buildings. Correlation between comfort levels and work engagement suggest the reduction of personnel rotation. The authors highlight the relevance of setting up laboratory conditions to the interconnection of IAQ aspects. Research gaps were identified in the social aspects while energy-related, environmental and economic aspects have greater importance on a normal basis. Moreover, previous studies are limited in the number of buildings analyzed and biases might have an effect on the result of certified buildings studies. (Feige et al., 2013)

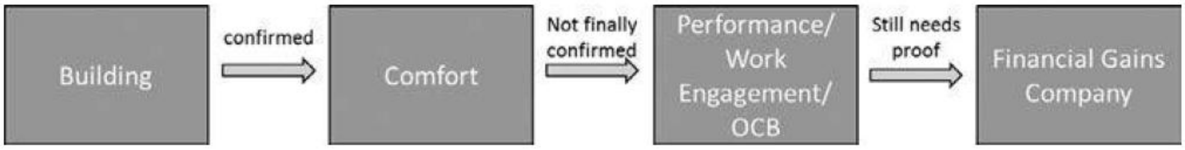


Figure 10 Relations in sustainable offices (Feige et al., 2013)

2.1.3 Moving towards regenerative design and development

In contrast of traditional green design, which seeks the reduction of resources consumption and lessen the damage caused to the environment, the regenerative design and development aims for a net positive impact of the building. Cole (2012) suggests the use of technological capabilities and strategies to respond the social, cultural and ecological challenges of the place. Thus, the approach requires local knowledge to be able to create social and natural capital, which is the final aim of regenerative design. This contrast mainly with most green building assessment tools that are rather standardized and do not rely on local characteristics (Cole, 2012). Regenerative design and development requires guidance through questions and challenges to obtain the aspirations of the project, rather than following the checklist of the assessment tools. (Cole, 2012)

In order to evolve from traditional green design to regenerative design it is important to switch and change some design practices. (Cole, 2012) For instance, returning to some traditional / indigenous practices and bring them to nowadays architecture practices. Another practice for regenerative design is to involve a big number of stakeholders in the current integrated design processes, potentially engaging them in the long term. Furthermore, a system thinking approach from designers is necessary to understand buildings as part of bigger systems (neighborhood, city, district level). (Cole, 2012)

2.2 Indoor Environment Quality (IEQ)

As stated before, green design and also regenerative design aim for a positive impact on the occupants of buildings, more precisely office buildings. As people spend approximately 90% of the time indoors one of the critical factors to achieve wellbeing of individuals is the Indoor Environment Quality (IEQ). IEQ traditionally has been divided into separate elements; thermal comfort, acoustics, light and indoor air quality.

2.2.1 Thermal Comfort (TC)

"Thermal comfort is that state of mind, which expresses the satisfaction with the thermal environment"

(ASHRAE 55, 2014)

Heat- Exchange

Research on Thermal comfort (TC) began due to the fast-growing air conditioning industry on the USA. The heat-exchange approach is considered the basis for the current comfort criteria. Laboratory and field studies led to empirical, statistically based indices for TC. Many thermal indices were based upon the heat-exchange approach such as: total thermal body comfort and later local thermal comfort aspects, such as draught, radiant asymmetry, vertical air temperature difference and floor surface temperatures. The data for these indices originated from lab studies focused on the heat exchange between a person and the thermal environment and the physiological conditions that are required for human comfort. For total body comfort the most important indices are: Operative temperature, Effective temperature and Predicted mean vote (PMV). (Bluyssen, 2009)

Predicted Mean Vote –Percentage of People Dissatisfied:

The model developed by Fanger in 1967 (1982) is one of the biggest contributions for determining the understanding of thermal comfort in indoor environments. The model aims to predict the thermal comfort of occupants taking into account variables like clothing and level of activity on the indoor spaces. The Predicted Mean Vote (PMV) estimates the Predicted Percentage of Dissatisfied people with the indoor environment given some variables. It is designed for adults and can be applied in all type of buildings. The model is based in six different factors that determine the thermal comfort; air temperature, radiant temperature, air speed, relative humidity, clothing and metabolic activity. The PMV model has been widely adopted by many standards and guidelines such as ISO 7730 or ASHRAE 55 and it is still in use and applicable for all types of buildings (Van Hoof, 2008). The factors in which the model has been based had later been validated by many researchers since its creation (De Dear and Brager, 1998) (Roefelsen, 2002) (Bluyssen, 2009).

Even though the model is still in use and is applicable to all type of buildings, there has been criticism regarding its consideration of occupants as passive recipients in the building (De Dear and Brager, 1998). The only aspect that is considered in the model is the physiological one, where psychological and behavioral/adaptive aspects are forgotten in the parameters (Cole et al., 2008). Furthermore, another major reason of criticism is that the system has been used globally in any type of building, event though; it was developed in a laboratory environment and based on college students. Another limitation of the model is the specific parameters that are established to effectively use the PVM method, which can be found within the ISO 7730. If those parameters are not among the limits of the norm the model cannot be applied. (van Hoof, 2008)

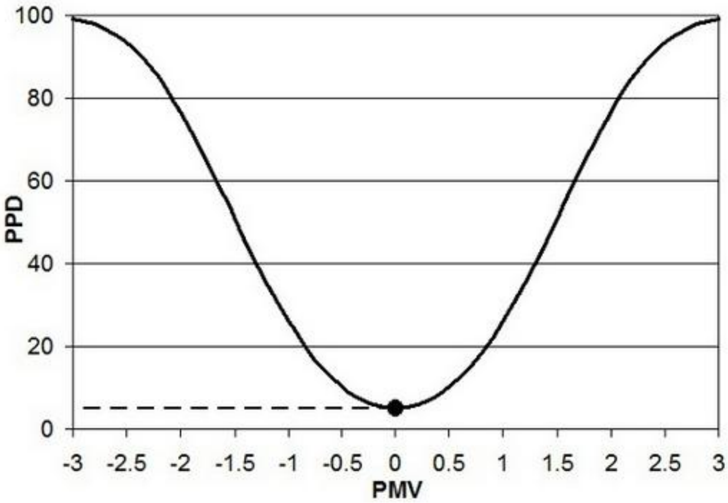


Figure 11 PMV Index, PMV (Predicted Mean Vote) in a seven point scale that goes from +3 (hot) to -3 (cold) correlated with the PPD (%). Thermal comfort model by Fanger (1982)

Adaptive thermal comfort:

In the late 90s the adaptive model of thermal comfort developed by Brager and de Dear (1998) introduced the new concept on the ASHRAE norms. In contrast with the traditional PMV model, which is a static model, they argued that building occupants play active roles on shaping their own thermal experiences. As a result of that three types of adaptations to the indoor environment were defined. First, behavioral adaptation which refers to the decisions occupants can take to adapt the indoor environment, such as clothing, building solutions (thermostats, windows…) or even cultural actions such as afternoon naps when the climate is too warm. A second type of adaptation regards the physiological changes undergone by different individuals, such as genetic adaptation of different generations and acclimatization of people to the environments where they live. Finally, the last typology refers to psychological adaptation, which is based on the previous experiences and the expectations of individuals. (De Dear and Brager, 1998)

The research conducted by Brager and de Dear (1998) on different office buildings in different climate zones concluded that occupants of naturally ventilated buildings were more tolerant regarding indoor environment temperatures. This can be explained with the previously mentioned adaptation types, specially the behavioral adaptation (access to windows and possibility to create and modify the indoor environment) and the psychological adaptation (expectations of the indoor environment). A correlation with the outdoor environment was also proven. This is due to the psychological adaptation, where people adapt to different temperatures during the year and the thermal comfort is affected by the experiences during the year. Thus, occupants of buildings in warm climates prefer warmer indoor environments that the ones living in cold climate zones. The resulting model (Olsen and Brager, 2004) included in the ASHRAE 55-2004 (Thermal Environmental Conditions for Human Occupancy) takes the PMV model by Fanger (1982) as a base. In this new model the range of indoor environment temperature to achieve an 80-90% of satisfaction are correlated with the outdoor temperatures. However, the adaptive model is only applicable for buildings with access to natural ventilation, for centrally heated and HVAC the Fanger model is still in use. The temperature ranges for 80% of satisfaction in centrally heated buildings is 2.05 K degrees above below the optimal temperature and in the case of naturally ventilated 3.45 K degrees above and below optimal temperature.

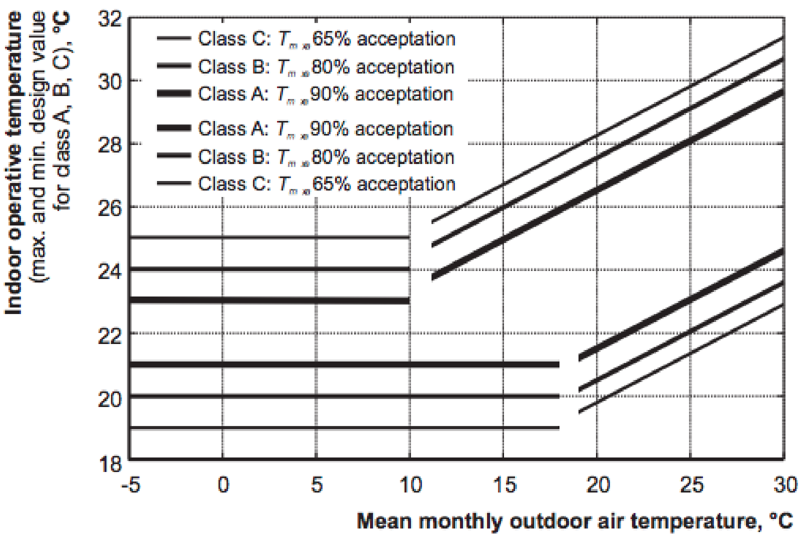


Figure 12 Adaptive thermal comfort model for naturally ventilated buildings. ASHRAE 55-2004

The simulation conducted by Toftum et al. (2009) supports the adaptive model and the tolerance to discomfort and a difference on the thermal sensation among occupants. Furthermore, loses in performance are almost insignificant on buildings with natural ventilation but higher indoor temperatures. This was proven even in cases where the temperature difference was 5.9 degrees higher in naturally ventilated than in mechanical ones. At the same time, the energy savings in naturally ventilated buildings were higher in all cases, but especially relevant in the case of very warm weathers as the one in Singapore. Concluding, the potential energy savings without compromising the comfort of occupants is considerable in naturally ventilated buildings. (Toftum et al., 2009)

2.2.2 Lighting/Visual Comfort (VC)

Lighting is an integral aspect when defining IEQ, as is a determinant factor that influences how we perceive indoor spaces. Furthermore, there is a tight relationship with thermal comfort and building's energy consumption. The concept of visual comfort is affected mainly by colors and luminance and also by the eye's sensitivity. The concept of visual comfort goes beyond being just a comfortable light; it also involves views to the exterior. Visible skylines, possibility to view objects far away and “green” landscapes are proven to be satisfaction sources for office users (Bluyssen, 2009).

Daylight is of major relevance, due to its condition as a free energy source and also the impact on occupant’s health (Baker and Steemers, 2014; Fontoynont, 1999). For instance since the 90s the European Daylight (ED) project has developed different tools and measurements regarding daylight luminance, reflectance in facades or roofs and also involving windows. Results from the ED project include tools such as the Daylight Performance Index (DPI) (Fontoynont, 1999). DPI serves designers to understand the minimal requirements of daylight but also to take into consideration illumination issues such as excessive glares and overheating.

2.2.3 Indoor Air Quality IAQ

Commonly, proper IAQ have been strongly associated with building’s ventilation rates (Bluyssen, 2009) Nowadays, the minimum rate established by the ASHRAE is 2.5 l/s per person plus an additional 0.3 l/s per m2 of space for that person. However, other aspects such as the substances included in the air and the levels at which are they present also determine the quality of the air indoors (Bluyssen, 2009).

Pollutant substances in office environments can be originated from different sources such as human activities (smoking, traffic pollution…), furniture, construction materials or the HVAC systems. The resulting effects to the exposure to those substances also vary from annoyance to health issues that can even result in deathly illness such as lung cancer or asbestosis (Bluyssen, 2009).

2.2.4 Reconceptualization of comfort beyond current standards

21st century has brought new paradigms when it comes to demands for thermal comfort and indoor environment. This is mainly due to the new ICT technologies and technological solutions. Individual controlling brought up by these tools has put pressure over engineers to deliver a 100% satisfaction. (van Hoof, 2008) Thus, to achieve the 100% there is a need of pushing further, as the traditional used standards and models such as ISO 7730 and ASHRAE 55 which only focus on large groups, volume conditioning and average values.

Furthermore, climate change and global warming will impose new challenges and higher cooling demands if the understanding of comfort is not re-conceptualized. The raising temperatures will require the installation of new air conditioning systems to keep the current comfort standards. Current practice and standardization bodies are leading the research towards efficient ways of delivering traditional indoor conditions based on a narrow concept of comfort. In contrast, an approach that would challenge the current concept of comfort (temperatures between 21-23 C indoors) could lead the future practices and standards towards ones with lower energy intensity and demand from the occupants (Chappells and Shove, 2005).

Following a similar approach based on the adaptive behavioral method developed by de Dear and Brager (1998) aspects, Cole et al. (2008) argue that the new context of climate change and green design practices require a reconceptualization of the office occupant comfort concept. The concept of “inhabitant” introduced to contrast the traditional “occupant” role, which refers to office users as passive recipients. The “inhabitant” role comes with responsibility on the performance and maintenance of the indoor space and buildings, which involves participation and adaptive behaviors. This perspective is aligned with the adaptive model, where active participation, dynamics in the building and control over environment creates a wider and more flexible experience of comfort. (Cole et al., 2008)

Cole et al. (2008) mention key issues that re-conceptualizing comfort would bring. Some considerations for the design team include aspects like the design of spaces to be adaptable and flexible, where inhabitants can adapt to the changing needs over time. The control and power to inhabitants also bring many challenges on the design of building systems and operation and maintenance of them. This requires emphasizing on the interactions that occur between inhabitant and operational manager, and of these two actors with the building itself. (Cole et al., 2008).

2.3. Impact of IEQ - Why is important?

"Perceptions may provide the missing link between the physical office environment and health, wellbeing and productivity outcomes."

(GBC, 2014 report)

2.3.1 Impact of IEQ in employees' comfort

According to Bluyssen et al. (2011a) many stressors that affect occupants have its origins on the Indoor Environment. Both physical and psychosocial stressors affect the body and cause different emotional states, behaviors and physical states. However, a big issue is to assess wellbeing as it imposes many difficulties. Three different methods can be applied to estimate wellbeing of office occupants; medical examinations, questionnaires (self-reporting) and monitoring for observing behaviors and responses of individuals to environment. (Bluyssen et al., 2011b)

Moreover, personal, social and building factors can influence the user perceived comfort on complex relations. Those relations exist between certain building characteristics (such as a HVAC system) and the perceived comfort of occupants. (Bluyssen et al., 2011a) Another aspect that affects the satisfaction of occupants is the control over the IEQ, as individuals need to feel the ability of control conditions for their individual preferences. (Day and Gunderson, 2015)

2.3.2 Impact of IEQ in employees' health

The indoor environment is healthy if certain conditions regarding physical, chemical and biological properties are met. Moreover, there is no aggravation or cause of illnesses and high levels of comfort secure the performance of occupants for the designated activities for which the building was conceived (Bluyssen et al, 2011a).

The health impact of indoor environment on occupants has been widely researched. Maroni et al. (1996) grouped the different symptoms and pathologies related to buildings into a common category named Sick Building Syndrome (SBS). The symptoms included in SBS range from irritation of nose or eyes to different headaches or mental fatigue. SBS symptoms are the most frequent health issue in office buildings. The symptoms are not directly correlated to one specific factor and factors such as psychosocial states and job stress can influence the appearance of SBS symptoms. However, the correlation with indoor environment quality is shown, and a good IEQ reduces SBS up to 50%. (Fisk, 2000)

Another type of health problems are the Building Related Illnesses (BRI), which are caused by different biological or chemical substances present on the indoor air. They range from infections such as Legionnaire's disease to hypersensitivity to chemicals present in the indoor environment to even chronic or deadly illness such as asbestosis. Lighting is also source of different health issues, especially when it comes to artificial lighting. The lack of wavelengths is a source of hormonal shortages. Inadequate lighting influences the mood, alertness and reactions of employees and, thus, reducing the performance and productivity. It can also be a source of physical accidents and influence the biological clock and sleep cycles of office users. (Bluyssen, 2009)

In terms of lighting, daylight access is reported to decrease issues such as eyestrain and headaches, improving overall health and also comfort of employees. The access to outdoor environment through vision has also been linked to reduced stress, better mood and less symptoms of Seasonal Affective Disorder that can lead to depressions. (Day and Gunderson, 2015)

2.3.3 Impact of IEQ in employees' productivity and performance

Fisk (2000) quantified the losses per year that occurred in the US due to bad IEQ and the health issues that were caused due to that fact. For instance, respiratory illnesses were a major reason due to lost and restricted activity days, which was quantified in losses in 34 USD billion. The losses can be majorly reduced with investments in IEQ with up to 35% less absence due to respiratory illnesses in office buildings with good IEQ (Milton et al., 2000). Other losses were quantified due to allergies, SBS, temperature and lighting. The total quantification of the possible gains of productivity when improving IE was estimated in 40-200 billion USD for the US offices in 1996. This quantity was higher than the total cost of energy consumed in those offices (Fisk, 2000).

Moreover, the performance is also affected by other factors which not necessarily imply health issues. For instance, according to Vimalanathan and Babu´s neurobehavioral test (2014) the lighting and temperature aspects are proven to have impact on employees´ responses and performance. Roelofsen (2002) presented equation showed that the factor that had bigger influence on worker performance was the dissatisfaction with the indoor environment, way above job dissatisfaction and stress. Furthermore, the control in the temperature and ventilation of the environment has impact over the performance. In general, it is concluded that the benefits and gains in human capital, make it attractive to invest in work environment quality (Roelofsen, 2002).

2.3.4 Impact of IEQ in energy performance

Energy consumption in office buildings is among the highest when comparing with other typology of buildings (Santamouris and Dascalaki, 2002). It can range from annual consumptions of 100 Kwh/m2 year to 1000 Kwh/m2 year depending on activities, equipment and design features. For instance, in the US office market the energy consumption related to Indoor Environment Quality (lighting, heating, cooling and ventilation) accounts for about a 60% of the total energy consumption (fig. 13). (NREL, 2013)

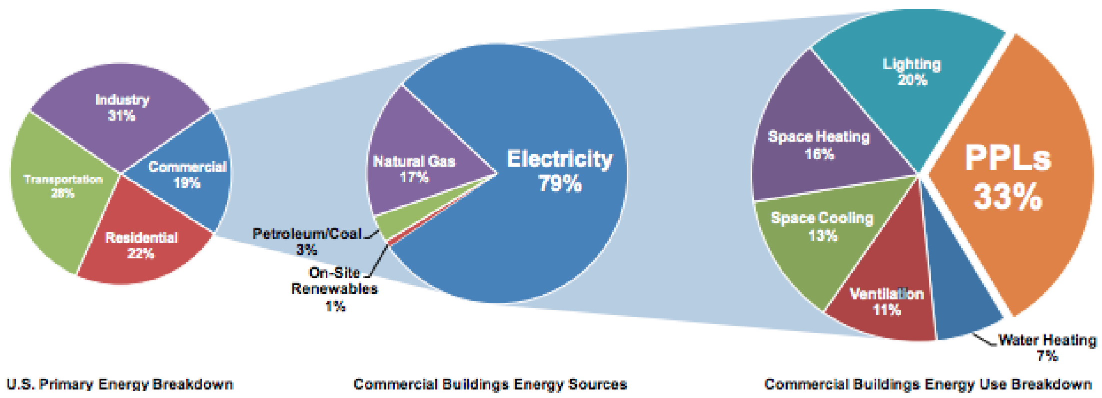


Figure 13 Energy consumption in commercial building in the US (NREL 2013)

The HOPE project (Alain et al., 2006) analyzed different typologies of office buildings, among them high-performance buildings, and aimed to understand the relations of a comfortable and healthy indoor environment with energy use. The high-performance buildings analyzed were defined as healthy, comfortable and energy efficient buildings. In some of the cases, conflicts arose when applying energy saving strategies on the indoor environmental quality. This implies a conflict with users well being when applying some certain strategies to save energy. However, in most of the high performance cases there was no appreciation of conflict between energy consumption and well being of occupants. The construction and operation of buildings for obtaining both, high quality IE and low energy consumption, is perfectly possible but the design phase is a key aspect to achieve it. (Alain-Roulet et al., 2006)

The report on commercial and institutional energy use in Canadian buildings (2012) indicates the average values for energy intensity in office buildings. The study indicates that the average office buildings in the Pacific coast area (Vancouver and British Columbia are included within this area) are of about 0.99 GJ/m2 (approx. 275 KWh/m2). However, this report includes different typologies of buildings, sizes and completion dates. When it comes to high performance buildings, the market research developed by the Canadian GBC (2015) in their analyzed case studies showed an average energy intensity of 366.5 MJ/m2 (102 KWh/m2), which is a number more comparable with the case study analyzed in this report.

2.3.5 Assessing Well-Being (POE)

Post-occupancy evaluations are techniques that are focused on the performance of a building during its occupancy phase, i.e. the use of the building after the occupants have started to occupy and experience it. Questions might be divided into eight groups: environmental comfort (36 questions); health symptoms (10); satisfaction with amenities (5 to 15); time spent in the building (1); time spent at the task (1); productivity (1 to 3); perceived control (5); and background data (3 to 10). (Bluyssen, 2009)

Architectural and interior design disciplines have used POE for decades to statistically measure the human perception on indoor environment. Besides satisfaction with the environment (perceived comfort), other environmental features such as office layout, amount of office space, satisfaction with other facilities and cleanliness can be assessed. Regarding the IEQ, the customization of questionnaires used might be focused towards finding associations between physical stressors and perceived well-being. Percentage of dissatisfied (perceived comfort), sick building symptoms (perceived health) and sometimes also self-reported productivity are gathered mainly in relation to indoor environmental aspects such as air quality, thermal comfort, light and noise aspects (Bluyssen, 2011b) During the last decades, designed and applied questionnaires have been developed to gather information on: the emotional state and trait among other personal factors, physical and psychosocial stressors and factors and perceived wellbeing over time.

2.4 Office Occupants' behavior

2.4.1 Understanding occupants' behaviors and interactions with systems:

The behavioral change theory has been mainly used in climate change policies, as result many strategies to promote "pro-environmental behavior" have resulted (Shove, 2010). Behavioral-change theory implies the act of choice, which is mainly influenced by attitudes and beliefs (Ajzen, 1991). The result of this approach is the categorization of individuals in groups depending on their willingness to change, which is mainly driven by their pro-environmental values (Shove, 2010).

Shove (2010) defines this paradigm as "ABC", which stands for Attitudes, Behaviors and Choice. Common strategies towards sustainable behavioral change are; first persuading through information regarding climate change and in that way increasing their commitment (motivators); and second removing the barriers that avoid translating green values into actions.

Recent review on energy related behaviors in office environments by Hong et al. (2015) has resulted in the development of the DNAs ontology framework (Table 1), which aims to provide understanding on reasons and motivations for office occupants' behaviors and actions. The framework is determined by four main components that serve to explain behaviors and cognitive processes in which are based (Drivers, Needs, Actions and Systems). First, Drivers are the environmental factors that determine and incite the needs from the occupants of a building. Needs refer to the inner world of each of the occupants and are defined as the psychological and physiological requirements for the occupant to feel satisfaction and comfort. Moreover, Actions are the factor that connects needs with the environment and how reflect the interaction of the occupant with the space (building). Finally, Systems are the mechanisms, strategies and processes available on the building, which can be used by the occupant to modify the environment to fit their inner needs. (Hong et al., 2015)

Table 1 Based on DNAs framework (Hong et. al., 2015)

	Description	Components
Drivers of dissatisfaction	Drivers that trigger actions or inactions on individuals. Physical or nonphysical causes.	· Building related: Components, properties and location. · Occupants: Attributes and attitudes. · State of the systems: After being opened a window is predisposed to be left open. · Environment: Climate and weather. · Time: During the day, week or year.
Needs for satisfaction	Characteristics that individuals need to fulfill to be satisfied with the surrounding environment.	· Physiological comfort: Indoor air quality, thermal, acoustical and visual. · Non-physical needs: Privacy, preferences, culture, habits, and previous experiences. · Biological needs.
Actions to satisfy needs	Actions taken by individuals when suffering from discomfort.	· Interact with systems · Inaction (Suffer discomfort) · Report discomfort · Movement to another space
Systems to interact with	Available systems to interact with that allow individuals to modify the environment.	· Windows · Shades · Lights · Thermostats · Use of space · Equipment · Other systems · Clothes and feedback can also be considered.

Criticism to giving control: Satisficing behavior

One of the biggest criticisms for giving control to the occupants refers to the issue of them taking suboptimal decisions. Cole and Brown (2009) indicated some issues that arose when control was given to the office users regarding operable windows. For instance, users tend to act too late and not at the moment they should. This is commonly named as suffering a “crisis of discomfort”. Furthermore, once the user interacts with the systems, those stay in the same state until another crisis is suffered. Another problem arises because users tend to overcompensate and choose the easiest and more at hand option when acting with the systems. This option in man cases is not the more suitable one. (Cole and Brown, 2009)

2.4.2 Towards a more holistic approach: Social practice theory

Practices are defined as*: "routinized type of behavior which consists of several elements, interconnected to one other: forms of bodily activities, forms of mental activities, 'things' and their use, a background knowledge in the form of understanding, knowhow, states of emotion and motivational knowledge."*

(Reckwitz, 2002)

Theory of social practice refers to the relation between the activities that humans develop (practices) and their correlations with existing social structures (Shove et al., 2012; Reckwitz, 2002). The greatest number of daily practices performed does not lie within consciousness, as they do not require of great decision making when people develop them. Furthermore, the model for social practices can be defined through three elements; materials, meanings and competences. The three elements by themselves do not originate practices, it is the links between them the ones that originate the different practices (figure 14). Practices emerge and evolve over time with different elements transforming and leaving actual ones behind or disconnected from the current practices. For example, Shove et al. (2012) show the change of practices through the driving experiences in the US and how they evolve with, material, competence and meaning elements evolutions over time.

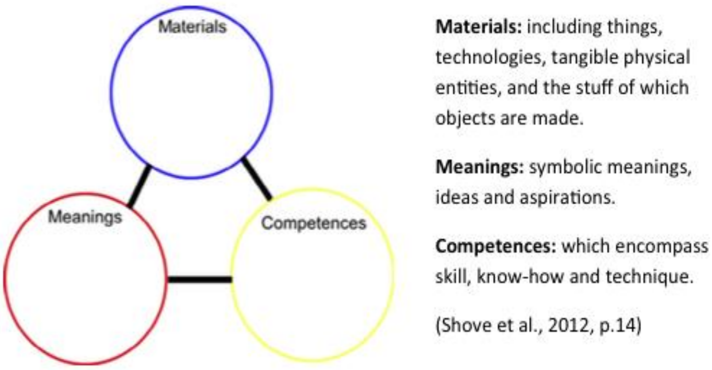


Figure 14 Influence of policy on current practices (top-down). Adopted from Shove et. al. (2012)

In contrast to the ABC approach presented (Shove, 2010), the practice theory advocates for a change in the current social practices rather than focusing on individual behaviors. Thereby, the motivators and barrier elimination strategies can still be used as a way for changing meanings and increasing competences, thus, modifying practice elements (Hargraves, 2010). Policies should be aimed towards tackling the bad elements (materials, meanings and competences) of the current unsustainable practices in order to let new practices emerge. They should also search and design those new elements to support the new practices. (Shove et al., 2012)

An example of policies changing practices and tackling the "bad" elements is the initiative taken by the Japanese government in 2005, "Cool Biz" (Shove et al., 2012). Public buildings would not be heat or cooled when the indoor temperature range was between 20 and 28 degrees, and based on the adaptive principles the occupants on the offices were encouraged to change their clothing and adapt to their indoor environments (less strict dressing codes). This initiative tackled directly the meaning element of traditional business clothing changing it towards a more normal and casual meaning. The policy was greatly effective, reducing CO_2 emissions due to HVAC on summer in almost 2 million tons, reducing energy demand and changing the dressing codes in and out of the Japanese offices. (Shove et al., 2012)

The contrast between the two previously presented theories are presented in the next table (2). Even though the two theories seem incompatible, which they are in many cases, Hargraves (2010) aimed to observe "pro-environmental behavior change" strategies from a practice perspective. Those pro-environmental strategies, in the analyzed case, shaped and changed the previously mentioned bad elements (meanings, materials and competences) and also the links that originated the unsustainable practices.

Table 2 Comparing behavioral-change and theories of practice. Adapted from Shove et. al. (2012)

	Theories of Behavioral-Change	Theories of Practice
What is the base of the action?	Individual Choice	Social Convention
Process of Change	Causal	Emergent
Role of policies	Drive behaviors as an external factor of influence (influence individuals)	Integrated in the system, aims to influence elements that conform practices.
Transferable Lessons	Clear: Universally applicable practice	Depends on cultural and historical contexts

2.4.3 Strategic Practice Management:

Recently, practice theory research (Cohen and Ilieva, 2015) has aimed to develop a framework for strategic practice management. The theoretical underpinnings of the model are the previously explained theories of practice (Rekwitz 2002 and Shove et al. 2012) and the socio-technical systems transitions (Geels, 2005), previously reviewed in the first section one of the report. The strategic practice management framework consists of six steps. The first step is to change the understanding of the current practices, which commonly is done through visualization of the impact of the practices (Cohen and Ilieva, 2015). Second, strategically choose the practice that is aimed to change. Third, target the relevant elements (meanings, competences and materials) that need to be shaped by the influence of the involved stakeholders. Fourth, understand the relationships of power that different stakeholders might have over the current practices. Fifth, understand the relationship of the practice that aims to be changed with other existing practices. This will provide an understanding on how other practices might be affected by the change on the targeted one. Finally, is important to track the effects of the resulting practice, both quantitatively when it comes to the outcomes of it but also qualitatively to understand the changes on meanings and competences. (Cohen and Ilieva, 2015)

2.5 Strategies and building systems for the provision of IEQ

In this chapter strategies and systems for creating IEQ will be presented. This section aims to provide an understanding and a framework for the later sections; case study results, analysis and context analysis.

2.5.1 Ventilation strategies: Mechanical vs Natural/Mixed

Choosing a mechanical, manual or mixed-mode ventilation building has many implications for the design of the building as it has influence in many aspects such as daylight, comfort, ventilation and energy consumption. Different mixed mode strategies are presented in the Table 3 below:

Table 3 Mixed mode strategies and systems. Adapted from Brager et al. (2007)

Classification of mixed mode ventilation strategies
- Zoning: Some areas are naturally ventilated, while others are mechanically ventilated.
- Changeover: Mechanical ventilation turns off when the natural ventilation is working. More energy saving potential.
- Concurrent: Mechanical and natural ventilation systems can be working at the same time.
HVAC system
- Ground Source heat pump or hydraulic geothermal loop
- Panel based radiant heating and cooling system
- Slab heating and cooling
- Under Floor Air Distribution
- Forced Air system. Typical Air Conditioning system.
Controls
- Red/Green notification to notify occupants when natural ventilation is OK.
- Window-HVAC interlock. When windows are open the HVAC switches off.
- Mechanical window operation.
- Manual window operation.
Natural Ventilation
- Through windows.
- Through vents that ensure the outdoor ventilation flow.
- Stack/chimney effect.
- Cross Ventilation driven by wind pressure across the building.

Mixed-mode systems:

Mixed mode system refers to a hybrid approach, where both natural ventilation (operable windows) and HVAC systems for cooling and heating are provided. The strategies of operation between natural and mechanic can be "concurrent", where both can work at simultaneous time, "changeover", when one works the other does not, and "zoned", where some zones are ventilated naturally and others manually. (Brager et al., 2007) For the case of naturally ventilated and mixed-mode is of relevance to pay attention to passive strategies that reduce the requirement of cooling or heating, such as shadings, mass and passive ventilation during daytimes, for instance through nighttime cooling (Brager et al., 2007).

Benefits of mixed-mode ventilation:

- *Energy-Savings*: Strategies to make the cooling fans unnecessary to maintain comfort conditions in most of the times. Use of energy in off peak times with strategies such a nighttime cooling. The assessment of energy savings is done using simulations (not very precise), and energy savings on mixed buildings range from 13% (Miami case study) to 79% (L.A. case study). (Brager et al., 2007)

- *Thermal-comfort*: As it has been shown before, the fact of giving control and possibilities of adapt the indoor environment to occupant preferences, results in higher satisfaction and tolerance to discomfort (De Dear and Brager, 1998). This can also be applied to mixed-mode, as they offer the possibility to manually control ventilation and thermal aspects.

- *Health and productivity*: The study by Fisk and Seppänen (2001), in multiple buildings, showed that mechanically ventilated had more reported cases of SBS, more precisely 30% to 200% more, than manually ventilated ones. Furthermore, the fact of having natural ventilation is estimated to provide around 1% of health savings and 3% to 18% of productivity gains (Brager et al., 2007).

2.5.2 Systems and strategies for control: Building Intelligence

Similarly to Brager's (2007) work on ventilation and cooling systems, Cole and Brown (2009a) discuss the implication of the control systems from a Building Intelligence perspective and what implications do they have on green building design. For instance, when it comes to control on the IEQ, this can be achieved through an automated system or it can be achieved giving the users of the building control so they can create their own IEQ. The automated strategies help to achieve good levels of comfort and health but at the price of high-energy consumption and in some cases compromising the productivity of employees. When applying manual and local control strategies, the energy consumption drops but on the other hand it can compromise health, when the decisions taken by occupants are suboptimal.

The different types of building intelligence and the implications they have for green building design are showed in the next table 4 (Brown and Cole, 2009a):

Table 4 Intelligent Buildings. Adapted from Brown and Cole (2009)

Intelligence Concepts in Buildings	
Intelligent Building Concepts	**Resultant strategies in green buildings**
Automated Intelligence	Efficient Building Operations
Informated Intelligence	Provision of feedback on performance. Responsive systems.
Occupant Intelligence	Personal control over the Indoor Environment.
Passive intelligence	Passive design concepts that take advantage of place characteristics. (Massing, orientation, natural ventilation…)
Intelligent use of space and organizational intelligence	Flexible and adaptive designs. Multiple uses for spaces.

2.5.3 Controls and sensors:

Another critical aspect identified is the access to controls for the systems to achieve the benefits of a good IEQ (Day and Gunderson, 2015). For instance, if daylight cannot be controlled, glare could be a dissatisfaction source for the employees, resulting in possible headaches or other health issues. In the case of natural ventilation the access to it, through operable windows or passive design strategies, is crucial for achieving thermal comfort on employees. However, in many cases the benefits are hindered by the wrong use of the building itself (Day and Gunderson, 2015). In their study of high performance buildings in the UK Bordass et al. (1999), the critical issues to take into account regarding design and use of controls are summarized;

- *Adaptability and changing demands*: Controls and systems are not responsive enough to adapt to changes on occupancy and users demands. (Bordass et al., 1999)

- *Controls and user intelligence*: Ease the systems so they are understandable for the occupants and also involve them on choices and use of controls (Bordass et al., 1999; Day and Gunderson, 2015). Furthermore, Brown and Cole (2009) indicate that the main reason why buildings that make use of passive technologies do not perform properly, even though their systems are very simple, it is the lack of understanding by occupants on how the building should be used.

- *Innovation issues*: Solutions out of the standards and usual practices are not valued. The fact of designers being too optimistic and neglecting probable drawbacks often results in new problems. Thereby, simpler and more understandable solutions frequently are the best. (Bordass and Leaman, 2001)

- *Last stages of building completion and after completion*: The rush on the handovers often resulted on controls and usability of them forgotten. Furthermore, adding the difficulty of configuring controls and systems before buildings are occupied and used. After completion designers often tend to oversee issues regarding operation of controls, unless those involve serious functioning defects. To solve the problem a "trial" period of the buildings is proposed, where it could be possible to gain feedback from occupants and calibrate the systems and controls to result in better performance. (Bordass and Leaman, 2001)

2.5.4 Occupants Intelligence: Knowledge, awareness and culture

According to Cole and Brown (2009) well-designed and intended buildings should reduce complexity and allow occupants create their indoor environment through easy to use controls and solutions. Thus, system design and "know-how" utilization of controls have a great influence on the perception of comfort regarding the indoor environment. Generally, the use of overly complex systems results in a lack of use or misuse from the part of the occupants. Furthermore, the "know-how" use of the systems to create a comfort environment is also a factor that affects the perception of comfort from occupants (Brown et al., 2009).

Other factors that influence behaviors of occupants are the prior experiences. The adopted habits and practices in previous office buildings, especially when those were automated, create preconceptions that will influence occupants. Moreover, the preconception will be more rooted depending on the time spent performing the habit. (Brown et.al, 2009)

Regarding the former proper education that supports the user is a key aspect. For instance, in the latter is necessary that the corporate culture of the company boosts the active use of the provided controls. The corporate culture should allow open discussion among the users regarding the control systems and indoor environments. (Day and Gunderson, 2015)

2.5.5 Informated Intelligence: Feedback strategies and responsiveness

The study of Brown et al., (2009), indicates that feedback on the adaptive behavior of occupants results in the development of knowledge. This knowledge has a greater importance in their activeness/passiveness attitude towards establishing the comfort conditions of the immediate environment. The methodology used was a Post-Occupancy Evaluation survey of end users combined with the interview of the project architect and facilities manager. Feedback strategies were possible during three phases of the building design and delivery briefing, design and implementation phases. (Brown et al., 2009)

The use of feedback systems in residential housing has been widely used with positive results when it comes to resource use and energy consumption. For instance, the ALIS project in North America (Velikov and Bartram, 2013), which used interactive and real time feedback on use of resources such as energy and water, resulted in savings and an empowerment on the inhabitants. The use of real time interactive feedback systems in office buildings is not as extended as it is in residential counterparts, however, some examples can be found. (Gulbinas and Taylor, 2014; Orland et al., 2014; Jain et al., 2013)

The feedback interface developed by Jain et al. (2013) has its theoretical underpinnings on the effects of social networks and its possibilities for promoting sustainable behaviors, which are shown next;

- **Homophily:** Create relationships with similar characteristics users.
- **Confounding factors:** Exposition to similar external factors than the other people on the network.
- **Social Influence:** A user actions are pushed by other users actions. In this case it can drive energy savings, when applied on a normative scale and comparing the consumption of different individuals.

The case study where the web-based interface was applied (Gulbinas and Taylor, 2014) drew some conclusions. Individual feedback did not provide the expected results. However, when the feedback was provided to organizational networks and showing the consumption of others, energy saving were achieved. Furthermore, there were an increased number of non-energy related sustainable practices reported. Similarly, the study from Orland et al. (2014) used a similar strategy with engagement of employees on energy savings. In this case the engagement was achievement through web-based game platform named “energy chickens”. Initially, the feedback provided was individual, but in-game incentives were provided when energy savings were achieved. In the latest stages, the feedback was for the whole group as it was possible to see the savings that other office colleagues have achieved. Other strategies such as incentives, setting of goals and competitions have also proven to be effective to engage occupants on energy conservation behaviors (Day and Gunderson, 2015).

However, both the web based interface (Gulbinas and Taylor, 2014) and the web based game platform (Borland et al., 2014) failed to achieve permanent and continuous behavioral changes in the long term. In the case of the interface, a decrease on logins occurred after the second month and energy consumption returned to the original pre-feedback levels (Gulbinas and Taylor, 2014). Correspondingly, in the case of the game approach, the energy consumption also returned to the original patterns (Borland et al., 2014). Thus, indicating that there is potential for energy savings and sustainable behavioral change through feedback systems, however, feedback alone cannot secure the change in the long term.

2.5.6 IT and Building Automation Systems (BAS)

Automation plays a vital role in improving energy efficiency in buildings and modern computer technologies can help reducing energy consumption in buildings by monitoring, controlling and managing energy consuming devices (Mousavi & Vyatkin, 2015).

A Building Automation System (BAS) controls electrical devices in a building such as heating, cooling, ventilation and lightning and it can be used to automatically manage and control the efficient utilization of these devices. Fig. 15 shows the three functional layers of a BAS containing one or more levels of automation functionalities and their respective support devices and used technologies.

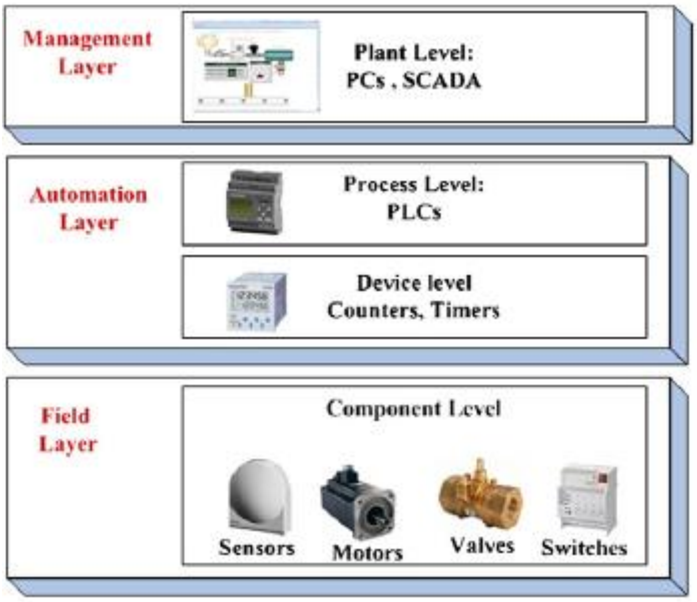


Figure 15 Building Automation System (Mousavi & Vyatkin 2015)

Intelligent software agents empowered by communication capability and capable of reasoning over human factor situations have been tested as a practical and effective solution. (Klein et al., 2012; Mousavi & Vyatkin, 2015) Therefore the development of self-reasoning software towards the efficiency of building´s devices while ensuring occupants wellbeing has been recently developed.

Multi-agent systems (MAS)

Multi-agent systems (MAS) aimed to manage the building indoor environment via computer technologies to optimize energy efficiency and comfort level. Agent is defined as a software (or hardware) application located on a specific building´s environment and is able to autonomously react to changes in that environment. (Yang & Wang, 2013)

Multi-agent systems encompass the collaboration of multiple agents towards the management of local goals within their area of action rather than an overall goal. According to fig.16 (Yang and Wang, 2013) The MAS gathers data from three different entities in order to process it and act on the building systems such as HVAC, electrical lightning and power grid. First, Sensors receive the input and make decisions to realize control on building systems. Environmental, occupancy and energy data can be gathered from a sensor network. Outdoor temperature, illumination intensity and CO2 concentration are some examples of the environmental data. Number of occupants, presence and absence of personnel are included in the occupancy data. Energy data focused on the supply of energy regarding price, availability of renewable resources and the grid´s condition. Second, Personal agents in the MAS read and predict occupants' preferences via learning their behaviors. Finally, policies act as principles for the MAS in order to guide the decisions and define constraints. Each policy specifies its condition or hierarchy for validation and its legitimacy among others. (Yang & Wang, 2013)

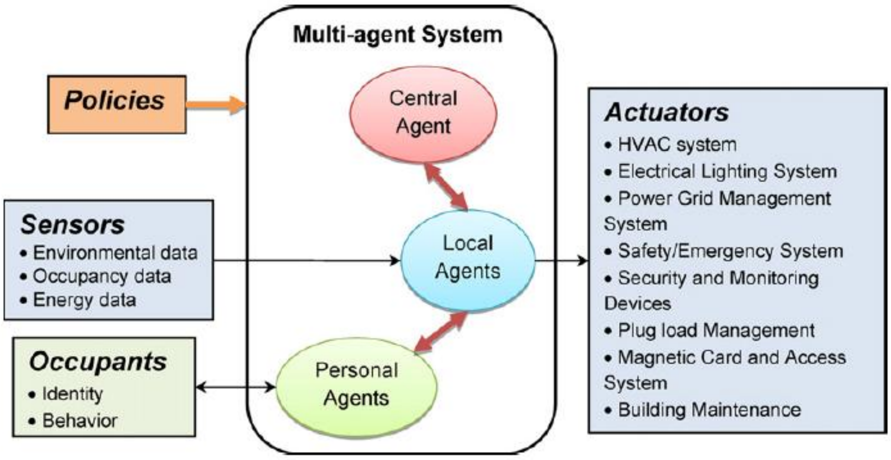


Figure 16 Overview of the multi-agent system for building control. (Yang & Wang, 2013)

Multi-agent comfort and energy systems (MACES)

New building energy and comfort management strategies must be designed and implemented to adjust towards buildings' systems and occupant behaviors. Indoor environments can be assessed and improved by focusing on building energy and occupant comfort. (Klein et.al, 2012)

MACES is a system to modify occupant behavior and the operation of building devices (Klein et al., 2012). It allows the building simulation of occupants, devices, and possible building conditions scenarios under different energy strategies. The strategies might include reactive and proactive control in which HVAC and lighting systems are automatically adjusted according to real-time or predicted occupancy and occupant preferences. The system consists of an Input/output Module, Reasoning and Planning Module, and a Simulation Module. As shown in fig.17. The Input/output Module first collects domain knowledge by accepting data about the physical building and the building occupants such as rooms, zones, and schedules. The data is included manually; however, real-world sensors and proxy agents such as mobile devices will assist data input. With this information, the first module is able to construct the virtual building model and agents that will be used in the simulation. The building model includes geometric layouts of rooms and thermal zones as well as definitions of the connections between the defined spaces. The agents include device agents representing HVAC, lighting, and electrical equipment, human agents that represent temporary and permanent building occupants, and meeting agents who are responsible for negotiating meeting relocation. Finally, the world state keeps track of global variables that are updated throughout the simulation including zone energy usage, zone temperatures, occupant satisfaction levels, cumulative energy usage, and actions taken by agents during the simulation. (Klein et al., 2012)

Building model, agents, and world state are constructed and passed to the Reasoning and Planning Module (Klein et al., 2012). This module is responsible for modeling agent reasoning and generating policies to achieve defined objectives while considering the uncertainties of agent decisions and interactions. The policies might include proactive control of room temperatures based on occupant schedules or changes to the latter. Schedule alternatives are generated using the multi-objective MDP process, whose objectives are focused on minimizing building energy consumption while increasing occupant comfort. These policies, including the uncertainty of their actual implementation based on predicted occupant cooperation, are realized and assessed in the Simulation Module. The Simulation Module models agent behaviors and communications in the virtual building model where policies and control strategies are applied. Throughout the simulation, building energy consumption is estimated in real-time in order to evaluate the simulated control strategies. Energy calculations are intended as approximations for relative comparisons of alternative control strategies and do not include all contributions to or effects on building energy consumption. Finally, the generated energy and comfort policies will be tested in the actual world via proxy agents of the Input/Output Module, which will communicate and coordinate outputs to actual building occupants. (Klein et al., 2012)

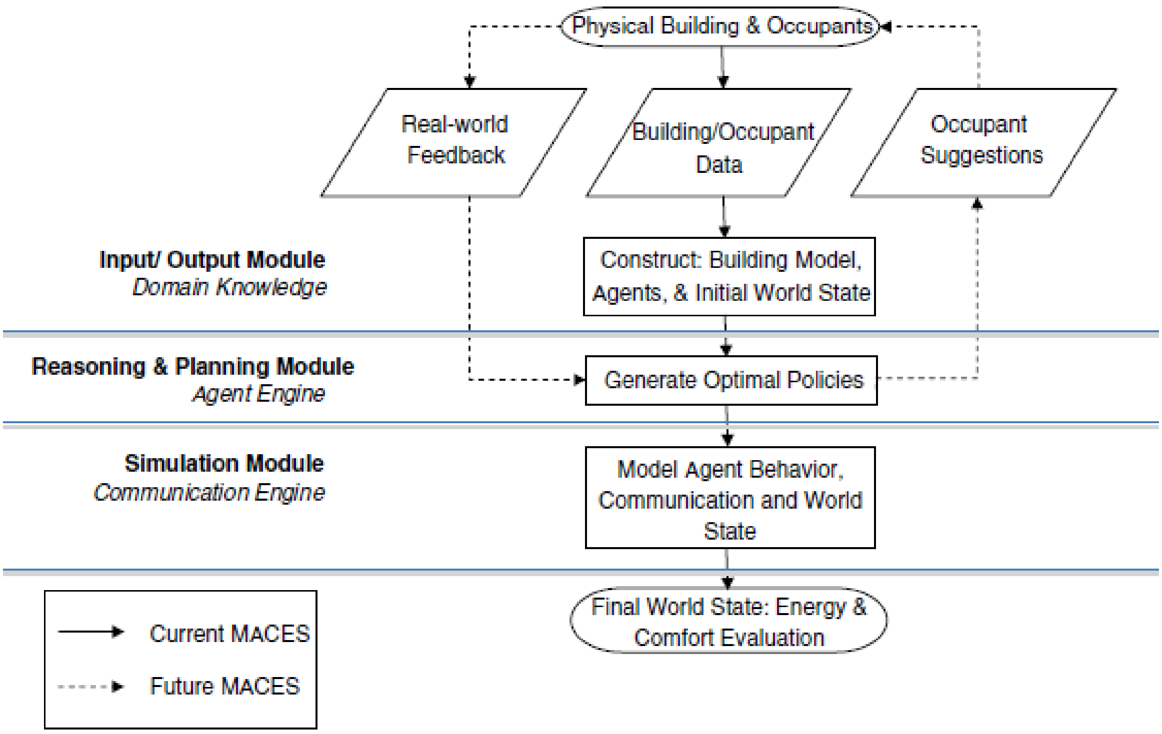


Figure 17 Representation of the input/output. Reasoning, planning and simulation models of MACES (Klein et al., 2012)

2.6 Theoretical Summary

This literature review has been developed with the aim to define a proper framework for the later analysis of the results from the case study. Starting, shortly summarizing the previous research on green buildings and sustainable offices. A review of IEQ, comfort theories and the impact that IEQ has in occupants will serve for the analysis of the strategies reviewed in the case study. The adaptive comfort theory suggests the importance of providing control to occupants to increase their tolerance to discomfort in indoor offices environments. The strategies and systems reviewed provide a background and overview of the different possibilities that can be applicable in an office building. Furthermore, they provide a framework for the analysis of the results gathered from the case study.

The theoretical framework proposed for the understanding of occupants' interactions with the building systems includes theories of behavioral change and social practice models. Both perspectives seem relevant when it comes to understand the interactions of occupants with the building systems for the provision of optimal IEQ. The latest research on practices proposes a strategic approach to change and shape the existing practices towards new ones. To understand the elements that conform the different practices (materials, meanings and competences) appear to be critical to find leverage points to shape through the establishment of new policies and strategies.

Section 3 - Methodology

The complexity of the relation between the building´s characteristics and occupants behavior led the authors of the thesis to conduct an extensive literature review (see section 2). A case study was analyzed in order to understand relevant and up to date strategies to positively influence occupant´s behavior towards the saving of energy. First, data gathering was performed through the available resources, such as the building manual and the articles published on the case study. Second, to better understand the strategies applied interviews with researchers and the director of operations and business development of CIRS in Vancouver were held via remote call. The results of the case studied were further analyzed and discussed. Finally and after the case-study analysis, an interview with the environment manager of a Swedish municipally owned property organization was held. The aim was to understand the applicability of the studied strategies on their organizational context.

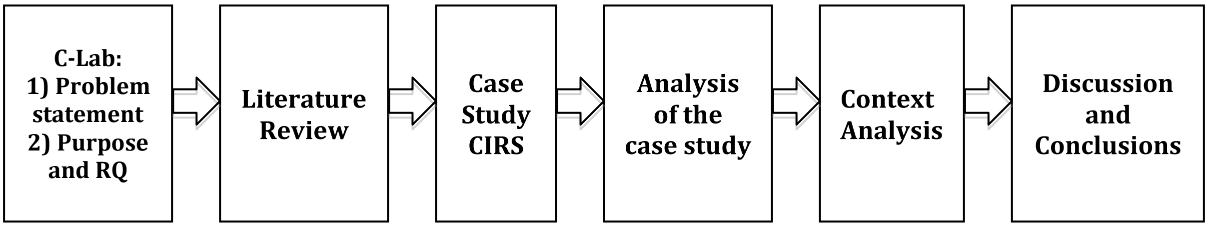


Figure 18 Overview of the process followed to conduct the thesis project

A literature review (section 2) was carried out to get an understanding of what is already known in the research field and what theories and strategies could be suitable for the research purposes, this is a way of legitimizing the research (Bryman and Bell, 2007). For this study Indoor Environment Quality (IEQ) concepts and the impact those have on occupants and energy consumption have been reviewed. Furthermore, theories and models for the understanding of behaviors of occupants and reasons for interaction with building systems have also been revised. Finally, more specific building systems and strategies for the provision of IEQ have been studied, with a primary focus on those applied during the Operation and Maintenance phase of the building.

3.1 Case Study: Centre for Interactive Research on Sustainability

A case study design has been chosen since the main feature of this study is to understand in greater depth operational strategies and processes. This corresponds to Bryman and Bell (2007) definition of a case study design, which is to execute a detailed and intensive analysis of a single case. This single case study is an academic and research office building that function as working lab. The selection of the case study has been driven as it represents a green building of the highest possible rank within the LEED assessment tool. The building is one of the few examples that have applied the principles of regenerative sustainability in its design, construction and operation and maintenance phase. The principles of regenerative sustainability indicate that solutions should aim to create net positive impact on people and also on the nature. Thus, resulting in our hypothesis that best practices regarding occupants´

engagement and satisfaction are performed within the chosen building. The final last reason to select this case study was the extensive information available and the possibility to conduct interviews with key stakeholders. However, Bryman and Bell (2007) indicate that external validity is an issue, especially when developing qualitative research. Furthermore, the use of a single case-study research arises the question of whether the results can be applicable in a general manner.

Building Manual and POE

Initially, data from the building manual have been collected. The building manual provided a general understanding of the building systems and some of the strategies regarding IEQ and wellbeing applied on the CIRS building. Furthermore, conference papers on the building performance and energy consumption were also reviewed. Finally, the results regarding occupants' perceptions of the IEQ from the latest POE have also been presented. The POE results provided quantitative data to correlate the impact of the IEQ and the provided control on the occupants.

Interviews

The initial contact with the stakeholders was through email with the head of research at CIRS. The interviewees were selected based on the recommendations provided on the email. The final selection of stakeholders was done after analyzing their implication on the building and suitability to provide valuable insights for the purpose of the research. In order to complement the information gathered from the building manual of CIRS and get deeper understanding of the systems, strategies and internal procedures on the building, interviews with relevant stakeholders at CIRS were held. These included and interview with researchers on behaviors and building systems and with the Director of Operations and Business Development.

The typology of interview selected was a "semi-structured" interview. According to Yin (2014), interviews are a good source of information when performing investigation based on a case study. Semi structured interviews were selected to gain a deep understanding on the ongoing processes and strategies at CIRS. The interviews were performed via telecommunications application software (Skype) and the duration of those interviews ranged from thirty minutes to an hour. The interviews were recorded, as memory notes, for later analysis.

3.2 Context analysis: Property Manager in Gothenburg

Interviews

The case study was conducted through two interviews. This first interview has served to understand the current strategies and practices that have been applied in Gothenburg. For the purpose of study and the interview, a similar building was proposed by the interviewed organization. (1) The client during design phase, (2) occupants and (3) property manager perspectives were the main outcome of the interview. Those three perspectives allowed the understanding of the Real State business in Gothenburg and from the perspective of the property owner, tenant and user of an academic/research building in the city of Gothenburg.

The second interview for the context analysis was based on an unstructured interview. Providing the interviewee with the strategies previously studied in the case study to get insights on them and to understand the possibility to apply them in the property manager's organization context. This methodology has been chosen to provide a very open setting for the interview to get a wide variety of inputs on the possible barriers and possibilities for the applicability. The main implications of applying the strategies in the local context were discussed from his professional perspective.

Section 4: Case Study CIRS

4.1 Background

CIRS aspires to be an internationally recognized leader in accelerating the adoption of sustainable building and urban development practices. (CIRS, 2015)

CIRS is UBC's sustainability flagship project that serves as working space for multiple researchers, planners and policymakers. It consists of a four-storey building and the total area is of 5,675 square meters. This includes open office spaces, laboratories, an auditorium, meeting rooms, a cafe and also spaces to facilitate social interaction like the atrium. The total cost of the project was C$35 million (C$24 million in construction costs). CIRS is currently certified through LEED assessment and it has a Platinum rank and has been awarded many times for its sustainability and high performance characteristics. (CIRS, 2015)

The Center for Interactive Research on Sustainability (CIRS) is part of the 20-year sustainability strategy at University of British Columbia (UBC) at Vancouver campus. The conception of the building has its principles and theoretical underpinnings on the regenerative design and development and regenerative sustainability theories (Cole, 2012; Robinson and Cole, 2014). CIRS aims to achieve net positive impact on the environment and on the human beings, both within the building but also on the surrounding communities. CIRS is central to the research programs and initiatives and it serves as a living laboratory to test sustainable practices over its lifecycle (100 years). Moreover, its capabilities for communication aim to facilitate the outreach to the general public and serve as a catalyst for a sustainable future. (CIRS, 2015)

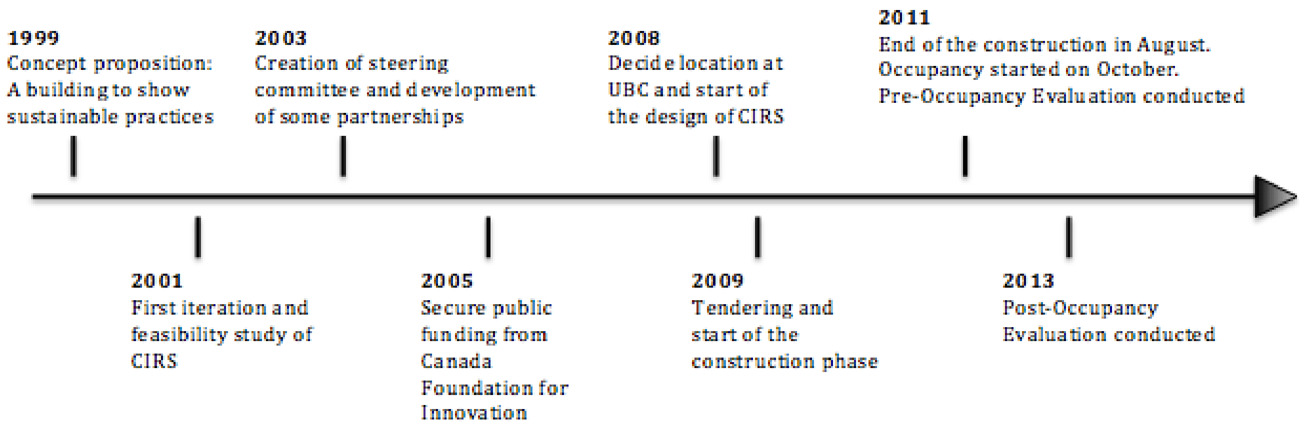


Figure 19 Timeline of CIRS: Based on building manual (CIRS, 2015)

4.2 CIRS systems for the provision of IEQ

Ventilation and HVAC Systems:

The building is ventilated through a mixed mode system. CIRS combines natural ventilation for most of the occupied spaces (offices and atrium) with extra support from mechanical systems for the rest of the building (auditorium, stairs…). The description of the systems (Table 5) is based on the classification developed by Brager et al. (2007):

Table 5 Ventilation, heating and cooling systems at CIRS, classified based on Brager et al. (2007)

Classification of mixed mode strategy: Zoning
- Stairs and auditorium mechanically ventilated. - Office spaces and atrium naturally ventilated.
HVAC system
- Underfloor Air Distribution controllable through diffusers on the ground. - Use of heating waste from an adjacent building (synergy) - Geothermal loops and heat pump system.
Controls provided for ventilation:
- Manually operable windows. - Mechanically operable vents on the roof. - Feedback regarding the state of systems (i.e. feedback on window state)
Ventilation Systems
- Manual windows in offices and labs for natural ventilation. - Vents on the top of the windows to ensure minimal outdoor ventilation. - The atrium acts as chimney with operable vents on the top, stack effect. - Underfloor ventilation in office spaces is based on cross ventilation.

The heating systems at CIRS are rather unique. Featuring a waste heat recovery system that uses the heat waste of a near building. Moreover, 30 geothermal boreholes and six heat pumps are also installed. During the summer the pumps are in cooling mode extracting heat from the building and cooling the water through the geothermal system. The heated air is displaced across the building through an underfloor ventilation system. In office spaces apart from the displacement ventilation, there are supplementary radiators for heating. (Salehi et al., 2013)

Lighting Systems:

CIRS has the aim to provide 100% daylight in all inhabited interior spaces; thereby the natural light harvest is of key relevance for this building. In order to reduce summer heat gains and excessive glaring passive strategies for shading are used. For instance, office spaces are shaded through exterior platforms that also serve as a surface for PV panels. Moreover, window blinds are available to control shading and gladding from the inside. In the atrium and social spaces like the cafe, the lighting is provided naturally and the glare and shadowing are regulated with a green wall that allows higher access to sunlight in winter than in summer/spring. The service spaces and stairs are illuminated through artificial lighting and controlled through motion sensors to meet the required regulations. (CIRS, 2015)

For the artificial illumination the designed values were 300 lux for the office workspaces with extra task lighting accessible when needed. However, when the tenants and needs were confirmed the strategies for private offices and glaring changed. Currently, it is required a higher use of artificial lighting and the average illumination is around 205 lux, which requires extra task lighting in most of the cases. The energy consumption of lighting is 15.7 KWh/m2 per year, which is approximately 56% lower than the average for this type of building. (CIRS, 2015)

Building Management System (sensors, controls):

CIRS is equipped with sensors and controls (around 3000 all across the building) that are part of a complex Building Management System (BMS) that Includes sensors for temperature, CO2, VOC and also photocells for light intensity. The aim is to monitor and measure the performance for future reporting and implementation of optimizations. Furthermore, as part of its purpose as a research facility the data collection is used in a variety of ongoing projects. The building, including its inhabitants and systems, is a living laboratory that is part of the UBC strategy. The aim is through the BMS analyze the data for future analysis and sharing of lessons learned, both successes and failures. (CIRS, 2015)

The BMS allows gathering the data from the multiple sensors in the building and to allocate it in a virtual server. The system monitors performance of the building's HVAC, lighting, energy management and safety on a single network. The fire alarm system is monitored from another network due to requirements by the Canadian regulation. This fact of gathering all in one single point makes it easier to manage systems and building performance.

Building Energy Performance:

An ongoing research project being conducted by Salehi et al. (2013) analyzes the performance of the building during its second year of operation. They developed a comparison of the actual building energy measurements with the ones used for the modeling at the design phase, using real inputs of climate and occupancy rates. This analysis had the purpose of understanding the performance gap that arises between design and reality. Furthermore, it aimed to understand the more sensitive parameters that cause the gap between design and operations. The input parameters used for the modeling are categorized in four parameters; weather data, envelope performance (the U values), the occupancy rates and the HVAC systems. The inputs from weather and HVAC models were the same for the designed building model and the as-built model. Therefore, the analysis was made comparing the data from occupancy and thermal transmittance of the materials, comparing the data used on the design with the real data from the measurements of the first year of operation. (Salehi et al., 2013)

In their analysis the resultant energy consumption is higher than the designed one and the most sensitive factor on this performance gap is the occupancy data. In contrast, the difference between real and designed U values did not have a big impact on the energy consumption of the building. Some conclusions that can be drawn from the study are the impact of lighting and plug energy, which are mainly dependant on occupants. The biggest uncertainties and differences appear on the warmest months of the year, in contrast, the energy on the cold months showed low variance between design and real measurements. Thereby, modeling does not symbolize the actual energy consumption during the operation phase, especially due to the difficulties establishing good parameters for occupancy and its related behavior. However, modeling appears useful when applying passive strategies as it serves to compare the relative energy consumption of the different design solutions. (Salehi et al., 2013) The energy consumption at CIRS from March 2012 until February 2013 is shown in the table 6 and in the figure 19 presented next: (Cavka et al., 2014)

Table 6 Energy consumption at CIRS (March 2012 - February 2013) (Cavka et al., 2014)

Energy consumption at CIRS (March 2012 – February 2013)	
Total electricity consumption	767,88 MWh
Energy Use Intensity	138 KWh/m2
Energy Use Intensity in the Design	112 KWh/m2

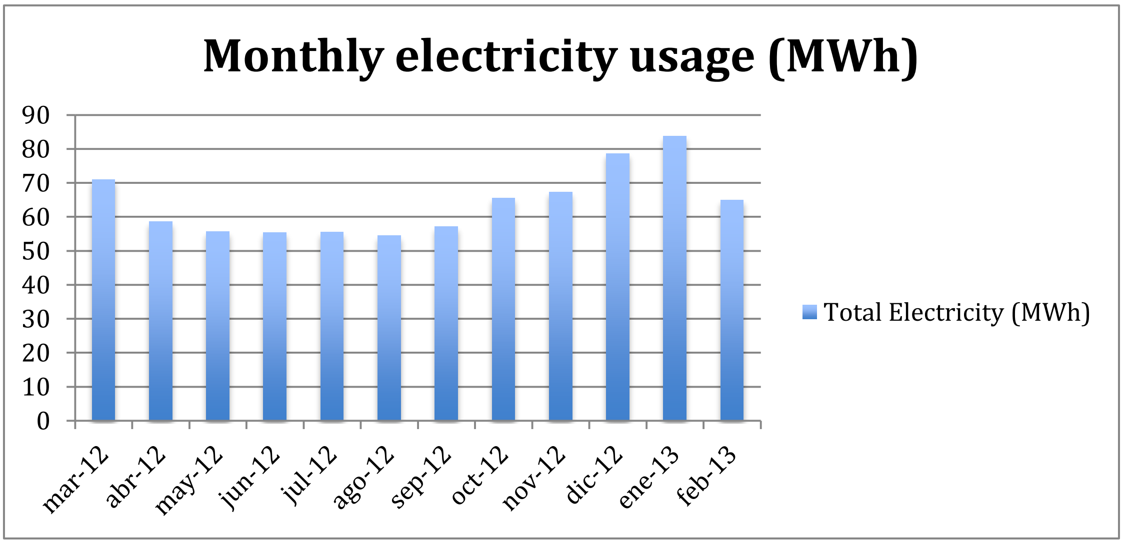


Figure 20 Monthly electricity usage in MWh (Based on Cavka et al., 2014)

4.3 Goals and Strategies

The Technical Manual is a 'living' document of the lessons learned from the design, construction and operation of the CIRS building. (CIRS, 2015)

During the project timeline, the CIRS project goals were modified to inform, direct and benchmark the design process. The goals were modified on 2008 after the CIRS project moved to the UBC Vancouver campus. This was an opportunity to analyze the goals on a new context which represented an advance in technology, process and priorities.

Eventually a set of goals and targets were structured into 22 categories in order to support the project´s vision and became the measure of the progress and project performance during the development of CIRS and its systems (CIRS, 2015). The categories (17) Comfort and control & (18) Seamless design and operation contained a series of strategies focused both on occupant´s health and comfort and building´s operation & maintenance respectively. Therefore, the study of the strategies contained within both categories was the main focus during the interviews with UBC´s personnel. The complete series of strategies can be found under Appendix C: Goals and Strategies of CIRS.

4.4 Interview findings

On an effort to develop an objective review of CIRS, the head of IRES John Robinson was contacted by email. The common interests regarding the aim of this thesis and the research around CIRS were presented. Prof. Robinson pointed at the professionals who are currently working on CIRS. The Director of Operations at CIRS, a PhD candidate in charge of Post-Occupancy Evaluations (POE) and a PhD researcher working on building performance were contacted to conduct interviews via Skype.

Impact on occupants well being: Post-Occupancy Evaluation

A summary of the POE results was provided by the interviewee, which contains results on satisfaction with workspace, wellbeing, productivity and health (figure 21 and figure 22). The evaluations were based on the Pre-Occupancy evaluations previously conducted by the MSc student (Reckermann, 2014). One tool to perform the evaluations was a questionnaire containing the core variables of Building Use Studies (BUS) methodology, commonly used for POE.

According to the interviewee, relevant aspects of POE studies include statistical comparisons between Pre and Post evaluations. The POE conducted at CIRS used a 7 point Likert scale from 1-7 in most of its questions and in some exception the applied scale was from 1-5. However, the gap between the conduction of the POE and the actual occupancy was two years. Generally, it is recommended to conduct a POE between half and one year after moving to the building, thereby the results of the POE could have been significantly different. The advantages of conducting a POE early (6 months) are the possibility to understand the deficiencies in the building.

In the case of conducting the POE late (2 years as the one in the case study) also brings a number of advantages and disadvantages. One of the advantages is that the results of a late POE will provide solid information on how occupants perceive and experience the new building with its systems running smoothly. However, memory lapses can result in difficulties if the aim is to compare the new experience with the previous experience lived in the old office. At CIRS, issues with lighting systems were common in the beginning; thus, this fact would probably have changed the results of the POE if it had been conducted 6 months after occupancy instead of two years after. Thereby, a good approach is to develop POEs multiple times, both to correct deficiencies in the building (early POE) but also to understand the perception of occupants when the building is functioning correctly (later POE).

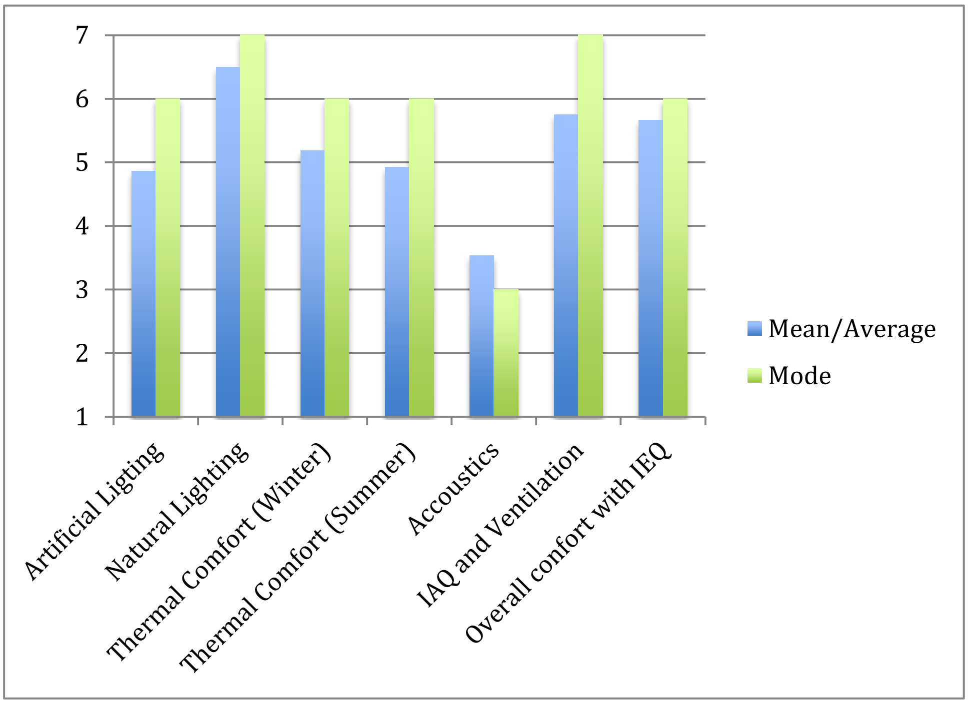


Figure 21 Self-perception effects of CIRS over occupants (Coleman, 2015)

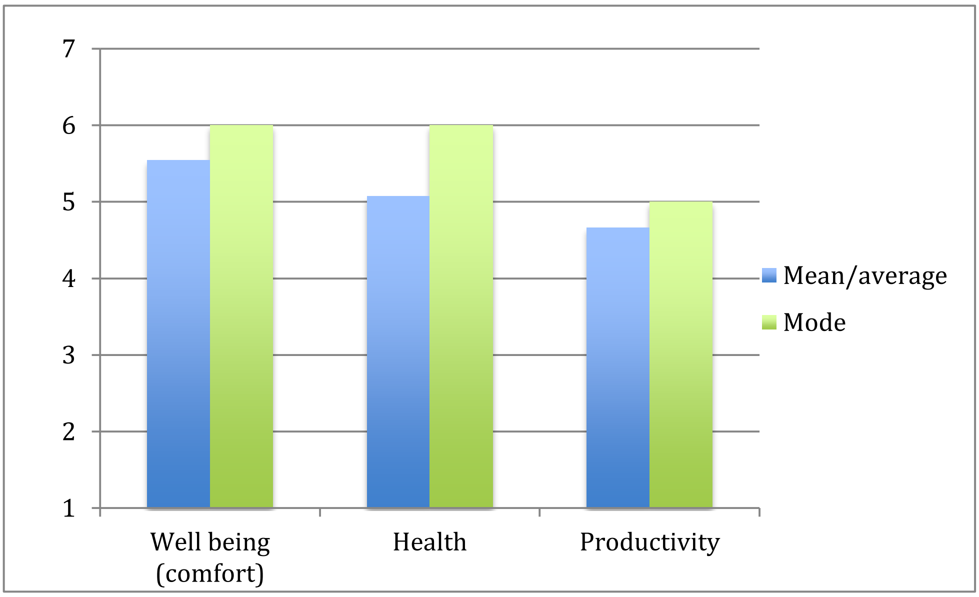


Figure 22 Satisfaction of occupants with IEQ at CIRS (Coleman, 2015)

The 7-point Likert scale in which the previous figures were answered is the next:

Figure 21	**Figure 22**
1. Very Dissatisfied	1.Strongly diminishes
2. Dissatisfied	2. Diminishes
3. Somewhat Dissatisfied	3.Somewhat diminishes
4. Neither satisfied nor unsatisfied	4.No effect
5. Somewhat Satisfied	5.Somewhat enhances
6. Satisfied	6.Enhances
7. Very Satisfied	7.Strongly enhances

Furthermore, the results in both Pre-OE and POE showed that the go to control system regarding IE at CIRS and in the occupied buildings before CIRS are the operable windows. They are used for regulating air quality and ventilation, thermal comfort and even lighting through operable shades and blinds. This contrasts with other systems available that are practically ignored, like the under floor diffusers for regulating air quality and temperature. This happens due to two main reasons; first, occupants are not used to them (habit, behavior) and neither are they told about them or about how to use them (knowledge and awareness).

The interviewee has been integral part of the ongoing research at CIRS and has also been involved in some of the strategies applied, apart from conducting the previously mentioned POE. For instance, she was responsible of the "inhabitant workshop" at the very beginning of the occupancy. The purpose of this workshop was to educate on the use of available systems, to explain the experimental nature of CIRS and to offer control to the future inhabitants of CIRS. The research has been mainly focusing in normative behaviors and how those are shaped and changed by the infrastructure provided by CIRS. Most of the behaviors are developed during the day as routines, which are largely unconscious, and do not require great decision-making or deliberation.

The Awareness

The creation of awareness at CIRS happened through educative strategies such as the "inhabitant workshop", but mainly through word of mouth among the users. Furthermore, the promotion of the UBC´s building with statements such as; "highest performing green regenerative building in North America at the time of completion" played a huge role on the creation of a story and an idea. This made people aware of what CIRS symbolized, what were its theoretical underpinnings and what was included within the CIRS concept.

The infrastructure of the building systems at CIRS

The infrastructure is established by the building itself. For instance, the automation of many systems such as the ones related to water, where the building does the water conservation in behalf of the occupants. The fact is that most of the controls in the building are automated, for instance lighting is controlled through zoning sectors with the exception of some specific areas where switches are provided. In the case of the windows they are operable providing control to the occupants. In general, the satisfaction with controls is high, however, there is no hard evidence that correlates the idea of empowerment with the control systems. The infrastructure is not so different from what could be found in a normal building. Some of the technologies that were initially expected to be accessible, such as the group feedback and the voting system for controlling the IEQ, will be installed in the future.

Regarding its societal impact, CIRS is a well known case among the architectural circle, however, among the general public it is still a stranger. The ambitions of the project are high as it is the flagship project of UBC. The result is the highest performance building at the campus, with the purposes of being an educational example and living lab. Some of the areas in the building were conceived for these purposes, like the public lectures in auditorium and the theatre. There is still the need to open its doors and invite people into the building to expand CIRS and UBC from the niches of green architecture and to really have an impact on outer society.

Operational Strategies at CIRS

For a better understanding of the building performance, an interview with the Director of Operations and Business Development at CIRS was performed. The interviewee has been involved with CIRS since the project´s conceptualization, which provides him an extensive knowledge about its development, and the details of the current status and expectations of the various systems in the building. The key aspects addressed during the interview where the Building Management System (BMS), the feedback strategies, how measurements and monitoring were performed and about the regular commissioning of building systems at CIRS. All the topics were addressed with a strong focus on the occupant´s experience at CIRS.

The monitoring of the building performance is measured and controlled through a state of the art Building Management System. The continuous monitoring and the fact that this data is later used on different research projects conducted at CIRS require a full time employed Building Technician. This way it is possible to facilitate the data in clearly for the different researchers at CIRS. Furthermore, the aim in the near future is to produce reports regarding building performance to be available for the building users and the public in general. Having a dedicated person continuously monitoring is required due to the fact that CIRS includes multiple mechanized controls and up to 3000 thousand sensors, this continual monitoring helps to immediately detect failures on the systems.

A core aspect of CIRS is the consideration of the building as a “100 year process” rather than a “single product that will be refurbished in 30-40 years”. (CIRS, 2015) This is aligned with the regular commissioning of the building systems strategy. CIRS have been operating for almost 4 years and in this time examples of the commissioning and calibration of systems are multiple. The measurement and verification conducted at CIRS allows a continuous optimization of the technologies and solutions applied.

Examples of this commissioning include the several components replaced such as wireless temperature sensors and reclaimed water aerator pumps and injectors. Lighting systems have been also continually optimized, through the installation of new sensors of photocells (for lighting level), occupancy sensors, switches and timers. Furthermore, lamps are being changed to light-emitting diodes (LED) providing same levels of luminance with substantially less energy consumption. Other commissioning projects include the recalibration and improvement of the heat exchange system, which did not perform well due to changes on the temperature of the heat-wasted collected from the nearest building. Currently, the process for selecting priorities involves the complaints received by the building technician that are directly reported to the Operations Manager. Later, decisions on priority projects are discussed planning future steps and optimization projects. According to the interviewee, currently, 30 commissioning projects are going to be developed during the next two years, with projects aiming to solve the acoustic privacy issues as priorities. In conclusion, the interviewee confirmed and provided actual examples the application of the regular commissioning and optimization strategy mentioned at the CIRS building manual.

Currently, a web based interface for the office users that is directly connected with the BMS is being beta tested. The interface provides a high potential for providing feedback to the occupants. Information regarding the building systems that are being used is provided to the occupants' instantaneously. This involves information on systems such as open windows. Furthermore, the control given to them will be increased, as people will be able to override the automatic lighting systems and also control the temperature. When changes affect an area a voting system to decide upon the new IEQ conditions is available for the users. Moreover, the interface allows users to provide opinions regarding the IEQ and also possible failures on the systems being used. Thus, providing a direct communication channel between users and the already mentioned building technician. This feedback can also be used for a regular assessment "happiness" of the building occupants.

Another aspect of the interface is its future availability as an application for mobile devices. Apart from making the interface more accessible to the users this will offer another possibility for the BMS to monitor occupancy rates at CIRS. This will be achieved through the dissection of mobile devices and Wi-Fi signals to monitor who is in the building.

The energy related feedback is also going to be provided by the interface connected to the BMS. However, as it has not been applied yet the most relevant way of providing information and knowledge to the users has been through social interaction. This is confirmed by the POE results from Sylvia Coleman which indicates the spoken communication as the common information channel regarding building performance, over other systems used such as lunch-workshops or the screen available in the atrium. The BMS will be further developed to provide automatic reports on building performance every three months and also to develop annual reports. Furthermore, when discussing the group level feedback and its social implications (social pressure, competitions, change of practices…) it has been considered as a future research project at CIRS but it has not been addressed yet.

The interface was not available since the beginning of the O&M phase resulted in the use of Pre-OE and POE as the tools for assessing well being and satisfaction of occupants. This has resulted in a six-year research project and currently they are collaborating with ASHRAE to develop a standardized protocol for the POE as an assessment tool for IEQ that will be reflected in future updates of the standards.

4.5 Case Study Results

The results of the case study have provided an overview of the building systems and procedures that have been taking place at CIRS in its first four years of occupation. For this purpose first a review of the systems used in the buildings, such and HVAC, ventilation strategies, heating, sensors and BMS have been reviewed. Furthermore, the performance of the building during the first year has also been shortly studied. This has bring the common issue that appears in many green buildings; the performance gap. The main reason of this has been the occupants and the miscalculation during the design stage.

One of the key aspects of the applied strategies is the provision of wellbeing and the engagement of occupants on the interactions with the building. The assessment of the wellbeing has been performed based on the BUS (Building Use Studies) methodology. The results were shared with us and discussed with the responsible of conducting them. Aspects such as knowledge and awareness and the provided controls were pointed out as key relevant factors for the engagement of occupants. Finally, the organizational structure in charge of the building operation and maintenance was addressed in another interview. One of the key aspects that arose from this interview was the continuous monitoring of the performance through a permanently employed Building Technician. Moreover, with the data gather from the continual monitoring and the wellbeing assessments; continual commissioning plans are developed by the operations manager, which makes CIRS a continuous process rather than a finished building.

Section 5: Analysis of CIRS

In this section the analysis of the case study is presented, in order to answer the first three research questions three subsections are addressed: Analyzing operational strategies at CIRS, adaptive comfort at CIRS and its impact and social practices and behaviors at CIRS.

5.1 Analyzing Operational Strategies at CIRS

- **RQ1: What strategies and systems during the OM phase of the building involve occupants' interaction regarding IE?**

5.1.1 Continually applied strategies (CAS) at CIRS

The strategies and systems were divided into Continually Applied Strategies (CAS) and Periodically Applied Strategies (PAS). As shown in figure 23, CAS represents the series of interactions within the IEQ context between the Operations Manager, Users and Building Systems on a regular basis. CAS integrates four different strategies; (S1) Provide individual controls for the occupants, (S2) Users receive feedback from Building Systems, (S3) Users provide evaluations to Operational Manager when the building systems performance is running under expectation and (S4) Operational Manager provides feedback to Users individually and in groups. For potential benefits and risks of the CAS on wellbeing and energy consumption based on the theoretical background provided check Appendix E: Energetic relevance and wellbeing impact of CIRS strategies.

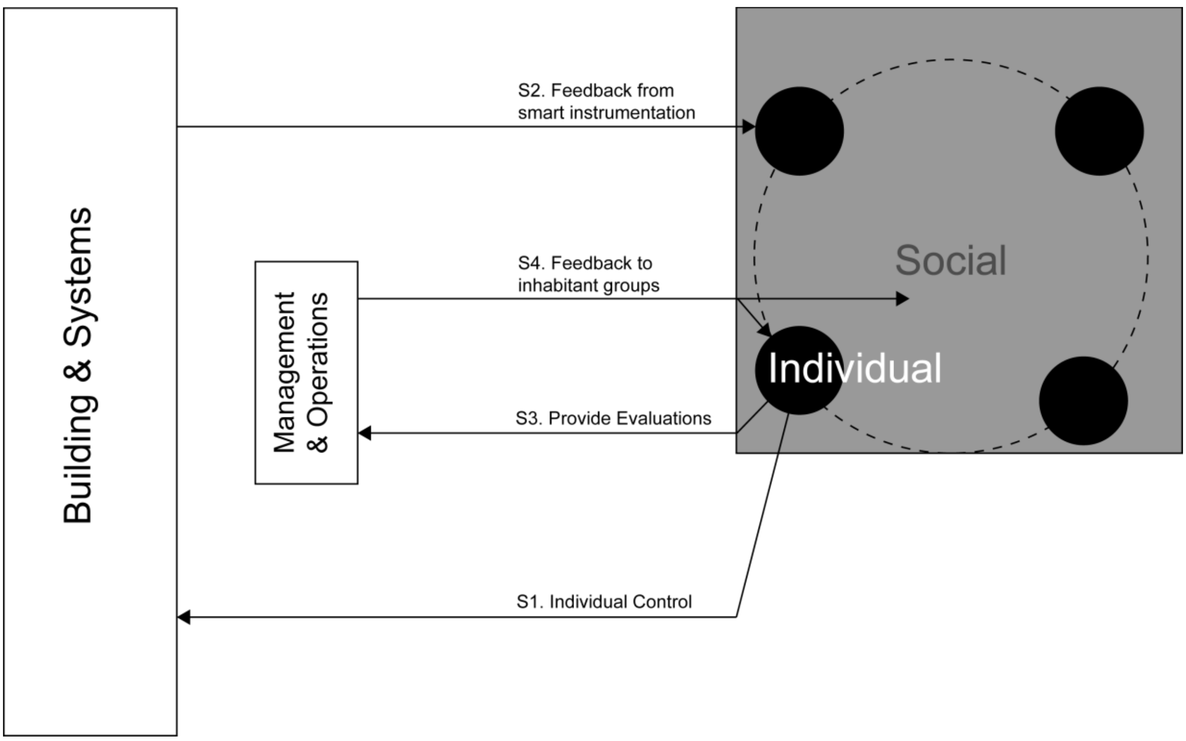


Figure 23 Graphic representations of continually applied strategies (CAS) at CIRS

Strategy 1 aims at energy savings from mechanical systems (HVAC) and cooling demand during summer via the wise use of natural ventilation from the users. At the same time, users who are aware of how to use operable windows get a higher tolerance to discomfort and positive effects on their wellbeing are likely to increase if they have access to daylight features.

On **strategy 2**, the awareness of users regarding their energy performance allows to shape their practices towards energy savings. Wellbeing is ensured by framing the expectations and perceptions regarding the IEQ so that there are no misunderstandings or false believes regarding the characteristics that the indoor environment will have; i.e. the users are aware of their performance regarding energy consumption as well as the measures they might apply to ensure the IEQ.

Strategy 3 is developed through the interface of the BMS and it allows an open and responsive communication channel between the Operational Manager/Building Technician and the occupants. This enhances the satisfaction and possibility to optimize systems in a more comfortable way, allowing a service recovery in the provision of IEQ. Similarly to S3, **strategy 4** is achieved through the BMS interface and it aims to show the impact on energy consumption that the actions taken by the occupants. The feedback is presented clearly and in a responsive way, aiming to shape habits of the occupants regarding their use of resources.

5.1.2 Periodically applied strategies (PAS) at CIRS

The Periodically Applied Strategies (PAS), as shown in figure 24, represent the series of procedures at CIRS that involve the interaction between the Operational Manager, the occupants, Building Systems and also the Building Technician that monitors the performance of CIRS. These strategies are periodical and applied through the whole process of CIRS (100 years). The periodicity varies between the different strategies. PAS strategies are the next; (A) create training and aware programs for staff, (B) conduct pre and post occupancy evaluations (Pre-OE and POE) to the new inhabitants, (C) conduct POE every 5 years on existing inhabitants of the buildings, (D) conduct regular commissioning of all mechanical and electrical systems and (E) employ systems for ongoing measurement on buildings performance. Use the data for developing annual reports and use it to optimize overall building performance. For potential benefits and risks of the PAS on wellbeing and energy consumption check the Appendix F: Periodically applied strategies.

Strategy A refers to the training and awareness programs undergone at CIRS before the occupancy of the building, such as the inhabitant workshop. The users are empowered through training to "know how" to use the systems in an optimal way. At the same time the psychological aspects of comfort are shaped due to the change on occupants' expectations.

Strategy B is applied each time that a new occupant enters in CIRS. It involves conducting a Pre-OE to understand the influence of the previous office space experiences. Furthermore, it also evaluates through a POE if expectations and satisfaction are fulfilled getting feedback for further improvements. Similarly, in **strategy C** POEs are conducted to all the inhabitants at CIRS every 5 years. This has a similar purpose as it gives an insight of the overall satisfaction and the possible sources of discomfort. All this data can later be used by the OM to define future commissioning projects.

Regarding commissioning, **strategy D** ensures a regular commissioning of all the mechanical systems in the building. The commissioning projects are defined based on results of POE and also suggestions from the Building Technician that is monitoring the building performance. **Strategy E** utilizes the data and measurements from the BMS to develop annual reports on the building performance in different areas, such as energy, CO2, production of sustainable energy sources and water. Through this strategy is possible to continually improve the different BS to improve the overall performance.

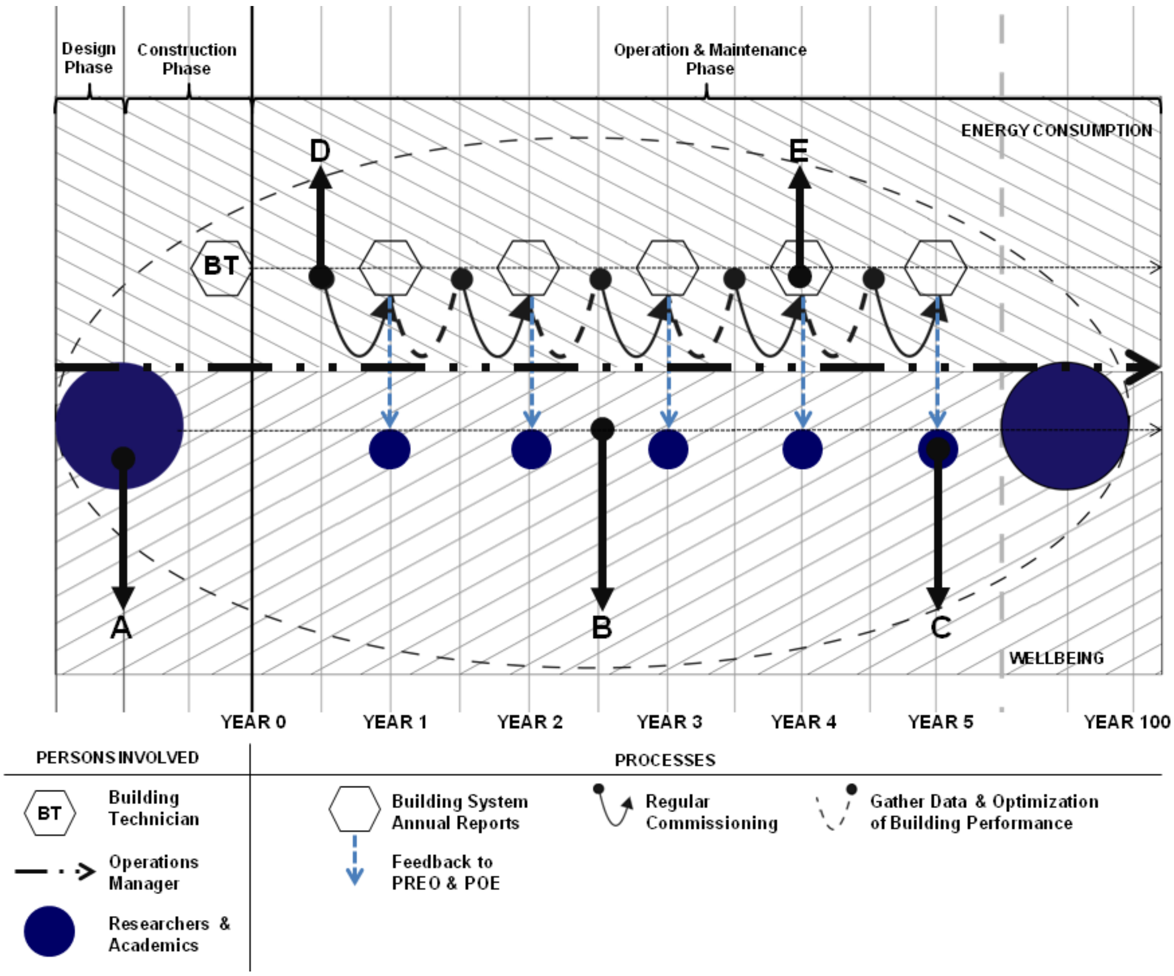


Figure 24. Graphic representation of the periodically applied strategies (PAS) at CIRS

5.2 Adaptive comfort at CIRS and its impact

- **RQ2 Which impact does the strategies have on energy consumption and occupants´ wellbeing?**

Extensive tables with the impact and relevance of the strategies are available in the Appendix E & F.

The reviewed case study at CIRS is an example of the application of the concepts that derive from the adaptive thermal comfort theory developed by de Dear and Brager (1998). For instance, the office occupants are referred as "inhabitants" in the available information sources of CIRS. The "inhabitant" term implies a sense of belonging and permanence to the location. This contrasts with the traditional occupant definition, which implies temporality. Furthermore, the "inhabitant" term was also used by the interviewed stakeholders at the building, which indicates that the consideration is deeply rooted and goes beyond the official narrative. This indicates that the office occupants at CIRS are considered as proactive users that participate and interact with the building systems to adapt and create their own indoor environment. In opposition to the traditional thermal comfort represented by the Fanger model (1982), which only considers the physiological aspects of comfort, at CIRS psychological and behavioral aspects are considered to play a key role on occupants' comfort.

With the intention of promoting the previously mentioned proactivity, CIRS provides comfort to the occupants through various systems. The bases of adaptive thermal comfort (ASHRAE 55, 2010) require the access to natural ventilation for the occupants, which in CIRS are provided through operable windows accessible from all the occupied office spaces. Furthermore, the building applies different natural ventilation strategies for almost all the occupied spaces, with the exception of the auditorium. This provides the possibility to adapt the conditions to the users, which results in a higher tolerance to dissatisfaction. Furthermore, more control is provided through an interface, controlling temperature and lighting levels, and also through access to underfloor diffusers to control the ventilation flows. Those features are not reflected in current standards such ASHRAE, although adaptive comfort theory indicates that they are enhancers of satisfaction on office users as they still provide a way to adapt the IEQ. This last statement is reflected in the POE conducted at CIRS where users showed high satisfaction with the given controls, even though, some controls such as the underfloor diffusers were not used frequently. However, when the building occupancy started back in late 2011 the fact that the web-based interface was unavailable for the users was origin of many complaints. Lighting systems were automated and managed through the BMS and without the interface; it was impossible to override those controls. This was a source of dissatisfaction among the occupants, which later has lead to a recalibration of the lighting systems.

One of the most important IEQ factors in CIRS is lighting, especially when it comes to the provision of natural light. The goal on the design stage was to provide all occupied areas with 100% access to daylight. One of the main factors for visual comfort is the provision of daylight although the access to views to the outside also plays a key role on the comfort of occupants. At CIRS natural light is the most valued source of satisfaction for the occupants, as it can be seen in the POE results (Figure 21 and 22). On the other hand, the previously mentioned issues with artificial lighting controls hinder the visual comfort satisfaction. The control and possibility to adapt their visual comfort over the natural lighting at CIRS is done by simple techniques, both passive, but also through controls such as window blinds.

5.2.1 Impact on wellbeing and perceived performance

When it comes to assess the impact on the occupants of the building, CIRS has two strategies in mind; a questionnaire based approach and a semi lab approach through monitoring of occupancy and the gathering of occupant feedback though the web based interface. However, the unavailability of the interface in the early years of operation of the building has resulted in only the possibility to assess the well being through questionnaire based POE. This questionnaire was based on the Building Use Methodology (BUS) and in the previously conducted Pre-OE, this was done to develop a comparison among the results of the Pre and Post evaluations.

The results obtained from the POE at CIRS indicate high levels of satisfaction and comfort with the IEQ provided (Figure 21 and 22). Among the different factors consulted the ventilation/IAQ, the natural lighting and the thermal comfort (winter and summer) resulted in high grades. This has also implications for the comfort, perceived health and perceived performance on the employees, which all result in high values on the *Likert scale* applied in the questionnaire. On the other hand, the results on artificial lighting and acoustical comfort are rather unsatisfactory (Figure 21). Optimization projects for the first have been developed after the POE, which are likely going to be reflected on the next evaluation. However, the use of an open office plant have resulted in issues with acoustics that according to the COO at CIRS are to be addressed in the next years through different optimization projects and solutions.

CIRS is considered a high performance building and it fits the definition of healthy building given by Bluyssen et al. (2011a), as it provides high levels of comfort to develop the activities without hindering performance. The access to natural ventilation is a key aspect that ensures the access to fresh air and enhances the IAQ and it is also highly valued by the occupants. This implies a great reduction on the SBS related issues up to a 50% that is the quantity commonly associated to IEQ conditions (Fisk, 2000). The biggest constraints at CIRS come from the artificial lighting and the acoustics. As research studies (Vimalanathan and Babu, 2014) (Bluyssen, 2009) both of these factors can have a notable impact on the performance and productivity of office occupants, which explains why there are plans to address those issues in the next years of building operation.

The general high satisfaction with the IEQ is a great sign when it comes to analyzing potential benefits on performance and cost savings on employees. In terms of saving costs the savings are rather difficult to quantify but good IEQ, such as the one provided at CIRS, was estimated to lower absences due to respiratory illnesses on a 35% (Milton et al., 2000). When it comes to performance it is difficult to quantify but the fact of reducing SBS symptoms, such as allergies, irritating eyes and noses, indicates potential productivity gains (Fisk, 2000). Furthermore, attempts to measure impact of IEQ on IE (Roelofsen, 2002) indicate that the impact of IEQ is the most relevant factor when it comes to measuring losses on workers performance in office environments. Thereby, the fact that CIRS provides a high quality on its indoor environment indicates that the benefits and impact on employees is satisfactory. However, quantifying the potential losses on productivity and the increase on health issues caused by the building requires further research.

5.2.2 Impact on energy consumption

CIRS showed the frequent issue of the performance gap, in this case the complexity of the systems and the occupancy are the major responsibilities for this gap. The energy intensity at CIRS resulted in a 23% more than the one calculated in the design model, which was of approximately 140 kWh/m2 (Cavka et al., 2014). These measurements were developed between 2012 and 2013 in a year time span. However, the lack of later available energy measurements complicates the analysis on the effectiveness of the commissioning of systems and training programs that have been ongoing since the early occupancy of the building. Furthermore, in order to assess the actual impact of the strategies is necessary to develop specific area measurements over time, which due to the geographic situation of the building could not be developed during the development of the present research.

The performance of the building in terms of energy intensity is below the average of the commercial buildings in the Pacific Coast of Canada (British Columbia). The report developed by the Natural Resources Canada office on energy efficiency in buildings (2012) provides an average energy use intensity of 0.99 GJ/m2 (approximately 275 kWh/m2) resulting in great savings comparing with similar typology buildings. However, when comparing with high performance buildings in Canada the energy use intensity is higher for CIRS. The Canadian GBC report (2013) analyses different case studies of other LEED platinum buildings and the resultant intensity on those ranges show about 40% less intensity than the one from CIRS (Around 100 kWh/m2). However, this data is based on the designed model of those respective buildings, thus not taking into account the real measurements and the possibility of existence of a performance gap.

5.3 Behavioral Change and Social Practice Models

- **RQ3: How to apply the strategies from an operations manager perspective in order to influence the behavior and practices of the occupants during the long term?**

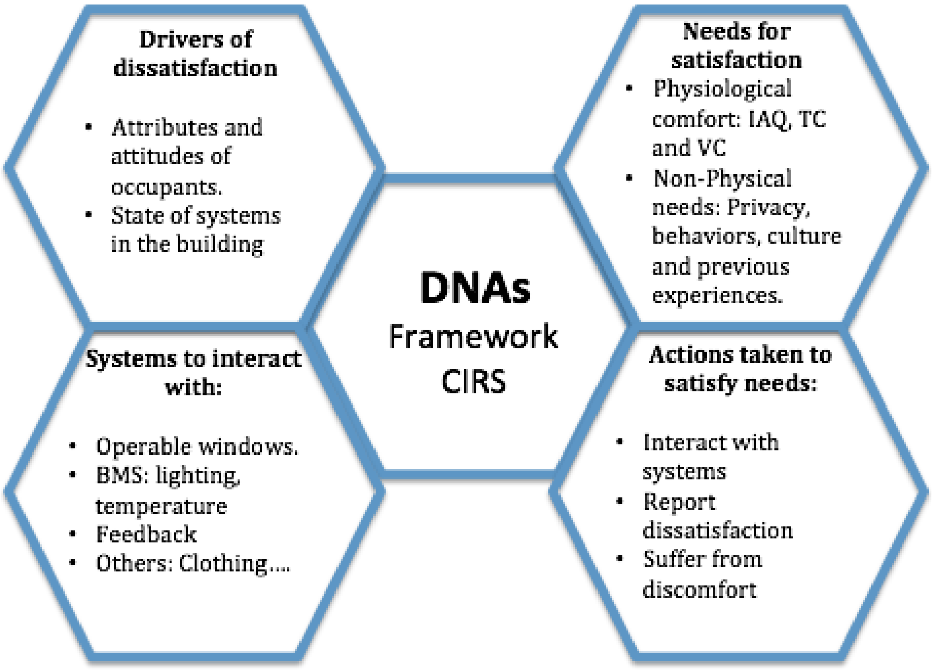


Figure 25 Considerations for OM regarding inhabitant behaviors at CIRS (Based on Hong et al., 2015)

When applying the DNAs framework (Hong et al. 2015) on the CIRS case it is possible to understand the different behaviors of the occupants. The drivers and needs that occupants have are rather uncontrollable for the facilities manager, however, it is important to take into account the factors of the weather, season, attributes and attitudes of the occupants etc. The strategies applied will be later discussed in order to understand how they actually aim to shape the needs of the occupants, especially the ones regarding "non-physical needs", such as knowledge and awareness programs.

On the other hand, the aspects related to individual actions are also uncontrollable from the OM perspective. In these cases the OM should still provide channels to allow the actions to happen. For example, at CIRS the corporate culture and narrative of the building engages and promotes the occupants interactions with the available systems through concepts and meanings such as "inhabitant". Furthermore, the interface gives an easy and accessible communication channel to report immediately discomfort and to provide feedback on the IEQ. This information allows the OM to better understand occupants' needs, to later calibrate the systems of the building to suit the preferences of CIRS occupants in a better way.

As mentioned before CIRS has applied the principles of adaptive comfort allowing control over the IEQ to its occupants and also bringing into the equation relevant aspects such as psychological comfort. As a result of this, the energy consumption is highly dependent on how systems are used by occupants, which is commonly named as "occupant behaviors". The behavioral change theories suggest the in order to promote new “pro environmental behaviors”, elimination of barriers and enhancement of proper attitudes are the key aspects. In the literature this is defined as “ABC” (Attitudes-Barriers-Choice) model (Shove 2010). At CIRS both aspects have been taken into account and awareness and training have play a key role during its lifecycle with different workshops and strategies that have involved occupants.

However, the principles that sustain CIRS (regenerative design and development) have a wider systems perspective of what can a building achieve. Thereby, in order to explain how people interact with the building is more important to look at CIRS from a wider systems perspective, rather than the individual focus that theories of behavioral change provide. In order to understand how practices are developed and which elements shape them at CIRS, social practice models theory can be applied.

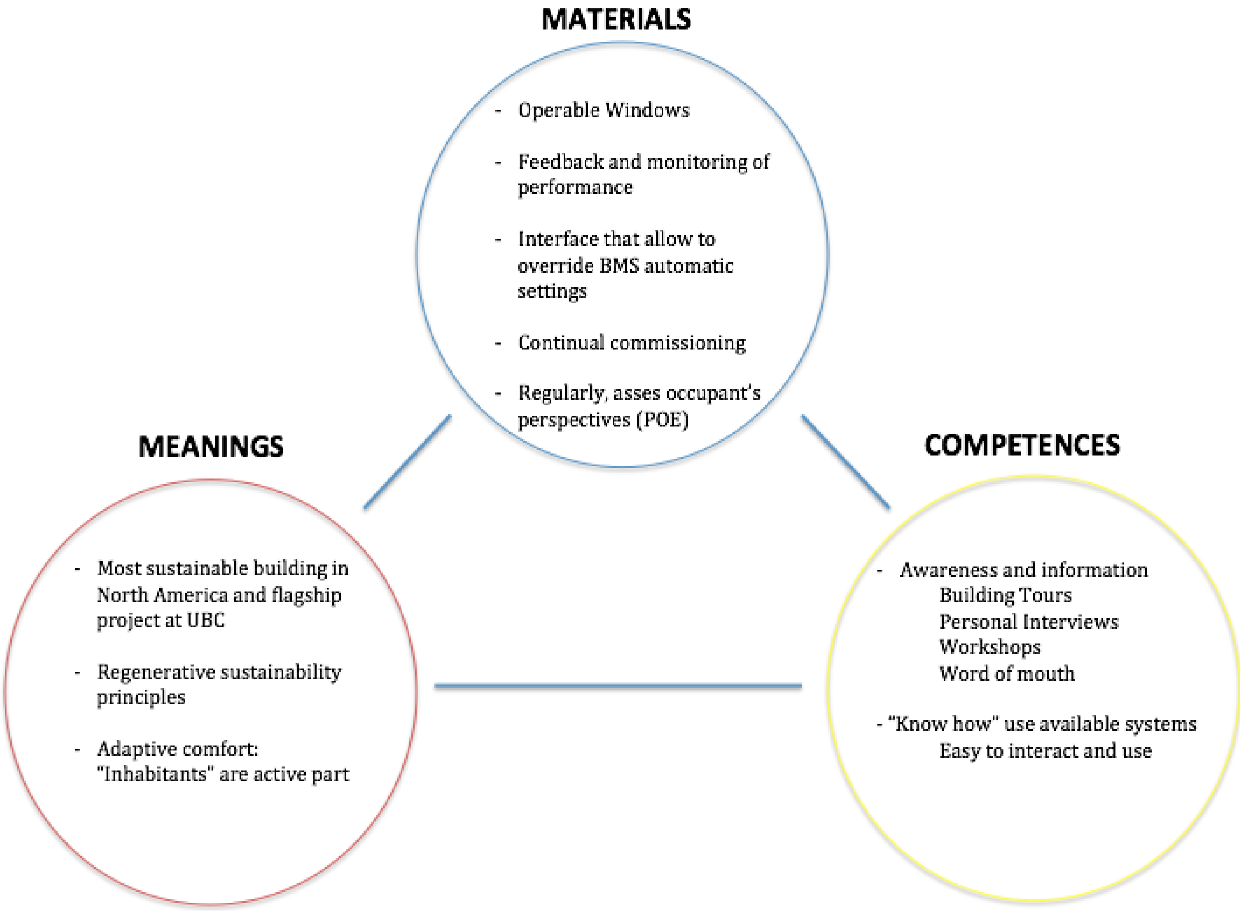


Figure 26 Model of practices at CIRS for the interactions with Systems for IEQ. (Based on Shove et al., 2012)

The Figure 23 approaches the CIRS strategies related to occupants' interactions and energy savings from a social practice model (Shove et al. 2010) perspective. This way of visualizing the elements that are part of the sustainable practices CIRS has been promoting since the conception of the project.

The **materials** refer to the infrastructure at CIRS, which is specifically designed to allow the interaction of occupants with the building. Thereby its main features are represented mainly by the operable windows or the features that the interface connected to the BMS provides; such as, overriding automatic settings or providing feedback. Other systems like the under floor diffusers have not been really integrated on the current practice at CIRS as they are practically ignored by the practitioners.

In terms of **symbolism or meaning,** CIRS is a clear example of how relevant this element can be on shaping practices within the building and also outside it. The adaptive comfort principles and the narrative found around CIRS have considered the occupants as "inhabitants" and attributed them an active role on creating their own IEQ. Furthermore, the fact that CIRS was widely considered as the most sustainable building in North America may have influenced the ongoing practices. For instance, the POE revealed that the xx% utilizes environmentally friendly practices for commuting such as bicycles, walking, bus use and car sharing.

Finally, **competences** have also played a key role at CIRS and on the engagement of the occupants on sustainable practices. For instance, the building tours and the inhabitant workshops together with the widely spread narrative have raised awareness among the occupants. This was reflected on the Pre-OE conducted at the very beginning where the future occupants were informed on the purpose of CIRS (living lab and research center) and also informed on its characteristics as a regenerative building. The building systems are also designed to be easily accessible from the workplace, specially the windows.

The results from the interviews have been analyzed based on Hong et al. (2015) and Shove et al. (2012). However, when reviewing both figures and the strategies applied at CIRS 5 key aspects can be appreciated. The proposed Figure 25 helps to visualize the 5 key aspects for the application of the strategies at CIRS during the O&M phase identified.

1) First, start with the **awareness and do it understandable** for everyone. Interviews, Pre OE, building tours, inhabitant workshops are activities were knowledge is spread to different actors during the operational management phase. At CIRS the informal discussions among employees during breaks were also indicated as an important source of knowledge.

2) Second, **create competence** by designing an easy to follow process. For instance, windows are accessible from the workplace without standing up and also the shades and blinds are easy to use. Furthermore, the interface can be accessed from the desktops of the workers. The interface is designed also to be easily understandable for overriding the BMS automatic settings.

3) Third, **meaningful and/or symbolic purposes** develop to implant an adequate culture that enhances the interaction with systems and sustainable practices. CIRS considers its occupants as "inhabitants" and openly provides them with an active role on creating their own IEQ. At CIRS for instance, the social focus in building occupants was framed rather than having a focus on individual change. Regenerative sustainability frames a positive solution rather than presenting a negative consequence.

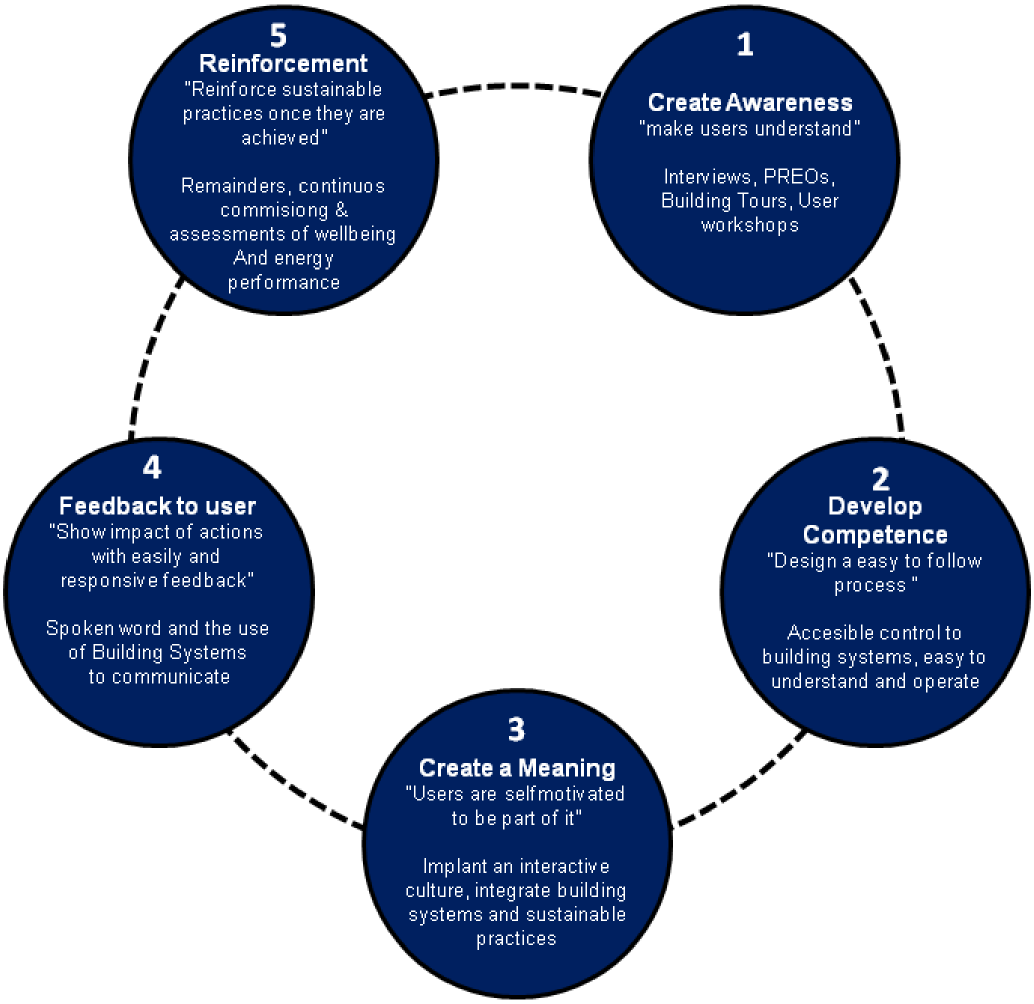


Figure 27 Stages for the implementation of strategies at CIRS (Based on Hong et al 2015, Shove et al. 2012, CIRS 2015)

4) Fourth, **feedback on occupant's actions on the indoor environment** with easily understandable and responsive feedback. The spoken word at a management level and the use of technology on the building systems is two processes for transmitting the data to users.

5) Finally, the **reinforcement of sustainable practices** by reminding building´s occupants through informal meetings and workshops, continual commissioning of the building systems and assessing the well being through POE.

Section 6: Swedish context Analysis

The building chosen to analyze opportunities and barriers to apply the operational strategies of the CIRS building in another environment was Idrottshögskolan from the property owner Higab in Gothenburg, Sweden. This company is owned by the city of Gothenburg and contributes to the development of the city. Higab business revenues come from leasing their properties, which vary from educational, cultural to commercial use among other uses.

Higab plans and construct new buildings, as well as the Facilities Management of their existing building stock. The Idrottshögskolan is Miljöbyggnad Gold (SGBC, 2015) certified building used by the department of food and sports nutrition of Gothenburg University. It is defined as a national and knowledge center for development in sport performance and health promoting work. The building has an area 3,600sqm consisting of offices, laboratories, a gym hall, a studio and classrooms.

Wellbeing indoors is the criteria with the highest importance when applying Miljobyggnad to classify green buildings (SGBC, 2015). In addition, the material´s lifecycle is closely considered and managed through a common database for architects, consultants and contractors. The materials are allocated on the database according to their characteristics and selected to fulfill the requirement of Miljöbygnadd. The environmental strategist controls the final selection of materials to be used in the building.

6.1 Findings of the context analysis

The environmental manager at Higab was interviewed to understand what strategies are being undertaken in Sweden regarding energy savings and well being of occupants. Higab is a property owner in the city of Gothenburg that owns around 350 buildings. The property types range from cultural (museum or libraries) to office buildings (city hall or research facilities). In this case the interview was primarily focused on Idrotthögskolan, a research facility for sport and nutrition rented by the Gothenburg University.

Involvement of client on the design process:

The project in Idrotthögskolan encompassed a big challenge, as it was one of the pioneers on the use of "Miljöbyggnad" assessment tool. The client was involved during the design phase and it was part of the integrated design team. However, the biggest concern of the client and the design team was the investment costs and the utility of the spaces in the building rather than the long-term environmental impact. Thereby, the client got involved especially on the proper design of the gymnasium and the laboratories. The occupants of the building were also involved in the process, mainly through meeting and presentations conducted by the property manager representative. Those presentations also included information regarding the use of systems in the building.

Occupants:

When it comes to occupants the property manager measures their wellbeing through the use of a questionnaire based on the "Örebro Modellen" (Miljömedicin MM Konsult AB, 2015). Örebro Modellen identifies problems on the indoor environment in a systematic manner and structures the information starting with the most healthy risk problems as priority. Complaints or illness represents the current state of a building with problems on the indoor environment. A three step process; mapping problems, surveys and technical measurements represent the bridge towards actual measures to remediate the issues that occupants may suffer on the "ill" building.
The assessment tool applied (Miljöbyggnad) requires by norm to conduct a survey every ten years, however, in Idrotthögskolan they have already conducted two surveys in its five years of life. This occurs due to the internal procedures at Higab, which specifies conducting it when a complaint is registered. The survey aims to identify the roots of the problems as it includes 72 questions in a number of different topics, such as IEQ, cleaning or working conditions (See Appendix G). Through this survey the property manager is able to determine if the problem is individual or common. Furthermore, it helps to determine the root of the problem; i.e. if it is due to a social issue in the office, a problem with the IEQ or other type of issues with their root out of the office environment.

The communication channel between the client and the occupants with the property manager allows them to register complaints. This is formally done through a web interface that allows the fulfillment of a formulary to report issues with the office environment. The internal policy of the property manager indicates that the complaint must be answered in the next 24 hours and depending on the urgency the time to solve the issue may vary. In the case of Idrotthögskolan, the relationship between client and property owner is good and therefore the most common communication channel is via phone call to the responsible building technician. This channel is considered informal and faster than the web formulary although it has some issues such as the lack of written documents. However, the belief at Higab is that collaboration is fruitful in most of the cases as the main purpose is to do their best to keep the clients satisfied.

The client directly receives feedback on their energy consumption, as they "own the bill". In the case of Idroothögskolan the client is Gothenburg University. However, the client is the one that decides if the energy consumption is shared with its office occupants or if it is kept private. In the studied building the environmental department of GU publicizes the information regarding energy consumption in its annual sustainability report. When it comes to control, the occupants at Idrotthögskolan are provided with basic possibilities to modify temperature, IAQ and ventilation rates. However, the provided control is not as extensive as it could be in regular buildings. The only rooms with a high control over the indoor environment characteristics, such as humidity or temperature, are the laboratories where they develop physical tests for athletes. Regarding the lighting, the building has occupancy sensors to determine if people are within the building or not. Once someone is in the building it is possible for that person to switch on or off the lighting depending on his specific requirements.

Property Manager: Organizational Structure

Higab is structured in two main departments; one works with development of project and the other is responsible of the operations and facilities management of the owned properties. When it comes to facilities management a two people team structure is established. One person is responsible of the client relationships, generally one per each client Higab has. The client relationship manager is responsible of regularly meet with the client and discusses major changes in the building or properties that might involve investments and changes on the rent. The other person in the team is the Building Technician, who takes the responsibility for the everyday operations of the building. The building technician takes responsibility of a number of buildings. This number can range depending on the size and characteristics of the given buildings.

Building systems and energy saving strategies:

The energy strategy at Higab implies working with a monitoring and control of the systems. The procedure indicates that when there is an alarm, such as temperature too high, the proceeding for solving the issue should start within the next 24 hours. The technicians receive education on energy efficiency and are provided with tools to diagnose buildings from an energy perspective. They are able to determine where an issue occurs; in an individual person, time, general issue… this procedure has been recently introduced into the daily work of Higab's building technicians. One of the biggest issues when it comes to energy saving strategies is caused by the rental contracts signed with clients. This happens, as Higab is the one investing on the energetic improvements, although the energy savings and subsequent monthly cost reduction benefits only the client. This has led to the establishment of a payoff for those investments in the rental contracts, which has been one of the biggest challenges faced in the latest years.

When it comes to applying energy saving strategies, first, Higab tries them in their headquarters before proposing them to the clients. Nowadays, there are plans to measure the energy consumption in different sections on their office space to try and compare different solutions for energy savings. For instance, they plan to utilize timers on the plugs so they can only be used during office hours. This way they are able to propose solutions to the clients and present them a percentage of energy savings to prove the effectiveness of the solutions.

Regarding the calibration of the building systems at Idrotthögskolan, there has not been any major procedure since the building was occupied. Only regular maintenance of heat pumps and HVAC systems has been done, which is commonly indicated by the system manufacturer. The technology available is still at the forefront and there has not been any major issue in the first five years of occupancy. The policy applied at Higab is to calibrate systems only when problems appear and this is a duty of the building technician.

6.2 Results of the context analysis

- RQ4: Which are the implications to apply the analyzed strategies in the context of a property manager in the city of Gothenburg?

The previously analyzed strategies aim to shape the way occupants interact with the buildings within the IEQ context. Those interactions occur in a rather unconsciously or at least without involving a thoughtful decision-making process (open a window, raise temperature or turn on the lights). Thus, it can be said that those actions fall on the definition of practices previously provided (Reckwich, 2002). Although the managerial approach towards social practices has not yet been profoundly studied, the most relevant aspects for shaping practices are commonly agreed by social practice researchers (Shove et al., 2012; Cohen and Ilieva, 2015). As an answer to the purpose, this thesis aims to propose a series of managerial recommendations that aim to tackle the existing elements (competence, meanings and materials) and to establish new ones that might facilitate the emergence of the practices previously studied (see Appendix G).

When it comes to address the applicability of the strategies in Gothenburg, a clear gap between the CIRS practices and the current practices at Higab has been found. However, the results of the interview indicate that the analyzed organization has some procedures on place, which indicate the proper direction towards the goal strategies reviewed at CIRS. However, as Shove et al. (2012) suggest for influencing the emergence of new practices is required first to tackle the elements that support the established practices. The strategic practice management approach developed by Cohen and Ilieva (2015) also suggests starting identifying the current practices and understand the impact of changing those practices, commonly done through visualization (see Appendix G). Furthermore, the next step is to understand which elements are to be shaped (materials, meanings and competences). The goal practices refer to the best practice achievable on the benchmark conducted with the previous case study at CIRS. Those practices have shown a high-assessed wellbeing among occupants. While a reduction on the building´s energy consumption attributed to these practices is not definitively proved, it is likely that high wellbeing (health & comfort) results in an easier engagement of the occupants towards energy related behaviors. In order to reach similar practices on occupants' interactions with building systems the next managerial recommendations are proposed by the authors.

Managerial Recommendations for Establishing New Practices:

- Understand Current Practices: In the case study refer to the understanding of the actual practices at the Sport and Nutrition center in the city of Gothenburg. They comply with local regulations, which have shown higher marks in terms of wellbeing, however, wellbeing is not assessed on the rest of their properties. Furthermore, the current procedures indicate the solution of issues when they arise, more like a just-in-time approach. In order to modify current state practices successfully a change on the ways of working and mindsets is required. Another key aspect is the understanding of the organizational structure and the power relationships between the practitioners.

-Shape Practices and provide a new infrastructure. Applying operational strategies directly on a different context seems not likely to produce any immediate effective impact on wellbeing and energy related behaviors. On the contrary, it might be rejected or develop resistance to be adopted by the local OM and occupants. In order to introduce such strategies, an iterative transition via testing, evaluation, use of latest technologies and commitment from managers and occupants is proposed in the Appendix G. The purpose of this is to provide a new infrastructure; materials, competences and meaningfulness to allow new practices emerge.

- Tracking Practice Changes: Once new practices emerge the need of assessing the impact it is critical. As the addressed practices involve energy consumption and wellbeing, those are the two key measurements. Furthermore, it is also important to include qualitative assessments to understand how practices have shaped individuals attitudes, motivations and meanings.

Section 7: Discussion

7.1 How the thesis addressed the purpose

The MSc thesis report has organized operational strategies which integrate energy related concepts and wellbeing assessment. Although POE showed positive results regarding the provision of wellbeing on the CIRS building, reduction on energy consumption could not be fully attributable to the application of the operational strategies. Definitive factors that might directly trigger energy savings among occupants remain unknown to the present research. However, a strong link is found on the awareness, knowledge and feedback concepts applied through a 5-step framework (Figure 27) in order to develop practices that might turn into energy saving habits in office environments.

Finally, the time to complete this MSc thesis after the analysis of the case study allowed the authors to develop a basic study of the context in Sweden. The proposed factors and managerial recommendations provide an opportunity for facilities and operation managers to shape occupant´s daily practices on a different context.

7.2 Interpretation and presentation of results

The results from the thesis have provided a review of the strategies on a specific case study (CIRS) that has applied the concepts of regenerative design and development, which implies a generation of positive impact on occupants and surrounding environment.

The results are presented in two frameworks encompassing the organization on short and long-term strategies analyzed from the case study. The Continually Applied Strategies (CAS) strategic framework organizes the daily interaction processes between the operation managers, building systems and occupants. Awareness and knowledge are key factors that continuously trigger either actions or information flow between the 3 stakeholders. The information flow is seen in both directions from occupants to the systems and management but also the other way around.

The Periodically Applied Strategies (PAS) strategic framework organizes the processes and persons involved in the periodical application of strategies on both the energy-related dimension and the wellbeing dimension during the lifecycle of the building. Both the CAS and the PAS has been further analyzed in base of the theory. This has served to understand the potential energetic relevance of the strategies and also the potential benefits for the wellbeing of occupants. The findings have been presented on the analysis and also on the table available in the Appendix E and F.

The Continually Applied Strategies bring potential benefits for wellbeing and also show potential benefits in terms on energetic performance of the building. The analysis of the benefits has been based, both on the case study but also on the reviewed literature. Similarly, the study of the four CAS (Figure 23) has also shown potential risks that have to be taken into account by the operational manager. Those risks can result in negative impact on wellbeing and also on energy performance (See Appendix E).

When it comes to the Periodically Applied Strategies an analysis of the impact on wellbeing and energetic relevance has been conducted. PAS (Figure 24) have shown to be mainly targeted towards the wellbeing improvement of the building occupants. Only the strategies A (training and awareness) and D (regular commissioning) might also result in an impact towards energy performance of the building (see Appendix F).

In addition, the strategy of regular commissioning of the systems is found to be the joint between the two concepts previously presented: wellbeing and energy consumption. This is a critical strategy where the information gathered from the wellbeing assessment and the monitoring of building performance are studied by the management and optimization plans for building systems are developed. This results in a constant improvement and optimization process for the existing building systems, based on the results of the energy and wellbeing evaluations. However, during the interviews some hinders for energy reduction were also identified. For instance, current building regulations, which might be outdated, e.g., unnecessary 24 hours artificial lightning.

Another finding is to determine the factors that support the successful application of the strategies. The 5-stage principles framework proposed a broader perspective to operations management and aims to develop a loop of principles towards the awareness, competence development, understanding, feedback and reinforcement of positive practices towards reducing the energy consumption. Ensuring that those 5 key factors are addressed might provide an answer to engage office occupants on sustainable practices.

Finally, on an attempt to study the applicability of the previous frameworks in the city of Gothenburg, an overview of the current practices in a property owner organization has been developed. The strategic practice management framework developed by Cohen and Ilieva (2015) has been the base to provide managerial recommendations for the studied organization to transition from the current existing practices to the practices and strategies that have been studied previously. The identified gap on the practices has its origins in different factors. An example is the one regarding the procedures; in Higab they aim to solve issues after they appear, while the previously mentioned established the review of the systems regularly to sport improvements. Understanding the gap is the first step to be able to adopt new sustainable practices. It is the opinion of the authors that the strategies can be applicable in different contexts. However, for this to happen it is key to identify current practices in each context and which elements are supporting them later target them and establish new ones to support the emergence of new practices.

7.3 Limitations of the research

The main limitation of the research is the use of a single building as a case study. The unique characteristics of the case study, considered the most sustainable building in North America, make it hard to extrapolate the findings to other office buildings even more in other environments. The context of the building in terms of geographical location (climate, culture…) and typology of office building (research center and working lab) might arise barriers when applying the findings in other contexts. The choice of the case study is justified as the aim has been finding best practices on occupant's interactions with the building systems. Acknowledging the limitation of the single case study, an extensive literature review has been developed to serve as a solid base for the analysis of the results. Furthermore, another aspect that might have affected the quality of the data collected is the fact that the interviews were developed via phone call. The interviews performed might have provided new insights if they would have been performed face-to-face, especially taking into account the inexperience of the authors with qualitative data collection.

Finally, the third research question aimed to determine the applicability the strategies into the Gothenburg context. However, the context analysis only took into account the perspective of a municipality owned organization. Thereby, the findings of the latest context analysis might have differed if other local organizations' perspectives would have been considered, for example, from a privately owned organization.

The limitations of the present master thesis could be overcome by future research. First, a biggest sample of high performing buildings in different geographical contexts could serve as a base to determine the best practices regarding operational strategies involving occupants' interactions with the building systems. The energetic impact of the application of the strategies has not been clearly determined and leaves room for future studies and monitoring of the energetic effect of the strategies.

7.4 Reflecting on the influence of the C-Lab on the thesis project

The thesis has been conducted within the Challenge Lab scheme, previously explained in the section 1 of this report. This has mainly influenced the selection of the topic and the research questions that have lead us to the current thesis report. This influence has been represented mainly by the strong focus on sustainable development, especially in the choice of the case study. The sustainability criteria decided among the Challenge Lab students (Appendix A) have also been a strong driver to bring wellbeing and social aspects as important factors into the equation of sustainable indoor office environments. Furthermore, the systems perspective provided in the early stages of the Challenge Lab have also been reflected in the thesis. The context analysis has also reflected upon the socio technical transitions presented during the first phase of the C-lab (Geels, 2005). We have mainly looked at occupant's interactions with building systems as social practices rather than individual behaviors, providing a more holistic approach on what is necessary to engage occupants into new sustainable practices.

The methodology on the Challenge Lab, back casting (Holmberg 1998), was also taken into account during the conduction of the thesis. The different steps of the thesis research are reflected in the back casting process. The phase one mainly serves to understand the first two steps; establishing a framework for sustainability and understanding the current situation in the city of Gothenburg. For the thesis project the second step has been enriched through a literature review on the topic. In an aim to design solutions for that transition a case study based on regenerative sustainability was analyzed. Finally, as a parallel of the fourth step in the back casting methodology, next steps to be taken in the Gothenburg context were proposed.

Section 8 Concluding Remarks

The MSc thesis has focused on the operations and maintenance phase of office buildings. OM deals with the energy consumption of occupants in buildings during the longest period of time of the lifecycle. The strategies that had been reviewed in the thesis have shown an enhancement of the self-perceived wellbeing (health and comfort) of the occupants. The key factors identified during this process are the awareness and knowledge, and feedback for and from the occupants. Finally, the strategy regarding regular commissioning has been found to be the key that integrates the building systems, occupants and operations management and is where human and technical aspects merge. The result is a continual learning process, where both energy aspects and human factors are studied, that aims to optimize and improve systems over the lifetime of a building. Even though the energetic data available is not enough to prove the direct reduction on consumption caused from the strategies, the fact that the strategies are a continual process of improvement suggests that optimizations are being made and will be reflected over time on the energy consumption of the building.

Furthermore, it is important understanding that a direct application of the strategies might impose resistance from occupants or building operators, which likely will result in the implementation failure. Finally, this thesis proposes a set of managerial recommendations for shaping and transitioning practices in different contexts. The recommendations aim to first tackle the elements (meanings, competences and infrastructure) that origin the current practices to further influence the emergence of new practices that involve the engagement and active participation of occupants for a sustainable indoor office environment.

There is still a long way to determine the perfect balance between energy consumption and occupants´ wellbeing to create optimal indoor environments especially when the psychological and behavioral dimensions of comfort are included into the equation. Engagement on a long term might shift the mindset of new occupant generations to create knowledge and awareness, and reduce their energy demand.

8.1 Further Research

This thesis presented a single case study of a particular living laboratory in Canada. Energy reduction derived from the application of the strategies still needs to be tested and proved locally. Assessment methods and tools to measure reduction on energy might result from such studies. The further application of such methods to different climate zones, contexts and cultures would scale up the local results. Knowledge, awareness and feedback might develop different results when applied to operation and maintenance strategies around the world.

Active occupant´s behavior and building systems monitoring through ICT technologies has been basically explored. The integration of the latest ICT technologies with the presented strategies allows the smart instrumentation of the building to keep track of occupant´s behaviors in order to ensure quality on the indoor environment. Occupant´s feedback would need to be integrated in order to know the level of comfort and wellbeing.

REFERENCES:

Agha-Hossein M.M., El-Jouzi S., Elmualim A.A., Ellis J., Williams M., (2013) Post-Occupancy studies of an office environment: Energy performance and occupants' satisfaction. Building and Environment. Vol 69 pp. 121-130'

Ajzen I., (1991) The theory of planned behavior. Organizational Behavior and Human Decision Processes. 50(2) pp. 179-211

ASHRAE (2013). Standard 55: Thermal Environmental Conditions for Human Occupancy.

Baker N., and Steemers K., (2013) *Daylight Design of Buildings*. London, UK: Earthscan, ISBN: 978-1-873936-88-7

Bluyssen P. M. , Aries M., van Dommelen P., (2011) Comfort of workers in office buildings: The European HOPE project. Building and Environment 46(1) pp. 280-288.

Bluyssen P. M., Jansen S., van den Brink L. H., Kluizenaar Y., (2011) Assessment of wellbeing in an indoor office environment. Building and Environment 46(12), pp. 2632-2640

Bluyssen PM., (2009) *The Indoor Environment Handbook: how to make buildings healthy and comfortable*. London, UK: Earthscan, ISBN 9781844077878

Bordass W. and Leaman A. (1997) Future buildings and their services: strategic considerations for designers and clients. Building Research & Information. 25(4), 190–195

Brager G., Paliaga G., de Dear R. (2004) Operable Windows, Personal Control, and Occupant Comfort. ASHRAE Transactions. 110 (2) pp. 17-35

Brager G., Borgeson S., Soo Lee Y. (2007) Summary report: Control strategies for mixed-mode buildings. Centre for the built environment: University of California, Berkeley. Available online at: <http://www.cbe.berkeley.edu/research/pdf_files/SR_MixedModeControls2007.pdf>

Brown Z., Cole R.J. (2009) Influence of occupants' knowledge on comfort expectations and behaviour. Building Research & Information. 37(3) pp. 227-245

Brown Z., Dowlatabadi H., Cole R.J. (2009) Feedback and adaptive beahaviour in green buildings. Intelligent Buildings International. 1(4) pp. 296-315

Brundtland Comission (1987) *Our Common Future: Report of the 1987 World Commission on Environment and Development*. Oxford: Oxford University Press

Canada Green Building Council (2014) Canada Green Building Trends: Benefits driving the new and retrofit market. (Accessed 14/03/2015) Available online at: http://www.cagbc.org/cagbcdocs/resources/CaGBC%20McGraw%20Hill%20Cdn%20Market%20Study.pdf

Cavka B.T., Salehi M.M., Frisque A., Bushe K. (2014) IBPSA Conference paper. (Accessed 14/04/2008) Available online at: <http://www.ibpsa.org/proceedings/eSimPapers/2014/7A.6.pdf>

Clegg S., Kornberger M., Pitsis T., (2011) Managing Organization: An Introduction to Theory and Practice. 3rd Edition. SAGE Publications Ltd; London: UK.

Chappells H., Shove E., (2005) Debating the future of comfort: environmental sustainability, energy consumption and the indoor environment. Building Research & Information. 33(1) pp. 32-40

CIRS, (2015) Center for interactive research on sustainability. Manual of the building. [online] Available at: <http://www.cirs.ubc.ca/building/building-manual.> [Accessed 16 February 2015]

Cole R.J., Robinson J., Brown Z., O'shea M., (2008) Re-contextualizing the notion of comfort. Building Research & Information. 36(4) pp. 323-336

Cole R.J., Brown Z., (2009) Reconciling human and automated intelligence in the provision of occupant comfort. Intelligent Buildings International. 1(1) pp. 39-55

Cole R.J., (2012) Transitioning from green to regenerative design. Building Research & Information. 40(1) pp.39-53

Cohen N., Ilieva R.T., (2015) Transitioning the food system: A strategic practice management approach for cities. Environmental Innovation and Societal Transitions. Article in Press. Available online at: http://dx.doi.org/10.1016/j.eist.2015.01.003

Day J.K., Gunderson D.E., (2015) Understanding high performance buildings: The link between occupant knowledge of passive design systems, corresponding behaviors, occupant comfort and environmental satisfaction. Building and Environment. Vol. 84 pp. 114-124

De Dear R.J., and Brager G.S., (1998) Towards an adaptive model of thermal comfort and preference. ASHRAE Transactions, Vol. 104 (1), pp. 145-167.

Fanger, P. O. (1982) *Thermal Comfort*. Robert E. Krieger Publishing Company, Malabar, Florida.

Feige A., Wallbaum H., Jenser M., Windlinger L., (2013) Impact of sustainable office buildings on occupant's comfort and productivity. Journal of Corporate Real Estate. 15(1) pp. 7-34

Fisk W.J., (2000) Review of Health and Productivity Gains From Better IEQ. Proceedings of Healthy Buildings. Vol 4 pp 23-34

Fontoynont M., (2002) Perceived performance of daylight systems: lighting efficacy and agreeableness. Solar Energy. 73(2) pp. 83-94

Gulbinas R., Taylor J.E., (2014) Effects of real time feedback and organizational network dynamics on energy efficient behavior in commercial buildings. Energy and Buildings. Vol.84 pp. 493-500

Hargreaves T., (2011) Practice-ing behaviour change: Applying social practice theory to pro-environmental behaviour change. Journal of Consumer Culture. 11(1) pp. 79-99

Hong T, D'Oca S, Turner WJN, Taylor-Lange SC, (2015) An ontology to represent energy-related occupant behavior in buildings Part I: Introduction to the DNAs Framework. (Available online 25 February) Building and Environment (Manuscript Accepted) doi: 10.1016/j.buildenv.2015.02.019.

Jain R.K., Gulbinas R., Taylor J.E., Culligan P.J., (2013) Can social influence drive energy savings? Detecting the impact of social influence on the energy consumption behavior of networked users exposed to normative eco-feedback. Energy and Buildings. Vol 66 pp. 119-127

Klein,L.,Kwak,J.,Kavulya,G.,Jazizadeh,F.,Becerik-Gerber,B.,Varakantham,P.& Tambe,M. (2012) Coordinating occupant behavior for building energy and comfort management using multi-agent systems. Automation in Construction. Vol.22 pp.525-536

Leaman, A. and Bordass, B. (2001) Assessing building performance in use: the Probe occupant surveys and their implications. Building Research & Information. 29(2), 129–143.

Maroni M., Seifert B. and Lindvall T., (1995) Indoor Air Quality – A Comprehensive Reference Book, Amsterdam, Elsevier.

Miljömedicin MM Konsult AB (2015) Available at: http://www.inomhusklimatproblem.se/ [Accessed 17 June 2015]

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

Mousavi A., Vyatkin V., (2015) Energy Efficient Agent Function Block: A semantic agent approach to IEC 61499 function blocks in energy efficient building automation systems. Automation in Construction. Vol.54 pp.127-142

Natural Resources Canada's Office of Energy Efficiency (2012) Survey of commercial and institutional energy use - Buildings 2009. (Accessed 14/03/2015) Available online at:

NREL, (2013) Assessing and Reducing Plug and Process Loads in Office Buildings. Available online at: <http://www.nrel.gov/docs/fy13osti/54175.pdf.> Last accessed: 28/03/15

Orland B., Ram N., Lang D., Houser K., Kling N., Coccia M., (2014) Saving energy in office environment: A serious game intervention, Energy and Buildings. Vol. 74 pp. 43-52

Reckerman, J.E., (2014) CIRS Pre-occupancy evaluation: Inhabitant feedback processes and possibilities for a regenerative place. MSc. University of British Columbia.

Reckwitz, A. (2002) Toward a Theory of Social Practices: A development in culturalist theorizing. European Journal of Social Theory. Vol. 5 (2): 243-263

Robinson J., Cole R.J., (2014) Theoretical underpinnings of regenerative sustainability. Building Research & Information. 43(2) pp. 133-143

Roelofsen P., (2002) The impact of office environments on employee performance: The design of the workplace as a strategy for productivity enhancement. Journal of Facilities Management, Vol. 1(3) pp. 247-264

Roulet CA., Johner N., Foradini F., Bluyssen P., Cox C., Fernandes E. O., Müller B., Aizelewood C., (2006) Perceived health and comfort in relation to energy use and building characteristics. Building Research & Information. 34(5) pp. 467-474

Salehi M.M., Cavka B. T., Fedoruk L., Frisque A., Whitehead D., Bushe W.K., (2013) Improving the performance of a whole-building energy modeling tool by using post-occupancy measured data.

13th Conference of international building performance simulation association. Chambery, France.

Santamouris M., Dascalaki E., (2002) Passive retrofitting of office buildings to improve their energy performance and indoor environment: the OFFICE project. Building and Environment. Vol. 37(6) pp. 575–578

Seppänen O., Fisk W.J., (2002) Association of ventilation system type with SBS symptoms in office workers. Indoor Air. Vol. 12 pp. 98-112

Shove E., (2010) Beyond the ABC: climate change policy and theories of social change. Environment and Planning. Vol. 42 pp. 1273-1285

Shove E., Pantzar M., Watson M., (2012) The dynamics of social practice: Everyday life and how it changes. London, UK: SAGE Publications. ISBN: 978-0-85702-042-0

Spotswood F., Chatterton T., Tapp A., Williams D., (2015) Analyzing cycling as a social practice: An empirical grounding for behavior change. Transportation Research Part F: Traffic psychology and Behaviour. Vol. 29 pp. 22-33

Swedish Green Building Council (SGBC), (2015) Miljöbyggnad - miljöcertifiering utifrån svenska förhållanden, Available at: <https://www.sgbc.se/var-verksamhet/miljoebyggnad> [Accessed 17 June 2015]

Toftum J., Andersen R.V., Jensen K.L., (2009) Occupant performance and building energy consumption with different philosophies of determining acceptable thermal conditions. Building and Environment. 44(10) pp. 2009-2016

UNEP, (2009) *Buildings and Climate Change: Summary for Decision Makers* Paris: UNEP DTIE Sustainable Consumption & Production Branch. Available online at: <https://www.unep.org/sbci/pdfs/SBCI-BCCSummary.pdf> Access on: 06/03/2015

US Green Building Council (2015) What is green building? (Accessed 06/03/2015) Available online at: <http://www.usgbc.org/articles/what-green-building>

Van Hoof J., (2008) Forty years of Fanger's model of thermal comfort: comfort for all? Indoor Air. Vol. 18 PP. 182-201

Vimalanathan K., Babu R., (2014) The effect of indoor office environment on the work performance, health and well-being of office workers. Journal of Environmental Health Science & Engineering 12 (113). Online at: http://www.ijehse.com/content/12/1/113

Velikov K., Bartram L., (2013) Empowering the inhabitant: Communication technologies, responsive interfaces, and living in sustainable buildings. In: Henn R., Hoffman A., 2013. *Constructing Green: The social structures of sustainability*. Boston: MIT Press.

World Green Building Council. (2014) Health, Wellbeing and Productivity in Offices. London, UK. (Accessed on 26/02/2015). Available online at: <http://www.ukgbc.org/resources/publication/health-wellbeing-and-productivity-offices-next-chapter-green-building>

Yang,R.,& Wang,L. (2014) Development of multi-agent system for building energy and comfort management based on occupant behaviours. Energy and Buildings. Vol.56 pp. 1-7

Yin, R. (2014). Case study research: Design and methods (5nd ed.). California: Sage Publications, Inc.

THE CHALLENGE LAB

Anand S., Sen A., (2000) Human Development and Economic Sustainability. World Development. Vol. 28 (12) pp. 2029-2049

Atkisson A., Hatcher R.L., (2001) The compass index of sustainability: prototype for a comprehensive sustainability information system. Journal of Environmental Assessment Policy and Management. 3(4) pp. 509-532

Daly, H.E., (1973) *Toward a Steady-State Economy*. San Francisco: W.H. Freeman and Company .

Dreborg, K. H. (1996). Essence of backcasting. Futures, 28(9), pp.813-828.

Geels, F. W. (2005). Processes and patterns in transitions and system innovations: refining the co-evolutionary multilevel perspective. Technological forecasting and social change, 72(6), pp. 681-696.

Geels, F.W. (2012). A socio-technical analysis of low-carbon transitions: Introducing the multi-level perspective into transport studies. Journal of Transport Geography. Vol. 24 pp. 471-482

Haraldsson, H. V. (2004). Introduction to system thinking and causal loop diagrams. Department of Chemical Engineering, Lund University.

Holmberg J., Robèrt, K-H. and Eriksson, K-E. (1996) Socio-ecological principles for sustainability. In: Costanza R., Olman S., and Martinez-Alier J., Getting Down to Earth – Practical Applications of Ecological Economics, International Society of Ecological Economics. Washington D.C.: Island Press.

Holmberg, J. (1998) Backcasting — a natural step in operationalising sustainable development. The Journal of Corporate Environmental Strategy and Practice autumn 199 (23) pp. 30-51

Holmberg, J. and Robèrt, K-H. (2000). Backcasting from non-overlapping sustainability principles – a framework for strategic planning. International Journal of Sustainable Development and World Ecology 7:291-308.

Holmberg, J. (2014). Transformative learning and leadership for a sustainable future: Challenge Lab at Chalmers University of Technology. In:Intergenerational learning and transformative leadership for sustainable futures, 1st ed.pp.91--102

Isaacs, W. N. (1999). Dialogic Leadership. The Systems Thinker. Vol. 10(1) pp.1-5

Max-Neef M.A., (1991) *Human Scale Development.* New York: The Apex Press

McCabe, D. (2010). Strategy-as-Power: Ambiguity, Contradiction and the Exercise of Power in a UK Building Society. Journal of Organization, Vol. 17 No.2, pp. 151-175.

Robèrt, K.-H., Daly, H., Hawken, P., and J. Holmberg, (1997) A Compass for Sustainable Development. International Journal for Sustainable Development. Vol. 4 pp. 79-92.

Robinson J.B., (1990) Futures under glass: A recipe for people who hate to predict. Futures. Vol. 22(8) pp. 820-842

Rockström J., et al. (2009) Planetary Boundaries: exploring the safe operating space for humanity. Ecology and Society. Vol. 14(2) Art. 32 Available Online at: http://www.ecologyandsociety.org/vol14/iss2/art32/

Ryan,R. M., & Deci, E. L. (2000). Self---determination theory and the facilitation of intrinsic motivation, social development, and well---being. American psychologist, 55(1), 68.

Sandow, D., & Allen, A. M. (2005). The nature of social collaboration: how work really gets done. Reflections: The SoL Journal, 6(2-3), 2-3.

Sen A., (1999) *Development as Freedom*. 1st ed. New York: Oxford University Press.

Simmie J., Martin R., (2010) The economic resilience of regions: towards and evolutionary approach. Cambridge Journal of Regions, Economy and Society. Vol. 3 pp. 27-43

UN Rio + 20 (2012) The Future We Want. Conference in Rio de Janeiro. Available online: http://www.uncsd2012.org/content/documents/727The%20Future%20We%20Want%2019%20June%201230pm.pdf

Appendix A: Sustainability Criteria

The Sustainability criteria was divided into four dimensions; Nature, Economy, Society and Wellbeing.

Nature:

The criteria reached are based on the socio-ecological principles presented by Holmberg et al. (1996). The urgency on the change towards a sustainable society is further reaffirmed by Rockström et al. (2009), where they reflect how mankind already have crossed three of the nine planetary boundaries established. The results of the review of the literature and the discussions conducted in the group are the next nature criteria:

- Not to increase the concentration of substances from the lithosphere in the ecosphere.
- Not to increase human made substances concentration in the ecosphere.
- Not to deplete, overharvest neither further manipulate natural resources such as water, land use, biodiversity.

Economy:

The criteria regarding sustainable economy is based on the principle of human development and freedom by Sen (1999) and the system required to support them (Anand & Sen 2000). It argues the issues of the opulence and consumption based system and the lackluster that the measurements such as GDP impose for a sustainable development. Furthermore, Simmie and Martin (2009) argue the issues of a global economic system and resilience issues that compromises other aspects that should not be affected by economic cycles in order to achieve sustainable and resilient regional economies. The resulting economy criteria from the literature and dialogues is the next:

- The economic system enables us to meet the other criteria efficiently and effectively. The economic system should be influenced by the other dimensions (society, well-being, nature) and not the other way around.
- The economic system is resilient in a way that it functions as a buffer against destructive disturbances, such as environmental catastrophes or economic mismanagement.
- Enable further use of resources and avoid dissipative use of materials.
- The economic system has an inherent mechanism of maintaining and serving societal infrastructure and institutions that permits human well-being to be met over time.

Society:

The criteria for sustainability regarding society are based on the outcome document from the UN RIO+20 conference "The Future We Want" (2012). They include a society with trusted and reliable institutions based on transparency, trust and accountability. Furthermore, society is seen as way to achieve the well-being and development of human beings. The results from the discussion regarding society criteria are presented next:

- Societal institutions are built on transparency, accountability, and mutual trust. They enable the well-being of the individuals in society.

- The societal system is an instrument for individuals to live together within the other criteria.

Well-being criteria

The criteria regarding well-being are based on the work developed by Max-Neef (1991), where needs for humans to develop are described and mentioned. However, the needs are also seen from the UN perspective in "The Future We Want" document (2012), where a classification between the most basic needs for survivability and the needs to develop can be seen among the sustainable development goals. The resulting well-being criteria after discussion among Challenge Lab participants is presented next:

- Everyone has basic needs fulfilled such as food, water, health, energy, shelter, and safety.

- Human life includes affection, understanding, morality, participation, leisure, *empowerment*, creation, identity, and knowledge.

- Each person has an equal right to the most extensive basic freedom compatible with a similar freedom for others. This includes freedom of opinion and assembly, expression, conscience, and choice - without deliberately harming others.

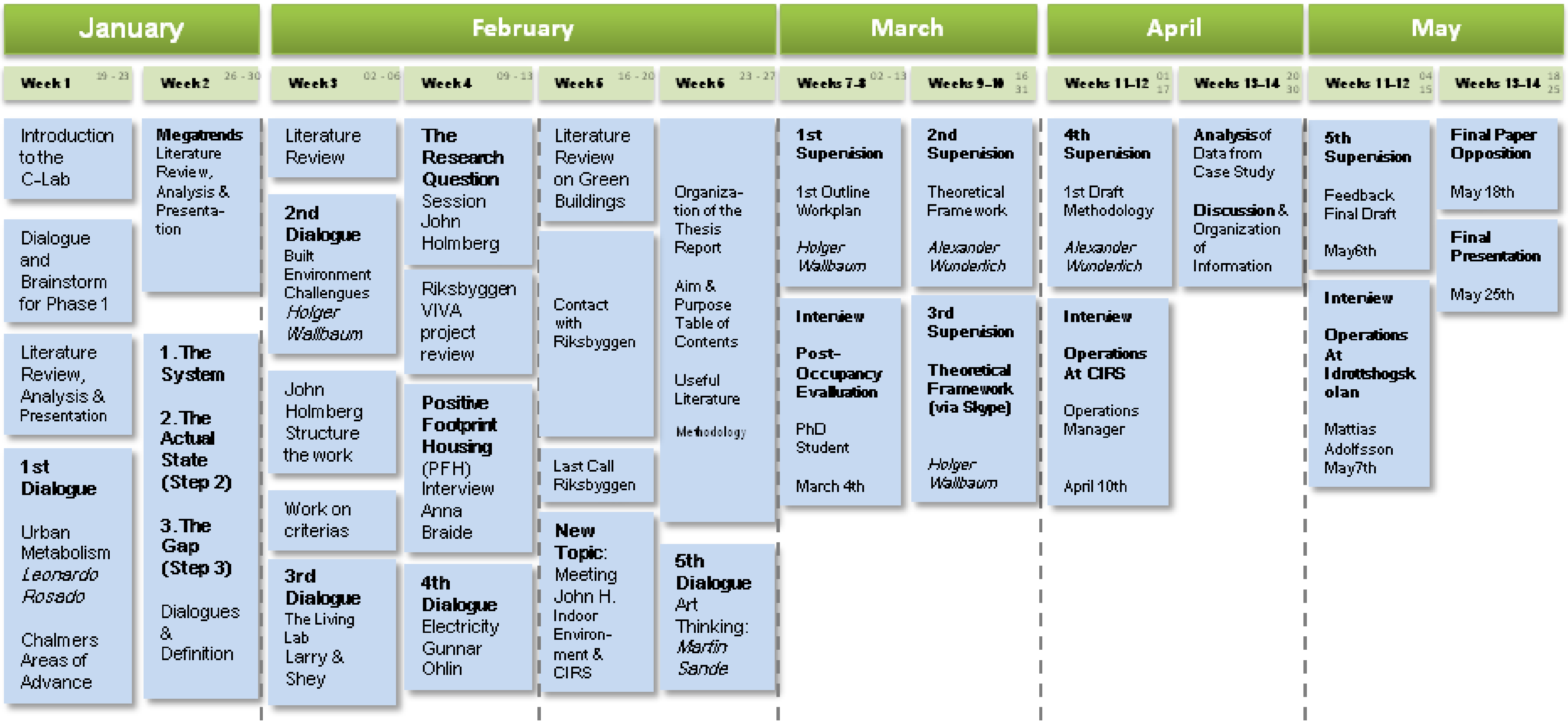
- Social and economic inequalities are not justified unless they are to the greatest benefit to the least-advantaged members of society.

Vision:

The previously presented criteria and the discussions around them have served to establish a common vision for the whole Challenge Lab group. The resulting vision is presented next:

"A sustainable future where we (~10 billion people) are able to meet our own needs within the planetary boundaries without compromising the ability of our future generations to meet theirs"

Appendix B: Complete Timeline of the Challenge Lab process



Appendix C: Physical space The Challenge Lab

Figure 25 Dialogue with stakeholder. Typical setting in the C-Lab

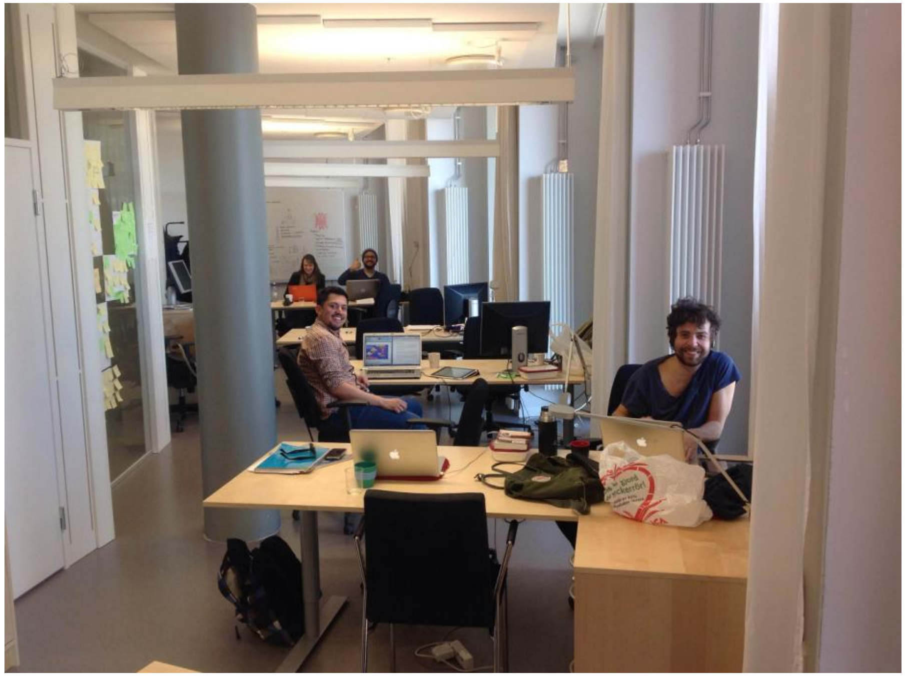


Figure 26 Office space provided by the C-Lab

Appendix D: Goals and Strategies from CIRS

Focus Area	Category	Goals	Strategies	Implementation
OCCUPANT HEALTH	17 - COMFORT & CONTROL	Provide local control over comfort conditions to adapt to individual preferences.	Provide individual controls for temperature, lightning, and air flow.	Y
			Examine acoustic qualities of designed workspaces and provide for acoustic separation for privacy when needed.	Y
			Install ergonomically sound office furniture.	Y
			Inhabitants receive feedback from building's smart instrumentation to create optimal indoor environments.	Y
			The building's smart instrumentation learns from its inhabitants through monitoring to deliver comfort where appropriate.	Future project through building BMS interface
			Inhabitants provide evaluations to operations management when systems run poorly.	Y
			Operations Management provides feedback to inhabitant groups as to how their areas are performing in terms of energy, water, and material use.	Y
BUILDING AND MAINTENANCE	18 - SEAMLESS DESIGN AND OPERATION	The building will seamlessly integrate the design and ongoing operations.	Consult the developers' operations staff early on in the design phase to ensure a minimal level of understands of the systems and technologies proposed.	Y
			Create training and aware program for staff to ensure the building is operated and maintained at an optimal level.	Y
			Conduct regular commissioning of all mechanical and electrical systems to ensure systems are operating in accordance with the design intent.	Y
			Employ systems for ongoing measurement and verification of building and systems performance.	Y
			Conduct post-occupancy evaluations and annual reports on building performance.	Y
			Conduct pre and post-tenancy evaluations to gather feedback from tenants.	Y

Appendix E: Continually Applied Strategies

	Strategies at CIRS	Impact on wellbeing	Energy Consumption Relevance
CONTINUALLY APPLIED STRATEGIES	**S1**	**Potential Benefits:**	**Potential Benefits:**
	Provide individual controls for the occupants: - Temperature - Lighting - Ventilation and airflow	o Higher tolerance to discomfort when operable windows are available (de Dear and Brager, 1998) (Cole et al., 2008) and increase on the IAQ (Bluyssen, 2009) o Positive health and comfort effects providing access to daylight (Bluyssen, 2009) o Customization and flexibility to adapt needs result in higher PPD (Hong et al., 2015)	o Natural ventilation provides energy savings from mechanical systems (Brager et al., 2007). o The energy saving potential due to reduction on cooling demand is great during summer time (Toftum et al., 2009)
		Potential Risks:	**Potential Risks:**
		o Wrong use of natural ventilation (operable windows) can result in potential health risks (Bluyssen, 2009) o Complex systems can result in lack of "know how" to use them. (Colemann, 2015)	o Satisficing behavior (Cole and Brown, 2009) o Wrong use of controls can result in higher energy consumption. (Bordass and Leamann, 1997)
	S2	**Potential Benefits:**	**Potential Benefits:**
	Inhabitants receive feedback from building's smart instrumentation to create optimal IEQ.	o Responsive feedback regarding use of systems avoids possible unsatisfactory IEQ creation. o Influence on expectations and perceptions regarding the IEQ (Cole et al., 2008; de Dear and Brager, 1998)	o Shape behaviors/practices with responsive feedback results in potential energy savings from optimal use. (Hong et al., 2015; Shove et al., 2010)
		Potential Risks:	**Potential Risks:**
		o Complex feedback information can result on lack of interest or lack (Gulbinas and Taylor, 2014) of "know-how" (Colemann, 2015) can result in ignoring the given feedback.	o Complex feedback information can result on lack of interest or lack (Gulbinas and Taylor, 2014) of "know-how" (Colemann, 2015) can result in ignoring the given feedback.

Appendix E: Continually Applied Strategies (continuation)

	Strategies at CIRS	Impact on wellbeing	Energy Consumption Relevance
CONTINUALLY APPLIED STRATEGIES	**S3**	**Potential Benefits:**	**Potential Benefits:**
	Inhabitants provide evaluations to operations management when systems run poorly.	o Responsive feedback regarding use of systems avoids possible unsatisfactory IEQ creation. o Influence on expectations and perceptions regarding the IEQ (Cole et al., 2008; de Dear and Brager, 1998) o Responsive feedback regarding use of systems avoids possible unsatisfactory IEQ creation. o Influence on expectations and perceptions regarding the IEQ (Cole et al., 2008; de Dear and Brager, 1998)	o Quick feedback from users can results in the continuous improvement and optimization of building systems. Potential energy efficiency improvements. (Cayuela, 2015)
		Potential Risks:	
		o No complaints and suffer of discomfort, if the corporate culture does not encourage (Hong et al. 2015). Too late complaints crisis of discomfort (Cole et al., 2008)	
	S4	**Potential Benefits:**	**Potential Benefits:**
	Operations Management provides feedback to inhabitant groups as to how their areas are performing in terms of energy, water, and material use.	o Redefinition of comfort, change expectations(Cole, 2008; Chappels and Shove, 2005)	o Responsive and immediate feedback can help to understand the impact caused by actions. Shape elements of practice (Shove et al., 2012) or shape energy behaviors through increase awareness (Shove, 2010)
		Potential Risks:	**Potential Risks:**
		o Social pressure and social discomfort (Jain et al., 2013)	o Complex interface or data presentation can result in lack of interest and effect (Gulbinas and Taylor, 2014; Orland et al., 2014)

Appendix F: Periodically Applied Strategies

		Strategies at CIRS	Impact on wellbeing	Energetic Relevance
PERIODICALLY APPLIED STRATEGIES (PAS)	A	Create training and aware programs for staff.	Physiological aspects of comfort are shaped. Expectations and competence “know how”. (Cole and Brown, 2009)	Provide occupants with “know-how” and allow them to use of given systems in an optimal way. Potential energy savings. (Cole and Brown, 2009)
	B	Conduct pre and post-occupancy evaluations to the new inhabitants.	Assess the previous experiences and contrast them with the evaluation after moving. Potential areas of improvement and biggest satisfaction enhancers. (Cole and Brown, 2009)	
	C	Conduct post-occupancy evaluations every 5 years on inhabitants of the building.	Assess the perception of well being of the occupants. Understand the sources of discomfort and dissatisfaction. (Bluyssen et al., 2011b; Colemann, 2015)	
	D	Conduct regular commissioning of all mechanical and electrical systems.	Check and control the proper functioning of building systems. Potential to recalibrate and optimize them to improve the provision of IEQ. (Cayuela, 2015)	Check and control the proper functioning of building systems. Potential to recalibrate and optimize them improving their energy performance. (Cayuela, 2015)
	E	Employ systems for ongoing measurement on building performance. Data from annual reports and use it optimize overall building performance.	Possibility to access to real data. Allow redesigning and learning lessons for future cases. Gain information to continually improve the BS. (Cayuela, 2015)	

Appendix G: Transitional Practices at Higab

Idrottshogskolan	Current Practices	Transition Practice	Goal Practice
S1 Provide individual controls for the occupants.	Provide basic options to operate some building system, i.e. Lightning - Operable Window - Heating	Run a testing period on a key building. Promote among users the interactions with the IE and evaluate their wellbeing, energy related behaviors and energy consumption.	High level of control (physical and electronically) to every user in order to operate the IE
S2 Inhabitants receive feedback from building's smart instrumentation to create optimal IEQ.	Users receive not feedback at all.	Provide users periodically with information to improve their IEQ, i.e. monitors displaying data at the lobby or gathering point.	Provide feedback at the same time the user interacts with the building systems, i.e. windows with 3 LED colored coding.
S3 Inhabitants provide evaluations to operations management when systems run poorly.	There is a 24/7 communication channel available to report when systems run poorly. Keep the system as it is.		
S4 Operations Management provides feedback to inhabitant groups as to how their areas are performing.	No feedback provided from Operations Management.	Initiate information plans to create awareness among final users regarding the use of building systems to save energy, i.e. newsletters by email.	Feedback is provided continuously from Operation Management individually and in groups.
A Create training and aware programs for staff.	Regular meetings regarding the use of building systems and energy goals among the professionals involved in the building´s development	Inform final users during the early phases of occupancy of new buildings and/or renovation regarding energy goals and how building systems work	Run Workshops, interviews and meetings during the early phases of the building including the final users to provide them with knowledge of energy goals and how building systems work
B Conduct pre and post-occupancy evaluations to the new inhabitants.	No evaluation of wellbeing at any moment for the new arriving tenants.	Run a pre and post-occupancy evaluation on a key building for the organization to explore the levels of wellbeing on the IE to further plan improvements generally.	Collaboration with experts for gathering data regarding wellbeing assessment and expectations of building systems before and after occupancy in the building
C Conduct post-occupancy evaluations every 5 years on inhabitants of the building.	Conduct an evaluation after a series of complaints regarding the same problem to identify the cause of it.	Set criteria on the organization´s policies to evaluate and identify whenever is necessary to run a post-occupancy evaluation on a new/renovated building.	Plan post-occupancy evaluations according to operational strategies
D Conduct regular commissioning of all mechanical and electrical systems.	No commissioning before a problem is registered	Evaluate the usefulness of commissioning of systems for the organization. Test with the latest ICT technologies and BMS to monitor and gather information more accurately.	Regular commissioning and designing of optimization plans are performed
E Employ systems for ongoing measurement on building performance. Data from annual reports is used it to optimize overall performance.	Building systems are measuring and data is presented on annual reports	Organize the measured data from building systems to set goals regarding energy consumption and wellbeing of the IE.	Building Systems are measuring, data is available at all time and improvement plans are launched every year