Ensuring good indoor environment in energy efficient office building

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ABSTRACT

New elements for business process of managing indoor climate conditions in changing circumstances over the lifetime of building has been developed. There is more focus in target setting and a new business model of verifying indoor conditions was introduced. The case study presents a chilled beam solution and certain process models that help to improve the adaptability of system and therefore flexibility of the building as well as the indoor conditions in the room through the lifetime.

1 BACKGROUND

In a sustainable building environmental, human health and wellbeing as well as lifetime cost issues need to be considered. Many environmental ratings like LEED in the USA or BREEAM in UK take into account various aspects in building itself, management of building, and also the health and wellbeing of users. As buildings are built for people, the human issues should always have some priority when selecting from various environmental options during design and use of buildings.

Lifetime costs are important to developers and owners of buildings and therefore both potential cost savings and increased value of building are of great interest.

Several hundreds of thousands of people die too early due to environment in Europe each year. Increased hospital admissions, extra medication and millions of lost working days are not only a financial issue but above all they influence the quality of our everyday life. [1] People in modern societies spend most of their time (90%) in indoor spaces such as at home, work, school and in vehicles. This is why the building envelope still have the same role than thousands of years ago, to protect people from outdoor environment.

There are many effects of inappropriate indoor environment quality, like increased need to keep breaks during work, decreased concentration or fatigue. In extreme cases problems can lead to absence from work due to permanent or temporary health effects like headache, eye, skin, throat or nose irritation, thermal stress, allergy or asthma. [2]

Tobacco smoking is the biggest indoor air quality problem. This is why smoking is already prohibited in indoor spaces in many countries. Solvents, paints and other building materials as well as aerosol sprays and dry cleaning may release volatile organic compounds (VOC) into air. Moisture damages can create serious indoor air quality problems. Growth of mould starts in wet structures. Regular maintenance of building improves the indoor environment, ensures well operating technical systems and prevents refurbishment debt of building but above all it prevents the wellbeing debt of users.

Occupants are an important source of information about indoor environment quality. Even though physical measures describe (numerically accurately) parts of the indoor environment only the perceived quality determines the functionality of the space to workers. People create the outcome of the work and therefore indoor environment's only purpose is to support the human performance and wellbeing. It is essential to measure the perception of people towards different indoor environment factors and in different parts of a building in order to find and correct the problems that affect human performance most. Even when the average satisfaction shows high scores there may exist major problems in some parts of the building. Occupant perception map is a beneficial tool to systematically solve the indoor environment related problems. [3]

Indoor environment can create dissatisfaction and health problems for users due to various reasons. Often the reason is the performance of technical systems. In many cases technical problems are local and that is why it is difficult to find and locate them. Occupants complain about too hot or too cold temperatures during summer, too hot or too cold temperatures during winter, draughts from ventilation system, stuffy or stale indoor air or lack of sound privacy in open plan offices. [3]

In addition to investment, energy and maintenance costs there are some other costs elements to take into account when designing sustainable buildings. Value of the real estate is based on the rental and sales revenue it generates. Rental revenue consists in utilization rate, cost of property and amount of rent. All these factors are greatly affected by quality of indoor environment as well as the features and condition of technical systems.

Customer satisfaction and loyalty improve when indoor environment is in good level. Satisfied clients stay longer in the building and makes longer contracts. Vacancy rate will become lower. Level of rent is much dependent on market situation and features of real estate relative to occupants' expectations. However advanced client is willing to pay back part of improved productivity as higher rent.

Good indoor environment improves productivity quicker than changes in working habits or skills, especially if indoor environment has not been in focus before. In a typical company operating in office environment 90 % of total company costs consist of employees' salaries. The rest of the costs include workplace related investment and running costs. International research has proven a development of 2-10 % in workers' productivity, when indoor environment has been improved. A minor 1 % (5 min/day) increase in office work can off-set the annual cost of ventilating the building. The full costs of installation and running the building can be off-set by productivity gains of just under 10%. A reduction of indoor air temperatures above 22 ^{O}C by 1 ^{O}C can roughly increase the performance of office work by 1%. Doubling the outdoor air supply rate can reduce sick leave prevalence by 10 %, and increase office work by 1,5%. [4]

In addition to the indoor environment, the functionality of the workspace significantly affects the productivity of employees. Often a compromise must be made among the needs of the employee, team and organisation when arranging workspaces. Addressing the interaction and privacy needs of employees, both of which are important considerations in organisations, is particularly challenging. In general, it can be stated that, from the perspective of dispersing silent information (views, experiences, intuitions), fully autonomous workspaces do not support the business models of most companies. On the other hand, reducing the autonomy afforded by individual workspaces reduces acoustic privacy, which disturbs concentration.

Organisational changes in most companies are continuous and require flexible changes in work methods and workspaces. The traditional one person office areas, or cells, and open offices, or hives, seen in traditional offices are today changing into spaces that are more suited to team work, referred to as dens or clubs (Table 1) [5]. In addition to this, information technology contributes to independence of time and location, transforming offices more into meeting places for sharing information. The office space must be utilised efficiently, and therefore a dedicated workstation is no longer deemed necessary for a worker who spends only a few hours a day at the office. Working at several workstations and at customer sites is becoming more common.

Table 1. Adapting space types and business processes in office buildings.

Space	*Interaction*	*Autonomy*	*Operation*	*Example*
Hive	low	low	customer service	call centre
Cell	low	high	support tasks	financial administration
Den	high	low	teamwork	media
Club	high	high	expert work	consultancy

Layout changes in workplaces are a rule, not an exception. Due to management reorganization, changes in business models, and technological innovations, companies may already change their workplace interior layout once a year. Churn cost is often one of the highest operating costs in modern offices being €330 to €2000 per moved person a year. [6] Building services are the major cost generator and a slowing, or even preventing factor in layout changes.

From environmental issues the building's energy efficiency and use of renewable energy sources are one of the most important, however there are many other issues to be considered, like use of land, location of building (e.g. near the public transportation), reduction of pollutions during construction and life time of building, and use of materials.

Focus on energy saving and use of renewable energy sources are identified as a major source to improve environmental focus and reduce carbon emissions in construction industry. Buildings are the largest end-user of energy in the EU with a 40 % share of total consumption. The building sector holds the largest energy saving potential, with a 22% reduction possible by 2010. The energy efficiency of buildings is greatly affected by air conditioning and ventilation systems.

The energy consumption of building depends on the design of building envelope, selected HVAC-systems and the maintenance of them.

The quality of building envelope and windows pays an important role, when building is designed. In Scandinavian climate conditions, the typical heating requirement is about 25 W/floor-m^2 with outdoor air temperature of –32 ^{O}C. In Southern Europe with much milder weather conditions it is typical to design buildings, which requires heating closer to 100 W/floor-m^2.

Solar shading is another important issue, where architects can greatly affect the quality of building and it's energy efficiency. With good solar shading the cooling requirement can be reduced close to internal load level e.g. 40 – 80 W/floor-m^2. This also expands the variety of HVAC-systems, which can be used in building. Low temperature heating and high temperature cooling systems (like slab cooling, chilled ceiling and chilled beams) can be used in such a buildings. Also full-air systems, like displacement ventilation, become more feasible.

Lower cooling and heating requirements allows also the better utilization of renewable energy sources like ground water heat pumps, outdoor air (free cooling), solar panels, bio energy, wind, etc. In some areas of Europe like in London, there is a local requirement, which states that minimum 15% of energy used in building must be renewable. In many cases this target is very challenging, but by reducing the total energy requirement, it is also easier and more cost effective to fulfil this renewable energy target.

2 PROCESS TO MANAGE INDOOR ENVIRONMENT QUALITY OVER LIFETIME

Regardless of importance, building performance assessment is currently very fragmented. There has been no continuity to the process of building performance assessment through the building lifecycle. Especially, the very early phase (client briefing) as well as commissioning and operation phases have been recognized the biggest potential to enhance indoor environment quality (IEQ) in an energy efficient manner.

The objective of this value adding process is to make it possible to set and evaluate performance metrics through the whole building process and improve IEQ during the lifetime of building (Fig. 1). The target contains both human comfort and economical considerations. In addition, new business models and services are developed which makes possible to verify the operation of the selected building services. Thus through decision-making process, indoor environmental quality and space related costs are possible continuously evaluate and compare with set performance metrics.

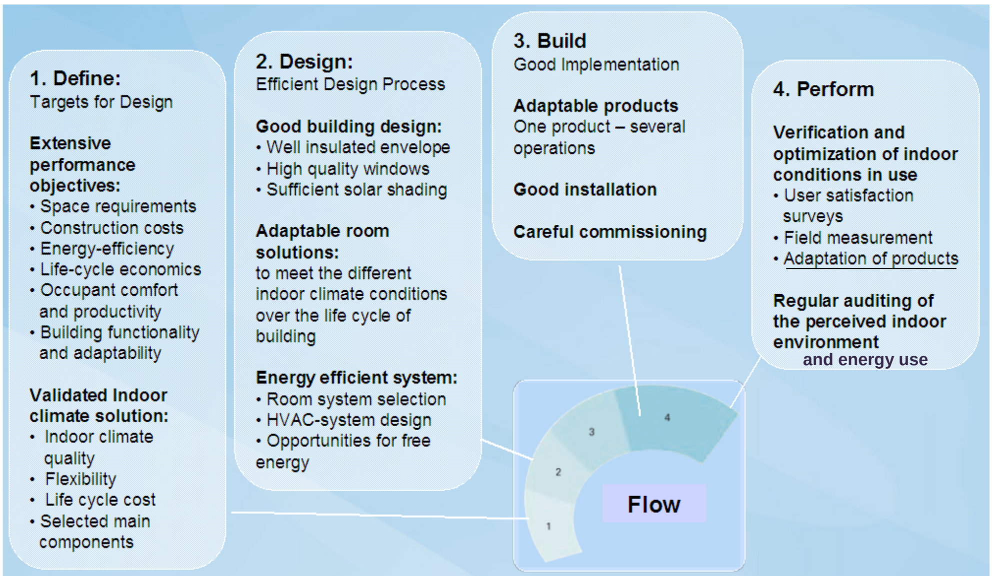

Figure 1. Total lifetime management process of indoor climate quality was developed. There is more focus in target setting and a new business model of verifying indoor conditions was introduced.

2.1 Target setting based on human comfort and performance of system

This process starts with a consideration of various performance objectives of interest to building stakeholders. While primary attention is generally given to space requirements and construction costs, a wide spectrum of objectives need to be considered at this stage, including energy-efficiency, life-cycle economics, occupant comfort and productivity, and building functionality and adaptability. The intent of client briefing phase is to define the desired performance for facility and systems so that design and operation decisions can be made to achieve this performance.

It is recommended to select and validate the room system (and if possible the solution supplier as well) before the actual design starts. This way the design can be based on the optimum performance of each selected component, and the problems of generic design can be avoided.

When system and product is used within the normal operation range, special demonstration of operation is not necessarily needed. But if the operational parameters of system or a selected product are close to or beyond the recommended limits, it is recommended to demonstrate the operation in the specified design and possible future operations conditions. There are two options to demonstrate the operation: full-scale mock-up tests and Computational Fluid Dynamics (CFD) simulations. CFD-simulation equations describing physical phenomena are solved numerically. Both options are capable of demonstrating the velocities and temperatures in the space in steady-state conditions, as long as the input parameters are correct. If there is no real boundary data of terminal units available (given by a manufacturer), the mock-up then gives more reliable information.

2.2 Designing and building comfort and energy efficiency for various operation points

In design phase it is important to pay attention not only to system and product operation in single operating points (e.g. cellular office in maximum cooling and maximum heating), but also analyse the operation in various usage situations (e.g. intermediate seasons, open plan office and meeting room operation).

Sustainable solutions matches each space with a suitable system e.g. full-air systems to areas where main heat loads are from people (e.g. auditorium) where as in office environment it is more economical to transfer heat using water as media. Target is to design solutions, which can be adjusted according the use of space to meet the different indoor climate conditions over the life cycle of building and use products, which are adaptable to various conditions and designed to create complete solutions.

Good indoor climate can be achieved with less energy by selecting such a room systems which allows optimisation of energy efficient cooling and heating.

During construction process the main focus is in good installation and especially in commissioning.

2.3 Lifetime management of good indoor climate

Indoor environment is actually not created, until people move in, decide how to use spaces and furnish them. Only then the room systems should be adjusted to their final operation point. Final result can be verified based on the human experience of indoor climate. This should be done 6 -12 months after the spaces have taken into use, however before the guarantee period is over.

Although the quality of indoor environment is in high level after construction project is finished, often the IEQ starts to decrease gradually due to low maintenance of indoor environment and technical systems. There are also many changes during the lifetime both in size and usage of spaces, but no alteration in technical systems are made. These increase the refurbishment debt of building, but also the wellbeing debt of users in the building (Fig. 2).

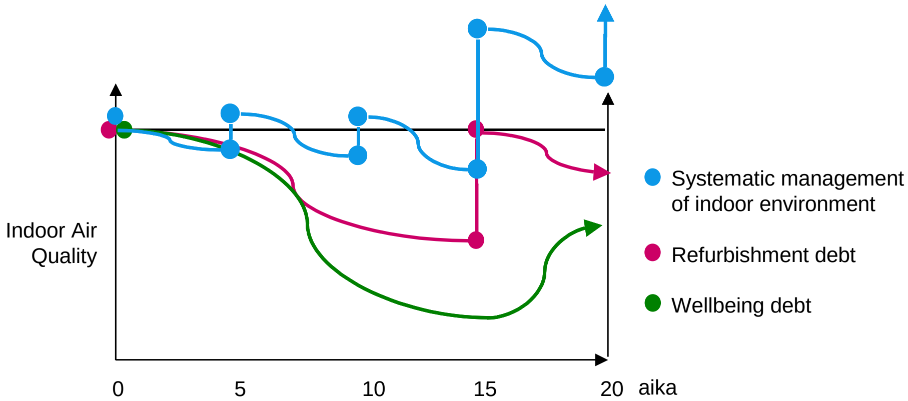

Figure 2. By managing and developing indoor environment systematically, indoor environment quality can be kept at higher level continuously, and therefore both the refurbishment and the wellbeing debt can be reduced.

A systematic method for assessing and improving indoor environment quality (IEQ) in existing and occupied office buildings is also important. The method begins with occupant satisfaction survey that is directed to everyone working in a building and the structure of the questions follows a pattern that offer valuable information of the technical reasons leading to dissatisfaction. Questions focus on the human experience of indoor environment, not leading respondent directly to problems or symptoms. By using occupant satisfaction survey all comments, also the silent, can be collected and taken into account when making decisions of improvements. The questions assess satisfaction with the following IEQ areas: office layout, office furnishings, thermal comfort, indoor air quality, lighting, acoustics, safety and security, and building cleanliness and maintenance.

A technical analysis requiring multidisciplinary knowledge is conducted in building areas where more than 30 % of respondents are dissatisfied. Systems creating and maintaining indoor environments consist of many components that are usually provided by different companies. Cross-scientific team of people representing various aspects of technical services conducts the technical analysis in the building. Improvement actions are determined based on the results of the survey and technical analysis. Sometimes technical problems are more complicated to solve, especially if there are any doubts of local thermal conditions e.g. drought. In those cases full-scale mock-up can be built into laboratory conditions to find a technical solution.

3 CHILLED BEAM SOLUTION TO PROVIDE LIFETIME COMFORT AND COST EFFICIENCY

In order to be able to manage indoor environment efficiently through the lifetime of building, it also requires changes in room unit design. This case study presents new features in chilled beam technology to enable both easy changes in operation point and also good indoor conditions in varying circumstances.

When a chilled beam system is designed and chilled beams are selected, there are several aspects to be considered. The main target is to achieve excellent indoor climate conditions in spaces for the whole life cycle of the building, even if there is a continuous need to make changes in the space usage or layout.

Designing and selecting chilled beams in traditional way allows indoor climate target to be met in the design conditions, but future changes in use or layout may influence the performance of products. This strategy results in lowest possible investment cost, but changes during operation are costly and often requires a project to select new operation points for chilled beams.

In practice this means that each chilled beam is optimized to one operation point by selecting nozzle size, length and active length individually room by room. This means various kinds of chilled beams in each project making selection and installation work labour consuming. After each change either during the design and installation process or after building is taken into use, this same selection work needs to be done.

If air flow rates need to be adjusted in the space, the changes requires hours of work first typically by plugging the nozzles or releasing the nozzles and after that balancing the ductwork. In the case of relocated wall the changes may even be bigger and the whole unit need to be either changed or relocated as well. Traditional chilled beams cannot be easily used with variable air flow rates due to too low chamber pressure with small air flow rates or respectively too high chamber pressure with maximum air flow.

3.1 Technical solution: adaptable chilled beams

Adaptability of active chilled beams ensures not only effective design and installation process but also easy changes over lifetime [7]. In adaptable design chilled beams are selected so that nozzle size, length and effective length are the same for all beams. Both the throw pattern and air flow rate is adjusted in building site during commissioning using two new patented technologies: Velocity Control and Air Quality control unit, which are integrated into an active chilled beam [8].

Velocity control (HVC) is used for adjusting room air velocity conditions and throw pattern of chilled beam either when room layout changes (e.g., in cases where the partition wall is located near the chilled beam) or when local, individual velocity conditions need to be altered. HVC is a manual induction rate adjustment with three different positions. It is recommended to design the chilled beam in the "normal" position in order to allow both throttle and full functions later on in the building's life cycle (Fig. 3).

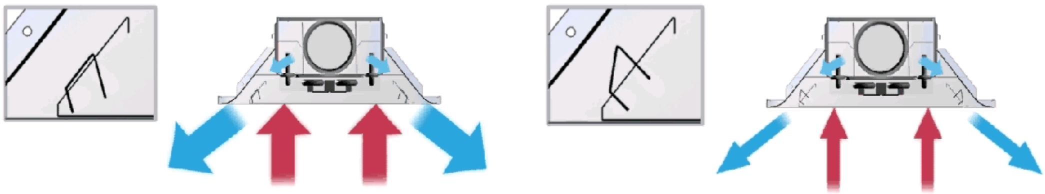

Figure 3. Velocity control is located into a supply air slot of an active chilled beam, where it adjusts both the induction rate of a chilled beam and a slot opening. This guarantees a good throw pattern also with reduced amount of induced air.

The air quality (HAQ) unit (Fig. 4) position and selection of chilled beam nozzle size are used for adjusting the airflow rate in the space. Airflow balancing is not needed because of constant pressure duct systems are used. Several nozzle sizes are available, to enable attaining the minimum supply airflow rate of the chilled beam in a typical room module.

The primary airflow rate of each beam is adjusted using the Halton air quality control unit during the installation and commissioning. There is no need to change or plug nozzles of the chilled beam. Halton air quality control also allows increasing the airflow rate of a chilled beam - e.g., to meet the ventilation requirements of meeting rooms (up to 6 $l/s/m^2$).

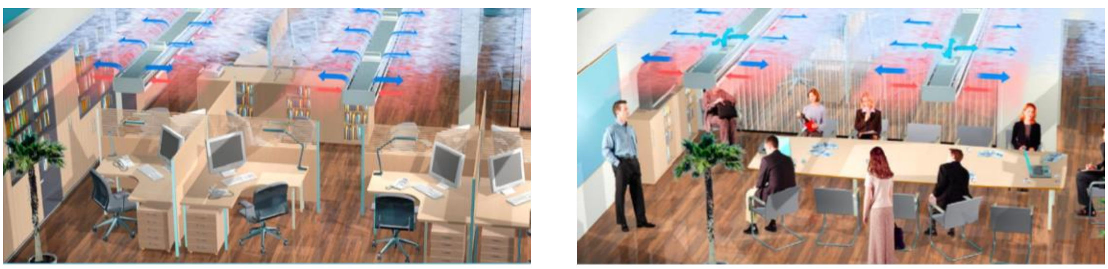

Figure 4. Air quality (HAQ) control unit to adjust the required extra air flow rate of a chilled beam. Minimum requirement is supplied through nozzles (left). In case of a high maximum airflow rate, this HAQ unit on the top of a chilled beam can be motorized (e.g. meeting rooms).

The typical Scandinavian office building's (Fig. 5) columns spacing is 8,1 m and it is divided into 6 modules (à 1,35 m). If active chilled beam is installed into every second module perpendicular to perimeter wall, it means that there may become two module rooms with one beam, three module rooms with one beam and three module rooms with two beams. In this kind of installation there is different airflow rates in each beam and also different kind of throw pattern is needed (Table 2).

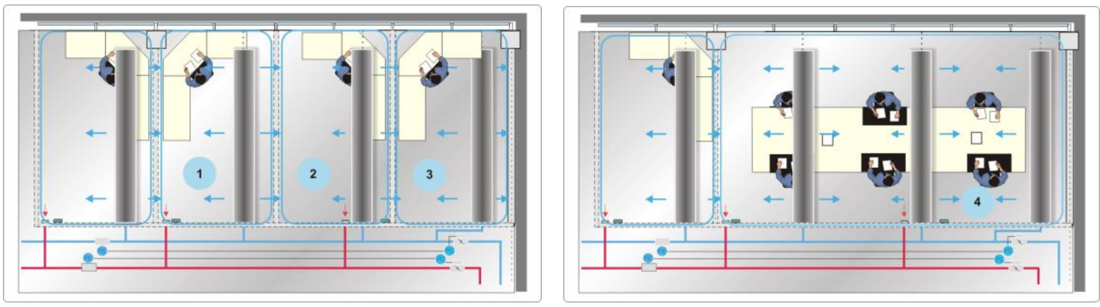

Figure 5. Typical floor layout where both velocity control and air quality control are used to adjust the operation of each chilled beam to provide right air volume and throw pattern.

Table 2. Adjusting air quality and thermal conditions in the case presented in figure 6.

Space type	*HVC position*		*Nozzles qv1*		*HAQ qv2*		*Total primary air flow rate qv1 + qv2*	
	left	*right*	*l/s*	*m^3/h*	*l/s*	*m^3/h*	*l/s*	*m^3/h*
Office	3	1	15	54	5	18	20	72
Meeting room	2	2	15	54	0…45	0…160	15…60	54…216

3.2 Better energy efficiency using chilled beam technology

Use of chilled ceilings and beams has a positive effect on the energy consumption of buildings. Since water is primarily used as an energy carrier instead of air, the system is using energy efficiently. Since water is the primary energy carrier, the system is more energy efficient than an all air system. Additionally it is possible to further improve the overall efficiency by using higher cooling water temperatures and lower heating water temperatures than are used in air based systems. Even sustainable energy sources (waste heat, ground heat etc.) and free cooling can be utilized in order to improve the energy performance of the building. [9]

Ventilation fan energy can be reduced using larger air-handling units and ductworks (lower pressure drop). Sometimes it is possible to leave away balancing dampers from ductwork by using constant pressure ductworks and higher terminal unit pressure loss e.g. 80-100 Pa (self balancing ductwork), which further reduces the total pressure required to run the ventilation system.

Good air quality can be achieved also in meeting rooms by adjusting air quality (HAQ) control unit. When motorized HAQ and variable air volume is used, the energy efficiency of system is improved due to optimum usage of air. Limiting ventilation in empty or only partly used meeting rooms can save a. 4 kWh/m2 of fan and cooling energy in a typical European office building. [10]

3.3 Turning well-being and flexibility into business profit

With adaptable chilled beam solution spaces support core business fully by providing flexible environment for high performance. Good indoor environment and high satisfaction in various usage situations can be achieved by ensuring fully functional indoor environments in change situations. After spaces are taken into use or after a major change, the indoor climate conditions can be verified by user satisfaction measurement and field measurements. The system is adjusted to meet user specific layout and load levels in order to provide user satisfaction and economical life cycle.

Adaptable chilled beam system allows flexible positioning of office and meeting rooms: users can select freely space layout. It also allows flexible changes from open-plan office to office rooms and flexible adaptation of individual conditions also in an open-plan office.

Fast layout changes are possible with minimal interruption and without a project. During the change, air-conditioning is running all the time.

Investment on flexibility can be done on demand and there is no need to invest just in case. Adaptable airflow rate actuators for meeting rooms are installed only when they are needed.

Minimized churn, energy and maintenance costs are assured. Typical change costs are about 1,000 €/room compared to 100 €/room with adaptable chilled beam solution.

Life cycle cost analysis (Table 3) shows that life cycle costs are the lowest with chilled beams concept: chilled beams with constant air volume in offices and variable air volume in other spaces. Investment costs of variable airflow system (VAV) and maintenance costs of fan-coil are considerably higher than with chilled beam system. [10]

Table 3. Life cycle costs of three typical room systems shows the cost efficiency of chilled beam system.

System	*Net present value*	*Cost difference*
Case 1. Chilled beam	177 euros/ m²	± 0%
Case 2. VAV	228 euros/ m²	+ 29%
Case 3. FANCOIL	189 euros/ m²	+ 7%

4 DISCUSSION

In the near future there is a clear need to improve both the energy efficiency of buildings and occupant wellbeing inside the buildings. As shown in this paper this can be done; also in the same building at the same time. However this requires both new technologies and new business models. It also requires a holistic view of understanding the total picture. It is easy to save energy by stopping all mechanical systems in the building. This way we quickly generate another problem – users are suffering inside.

Occupants are an important source of information about indoor environment quality. Even though physical measures describe (numerically accurately) parts of the indoor environment only the perceived quality determines the functionality of the space to workers. People create the outcome of the work and therefore indoor environment’s only purpose is to support the human performance and wellbeing.

This challenges our industry not only to search easy solutions for energy saving or human wellbeing but solving these both challenges at once utilizing new innovations both in technology and processes.

5 CONCLUSIONS

New drivers in the construction industry sets new requirements both for construction and building’s management processes as well as sets new demands for future room solutions. New elements for business process of managing indoor climate conditions in changing circumstances over the lifetime of building has been developed.

The objective of new business process is to make it possible to set and evaluate performance metrics through the whole building process and improve IEQ during the lifetime of building. The target contains both human comfort and economical considerations. In addition, new business models and services are developed which makes possible to verify the operation of the selected building services.

A systematic method for assessing and improving indoor environment quality (IEQ) in existing and occupied office buildings is also important. The method begins with occupant satisfaction survey that is directed to everyone working in a building. A technical analysis requiring multidisciplinary knowledge is conducted in building areas where more than 30 % of respondents are dissatisfied.

With adaptable chilled beam solution spaces support core business fully by providing flexible environment for high performance. Good indoor environment and high satisfaction in various usage situations can be achieved by ensuring fully functional indoor environments in change situations. Minimized churn, energy and maintenance costs are assured.

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