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Indoor Environment in Smart Energy-Efficient Buildings A State-of-the-Art Report

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TECHNICAL REPORT

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Indoor Environment in Smart Energy Efficient Buildings – A State-of-the-Art Report

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RESULT (summary)

The aim of the SmartBuild programme is to develop new knowledge, integrated solutions, and technologies that will make it possible to reduce energy consumption, and satisfy user needs like indoor air quality, comfort, aesthetics, costs, operability, reliability and functionality. The programme is divided in different subtasks like, user needs, ambient and indoor environment, implementation, integrated design, photovoltaic, energy and lightening systems, heat pumps, heating, cooling, ventilation, operation, automation, and thermal storage.

"Indoor environment" is both an integrated part of the SmartBuild programme and a foundation for the other subtasks. The overall objective of this subtask is to contribute to a satisfactory and pleasant indoor environment, stimulating for work purposes and with no negative effects on health.

This report provides a state-of-the-art analysis for the area indoor environment. Several weaknesses in today's practice have been revealed, especially the incoherence between choice of solutions and systems and their impact on the indoor environment. In order to provide a healthy indoor environment, the indoor environment requirements and ramifications must be considered before developing new systems and solutions.

The objective is to develop key elements of a strategy by which designers, engineers, manufacturers, and other decision makers can achieve a good balance between energy use in building and indoor environmental quality (IEQ), when applying the smart building technologies to be developed within the programme. The goal is to reduce the risk of poor IEQ and waste of energy, in other words, how to reconcile good indoor environmental quality with a rational and efficient use of energy.

In the next stage of the project the key action will be to ensure satisfactory directions and requirements. They should include functional requirements on both on short and long-term basis. In relation to the SmartBuild perspective, indoor environment guidelines should be a major part of the first stage. It is essential to develop practical tools and checklists for Norwegian conditions, which can be implemented in the other subtasks.

KEYWORDS

SELECTED BY AUTHOR(S)	Indoor environment	Health effects
	Air quality	Energy

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1 INTRODUCTION

This report provides a state-of-the-art analysis for the area Indoor Environment, a subtask in the project “Smart Energy Efficient Buildings” (“SmartBuild”). The aim of the program SmartBuild is to develop new knowledge, integrated solutions, and technologies that will make it possible to reduce energy consumption, and satisfy user needs like indoor air quality, comfort, aesthetics, costs, operability, reliability and functionality.

The goal for indoor climate control is to provide comfort and well-being and prevent illness and negative health effects. In practice, however, it is not possible to fulfil this goal for everyone. In today’s society, with it’s a growing number of hypersensitive individuals, a certain risk of problems must be accepted. The best we can expect is for the health risk represented by indoor climate to be either trifling or negligible, even for groups that are somewhat more sensitive than average. Nonetheless, it is astonishing that the annual costs of heating, ventilating and cleaning an office building, for example, are tiny compared with the loss of health and productivity that may result from poor indoor climate or unsatisfactory hygienic standards.

2 CENTRAL CONCEPTS

Good indoor environmental quality (IEQ) is one of our most fundamental needs. Poor air quality affects our health, well-being and quality of life in general. European urban and non-urban areas, in particular large cities, struggle with the problems of high levels of air pollutants. At present 60% of the European population is living in cities. For the next decades it is foreseen that this percentage will further increase (Kotzias, D., 2000). The substantial growth of the urban population is associated with a further increase of the macro and micro economic activities in the cities including progressively growing energy use and more air pollution.

Regrettably, today too many occupants express annoyance or become ill in modern buildings. Terms like Sick Building Syndrome (SBS), Tight Building Syndrome (TBS), Building Related Illness (BRI), and Multiple Chemical Sensitivity (MCS), are introduced in order to define the problems and group the different characteristics. Symptoms commonly attributed to IEQ problems include headache, fatigue, shortness of breath, sinus congestion, cough, sneezing, eye, nose, and throat irritation, skin irritation, dizziness and nausea. Several of these symptoms may occur at the same time.

Further, the number of allergic and asthmatic people is rapidly increasing in the Nordic countries, a problem shared also with other European countries. One explanation for this increasing Nordic problem could be found in the fact that people in the Nordic countries, due to the harsher outdoor climate, are spending more time indoors than people in other parts of Europe. Another issue referred to as a potential cause, is that buildings have become too tight. The first oil crisis resulted in a nearly tenfold increase of the heating costs for buildings in the Nordic countries. To reduce the dependence on heating and imported oil, new building codes required tighter buildings, better thermal insulation and reduced ventilation airflow. In many cases this resulted in higher concentration levels from emission of chemicals emitted from building materials and indoor activities. Finally, high relative air humidity and damp buildings often have led to building related illnesses and symptoms.

To meet some of these challenges, new building constructions have been introduced. The optimistic goal is that buildings shall provide occupants a comfortable environment in which health and safety is ensured. This does not imply absence of risk, but an acceptable level of risk guided by comparative risk assessments. However, the environmental conditions required for health and comfort is not the same for everyone. There are large variations, physiologically and psychologically, from person to person, which makes it difficult to satisfy everybody. (Hanssen, S.O., 2000). Further, there are adverse short or long-term health affects. For some effects, clear relationships with exposure to indoor air pollution have been reported in literature. Among these are respiratory diseases, allergy and mucous membrane irritation. A large number of people has been, and is still, affected (Lindwall, T., 1996).

Additionally, there are significant socio-economic costs of poor indoor environmental quality. Adverse health effects or general discomfort due to unsatisfactory indoor climate may result in lost productivity in a variety of ways. First, there is the loss of productive years owing to premature disability or death, and then losses due to increased absenteeism of varying duration and finally, less-than-optimal job performance. This includes diminished performance and worker productivity, especially in non-industrial buildings like offices and educational buildings. In discussing the effects of indoor climate, we must consider all reductions in the country's productive capacity, including service occupations, work in the home and teaching.

The potential economic impact of indoor air pollution is high, and is estimated in the tens of billions of € per year for Europe alone. Such impacts include direct medical costs and lost earnings due to major illness, as well as increased employee sick days and lost productivity. Labor costs alone are estimated to be 10 to 100 times higher per square meter of office space compared to energy and other building related maintenance costs (EPA 1989, Djukanovic, Wargocki and Fanger 2002). In 1991, The National Office of Building Technology and Administration in Norway estimated that the costs to society related to poor IEQ is in the order of € 1 to 1.5 billion per year, or € 250 to 350 per inhabitant. This estimate only includes costs related to adverse health effects requiring medical attention and does not include reduced worker efficiency or job-related productivity losses (Pillgram Larsen, 1991). Regrettably, there is reason to believe that this negative development is an increasing problem, both on a national and on an international level.

The cost of discomfort or bad IEQ is not only a problem for the society and the employer; it may also be a serious issue for the building owner. An illustrating example of the costs related to losing a tenant is reported in "ENVIROS, The Healthy Building Newsletter" (Lewis, F.A., 1992). The figures are based on a study done by the Building Owners and Managers Association (BOMA) in the USA. The study reveals that if a tenant lodges a major complaint regarding building comfort to the building manager at least three times in one year, there is a 52 percent chance the tenant will move out at the end of the lease. Further, the newsletter presents an estimate of the cost of losing a 5,000 sq. ft (500 m²) tenant at $ 20/sq. ft (€ 200 /m²)-gross rent in a

100,000 sq. ft (10.000 m²) building: The $150,000 total costs represent $1.50/sq. ft of lost revenue or 1.5 years of rent. In addition, there could be additional loss of revenue from non-occupancy due to lack of use. In conclusion, improving indoor environmental quality (IEQ) in domestic and non-industrial public and commercial buildings is probably one of the most profitable investments societies and the business world can make. Smart energy efficient buildings may be one of the major tools in achieving this goal.

3 TECHNOLOGY AND MARKET

In contradiction to the other subtask The primary focus of the indoor environment activities will be to provide premises for the other subtasks under the SmartBuild programme, rather than development of new technical solutions.

Already during the design process, the possibility for the building to fulfil indoor air quality requirements is established. Erroneous decisions during this phase are costly to rectify. Incorrect handling and unsuitable methods during the building process often lead to inferior and unsuitable buildings. A recurrent problem is the lack of methods for quality assurance leading to damp buildings, mould and sick buildings. Unsuitable building materials and insufficient airflow lead to high emission concentration levels and to increased health risks for the building users. There is also a risk that efforts in reducing the energy use in buildings lead to inferior indoor air quality and a non-optimal thermal climate.

Therefore, it is paramount that a healthy indoor climate and the important energy issue are considered simultaneously. However, this task is not easy because the discipline of indoor environment is very complex. The total concept of indoor environment comprises several intertwined parameters:

- Thermal surroundings
- Atmospheric environment (airborne particles, bacteria, virus, mould, VOCs, etc.)
- Acoustic background
- Actinic background (lighting, radon and electromagnetic background)
- Mechanical environment (ergonomics, shape of the room and equipment etc)
- Aesthetic surroundings (office lay-out and design, colours on walls etc)
- Psycho-Social environment (job content, work load and pace, job control etc

Whereas for thermal comfort, an optimum range can be defined (NS ISO Standard 7730), such a situation does not exist for indoor air quality. As shown in Figure 1, the number of dissatisfied people reduces with increased airflow rates. The three categories A, B and C as given in CEN CR 1752 (CEN, 1998) are indicated. For category A, the flow rate (10 l/s person) is 2.5 times higher than the flow rate required for category C (4 l/s person).

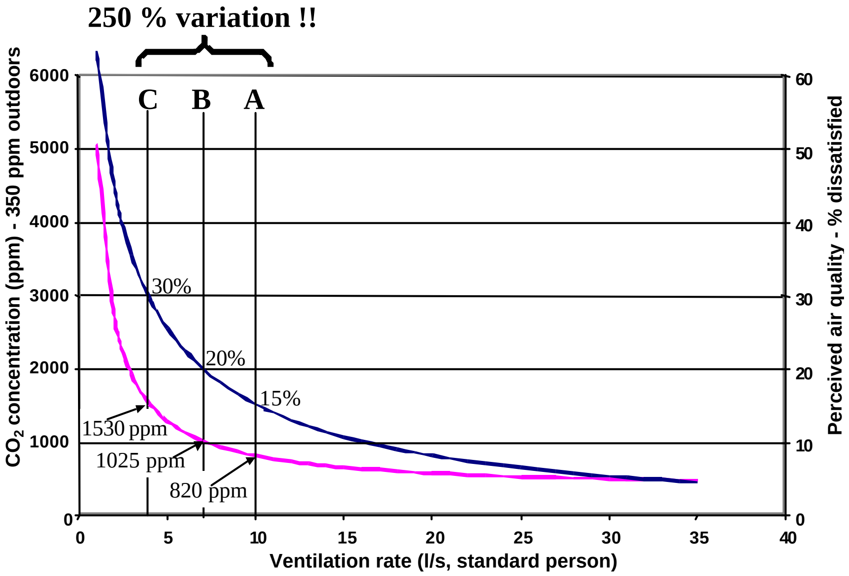

Figure 1: Limit values CO_2 concentration used in CEN technical report CR1752

Some of the difficulties in measuring IEQ may be illustrated by human response on two of the main parameters, thermal surroundings and atmospheric environment. Differences between some features of thermal comfort and indoor air quality with important relevance for standard setting are:

Features	Thermal comfort	Indoor air quality
Comfort range	Relatively small and identified optimum	Wide range and no identified optimum
Sensory warning to occupants	Very pronounced	Less pronounced and complex
Adaptation possibilities by users	Quite large by changing clothing and activities	Efficient odour adaptation but otherwise few possibilities

Air flow requirements found in standards therefore are the result of a weighing of various concerns e.g. air quality, health, energy, productivity, etc. This weighting process can be strongly influenced by external factors (e.g. oil crisis in the seventies) and new findings of research (e.g. impact on health and productivity). Given the lack of precise knowledge on some of these facts, it is not surprising that the air flow requirements in standards may vary considerably as function of time. ASHRAE 62, of which each revision is the outcome of an intensive review process, is a good example. In Figure 2, the evolution of the airflow requirements per person is presented, whereby the major discussion items are indicated. As illustrated, major variations occur as function of time (Wouters, P. (red.), 2002).

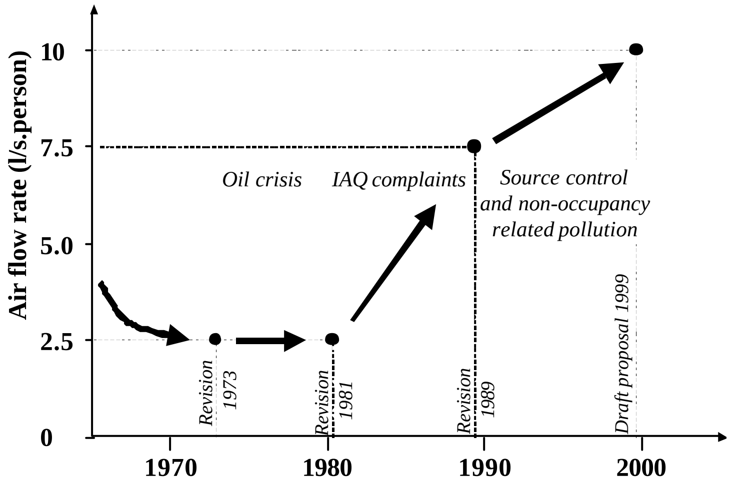

Figure 2: Evolution of air flow requirements in ASHRAE 62-1989. "Ventilation for indoor air quality".

A recent meta-analysis of 20 field studies in office buildings involving more than 30,000 subjects (Seppänen et al, 1999), reviewed the connection between ventilation rates and human responses of perceptions and symptoms. Almost all studies found that ventilation rates below 10 l/s person in all building types were associated with statistically significant worsening in one or more health parameters or perceived air quality. Some studies determine that increases in ventilation rates above 10 l/s person, up to approximately 20 l/s person, were associated with further significant decreases in symptoms or with further significant improvements in perceived air quality.

In conclusion, ventilation standards throughout Europe, but also worldwide, differ considerably in philosophies, in ways to express the ventilation target, as well as in the comparable values. In Figure 3, an example of the variation in requirements is presented for office buildings.

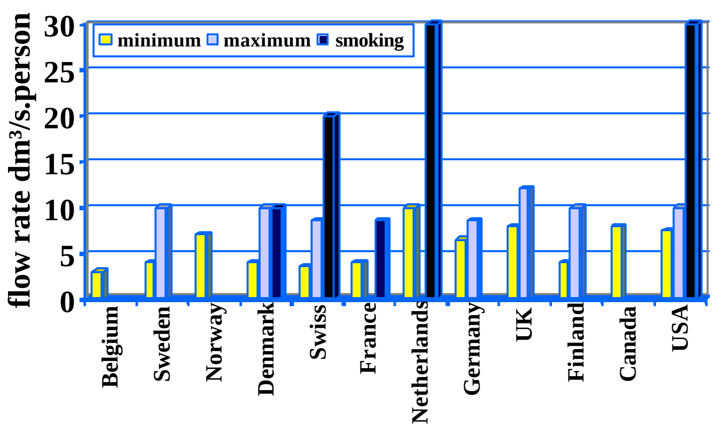

Figure 3: Required flow rates per person for offices in standards (Wouters, P. (red.), 2002).

The practical implications is that ventilation requirements in many existing guidelines and standards may be too low to protect occupants of offices, schools, and homes from health and comfort problems and may not be optimal for human productivity. Higher ventilation rates will increase energy costs. Ventilation rates can be reduced by lowering pollution loads on the air indoors, e.g., by prudent and systematic maintenance of the heating/ventilation/air-conditioning (HVAC) systems and by reducing superfluous pollution sources indoors. Use of efficient heat recovery systems can also reduce energy costs for ventilation. Source control and new ways of conditioning air are required to ensure a satisfactory indoor environment.

In the future, governmental regulations and the call for economic profit in the business world will most likely enforce IEQ quality assurance. The coherence of “Facility Management, Employee Productivity and Environmental Issues” will probably become more important, and in this context, the premises will be given by:

- IEQ as a denominator for increased real estate market values
- The building as a means of increased employee productivity
- Litigation, liabilities and legal responsibilities
- Health, comfort and well-being

Especially, health and productivity will probably be focused more intensively in the future. The health issue is underlined in for instance the European Health21 Target 10, “A Healthy and Safe Physical Environment”. (Adopted by the WHO Regional Committee at its forty-eight session, Copenhagen, September 1998) “By the year 2015, people in the Region should live in a safer physical environment, with exposure to contaminants hazardous to health at levels not exceeding internationally agreed standards”.

Likewise, the WHO European Centre for Environment and Health in Bilthoven, has underlined the issue in its report “Strategic approaches to indoor air policy-making”, 1999. It is emphasised that: ; “Indoor air quality is an important determinant of public health and comfort. This document informs and advises governments, public health authorities and other policy makers, representatives of sectors relevant to indoor air quality (IAQ) management, on how to develop and strengthen IAQ policy in order to protect and promote health in the indoor environment. It specifically addresses strategies for the development of IAQ policies for non-industrial buildings such as homes, schools, offices, health care facilities and other public and commercial buildings.

Development and implementation of a comprehensive, scientifically sound “action plan” is proposed as a key strategy tool. The document outlines the content of such an action plan, addresses the roles of public and private sector in policy implementation, and the roles of various levels of government, industry and research”.

4 INTERACTION WITH OTHER SMARTBUILD STATEGIES AND TECHNOLOGIES

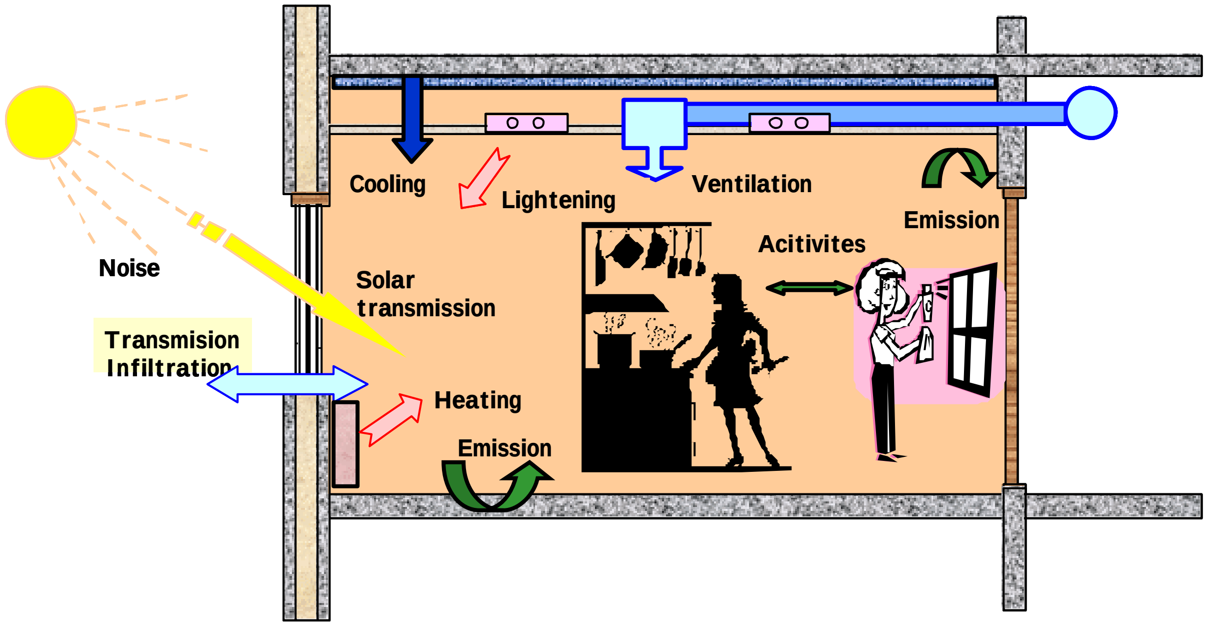

Figure 5: A selection of the different parameters that affect the indoor environment

Indoor environment consists of and is influenced by, several different parameters, in the following chapter the term healthy environment is used instead of describing every single parameter.

4.1 Indoor environment and user needs

User needs are based on what humans need to maintain a healthy environment, in their different environments for instance at home, at work, public places, schools, kindergarten, restaurants, hotels and cinemas. Healthy indoor environments fulfil the needs of both healthy adults and risk groups that are more sensitive than the average (infants, elderly people, hypersensitive).

At present there exist no single systems that can guarantee an indoor environment without risk factors. Economically, is it impossible to achieve such a goal, if for instance ventilation is the only selected strategy. The energy consumption would rise tremendously, and there would be no guarantee that this would ensure satisfactory indoor environment.

Resent studies indicate that too sterile indoor environment also might cause problems. Microbiologists (SINTEF Unimed) claim that a normal microbiological flora is important and an acceptable risk. Specific dominance or thermo-tolerant species should be avoided. Other kinds of pollutants might also influence the indoor environment. Minimization and reduction of the pollutants is the primary strategy along with maintenance of a correct operative temperature.

Research has changed focus from exploration of factors that might have a negative impact on people's health, towards a more holistic approach focusing on factors that influence people's productivity and well-being.

Different proficiencies have numerous approaches to user and definitions of user needs. Tree different categories of users can be defined:

Categories	Relevant issues
1.1.Individuals and families 1.2.The government	Common and separate interest in people's health, well-being, productivity. The indoor environment should be as good as possible to prevent illness and discomfort.
2. Building owners	Primary focus on; maximum profit, short building period, low investments, optimal facility management, flexibility. A satisfactory indoor environment are competitive advantage, something that makes investments to achieve a superior indoor environment more interesting
3. Designers, architects, engineers	User need should be the basis for design and development of buildings and necessary systems and equipment. In the early stage of design – adequate knowledge have a significant impact on the final indoor environment. It is also important to emphasize that changes during the building period should result in a revived consideration of the selected solutions.

4.2 Indoor environment and environmental criteria

Systems used to provide a satisfactory indoor environment like heating, cooling and ventilation equipment demand energy both when used and produced.

Energy demand is related to

- Production
- Operation
- Demolition

Materials and recourses are consumed during

- Manufacturing /production
- Maintenance

Production might lead to pollution like

- Emission to air
- Discharges to water and soil

In order to fulfil user demands and assure a healthy indoor environment, energy in some form is needed. Solutions without unnecessary strain on the environment is not rewarded, electrical energy is utilized instead of renewable energy sources for heating and cooling.

Development of new strategies where heating, cooling and ventilation are designed in proportion to the number of people present in the building is necessary. The systems must also consider the influence they might have on each other. However, demands for a healthy and clean indoor environment should not be exaggerated, because this consumes unnecessary recourses.

At the time being there are no systematic and comprehensive Life Cycle Analyses (LCA) methods that are able to compare the different solutions and their overall environmental impacts.

Systems for temperature control

Systems for cooling might, dependent on refrigerants, contribute to the greenhouse effect. When designing such systems, emphasize should be put on passive solutions. It is more energy efficient to use simple shades outside the window than using energy to reduce the heat load.

Heating systems can preferably use heat from renewable solutions.

Systems for ventilation

The different ventilation strategies; natural, mechanical and hybrid systems might have a significant influence on energy use. Nevertheless, it is important to make a realistic evaluation of the whole system and indirect effects on the building design. Natural and hybrid systems are often claimed to use less energy than mechanical solutions, but they demand larger rooms, and more use of building materials. They might even have a larger heat loss than other systems. To obtain a healthy indoor environment, without unnecessary strain on the environment, the entire system should be analysed.

Most of future buildings already exist. It is a challenge for the different professions to create a healthy environment, when a building is refurbished or rebuilt. This imply that the environment must be taken into consideration, when buildings are refurbished or rebuilt, and at the same time create a healthy environment.

4.3 Indoor Environment and Implementation Strategies

It is essential that "everybody" understand why indoor environment is important and why different guidelines and regulations are developed. Indoor environment as described in Chapter 2 is essential for health, well-being and productivity. Indoor environment is important even before health effects are noticed (Fanger).

Indoor environment has often been considered synonymous with ventilation. In addition the building materials, ongoing activities, other pollutants, temperature, humidity, lightening, noise etc. influence indoor environment.

The following statements should be embraced and understood by the different parts involved;

- Why the indoor environment is an important part of a smart energy efficient building
- Ventilation is not the problem
- Pollution is the problem
- Fresh, dry, cool air is the solution (ventilation is the remedy)
- Heating and cooling should be separated from ventilation
- The whole building and its envelope should be considered
- Different systems and solutions interact with each other and integrated design is needed.

There is a growing awareness among inhabitants of the negative effects of poor indoor environment, but they are overwhelmed with information from different sources. Few are able to study and demonstrate the impact that different solutions will have on the indoor environment.

Separate strategies have to be developed for the different target groups:

- Public – why is indoor environment important?
- Professional – why, how should systems and solutions be implemented? The impact of ventilation, heating, cooling, regulation, automation, maintenance, building materials, design, planning etc. on the indoor environment.
- Owners – why, and what they can profit on a healthy indoor environment

4.4 Indoor Environment and Integrated design

Some of the systems that are necessary to provide a healthy indoor environment e.g. ventilation, heating, cooling and lightening are a natural part of the integrated design.

Other parameters like materials, emission from materials, maintenances, cleaning etc. are often not included when integrated solution is discussed. Nevertheless, these factors must be taken into account when planning the building and its systems.

At present natural and hybrid ventilation systems are considered an obvious part of the integrated design, but there is no reason to have such a distinction between those solutions and mechanical ventilation. Rehabilitation projects are often used to illustrate how hideous technical solutions, especially mechanical ventilation, can be when they are installed and used without any effort to integrate the system.

Maintenance of the integrated solution is important; ductworks e.g. should be designed to permit cleaning and inspection. Latent defects might arise and cause serious indoor environmental problems. Water leakage due to condensing water can induce microbiological growth.

Integrated design in cooperation with intelligent control systems is central to ensure a successful solution.

4.5 Indoor Environment and integrated energy systems

Integrated energy systems interaction with the ventilation system must be evaluated before implementation. Energy systems might influence the ventilation efficiency, and thereby result in an unsatisfactory indoor environment. This might also have an effect on the energy consumption.

Integrated energy systems should be able to maintain a satisfactory indoor environment regardless of variation in outdoor climate like wind velocity, direction, latitude, shielding, in coherence with activity level, number of persons and rooms in use.

Some of previous developed systems, have a large time coefficient, the systems are not capable to respond according to the user needs and give an immediate reaction. The systems must also be able to act in response to weather forecast, predicted energy consumption etc to be able to utilize thermal storage.

4.6 Indoor Environment and Building Integrated Photovoltaic

To maintain a healthy indoor environment, the Building Integrated Photovoltaic (BIPV) system should be an integrated part of the heating, cooling and ventilation system of the building. BIPV is a challenge for architects, HVAC-engineers, building/constructional engineers and contractors.

Depending on the location and design, the BIPV “elements” might have an impact on the indoor environment, for example as part of a double-glazing outer wall. People located in the upper floors might be unable to get air through the windows; something considered being a human right in Norway. Problems with condensation has also been reported, condensate is a risk factor for microbiological growth.

BIPV elements might reduce daylight availability in the room, which again might reduce the need for cooling and/or increase the need for artificial lightening. On the other hand, the temperature outside the outer wall will rise, and this must be taken into consideration when the heating and cooling loads are calculated.

4.7 Indoor Environment and lightening systems

Lightening systems are also important parameters that affect the perceived indoor environment. Complaints caused by insufficient or incorrect lightening systems can erroneous be mistaken as problems in connection with the air quality. The symptoms are similar to SBS, and cannot be cured with more air or better air quality. Headache cased by use of old standard luminance fluorescent tubes have been documented, and can be prevented by use of 20-25 kHz lightening systems. The surrounding surfaces and their reflection of light can cause unspecific complaints of indoor environment. Lightening systems might also influence on the well-being and productivity.

The age of the users must be taken into account, the older a person gets, the more light is needed to perform several tasks like reading and sewing. It is preferable to have different systems, one system for general lightening of the room and a flexible system with the possibility for individual regulation.

Even though use of energy saving lamps reduces the heat load, the heat might still cause convection currents, which can lead to burning of dust on top of the lamps. Up-lights are usually equipped a lightening tube; research performed at NTNU verifies that this might cause combustion of dust, and thereby unwanted pollution of the indoor air. Lightening systems should always be designed for quick and easy cleaning to provide a healthy indoor environment.

The lightening fixtures are often installed after the ventilation system; this might disturb the designed airflow pattern in the room. Heat from the lightening system installed in the ceiling may increase the temperature above the ceiling, and might cause a rise of several degrees in the supply air. This is a problem that can be solved by insulation of the ducts or use of special reflectors.

In order to achieve a healthy indoor environment the lightening systems should be designed in coherence with the ventilation, heating and cooling system based on indoor environmental requirements.

4.8 Indoor Environment and heat pumps

Heat pumps are used in connection with different systems designed to provide heat and to maintain a satisfactory indoor environment. Usually heat pumps do not pose negative effects with regard to indoor environment. However, the most important factor that should be kept in mind; do not use supply air as the only heat source. Systems that use ventilation as heating are energy ineffective, and will have a negative impact on the indoor environment due to temperature stratification and short-circuiting. Hot air will be gathered just below the ceiling instead of in the occupational zone.

When a heat pump is running, noise is generated, both from the heat pump itself and from system vibration. This might have a negative impact on the indoor environment. To prevent annoyance the Norwegian Building Code has a limitation on noise generated from technical equipment.

On the condenser surface, moisture and dust might gather and be a risk factor for microbiological growth. Condensate water must also be collected and removed.

When air-to-air heat pump systems are installed after the ventilation and cooling system the original and designed airflow patterns and heat distribution may be disturbed. This might lead to unstable systems and have a negative impact the indoor environment.

Depending on the heat pump location, sediment dust might be whirled into the air and cause negative health effects. Filters and the other parts of the heat pump should be manufactured in order to make maintenance and cleaning simple.

Leakages of refrigerant e.g. Ammonia might impact peoples health. People are not aware of the difference in threshold limit (smell) and hazard risk. Psychologically, this may lead to panic and unnecessary concern about health damages. Refrigerants should be selected in order to minimize the health effect in case of a leakage.

To provide a healthy indoor environment – the focus should be on system solutions rather than on optimisation of the technical solutions!

4.9 Indoor environment and heating, cooling and ventilation systems

Ventilation

Ventilation is necessary to remove pollution generated from building materials, activities and people. The ventilation system must be able to meet user needs and requirements based on regulations, information of the activities performed in the actual building and what kind of people (employees, elderly, children, risk groups etc.) that will use the building. To ensure an efficient utilization of supply air, heating and cooling must be separated from the ventilation system cf. chapter 3.8. Supply of air is needed to achieve a healthy indoor environment, notwithstanding heating or cooling load. Presently, there is a discussion about the air quality requirements; there is no commonly accepted international standard.

In principle, three different methods of ventilation are introduced:

- Mechanical ventilation
- Natural ventilation
- Hybrid ventilation

The different methods have various advantages and disadvantages. A mechanical system is relatively uncomplicated to operate and air quantity can easily be adjusted according to user needs. Mechanical ventilation has an undeserved bad reputation, mainly because of incorrect planning and design of the system and insufficient operating and maintenance.

Natural ventilation might be inadequate in buildings crowded with people. The driving forces of the system are wind generated pressure and temperature differences (stock effect). Consequences might be excess and too high ventilation in the wintertime and lack of ventilation in the summer. In addition there is no method of controlling the pollutant level. Natural ventilation might result in undesirable levels of gasses and pollutants that may have a negative impact on the occupant’s health.

Hybrid ventilation is combination of a mechanical and a natural ventilation system. When the natural driving forces are insufficient, fans are automatically started.

In most buildings mechanical or hybrid ventilations systems are an important part of the systems installed to provide a healthy indoor environment. The ventilation principle, how air is supplied into the room, (displacement or mixing) is even more vital. If ventilation air is supplied incorrectly the fresh air will have inadequate influence on the perceived indoor environment.

In the future systems for personal ventilation might be developed, which may significantly reduce the need for supply air.

Plants and all parts of the system should be designed with cleaning and inspection possibilities in mind. Dirty and moist air intakes, filter, ductworks, supply units, heat recovery units, humidifiers, etc. might cause seriously health problems and give rise to pollution in the indoor environment.

Heating and cooling,

There is a consensus about requirements and acceptable level with regard to temperature. The temperature sensation/perception is a combination of the following factors;

- Temperature
- Radiation from surrounding surfaces
- Air velocity
- Activity level (metabolism)
- Clothing –insulation
- Humidity

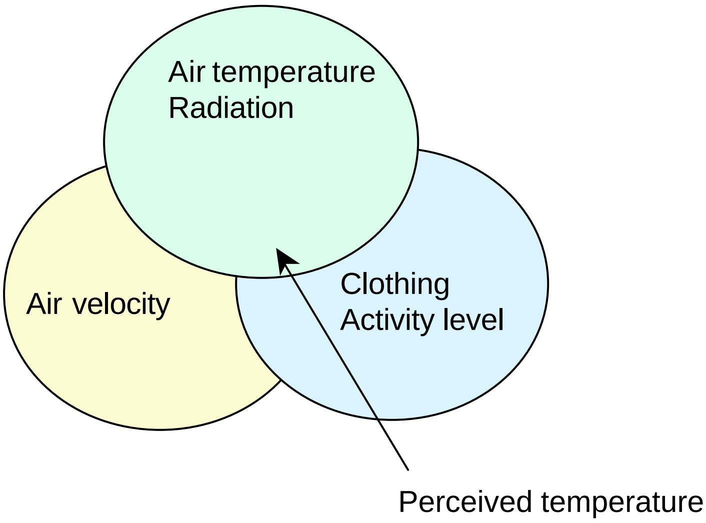

Figure 4: Perceived temperature is a function of different parameters

To obtain a satisfactory indoor environment in the Nordic climate is it often necessary to heat the buildings at least for a part of the year. Even though super insulated building materials might be developed in the future, this cannot be the basis for design, since most of the buildings that we will have to deal with are already built.
As mentioned heating and cooling should not be a part of the ventilations system. Interaction between the different systems is essential, or else there might be, unnecessary energy consumption, fluctuations in temperature etc. The type of ventilation system might affect the operative temperature, e.g. displacement ventilation creates a vertical temperature difference in the occupied zone.

In order to ensure thermal comfort, physiological effects must also be considered. People have a different tolerance of low and high temperature depending on which part of the body that is exposed to heating and cooling.

ASHRAE Standard 55-92 "Thermal Environmental Conditions for Human Occupancy" recommends upper limits for allowable air velocities in buildings to avoid draft discomfort. However, based on experiments, building occupants were significantly less sensitive to draft than prescribed in the standard (Human response to air movements - Part 1: Preference and draft discomfort, DTU)

An ongoing project makes a comparison of comfort responses at combinations of low air velocities and moderate temperatures and at elevated air velocities and temperatures (DTU). The results will show whether a thermal environment with moderate temperature is subjectively preferable to an environment where an elevated air velocity is used to offset a high temperature.

Condensation from cooling systems might cause moist and subsequent microbial growth; which might have a negative impact on the indoor environment.

4.10 Indoor environment and operation and automation

To ensure a healthy environment, rational operation and automation is essential. It is important to keep in mind – the controlling system should not be the “engineers dream and the users' nightmare”. Future systems might operate more efficient than existing systems. They will be based on user demands and requirements and include adaptive solutions, which will provide a satisfactory indoor environment with minimum use of energy.

The control systems should:

- Be easy to operate
- Be easy to understand
- Correspond to the users needs
- Make it possible for each user to satisfy his/her personal preferences
- Give an immediate response
- Return to default value after having been adjusted/tampered with by the users after a certain period.
- Not only be based on user participation. Natural ventilation systems based on user participation and intervention have proven that even engaged people are not capable to contribute as time goes on.
- The automation itself should not cause problems.
- Obtain interaction between ventilation, heating and cooling systems

The control systems provide new possibilities to optimise the indoor environment on condition that the functional requirements are known of the different professionals involved.

4.11 Indoor environment and storage

Thermal storage might be an important part of the heating and cooling systems. External storage in the ground is an opportunity to reduce energy costs. Depending on system solution, it is essential to ensure that it is impossible to contaminate supply air with for example microbes from the ground.

Integrated systems, thermal sinks in walls, roof and floors might influence surface temperature and thereby affect the operative temperature and emission from the surfaces. Different strategies are, and will be developed. Thermal storage will reduce energy needs by reducing the period with need for external heating or cooling.

As a part of the heating and cooling system, storage might have a positive effect on the indoor environment.

5 INDOOR ENVIRONMENT AND SMARTBUILD

During the preparation of this state-of-the-art rapport, several weaknesses have been revealed. The most important is the incoherence between choice of solutions and systems and their impact on the indoor environment. In order to provide a healthy indoor environment, all participants should consider the indoor environment requirements before developing new systems and solutions.

The main objective of the indoor environment activities is to ensure satisfactory recommendations and basic requirements. They should include functional requirement on both on short and long term basis.

The requirements should take into account that the building physics are altered with:
- Time
- Utility
- Design and redesign

The design of new solutions shold:
- Be flexible
- Be able to face altered utilization of the buildings/rooms
- Implement new information and knowledge
- Satisfy more demanding users

According to Fanger, human criteria for air quality should be established at three different levels of response:
- Behavioural (task performance, self-estimated performance, observed spontaneous behaviour).
- Subjective perception (acceptability, satisfaction, whether air quality has positive or negative effects, description of odour type and character).
- Physiological (self-estimated intensity of health symptoms, objective measurements, e.g., blinking rate, breathing pattern, measurements of metabolic rate and level of activation).

In relation to the SmartBuild perspective, indoor environment guidelines should be a major part of the first stage. It is essential to develop practical tools and checklists for Norwegian conditions, which can be implemented in the other subtasks.

The targets of this subtask is to provide; Satisfactory and pleasant indoor environments, stimulating for work purposes and with no negative effects on health.

The objective is to develop key elements of a strategy by which designers, engineers, manufacturers, and other decision makers can achieve a good balance between energy use in building and indoor environmental quality (IEQ), when applying the smart building technologies to be developed within the Program. The goal is to reduce the risk of poor IEQ and waste of energy, in other words, how to reconcile good indoor environmental quality with a rational and efficient use of energy.

6 LITERATURE AND CENTRAL R&D INSTITUTIONS AND INDUSTRY

6.1 Literature

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6.2 Central R&D institutions

WHO World Health Organization

http://www.who.int/en/

The World Health Organization, the United Nations specialized agency for health has Collaborating Centres in Protection of Human Environment, and a Department for the Protection of Environmental Health. WHO Guidelines for Air Quality have been developed. The primary aim of the guidelines is to protect public health from the effects of air pollution, and to eliminate or minimize exposure to hazardous pollutants. Air quality guidelines are set up to help governments derive legally enforceable air quality standards, and to guide the environmental health authorities and professionals who are trying to protect people from the harmful effects of environmental air pollution.

EUROVENT
http://www.aecportico.co.uk/Directory/EUROVENT.shtm
EUROVENT, the European Committee of Air Handling and Refrigerating Equipment Manufacturers, is made up of 11 national trade associations representing the manufacturers of air handling equipment in Europe.

DTU, Technical University of Denmark
http://www.dtu.dk,
The International Centre for Indoor Environment and Energy at the Technical University of Denmark is a leading research centre.

ECA, European Collaborative Action
http://www.jrc.it/
For more than 16 years now the European Collaborative Action ECA "Indoor Air Quality & it's Impact on Man" has been implementing a multidisciplinary collaboration of European scientists the ultimate goal of which was the provision of healthy and environmentally sustainable buildings. To accomplish this task ECA has dealt with all aspects of the indoor environment including thermal comfort, pollution sources, the quality and quantity of chemical and biological indoor pollutants, energy use, and the ventilation processes, which may all interact with indoor air quality. The work of ECA has been directed by a Steering Committee.

CEN, The European Committee for Standardization
www.cenorm.be/
CEN´s mission is to promote voluntary technical harmonization in Europe in conjunction with worldwide bodies and its European partners.

ISO - International Organization for Standardization
www.iso.ch/
ISO is the source of ISO 9000 and more than 13 700 International Standards for business, government and society. ISO is a network of national standards institutes from 145 countries working in partnership with international organizations, governments, industry, business and consumer representatives. A bridge between public and private sectors.

ASHRAE, American Society of Heating, Refrigerating and Air-Conditioning Engineers
http://www.ashrae.org/
ASHRAE is an international membership organization founded to advance the arts and sciences of heating, ventilation, air conditioning, refrigeration and related human factors to serve the evolving needs of the public and ASHRAE members.
ASHRAE, the American Society of Heating, Refrigerating and Air-Conditioning Engineers is an international organization of 50,000 persons with chapters throughout the world. The Society is organized for the sole purpose of advancing the arts and sciences of heating, ventilation, air

conditioning and refrigeration for the public's benefit through research, standards writing, continuing education and publications.