# Solving Indoor Environmental Problems: What Can Be Found Out Using Individual Studies?

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**SUMMARY**

In most of the buildings there is not a one single problem in indoor environment, but field studies indicates typically several problems. This is why it is impossible to improve indoor environment comprehensively by only focusing on individual measurements. To be able to decide what are the right measurements and studies in each project, it is important to be aware of what each individual measurement can illustrate. The most common field measurements used in office type environment are presented in this paper in general level. It describes some benefits and disadvantages of them and what kind of conclusions can be drawn from each measurement. Only by understanding the entire indoor environment it is possible to improve the perceived indoor environment for users' benefit.

**KEYWORDS**

Perceived IEQ, Field Study, IAQ, Thermal Comfort

**INTRODUCTION**

Problems with indoor environment cause continuous complaints and increase the number of unplanned service visits. User satisfaction is also low, and sometimes the problems lead to illness caused by the indoor environment, such as symptoms in the upper respiratory tract, allergic reactions, or asthma. Unfortunately corrective actions to improve IAQ are not always taken until serious health problems of users have been found. Problems in thermal comfort are typically corrected only after users have been sending continuous feed back to facility manager and owner. However corrective actions are not taken systematically throughout the building, but only in those areas from where the complaints are coming. So lots of time is already wasted and problem has become serious, before corrective actions finally start. This is why all parties involved are already very concerned and interested in to follow them.

Typically there is not a single problem in indoor environment, but field studies demonstrate several problems at the same time (Reinhold et al. 2005; Lahtinen et al. 2006). Sometimes there are problems in indoor air quality, but often reason is also the performance of mechanical systems. In many cases both IAQ and mechanical problems are local and that is why it is difficult to find and locate them (Takki and Virta 2007). Therefore it is important to plan carefully what kind of measurements and analysis need to be done and to be aware of what each individual measurement can illustrate. This way all necessary information can be collected in as short time period as possible and right decisions can be made to improve the situation comprehensively.

Comprehensive analyse of indoor environment requires a cross-scientific team of people representing at' least IAQ, building physics and HVAC-system knowledge. The team also needs know-how of various aspects of technical room services like lighting, acoustics, and air diffusion. Thanks to systematic method, it is possible to rectify defects and errors in the system, not just the symptoms of these errors. User satisfaction improves, complaints are reduced, and often also the energy efficiency of the system is enhanced.

## TYPICAL METHODS TO ANALYSE INDOOR ENVIRONMENT QUALITY IN OFFICE ENVIRONEMENT

There are various methods to analyse indoor environment problems in existing buildings, and there is no individual measurement, which is necessarily better than the others. However there are a variety of methods and measurements, which are more useful in the beginning of the process, because they are better describing the overall situation. In case these methods are not sufficient or the reasons of problem cannot be found using them, there are other possible ones to be used.

The most common field measurements used in office type environment are collected from literature and presented in this paper in general level. It describes some benefits and disadvantages of them and what kind of conclusions can be drawn from each measurement. This paper also presents a comprehensive process to improve both indoor air quality and thermal comfort using perceived indoor environment quality and users' health symptoms as starting point.

### Comprehensive Process to Analyse Indoor Environment

The method begins with occupant satisfaction survey that is directed to everyone working in a building, and focusing on various aspects of indoor environment, like thermal comfort, indoor air quality, lighting, acoustics, and cleaning, not only to a specific problem (Zagreus et al. 2004). Using occupant satisfaction survey all comments, also the silent, can be collected and take into account when doing decisions of improvements. Typically a web-based survey has been utilized as a diagnosis tool to identify specific problems and their sources. The approach of the web-based survey gives two main benefits: it can inexpensively be administered to all occupants in the building and its an interactive tool to "drill down" into areas that occupants rate poorly and thus in many cases diagnose the root of the problems. It is recommended, that the Örebro MM40 questionnaire (Andersson et al. 1993) is incorporated into the survey in order to collect users' health symptoms related to indoor environment quality. In many cases users are also reporting visual moisture damages in the building.

After that a preliminary technical analyse by multidisciplinary professionals is conducted on site in building areas where respondents are dissatisfied. These areas are defined using the indoor environment perception map (Takki and Virta 2007), which locates the problem more exactly into floors and facades as well as to specific areas of indoor environment.

The preliminary conclusion of problem areas and sources can be made based on the field analyse, users health symptoms and users' free comments. This is a basis of an action plan to further analyse the situation in specific areas of indoor environment, like in this paper IAQ or thermal comfort. After that first indoor air quality samples are collected, not as a first action. While all corrective actions are made, it is important to check that all problems are really solved. This can be done by analysing IAQ post-measurement samples and by conducting the post occupancy survey. Process is presented in Figure 1.

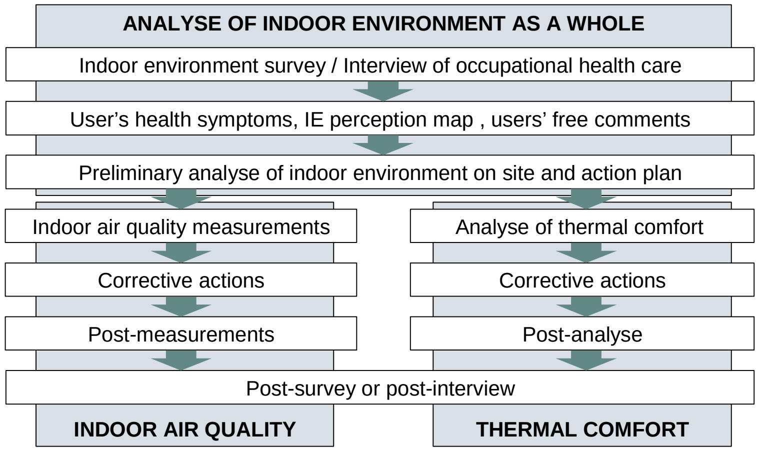


Figure 1. Comprehensive process is needed to improve indoor environment. Process should start by evaluating indoor environment as whole, and then focusing on the specific problem areas, like IAQ or thermal comfort.

**Methods to Analyse Indoor Air Quality**

Often the specific health problem of large number of users is the first sign of indoor air quality problems. However it is difficult to make concluding assumptions of reasons based on them, because various problems in indoor air quality can cause very similar health symptoms. Typical health symptoms are collected from literature and presented in Figure 2 (Reijula 2002; Mäkinen-Kiljunen and Mussalo-Rauhamaa 2002, Villberg et al. 2002). Many symptoms are similar, but main problem areas, i.e. mineral wool fibres, material emissions and building moisture, have some specific symptoms as well.

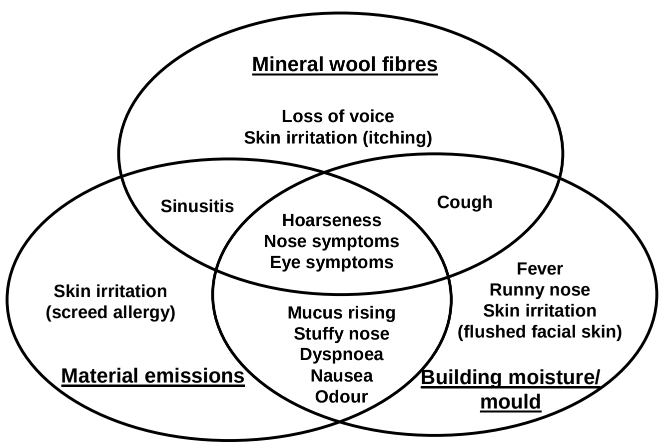


Figure 2. Typical health symptoms of users are often same, but each main problem has some specific symptoms as well.

Based on the health symptoms and preliminary field analyse, the indoor air quality measurements can be planed to clarify reasons behind the problems. It is recommended to start with measurements, which can provide information comprehensively. In the Table 1 some typically methods used in field surveys are collected. There is a short description of each method, what kind of general knowledge is needed and what kind of conclusions typically can be made based on them.

Table 1. Typical field analyse methods to study indoor air quality problems.

| Method | Measurements *(Required speciality)* | Conclusions |
|---|---|---|
| Settled surface dust sample (Wipe sampling) | - Contaminants in settled surface dust like mineral wool fibres, mould spores, soot, pollen from outdoor air, pet scurf and asbestos<br>*(IAQ specialist)* | - If sample include any contaminants, further analyse is needed to find pollutant sources.<br>- If sample do not include any contaminants, space is clean or surfaces have been cleaned in less than a week. |
| Indoor air / material emission sampling (TENAX) | - Chemical contaminants (VOC) in indoor air<br>- Material VOC emissions (FLEC)<br>- Others like PAH, ammonia and formaldehyde using other adsorbent<br>*(IAQ specialist)* | - Clarifies from which materials the divergent result comes (locates the problem)<br>- If sample do not contain vapour contaminations, there is no chemical emission sources in the space or the space has been ventilated just before collecting samples. |
| Volumetric air sampling (Andersen sampler) | - Culturable fungal spores present in the air<br>*(IAQ specialist)* | - If a sample contains divergent amount or distribution of mould spores compared with other spaces and outdoor air, further analyse is needed to find pollutant sources.<br>- If sample do not contain fungal spores, the space can be clean or there is no living spores in the air at time of measurement or spores do not germinate on the sampling media. |
| Surface and material sampling (bulk) | - Moulds actually growing on the surface sampled<br>*(IAQ specialist)* | - Determine whether the suspected surface (visible stain, discoloration, etc.) or material sampled is indicative of mould growth on the sample location.<br>- Determine whether there is a skewing in the normal distribution of spore types present on the surface.<br>- Direct microscopic examination of a surface shows exactly what is there.<br>- Surface sampling may also reveal indoor reservoirs of spores that have not yet become airborne.<br>- The presence of biological materials on a particular surface is not a direct indication of what may be in the air. |
| Surface moisture measurement | - Locating wet areas in floors, roofs and wall made of homogeneous material.<br>*(Building physics specialist)* | - Rapid and non-destructive determination of the moisture content of building and wood materials<br>- For preliminary analyse before destructive methods |
| Structural humidity measurement | - The water content of concrete in measured depths.<br>*(Building physics specialist)* | - Determine whether the structure is dry enough.<br>- Determine whether the conditions in specific structure are favourable for mould growth. |
| Thermal infrared imaging | - Air and thermal leakage in structures e.g. windows and external walls<br>- Temperature differences on the structure.<br>*(Building physics specialist)* | - Detect building abnormalities that result into energy losses.<br>- Find valuable information regarding moisture damage and possible mould infestation. |
| Room conditions measurement | - Room air temperature, relative humidity and $CO_2$-level in the measurement point<br>*(HVAC system specialist)* | - Give information about general quality of air and ventilation efficiency in the space.<br>- People experience too high room air temperature or too high $CO_2$-level as stuffy.<br>- Too humid room air is a risk factor to people and structures. |
| Airflow visualisation using smoke | - Air diffusion in the space<br>- Airflows between spaces<br>- Pressure difference between spaces<br>*(HVAC system specialist)* | - Determines whether the fresh air is ventilating the whole space (air diffusion)<br>- Determine impurities coming from other spaces. |

Poor indoor air quality can originate from various reasons like mould growth, unprotected or damaged mineral wool surfaces or chemical emissions. But at the same time there can be poor air diffusion in the space or problems controlling heating system. People experience too high room air temperature or too high $CO_2$-level as stuffy (Fang et al. 1998). Some of the measurements follows international standards and accredited methods, like indoor air emission sampling to measure volatile organic compounds (VOC). The result is always verified using reference sampling. This way the result is always reliable as long as the person carrying the test is qualified. Unfortunately this is not a case in some other measurements. There is a lot of variation in the field how the methods are used and how the results are construed. This is why it is important to understand the limits of each method.

The main rule when analyzing result is that, if the measured value is lower than time weighted average (TWA) concentration or other equivalent limit value, the room air quality is good. Luckily this is the case most of the time, but sometimes several contaminations at lower concentrations simultaneously can irritate people. As an example, high TVOC-value does not necessarily cause any health symptoms to people and there is no smell. Respectively we can measure low TVOC-value in the space, but people suffer from poor indoor air quality caused by VOC.  In these extreme situations the interpretation of result by professional is very important. Individual VOC-compounds are known to correlate already at low concentrations with users health symptoms like eye irritation and asthma. (Villberg et al. 2008; Metiäinen et al. 2006; Kim et al. 2006)

Mineral wool fibre irritation has been implicated as a significant agent correlated to the sick building syndrome and to health complaints (Schneider et al. 1986; Hedge et al. 1993)). The complaints associated with exposure to short fibres less than 500 µm in length. Often mineral wool fibre symptoms are interpreted wrongly due to very similar symptoms caused by mould spores or chemical emissions. Main sources in office environment are damaged sound absorption panels in the ceiling or sound attenuation materials inside the ventilation system. Repeated studies have shown correlation between surface concentration and air borne concentration of mineral wool fibre in the environment (Schneider et al. 1990). This is why the settled surface dust wiping method is very useful to identify both mineral wool fibre and other contaminants settled into the surfaces like mould and pollen (Morawska and Salthammer 2003).

Moisture damages and mould growth are the most difficult to locate and measure. There is not a single method, which in all conditions determine the mould growth. Sometimes the visual signs of moisture are clear and this is the time to repair them. It is very important not just to repair moisture damages, but also to prevent further damages in structures. However, if there is already a mould growth, it is difficult to locate it using non-destructive methods. This is why typically several methods and measurements are needed before even professionals can say is there a mould growth in structures or inside the ventilation system.

The most recommended methods are surface and material samples in case of clear moisture damage. Mould growth can be determined by comparing samples from damaged and health materials. If the damages are not visible, mould growth can be found using either settled surface dust samples or volumetric air sampling. Air sampling should not be the only method collecting information from moisture damage due to limitations on method (Meklin 2002). Culturable sampling methods require that the spores in the air are alive, survive the sampling process and germinate on the sampling media. Another problem is the background level of mould spores in the indoor air. This can be increased due to high concentration in outdoor air, human operation in the space or type of building. Wooden old buildings have higher background concentration than new concrete buildings. (Lignell et al. 2005, Meklin et al. 2005)

There are also some new methods to analyse mould spores. The recent studies demonstrate promising results using DNA techniques like quantitative polymerase chain reaction qCPR method. Methods based on DNA techniques are not dependent of the viability of the microbes, and they can be designed to work at different levels of specificity, detecting a whole group of microbes, a genus, or for example, a biosynthetic gene. (Rintala 2003; Lignell 2007)

**Methods to Analyse Thermal Comfort**

Based on the result of indoor environment survey, users' health symptoms and preliminary field analyse, more detailed thermal comfort analyses can be planed to clarify reasons behind the problems. Poor thermal comfort and drought causes typically following health symptoms: fatigue, feeling heavy-headed, headache, difficulties concentrating, thermal stress, sweating, cold hands and feet, and muscular pain.

Performing the technical analysis on site typically takes a few days. Typical methods to study thermal comfort are presented in Table 2.

Table 2. Typical field analyse methods to study thermal comfort.

| Method | Measurements *(Required speciality)* | Conclusions |
|---|---|---|
| Trend logs in building management system | - Room air temperature and $CO_2$-concentration near the room sensor<br>- Primary airflow rate and duct pressure<br>- HVAC-system set values<br>*(HVAC-system specialist)* | - System failures in building management system (BMS), in air handling unit (AHU) or in other system components.<br>- Major variation in room conditions caused by broken fan or released fire damper. |
| Airflow visualisation using smoke | - Air diffusion in the space<br>- Airflows between spaces<br>- Pressure difference between spaces<br>- Air tightness of window<br>*(HVAC-system specialist)* | - Determine the air movements in the space.<br>- Clarifies reasons for draught in occupied area, e.g. terminal unit, cold window surface, infiltration or pressure difference between spaces.<br>- Determines the operation of terminal unit. |
| Room conditions measurement | - Local air temperature, air velocity, $CO_2$-concentration and relative humidity<br>- Window and other surface temperatures<br>*(HVAC-system specialist)* | - Determine the room conditions during the measurement moment.<br>- Result is dependent on the actual measurement timing i.e. heat loads in the space, supply air condition (cooling or heating), sunshine, etc. |
| Measurement and audit of HVAC-system parameters | - Local airflow rates in ductwork branches and terminal units<br>- Water flow rates in heating and cooling system<br>- Condition of all HVAC-components<br>*(HVAC-system specialist)* | - Determine whether the ductworks and pipe works are in balance and operating with designed values<br>- Determine whether the system components, like AHU, fans, filters, condensation drain and valves are clean and in good condition |
| Thermal infrared imaging | - Air and thermal tightness of window<br>-Air conditioning room unit operation (e.g. chilled beam and radiant ceiling)<br>- Window surface temperature<br>Note: measurement is difficult due to reflections<br><br>*(HVAC-system specialist)* | - Determine the condition of window structures (window frame, between frame and wall structure).<br>- Determine too low or too high surface temperature of window or other surfaces.<br>- Give information of operation of room units and their management system .<br>- Give information of system failures in pipe work and BMS. |

When it comes to thermal conditions, the analysis concentrates on the locations of heat loads and heat losses, and on the functioning of ventilation, heating, and cooling systems. If the problem is draught feeling, it is important to study the airflows in the room with the help of e.g. smoke visualisation. In areas where the air quality is concerned, the focus is in the efficiency of ventilation in the space as well as in the pressure differences between spaces. The cleanliness of the air conditioning systems and inspection of the air conditioning devices are also important. The technical analysis results in an action plan that addresses reasons for problems and proposes future actions.

Problems in thermal comfort are often related to badly performing ventilation and heating systems. There are lots of problems both in HVAC system set values like, operation times of air handling units as well as air and water temperatures, and in operation of building management system. Sometimes bad thermal comfort is suffering from lack of cooling or heating capacity in the building or occupants and building maintenance personnel do not know how to use and operate building.

Solving draught problems using air velocity measurements specified in international standards e.g. ISO EN 7730 and ASHRAE Standard 55 is challenging. These standards specify the draught rating (DR) value i.e. the percentage of people dissatisfied due to draught. The draught rating is a function of local air temperature, local mean air velocity and local turbulence intensity. Recent studies indicate that this model should also take into account length of exposure, activity level and influence of the velocity directions (Griefahn et al. 2000; Toftum et al. 1997; Melikov 2005). The revision versions of both standards include a diagram estimating the air speed required to offset an increase in temperature. Also the individual control possibility is important for acceptance (Toftum and Melikov 2000).

By measuring the air velocity at the occasional moment in the empty space without occupant and internal loads, it is difficult to identify possible draught. Velocity field in a certain moment in the space is very much depending on the amount and the location of heat sources and primary air conditions. Loads, especially occupants and solar load as well as the airflow rate and supply air temperature of terminal unit varies all the time in the space. This is why the velocity field is not a stable, but there is both small turbulence and large-scale air movements in the space all the time (Kosonen et al. 2007).

This is why solving draught problem requires professionals, who are well aware of operation of terminal units and behaviour of heat plumes and air movements in the space. This is why this phenomenon is easier and faster to visualise using smoke instead of measuring local velocities and temperatures.

## CONCLUSIONS

Solving indoor environmental problems requires multi-professional skills, where at' least IAQ, building physic and HVAC-system specialists works together. It is also impossible to improve indoor environment comprehensively by only focusing on individual methods or measurements. This paper also presents a comprehensive process to improve both indoor air quality and thermal comfort using perceived indoor environment quality and users' health symptoms as starting point. To be able to decide what are the right methods in each project, it is important to be aware of what kind of conclusions can be made from each of them. Only by understanding the entire indoor environment it is possible to improve the perceived indoor environment for users' benefit.

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