

Indoor Technologies and Quality of Indoor Environment

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Abstract—Indoor technologies make every building a smart building generally. This enhances the user experience and convenience of your employees, visitors, patients and/or suppliers. The smart indoor technologies in the building help us to make the buildings more comfortable and healthy. The building becomes easy for using and the right operation of indoor services systems. The smart building also makes it possible to optimize processes, reduce costs and increase the environmental safety. The smart design approach makes innovative solution possible for every building and every expectation of indoor air quality. Today's HVAC technology offers the modern homeowner more options that make it much easier to meet your family's unique indoor comfort needs. Modern HVAC systems are becoming more and more energy-efficient, and you can choose a heating and cooling system that uses advanced, environmentally-friendly technology. Some of the new HVAC technologies and perceived indoor environment quality are presented in the paper.

Keywords—indoor technologies, indoor environment, perceived indoor environment quality

I. INTRODUCTION

In recent years, indoor environment quality has become a major issue in the concerns for healthy living. Indoor environmental problems have four common causes, and more than one may be active at any time: an inadequately cleaned or maintained environment, insufficient ventilation, pollutants emitted from sources and activities inside the building and contamination from outside sources. These causes can often intensify or add to the stress that occupants suffer from inadequate temperature or level of air change. The right design for and selection of the HVAC-system is extremely important from the hygienic thermal condition. Therefore, it is obvious that the indoor environment becomes at present the matter of broad interest. Indoor thermal comfort and indoor air acceptability are in consideration of specialists. The indoor thermal comfort auditing must nevertheless be the guiding factor for building design [1].

The problem of achieving healthy and comfortable buildings is well recognized by scientific community. The built environment is the place where people spend 60-90% of their life [2] and where about the 40% of the European energy is consumed [3], also to maintain and guarantee the required living quality. It is estimated that HVAC (Heating, Ventilation and Air Conditioning) energy consumption accounts for 10 - 20% of total energy consumption in developed countries [4]. The application of the integrated solution showed an improvement of the indoor air quality and comfort with a 15% of energy saving, compared to the

traditional thermostatic control [5]. Mostly buildings are designed to provide maximum comfort to inhabitants. HVAC systems are designed to provide fresh outside air for each building occupant. There is tendency to design the buildings to save energy. The size of spaces for heating and cooling is reduced, and outdoor air ventilation lowered. Moreover, many ventilation systems do not effectively distribute air directly to people in the buildings. Inadequate air diffusion combined with reduced ventilation causes reduced air quality level and complaints of the users [6].

Thermal comfort reception associated with the indoor temperature and air quality has nevertheless come to constitute a major problem in recent years. These problems are frequently linked to energy conservation. The development of reduction in energy consumption of buildings has been till this time realized mostly by using various types of materials respecting the thermal-technical properties of building constructions. It is necessary to use the theoretical approaches in design conception in order to accept energy conservation and environmental aspects on the way to the designing of acceptable thermal comfort in the buildings. The energy consumption is closely connected with arranging thermal comfort in the buildings and continual watching the indoor air quality by ventilation system. The dilemma does exist in the problem of air change and indoor air quality level as well as in the problem of energy consumption and thermal comfort.

Typically, the HVAC-system is designed for average person, with an assumption that up to 20% of the occupants may not be satisfied with environmental conditions. However, the dissatisfied people percentage can be much higher. The purpose of personally controlled environmental systems is to provide for the user an opportunity to control his indoor environment not only from energetic but also from hygienic point of view. One approach is to collect data from indoor environments and compare these indoor air pollutant measurements statistically with symptoms and perceived air quality indicated by responses to questionnaires. A more productive and economical method is to measure pollutant concentrations at problem sites and compare these results with measurements from environments, which are considered acceptable by occupants. Both approaches try to establish the critical concentrations of individual pollutants or the total amount of pollutants, which could be considered as acceptable safe limits to eliminate indoor pollution and for comfort.

Even all designed indoor environmental standards are met the users are usually not satisfied and perceived discomfort is occurred in their indoor environment [7]. This is an exciting

time to be a prospective designer of one of the latest models of heating, ventilation and air conditioning equipment that are currently on the market. Today's HVAC technology has advanced to such a degree that the indoor comfort systems available to modern homeowners offer more state-of-the-art options and features than heating and cooling systems have at any other time in the history of HVAC. Plus, there are even more emerging technologies on the horizon. This makes it much easier than ever before to find the system that will work best to meet your family's home comfort needs in our climate. The following information will help better understand and apply the many advantages of today's high-tech HVAC technology to family's own unique indoor comfort challenges. The main function of HVAC-technology design is to provide for thermal comfort, sufficient ventilation and air cleaning in order to create good environmental conditions from thermal comfort and hygienic indoor environment point of view.

II. INDOOR TECHNOLOGIES

The inadequately maintained environment is the consequence of inattention to the different emissions and by products of activities indoor and the need for constant ordering. There are some new technologies as programmable thermostat technology, whole-house ventilation system, mini-split or multi-split system, variable-speed system, dual-fuel heat pumps etc. Some people like to dictate every nuance of their climate, from humidity to temperature. Some like remote access to tinker with temperature and save money even when they're not at home. Some like to specify preferences in eight different rooms. And some people simply don't want to have to think about it at all.

A. Programmable Thermostat Technology

Your heating and cooling system is where you spend most of your energy so saving on your utilities is important. The innovative thermostats are designed to combine home comfort with reduced energy use. Homeowners saved an average of 20% on their heating and cooling energy costs. Based on our comparative study of programmable thermostat technology to the estimated cost of a non-programmable thermostat set to 22°C at all times. It's what we call the heart of a smarter home. You can set a programmable thermostat based on when you wake up, or according to whether you are asleep or at home. These energy-saving settings should also be applied for periods of eight hours or more. With many models, you can control multiple areas or zones, so you never have to waste energy conditioning an unoccupied room. Zoning is also a great way to make places that are usually too warm or cold more comfortable. Many programmable thermostats can also connect wirelessly to your computer, tablet, or smartphone. They can even remind you to change your air filter or monitor your indoor air quality and humidity. User-friendly touchscreens make them easier to use than standard thermostats.

B. Whole-building Ventilation Systems

Whole-building ventilation systems, also called advanced fresh air systems, provide ventilation without

wasting energy and use a filter to remove pollutants that come from outside. They lower the concentration of contaminants like mold spores, dust, dirt, pet dander, and pollen in home. Many states require advanced fresh air systems in new homes. These systems have two small fans placed next to each other. One fan pumps fresh air into your home, and the second pumps the same amount of stale air out. As the air streams pass each other, heat exchangers move energy from one to the other, heating or cooling the fresh air like a heat pump. This is more efficient than generating heat from scratch. They can also remove moisture to lower your indoor humidity. Poor ventilation sometimes is the result of dirty air filters that need periodic cleaning or replacement. Left alone, they accumulate, causing odors, and in some cases increasing environmental risks to humans. They need to be removed through cleaning and maintenance.

C. Mini-split or Multi-split Systems

Ductless HVAC systems, also called mini-split or multi-split systems, have an outdoor unit and one or more indoor units linked by a conduit that's only about 8 cm wide. Since there's no ductwork, you'll never have to worry about leaks in your ducts or pollutants that accumulate there over time. A ductless system leaves you with more room in your attic and throughout your home, saves energy, and does more to improve indoor air quality. It's also much quieter than a traditional system. The indoor units make zoning with a programmable thermostat easy and some systems even come with remote controls. They are also easy to install which translates to lower costs when compared with a standard system. The outdoor unit can be placed up to 15 m away from the indoor units.

D. Variable Speed Technology

One of the most valuable features today's systems offer is variable speed technology. Unlike single-stage, which runs at one fixed speed, variable speed technology continuously adjusts the system's speed depending on the conditions present inside your home at any given time. This technology allows the system to be more responsive to your family's indoor comfort needs, while avoiding the sudden blasts of hot or cold air that fixed-stage systems routinely deliver. Instead, variable speed technology is designed to keep your home more consistently warm or cool over time. This technology is available in both indoor units (air handlers) and outdoor units (compressors) — a combination that provides the ultimate mix of responsive HVAC technology. Variable-speed HVAC systems can automatically run hotter or colder, increase or decrease airflow, based on your needs. Standard systems simply turn on until the temperature matches the setting on your thermostat. The added features that come with a variable-speed system save energy and make your home more comfortable.

E. Dual-fuel or Hybrid Heat Pump

Conventional heat pumps are inefficient when temperatures are near freezing, so upgrading to a dual-fuel or hybrid heat pump can be more beneficial. A hybrid heat

pump incorporates the furnace for added heat during the colder months. However, these systems are ideal in regions with a moderate climate and in warmer seasons, the heat pump part can heat or cool your home for less. With most hybrid systems, you can also switch between fuel sources manually, so you won't have to use a furnace when natural gas is more expensive.

III. THERMAL COMFORT

The thermal comfort is defined as the state of mind that expresses satisfaction with the indoor thermal environment. It is a subjective impression based on the occupant's perception of temperature, humidity and air movement and the effort needed to remain comfortable. Although overall room temperatures may be comfortable, occupants can still experience local discomfort. The local horizontal and vertical temperature differences, either over a room or radiating from a source, can create local discomfort.

The room temperature is probably the most important factor perceived by the individuals and affecting the acceptability of indoor climate. Usually in the countries with cold climate the most acceptable room air temperature seems to be approximately 22°C for winter period of the year and 25°C for summer year period.

The percentage of dissatisfied usually increase rapidly with deviation from this temperature. The occurrence of sick building symptoms increases with increasing temperature, and draft complaints with decreasing temperature. Because of personal, physiological and behavioral differences, individual control of temperature between 20 - 24°C is recommended in the winter season and 23 - 26°C is recommended in the summer season. If occupants complain of hot or cold areas, building operators must ensure that vertical temperature differences are no greater than 3°C. The air humidity affects thermal sensation even in neutral conditions. Dehumidification can be used to decrease the effect of high temperatures. A decrease in relative humidity of 15% corresponds with the temperature decrease of 1°C. The humidification increases the sensation of warmth. The influence increases with the deviation from the neutral temperature.

From obtained experiences on the base subjective assessment processing of indoor thermal conditions the parameters of thermal comfort usually don't respond of thermal comfort real perception of users majority. The requirements of the users for the room temperature are mostly substantially higher. The sensory assessment was realized in the winter season. The thermal resistance of single-layer clothing was specified as $R_{cl} = 0.3$ clo, airflow was negligible, relative humidity was in the range $rh = 35 - 45\%$. Percentage representation of man and woman was 50%. For subjective assessment was used scale from -3 to +3, according to the building users were expressed to level of thermal comfort. They indicate their sensory acceptance numerically in accordance with scale signed as comfort, moderate discomfort.

In the Table 1 the results of thermal parameters subjective sensory assessment are presented for indoor thermal conditions: some indoor technology used (A) and no indoor technology (B) building.

TABLE I. INDOOR THERMAL COMFORT PERCEPTION [%]

	18°C		20°C		22°C		24°C		26°C	
	A	B	A	B	A	B	A	B	A	B
Comfort	0	0	15	20	50	52	61	18	17	11
Moderate discomfort	14	18	23	34	12	30	25	52	47	25
Discomfort	19	21	48	27	31	14	12	22	26	40
Considerable discomfort	67	61	14	19	7	4	6	8	13	19

Source: Author

Generally the temperature 18°C was considered only by 14 - 18% of respondents' sense as comfort or moderate discomfort, while 82 - 86% respondents indicate discomfort or considerable discomfort. By the standard temperature 20°C only 15 - 20% users indicate comfort and 14 - 19% users indicate considerable discomfort. The 23 - 34% respondents indicate moderate discomfort and 27 - 48% discomfort. The 62 - 82% respondents answer on the behalf of temperature 22°C. The temperature 24°C was considered by 70 - 86% of respondents' sense as comfort or moderate discomfort. The temperature 26°C was considered by 39 - 59% of respondents' sense as discomfort or considerable discomfort. The environment is considered as satisfactory, with which 80% of users are satisfied, i.e. 20% are not fully satisfied. From this point of view the satisfactory temperature is 22 - 24°C in dependence how is the room used.

The term as minimum, maximum or optimum don't have relevant importance by the design and assessment of indoor thermal comfort by reason of various thermal comfort level perceptions. Non-uniform thermal conditions are sometimes created on purpose, for example, with displacement ventilation. The recent experiments show that people are not very sensitive to a vertical temperature gradient as long as the thermally neutral conditions for the whole body are maintained. The temperature at the height of 0.6 - 1.0 m is the most representative for users of indoors.

Preliminary experimental results showed that in the range of 23 - 24°C, the increase of global temperature by 1°C had approximately the same effect on total comfort as the increase of the noise level by 4 dB(A). Draft is caused often by cold vertical surfaces. The maximum velocity and minimum temperature on the floor level can be calculated with the surface temperature, height of the cold surface and the distance from the wall.

IV. THE IMPORTANCE OF USER CONTROL

If users are allowed to participate in the process of determining the characteristics of their environment, they are far more likely to be satisfied and comfortable. As appears to be the case for thermal comfort, increasing user control over the indoor environment potentially provides greater occupant comfort and satisfaction with lighting, acoustics, and indoor air quality. If users don't control some important characteristics of their indoor environment, it is virtually impossible to create conditions that will satisfy the vast majority of occupants. So why, then, don't building designs simply enable users/occupants to control the fundamental decisions about their indoor environment, at least those that are easy for users to control? Historically important methods of environmental control by occupants have included among

others operable windows, local heating/cooling devices, and personal fans. These means of occupant control can enhance user selection of light intensity and spectral quality; view to the outdoors, local air movement, temperature, among many others.

Because many strategies and technologies that increase user control require less energy intensive technologies and avoid the need for centralized control, such systems are potentially less costly to construct and less costly to operate. They are also less susceptible to catastrophic failure that can result in very uncomfortable or unhealthy conditions. The examples of user controlled technologies for the indoor environment are noted in the Table 2.

TABLE II. EXAMPLES OF USER CONTROLLED TECHNOLOGIES

Technology	Controls
Operable windows	Ventilation, thermal environment, air quality
Local heaters, coolers	Thermal conditions
Personal air supply	Ventilation, air quality, noise

Source: Author

In naturally-ventilated buildings, sometimes referred to as passively-ventilated buildings, where outdoor air ventilation rates are generally half and volatile organic chemical (VOC) concentrations are roughly double those found in mechanically-ventilated buildings, occupants report lower SBS symptom prevalence than in buildings with central heating, ventilating, and air conditioning systems [7]. Occupants also report higher levels of thermal comfort under a far wider range of conditions in naturally ventilated buildings. Most such naturally ventilated buildings have operable windows occupants can control. In contrast, engineering solutions to ventilation and thermal control with central HVAC in buildings without operable windows are designed with the expectation that they might deliver thermal comfort and acceptable indoor air quality to 80% of the occupants, even when the systems work properly as designed.

Is it necessary to aim so low in providing control of environmental conditions in buildings? Is there a compelling reason to ignore the available, less energy-intensive, less costly approaches that involve users in the control of their own environments? Why is it that naturally-ventilated buildings with operable windows produce more desirable environments?

Naturally ventilated buildings may be noisy due to traffic and other urban noise outside, and if predominantly illuminated with daylight, they may have more uneven illumination among various parts of the space. Thus, it is exactly the opposite of what laboratory and field research has described as the most desirable indoor environment. Why is it so? Answers to these questions might help us understand better how architects and engineers can design environments that fulfill the aspirations of their occupants.

V. PERCEIVED INDOOR ENVIRONMENT DISCOMFORT

In the case of perceived discomfort in smart buildings, the questionnaire as subjective assessment tool includes demographic characteristics covering age, gender, type of

work and type of work. Questions also ask about users' perceived comfort related with physical factors in the indoor environment covering temperature, indoor air quality, lightning and noise; including users' self-assessment of productivity in relation to physical factors. Important part of the questionnaire includes questions related with smart buildings negative factors affected primarily psychological well-being of users. Occupants would then ask about other unknown factors with impact on their well-being and perceived comfort. Environmental factors (temperature, air change, air quality and noise) were perceived in indoor environment at conditions where some new technologies are used and where no indoor technology is used. The TVOC and CO2 are the crucial parameters to assess the indoor air quality. The differences in perceived air quality were obvious between the different indoors conditions. The perceived indoor environment quality and thermal environment was considered more comfortable at higher ventilation rates and higher indoor temperatures. Perceived indoor environment discomfort expressed as percentage of dissatisfied with used and not used indoor technologies are noted in the Table 3.

TABLE III. PERCEIVED INDOOR ENVIRONMENT DISCOMFORT

Environmental Factors	Perceived Discomfort	
	Indoor technologies used	No indoor technology
Thermal condition	16	27
Ventilation	21	18
Air quality	14	36
Noise	29	12

Source: Author

VI. CONCLUSION

The paper confirmed that smart buildings with controlled ventilation, heating etc. does not always provide sufficient user comfort even though the standards and legislative requirements are met. It was also shown that the thermal comfort is very important as the primary factor of indoor environment quality perception. The other physical, chemical and biological pollutants are after-watching by occupants and usually have negative health impact. Inadequate HVAC system design affects too much warmth or too much cold, uncomfortable humidity and annoyed air movement. The building users need the freedom to satisfy their thermal comfort preference. People regulate their comfort by changing their clothing, activity levels, posture or location. They may alter the thermostat setting, open or close a window or leave the space. Unacceptable indoor environmental conditions can make occupants physically uncomfortable. The quality of this environment is determined by operation of the HVAC-systems. The right design for and selection of the HVAC-system is extremely important not only from thermal comfort but also from indoor air quality point of view. There is an evident need for better understanding of the impact of the environmental conditions on the health and comfort of humans.

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