Understanding the Indoor Environment: How To Assess and Improve Indoor Environmental Quality of People?

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Abstract
For the establishment of basic requirements and needs a different view on indoor environment quality (IEQ) is required. An integrated approach towards risk assessment of IEQ, in which the focus is on real exposure situations rather than only on single components, will form the basis for creating healthy and comfortable indoor environments. Additional, a multidisciplinary interactive top-down approach is required to facilitate the design, construction, maintenance and operation of an indoor environment, in which the architect as well as the other stakeholders fulfil a new or different role. It is important to accept that IEQ is a multi-level, multi-factor and multi-stakeholders issue, therefore cooperation is a must.

Keywords – indoor environment; risk assessment; multi-disciplinary approach; health and comfort

1. Introduction

The challenge of today lies in the accomplishment of sustainable and low-energy built environment and at the same time healthy, comfortable, accessible and safe built environment. Health and sustainability are interrelated in many ways. In the built environment a major reduction of the fossil fuel consumption should be achieved in order to meet the Kyoto targets. The existing stock is however, far from the currently discussed low-energy standards and the path towards future low-energy use, or even energy autonomy or energy-positive buildings is seriously hampered by the fear of introducing a negative impact on human health. No consensus understanding of this relationship between energy efficiency and IAQ exists.

How to achieve a healthy indoor environment has been an issue among architects, engineers and scientists for centuries. However, it was not until the early decades of the twentieth century that the first relations between parameters describing heat, lighting and sound in buildings and human needs were established. In fact, the last hundred years have seen much effort put into management of the indoor environment with the goal of creating healthy and comfortable conditions for the people living, working and recreating in them for more than 90% of their time [1]. Nevertheless, enough health problems and comfort complaints still occur to trigger more research and development. For most of the time, science has relied on the optimisation of single factors such as thermal comfort or air quality. The realisation that the indoor environment is more than the sum of its parts, and that its assessment has to start from human beings rather than benchmarks, has only been gaining ground in recent years.

2. Fact and Gaps

2.1. Wellbeing and Health

Previous studies have shown that the relationships between indoor building conditions and wellbeing (health and comfort) of occupants are complex (e.g. [2], [3], [4], [5]). There are many indoor stressors (e.g. thermal factors, lighting aspects, moisture, mould, noise and vibration, radiation, chemical compounds, particulates) that can cause their effects additively or through complex interactions (synergistic or antagonistic). It has been shown that exposure to these stressors can cause both short-term and long-term effects. In office buildings, a whole range of effects have been associated with these stressors such as Sick Building Syndrome (SBS), building related illnesses and productivity loss [1]. People in the Western world in general spend 80-90% of their time indoors (e.g. at home, at school, at the office etc.). And the increased asthma prevalence in most countries in the past decades, it has become the first chronic disease in childhood [6], seems to put a finger to the indoor environment of schools and homes. More recent studies have indicated that indoor building conditions may also be associated with mental health effects [7], illnesses that take longer to manifest (e.g. cardiovascular disease [8], [9]; a variety of asthma-related health outcomes [10]) or obesity [5].

On the other hand little is known on how indoor building conditions can contribute in a positive manner. What is known is mostly related to single aspects as for indoor stressors, e.g. the benefits of additional light for elderly suffering from dementia. How are interacting IEQ aspects contributing to feelings of well-being, health, productivity and/or recovery? If we are serious about improving the indoor environmental quality, indoor stressors are important as a means to prevent possible harm but opportunities to contribute in a positive manner, should not be overlooked.

2.2. Methodologies

Methods applied in IEQ investigations vary from an epidemiological approach, in which questionnaires and health/comfort data may be used either in combination or not with biomarker sample collection (e.g. blood, urine), field studies in which in general a smaller sample of persons is studied in combination with environmental inventories, to laboratory studies in which persons or animals are exposed to controlled environmental conditions. Health and comfort data are then combined with information on characteristics of the indoor environment in order to find relations. However, other risk factors that may cause psychological or physiological stress (e.g. major life events), individual differences caused by personal factors (e.g. states and traits), or history and context can all affect the outcome that is being studied. These factors are taken into account only to a limited extent in current methods commonly applied to identify relationships between health and comfort of people and the physical environment 11].

2.3. Indoor Environmental Control

Over the years, control of indoor environmental factors has focused merely on the prevention or cure of their observed physical effects in a largely isolated way - i.e. trying to find separate solutions for thermal comfort, lighting quality, sound quality and air quality with models that in general consider only physical conditions and address only one parameter at a time. Many control strategies for these parameters have been implemented in order to minimise or prevent possible diseases and disorders of the human body and its components. Only in the last decades of the 20th century an attempt was made through epidemiological studies to approach the indoor environment in a holistic way. The scientific approach towards evaluating and creating a healthy and comfortable indoor environment developed from a component-related to a bottom-up holistic approach that tried simply to add the different components. Performance concepts and indicators emerged, including not only environmental parameters but also possible associated variables such as characteristics of buildings. New methods of investigating IEQ from different perspectives were introduced. Nevertheless, control strategies were still focused on a component basis. Even though these control strategies are currently being applied, complaints and symptoms related to the indoor environment still occur.

Our current standards are focussed mainly on single-dose responses. With the exception of health-threatening stimuli, the complexity and number of indoor environmental parameters as well as lack of knowledge make a performance assessment using only threshold levels for single parameters difficult and even meaningless. Most standards are based on averaged data and do not take into account the fact that buildings, individuals and their activities may differ widely and change continuously; not every person receives, perceives and responds in the same way. This is due to physical, physiological and psychological differences but also to differences in personal experience, context and situation. Considering both the numerous indoor stimuli and the lack of a solid scientific basis, it appears implausible to make the final and complex integrating step.

2.4. Building Process

Besides the discrepancy between standards and end-users wishes and needs, there also seems to be a discrepancy between what end-users want and what they get. The latter is often blamed to be related to the complex communication and the fragmented structure of the building sector, leading to lack of coherency, lack of life cycle orientation and slow take-up of innovation. Additional, the general awareness of what indoor environmental quality is, how you can improve it and who should or can undertake actions, is poor. The dynamic process of designing, constructing and managing the indoor environment, involves many stakeholders, such as the investor, owner, the end-user, the contractor, sub-contractors, local authorities and pressure groups, but also the persons that maintain the indoor environment. If those stakeholders do not understand each other, problems can occur.

Well-being (health and comfort) is an important aspect determining the quality of life of an occupant. In late 1980s and during the 1990s, the WHO concept of health, became significant for identifying the concept of a "healthy building" in terms of building performances (i.e., indoor air quality, thermal comfort, lighting quality and acoustics). A healthy building is free of hazardous material (e.g., lead and asbestos) and capable of fostering health and comfort of the occupants during its entire life cycle, supporting social needs and enhancing productivity. Human health and comfort needs are recognized as priorities. In addition a healthy building should be ready for the future, adaptable to 'new drivers' such as climate change, the change towards a multifunctional and diverse society, the increasing individualisation and the observed change in the type of end-users wishes and demands.

3. Needs and Opportunities

3.1. A Different View

Although previous studies have shown associations between indoor stressors and comfort, health and productivity, relevant relations between measurements of chemical and physical indoor environmental parameters and effects have been difficult to establish (Review in [1]). This may be explained by [12]:

- Many exposure-response relationships have not yet been (sufficiently) quantified or identified.
- Little is known on the complex interactions between risk factors (or parameters) in the indoor environment and effects are not all known.
- Other factors other than indoor environmental aspects (e.g. social and personal factors) may influence the effects.
- Exposure and response may be time dependent (e.g. daily, weekly and seasonal patterns).

For the assessment of health and comfort risks of people have when staying indoors, it is clear that a different approach or procedure seems inescapable. A ‘different view on IEQ’ could help to better understand the indoor environment and the effects on people. A view in which IEQ is approached in an integrative multi-disciplinary way, taking account of possible problems, interactions, people and effects, focusing on situations rather than single components (see Fig. 1 and Table 1) [13].

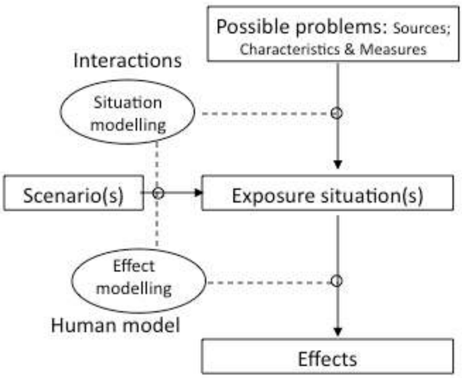

Fig. 1. A different view on indoor environment quality.

Table 1 The implications of working with an integrated approach for IEQ.

FROM	TO
Insight in single dose and response relationschips	Insight in interacting parameters
Attention directed mainly to negative impacts	Attention to positive and negative impacts
Distributed knowledge on effects on indoor environment quality	An integrated framework on indoor environment quality effects
Ad hoc collection of recommendations to improve IEQ	An integrated approach for IEQ improvement
Management of incidents	Integrated risk management
Ad hoc communication of possible roles for different stakeholders	An integrated approach which provides insight in the tasks for all stakeholders

3.2. Systems Approach

Optimization of IEQ and energy efficiency is on the one hand hampered by a lack of information regarding which indicators, criteria and interrelations need to be considered and on the other by the organizational structure and processes of the life cycle of construction.

First of all, a framework that makes the links and interactions between overall (system) requirements design and technical requirements for the different phases of a building clear to all stakeholders is needed [14].

Secondly, to get more grip on the communication and risk related processes in the building process, including the IEQ issue as well as the energy consumption issue, an interactive top-down approach can be applied, such as systems engineering (SE). SE is already employed in the aerospace and the automobile industries, but much closer to home in public civil works. SE can be applied to guarantee that all parties involved in a project, work together in achieving predefined goals with respect for the environment and stakeholders values (see Table 2). In this systems approach the built indoor environment is considered a system with sub-systems that do matter, but the system will only function if all sub-systems (components) are optimised along with the total system, whether this is related to health, comfort or sustainability issues. [14].

Table 2 Possible goals and stakeholder values.

	Human being	Building	Control/ services	Total Life cycle manage-ment
Goals	Wellbeing and society	Energy-efficieny and Functiona-lity	Control and maintenance	Sustaina-bility and Economics
Values	Health & Comfort Safety & Security Usability & Accessibility Aesthetics & Image Cultural & Social	Energy efficiency Adaptability & Expandability Obsolescence & Degradation	Operational reliability & Maintainable Inside & Outside services Security & Emergency	Environment & Energy management Water & Waste management Investment & Life cycle costs
Info type	Basic criteria occupants and stakeholders	Basic criteria building structure and materials	Interactions occupant and building	Interactions building and environment

To accomplish this optimization, a set of processes can be applied throughout the life cycle of the systems created by humans through the involvement of all interested parties (stakeholders) with the ultimate goal of achieving customer satisfaction (see Fig. 2).

Fig. 2. Values, processes and requirements.

4. Next Steps

4.1. Human Model

Response mechanisms of the human systems (e.g. oxidative stress, endocrine disruption, circadian entrainment, anti-stress hormonal responses, cell changes and cell death) are being studied extensively. Nevertheless, we simply do not know all the interactions or mechanisms taking place between the sources that produce/cause the stimuli (stressors), among the stimuli, and between the stimuli and the exposed persons. To be more successful in determining the health and comfort effects of certain indoor environmental aspects it is essential to understand the mechanisms behind how and why people respond to external stressors. The next step is then to determine which parameters or indicators can be used to explain these responses and how to assess those. When the picture is more clear, procedures can be improved in such a way that the chances to successfully assess the effects caused by different stressors (or combination of stressors) increase.

4.2. Scenarios

Depending on the scenario and the profile of the occupant of concern, patterns and interactions of cause-effect relationships need to be established, starting with the indicators of both causes and effects and the assessment protocols. To be able to perform such a situational analysis, the 'right' model or algorithm is required. A model that is suitable for determining patterns and interactions, and take account if dynamic behaviour. The normally applied regression-based models are concerned with assessing the relation between 'independent; variables and 'outcomes' of interest, and do little to take into account the dynamic and reciprocal relations between some 'exposures' and 'outcomes', discontinuous relations or changes in the relations between 'exposures' and 'outcomes' over time.

4.3. Indicators

Since we cannot wait until we fully understand all the interactions or mechanisms taking place between the sources that produce/cause the stimuli, among the stimuli, and between the stimuli and the exposed persons, for defining the performance criteria of the system and its sub-systems, the use of *short-cuts* is being investigated [15]. In a short-cut, the building characteristics (such as having an HVAC system) or measures taken (such as a maintenance or cleaning schedule) are directly related to comfort or health responses of occupants. A framework of short-cuts determined in previous studies and projects and other bottom-up information conceived during the life-cycle, could serve as a database of knowledge during the whole building life cycle. This framework or verification matrix can also contain information on the end-user wishes & needs both present and future, the (social) context & factors of influence on health, comfort, sustainability and other aspects; and information on the interactions at all interfaces of human being, indoor environment, building (elements) and outdoor environment (over time). That information can be used to make optimal choices, also in relation to other values (e.g. sustainability, affordability) (see Fig. 3).

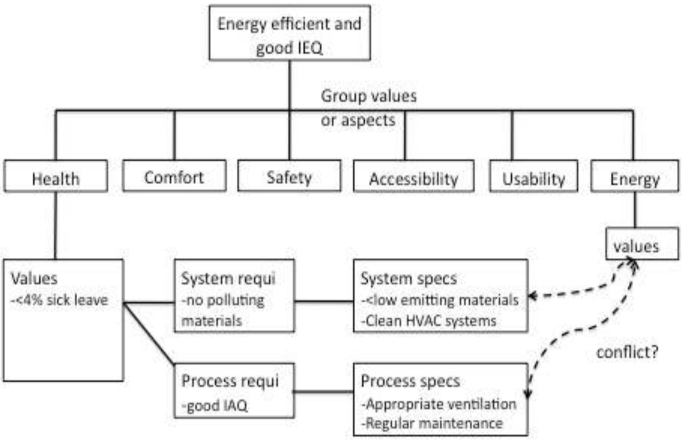

Fig. 3. Pathways for optimal choices.

4.4 Systems Engineering Process

How to use life-cycle based systems engineering [16] as an integrated project management process, to embed the research results in a concise and effective manner to achieve the general objective(s), is then the final step. For translation of the indoor environmental requirements to technical performance requirements of the built environment, the interactions are of utmost importance but also the applied communication process in the top-down approach and the realisation that performance requirements as well as wishes and demands can change over time and are context related. Eventually, the wishes and demands of end-users have to be translated into real building products (building and elements) and processes (maintenance, energy use, security, environmental services) by the stakeholders involved in the whole life-cycle of the indoor environment of concern. Component related and holistically at the same time.

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