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The need for understanding the indoor environmental factors and its effects on occupants through an integrated analysis

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Abstract. Research has shown that, even though the conditions seem to comply with current standards for indoor environmental quality (IEQ) based on single-dose response relationships, staying indoors is not good for our health. In the last three decades, many studies all over the world have been performed to identify and solve health and comfort problems of occupants. In our current standards, IEQ is still described with quantitative dose-related indicators, expressed in number and/or ranges of numbers for each of the factors (indoor air, lighting, acoustics and thermal aspects). Individual differences in needs and preferences of occupants (over time) are not accounted for. Other stressors and factors, whether of psychological, physiological, personal, social or environmental nature, are rarely considered. Interactions of stressors and effects at and between human and environment level are ignored. The focus is on preventing negative effects: positive effects are usually not considered. There is a need for an integrated analysis approach for assessing indoor environmental quality, which takes account of the combined effects of positive and negative stress factors in buildings on people (patterns), interactions, as well as the (dynamic) preferences and needs of occupants (profiles) and dynamics of the environment.

1. Introduction

People, in general, spend 90% of their time, or more, indoors: more than 60% of their time at home [1] and the rest of their time at their work, at school and/or commuting. Staying indoors is not good for our health, even though the conditions seem to comply with current guidelines for IEQ, that are based on single-dose response relationships, and on preventing diseases and disorders rather than focusing on positive effects [2]. Studies all over the world have shown that relationships between indoor building conditions (thermal aspects, ventilation, lighting, moisture, mould and noise) and wellbeing (health and comfort) of occupants of office buildings, schools and homes are complex and not easy to unravel (e.g. [1, 3, 4]). There are many indoor environmental stressors that can cause their effects additively or through complex interactions: thermal factors (e.g. draught, temperature), lighting aspects (e.g. reflection, view, luminance ratios), air quality (e.g. odours, moisture, mould, radiation, chemical compounds, particulates) and acoustical aspects (e.g. noise and vibration) [5-6]. Studies show that indoor building conditions may be associated with discomfort (annoyance), building-related symptoms (e.g. headache, nose, eyes and skin symptoms, and fatigue), building related illnesses (e.g. legionnaires disease), decrease in learning ability and productivity loss [2]. Mental health effects [7], obesity [1] and illnesses that take longer to manifest (e.g. cardiovascular diseases [8]; asthma-related health outcomes [9]) all have been associated with exposure indoors. It is known that these effects can be influenced by other factors and stressors than the environmental parameters used in guidelines, whether of psychological, physiological, personal, social or environmental nature (Figure 1). This mixture of stressors, people are exposed to, changes over time and exposure is influenced by past exposures and interactions that occur between those stressors (e.g. [2]).

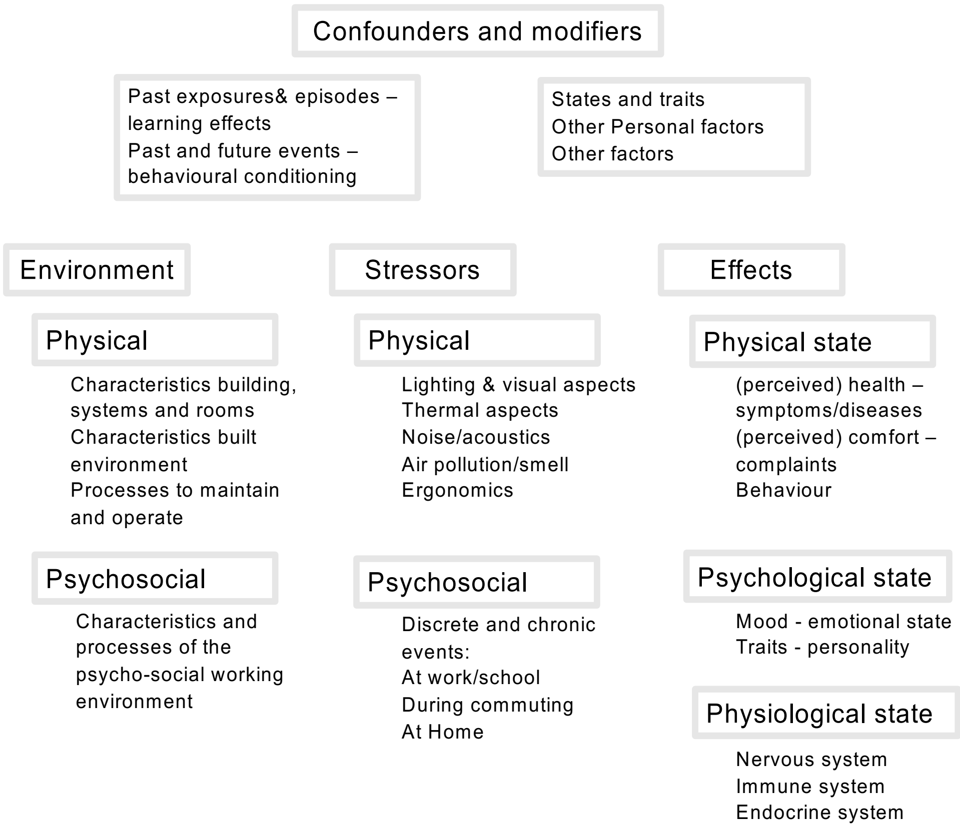

Figure 1. Stressors, factors, causes and effects (adapted from [10]).

The built environment and its indoor environment with occupants is clearly a complex system characterized by feedbacks, interrelations and discontinuous non-linear relations [11]. Nevertheless, IEQ is still most of the time assessed by dose-related indicators, based on linear single dose-response relationships for negative stressors, developed for the average occupant (whoever that is); ignoring that weare dealing with *individuals in different scenarios* (e.g. homes, offices and schools) and *situations* (sitting behind a desk, in a meeting room listening, on the phone, washing, cooking, sleeping, etc.); ignoring *other stressors* (physical, physiological, personal, psychological and social) and their *integrated effects* over time; and ignoring *interactions* between stressors in real-life exposure situations at environment level and interactions between various body responses to exposure(s) at human level.
Current standards are mainly focused on single-dose relationships. Which works well for health threatening exposures for which a clear dose-response relationship has been determined, but complexity, number of indoor environmental parameters and lack of knowledge, make a total performance assessment using only threshold levels for single parameters difficult and even meaningless.

2. Need for a more complex research model

There is a need for an integrated analysis approach of indoor environmental quality, which takes account of the combined effects of positive and negative stress factors in buildings on people (patterns), interactions, as well as the (dynamic) preferences and needs of occupants (profiles) and dynamics of the environment [2]. This requires a more complex research model than the conventional 'dose-response' model. A model that includes all *interactions* for both the environment (the situation) and the occupant: the stress factors caused by the (indoor) environment a person is exposed to (patterns of stressors) as well as the individual differences in needs and preferences (profiles of people), depending on their behaviour (activities) [11]. The research model presented in figure 2, includes therefore two sub-models [11]:

- *The human model* (Figure 3), that defines preferences and needs (profiles) of the occupants for which the assessment is performed.
- *The environment model* (Figure 4), that includes patterns of stressors (positive and negative) that should be taken account of in the assessment.

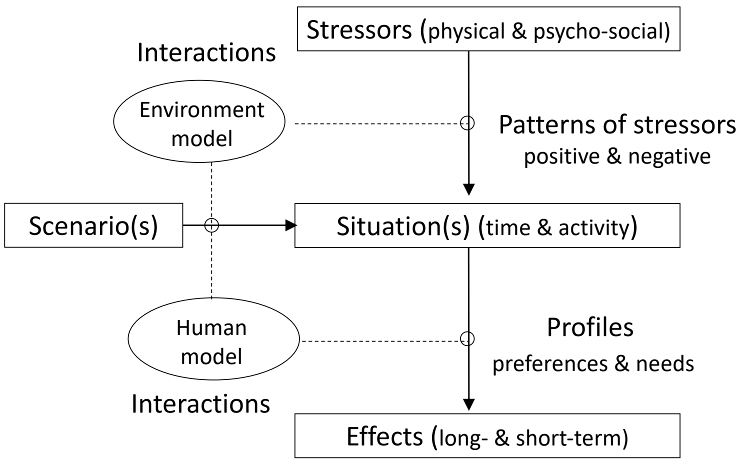

Figure 2. Model for the integrated analysis approach [11].

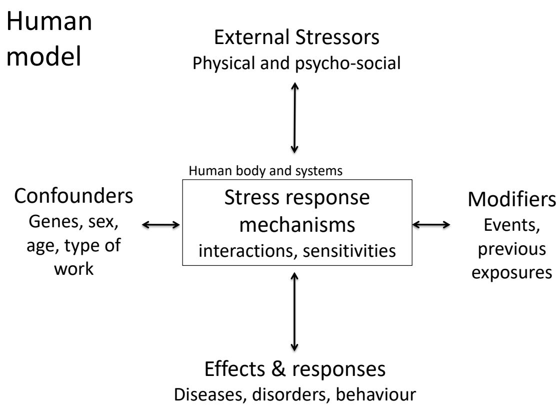

Figure 3. The Human model [11].

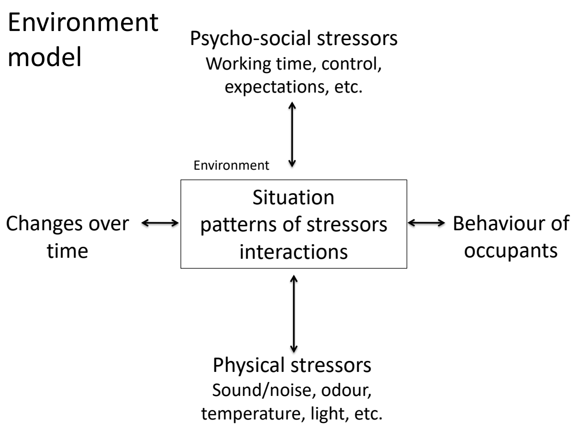

Figure 4. The Environment model [11].

2.1. Interactions

Interactions occur both at environmental and human level. Indoor air, thermal environment, acoustics and lighting conditions are all interconnected in the indoor environment. At environmental level, for example:

- Chemical interactions between pollutants in the air and on surfaces.
- Interactions between thermal, light and air conditions, when sunlight heats indoor surfaces, and emission rates usually increase.
- Acoustics and air, via the introduction of (air flow and equipment) noise caused by mechanical systems, or via natural ventilation through open windows, bringing in the noise produced outdoors indoors.

Previous studies have shown that at occupant level interactions occur via the mechanisms (see Figure 5) the human body has to cope with the different environmental stressors, influenced by confounders, modifiers and individual differences [10]. The faling to cope can result in several diseases and disorders.

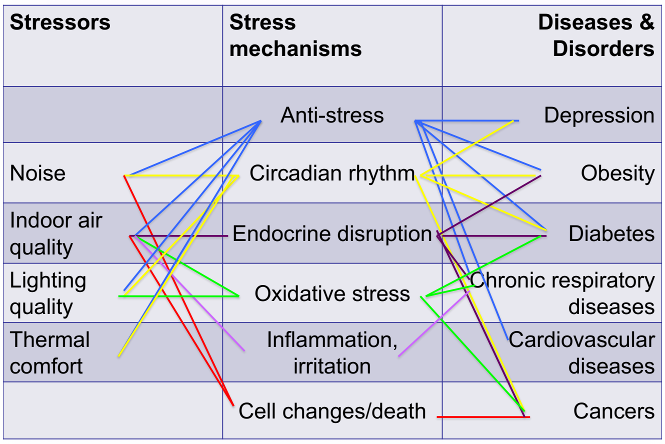

Figure 5. Possible associations between stressors, mechanisms and diseases and disorders (Figure 1.3 in [10]).

More recently, it was seen in a lab study with 250 children from seven primary schools who assessed in a four-way factorial design with 18 groups on eight different days temperature, noise, light and smell of in total 36 different environmental configurations in the experience room of the SenseLab [12], that interactions between the different acoustical, olfactory and visual stressors probably occur at the level of the central nervous system [13].

2.2. Human model (Profiles)

It is clear that we are dealing with individuals in different scenarios (e.g. homes, offices and schools) and situations (e.g. sitting behind a desk, in a meeting room listening, washing, cooking and sleeping, making an exam or listening to the teacher). Profiling of people for different scenarios and situations is required in order to understand the individual reactions to indoor environments better. Indeed, several studies showed that people can differ in their preferences and needs, and that it seems possible to distribute them into clusters [14, 15].

2.3. Environment model (Patterns of stressors)

Recent studies, have given preliminary proof for the determination of patterns of stressors for 'offices and workers' [16], 'homes and students' [17] and 'schools and children' [18]. With regards to stressors, so far, most studies have focused on identifying and preventing negative stress factors: assessing why people get sick or complain in order to define requirements/threshold levels. Few studies (performed in offices, mainly) have considered positive experiences (needs and preferences). A holistic analysis including preferences and needs to identify the positive as well as the negative effects for different scenarios is required.

3. Need for different assessment and analysis methods

3.1. Assessment

Most guidelines for health and comfort indoors, are based on lab studies performed from more than 50 years ago, using quantitative methods that make it possible to perform linear based analysis resulting in a mean effect/response of a certain group to one aspect. To identify other factors and stressors than the environmental parameters used in guidelines, whether of psychological, physiological, personal, social or environmental nature, additional assessment methods are required. In the European research project OFFICAIR, a procedure was developed to determine associations between characteristics of European offices and health and comfort of office workers, through a checklist and a self-administered questionnaire including environmental, physiological, psychological and social aspects [16]. This procedure was applied in 167 office buildings in eight European countries (Portugal, Spain, Italy, Greece, France, Hungary, The Netherlands, and Finland) during the winter of 2011-2012. Physical building characteristics were associated with occupants' overall satisfaction (acoustical solutions, mould growth, complaints procedure, cleaning activities) and health (number of occupants, lack of operable windows, presence of carpet and cleaning activities). Building characteristics were associated with dry eye complaints of office workers [19], and work-related stress was shown to have an impact on health related to the building [20], confirming the need to consider the psychosocial environment besides the physical environment. In a field study of 21 schools, 54 classrooms with 1145 primary school children, a similar procedure was applied, but additional questions on preferences and needs were included in order to identify the positive side of stressors [18]. The lab study performed with 335 children from 7 of the 21 schools [13], indicated that combined field and lab studies using a mixed study design (qualitative together with quantitative methods) are worthwhile exploring.

3.2. Analysis
For the analysis of dose-effect relations usually linear regression-based methods are applied, while many IEQ factors show non-linear relations with both satisfaction and health effects that can differ per situation and individual [21]. For example, Kim and de Dear [3] found that factors influencing satisfaction can be divided into basic factors, so-called minimum requirements, and other factors that can either have a linear or a non-linear relation with satisfaction. Also, interactions, feedback loops and confounding and mediating factors should be considered, indicating that in order to determine patterns of stressors that are associated with certain effect, other analysis methods than the usual linear based methods are needed [5]. Recent field studies in three scenarios, office buildings and office workers [16, 19, 20], schools and children [18], and homes and (young) adults [17], showed that with the use of multivariate analysis it is possible to determine patterns of stressors that are associated with certain effects. The study with 396 students showed that besides genetics, rhinitis was associated with biological pollutants (presence of pets) and chemical pollutants (presence of MDF from less than one-year old furniture), ventilation (opening windows in bedroom more than once a week), and with personal factors, working out (physical activity) [17]. Based on two-step cluster analysis, six clusters (profiles) of children based on their comfort perceptions and the importance of environmental factors were identified in the study in the schools identified [14]. Among them, one cluster was concerned about all IEQ factors in the classroom, and another cluster (being also the cluster with the healthiest and most comfortable children) did not show any concern. Four clusters of children had specific concerns related to the IEQ factors: sound, air & sound, thermal & draught, and light. In a study on the relationships between behaviours, energy use, and comfort and health of 223 students and their homes, six clusters (profiles) were identified by Ortiz and Bluyssen [15], using two-step cluster analysis.

4. Integrated analysis approach
From the above it is clear that for successful implementation of this integrated analysis approach, the following research is needed:

- To be able to determine *patterns of stressors* of importance to people in different situations, other factors and stressors than the environmental parameters used in standards, whether of psychological, physiological, personal, social or environmental nature, will need to identified.
- To be able to determine *profiles of people* for different scenarios and situations, preferences and needs of individuals as well as positive and negative effects, will need to be identified.
- Possible *interactions* at and between different levels (human and environment) over time need to be explored for different scenarios and situations.
- To determine patterns of stressors, profiles of people, and interactions at both environmental and human level, combined *field and lab studies* using a mixed study design (*quantitative and qualitative methods*) and *non-linear analysis* methods are required.

Eventually, the integrated analysis approach will help us better understand the interactions in the environment (the situation), the occupant and between them; the stress factors caused by the (indoor) environment a person is exposed to (patterns of stressors); as well as the individual differences in needs and preferences (profiles of people), depending on their behaviour (activities). Thus, to make it possible to match profiles of people with patterns of positive and negative stressors for a certain situation.

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