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(Dis)comfort and Health-induced Stress: the need for unravelling their effects

Key words: Indoor Environmental Quality, health and Comfort indicators, Preferences and needs, Patterns of stressors

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This article is a summary of the article presented at the IEQ conference in Montreal [1], in which the question "What is needed to determine other indicators that can help to prevent long-term health effects?" is answered in four steps.

Exposure to air, noise, light and thermal stressors indoors, contribute to diseases such as mental illnesses, diabetes, obesity, cardiovascular and chronic respiratory diseases, cancer, and very recently, COVID-19 [2,3]. Research has shown that even though the indoor environmental conditions seem to comply with current standards and guidelines and those conditions seem 'comfortable' enough, staying indoors is not good for our health (review in [2]). Reasons for this discrepancy might be the fact that these guidelines are mainly based on single-dose response relationships (effect modelling using dose-related indicators) for the physical stressors (odour, light, sound, and temperature) determined for an average adult person; aimed at preventing short-term discomfort, not long-term health effects, ignoring situation-related aspects, ignoring different preferences and needs of occupants (e.g. [4]). Building-related indicators (such as type of building materials and furnishings, ventilation system types, and maintenance protocols) and occupant-related indicators (e.g. preferences and needs, personal factors) are rarely considered [5,6]. For health threatening exposures for which a clear dose-response relationship has been determined this single-dose response model tends to work well; For example, dose-related maximum allowed sound levels to prevent damage to the inner ear causing tinnitus, and/or hearing loss (e.g. [4]). Unfortunately, for a lot of these indicators the mechanisms used behind the values or ranges, are not always that clear. The minimum ventilation rate is a good example is. Based on either CO_2, carbon dioxide, as an indicator for bioeffluents, or on certain emissions of building materials, minimum ventilation rates have been discussed and are still being discussed for almost two hundred years. All of the introduced schemes, rating tools, models, digital twins, and intelligent monitoring and feedback systems for the integrative evaluation of IEQs are still merely focussed on the separate IEQs (thermal, air, acoustic, and lighting quality) due to a lack of knowledge on the interrelationships and integration between and among environmental factors and their effects on health, comfort, and behaviour (review in [6]). To "set requirements for the implementation of adequate indoor environmental quality standards in buildings in order to maintain a healthy indoor climate", as mandated by the EPDB [7], it is important to go beyond the comfort-based dose-related indicators and determine other indicators that can help to prevent long-term health effects. The question is then "What is needed to determine those other indicators?"

Step 1 Need for another research model

The first step is to acknowledge that IEQ is more than the sum of its parts and that people differ in their preferences and needs. This requires a different research model than the 'single dose-response models on which our guidelines are based. A more comprehensive model, accounting for integrated effects of all stressors, and different preferences and needs of occupants in different scenarios and situations, based on situation modelling making use of building and occupant-related indicators, was introduced [6,8] (**Figure 1**). This model includes all situation-related stressors (physical and psycho-social; positive and negative), modifiers, and confounders. The model features the stress factors caused by the (indoor) environment that a person is exposed to (represented by patterns of stressors) and the individual differences in needs and preferences (expressed with profiles of people), depending on their scenario (e.g. home, office, school) and situation (activity and time).

Step 2 Validation 'new' research model

The second step is the validation of the 'new' research model. The 'new' model was validated for 1) office workers and their workplace; 2) students and their homes & study places; 3) primary school children and their classrooms; and 4) employees of outpatient areas in hospitals [6]. For each scenario, occupant-related indicators and building-related indicators were collected through a questionnaire and checklist(s) to associate patterns of positive & negative stressors to occupant-related indicators (health: symptoms; comfort: complaints) using multi-variate analysis; and to determine clusters of occupants and their profiles (preferences and needs) using 2-steps cluster analysis. With these studies it was shown that for different scenarios (and situations) 1) occupants can be clustered into clusters with different profiles (preferences, needs and behaviours), and 2) patterns of stressors can be associated with different effects (when leaving the building the severity of the symptom (e.g. stuffy nose) or disorder (e.g. rhinitis) decreases) for different profiles, resulting in better insight which risk factors play a role in such an effect. The studies resulted in 'other' factors and stressors than used in guidelines confirming the importance of considering all possible stressors as well as personal and psycho-social factors, when studying a certain disease or disorder. Moreover, clustering showed the importance in better pinpointing the patterns of stressors that form a risk for getting a disease or disorder for a particular group. The outcome showed that profiles can differ even when the occupants are exposed to the same situation at the same time. It was observed, however, in some of the field studies that environmental level changes in context (situation) may affect the preferences and needs of the occupants (profiles). How these changes in context affect the number of clusters (and their profiles) for a certain situation is unclear, and therefore, needs to be investigated further.

Step 3 Need for 'other' research methods

The third step is to acknowledge that our current guidelines do not account for integrated health effects of different exposures over time, which requires 'other'

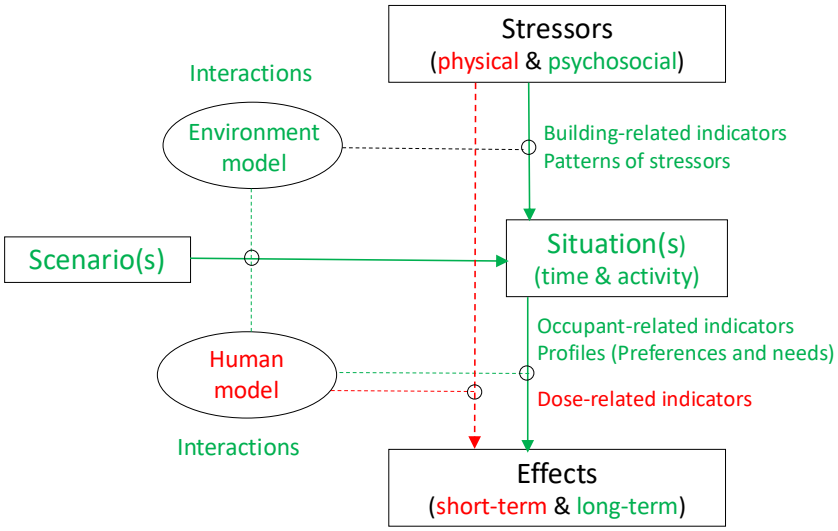

Figure 1. New model (situation modelling), including the old model (effect modelling). (Note: red colour refers to the old model, and green to the parts that have been added in the new model).

research methods than applied in the field studies. We are exposed to a mix of stressors in different situations, resulting in both short-term and long-term effects. In the field studies, the focus was on short-term effects and on one situation at the time. Building-related risk factors were correlated to self-reported comfort conditions and symptoms (that get better when away from the building) of the past three months, and self-reported diseases of the past 12 months. The outcome was based on self-reported occupant-related indicators, assessed once. Unfortunately, diseases that usually take longer to manifest (longer than 12 months), such as chronic respiratory diseases, cancer, and obesity, cannot be studied in this way, and therefore might require 'other' methods (study design) and/or indicators. Moreover, other studies have shown that perceptual interactions at brain level can occur when exposed to different environmental stressors at the same time. During perception with our senses interactions of different environmental stressors (olfactory, auditory, visual and thermal stimuli) at brain level (central nervous system) might occur (e.g. [9]). IEQ perceptual assessments and preferences for them, on which our comfort-based guidelines are largely based, can be affected by previous experiences and exposures, mood, state of health, preferences, etc. [2]. There is need for unravelling these interaction effects; it might help to explain why people have different preferences for comfort-related aspects, why they differ in different contexts. Next to perceptual interactions, from research in different fields it is seen that interactions at human level that occur through the mechanisms that take place in the human body to cope with the different stressors, causing diseases when not coping, are complex [2] (see **Figure 2**) and might explain why it is so difficult to correlate a certain dose-related indicator to a certain health effect. There is clearly a need for 'other' research methods, including 'oher' indicators.

Step 4 Unravelling the human model

Finally, the fourth step is to determine which indicators can be used to predict long-term health effects from 'short-term' perceptual assessments and/or physiological measurements. To get a better understanding of which indicators can be used, we need to investigate how our body copes with the different stressors. Our body has three systems available to cope with the external stressors: the nervous system, the immune system and the endocrine system. Stressors can be grouped into stressors that trigger the so-called a) (dis) comfort-induced mechanisms (such as the anti-stress mechanism and the circadian rhythm mechanism) and b) the health-induced mechanisms (for example oxidative stress and inflammation) (see **Figure 3**). With '(dis)comfort' induced stress, the nervous system and the endocrine system cooperate, while the 'noxious or health' induced stress is handled by the immune system and the endocrine system [10]. The effects of not coping with the (dis)comfort-induced stress can be seen in the nervous system induced bodily responses (e.g. heart rate, breathing rate, blood pressure, local responses), metabolism (e.g. fat tissue, cholesterol), and disbalance in hormones (e.g. cortisol, melatonin) that is created with chronic stress [2], all potentially occupant-related indicators. Our current IEQ-guidelines, to keep people 'comfortable' and performing well, are based on short-term assessment of dissatisfaction or annoyance (perception) of the individual IEQs, expressed with dose-related indicators in combination with building-related indicators focussed on preventing discomfort. An interesting occupant-related indicator that has been correlated to light, air, noise, and heat pollution through (dis)comfort-induced stress, is 'quality of sleep'. With health-induced stress our immune system responds at cell level and by production of substances to deal with the stress (e.g. cytokines). Coping fails when damage to cells prevent your immune and/or endocrine system to

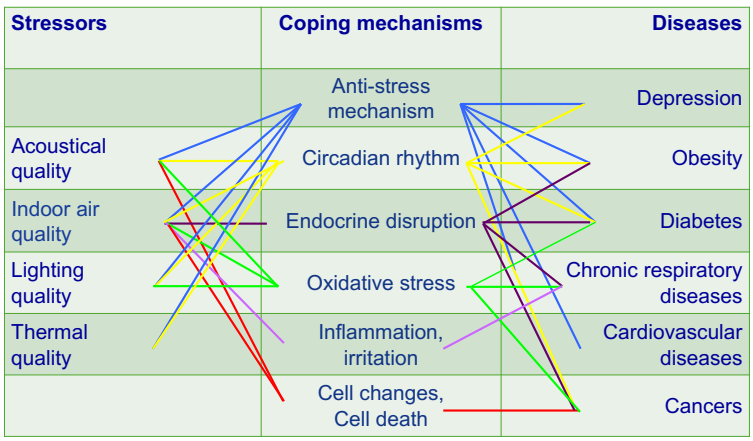

Figure 2 . Possible associations between stressors and diseases (adapted from [2]).

work properly [2]. Next to indicators in blood and urine, several skin, eye, and airway symptoms have been correlated with exposure to health-induced stress. To prevent oxidative stress, in particular, exposure time limits for several dose-related indicators have been established (e.g. for sound, light, fine particles). Additionally, several building-related indicators focussed on 'source' control can help to prevent health-induced stress. Moreover, the DALY (Disability adjusted life-years) concept has been proposed to estimate how harmful the indoor air is during a specific time frame [2]. However, to estimate the integrated effect of health-induced stress on a disease based on the DALY calculation, the exposure-function, the other risk factors, and the interactions of those risk factors, need to be known.

Conclusion

The question "What is needed to determine other indicators that can help to prevent long-term health effects?", was answered in four steps. In steps 1 and 2, a more comprehensive research model than the single dose-response model was, respectively, introduced and partly validated. Then step 3, following from the outcome of the validation of the 'new' model, addressed the need for 'other' methods (and indicators) that enable us to study interactions occurring at human level (perceptual and physiological) induced by indoor environmental stressors resulting in both short-term and long-term (integrated) effects. Finally, in step 4, the need for unravelling the human model to determine those 'other' indicators is emphasized. Only when the 'right' indicators and methods are identified, it will be possible to determine the 'right' algorithms that are needed to predict (prevent) health effects of each individual over time.

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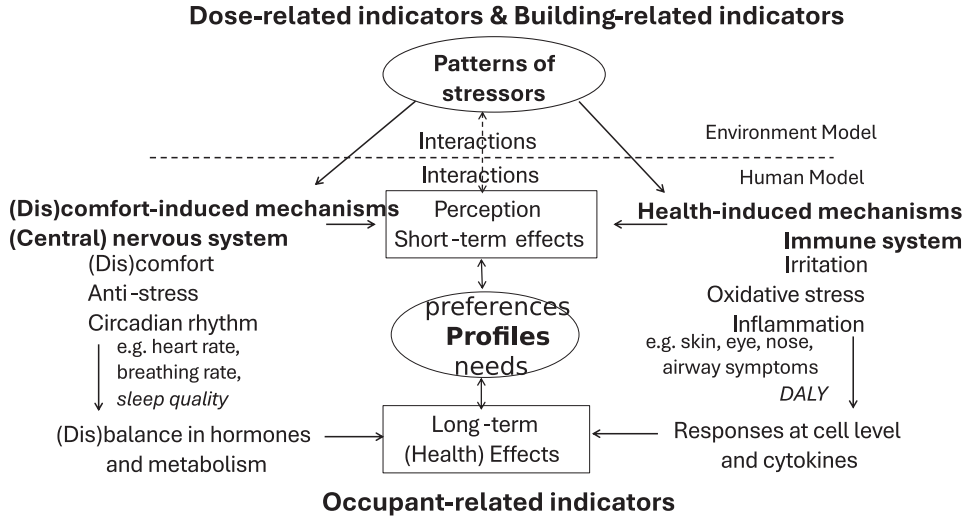

Figure 3. Human model: stress, coping mechanisms, and effects.