

Healthy environments from a broad perspective : an overview of research performed at the unit Building Physics and Systems of Eindhoven University of Technology

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Healthy environments from a broad perspective – an overview of research performed at the Unit Building Physics and Systems of Eindhoven University of Technology

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ABSTRACT

The design and realization of a healthy indoor environment is a challenge that is investigated from different perspectives at the unit Building Physics and Systems (BPS; Faculty of Architecture, Building and Planning) of Eindhoven University of Technology. Performance requirements (for instance, with respect to air quality, thermal comfort and lighting) and performance based assessment methods are the point-of-departure, focusing at computational techniques supporting the design process. Different specific application fields such as dwellings, offices, schools, but also, operating theatres, churches, musea and multifunctional stadiums, underline the applied approach that is part of the research within the unit.

In the design of healthy environments, the performance based design assessment is crucial in arriving at innovative design solutions and optimized indoor and outdoor environments. In this assessment computational support tools and experimental verification play an important role. However, assessing the right indicators in an objective way, applying the correct tools and correct application of these tools is not yet well established. Alongside, developments are still ongoing. The work performed in the unit by the different researchers relates to the research questions that can be derived from this notice.

The paper gives an introduction to the Unit BPS and presents a brief overview of recent and ongoing research. An extensive list of references is provided for further reading and supports the conclusion that healthy environments can and should be addressed from a wide angle.

1. INTRODUCTION

Within the unit Building Physics and Systems (BPS; Faculty of Architecture, Building and Planning) at Eindhoven University of Technology, the realization of a healthy environment is investigated from a broad perspective. This is visualized in Figure 1. This approach comes from the understanding that the (indoor) environment in which people live, work and spend their time and artifacts remain, is the result from a complex integration of a large number of physical attributes which in itself are the result from an integration of a large number of building components. Assessing the individual components and assessing attributes individually is important in itself but does not allow to arrive at healthy environments unambiguously. For that the integrated result of the components applied and the relation of the different physical attributes in an

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environment is important as well. The significance of these relations relies on the requirements that are posed by the occupants and artifacts which are exposed to the environment. As people differ and the requirements requested as well, they are not fixed for every design problem (for instance, Bluysen, 2008).

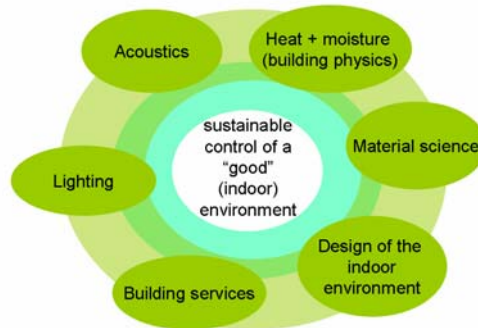


Figure 1. The (indoor) environment engaged from different angles at the unit BPS (Hensen, 2008).

2. HEALTHY ENVIRONMENT RELATED RESEARCH AT BPS

Research at the Unit BPS deals with all building physical aspects that might impose an effect on the healthy environment. This starts with the outdoor environment, e.g. local wind climate and dispersion of pollutants, to optimize the local conditions in which buildings are situated and to optimize building designs to this environment.

The building envelope is the main barrier between outdoor and indoor environment and therefore has an important contribution as well. Knowledge of the building physical performance of the construction, e.g. thermal and hygric, is crucial, as well with regard to health as to sustainable aspects. Also use of daylight is incontestably related to these aspects and requires attention at the same time.

The indoor environment of a building design results from the outdoor conditions present, the performance of the building envelope and the indoor activities. This should match the performance requirements set for thermal comfort, health and productivity. Despite an optimization of the building design (for instance, orientation, lay-out, construction) generally building services are indispensable to arrive at the required performance conditions year-round. Ventilation and air-conditioning systems are well-known examples.

Following the above, arriving at healthy environments is the result of a complex combination of different research areas, all present at BPS (see Figure 1). It, however, also requires an integrated design approach to take all these topics into account. Assessment of the (indoor) environment in the design phase in any case is important to determine the effectiveness of the design, also from a sustainable point-of-view. This type of evaluation is generally performed through computational building performance evaluation techniques. Such evaluation tools may encompass whole building design assessment, but also be restricted to dedicated areas of a building or building component or focus on individual performance characteristics (e.g. lighting, ventilation efficiency, ...). Also research in this area is well established at BPS.

The above presents an overview of the type of research performed at BPS. This research all contributes to arrive at healthy environments. In addition to the above, the next sections will present examples of research in most of the different areas mentioned above. This overview is not complete and cannot be very detailed. For more information, the interested reader is referred to the references for further reading or to the website (http://w3.bwk.tue.nl/nl/unit_bps).

2.1 Lighting

Lighting is one of the key parameters in the indoor environment. For performing tasks minimum illuminance levels are required. The recent discovery of a third photoreceptor which is directly connected to the biological clock (Berson, 2002) put the importance of light on human well being in a different perspective. Light also influences the circadian rhythmicity and, as a result, several processes in the human body. Core temperature of the human body and the sleep/wake rhythm (see Figure 2) are examples. Significant higher lighting levels than for vision are required. For energy saving reasons, optimal use of daylight is preferred.

The visual and non-visual aspect of lighting and daylighting in particular has been the topic of research in a number of studies (Aarts and Westerlaken, 2005; Westerlaken, 2003). In these studies special attention was given to mentally fit older adults and their living environment. Older adults require higher illuminance levels due to aging (also of the visual system). Results of these studies indicate that older adults are living in an indoor environment where lighting levels are significant lower than required (110 lux compared to required values of 1500 lux). A recent study showed that a high color temperature of the lighting might compensate for these lower illuminance levels, though not completely (Huijbregts, 2008). Remark that low lighting levels do not only restrict visual task such as reading, it also increases the risk of stumbling (Westerlaken, *et al.*, 2004). A field study (Aarts, 2006) showed that when healthy older adults spent more time outside in high lighting levels, their sleep quality improved the following night (Figure 2). Good lighting is especially important for institutionalized elderly people with dementia. Research from van Hoof, *et al.* (2009) confirmed reduction of typical symptoms of dementia when lighting levels and specifically also color temperature were increased.

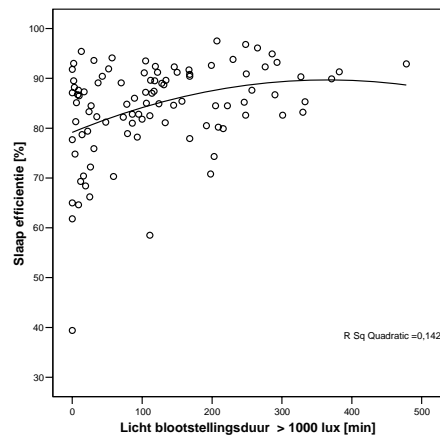
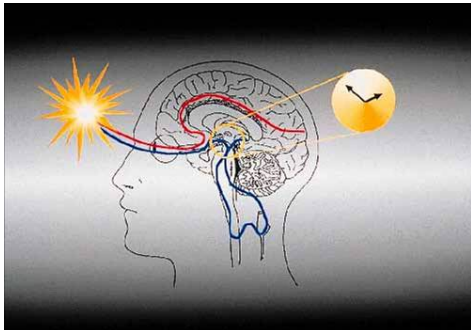


Figure 2. Influence of lighting on our biological clock.

2.2 Heat and moisture

Moisture in air and building constructions is directly related to the relative humidity (RH). The relative humidity plays an important role with respect to health. The direct effect of a too low RH value not only concerns the thermal perception but also dry skin feeling, dry mucosa, eye irritation, respiratory tract irritation and electrostatic discharge. Other health effects, as a result of high RH values, follow indirectly from mould and mite growth (IEA, 2008). Control of RH in air and building constructions therefore is part of current research on heat, air and moisture transport in buildings and systems (Van Schijndel, 2007; De Wit, 2006). Besides modeling aspects of this type of transport, special interest is related to thermal comfort in historical buildings and the preservation of these buildings and artifacts (Schellen, *et al.*, 2007).

Thermal conditioning (heating, cooling) of buildings is required to arrive at comfortable conditions. As a part of the project Exergetic System Approach (LowEx.nl) research is

performed to obtain more insight in the thermal comfort of occupants in relation to non-uniform environments. This type of environment may result from the application of so-called low-exergy systems. The project is conducted within the 'EOS-LT' research, funded by SenterNovem, and carried out by the 3TU federation. The research in Eindhoven focuses on the assessment of thermal comfort in non-uniform environments. This follows from an IEA Annex 37 study (IEA, 2003) that revealed that an optimal energy use not always results in an increased comfort level. In some cases it proved to be more difficult to achieve thermal comfort. Application of low-exergy systems can result in local and/or global discomfort from for example unintended air movement, in case of application of a natural ventilation system in combination with low temperature heating. The indoor air flow is most critical, both for cooling and heating cases. More knowledge on the interaction between the system, indoor climate and the human body is indispensable to design optimal systems in the future. The main objective of this research is the development and verification of a tool to assess the thermal comfort of occupants under non-uniform and transient conditions, which can occur in buildings where low-exergy systems are applied (e.g. low temperature heating). For that a thermo-physiological model is applied and experiments with test persons are foreseen that will be exposed to controlled non-uniform conditions. An example of these type of experiments are shown in Figure 3 (Schellen, *et al.*, 2008).

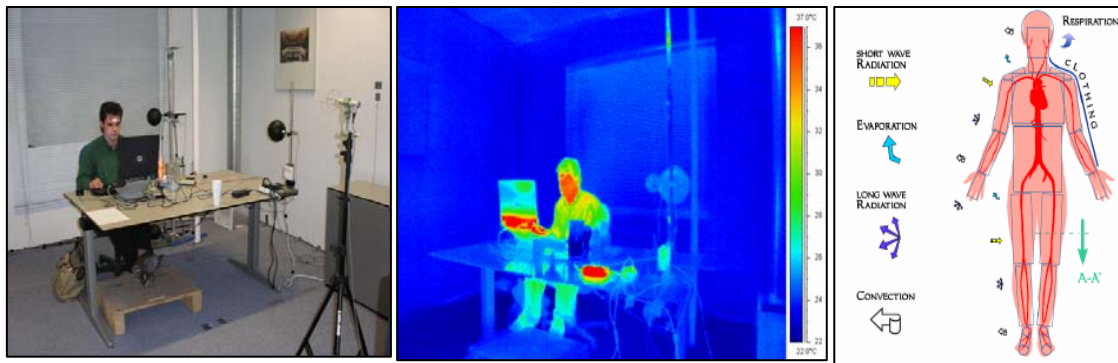


Figure 3. Example of experiments performed to determine thermal comfort.

2.3 Urban Physics

Urban Physics is the engineering discipline that covers all physical aspects related to urban environments, including the transfer of heat, air, moisture and pollutants. Examples are the study of urban heat island effects, evaluation and optimization of district energy consumption, air pollutant concentration distributions in streets and around buildings, natural ventilation of buildings, pedestrian wind conditions around buildings and wind-driven rain on building facades.

The aim of Urban Physics is to provide a healthy, comfortable and sustainable outdoor and indoor environment of buildings, taking into account energy, economical and ecological constraints. This includes the sustainability of the building envelope, as the separation between outdoor and indoor environment. The outdoor environment often provides the boundary conditions for the physical processes of the building envelope and the indoor environment. As an example, outdoor air pollution by industrial, traffic and building exhaust can be reingested by the ventilation inlets of buildings and adversely affect indoor air quality. Another example is wind-driven rain on building facades and rain penetration, which affect the hygrothermal behavior of the building envelope and subsequently the physical conditions of the indoor environment (e.g., surface condensation and mould growth). Also natural ventilation of the indoor environment of buildings is driven by the physical processes in the outdoor environment, namely wind pressures and indoor-outdoor temperature differences.

Urban Physics research at the Unit BPS has both a fundamental and an applied component. In each component, research is performed by full-scale experiments, reduced-scale experiments and advanced computational modelling with CFD (computational fluid dynamics). Urban Physics research at BPS covers most of the individual topics mentioned above: atmospheric boundary layer modelling (Blocken, *et al.*, 2007), evaluation and optimization of district energy consumption (Vreenegoor, *et al.*, 2008), air pollutant dispersion (Blocken, *et al.*, 2008), natural ventilation of buildings (Costola, *et al.*, 2009; van Hooff and Blocken, 2009), pedestrian wind conditions around buildings (Blocken, *et al.*, 2004) and wind-driven rain on building facades (Blocken and Carmeliet, 2004; Briggen, *et al.*, 2009). It also and especially covers the coupled approach in which outdoor, building envelope and indoor physical processes are addressed simultaneously and in full interaction with each other (Hensen, 1991; Costola, *et al.*, 2008; Mirsadeghi, *et al.*, 2008).

As an example, Figure 4 provides a brief illustration of the computational part of the natural ventilation study that was performed at the unit BPS for the Amsterdam ArenA football stadium.

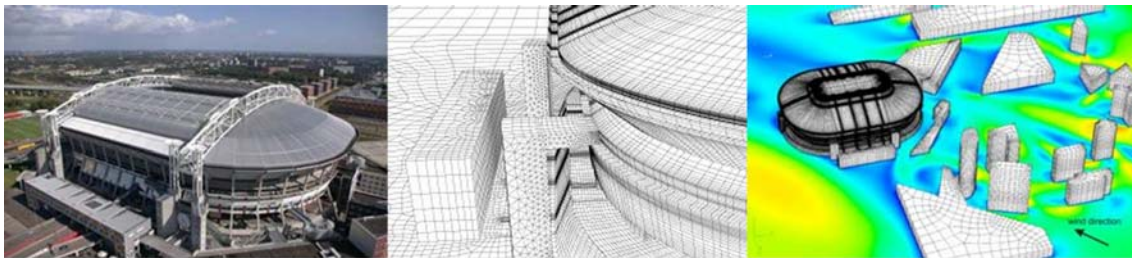


Figure 4. Computational Fluid Dynamics simulations of the Amsterdam ArenA football stadium for natural ventilation analysis (van Hooff and Blocken, 2009).

2.4 Building services

In recent years there has been a growing awareness of the negative effect of energy saving solutions on the indoor air quality in classrooms. In three inventory studies (Joosten, 2004; Van Bruchem, 2005; Scholten, 2006) in a number of naturally and mechanically ventilated schools this was confirmed. Specifically for natural ventilation there is a clear trade-off between indoor air quality, thermal comfort and energy saving. As classrooms have a relative standard lay-out, based on the information obtained from these studies a 'plug and play' ventilation concept was developed that addressed the identified air quality and thermal comfort problems (Boxem, 2006). A first prototype was tested by Schuiling (2008) in a renovated class room (see Figure 5). Results from this field test confirmed the improved air quality that was obtained in the class room, without deteriorating thermal comfort (Zeiler, *et al.*, 2008).

In addition to the ventilation, much attention also is given to sustainable solutions. The design of, e.g., hospitals however is very complex as such buildings have extensive building service systems. Integration of these required technical systems can lead to complications, high failure costs and often to unnecessary high energy consumption. To answer these problems focus is put on the integral design approach for hospitals. Whereas within integrated design the focus is on combining different disciplines, in integral design the focus is on the whole building approach and all required different disciplines.

Furthermore, public-private-partnership constructions, cradle-to-cradle, etc. have changed the design process from a focus on initiation costs to running costs and environmental burden. The building therefore is no longer shaped solely by the will of an architect, but the design rather emerges from the necessities and requirements of

the assignment. In a long-year study together with the royal Dutch society of architects (BNA) and the Dutch society of technical consultant (ONRI) this integral design approach is investigated and facilitated. Results show the added value of this approach (Savanovic and Zeiler, 2008; Zeiler and Savanovic, 2009).



Figure 5. Example of the investigated displacement ventilation prototype as applied by Schuiling (2008).

2.5 Design of the Indoor Environment

The indoor environment has a direct effect in arriving at a healthy environment. The objective assessment of this environment however is not straightforward. A means to support this assessment process is through the Performance Based Building approach (CIB, 1982). Unambiguously defined performance indicators are an important part of this approach. A recently started 7th FW EU project wants to contribute to the development of a clear list of indicators that relate to the health, comfort and safety aspects of the indoor environment (BBRI, 2008). An example of the application of the approach for the ventilation efficiency in an operating theatre is described in Loomans, *et al.* (2008).

Currently a number of research topics have a direct relation with the indoor environment in health care facilities. As an example, research is being undertaken with Universitair Medisch Centrum Groningen (UMCG) and Arup on the architectural and environmental design of ICUs (Intensive Care Units; Van Roosmalen, 2009). Objectives are to determine a relation between architectural design parameters (such as shape, colors, view, contact opportunities) and indoor comfort parameters (visual, acoustic, thermal and olfactory) and the well being of patients. Measurements are planned in regard to indoor parameters and sleeping behavior in three different ICUs during a half year timeframe starting in April 2009.

The open building approach (Habraken, 1998) is being applied in cooperation with prof. Habraken on the design of a large hospital in Zaandam, the Netherlands. Objective of the project is to determine practical barriers on the introduction of this design approach in the building industry and to give an overview in respect of the ways and means to overcome these barriers.

Another study investigates the contribution of the indoor environment on well-being and care support for community-dwelling older adults with dementia, in order to support aging-in-place, and to delay the demand for institutional care (van Hoof and Kort, 2009). It does so by coupling the International Classification of Functioning, Disability and Health (ICF) of the World Health Organization (2001) and the Model of Integrated Building Design developed by Rutten (1996) as shown in Figure 6. There is a special focus on the role played by lighting in relation to behavioral problems and disturbances in circadian rhythmicity seen in dementia (see section 2.1 Lighting), and the needs in terms of thermal comfort and comfort systems.

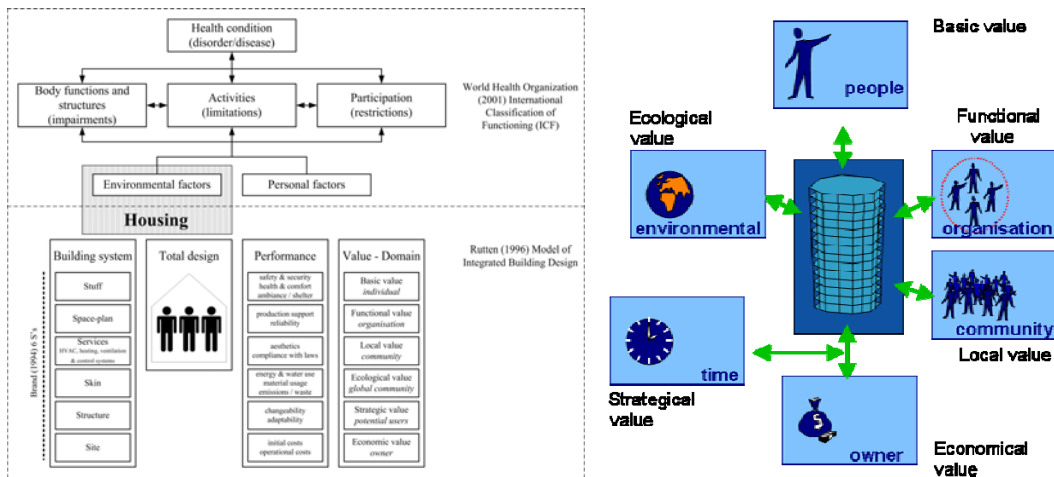


Figure 6. Interactions between the components of ICF, and the integration of the Model of Integrated Building Design (left) and visualization of the Value-Domains (right).

2.6 Building Performance Simulation

Application of the performance based approach requires performance assessment in the design phase of a building. For this purpose building performance simulation techniques are used. Several categories of these techniques can be identified. On the one end they start from relatively simple techniques, with few input and limited information requirements. These types of tools are generally applied for exploration of design concepts. Detailed simulation tools require a higher information level, but do allow a more detailed design assessment. Where the previous categories include the whole building functioning, special purpose simulation techniques are available to investigate individual building parts/components, e.g., shading or an HVAC system.

Though special purpose simulation techniques generally allow the highest information quality for the assessment, it is the coupling with the building that allows for the assessment of the actual whole building performance. As whole building simulation tools not always are equipped with up-to-date models of individual and innovative building components research efforts have been invested in the external coupling or co-simulation of special purpose simulation tools with whole building simulation environments. Examples are external coupling between building energy simulation and CFD (Djuneady, 2005), co-simulation of innovative integrated mechanical energy systems in buildings (Trcka, 2008), run-time coupling of control in building performance simulation (Yahiaoui, *et al.*, 2007) and the co-simulation of heat, air and moisture to realize a reduction of the energy consumption of a building while improving the durability of the building enclosures and raising the comfort level and indoor air quality of its inhabitants (Costola, *et al.*, 2008).

Apart from focusing on improvement of the quality of the simulation techniques, research also deals with appropriate application of building performance simulation and extending the application to the other phases of the building design. In practice, building simulation is assessed as a useful tool to demonstrate code compliance for obtaining planning permission. Therefore it is predominantly used to predict thermal and energetic performance of buildings. Building performance simulation is not often used in the early design stages where important design decisions are taken and benefit of usage appears largest. In the early design stage decisions are based on extensive design experience, due to the limited amount of design information that is available. Techniques such as uncertainty and sensitivity analysis that can be applied through building simulation however can add value to support decisions at that stage (Struck, *et*

al., 2007). Also in the later stages of the design these techniques are valuable as part of design optimization (Hopfe, *et al.*, 2007).

Appropriate application of tools in practice is researched specifically for the application in operating theatre environments (Melhado, *et al.*, 2007). E.g., good indoor air quality and high ventilation efficiency are important to reduce the risk of post-operative infections. CFD is the single tool applicable for that. It allows for supporting design decisions, but its usage is not straightforward (Zoon, *et al.*, 2008). In this research the VDI 2167 standard (VDI, 2007) is applied as reference to assess performance of operating theatres experimentally as well as numerically (see Figure 7).

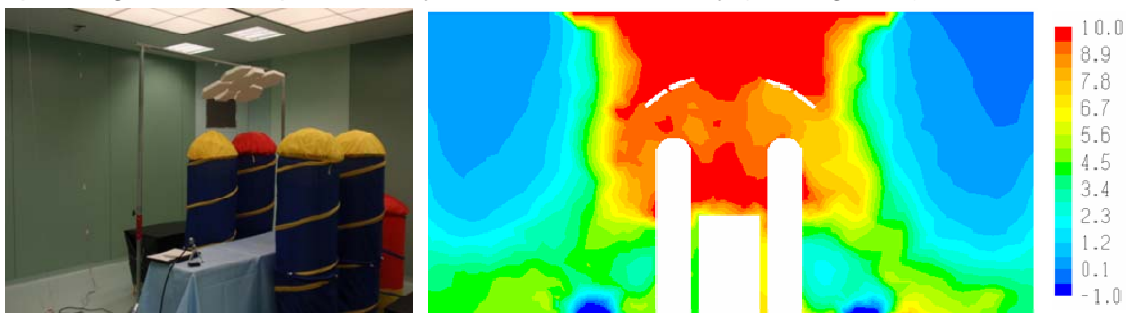


Figure 7. Example of experimental set-up for an operating theatre and of a CFD-result representing indicating protection factor according to VDI 2167.

3. CONCLUSION

This concise overview indicates the wide context within which the healthy environment is researched at the unit BPS. It also indicates the complexity to arrive at a truly healthy environment and the research areas that still are found to contribute to this.

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