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Bioclimatic tools for sustainable design – uncertainty perspective

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ABSTRACT

Overall, holistic approach in which the building is integrated into its environment with respect to building physics principles allows for discussion of a variety of passive strategies regarding the building placement (local climatic conditions, microclimate etc.), building types, building materials and technical systems. Bioclimatic design is referred to as a proper approach to highlight the connection of a building with the natural environment, which can be treated as the prerequisite for energy efficient design.

The research results within the reliability studies of building performance become an inspiration for architects and engineers to further discuss tools supporting decisions at the early stage of design process from the reliability perspective. The bioclimatic tools allowing for interpretation of the sense of comfort as a variable dependent on the variability of climatic conditions, and human factors are suggested for the analysis at the early stage of building design. A framework for the probabilistic analysis of comfort performance to be included in bioclimatic design tools is proposed.

The uncertainty of the variables and unknown parameters are critically (qualitatively) examined. Further research is needed to quantify the uncertainty of the boundaries of the comfort caused by the variability of climatic conditions and the uncertainty of human perception of comfort.

KEYWORDS

Bioclimatic design, uncertainty, passive strategies, thermal comfort, reliability.

INTRODUCTION

Low-energy building design, ensuring comfort and safety in built environment, addresses mainly the following three sustainability goals as propagated by United Nations: number 3 – good health and well-being, number 7 – affordable and clean energy, and number 13 – climate action. ‘Energy is the dominant contributor to climate change, accounting for around 60% of total global greenhouse gas emissions’. Reducing the carbon intensity of energy is a key objective in long-term climate goals (goal 13). Hence, choosing a strategy based on integrating the building form and structure with its external environment to take advantage of natural forces (for wind induced ventilation, solar heating, etc.) is an example of design decisions leading towards mitigation of climate change (Pietrzyk & Czmoch 2018). It also promotes using affordable and clean energy (goal 7). Considering uncertainties coupled to climate and comfort conditions will give the chance to make the design process more reliable in achieving good health and well-being in built environment (goal 3).

To encourage architects to consider the passive design strategies to contribute to comfort and health in buildings, tools are needed. Such a tool could be a bioclimatic chart (Givoni 1998) which shows the relationships between climatic parameters (temperature, humidity) and a comfort zone. Introducing certain design solutions (lightweight construction or thermal mass, natural or mechanical ventilation etc.) does influence the location of the boundaries of the climatic conditions within which the building design can provide interior comfort (Szokolay 2004). Some pedagogically described examples can be found in (Manzano - Agugliaro 2015) and the comfort boundary (in blue) of enhanced ventilation is shown in Figure 3. Significant research has been carried out within the field of thermal comfort in building resulting in the formulation of adaptive criteria that have been included in the International Standards such as ANSI/ASHRAE standard 55 (2013). However, the boundaries of the comfort zones do not include explicitly their uncertainty associated with human behavior (especially its psychological and cultural aspects) and the higher frequency of variability of climatic conditions. The discussion about the variability of comfort performance can be found in (Tuohy et al 2009; Humphreys et al 2013). For an architect it is important to design for the client representing a group of potential users. The uncertainty in human perception should be treated separately from the variability of climatic conditions. Within human perception physiological, behavioral and psychological requirements should be accounted for.

It is proposed to take into consideration the above uncertainties to elaborate on the uncertain boundaries of the adaptive comfort zone using uncertainty/risk analysis tools.

Architectural approach – climate as a generative principle for built form

Bioclimatic approach is not very common in the architectural practice. It seems to be still more related to the traditional architecture and certain climatic zones. One can also find the contemporary designs driven by the philosophy of 'form follows climate' where climate is given a generative roll for built form for ex. the houses designed by Philippe Rahm Architects (Rahm 2007).

Rahm creates spaces with stratified level of humidity to be occupied freely according to the weather and the season (Mollier's house). Activities in the rooms are related to the climate existing in the different parts of the house. It means that functionality is secondary to the climate generated form. In that way the problem of building physics is transformed into an architectural question. Another example is Archimedes's house designed as a vertical structure reflecting a relation between the house and the air, its temperature and its movement. The various temperature of interior spaces driven by the seasonal changes allow for the seasonal movement of the occupants within the house (migrations from downstairs to upstairs according to the vertical stratification of the temperature). In that way the functionality and the interior conditions are specified as different for various rooms. Those examples show how architect can be inspired by the opportunities created by nature. However, his philosophy can result in infinitely extended comfort zone.

Anyway, this kind of examples could suggest that bioclimatic chart is a good inspiration and communication tool for architects at the early stage of a design process promoting sustainable solutions. During the last 5 years new software became available to support climatic/environmental design based on bioclimatic tools (Climate Consultant, Grasshopper etc.). Starting design brief from the analysis of space in terms of bioclimatic parameters has been also appreciated by the students of architecture studying Building Climatology for Sustainable Design course at Chalmers University of Technology.

METHODS AND RESULTS

Communication of building climatology principles to support architect decisions at the early stage of design.

A design process promoting passive strategies should be supported by knowledge and analysis tools from different fields of building climatology (climatology, building physics, physiology/psychology and architecture). Climate is treated as a resource supporting natural ventilation, free cooling, and free heating. Results of the analysis of the climatic/environmental conditions could be synthesized and adapted to architectural expression. In that way, 'architecture can mediate the design with the goals of sustainability' (Brennan 2011).

Designed object offers passive and active controls over the interior climate according to the comfort requirements. A passive control creates an extra climate-comfort loop (see Figure 1).

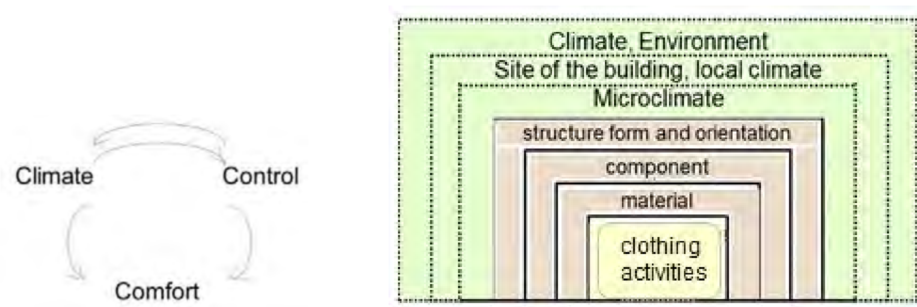

Figure 1 Bioclimatic thinking at the early stage of the design process – systemic approach; modified from (Pietrzyk 2015).

Climate: climate, local climate, microclimate (temperature, moisture content, wind speed, wind direction) in view of uncertainty (Pietrzyk & Czmoch 2018)
Control: materials (strengths and vulnerabilities), components, structures form and orientation, technical systems, topography, urban design, wind/surface interaction etc.
Comfort: uncertain adaptive comfort zones within enclosure extended by using passive or hybrid strategies of heating, cooling, and ventilating

Architectural criteria include the site of the building (also in urban context), the local environment being the result of feedback loop between natural and man-made elements, and the building orientation, form, layout/volume, material (see Figure 1). The criteria account also for integration of technical systems within building/environment system considering potential of the system to use locally produced renewable energy. The concept could be extended to include the user perception as a variable dependent on the climatic conditions and the design solution. A systems approach provides proper theoretical tool for the analysis of the interrelations between structure, its environment, and its performance. Use of bioclimatic chart (psychrometric chart with comfort zones) in the early stage of design process is considered. It can be considered as a means of raising awareness of the integration of a range of environmental and design parameters. The concept of bioclimatic design has been proposed in (Olgyay 1953) and further developed (see Givoni 1998, Szokolay 2004, etc). The comfort zones refer to both seasonal climatic conditions and the traditional living style (clothing and the level of activity), see Figure 2. It is proposed to consider the relevant variables evaluated for local conditions and to elaborate on the uncertain comfort zone due to cultural/psychological and climatic aspect. In that way comfort zone could be treated as a dynamic concept addressing users' perception related to the local climatic conditions, habits, behaviors, and the level of possible control.

The bioclimatic chart showing the properties of moist air is built on the analysis referred to the perfect gas relations. It could be the valuable visual aid for architects in analyzing different solutions at the early stages of the design process. First the local climate conditions are collected in the form of averaged values over the period of hour, day or month. Then, the analysis of the neighborhood results in the microclimatic characteristics that are superimposed on the chart. The relation between the outdoor climatic conditions and the required interior conditions gives the indication about the passive/active strategies that could be designed for.

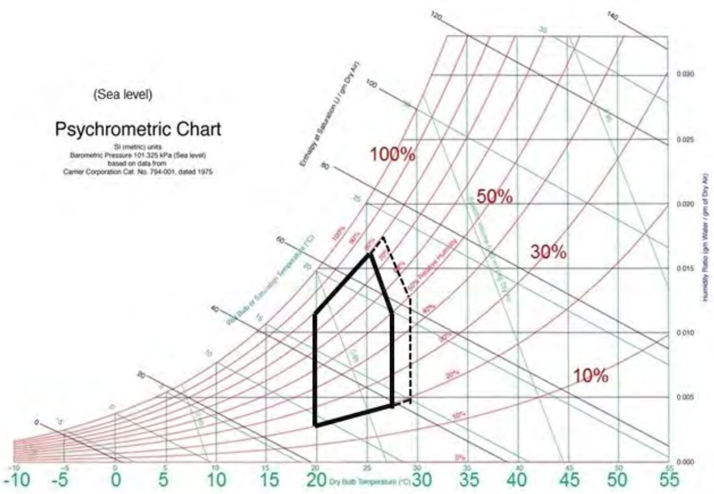

Figure 2 Bioclimatic chart with superimposed boundaries of climatic zones: temperate climate, summer - solid line; hot climate – dashed line from (Givoni 1998) modified from the psychrometric chart from Wikipedia

Building physics tools based on the rough modeling or/and qualitative evaluation are proposed to give the preliminary answers about the potentials of the building/environment system performance. The structure/environment interaction based on the source free enclosure (for example estimation of free running temperature – the temperature inside a naturally ventilated building without any heating source) accounting for wide boundary conditions could give the first evaluation (Ghiaus & Allard 2003). These results will constitute the reference for the qualitative tools developed based on psychrometric chart.

The boundaries of the comfort zones should be modified to visualize different design strategies directed to different groups of end-users. It is meant to be used as a communication tool at early stages of design

Boundaries of a comfort zone – a probabilistic approach

While evaluating a building performance the very important issue is to find criteria to differentiate between good and bad performance. A critical state dividing the space of the possible results into two subspaces the reliable one and the failure one is related to the performance criterion relevant for the chosen performance aspect. The critical state can be defined by a deterministic value, or by probability distribution function assigned to that parameter. The way of presenting performance criterion depends on the investigated problem and availability of data. Stochastic threshold criterion is built up because of the uncertainties regarding the climatic conditions or humans response (Pietrzyk 2008, Pietrzyk 2015).

Generally, variability in time, space, and among individuals can be included in the performance criterion R (see Figure 3). The chosen kind of variability depends on the performance aspect considered. In current case the performance aspect is the interior thermal comfort that can be presented in terms of temperature (sensible or operative). When considering the response of people to a certain state described by a physical parameter (temperature), inter-individual variability in the form of the number of people being affected can be included in stochastic threshold. Variability among individuals in the response to specified interior conditions are caused by their different physical and behavioural conditions. Hence, a criterion for human's wellbeing can be stated for the population, specified group of people or for the individuals depending on the client group in focus, in the form of estimated for the group probability density function (uncertainty is represented by probability). Then, the general standards-based design or client controlled (adapted) design responding to the needs of target group can be considered.

Figure 3 shows the framework for the probabilistic analysis of thermal comfort performance. The results are proposed to be included in the description/communication of the comfort zones in terms of reliability. Reliability is understood as a complement to the probability of failure (P) as given in Figure 3.

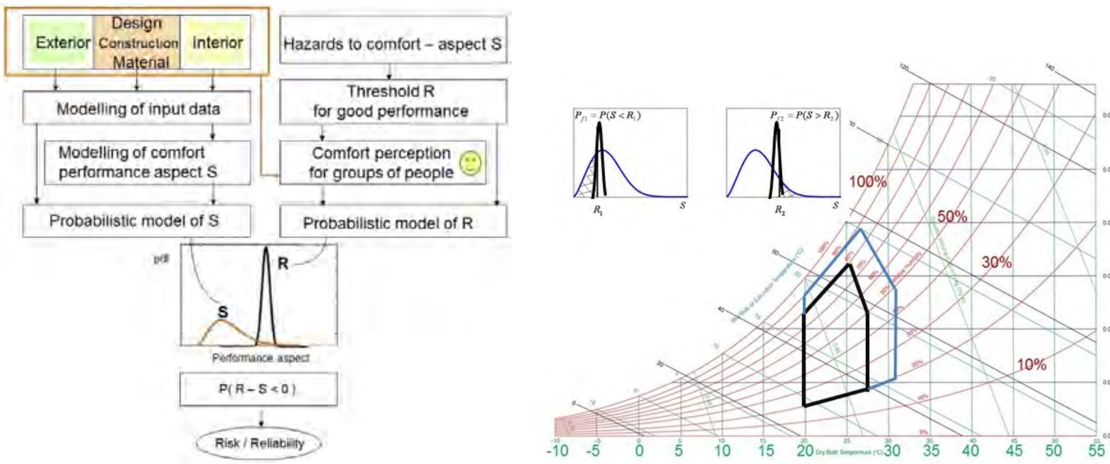

Figure 3 Framework (modified from (Pietrzyk 2015)) for the probabilistic analysis of comfort performance proposed to be included in the description/communication of the comfort zones: for temperate climate – black line: extended comfort zone because of ventilation – blue line. (Psychrometric chart modified from Wikipedia using data from (Manzano - Agugliaro et al 2015)).

Outdoor temperature is an important variable for the boundaries of the adaptive thermal comfort. They are given for each month by the regression equations characterizing lower and upper limits of the comfort zone. Those uncertain limits could be revised with the help of analysis of uncertainties coupled to the probability distribution of outdoor temperature (variability of S) as well as by analyzing the possible contribution of differences in perception/adaptation of various groups of people (variability of R). Eventually, the reliability of the stated boundaries would be estimated to be used in the design process.

Other thermal performance indicators like PPD (percentage of dissatisfied people) or allowable excess of operative temperature in offices could be used to estimate the uncertainties of thermal comfort performance R (Pietrzyk 2008).

CONCLUSIONS

The purpose of this paper is to elaborate on a reliable visualization tool based on bioclimatic approach that architects could use to effectively follow the strategies of passive environmental design of low energy, comfortable and healthy buildings. Climate is treated as a resource supporting natural ventilation, free cooling, and free heating. The theory and methods of the interdisciplinary field of building climatology (climatology, building physics, physiology/psychology and architecture) are addressed. The performance aspects (air exchange, heating or cooling load, comfort indicators. etc.) are treated as random, as they are dependent on the random climatic characteristics and uncertain human perception. It is proposed to introduce to the bioclimatic chart the reliability of the boundaries of the adaptive comfort standard dependent on target group's perception. The paper presents only an idea that must be further developed. Research is needed to quantify the uncertainty of the boundaries of the comfort zones in relation to various passive strategies. Different thermal comfort standards and thermal comfort indicators could be considered.

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