Abstract

“Performance approach in buildings” was developed as a result of usage of performance concept which has a definition of behavior of a product related to use in buildings. The integration of this approach into the design process of building design brought out the “performance based building design”. Performance based design contains the transformation of the functional and technical requirements which were determined at the initial phase of design into the performance requirements, and making design towards those performance requirements.

In the performance based design process, the evaluation of performance of design is made by the usage of some methods (simulation tools, calculations, quantification methods) in obligatory conditions. These evaluations are applied to control the required performance is met or not by design, the accuracy of the design and desired performance goals are achieved or not.

In the content of this study, the models that were developed on performance based design is discussed based on literature survey. These models are performance based design teaching method (Atiuno model), building evaluation domain model for existing building evaluations, the model that shows the relation of performance based design and knowledge based tools, design process model for high performance buildings, design decision network model, cognitive model and aspect system models. The positive and negative aspects of these models are explained, methods and procedures that were used in them are examined. As a result of the examination of these models; to increase the usage of performance based building design in the practical architectural works, a lack of approach which can turn the issue from a technical point to a business issue is established. This approach should clearly define the components of the design process and determine the steps that enable the evaluation of design and should be user-friendly.

Keywords: building performance, design performance evaluation, performance based design, performance approach on buildings

1. Introduction

Performance is defined as “behavior of a product related to use” by ISO 6241-1984 [1]. Here, the product might mean an entire building as well as a part of it. Preiser et al. [2] suggest that the concept of performance in buildings was developed by Eberhard [3] in the 1960s, and was first introduced into the profession of architecture at the end of the 1970s. Bakens et al. [4] state that the performance based principles introduced in the 1970s could not be adapted within the building industry, despite a number of previous efforts in the field [5-15]. The report titled “Performance-Based Study of Buildings” prepared for CIB provides the most basic definition of performance-based approach as follows: “The performance approach is, first and foremost, the practice of thinking and working in terms of ends rather than the means. It is concerned with what a building or building product is required to do, and not prescribing how it is to be constructed.” [16]. This definition is the very first and the most basic definition of the performance-based approach to buildings and main its validity, as it is still being used in many recent studies [17-32]. In addition to this basic definition, the first record that mentioned building performance was made in the Code of Laws drawn up by King Hammurabi, who
lived in 1700s B.C. Article 229 on obelisks that are on display in Louvre Museum in Paris reads as follows: “The builder has built a house for a man and his work is not strong and if the house he has built falls and kills a householder, that builder shall be slain.” This expression, despite not including any information with regards to the construction technique, material, thickness, size, etc..., clearly states that the building is expected to provide the desired performance. The content of this article is compatible with the definition suggesting that the performance approach pertains to a thinking and working principle relevant more to the ends than the employed means.

2. Performance Based Building Design

After the performance based approach started to be used in relation to buildings in the 1970s, studies aiming to apply and extend this approach [33-40] began using “performance-based building” or “performance-based design” terms instead of “performance approach in buildings” or “performance concept in buildings”. All these terms have the same focus: to design and construct buildings with high or desired performance [41]. The PeBBu (Performance Based Building) Thematic Network that was initiated as part of European Union 5th Framework Program defines performance-based design in their final report as follows:

“A Performance-based design is a building design that is based on a set of dedicated performance requirements related to the intended use of the building, and that can be evaluated on the basis of performance specifications” [26]. The same report defines the performance-based design process as “a process in which performance requirements are translated and integrated into a building design.”

3. Constituents of Performance Based Building Design

The most important starting point in performance-based building design is to accurately define the requirements. While defining user requirements, it should be kept in mind that the user profile can include a wide range of individuals, including the permanent users of the building, visitors, building staff, public in buildings providing a public service, and animals in buildings with an agricultural function. All these individuals are recognized as stakeholders. The requirements of the stakeholders might include technical, physiological, sociological, and psychological aspects. These are mostly qualitative terms and quantifying these is a special step in the design process. The application of the performance approach to buildings is possible via converting user requirements into performance requirements. User requirements are expressed in terms of means and conditions provided by a certain building for a certain aim, independently from where the building is located. Performance requirements, on the other hand, are quantitative means and conditions reflecting the design decisions provided by building construction and systems, mostly for a particular aim and location [26]. The differences between user requirements and performance requirements are shown in Table 1.

Table 1. Comparison of user needs and performance requirement [26]

<table>
<thead>
<tr>
<th>User needs</th>
<th>Performance requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Have meetings with max. 25 people in different settings (theater and round table)</td>
<td>- Required space: 3 m² per person</td>
</tr>
<tr>
<td></td>
<td>- Space shape: ratio length : width ≤ 1,5 : 1</td>
</tr>
<tr>
<td></td>
<td>- Ventilation: min. 30 m³ fresh air per person and per hour</td>
</tr>
<tr>
<td></td>
<td>- Air temperature: 19° C &lt; t &lt; 21° C</td>
</tr>
<tr>
<td></td>
<td>- Back ground noise (due to external sources): max. 35 dBA</td>
</tr>
<tr>
<td></td>
<td>- Reverberation time: 0,8 – 1,0 sec</td>
</tr>
<tr>
<td></td>
<td>- Lighting level on desktop (level): min. 500 lux</td>
</tr>
</tbody>
</table>

Another important stage in performance-based design is to carry out the design for the targeted performance in line with user requirements, as well as performance requirements defined on the basis of these. During the performance-based design process, the design team that is led by the architect works in collaboration with different engineering disciplines. From the first stages of the design process onwards, everybody should work in a coordinated manner, in line with the defined target performance.

While computational design is an advantageous design technique widely used for performance-based design, other computational techniques are used within the design process for an appraisal of design alternatives and of the possible outcomes. The assessment of whether the design meets the performance requirements is another important component of performance-based design. For performance evaluation within the design process, the measurement of performance is an activity embedded within design production. The evaluation of a design solution and its suitability for stakeholders’ requirements, as well as other design components that should be integrated to this particular solution, are other elements of this embedded activity [42]. The most significant computation tool that is used for the design performance evaluation is simulation. Building simulation software has gained considerable importance as it accelerates the design process, increases productivity, allows a comparison of different design schemes in a wide area, and shows more optimal solutions. Simulations increase the efficiency of the design process and help gain a better understanding of the results of the design decisions [43].
This performance-based design process is quite deficient compared to today’s performance-based design approach. Particularly in the stage where user requirements are defined, the content user profile is not considered. In other words, stakeholders that are a components of performance-based design are not included within the process. Their roles in and contributions to the design process are not reflected upon. Performances are not checked at the schematic design stage. The methods used for the performance program suitability analysis made in the detailed design stage and for the final performance checks in the design process for different building components are not clear. Based on the current performance-based design approach, the methods and tools used to assess whether design ends provide targeted performance level are not explicitly stated. Furthermore, the model has a linear structure and it does not allow feedback from and return to stages before checks [41].

4.2. Building Evaluation Domain Model

Mallory-Hill [45] suggested a 3D model called the building evaluation domain model, as shown in Figure 2. The components of this 3D model are as follows:

- **Human system level** (forms the demand scale and represents the requirements)
- **Architectural system level** (represents building scale and complexity)
- **Building system level** (forms the supply scale and represents building systems meeting the requirements)

This model developed by Mallory-Hill is not a model to be used for performance evaluation in the design process, but to assess the performance of the existing buildings.
Mallory-Hill applied this model to an existing office building with post occupancy evaluation method. The lighting comfort of the office space was chosen as basic (personal) contentment performance demand in the human system level, while the system level services were defined as office performance supply. The demand-supply comparison was achieved via user satisfaction. Mallory-Hill states that this model can be used for the aim of performance evaluation using tools to simulate office space. This model is also deficient, as it does not take the design process into account and does not include the stakeholders [41].

4.3. Performance-Based Design Framework Model

Becker [46] expressed the performance-based design model shown in Figure 3 as a model related to database tools, reflecting a common engineering approach that can be used in many performance applications.

Figure 3. Schematic of performance-based design and required knowledge-based information and tools [47]

In this model, Becker defines the performance-based design process as an algorithm composed of ten steps. These steps are:

- List potential user activity groups and their requirements.
- Identify all relevant actions/conditions that tend to adversely affect building performance and threaten achievement of the user requirements and the combinations that should be addressed simultaneously.
- Identify all relevant performance indicators for every user requirement.
- For each performance indicator, define the building-related meaning of the term dissatisfaction or performance failure.
- For every user requirement associated with every User-Activity, define the accepted percentage of dissatisfied or the accepted level of failure.
- Determine the characteristic values of the generalized loads.
- Determine the characteristic limit values of the performance indicators.
- Determine safety/modification factors for transforming characteristic values into design values.
- Establish acceptable evaluation tools reliably predict the consequences of exposing the suggested design solution to the relevant combinations of generalized load (simulations, PTMs).
- Establish methods for deriving design values for all relevant material or component properties required in the evaluation process.

Becker has not conducted a case study application of this model. According to Becker, this algorithm is useful to define the relationship between databases and tools needed for an accurate application of performance-based design. Becker states that this schematic algorithm is a basic tool not only as a conceptual model but also for the development and adaptation of simulation tools used for performance-based design and evaluation purposes. However, as she also acknowledges, this model remained at the level of a schema, framework, or a conceptual model. She underlines that further tools, procedures, and model documentations are needed for the application of performance-based design [46].

4.4. Design Decision Network Model and Design Process Model for High Performance Buildings

Magent [48], as part of his PhD research, investigated the design process for high performance buildings and developed a new design process. Magent stated that the design process is not clearly defined for high performance buildings and to fill this gap, developed an integrated design process that is considered useful for high performance buildings using “decision focused process” and “competency based approach.” In the initial stages of this study, Magent proposed a design-decision model. This model, as shown in Figure 4, has a conical structure. This conical model is used to reflect the nature of decision making process. The possible decision options are reduced in number using analysis and information, to finally reach a conclusion on the basis of a commitment. Any uncertainty at any time within the decision time schedule is represented by means of the cone diameter. When new options are considered the uncertainty increases, while it decreases when new information is provided and options are analyzed.

Figure 4. Proposed design-decision model [48]
Magent states that this design-decision model is a part of the design environment. He models this design environment as a conceptual design decisions network and defines the model shown in Figure 5 as design decision network model. Magent suggests that in this model, the commitment obtained at the end of the decision making period provides the information that is needed for subsequent decision making processes. According to him, in addition to the decisions, this model helps carry out analysis in the design process. Magent represented these analyses (simulations, cost calculations, and research) by rectangular boxes within the model. Furthermore, he states that this design environment includes not only decisions and analysis, but also the individuals responsible for the design. The skills and knowledge of these individuals have a direct influence on the decisions, information, and analyses forming the design decision network. These information and skills are characterized as competences within the design decision network, and represented as hexagons.

Magent, in his study, has also developed a design process model to be used to evaluate the design process of energy systems, based on the theory established within the Design Decision Network Model. In this model, the IDEF (Integrated DEFinition) model method was employed. The IDEF model represents the process of a series of diagrams and defines the information relationships between activities. Activities in these diagrams are represented as boxes, while the interfaces between activities are shown as arrows or lines between these boxes. IDEF uses hierarchical diagrams. A0 activity located at the uppermost level of the diagram is expressed as a single activity. Then to this activity, sub-activities are added, shown as A1, A2, A3... to form a more detailed diagram. This disintegration continues until model reaches its target [49].

Magent defines the design process model, shown in Figure 6, with activities and sub-activities and shows sub-levels of the model within IDEF. He developed a total of three different models: Design Decision Network Model, Design Process Model for High Performance Buildings, and Design Process Evaluation Model for High Performance Buildings. The Design Process Evaluation Model has been developed as a decision-based process evaluation model on the basis of the two previously developed models, summarizing the steps to be taken in the design process of high performance buildings. Magent, as part of his study, has not conducted any testing or validation of this design process evaluation model. He states that this model provides a decision-based process/evaluation tool summarizing design steps for high performance buildings and based it on two other models he developed. In this model, the first step is to form a team. Then, the function of the building will be defined. The next step is to develop a decision-based design process map. Following this, key decisions are evaluated both within the time slots allocated to them within the whole process and when they are individually organized. Then, the information needed for the aim of decision-making will be identified. The last step is to define competencies required for the process application [48].

Figure 5. Proposed design decision network model [48]

Figure 6. Design process model for high performance buildings [48]
shown in Figure 7, includes methods such as genetic algorithms, fuzzy neural trees, and Pareto optimization. Genetic algorithms are a procedure based on Darwin’s “survival of the fittest” principle. This procedure is an evolutionary process including the competition among potential solutions and elimination of some [51]. The fuzzy neural tree method, on the other hand, was developed by Bittermann himself, using fuzzy logic and artificial neural networks. The method called Pareto optimization is used for a multi-purpose optimization and multi-criteria optimization (non-dominant optimization) [52]. Furthermore, the visual perception model he developed as part of his study was used in the “measurements” section to calculate perception. In his perception model, Bittermann modelled perception using an avatar and mathematical calculations.

Augenbroe uses the visual comfort example to explain the system that he calls the aspect model. In order to be able to understand the problem physically, the technical systems that play a role on the targeted visual comfort level are listed below. Among these technical systems, the most important members and parameters that have the greatest influence on the visual comfort are given in parenthesis.

• External enclosure system (elevation: type, size, and location of windows, shading devices, shading control)
• Neighborhood system (nearby buildings, vegetation)
• Electric lighting system (type of fixtures, location, control)
• Internal enclosure (surface finishes (color, reflectivity))
• Organization system (workplace location and orientation, internal partitions height and finishes)

These systems show that the entirety of members and parameters that comprise the different technical systems are responsible for the visual comfort. In addition to these, a functional system that can be described as the conglomeration of different technical (sub)system elements is also formed. The selection of these elements is made on the basis of whether these make a contribution to the building behavior in relation to a certain function. This functional system is defined by Augenbroe [54] as the “Aspect System”. The quantification method to be employed on a performance requirement (generally simulation) works on the Aspect System as in the visual comfort example. As seen from Figure 8, each functional requirement depends entirely on an “Aspect System”. The relationship between a functional requirement and an “Aspect System” is concretized in the form of performance indicator.

This model does not take into account stakeholders, who should be actively involved during the definition of user requirements stage, one of the basic components of performance-based design. Furthermore, it is should also be questioned if design alternatives being produced by genetic producers change the role of the designer and design team [41].

4.6. Aspect System Model

Augenbroe [53] bases performance-based design on building performance requirements and a set of standardized performance indicators forming a series of well-established values that show possible results. The expert of the design process analyzes and evaluates different designs on the basis of these performance indicators.

5. Conclusions

Croce et al. [44] proposed a model that was systematically divided into different stages with regards to performance. Mallory-Hill’s model [45] is different from other proposed models, as it is not related to the design process and aims
to evaluate the performance of existing buildings. However, this model was discussed in this study because Mallory-Hill suggested that his model can also be used in the design process with the help of simulation tools. In the performance matrix in Mallory Hill’s model, which is formed independently from the time dimension, the matrix components are expressed within a certain hierarchy. The building, which is one of the matrix components, is divided into sub-systems formed by a variety of elements. The other components, dissimilar to the elements forming the building, were expressed within a hierarchy as building and the surroundings. The last component of the matrix is the people and situations affected by the performance. The content of this component is given in a hierarchy, varying from the individuals’ level to the global level. Becker [46], in her model, defined a ten-step process to draw the general framework. Becker’s model is a conceptual, general model, and does not include any other hierarchy than steps that need to be followed. One of the three models developed by Magent [48], the design process model for high performance buildings, is formed using the hierarchy-based IDEF model. As this model’s language is a model composed of hierarchy diagrams, it has also a hierarchical nature. Both Augenbroe’s model [54] and fuzzy neural trees within Bitterman’s cognitive model [50] are both based on the formation of a hierarchy.

The Building Evaluation Domain Model, Framework Model, and Aspect System Model define performance-based design independently from the design process. Among other models that were examined here, the Atiuno model, Design Process Model for High Performance Buildings, and Cognitive Model illustrated performance-based design as a whole process. The Atiuno model is linear, does not include feedback, freezes performance checks at certain stages throughout design, and does not incorporate stakeholders’ participation into the process for the identification of requirements. The Design Process Evaluation Model for High Performance Buildings, which Magent states is composed of his two other models, the Design Decision Network Model and Design Process Model for High Performance Buildings, is claimed to include a team to develop the targeted function for the building. However, this model has not been put in application and has remained in at the cognitive level. The cognitive model is composed of a series of complex methods that are difficult to employ in architectural practices, such as genetic algorithms, Pareto distribution, and fuzzy neural trees, and does not incorporate stakeholders, an important component of performance-based design [41].

As a result, the examination of performance-based design models revealed a lack of a certain approach that is needed to increase the usability of performance-based building design within architectural practices. To this end, this approach should explain the design process components thoroughly, identify steps allowing a design evaluation, be easy to use, and capable of transforming this subject into a business field rather than a technical one.

Acknowledgement: This study is produced from the Phd Thesis named “Proposal of A Model for Performance Based Building Design” which is fulfilled by Selçuk SAYIN under the supervision of Prof.Dr. Gülser ÇELEBi at Selcuk University Graduate School of Natural and Applied Sciences in 2014.

References


