Energy and Exergy Performance as Parameters in Architectural Design Sketching - a Case Study

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Abstract. Buildings account for 40% of the worldwide CO2 emissions. These emissions are directly related to their energy consumption. 80% of the design decisions impacting energy consumption are made during the first 20% of the design process and therefore address the architect. Necessary decisions do not only concern building geometry but also materialization and building service systems. Choices in either of these fields significantly influence the future energy consumption of the building. Therefore it is necessary to support the architects’ decision-making. From the first sketch on, the evaluation of energy performance needs to be incorporated into the design process. This paper shows a method and results which were produced in a case study at the ETH Zurich by using a special tool in early design phases for energy and exergy analyses. Keywords: energy, exergy, early design phases, performance, sketching.

Introduction

In order to estimate the energetic consumption of a sketch or preliminary design, most architects have only their experience and physical understanding available. The increase in regulations, laws and the desires of owner for energetically optimized buildings increases the requirements concerning the efficiency. This extends now all the way back to the initial draft, and thereby increases the need of the architect for energetic evaluation of his ideas in the first design phase. In order to not to interrupt the early intuitive design process, it is important that the architect gets the expert knowledge from energy engineers while designing. This knowledge must be readily available with clear visualizations of the performance indices so that the architect can make use of it while sketching.

In the last decades simulation tools became simpler and faster. Today they already make a better estimation of the building energy consumption possible. Fast generation of the results allows production of a lot design variants. This leads to a wider spread of possibilities to optimize the design. A problem with the application of the energy simulations is on the one hand a long computation time interrupting the intuitive design process, and on the other hand the draft or the CAD file must be adapted to the
simulation tool, again costing work and time.

This paper presents in the first section a method and a prototypical software tool that was developed at the chair of building systems at the ETH Zurich. This tool solved the problem of the long computational time of common physical simulation tools. It visualizes the complex performance parameters quickly, and it is directly connected to the design software. In the second chapter a case study will then show the influence of exergy and energy parameters when they are available on the draft while sketching.

**Method**

The following presented sections explain the needed components for the integration of the performance indices into the first design phase.

**BIM (Building Information Model)**

In the last years CAD-systems were developed that are able to implement not only geometric information but also topological and semantic information. This so called Building Information Models (BIM) offer the potential for the energy and exergy calculations in the sketch phase because they supply the needed parameters. The needed parameters are stored internally in a database and can easily be changed by the designer. This offers the opportunity to develop design variants and helps the architect find the best solution.

**Exergy/Energy - Tool**

One part of the implemented calculations is the exergy calculation. From the architectural point of view this is meaningful because the designer receives a more detailed view on the energy and exergy flows. This offers him better scope.

In thermodynamics exergy takes the concept of energy and the 1st Law of Thermodynamics and extends it to include the concept of entropy and the 2nd
In concept, Exergie = Energy + Anergy. Anergy is the portion of exergy that is destroyed through irreversibilities that generate entropy. Anergy can also be seen as the part of exergy that can be obtained freely from the external environment. This includes the ground, groundwater, and outside air. It also could be considered to include energy from sources that would otherwise be lost into the external environment such as exhaust air and wastewater.

The tool implements exergy calculations based on the work of Dietrich Schmitt (2004). The exergy calculation computes, in steady state conditions, the necessary power for heat production and for the needed primary energy. It computes the exergy losses that were produced along the heating chain. The complex interactions between insulation, geothermal probes, heat recovery and supply temperature must be taken into account for optimizing the preliminary design. The exergy calculation makes this possible. This is a new approach for building optimization.

On basis of valid standards, like the German EnEv or the Swiss SIA 380/1, energetic performance indices of the design are computed. The first advantage of the static calculations is the fast computation (less then 1 second), and second due to the simple algorithm it is easy to implement them in the software tool. A disadvantage of these calculations is the restriction that they compute only certain building typologies. For example the total window area must be less then 30% of the total building envelope.

**System choice – Tool**

For the performance estimation of the sketches form and construction evaluation is not only relevant, but also the technical systems must be implemented and checked. The selected BIM has no building system or services data. For that reason a system choice is implemented in the tool. A differentiation of the many systems is reached by the preselection of heating systems. In the tool the architect is able to choose only systems that do not produce CO₂.

**Performance Visualizations**

Special attention in the development was given to the visualization of the complex information computed in the tool. For the architect it is very important that he can recognize the performance values just by a short look at the visualization. Otherwise the values would interrupt his intuitive design process. For this purpose different parametric representations are offered.

**Kiviatgraph to analyze the specific power of the building components**

The Kiviatgraph is used to show the specific power that is used by the different building components. Losses and gains through the components are represented by the use of one polygon (fig. 1) The shape and area of the polygon describes the performance of the walls, windows, roof, internal gains and lighting gains.

**Sankey diagrams to analyze the energy flows**

A sankey diagram is used to show the energy flows through the building components. (fig. 2) This method is typically used to visualize energy or material transfers between processes. The widths of the arrows show proportionally the quantity of flow.

**Bar chart to analyze the exergie flows**

To analyze the exergy flows a bar chart was developed. (fig. 2) This chart is normally used to illustrate measurement values. A virtual measurement is made in the exergy calculation because the formulas used in the computation are steady state. For that reason this representation was a good solution to visualize the exergy flows.

The diverse types of charts make a differentiated view of the building performance available. The break down of the complex information into charts allows the architect to analyze his draft and makes an optimized workflow possible. In this case study the different workflows are demonstrated.
Case Study

Introduction
Architecture students at the ETH-Zurich must take special classes during their Master studies. These classes are offered for the students to get a deeper knowledge in a special branch of architectural design. The Chair of Building Systems, as one important part, offered in autumn 2007 a course called LowEx + Arch (Low Exergy and Architecture). 25 Students took part in this course. The goal of this course was to introduce on one side the low exergy theory, and on the other side the students would design a house by taking the energy and exergy performance into account. To do this they have to use the tool that was developed at the chair.

At the beginning of the 10 week course the low exergy concept was explained. The students have to learn how to deal with a building information model. This was done with the REVIT software from Autodesk. After 2 Weeks the developed tool was introduced and the students started with their drafting. An important aspect was that the students had to document their design decisions. This helped to maintain a perspective of both good designs and bad designs. The students have to make their own set up and they have to explain why this design is better then the other.

Results
At the end of the course two different design approaches came of the concepts as they were developed: ‘Concept optimization’ and ‘Variants comparison.’

Concept optimization
One student group conceived one basic type. In this type the owner specifications like total building height, floors and the space allocation plan was
implemented. After the definition of this given geometry the students develop a flexible front concept. (fig. 3) The focus was the energy performance. Due to the variability of the concept and with the use of the performance tool they developed a lot of design variants. A finalized architectural façade was not part of their approach. Their approach was an idealized glass house. This couldn’t be reached because the offered heating system was not strong enough to heat up the rooms in winter, because pure glass walls produce a huge amount of heat losses. The use of primary energy and exergy is in this case is exorbitant. This was shown in the tool. In the further development they replaced the walls with a transparent heat insulation, and they increased the anergy source temperature by using a deeper borehole for the heat pump. The balance between performance, material, geometry and systems produce an energetic and exergetic optimized draft.

This ‘curtain’ concept was a simple presentation of how concept optimization influences the final draft in the design process.

**Variants comparison**

The starting point for this student group was 2 finished building drafts (fig. 4). The drafts were changed neither in geometry nor in the design. This fixed architectural idea should only be optimized with materials and by with technical systems. From the available heating emission systems (slab heating, floor heating, ceiling heating, radiator), the group chose two for analysis. They compared only floor heating and slab heating. The comparison of the material is done with three different materials. Brickwork, lightweight concrete and steel-concrete. On the basis of the 2 building drafts, 12 variants are produced.
combined and compared with the material and the technical system. The comparison analyses did not show a clear ‘winner’. For that reason the group did not have a clearly optimized draft. They figured out that different combinations between material and systems could deliver similar results. Although it did turn out that low U-Values produce a more exergy efficient system, nevertheless the total exergy demand increases. Furthermore the use of an efficient heating system is more useful then the increasing of solar gains by the window area.

In comparison to the ‘curtain’ concept the students have learned that the results which were produced by the variation of a few specific parameters have often the same impact. A more detailed view is necessary to get an optimized draft.

**Conclusion**

Working with the students has shown that with the use of early performance analyses, the consideration increases for exergy and energy demand in the draft. Also a greater consciousness for the complex connections was developed between construction, systems and architecture. Simple visualization and fast computation provided a quick and intuitive draft process, and it enriched the form finding process with new parameters.

In the future the architect must consider the energetic performance of their drafts more strongly. When they have a tool in which these analyses are possible in the early design phase this leads, as in the case study pointed, to optimized drafts. The importance of the course was that the students took these parameters into account. This demonstrates that architects could easily develop energy and exergy optimized drafts in the early design phase. Moreover these performance parameters produce more and better ideas. Architecture is enriched.

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