Method for Integrating Simulation-Based Support in the Building Design Process

Steffen Petersen*, Jacob Bryder, Kristian Levinsen, Jon Strunge

stp@eng.au.dk, j.bryder@gmail.com, kristian.levinsen1@gmail.com, jonstrunge@gmail.com

Department of Engineering, Aarhus University, Denmark

Abstract: This paper presents a proposal for a method to incorporate simulation-based support in the early stages of building design. The aim is to develop a method that can be applied without any drastic interference or modification of prevailing architectural design processes. The simulation-based support consists of results from fast and reliable indoor climate, daylight and energy performance prediction of a design proposal. The performance prediction is embedded in a software platform which is already widely used in the architectural sketching phase. Besides the immediate performance prediction, the method will also provide design advice to improve indoor climate, daylight and energy performance. The paper also presents the outcome from interviews of representatives from five reputable Danish architecture companies. The aim of the interviews was 1) to investigate the state-of-the-art in the use of building simulation tools and collaboration between architects and engineers in the early design stage, and 2) whether the proposed method is desirable for architects. The outcome from the interviews is used to target the further development of the method.

Keywords: Design Method, Building Simulation, Parametric Design, Indoor Climate, Low-energy Buildings.

Introduction

Building designers should strive to design buildings that fulfil user expectations with regard to the quality of the indoor climate and environment. Furthermore, designers must also make designs that contribute to a sustainable development. In the European Union, this especially means that compliance with an increasing regulatory pressure (EPBD 2010) on the building industry to produce low-energy buildings becomes decisive for design decisions in the building design process.

The fact that early design decisions have greater impact than later decisions is widely accepted and even considered ‘self-explanatory’ (Struck and Hensen 2007). Designers therefore need to know how potential design decisions would affect the quality of the indoor climate and environment as well as energy performance before making any actual design decisions in the early design stages. This requires the management of a large amount of information on the detailed properties of design options and the simulation of their performance. Computer-based building simulation tools are ideal for this and, consequently, there is an increasing interest in the use of building simulation tools to generate decision support in the early design phases. Early research on this like Robinson (1996) argues that easy-to-use tools with comprehensible interfaces are of crucial importance if simulation tools are to be adopted in the design process. This is supported by de Wilde *et al.* (2001) who also argue for the development of procedures in the building design process in which the use of building simulation tools can be embedded. Current research aimed at enhancing the use of building simulation tools in the early stages of building design agrees with these findings. New and existing tools with facilitating interfaces and support for analysis of performance data are often presented in combination with proposals for procedures and methodologies to integrate their use in the building design process, e.g. Soebarto and Williamson (2001), Morbitzer (2003), de Wilde (2004), Ochoa and Capeluto (2009), Petersen and Svendsen (2010), to cite but a few. However, there is no firm knowledge on whether any of these approaches are actually adopted by designers or design teams in real building design projects. The notion is that it is rare. A reason might be that current proposals for procedures and methodologies are only assumptions of, or they interprets wrong, what architects actually need (de Souza 2011). This is why we in this paper are reporting on an interview-based qualitative study where representatives from five reputable architecture companies in Denmark were asked to give their opinion on a proposed method to incorporate simulation-based design support in the building design process. The aim is to investigate implications that may hinder a more widespread use of performance simulation in the early stages of the building design process. This knowledge is valuable to target the development of methods and tools useful to architects.

Method

Building Simulation Tools for the Early Design Phase

In this section, recent studies regarding the use of building simulation tools in the early design phase is reviewed to identify what architects consider to be important traits for building simulation tools if they are to be used in the early design phase. The purpose is to form a basic argumentation for dispositions in our proposal for a method to incorporate a tool for simulation-based support in the building design process.

de Souza (2011) finds that when design proposals are investigated, architects want information about how their moves affect the overall thermal performance, and thus expect simulation inputs and output to be coherent with this. The meaning of performance results should somehow to be connected with the form. Time graphs and temperature tables are meaningless for architects to use, and should instead be linked as consequences of the building manipulation.

Attia (2011) finds that informative support and instant feedback is important. This informative support should include geometry rather than just constructions and systems. The information and suggestions should be based on performance evaluation of the previous iteration to develop and improve a design concept.

Lehrer and Vasudev (2010) find that architects are interested in using simulations for generating general performance data which is visualised in a way which provide a quick overview to inform the design.

Attia (2010) finds that architects believe that the most important trait for a simulation tool is intelligence, i.e. the opportunity to inform the decision making rather than being just evaluative. Other criteria were (in prioritised order) usability, interoperability and accuracy. Architects furthermore valued (in prioritised order) the ability to compare multiple alternatives, graphical output, exploration of alternatives, easy change of input parameters, user friendly HVAC templates and error checking to ensure models are correct.

Petersen (2011) used a building simulation tool specially developed to inform design decisions in the early design phase in three different building design projects. The experience was that there were differences in the extent to which the design support was allowed to influence the design. This was mainly due to different attitude towards the idea of multidisciplinary collaboration in the early stages of design and whether considerations regarding indoor climate and energy use were considered relevant at this stage.

Koch and Hauberg (2011a, 2011b) investigate the practical use of integrated design process models in two different design competition projects. All teams used energy calculation tools to inform decisions. They found that there was a lack of tools and procedures to support interaction between architects and engineers evidenced by statements from participants, predominantly architects, who felt that the use of calculation tools was constraining the interactive process.

According to Banke (2013) the most desired value when using simulation tools is the support of design development and secondly to improve communication with specialists. The most crucial parameters of functionality was speed and to get visual output. To achieve speed in the architectural design process, not only simulation speed but also the operability and flexibility of simulation software influence the time consumed in getting useable outputs.

From the literature it can be learned that architects are interested in using building simulation tools in the early design phase but only if they are conformed to fit their design process. Experiments where the design process has been altered to accommodate the functionality of building simulation tools are rare but the same conclusion applies: building simulation tools that does not "interfere" with the design process needs to be developed if they are to be useful to architects in the early design stage.

Proposal for Method

Based on the literature review, it might seem contradictory to propose a certain method. However, we believe that a methodical context is needed to be able to discuss cross-disciplinary collaboration and the development of useful design support generated by building simulation tools. The main idea of the method is to generate reliable indoor climate, daylight and energy predictions directly in the software platform already used by architects in the sketching phase. Besides the immediate performance prediction, the method should also generate design advice, i.e. suggest means that will improve the indoor climate, daylight and energy performance.

A workflow of the proposed method is shown in figure 1. The method consists of two parallel tracks: an "architect" and an "engineer" track. Different consecutive tasks are executed within these tracks. First, the architect proposes a design in the 3D drawing program Rhino (2014). Next, the geometry is set up as a parametric model in the Grasshopper programming environment (2014). The engineer may help linking the model to the simulation tool and set up simulation parameters. Details on the simulation tool are described in Petersen and Lauridsen (2014).

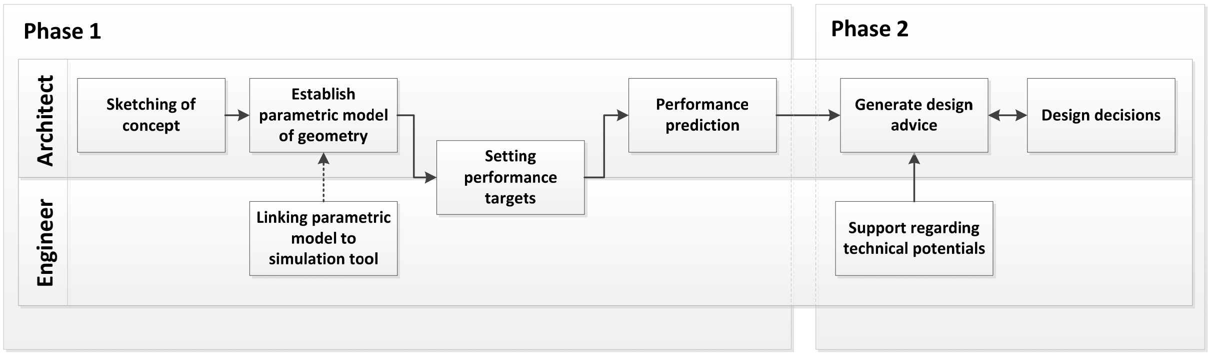

Figure 1. Workflow of the Suggested Method

Performance targets regarding indoor climate, energy and daylight level are then defined; perhaps in a joint workshop. The architect can then make a performance prediction and evaluate the outcome in relation to the performance targets. This is where the typical evaluative use of building simulation tools stops and enigmatically leaves the task of remedying oversteppings of performance targets to the architect. As an alternative, we suggest that the architect continues to phase 2 of the method. Here, the architect decides on a number of design variables (e.g. window size, and orientation) and their boundary conditions (e.g. window height between 1 m and 2.1 m, orientation between 0° and 35°). The simulation tool then automatically generates design advice. The design advice could be the output from a sensitivity analysis of variables or output from an optimization algorithm, e.g. as proposed by Petersen and Lauridsen (2014). An iterative process of design decisions and performance predictions then starts and later ends when a satisfactory design is obtained. In this process, the engineer may support regarding technical aspects of the solution space.

Interviews

Representatives from five reputable Danish architecture companies were interviewed to assess whether design practitioners finds the proposed method compatible to their design process. This is important because the core idea behind the proposed method is to have a platform where use of building simulation tools would have an actual chance of being implemented in the early design phase. The interviews were performed in a semi-structured manner where a number of predefined questions concerning design process and building simulation tools was used to initiate discussions. The data from this type of interviews are qualitative and it allows discussions that might bring up data that would not have been obtained through a more rigorous approach. The interviews started out by asking questions aimed at getting data on their usual process when it comes to collaboration with engineers and considerations about performance. Subsequently, questions regarding the use of performance simulation tools in the early design phase were asked. Finally, the proposed method was presented together with different proposals on how to illustrate the design advice generated in the method (see section “Proposal for method”), and the interviewees were asked to express their immediate opinion.

Results

This section summarises the prevailing answers and main tendencies from the interviews. The authors are in possession of audio files and transcripts of all interviews in their full length.

Collaboration with Engineers and Considerations About Performance

What is the degree of collaboration between architects and engineers in the early design stage?

In competition projects, the architects often take care of the whole project alone. Performance issues, if considered, are treated based on past experience and some rules of thumb. This is, according to the interviewees, because these projects are much more about the design itself, and not so much about the engineering performance indicators (indoor climate, energy performance, etc.). In commissioned projects, where the economy is fixed, the engineers are much more integrated in the process. However, engineers are still primarily contributing with guidance based on experience and rules of thumb.

Have you ever practiced a formal Integrated Design Process?

The interviewees were aware about the existence of the concept of integrated design process (IDP) but they had no or little theoretical knowledge about IDP. They associated IDP with some sort of process where engineering calculations and analysis is used to assess design proposals in the early design phase. The major concern about their notion of IDP was that it may compromise aesthetics and the architecture in general, e.g. if (measurable) performance criteria and architectural (non-measurable) criteria are equal. However, some perceived elements of IDP to be an advantage as the inclusion of the engineers in early design decisions may make it easier to collaborate with the engineers in the detailed design stage: the engineers can vouch for the design and, consequently, fewer corrections have to be made. Another argument for early inclusion of engineering calculations was that it also becomes easier to make arguments for the design directed at the building contractor. IDP is currently not a part of the Danish architectural culture. The interest and willingness to learn more about IDP was present but there is no time available to overcome its steep learning curve. One suggested that IDP could be taught as a part of the basic training programme in architectural studies.

Describe barriers and experiences associated with collaboration with engineers in the early design phase.

A main barrier for cooperation in the early design stage is economy. Handling engineering performance aspects in this phase increases the workload which is not compensated in fees. Another barrier is that some are worried that the early inclusion of engineers in the process is limiting their architectural freedom. The experience is also that the engineer’s desire for preciseness and measurability is slowing down the dynamics of the early design phase where changes are made rapidly. There is a general perception that the engineer only wants to make one calculation on the final design rather than making numerous calculations as design advices.

Are architects considering performance issues like daylight levels, indoor climate, energy consumption and HVAC sizing in the early design phase?

Daylight issues are often considered and are mostly taken care of by the architects themselves. A few are also doing some overall building energy analysis. Indoor climate (thermal and air quality) is not considered. However, some points out that there is a risk in letting the architects do the analysis as they are likely to downgrade the issues in favour of the architectural aspects. Technical aspects such as HVAC systems are not considered.

Are architects interested in increasing the focus on these issues in the early design phase?

All are aware that the industry is moving towards a more performance based design culture and the willingness to focus more on the energy and indoor climate issues is present. However, engineers are considered to be too slow when it comes to performance simulations which make the architects highly interested in doing the performance simulations themselves to speed up the overall design process. The main disadvantage of making simulations without the presence of the engineer is that the architects are not trained in setting up models and interpreting results from simulations which can lead to serious mistakes. Another crucial concern in the increased focus on energy and indoor climate is that the architects feel that the softer architectural values are lost in the discussions on the energy and indoor climate performance.

Indoor climate is related to rooms. Are architects willing to design on room level in the early design phase?

The design process starts by considering the overall building geometry. Room level analysis is done at a later stage when the overall building form is established. In general, the architects are not interested in getting information on room level when they are in the creation of the overall building geometry in the early design phase: it is considered irrelevant. Defining model in existing tools is time consuming and requires too detailed information about the design which is not present at this early stage.

The Use of Performance Simulation Tools in the Early Phase

Which building simulation tools are used in the early design phase?

The primary interest is daylight, and especially two programs for the daylight simulations are mentioned: Velux Daylight Visualizer (VELUX 2014) and the DIVA plugin to the Rhino platform (DIVAforRhino 2014). When it comes to tools for evaluating energy consumption of different of different building designs, one company mentions Ecotect (2014), Vasari (2014) and Green Building Studio (2014). The mentioned tools are used by the architect without interaction with the engineer. Some express a concern that the architect lack of proper skills to use the simulation programs correctly.

Are currently available performance simulation tools fit for the design process workflow?

The short answer is no. Several problems are mentioned: poor interfaces, poor interaction between designer and program, output difficult to comprehend, too slow, import/export of data, incapability to handle complex construction geometry, extra time consumption and data loss when moving geometry between different programs.

How should performance simulation results be presented?

The majority of the interviewees expressed that they would like very graphical presentations of performance data instead of showing a lot of numbers, which should only be secondary. This would help architects to decipher data but also make data presentable to clients. One finds that even simple graphs are only for engineers, and that design consequences should be related to building geometry.

Thermal indoor climate seems to be hardest performance issue for architects to comprehend. One interviewee elaborates that he would not know how to act if a thermal diagram showed excessive overheating. Another thinks that standardized indoor climate classes are minded more at engineers. Despite this resignedly attitude, thermal performance is considered a relevant design issue.

Immediate Opinions on the Proposed Method and Proposals on How to Illustrate the Design Advice

The Proposed Method

The feedback regarding the method mainly concerned the simulation tool enabling the generation of performance evaluation and design advice. The most important functional trait was considered to be the relatively fast calculation time (approx. 30 seconds per performance prediction). This was mentioned by many as crucial when it comes to the potential of having building simulation tools properly implemented in the design process. Some do actually even find it to be almost too slow and would like if simulations could be real time even if it means loss of accuracy. Others do care about accuracy and stress the importance of a validated simulation engine.

One of the interviewees was somewhat skeptical towards the chosen platform because it is not a tool used by his company. However, the majority were positive as many of them use this platform already.

A major concern was that the tool operates on room level. The majority feel that this is way too specific and detailed for the early phase and more in the engineer's field of expertise. However, there are a few that do not consider this a problem but as a new and useful option.

Sensitivity Analysis as Design Guidance

The idea of making sensitivity analysis to inform the design process was in general very positively received. Some of the companies are already doing this primarily with regards to daylight performance. One company also compares energy consumption via Ecotect (2014) or Vasari (2014). Sensitivity analysis is considered a powerful method for processing design proposals. Another stated that he likes the sensitivity analysis because it can help coupling answers to the questions of "what is the performance?" with an explanation of "why is the performance like this?" and "which parameters do I need to work on?".

Optimization as Design Advice

The idea of automatically optimizing a design for the best performance was by some considered an interesting option but primarily for inspiration or guidance. One expressed skepticism concerning that you cannot count on the software to be creative and that there needs to be room for innovation. Another explained that it is important not to dictate a solution but to guide the architects in a good direction and explain the context and why a given solution might be good. A suggestion was that optimization can be used later in the process to optimize e.g. window sizes or orientation. Almost all preferred the sensitivity analysis approach over the optimization approach.

Suggestions for Improvements and Added Functionality

Many suggested that there should be separate simulation tool user interfaces for architects and engineers to ensure that the architect is not confronted with too much (or any) technical information. The architect interface should be quite simple e.g. with drop down selections whereas the engineering interface is completely open and fully adjustable.

One suggested that some sort of check box system could enable designers to easily select which parameters from the sensitivity analysis to include in your next design iteration. Another suggestion was to evaluate data according to the demand for documentation in the Danish DGNB certification system (DGNB 2014). One suggested implementing some sort of function that helps to store knowledge learned in individual projects so it can be transferred and used in the next project. Other suggestions were to have the ability to evaluate solutions with natural ventilation, evaluation of wind pressure on façades, and some sort of area management where you can clearly see the number of square meters for all surface areas.

Discussion

Based on the interview, it seems that architects in general works alone in the early design stage. The architects may ask the engineers to provide some rules of thumb regarding engineering performance issues like daylight level, thermal indoor climate and energy use prior to initiating their mono-disciplinary design process. It is difficult to identify the exact reason why this is, but statements indicating that engineers are “too slow”, “not willing to participate” and “limiting design freedom” are prevailing. A barrier seems to be the engineer’s desire to calculate and measure before taking any decisions. This is often a slow process especially compared to the process of architects which seem to move faster forward because they mainly prefer to operate with design criteria that they consider to be “non-measureable” and therefore can judge by immediate intuition.

It was striking that the indoor climate was not mentioned as a design issue in the early design stage. The understanding was that this can be fixed in the detailed design phase. The lack of interest in indoor climate is a barrier for integrating thermal building simulations in the early design stage as a major functionality of building simulation is to evaluate indoor climate and, consequently, energy performance. Another barrier is that some of the interviewee states that engineering performance always comes in secondly if there is a conflict between architectural and engineering performance issues. If this is the case, then why even bother with building simulation if their information ultimately always will be overruled?

The interviews indicated a certain collaboration crisis between architects and engineers. This crisis was underlined when we presented the tool used in the method: now it seemed that the architects want the knowledge and ability of the engineer packed into a piece of software. This reaction was not surprising taking into account their statements regarding lack of proactivity among some engineers and the lack of suitable tools. However, we are of the view that the use of building simulation tools – simple or advanced – requires specialist knowledge coming from years of training. The design process therefore have to include a certain degree of interpersonal cooperation between experts in architecture (architects) and experts in building simulation (engineers) if building performance simulation is to be integrated as a useful tool in the design process. The collaboration crisis therefore has to be solved. The method proposed in this paper is an attempt to create a platform to vitalise the collaboration between architects and engineers. The method and its tool hopefully enable and motivate engineers to become a more active participant in the dynamic process of early stages of building design while intensifying an interest among architects to integrate considerations regarding engineering performance issues in design decisions made in the early design phase.

Conclusion

This paper reports on a qualitative study based on interviews of representatives from five reputable architecture companies in Denmark. The aim was to investigate implications that may hinder a more widespread use of building performance simulation in the early stages of the building design process. The following main implications are identified:

- Engineering performance issues regarding indoor climate is basically considered irrelevant in relation to form-giving in early design phases.
- A concern that (measurable) engineering performance issues may overrule (non-measurable) architectural design issues.
- Mindset and workflow mismatch between architects and engineers.
- Insufficient and inappropriate simulation tools.
- Limited economy allocated to the early design phase (e.g. in competitions) is a barrier to close collaboration between architects and engineers.

A conceptual idea for a method to generate simulation-based indoor climate, daylight and energy predictions and design advice using a rapid, yet precise, simulation tool was presented and discussed. The immediate feedback from the interviewees mainly aimed at the functional traits of the tool. The rapid simulation time and the fact that simulations could be performed within one of the preferred sketching platforms were considered to be a very important step towards the implementation of building simulations in the early design stage. During discussions it was suggested that future development of the tool should include a simple user interface with few settings but with an opportunity to access detailed settings, and careful consideration about how to present simulation output for intuitive interpretation.

The suggested method for collaboration was given little attention in the discussions. But statements in other parts of the interviews showed that the interviewees had a genuine desire for closer collaboration with engineers in the early design stage. There is a hope that the development of various BIM systems and strategies will generate platforms for communicating design issues in an interdisciplinary collaborative design process. Furthermore, collaborative processes like the integrated design process was suggested to be a discipline taught during the basic training at architectural and engineering schools/ universities.

Acknowledgements

We would like to express our gratitude to the representatives from the architectural companies for their hospitality and willingness to be interviewed.

References

Attia, S. (2010) *Building Performance Simulation Tools: Selection Criteria and User Survey,* Technical report, Université catholique de Louvain, Louvain La Neuve, Belgium.

Attia, S. (2011) *State of the Art of Existing Early Design Simulation Tools for Net Zero Energy Buildings: A Comparison of Ten Tools,* Technical report, Université catholique de Louvain, Louvain La Neuve, Belgium.

Banke, T. (2013) *Parametri i praksis - Generativ performance i arkitektur*, Ph.D. thesis (in Danish), Copenhagen, Denmark, Designskolens Printcenter.

de Souza, C. B. (2011) Contrasting paradigms of design thinking: The building thermal simulation tool user vs. the building designer. *Automation in Construction*, Vol. 22, pp. 112–122

de Wilde, P., Van Der Voorden, M., Brouwer, G., Augenbroe, G., Kaan H. (2001) The Need for Computational Support in Energy-Efficient Design Projects in the Netherlands, *Proceedings of the 7th International Building Performance Simulation Association (IBPSA) Conference*, Rio de Janeiro, Brazil, pp. 513–520.

de Wilde, P. (2004) *Computational support for the selection of energy saving building components*, Ph.D. Thesis, Delft, The Netherlands, Delft University Press.

DGNB (2014), Green Building Counsil Denmark, Denmark, http://www.dk-gbc.dk/

DIVAforRhino (2014) Solemma, US, http://diva4rhino.com/

Ecotect (2014) Autodesk, US, http://www.usa.autodesk.com/ecotect-analysis/

EPBD – Directive 2010/31/EU of the European Parliament and of the Council of 19 December 2010 on the energy consumption of buildings (recast).

Grasshopper (2014) Scott Davidson, US http://www.grasshopper3d.com/

Green building studio (2014) Autodesk, US, https://www.gbs.autodesk.com/GBS/

Koch, C. and Haubjerg, E. L. (2011a) Designing clean, *6th Nordic Conference on Construction Economics and Organisation–Shaping the Construction/Society Nexus Volume 2: Transforming Practices,* Copenhagen, Denmark, pp. 329–340

Koch, C. and Haubjerg, E. L. (2011b) Performing the transistion – integrated design process in climate change mitigation, *Proceedings of the 27th Annual ARCOM Conference,* Bristol, UK, pp. 1155-1164.

Lehrer, D. and Vasudev, J. (2010) Visualizing Information to Improve Building Performance: A Study of Expert Users, *ACEEE Summer Study on Energy Efficiency in Buildings*, pp. 141–515.

Morbitzer, C. (2003) *Towards the Integration of Simulation into the Building Design Process*, Ph.D. thesis, University of Strathclyde, Glasgow, Scotland.

Ochoa, C. E. and Capeluto, I.G. (2009) Advice tool for early design stages of intelligent facades based on energy and visual comfort approach. *Energy and Buildings*, Vol. 41, pp. 480–488.

Petersen, S. and Svendsen, S. (2010) Method and simulation program informed decisions in the early stages of building design. *Energy and Buildings*, Vol. 42, pp. 1113-1119.

Petersen, S. (2011) *Simulation-based support for integrated design of new low-energy office buildings*, Ph.D. thesis, Kgs. Lyngy, Denmark, DTU-Tryk.

Rhinoseros (2014) Robert McNeel & Associates, US, http://www.rhino3d.com/

Robinson, D. (1996) Energy model usage in building design: A qualitative assessment. *Building Services Engineering Research and Technology* vol. 17, pp. 89–95.

Soebarto, V.I. and Williamson, T.J. (2001) Multi-criteria assessment of building performance: theory and implementation. *Building and Environment*, Vol. 36, pp. 681–690.

Struck, C. and Hensen, J. (2007) On supporting design decisions in conceptual design addressing specification uncertainties using performance simulation, *Proceedings of the 10th International Building Performance Simulation Association (IBPSA) Conference*, Beijing, China, pp. 1434–1439.

Vasari (2014) Autodesk, US, http://www.autodeskvasari.com/

VELUX (2014) VELUX Daylight Visualizer, Horsholm, Denmark, http://viz.velux.com/