Simulation support for research and development of advanced building skin concepts

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Innovations in high-performance building envelope components are an essential step towards reaching the ambitious targets for a more sustainable built environment. Enhancing product development workflows can turn out to be an invaluable resource in this process. In this paper we illustrate how building performance simulation (BPS) can be used to support research and development activities for innovative building skin concepts. The key opportunity lies in assisting informed decision-making. The increased availability of information on whole-building performance can be used as a resource for communication with internal and external stakeholders. We outline a systematic approach that shows how BPS can be embedded in all phases of the widely used Stage-Gate approach. Experiences from two case studies are discussed to show the potential of this method in practical settings.

Keywords: Product development; innovation support, building envelope, building performance simulation

1. Introduction

1.1 Background

The building industry is confronted with unprecedented challenges. Energy efficiency and reduced greenhouse gas emissions are becoming increasingly important design objectives. At the same time, there is more attention for achieving high indoor environmental quality (IEQ) standards, and all this has to be done within the limits of tight budget constraints in a competitive market.

The integration of new materials and advanced components in the design of building envelopes for both new buildings and refurbishments has the potential to act as a solution to these challenges (Jelle et al. 2012; Sadineni, Madala, and Boehm 2011). Technology roadmaps such as those recently issues by the International Energy Agency (IEA 2013) and the U.S. Department of Energy (US DOE 2014) recognize an important role for innovations and product development in this direction. Moreover, Horizon 2020, the European Framework for Research and Innovation, considers transitioning of innovative building skin technologies from laboratory scale to commercial products as an important strategy for further development (EC 2013).

Successful introduction of innovative building envelope products contributes to high performance building operation with direct positive impacts for occupants, building owners and the environment. Enhanced product development strategies can also open up many promising business opportunities in the construction industry. Companies that are able to bring new products to the market with more focus, fewer failures, and faster development times are likely to develop better products, and hence, achieve competitive advantage.

1.2 Product development of advanced building skin concepts

The research and development (R&D) route of each individual product development process is different, due to unique conditions, such as stakeholder involvement, product requirements, legislation, research infrastructure, project time-lines, etc.

An analysis of product development processes for various innovative facade technologies, nevertheless, revealed a number of commonly found inefficiencies (Loonen et al. 2014), such as: a mismatch between information need and availability, a disconnection between material research and building integration issues, and the inability to perform “what-if” analyses.

Many of these inefficiencies originate from the limited availability of quantitative data and the ensuing lack of insight into performance criteria in early product development phases (Lee et al. 2013). Due to these limitations, it is difficult for R&D teams to steer the innovation process towards the most promising direction.

1.3 Goal and outline of this paper

In this paper we identify how building performance simulation (BPS) and analysis can be used to assist in product development of innovative building envelope components. By acting as a virtual test bed, the application of BPS software can bring information on whole-building integration aspects to the development team. Using this information in an interactive way, BPS output can be leveraged by the development team as input for managing risk and uncertainty. We demonstrate this potential by means of the two case studies in Section 3, in the framework of the widely-used innovation management scheme described in Section 2.

2 Simulation support for product development

2.1 Stage-Gate approach

Product development cycles are critical, yet complex processes, that are difficult to manage (Toole 2001). It turns out that many companies in the construction industry are not materializing their full innovation potential (Gambatese and Hallowell 2011), and that due to shortcomings in the process, some promising products may fail to reach the market (Ryghaug and Sørensen 2009; Winch 1998). To manage risks and give direction to R&D activities, a number of companies have adopted structured procedures that guide them through the innovation process. One of the most widely-used tools for new product management is the Stage-Gate approach (Figure 1).

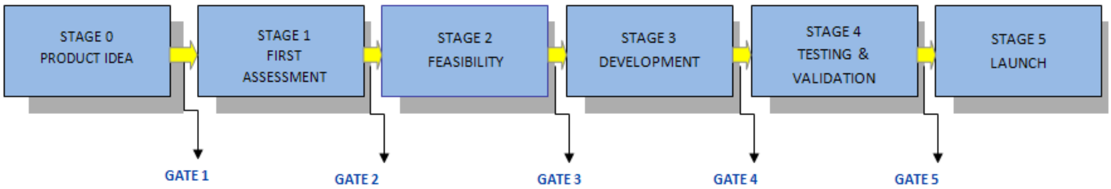


Figure 1 Stage-Gate Process Diagram

The Stage-Gate approach was developed as both a conceptual and operational framework for helping development teams to move new products from idea to launch (Cooper 1990, 2008). Stage-Gate divides the development process in multiple project phases, the stages, separated by evaluation points or decision moments, the gates. It is an incremental process; each stage requires more time and resources than the preceding one. At each gate, the decision making team evaluates the progress based on some pre-specified criteria and assesses whether the different tasks have been performed effectively and efficiently. Based on this information, the decision is made as to whether the project (i) can proceed to the next phase, (ii) is suspended because it requires reiteration of process steps, or (iii) should be terminated. In addition, the plan for the next stage is defined at each gate.

The activities in a stage are designed to gather the information needed to move the project through the next gate (Table 1). The type of activities evolves together with the process, but typically includes: experiments, market research, interviews, calculations, financial analysis, etc. This information is used to narrow down the scope of the project, and to refine design specifications of the product in such a way that it finds a right balance among all relevant performance objectives. By addressing both technical and business challenges in this way, levels of performance uncertainty and perceived risk are gradually reduced.

Table 1 Overview of stages in the Stage-Gate approach

Stage	Description	Typical activities
0	Product idea	Identification of the problem to be addressed in the product development. Strategic fit. Product idea and expectations benchmarking.
1	Initial assessment	Preliminary assessment of technical and economic merits, market potential. Low cost, short duration.
2	Feasibility study	Match customer needs to product specifications and performance. Technical and economical feasibility. Assessment of development risks

3	Development	Actual design and development of the new product. Manufacturing and operations plan. Evaluation of scalability. Patent and copyright issues.
4	Testing and validation	Validation of the entire project: the product itself, the production/manufacturing process, customer acceptance, and the economics of the project. Pilot project.
5	Launch	Beginning of full production and commercial launch. Implementation. Marketing and sales.

The main asset of the Stage-Gate approach is in its focus on performance and the aptitude for effective communication between various members of the R&D team. Decisions are made on the basis of quantifiable information and pre-specified criteria. This allows for strategic decision making. Throughout all stages of the R&D cycle, there is a need for information about the performance of the envisioned product. The required type of information evolves with the unfolding level-of-detail, changing target audience (from internal to external), and different gate requirements.

Modelling and simulation can be useful tools for generating the information that is needed to make informed product design decisions. Model-based analysis is part of the conventional Stage-Gate approaches, but is usually only used in a small sub-set of the stages (US DOE 2007). In this paper, we argue that more thorough use of BPS as an active research tool can add value to every stage of the Stage-Gate process.

2.2 Integration of BPS in the Stage-Gate approach

The key motivation for the integration of BPS tools to the Stage-Gate approach is that it allows for structured design space explorations (Clevenger and Haymaker 2011), without the need for having expensive prototypes. BPS establishes a direct connection between proposed product design variants and their corresponding impact on whole building performance indicators such as energy savings and indoor environmental quality. This type of computational work is commonly done for supporting informed decision-making in building design projects (Hensen and Lamberts 2011; De Wilde and Van Der Voorden 2004). Recent studies have investigated the options for widening the application area of BPS to facilitate decision-making in alternative settings (Franconi, Field, and Deru 2013; Hamza and DeWilde 2014). The potential of BPS to support product development is, however, still relatively unexplored (Loonen et al. 2014). Three principles for the use of BPS in product development have been identified (Trcka et al. 2011):

- Design decisions should be based on multiple design alternatives or options;
- The decision between alternatives has to be made by comparing performance on the basis of multiple criteria;
- For each design option the same type of performance information must be available.

In the remainder of this Section, we describe in more detail how BPS could be incorporated in the Stage-Gate process to stimulate innovation of building envelope components.

2.2.1 Stage 0 – Product idea

In this preparatory step, the actual project has not yet started. Many alternatives are still under consideration, but since minimal resources are available, the analyses should focus on exploratory aspects, such as:

- Benchmark comparison (product family): BPS software is used to evaluate the performance of the current state-of-the-art in a simple, generic building model. This type of comparison gives a good indication of the scope for improvement.
- Benchmark comparison (competitors): Performance assessment of the leader in the defined market as a target for the new product.

The results obtained from the suggested steps provide a number of insights for the subsequent Gate 0 at which the decision for the initiation of the process is made. The information generated regarding the problem and market definition pave the way for solution-oriented research that addresses the most relevant performance aspects. In addition, an in-depth understanding of the current product landscape helps identify strengths and weaknesses, and the issues to be addressed in the new product development.

2.2.2 Stage 1 – Initial assessment

The objective of Stage 1 is the identification of research topics which have potential to meet the targets set in the previous Stage 0. Furthermore, an understanding of potential future benefits (energy performance, environmental, financial, etc.) of the identified research topics should be gained. In this *scoping study* phase (van Dronkelaar et al. 2014; Kasinalis et al. 2014), the simulation team should be the "interface between the design process and the building performance simulation tools" (Hensen 2004). Simulations for this stage are based on the following directions:

- Qualitative comparison of product variants. At this conceptual design phase, simulations of potential solutions can be performed on a simplified reference building, for a rough potential estimation rather than the detailed assessment for a single case. The level-of-detail at which these calculations are conducted depends on the resources available, the number of potential solutions and the time allocated for that stage.
- Identification of the analysis activities (Stage 2) that are needed in order to evaluate the research topics. That would mean that for the several candidate concepts, specific software requirements and tools should be chosen, modelling techniques and simulation times, suitable performance indicators and interesting simulation cases.

For the selection of the research topic, taking place at Gate 1, information regarding technical issues, knowledge gaps, and comparison with competing technologies, possible energy savings, timing, and costs and benefits for the project should be identified. The proposed simulation plan should be devised to provide this information.

2.2.3 Stage 2 – Feasibility study

At this stage, after research project selection, the objective is concept definition. This is typically an iterative process. Activities focus on acquiring a thorough understanding and description of the technology and its capabilities. In addition, preliminary technical concepts with product specifications are worked out. This includes the following tasks for the simulation team:

- Performance evaluation of selected concepts: The effect of the selected concepts on a building's energy and IEQ performance is estimated. For that, the model developed in stage 0 and the same set of performance indicators are used and further expanded where needed.

- Comparison with results generated in Stage 0: The performance of the interesting concepts is compared with those of the current company product and its main market competitor simulated in Stage 0.

Go/no-go questions raised at Gate 3 refer to technical specifications of the concept, its expected performance, estimates regarding energy or other benefits and performance of competing technologies. The answer of such questions comes from the suggested simulation work. The R&D team becomes familiar with possible product structures, based on the ones identified, and is provided with information regarding their energy saving potential. The simulation of common market solutions offers a benchmarking of expectations for the new product. Finally, the comparison of options provides an indication of the strengths and weaknesses of each concept.

2.2.4 Stage 3 - Development

During this stage, research, development and testing activities are conducted on the basis of prototypes. The simulation work includes the next four steps:

- Assessment of importance of the product properties: During this set of simulations, sensitivity analysis techniques (Hopfe 2009; Tian 2013) are used to evaluate the importance of the effect of the various product properties, to the selected performance indicator. This helps giving priority to the most important factors for further refinement.
- Computational optimization of important product parameters: Parameters identified as important, from the outcome of the sensitivity analysis, are selected for computational optimization with respect to performance objectives already specified.
- Guidelines for potential build-ups and regulations: Based on optimization results, guidelines for potential product build-ups are extracted. Possible build-ups are also evaluated from the perspective of current building regulations.
- In-depth analysis of selected cases: Whereas previous steps focused on the bigger picture, more extensive analysis in cases with a higher level of detail (e.g. geometry, occupancy, HVAC systems) help gain insight into issues that only arise in situations that are close to the real-world. This phase should also include secondary performance aspects, such as condensation risk, thermal bridges or local discomfort.

The information required at Gate 3 includes results on prototype testing, modelling and experimental results, able to demonstrate technical feasibility. Simulation work performed enables the team to answer these questions. Sensitivity and optimization analyses not only assess and improve the effect of design parameters but also calculate the performance of a large design option space. In this way, part of the tests is actually performed in a virtual way, without the need for having real prototypes.

2.2.5 Stage 4 – Testing and validation

Among the activities of this stage is the preparation for the commercial launch of the product. By combining BPS results with outcomes of marketing research, it can assist the successful entry of a product in the market. Questions about how the choice for the specific product will deliver value to the end users, are among the ones frequently asked. The suggested simulation path for this Stage comprises the following simulation activities:

- Identification of potential markets. Exploration of the product's potential in sales areas defined as interesting from the marketing point of view. Through simulations, the performance of the developed product in different applications and markets is evaluated. Combination of these insights leads to selection of areas where the product can make a successful business case.
- Translation of performance metrics to meaningful values for the end customer. Common questions that the sales team receive are related not only to quantification of the product's energy saving potential, but also to translation of that, to other meaningful customer-oriented metrics, such as, return on investment, payback times, energy labels and compliance with regulations. Use of BPS tools plays a significant role to that part as well, since it generates the raw data that is transformed in different ways in order to formulate the marketing material. Moreover, scores or credits points on green building certification schemes, such as LEED and BREEAM can be calculated.

2.2.6. Stage 5 - Launch

In Stage 5 the commercial and production launch of the product is taking place. Simulation can continue to play a role in this operational phase:

- Development of a large database describing the performance of the developed building component/ product in many different applications. This database gives an extensive overview of a variety of applications of the developed product which helps increase the knowledge internally and in addition can be used as an argument in sales discussions.
- As a follow-up, information contained in the database can be taken one step further in the form of a dedicated software tool (De Conick et al. 2011). Such a tool should be able to visualize the product's performance in an intuitive way, with information relevant to the end customer.

3 BPS in action: highlights from two case studies

The Computational Building Performance Simulation group at Eindhoven University of Technology has gained experience with the integration of BPS in product development of innovative façade components in a range of projects in collaboration with various industrial partners, throughout several phases of development (Hensen 2014). In this section, we illustrate the potential role for BPS in product development by presenting findings from two case studies in a selection of R&D stages.

3.1 Self-sufficient switchable window

3.1.1 Introduction

Switchable windows, that automatically change transparency in response to weather conditions or comfort requirements, are a typical example of academia-driven product development in the construction industry. After years of research, the first products have now found their way to the market (Loonen et al. 2013). It is expected that widespread application of switchable windows can make significant contributions to low-energy building operation with high comfort levels (NanoMarkets 2014).

The majority of currently available switchable window concepts are based on electrochromic (EC) coatings (Baetens, Jelle, and Gustavsen 2010). This technology, however, also comes with some limitations and challenges, such as:

- Spectral selectivity: EC coatings absorb light in the visible wavelength range. In tinted states, the window takes a bluish or otherwise non-neutral colour.

- Energy consumption: the window uses electricity to drive its operation. Because wires need to be connected to the fenestration system, the integration in renovation projects is problematic.
- Low switching speeds: EC windows have a relatively slow response time (in the order of ten minutes), which makes it difficult to respond to quick fluctuations in daylight availability.

An alternative direction for creating switchable windows is by combining liquid crystal (LC) display technology with luminescent solar concentrators (Debije 2010). In this way, part of the solar energy absorbed in the window is converted into electricity, to drive its own operation and make it a self-sufficient device. Because of the specific LC switching technology, also the other two aforementioned limitations are tackled by this product.

Simulations are embedded in ongoing efforts of scaling the technology from proof-of-principle to commercial building product, and focus on the whole-building integration issues of this high-tech product.

3.1.2. Stage 2 – Feasibility study

In the initial phases of development, a simple simulation study was performed to get a first assessment of the potential. A simulation model in Trnsys and Daysim was developed based on lab measurements and experiments on a reduced-scale prototype (Loonen et al. 2010). The results of this analysis (Figure 2) show that compared to a reference with exterior solar shading (case A), the switchable window (cases B-F) has mainly the potential to improve performance in terms of visual comfort. Cases B to F represent different switching control strategies. It became clear from these simulations that the type of control strategy is an important consideration for further development. Especially control strategies based on visual comfort criteria (cases E-F) show the ability to perform well on all performance aspects.

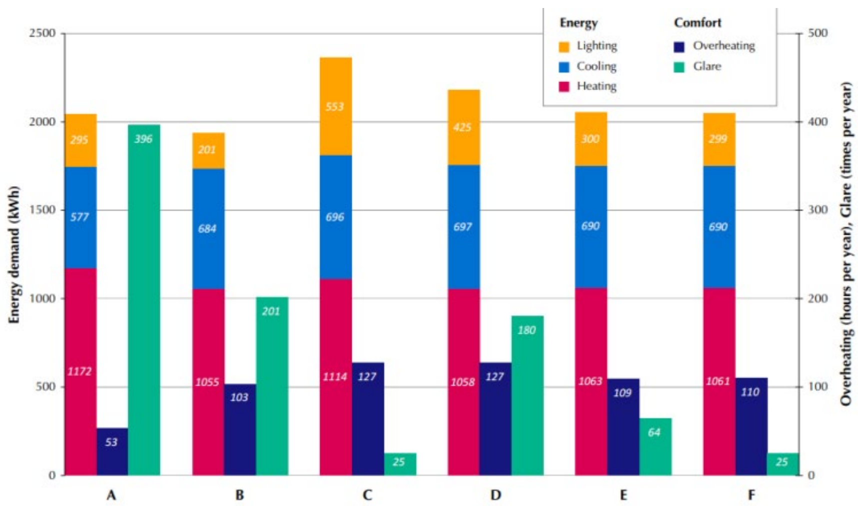


Figure 2 Results of the exploratory simulation study in terms of energy consumption and comfort. Cases A is a reference case with external solar shading. Cases B-F represent different window control strategies (Loonen et al. 2010).

3.1.3. Stage 3 – Development

During Stages 1 and 2, ample scope for further improvement of the prototype's energy performance was identified. To examine this aspect in more detail, virtual experiments were carried with window configurations of different light-to-solar-gain ratio (Figure 3). The results indicated an additional energy saving potential of up to 10% when the product's operating range is shifted toward the non-visible part of the solar spectrum. A finding that clearly justifies further development in this direction, which was done, both by careful selection of the complementary second window pane, and through further tuning of the coating's absorption spectrum towards the near-infrared part of the solar spectrum.

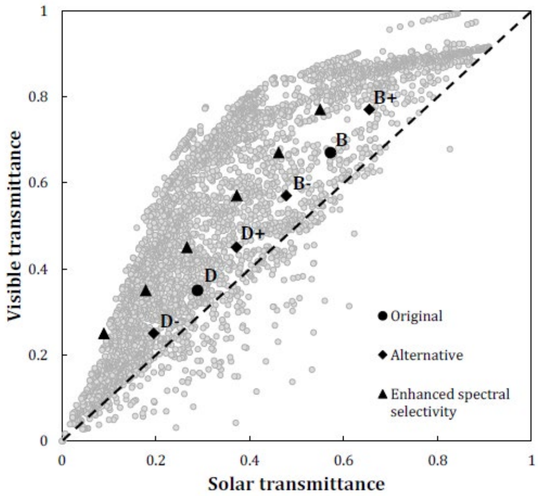


Figure 3 Overview of window properties showing dark (D) and bright (B) states.
Triangles indicate window options with enhance spectral selectivity.

Another important part of the simulation research addressed the issue if it is wise to invest time and effort in developing a window product with the widest modulation range possible, or whether it is better to define multiple product variants with a narrower range of operation, but tuned in response to the demands of specific situations. This question was addressed via an extensive simulation study, based on sensitivity analyses and parametric runs (Loonen et al. 2014). It turned out that, indeed, in some cases, a high light transmittance in the bright state is essential for achieving high performance. However, in other building applications, low transparency in the dark state is the most critical design parameter. These findings helped in outlining short-term material science objectives, and influenced the decision to develop window coatings with customizable switchable range.

3.1.3. Stage 5 – Launch

Now the R&D process is moving towards the commercialization phase, there is a demand for communicating information about the expected benefits of the product with potential clients. This requires a platform which makes performance information easily accessible, and presents the results in a quick and intuitive way. To this end, a large-scale simulation campaign (>100,000 cases) was administered to populate a database, with input variations in terms of climate, orientation, usage patterns, insulation standard, window properties, etc. The range of possibilities is further extended through the use of a surrogate model that interpolates results between simulated cases. By connecting this database to an online graphical user interface, a dedicated simulation-based tool is created as a supporting instrument for marketing and sales (Figure 4).

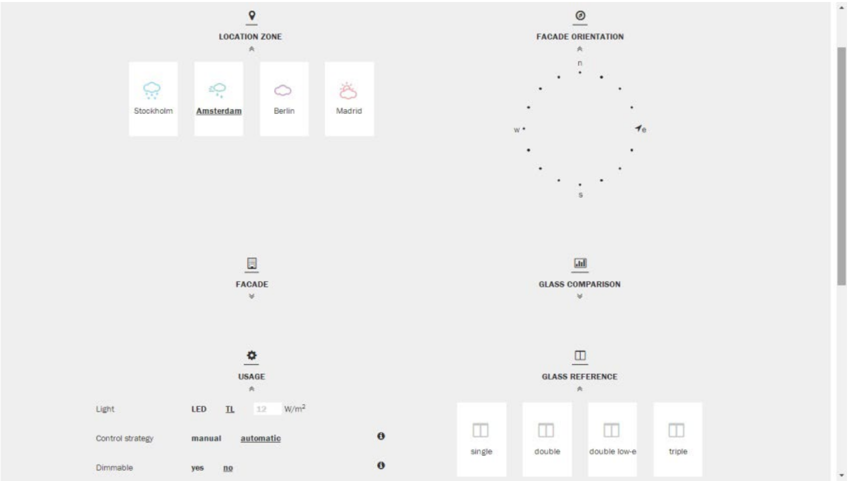


Figure 4 User interface design of the dedicated software tool.

3.2 Trespa® *Meteon® with Solar Reflectance Technology (SRT)*

3.2.1 Introduction

This product development case study is a collaboration between Trespa International B.V. and the Computational Building Performance Simulation group at Eindhoven University of Technology. Trespa® Meteon® HPL (High Pressure Laminate) panels have established a long reputation for their longevity, colour stability and weather resistance properties. With the development of Trespa® Meteon® SRT a new architectural opportunity is made possible, addressing at the same time the key challenge of energy savings, in warm climates. Trespa® Meteon® SRT offers architects the possibility of incorporating dark colours in the design of a façade without compromising the energy performance as obtained with lighter colours. In this way, the Trespa façade contributes to the reduction of a building's energy consumption, while maintaining a comfortable indoor climate (Santamouris, Synnefa, and Karlessi 2011).

This is made possible through the improvement of the Solar Reflectance Index (SRI) (ASTM 2014) of darker colours. Figure 5, illustrates the difference between Trespa® Meteon® standard and Trespa® Meteon® SRT. Note that the percentage improvement of SRI achieved, is different for each colour.

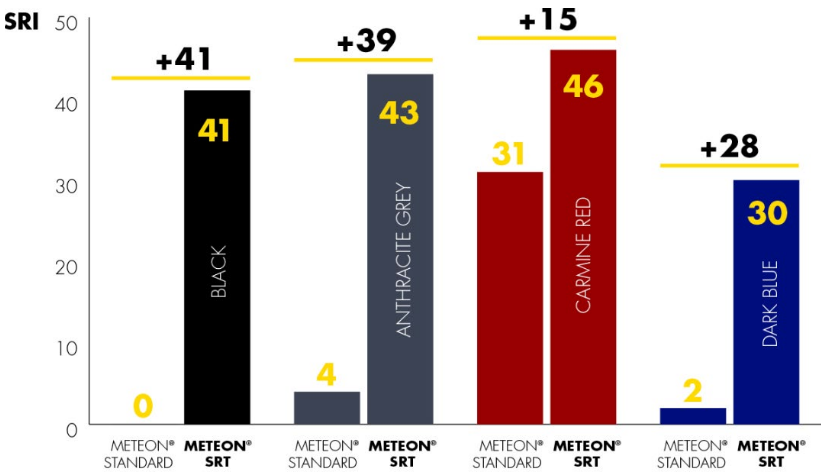
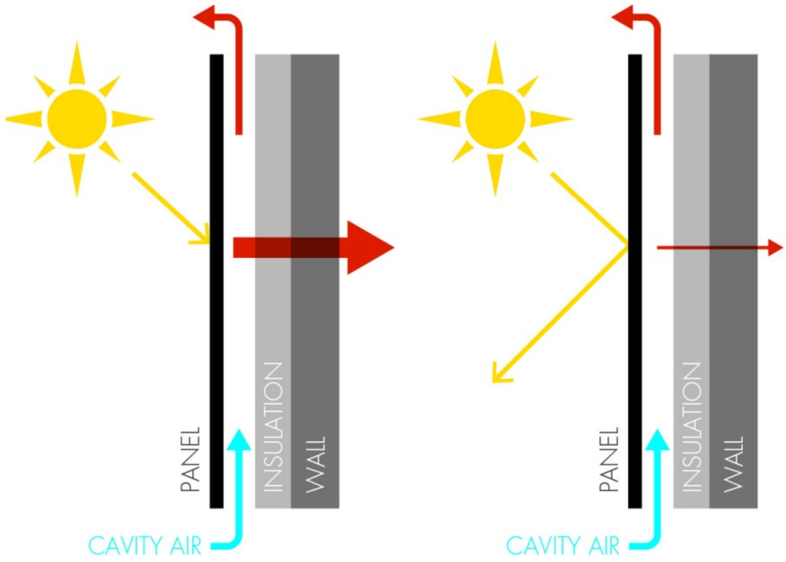


Figure 5 SRI difference between Meteon® Standard and Meteon® SRI

In addition to a reduced absorption of heat from the opaque façade part (Figure 6), the improved SRI contributes to the mitigation of the heat island effect caused by large buildings in urban areas.



Meteon® Standard **Meteon® SRT**

Figure 6 Energy balance in opaque facade part with Trespa® Meteon® SRT panels

Integration of building performance simulations was of definitive importance in assisting the whole development process for Trespa® Meteon® SRT from the early stages of development until marketing and information dissemination stages.

3.2.2 Stage 2- Feasibility study

The main objective of the building performance simulations conducted at this early development stage was to assess the importance of various design parameters and facilitate the selection that has to be made among competing, potential product build-ups, based on their impact on a building's thermal load.

Table 2 presents the total solar reflectivity (TSR) values for three standard colours and possible improvements of it for the same colours. Different improvements of the same colour – marked as IR improved – illustrate that a different technology was used each time in order to obtain the solar reflectivity increase (e.g. Dark Grey). These values are examples of initial concept assessments and do not represent the ones finally obtained.

Table 2 Reflectivity of possible solutions

ID	1	8	3	25	21	10	26
Color	Dark grey	Light grey	Dark grey	Red	Dark grey	Light grey	Red
Standard / IR improved	Standard	Standard	IR	Standard	IR	IR	IR
TSR (%)	6,2	6,3	10,4	23,6	37,6	48,8	53,9

The variations in primary energy consumption due to total solar reflectivity changes were calculated for the cases of Table 2, in order to assist the selection of possible build ups. Additionally, these calculations were repeated for different thermal insulation thicknesses, panel fixing systems and geographical locations. An example of these simulations for the case of Madrid is illustrated in Figure 7.

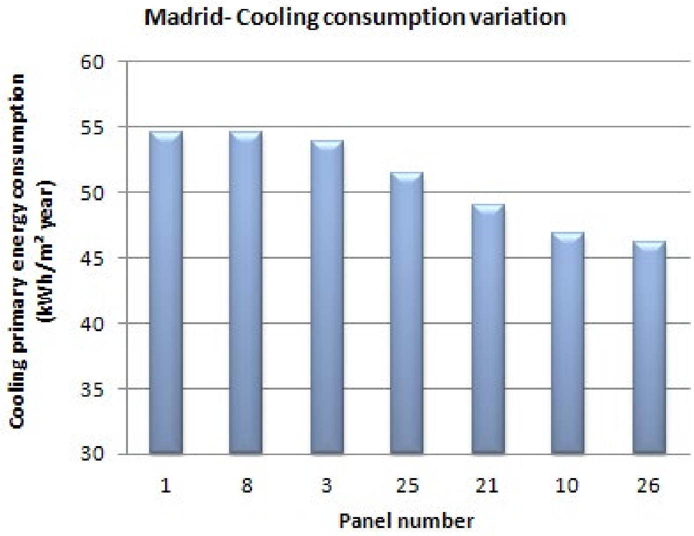


Figure 7 Variation of cooling consumption due to TSR variation of HPL

The conclusions communicated to the decision making team, as a result of these initial calculations, were that:

- Improved IR reflectivity of HPL surfaces demonstrates a potential of cooling energy saving, which is more pronounced in climates where cooling plays a major role and in buildings with lower thickness of thermal insulation.
- Fixing system was found to have a minor effect on the result.

The main purpose of the calculations of this stage was to provide a comparative assessment among the different design alternatives, rather than absolute values of energy consumption of the simulated cases. Large simplifications were adopted during these early design calculations.

3.2.3 Stage 4- Testing and validation

As paragraph 2.2.5 describes, one of the key activities of Stage 4 is the preparation for the product's commercial launch. This includes the selection of the sales areas for the product launch along with the preparation of information to be made public through commercial brochures and sales presentations.

The two proposed BPS integration steps followed in that case were:

I. Identification of potential markets.

The information gained from the energy calculations conducted in previous stages, including the previously analyzed Stage 2, indicates that the effect of Trespa® Meteon® SRT in the reduction of energy consumption is positive in climates with increased cooling loads and mild winters. Additionally feedback from marketing research provided insights regarding sales areas suitable for the initial launch of the product. This decision was also supported through technical information. A series of annual simulations were conducted with the use of ESP-r software for several locations worldwide. For these locations annual primary energy consumption was calculated and compared for an office building model cladded with Trespa® Meteon® Standard and one with Trespa® Meteon® SRT both in black colour (Figure 8).

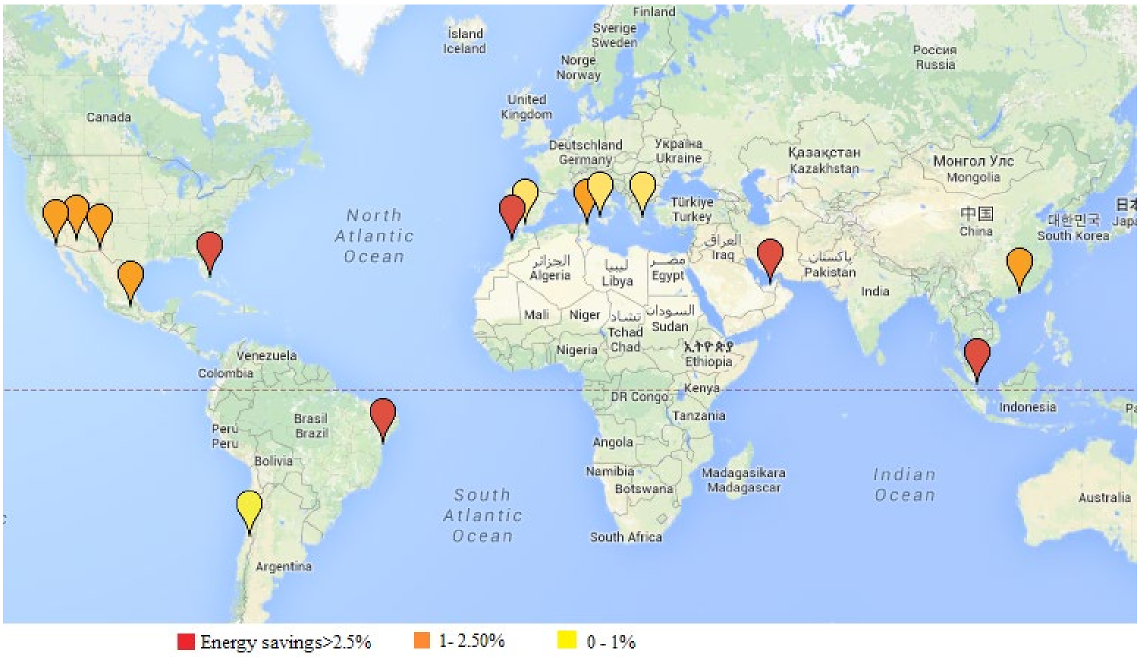


Figure 8 Trespa Meteon SRT- Worldwide Energy Saving Potential

As a result from these calculations the information communicated to the decision making team was:

- Several locations worldwide prove to benefit from the application of Trespa® Meteon® SRT;
- Locations closer to the equator are the ones of highest interest in terms of reduction of annual primary energy consumption;
- Quantification of potential in terms of percentage reduction of primary energy consumption.

The combination of these results along with the outcome of the marketing feasibility conducted in previous stages contributed to the final decision. Trespa® Meteon® SRT would initially be exclusively available for the Middle East and North African regions.

II. Translate energy savings into meaningful values for the end customer

Collaboration among different departments and professionals within organizations, further promotes the role of simulation tools in assisting different phases of a product development. The preparation of relevant marketing information was initiated following the decision to launch Trespa® Meteon® SRT in the Middle East and North African regions. Research conducted by sales and marketing departments concluded that the typical question to be answered in these sales areas is: "what is the energy saving potential of the product in an actual office building?".

Working together, the sales team and simulations specialists translated this need into model specifications. A model representative of the geometry and operation of an office building located in Abu Dhabi area was developed (Figure 9).

The building consists of five floors and its total building floor area is 5000m^2. Glazing is located in the north and south façade and represents 6% of the ratio window surfaces/ indoor conditioned zones. Windows have a height of 1.2m and consist of double glazing (U value=2.78 W/m^{2}K). Shading devices are active when incoming solar radiation in the vertical plane is higher than 200 W/m^2.

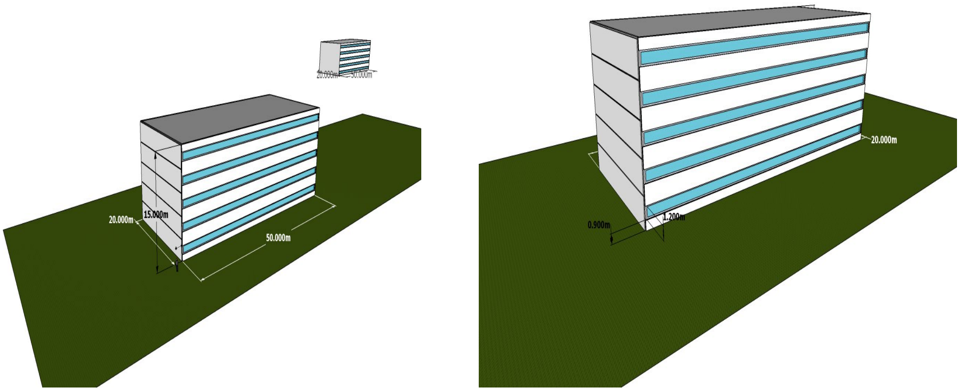


Figure 9. Model geometry

External walls consist of concrete and mineral wool insulation. Ventilated cavity has a thickness of 34mm and the total panel thickness is 8mm. Its thermal conductivity is 0.3 W/mK.

The results indicated the reduction of cooling load (kWh/m²) - which is also the total thermal load in Abu Dhabi - on a monthly basis as a result from the application of Trespa® Meteon® SRT. Figure 10 illustrates that a decrease of the cooling load was achieved in all months of the year.

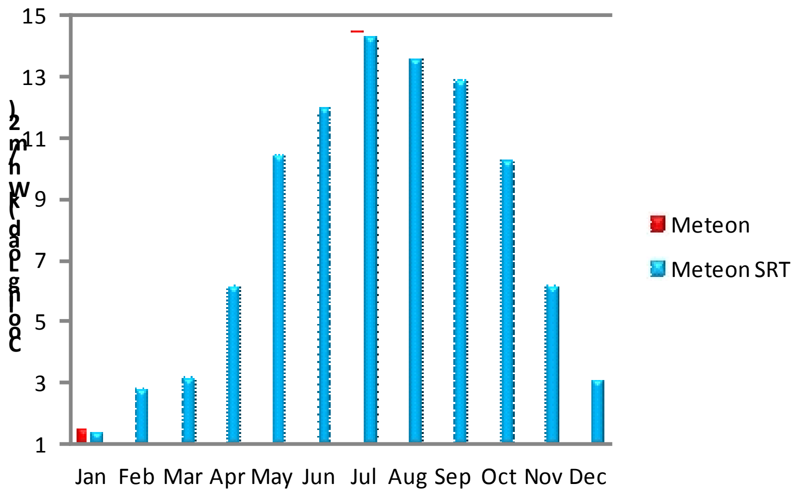


Figure 10 Monthly cooling loads kWh/m²

The reduction of cooling load on an annual basis, as a result of the calculations, was found to be 2.3%.

These simulations answered to the questions identified by marketing research. They were included in the sales presentation developed to introduce and promote the product, in order to demonstrate the energy saving potential by the application of Trespa® Meteon® SRT in locations in the Middle East. Afterwards, the results were correlated with the possibility of gaining credits related to energy savings, in popular green building certification schemes (LEED, ESTIDAMA). This is also valuable information for the customer and was included in the sales material.

The BPS tools integration in Stage 4, is an example that BPS tools could be part of the whole product life cycle, further developing the idea of integrating simulations in the early design phases, to a more holistic approach that uses BPS tools as marketing material as well.

4 Conclusion and outlook

This paper has highlighted the potential virtues of increased use of building performance simulation (BPS) as a decision-support tool for product development of innovative building skin concepts. With the Stage-Gate approach for innovation process management as a starting point we described how BPS can provide added value from the earliest phase of idea generation, all the way through to marketing and sales support after commercial launch of the product. We emphasized this potential role of BPS by presenting an overview of how simulation studies were tied into the research and development activities of two innovative building envelope components: a self-sufficient switchable window, and a new type of HPL façade panel.

This paper has demonstrated the value of simulation support from multiple perspectives, under a wide range of conditions: a university spin-off vs. R&D in a multinational company; transparent vs. opaque façade components; disruptive innovation vs. next-generation improvement of an existing product-line. Nevertheless, these projects only scratch the surface of what is possible by thoroughly embedding BPS in other R&D processes in the future. The synergy between BPS-based decision-making and the Stage-Gate approach is well-suited to further push the envelope of high-performance building design with innovative façade components.

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