Integrated Approach for Intelligent Envelope Design: Simulation performance of building envelope design strategies and technologies during the early design stage

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ABSTRACT: The increase in complexity for building design has led to intelligent envelope design and integrating simulation performance evaluation. Moreover, there is a very limited guidance for architects and façade engineers to be able to understand and integrate the simulation performance in the early design stage. This paper concerned about the integrated approach for intelligent building envelope design and simulation performance during the early design stage. This approach aims to put the necessary tool in the hands of architects and façade engineers so they can make informed decisions over optimizing building envelope performance. The integrated approach could be applied for a wide range of buildings type and climate context, however the research will address the tall office building type and hot arid climate context to be an example of application in the research study. The research methodology is based on analyzing case studies, computer performance simulation and a questionnaire survey. The case studies aim to underline the most important parameters that have the most effects on envelope performance. The simulation aims at evaluating the effects those parameters have on building performance. The questionnaire survey aims at underline the problems and the challenges of integrating building performance simulation in the early design stage. The outcome of the survey provides an outline how the designer regards the use of building performance simulation and emphasizes the way to integrate the building simulation in the early design stage. Adequate climatic strategies for intelligent envelope design in hot climates were determined. The research provides a series of practical guidelines for the implementation of building performance simulation for intelligent envelop design in the early design stage.

1 INTRODUCTION

In the early design stage the building design team has to choose from a wide variety of design options and because the building envelope is related to different aspects of building performance (heating, cooling, and lighting) and human comfort (thermal and visual comfort), the integrated approach for envelope design and simulation performance should be followed from the early design stage.

Approximately 80% of the design decisions that influence building's energy performance are made by the architect in the early design phase; the remaining 20% are made by engineers at the later phases of design (Augenbroe 2002). The same Study shows that the early decisions about the environmental technologies are taken without adequate evidence. The architects and façade engineers need to evaluate the design alternatives early in the design process as they deal with parameters that influence the energy and environmental performance of the building.

Although there are many building performance simulation tools available (Hensen &Augenbroe 2004), (Crawley et al. 2008) the simulation process in building design project is limited and mostly restricted to the final stage of building design. Most of the simulation software are used by the consultant and specialists and usually used in the late phase of design, when the geometric characteristics of the building are fixed. In this stage the ability to utilize passive design strategies may be restricted and mechanical conditioning systems are needed to maintain the occupancy comfort. However, the decisions made in the early design stage have great effects on comfort and energy performance (Ochoa & Capeluto 2009), (Petersen & Svendsen 2010) & (Stuck et al. 2009). At the early design stage changing the design alternatives will be at low or zero cost. While in the detailed design and construction stages, the modification of the envelope design alternatives will be difficult and the cost will be higher.

models have been proposed for early design stage, as well as simplified tools, (Westphal & Lamberts 2004) but they are used to evaluate finished alternatives and they are not suitable as a practical design guide, and because none of them follow the logic of architectural design process. They focus on the development of a platform for the evaluation rather than giving actual design advice (Petersen & Svendsen 2010). The decisions are based on general ideas and cannot be evaluated with tools to give affordable results (Ochoa & Capeluto 2009), (Wilde & Voorden 2004). Moreover, many of those models are designed for the use of engineers and consultants in the final design stage. There is a very limited guidance for architects to be able to understand and integrate the simulation performance in the early design stage (Bambardekar & Poesechke 2009). De Wilde & Voorden (2004) considers that the building performance simulation neither used to support the generation of design alternatives, nor to make informed choices between different design alternatives. The fact is that the simulation is used for performance confirmation and not as a design support tool.

During the early design stages there is a need to evaluate a large number of design alternative with small information available. Building design can significantly impact energy efficiency and can result in substantial reductions in operating costs over the lifecycle of the building. Design changes can be readily evaluated in the early design stage for performance efficiency. The work will emphasize the parameters that relate to large energy use and can produce the largest energy saving. The properties of those parameters may change greatly from one climate to another and from one building type to another.

2 INTELLIGENT BUILDING ENVELOPE VS INTELLIGENT DESIGN

The term “intelligent building envelope” has become a common denominator for a certain type of built form that use artificial intelligence to provide the indoor environment with dynamic heating, cooling, lighting and air supply respond to the occupant comfort and energy efficiency. Intelligent building needs to respond to the change and to meet the requirement of the users (Wong et al. 2008) & (Wong et al 2005). Wigginton and Harris (2002) list over 30 definitions of intelligence related to building and building envelope using different terms like: Advanced envelopes, High performance envelopes, Innovative envelopes, Smarts envelopes, Intelligent envelope, Active envelope, Interactive envelope, and Responsive envelope. *“An intelligent building envelope adapts itself to its environment by means of perceptions, reasoning, and action. This innate adaptiveness enables the envelope to cope with a new situation and solve problems that may arise in its interaction with the environment”* (Wyckmans 2005: page 203).

Intelligent design, on the other hand is an approach that integrates and takes advantage of the climate through the application of building technologies and design strategies at the design phase, in order to achieve comfort and energy efficiency (Maciel et al. 2007) & (Tzikopoulos et al. 2005). Intelligent design may be related to the responsive performance of the building envelope. According to Compagno (2002) *“an “intelligent” facade is not characterized primarily by how much it is driven by technology, but instead by the interaction between the facade, the building’s services and the environment”.*

3 RESEARCH METHODOLOGY

The research methodology is based on analyzing case studies, computer performance simulation and a questionnaire survey. The case studies aim to underline the most important early design stage parameters that have the most effects on envelope performance. The simulation aims at evaluating the effects those parameters have on building performance. The questionnaire survey aims at underlining the problems and the challenges of integrating building performance simulation in the early design stage. The outcome of the survey provides an outline of how the designer regards the use of building performance simulation and emphasizes the way to integrate the building simulation in the early design stage.

4 RESULTS

4.1 *Envelope performance parameters*

The most important early design stage performance parameters of the building envelope, which are related to the performance evaluation and sustainability features were set to be:

1. Daylight and visual comfort
2. Thermal comfort
3. View in-out
4. Energy efficiency

These functional requirements are the key features to assess the performance of envelope technologies and design strategies. Several case studies taken from different climate context were analyzed in terms of the functions mentioned above. The study of comfort and energy efficiency as main elements in the sustainability rating systems. On the other hand, minimizing the energy use to achieve the energy efficiency and low CO2 emission is the second objective for the integrated design approach.

The following design alternatives and technologies will be considered in the building envelope design evaluation during the early design stage:

1. windows to wall ratio
2. building orientation
3. natural day and night ventilation
4. insulation
5. thermal mass
6. glazing type
7. shading and solar control

4.2 *Performance Simulation*

A virtual reference office building was created. The simulation model is one floor of a tall office building. The floor is divided into 9 thermal zones; each zone has a 24 meter square surface area, 4 m width and 6 m depth. The floor height is 3 m. The windows areas are fixed to be 30%, 50%, 70%, and 90%. The simulations were done for five cities in hot climate: Riyadh - Saudi Arabia, Abu Dhabi - UAE, Doha - Qatar, Kuwait city - Kuwait, and Basra - Iraq. Meteonorm climate data file were used. ECOTECT and TRNSYS Computer simulation software were used. For these models a parametric study of energy use was carried out. The building orientation, the window to wall ratio, the use of natural day and night ventilation, glazing type, shading devices, façade insulation, and thermal mass were changed, while other parameters such as the building shape, occupants activities and schedules etc. were kept the same. Moreover, acceptable thermal and visual comfort levels were introduced in order to evaluate the effects on the overall building performance. Indoor comfort and energy efficiency were used as performance parameters. Figures 1-6 show the effects those parameters have on building envelope performance.

The simulation results show the effects that early design alternatives and design decisions have on the building envelope performance. Although the simulations were carried out for the five locations we are presenting it for Riyadh city in Saudi Arabia as representative case.

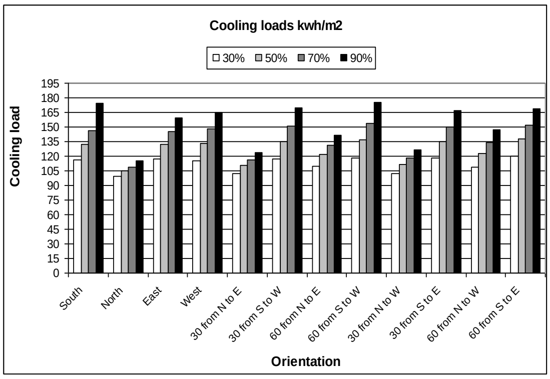

Fig. 1: Summary for the effects of orientation and glazing percent's on annual cooling loads

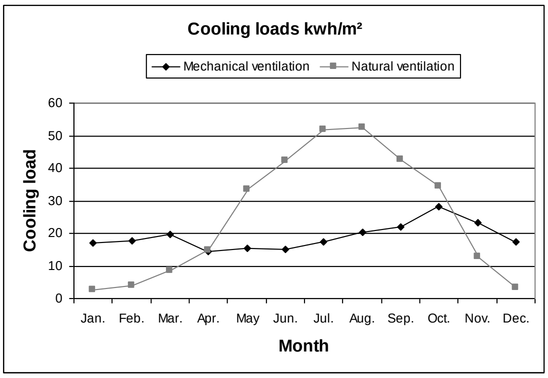

Fig. 2: The effects of daytime ventilation on the average monthly cooling loads

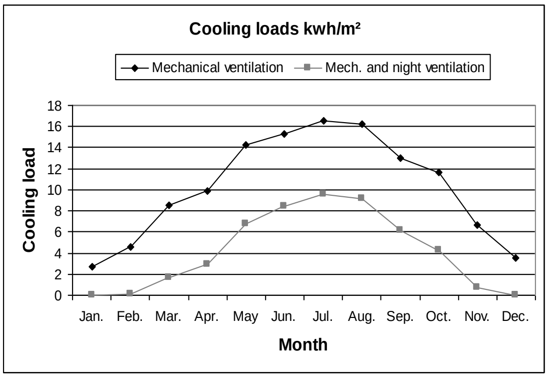

Fig. 3: The effects of night-time ventilation on the average monthly cooling loads

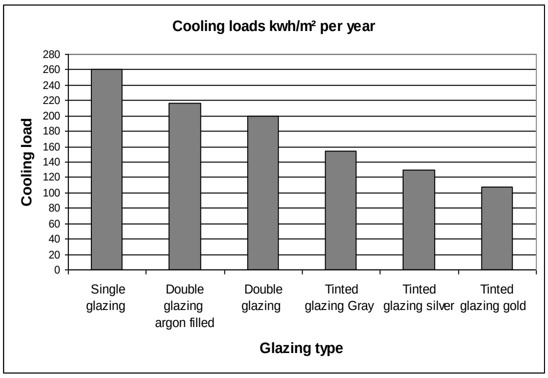

Fig. 4: Effects of changing glazing types on annual cooling loads

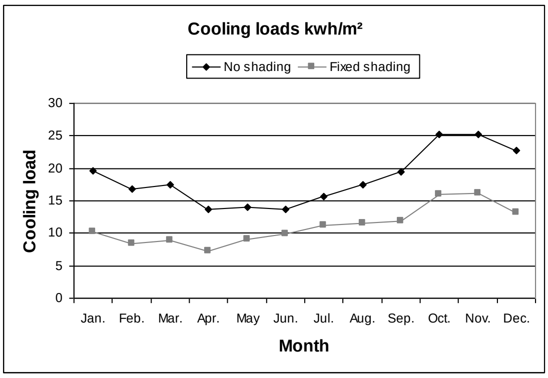

Fig. 5: Effects of fixed shading on the monthly average cooling load

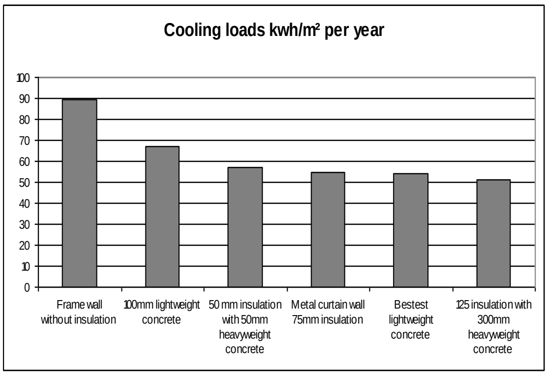

Fig. 6: The effect of insulation and thermal mass on annual cooling load

4.3 *Questionnaire survey*

The research included questionnaire survey for building performance simulation use during the early design stage. The survey has been concluded for the representative of the results. The responses for this survey were split almost between architects, building designer and façade engineers. The questionnaire addressed the following categories:

1. The support of the design decision making during the early design stage

2. The usefulness of integration of building performance simulation in the early design stage
3. The satisfaction of the role of building performance simulation in the early design stage.

The results give a summary about what can be improved in the integration of building performance simulation during the early design stage and the satisfaction level. The results show that there is a need to improve the role of building performance simulation in the early design stage as illustrated in Figures 7- 9

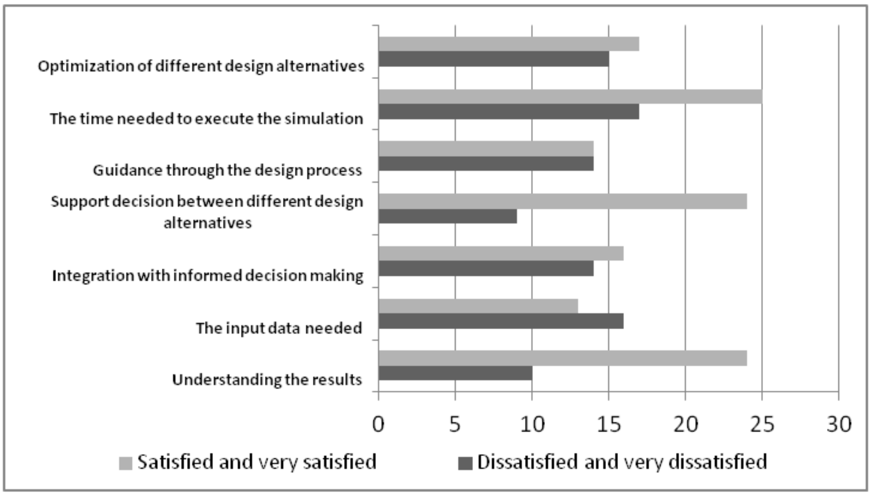

Fig. 7: Summary of the satisfaction level in building performance simulation during the early design stage shows the number of people dissatisfied (up to 50%) and the need to improve the role of building performance simulation during the early design stage

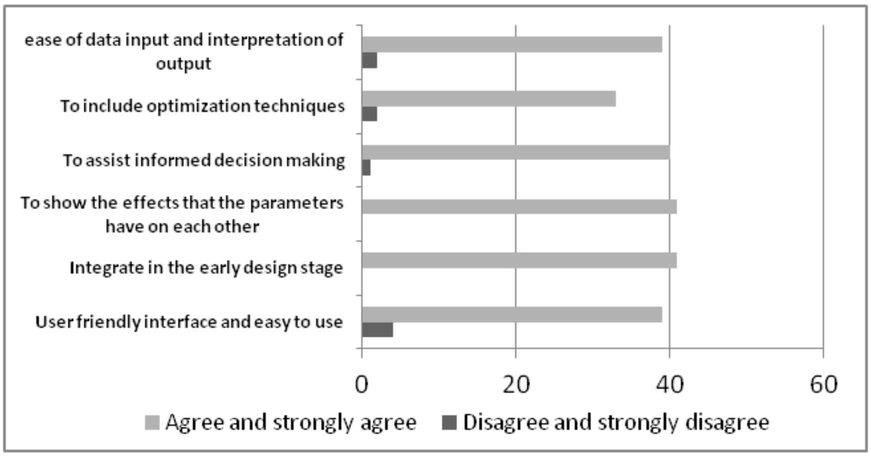

Fig. 8: What can be improved in the available simulation tools to be used in the early design stage shows that up to 90% of people agree with the fact that building performance simulation should be improved to achieve the desirable results

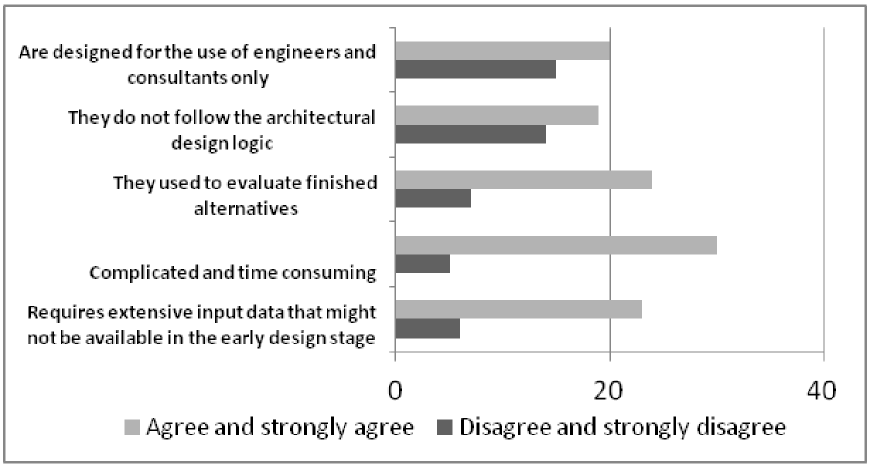

Fig. 9: The limitation in the current simulation tools for the early design stage shows that most people agree that the current building performance simulation tools have many limitations to be used effectively in the early design stage

4.4 *Integrating building performance simulation in the early design stage*

Currently the most powerful technique available for the analysis and building performance evaluation is computer modeling and simulation. Simulation should provide the necessary understanding of the consequences of the design decisions to increase the effectiveness of the design alternatives.

The aims of the approach are to provide the designer with an understanding of the performance of the buildings with changes in design parameters, provide reason for integrating the performance predictions into the early design stage decisions.

The design support approach in Figure 10, shows the flow work for a proposed methodology for the decision making for early design stage alternatives priority evaluation. The development of the approach methodology also included research into design parameters to be evaluated at the early design stage. These design parameters were selected according to the following conditions: passive design alternatives parameters which have a large effect on building envelope performance and can be modified in the early design stage at low or no cost, and the possibility to use renewable design strategies which make use of solar and wind energy and building envelope technologies which can be used to solve problems cannot be solved by using the passive alternatives.

5 PRACTICAL IMPLEMENTATION

The research gives an example to a matrix and the necessary tools to be used by architects, building engineers and building simulation tools developer. The matrix tool is based on the proposed approach methodology.

The aims of the guidelines are to provide the designer with an understanding of the performance of the buildings with changes in design parameters, provide reason for integrating the performance predictions into the early design stage decisions. Figures 11-13 are examples for those guidelines.

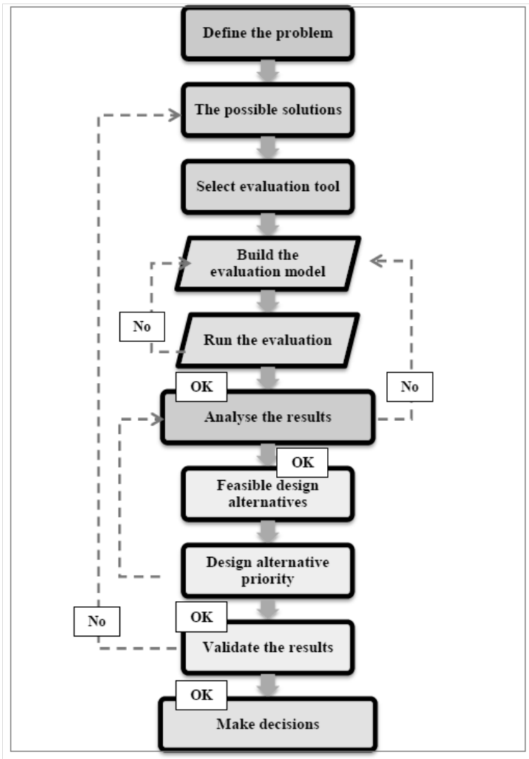

Fig. 10: proposed integrated approach

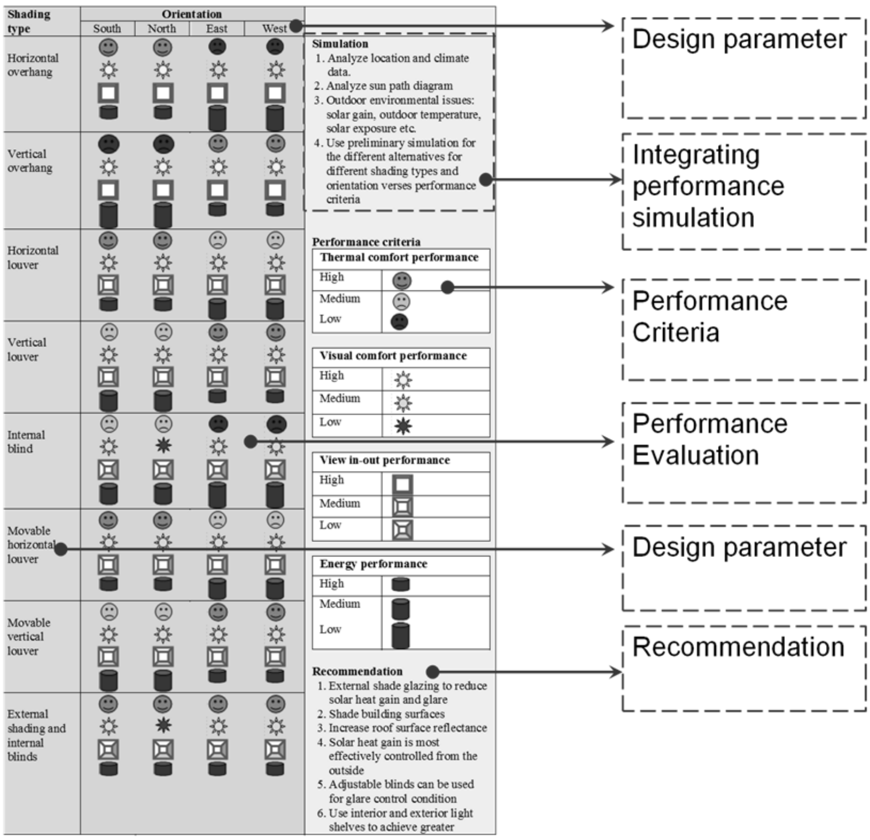

Fig. 11: Example for a design guide to use simulation for shading selection

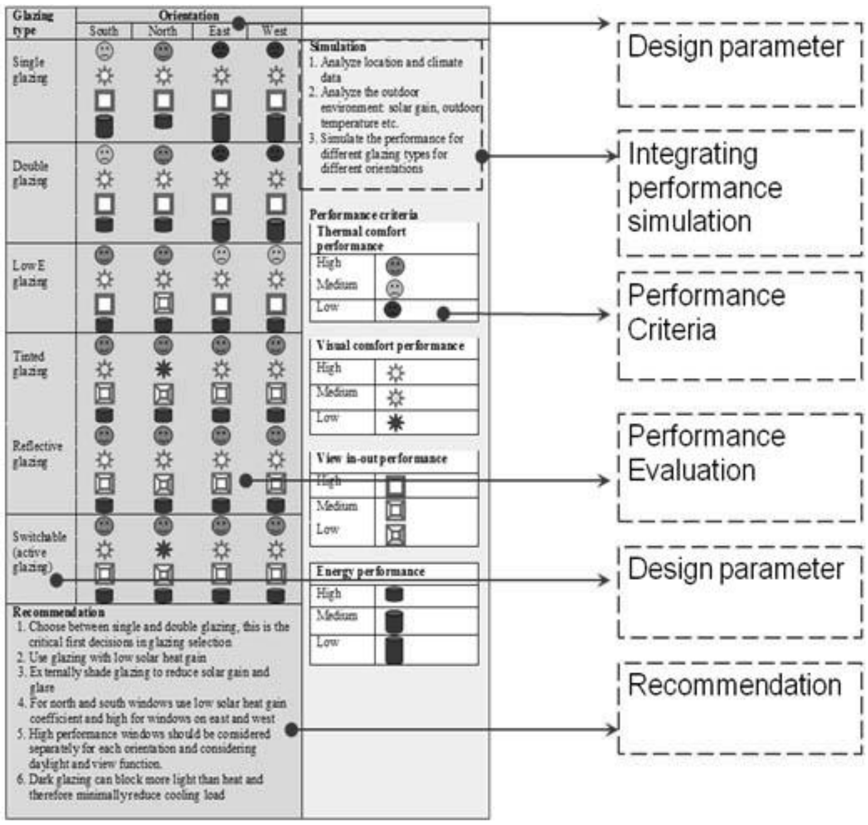

Fig. 12: Example for a design guide to use simulation for glazing selection

6 CONCLUSION

The complexity of the contemporary building design process has led to the development of the design decision support for building envelope design. Building performance simulation is one of the most important ways to predict the building performance during the design process. And not using such a tool early in the design can results in poor design quality because the designer is unaware of the performance implications of design choices.

Design decisions which are made at the early design stage fundamentally influence the environmental performance of the final building design. Although there is an impressive tools capability in terms of simulation tasks and results accuracy they can carry out, there still a number of barriers which restrict the use of building performance simulation as integrated part of the design especially for the early design stage.

There is a need for the integrated approach for the following reasons

1. architects need to be able to perform elementary thermal analysis when designing the building envelope
2. using simulation tool at the early design stage make it possible to determine what effects various design decisions will have on the building performance
3. in the early design stage change can be made before major decision are fixed at zero cost
4. early thermal evaluation helps architects to generate concepts, optimize envelope solution and quality assurance

Following are the most important goals the research will achieve:

1. Underline the outlines to develop an approach methodology for the use of simulation as integrated part of the early design stage.
2. Put the principles for tools developers, to develop a tool that enable non simulation experts to create a detailed simulation model at early building design stage.

3. Provide the guidelines and concepts needed for appropriate performance prediction analysis.
4. Monitoring the use of building performance simulation at the early design stage and the architectural design practice.
5. Examples to demonstrate the practical design decision support approach

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