DEVELOPMENT OF A THERMALLY ROBUST SCHOOL OUTLINE DESIGN FOR THE DIFFERENT CLIMATE REGIONS OF TURKIYE

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ABSTRACT

This paper presents the development of a novel school outline design, which can be applied in the different climate zones of Turkiye, underpinned by building performance simulation. The work builds on an earlier study, presented at the Building Simulation 2007 conference, which analysed the sensitivity of an existing scheme that had indeed been applied in all different climate zones, with different degrees of success.

This follow-on project goes one step further and attempts to develop a new, more thermally robust school outline design. The underlying research bases itself on building performance simulation, using the ESP-r simulation engine and applying global sensitivity analysis (Monte Carlo Method) to assess the robustness of different design variants in a large, multidimensional option space of outline design parameters.

The outcome of the study is an outline design concept called Modulsco that is significantly more robust than the current general scheme.

Overall, this paper demonstrates how building simulation can contribute to the pre-design of better (school) buildings. It is hoped that the scheme will help make these future buildings more comfortable and more energy efficient.

INTRODUCTION

Recent developments in the building industry move increasingly towards making design performance evaluations compulsory, all the way from the beginning of the design process to the operation life cycle (Augenbroe and Hensen, 2004; Hopfe et. al., 2006). New and re-developed codes and regulations set baseline requirements for better buildings; however it is obvious that actually achieving "high performance buildings" is more than just code-compliance.

This paper presents the outcomes of a research project that has developed a novel thermally robust school outline design, which can be applied in the different climate zones of Turkiye. The country is considered to contain four major climate zones, based on TS825 Standard for Heat Insulation in Buildings (TSE, 2008) which includes the city lists of the zones. The general approach of zoning in TS825 is based on degree days. Table 1 shows heating and cooling degree days of each degree day region (DDR) besides heating and cooling seasons. As the latitudes of Turkiye are between 36°-42° North, there are no non-heating or non-cooling seasons.

Table 1. Four Degree Day Regions of Turkiye.

	1.DDR	2.DDR	3.DDR	4.DDR
Heating Degree Days (Ref. temp. 15ºC)	512.5	1285.3	2676.9	3857.1
Heating season (months)	6	7	8	10
Cooling Degree Days (Ref. temp. 18ºC)	1285.3	567.8	423.8	291.1
Cooling season (months)	6	5	4	2

The earlier study, presented at the Building Simulation 2007 conference (Harputlugil et al., 2007), analysed the sensitivity of an existing scheme that had actually been applied in all different climate zones, with different degrees of success. The earlier work concluded with a set of design guidelines that were intended to help designers develop specific individual schemes in response to the local conditions.

The aim of this follow-on project is to develop a new, more thermally robust school outline design. This new outline design is engineered to be maximally adaptable to the different climate conditions, while at the same time maintaining thermal comfort and keeping energy use for heating and cooling as low as possible.

The underlying research bases itself on building performance simulation, using the ESP-r simulation engine (ESRU, 2008) and applying sensitivity analysis using SimLab 2.2. (SIMLAB, 2006) to assess the robustness of different design variants in a large, multidimensional option space for outline design parameters through Monte Carlo Analysis.

The outcome of the project is an outline design that is significantly more robust than the current general scheme. However, optimal adaptation to actual local conditions still requires some individual responses to local conditions. The paper describes which options for local adaptation have been retained in the outline scheme, and the rules for their application.

Sensitivity analysis

According to Hamby (1994), Helton et al. (2006), and Saltelli et al. (2006) the general definition of sensitivity analysis is the study of how the variation in the output of a model can be apportioned, qualitatively or quantitatively, to different sources of variation. In sensitivity analysis, a mathematical model is defined by a series of equations, input factors, parameters, and variables aimed to characterize the process being investigated. Input is subject to many sources of uncertainty including errors of measurement, absence of information and poor or partial understanding of the driving forces and mechanisms. This uncertainty imposes a limit on the confidence in the response or output of the model.

Specifically, sensitivity analysis differs from uncertainty analysis in that uncertainty analysis refers to the determination of the uncertainty in analysis results that derives from uncertainty in analysis inputs. On the other hand, sensitivity analysis refers to the determination of the contributions of individual analysis inputs to the uncertainty in analysis results (Helton et al, 2006).

In this specific research project, sensitivity analysis is only concerned with the sensitivity of the actual building performance to climate and local context factors, rather than the whole spectrum of issues that apply to modelling work.

For sensitivity of energy simulation models, a set of input parameters and their values are defined and applied to a building model. The simulated energy consumption of the model is used as a base for comparison to determine how much the output (here measured in terms of energy use per year) changes due to particular increments of input values (Corson, 1992). Consequently the results show which parameters can be classified as "sensitive" or "robust". Sensitive parameters are the parameters that by a change in their value cause effective changes on outputs (in this case energy consumption). Contrarily, change of robust parameters causes negligible changes on outputs.

Previous works done by Hamby (1994), Saltelli (2006) and Hansen (2007) states that there are various classifications of sensitivity analysis. The distinction of sensitivity analysis between local sensitivity analysis and global sensitivity is accepted in this study. The differences are listed by Hansen (2007) as follows:

Local analysis	**Global analysis**
•One at a time (OAT)	•Random sampling
•Less complex	•Large degree of complexity
•Sensitivity ranking is dependent on the reference building	•Sensitivity ranking is less dependent on the reference building than in the local analysis, it is however still dependent on the input data in the reference building that is not varied in the global analysis.
•Parameters are assumed independent	•Provides information about possible correlations (inter-dependencies) between parameters.

The previous study (Harputlugil et al. 2007) was based on local analysis. It is obvious that global analysis results are more valuable, but complex and time consuming. However, local sensitivity analysis already provides relevant information on what value(s) of which parameter(s) is most effective to minimize energy consumption. According to the previous sensitivity analysis work (Harputlugil et al. 2007), which was based on one at a time approach (OAT), each degree day region has been found to have more or less similar parameters that can influence both heating and cooling energy consumption.

The list in table 2 shows the priorities of each DDR where;

- *glz-vt* is total transmittance of glazing,
- *wdw-ratio* is window to wall ratio,
- *ACH* is infiltration rate
- *wall/floor/roof-R* is thermal resistivity of constructions.

Table 2. Prior parameters of each degree day region (DDR)

PRIORITIES		1. DDR		2. DDR		3. DDR		4. DDR	
		heating	**cooling**	**heating**	**cooling**	**heating**	**cooling**	**heating**	**cooling**
	1.	glz-vt	Wdw-ratio	ACH	Wdw-ratio	ACH	Wdw-ratio	ACH	Wdw-ratio
	2.	wdw-ratio	Floor-R	Glz-vt	Glz-vt	Roof-R	Glz-vt	Roof-R	Glz-vt
	3.	Floor-R	Glz-vt	Floor-R	Floor-R	Glz-vt	Floor-R	Glz-vt	ACH
	4.	ACH	Roof-R	Roof-R	ACH	Floor-R	ACH	Wall-R	Floor-R
	5.	Roof-R	İnt-gain	Wall-R	Roof-R	Wall-R	Wall-R	Floor-R	Wall-R

The base case used in the previous work is illustrated in Figure 1. This model has five zones, four classrooms and a corridor; however it is not a representative scheme of the current general approach of Turkish School design, where there are other types of space organisations as well. This scheme is only used as a sample and it should be noted that the methodology used in this work can be applied to any other types of school outline design schemes.

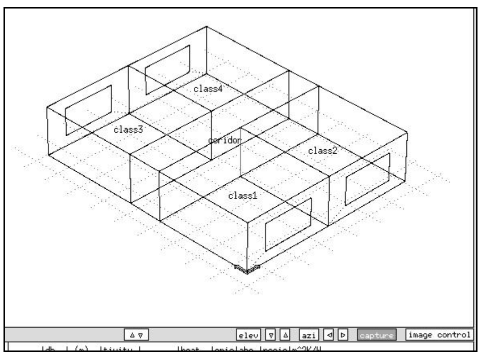


Figure 1. Base case model.

METHODOLOGY

This work takes the investigation one step further by analyzing the sensitivity and robustness of the parameters for all degree day regions by means of global sensitivity analysis. Moreover, global analysis will reveal possible interrelations between design parameters.

The results of the local sensitivity analysis have been used to reduce the number of parameters used in the global sensitivity analysis.

The following steps have been taken:

- A brief review of the local sensitivity analysis results.
- Selection of the top 5 priority parameters of each degree day region, to be taken forward for the global analysis.
- Global sensitivity analysis done by SimLab 2.2 (2006).
- Interpretation of the results by classifying the parameters as "sensitive" and "robust".
- Development of a robust design scheme applicable to Turkish climatic conditions.

RESULTS

Review of local SA results

Previous work (Harputlugil, et al., 2007) allowed drawing a conclusion from the OAT sensitivity analysis. Based on these results, a priority list of parameters for each DDR can be summarised; this is presented in figure 2 and 3.

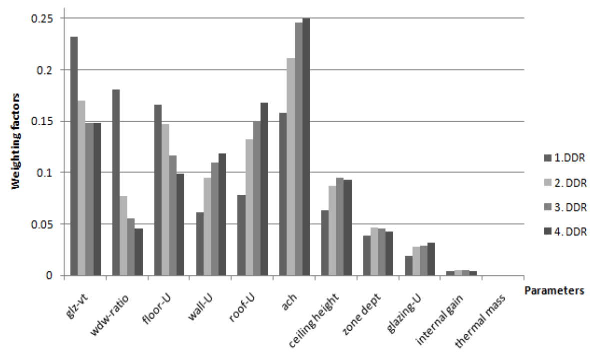


Figure 2. One at a time approach (OAT) results of heating energy consumption

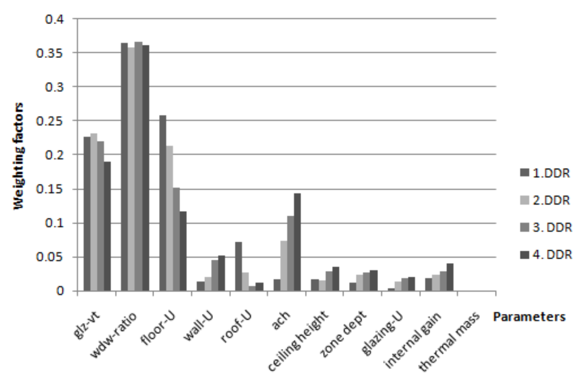


Figure 3. One at a time approach (OAT) results of cooling energy consumption

It can be seen in the figures that in general the most sensitive parameters are those parameters that directly cause a response in terms of heating gains (window ratio and total transmittance value of glazing) and energy conservation (U-values and infiltration rate). It is interesting that zone height and dept, thermal mass and even internal gains can be listed as relatively robust parameters.

Parameter selection for global SA

As listed in Table 2, the most important parameters to consider for each degree day region are more or less the same. Considering the long duration of the heating seasons (Table 1) the priority list of parameters impacting heating energy is taken as the base for global sensitivity analysis parameter selection. Consequently the list of parameters used in the global analysis is as follows:

- Glazing total transmittance (glz-vt).
- Floor R value (difference in the thickness of insulation material).
- Roof R value (difference in the thickness of insulation material).
- Wall R value (difference in the thickness of insulation material). An exception is made for 1. DDR where the window/wall ratio has been considered instead of Wall R value.
- Infiltration rate.

The parameters and their maximum and minimum values are listed in table 3. These values are similar to the perturbations to the selected parameters across their base case values in the previous one at a time analysis work (Harputlugil, et al, 2007). In this work these values aimed to cause changes in the parameter that would be large enough to result in a numerically significant change in the simulation outcomes.

Table 3.Maximum and minimum values of parameters that are selected for global SA.

Parameters	**Min.**	**Max.**
Glz-vt	0.15	0.76
Floor-R	0.84 m^2C°/W	3.12 m^2C°/W
Roof-R	0.84 m^2C°/W	4.54 m^2C°/W
Wall-R	1.35 m^2C°/W	3.03 m^2C°/W
ACH	0.30 ACH	1.40 ACH

In order to generate a sampling matrix, Latin Hypercube Sampling (LHS) is used. LHS performs better than random sampling when the output is dominated by a few components of the input factors. The method ensures that each of these components is represented in a fully stratified manner, no matter which components might turn out to be important (SIMLAB, 2006).

Results of global SA

For the global SA the Monte Carlo Analysis (MCA) is used. The MCA is one of the most commonly used methods to analyze the approximate distribution of possible results on the basis of probabilistic inputs. (Lomas et al. 1992, Hopfe, et al. 2007).

When a Monte Carlo study is being performed, propagation of the sample through the model creates a mapping from analysis inputs to analysis results of the form:

$[y^i, x^{i1}, x^{i2}, ..., x^{in}]$, i = 1, ..., m , where n is the number of independent factors and m is the sample size.

Once this mapping is generated and stored, it can be explored in many ways to determine the sensitivity of model predictions to individual input variables (SIMLAB, 2006). There are various sensitivity analysis techniques; here scatter plots and the Pearson Product Moment Correlation Coefficient (PEAR) as a regression analysis are used.

The generation of scatter plots is the simplest sensitivity analysis technique. This approach consists of generating plots of the points

(x^{ij}, y^j) , i = 1, ..., m, for each independent variable xi.

Scatter plots may sometimes reveal the relationship between model input and model predictions; this is often the case when only one or two inputs dominate the outcome of the analysis. Further, they often reveal non-linear relationships, thresholds and variable interactions, thereby facilitating the understanding of the model behaviour. They can be considered as a global measure of importance, and are model independent, as the plots can reveal even strongly non-linear or non-monotonic features (SIMLAB, 2006).

Figure 4 and 5 are exemplary scatter plots for degree day regions where the correlation between dominant parameters and heating energy consumption can be seen. As the amount of assessed samples is limited, each correlation between heating energy consumption and any of design parameter cannot be easily exposed by scatter plots. Nevertheless, in figure 4, the effect of total transmittance of glazing on heating energy consumption can easily be followed.

Another simple measure of sensitivity is given by the Pearson Product Moment Correlation Coefficient (PEAR) which is the usual linear correlation coefficient computed on the

x^{ij}, y^i (i = 1, ..., m) (SIMLAB, 2006).

The PEAR analysis results of heating energy consumption for the four different DDRs can be seen in figure 6. The correlation coefficient (CC) values are on the x-axis. Positive values of CC indicate that when parameter value increase, heating energy consumption increase. Contrarily negative value of CC represent that the value of the parameter increases while heating energy consumption decreases.

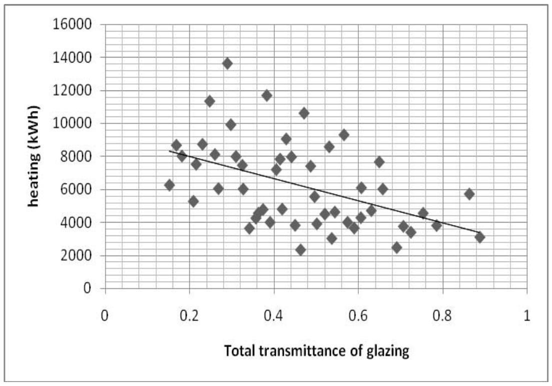


Figure 4. Scatter plot of total transmittance of glazing to heating energy consumption of 1. DDR.

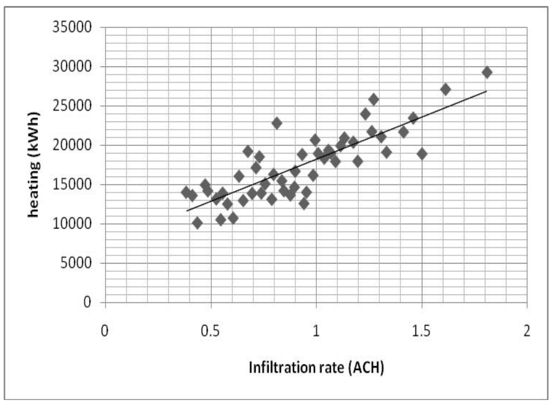


Figure 5. Scatter plot of infiltration rate to heating energy consumption of 2. DDR.

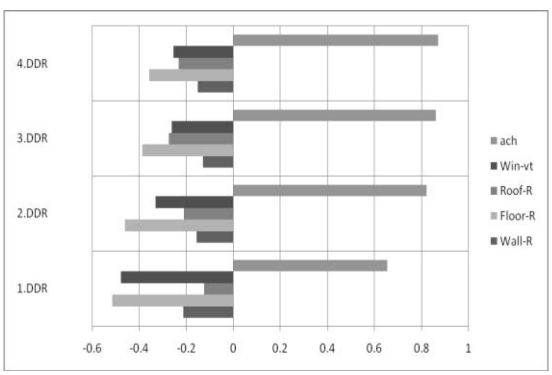


Figure 6. PEAR analysis results of four degree day regions (DDR).

Sensitive and robust parameters

According to the MCA results, the thermal resistivity of the building envelope is highly sensitive where it comes to energy consumption. Additionally the infiltration rate (ACH) is another sensitive parameter which is closely related to accurate design and careful construction of the building envelope.

The rest of the parameters scrutinised in this paper and previous work (i.e. Harputlugil, 2007) remained as relatively robust parameters, with one notable exception: orientation. It is well known that the first rule of designing with climate is to find an optimum orientation based on solar charts. This is confirmed by the results, confirming that orientation always is a sensitive parameter.

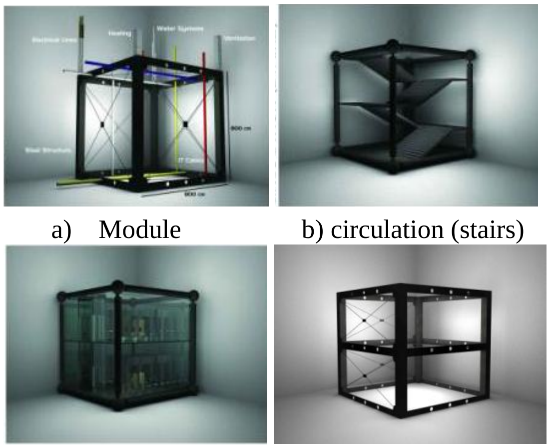
Robust outline design for schools in Turkiye

The results of global SA reveal the robust parameters which must be considered when developing a robust design scheme. The idea behind a robust outline design is to fix the robust design parameters, while the sensitive ones will remain open to allow for tuning the design to the local context (in this case different DDRs) where the building is located.

As the envisioned product is an outline scheme, the design should be flexible and easily adaptable to changing conditions. Here a classroom module is proposed which is a box-like system that includes all required facilities. This classroom module is named "*Modulsco"*. With 8x8 meter dimensions of all axes, *Modulsco* has a semi-fixed zone dept and height, and thus it provides a 512 m^3 volume. It is easy to adapt the module to various expectations (see figure 7).

Proposing a module box may seem simplistic. However it is aimed to be simplistic enough to adapt easily to other aspects of design for school buildings (eg. local context, culture, education system, student learning strategies, etc). The box (*Modulsco*) would be a module of circulation, classrooms or WCs as seen in figure 7. It should be emphasised that *Modulsco* is not suggested as a design scheme for a better building. *Modulsco* is a concept tool to be used when developing thermally robust outline design schemes.

Each module is a kind of Lego® piece that can be attached each other in various compositions to form module groups. Based on the local context, these module groups make a cluster of zones which can be rotated in order to fit to the best orientation. Then the most effective facade is installed to these clusters, taking into account sensitive parameters and values for each degree day region.



a) Module b) circulation (stairs)

c) WC d) Classroom floors

Figure 7. Various functions adapted to the proposed modules called Modulsco.

DISCUSSION AND CONCLUSION

This paper has presented the development of a thermally robust design concept, which is aimed to be an alternative solution to bridge the gap between designers and building simulation experts that has become evident in the last decade. The designers need to be free during design while taking decisions, contrary to the approach of many simulation programs which require more inputs to be fixed in the earlier phases of design (Hopfe et al., 2006, Palme et al., 2006).

A local and global sensitivity analysis of parameters was done in order to reveal robust and sensitive parameters. LHS (Latin Hypercube Sampling) is used for sample matrix and MCA (Monte Carlo Analysis) is used for the global sensitivity analysis. The parameters addressed in the study were limited to a set of the ones which will have a good prospect of importantly influencing building performance. It is noted that taking into account only heating and cooling energy consumption as performance indicators may raise a contradiction with for instance day-lighting. Further analysis will be done for optimization of more potentially contradictory indicators in future work.

Overall, this paper demonstrates how building simulation can contribute to the pre-design of better (school) buildings. As such, it shows how simulation can inform a design process which is yet to start, thereby taking the integration of building design and building simulation to a next level. It should be emphasized that each building design has its own context and develop its own parameters based on this context. Therefore the parameters addressed in the study are the ones which are expected to be mainly independent from the building type. This will assist the easy application of the proposed outline scheme to other building types.

Relatively robust parameters such as zone dept and ceiling height enabled to develop a module concept which is called *Modulsco*. Various functions can be assigned to the proposed module and help it to respond to local expectations of the building envelope, allowing the module to be high performance in terms of maximizing heat gains and energy conservation.

As a future work, it is aimed to test *Modulsco*, in various design alternatives applied to different climatic regions of Turkiye to allow validation of the outcomes proposed in this study.

It is hoped to suggest the resulting outline scheme to the Ministry of Education of Turkiye, as there still is a substantial demand for new and better school buildings in this country. It is believed that the scheme will make these future buildings more energy efficient in achieving thermal comfort.

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