Simulation as a tool to develop guidelines for the design of school schemes for four climatic regions of Turkiye

Ulukavak Harputlugil, G., Hensen, J.L.M. & Wilde, P.J.C.J. de (2007).
Simulation as a tool to develop guidelines for the design of school schemes for four climatic regions of Turkiye.
In Jiang, Yi (Ed.), Proceedings of the 10th IBPSA Building Simulation Conference, 3-5 September, pp. 1805-1812.
Beijing: Tsinghua University.

SIMULATION AS A TOOL TO DEVELOP GUIDELINES FOR THE DESIGN OF SCHOOL SCHEMES FOR FOUR CLIMATIC REGIONS OF TURKIYE

Gülsu Ulukavak Harputlugil[1], Jan L.M. Hensen[2] and Pieter de Wilde[3]

[1]Department of Architecture, Faculty of FT Fine Arts & Design, Zonguldak Karaelmas University, Safranbolu, 78600-Karabük, Turkiye
[2] Eindhoven University of Technology, Unit Building Physics and Systems, Building Performance Simulation, Eindhoven, The Netherlands
[3] University of Plymouth, Faculty of Technology, School of Engineering, Plymouth, UK

ABSTRACT

This paper describes the use of transient building performance simulation in order to develop design guidelines for educational buildings in Turkiye. The premise of the work is that design decisions taken during early stages of the building process have a large impact on the performance of the resulting building and hence need solid underpinning. Yet straightforward application of building performance in these early stages has proven to be difficult. Hence this paper applies sensitivity analysis to the outcomes of simulations carried out with the ESP-r simulation program in order to identify the most relevant parameters in school design. This allows building designers to make informed decisions, without having to revert to modelling and simulation. The research described in this paper is part of an ongoing project of preparing a design guideline for Turkish building designers who intend to design with climate.

KEYWORDS

Design guideline, sensitivity analysis, performance simulation, design of educational buildings, design with climate

INTRODUCTION

It is widely accepted that the design decisions taken during the early phases of building design can have a large role in ensuring the performance of the end product. Thus it is during these early stages that information on building performance is important towards expanding the capabilities of the design team to make well-informed choices. Yet several research projects have identified the problematic nature of using building performance simulation to inform design decisions during these early stages; see for instance Hopfe *et al* (2005), de Wilde (2004), Morbitzer (2003) and Hensen (2004).

The work presented in this paper employs sensitivity analysis to evaluate the impact of design parameters on building performance as quantified through building performance simulation, thereby identifying which parameters are the most important ones.

In this study, school buildings were selected as an examplary building type for the exploration of the relation between design and performance. There are various performance aspects which are essential for school buildings like thermal comfort, CO_2 levels/ventilation, lighting, acoustics/noise, etc.; see for instance Wong and Jan (2003), Daisey et al (2003), Heschong et al. (2002), or Berg (1993). Based on the report of Turkish Government (NECC, 2004) one of the critical issues for school buildings in this specific country is energy consumption levels. Therefore amongst all performance aspects, the focus of this paper is on energy performance of school building schemes which are still at an early stage of the building design process. Furthermore the paper deals with the sensitivity towards climatic conditions, for four different climatic regions of Turkiye.

Currently there are four degree day regions in Turkiye, for evaluation of different climatic conditions. Thermal requirements and acceptable total heating energy consumption of each are listed in the regulation of heat insulation (TS825-Standard for Heat Insulation in Buildings). Based on the IEA (International Energy Agency) Turkiye report (2002), 80 percent of the energy consumption in the building sector is for heating. Thus only heating degree day values are considered for assessment of energy efficiency in the Turkish regulations, despite a potential large contribution to energy consumption by cooling.

This study aims not to prescribe parameter values effective for each climate region, but rather to explore the acceptable ranges of the parameters and their priority based on the characteristics of each degree day region. This will then become a guideline for designers who intend to design with climate in Turkiye.

There have been several research projects that listed important parameters categorized based on design phase details. However it should be considered that each project has its own context and hence comes with its own design parameters. Therefore assessment of parameters in this study is limited to a set of the ones which will have a good prospect of importantly influencing building performance.

The parameters considered in this study are listed below:

- U-value of the external wall
- U-value of the floor
- U-value of the roof
- U-value of the glazing
- Direct transmittance of the glazing
- Window to wall ratio
- Thermal mass of the external wall
- Thermal mass of the floor
- Ceiling height
- Zone depth
- Air change rate
- Orientation

These are studied as a set of basic parameters that are mainly set during early design phases, and which are highly relevant from an energy consumption point of view.

METHODOLOGY

In their study on validation of building simulations, Judkoff (et al., 1983) classified the reasons of inaccurate results as internal and external errors. Error sources which are directly linked to the internal workings of a prediction technique were called internal and they are contained within the coding of the program. External errors were defined as the ones caused of differences between user assumptions and actual conditions. Recently, these external errors are examined as the uncertainties of input data and various solutions were published towards converging to accurate interactions of real building. (ie. Fülbringer and Roulet, 1999; Tamburrini, et al 2003; Macdonal, 2004; Sargent, 2005; Westpal and Lamberts, 2005).

This study concentrates on uncertainties which are caused by differences between the actual thermal and physical properties of the building and those input by the user derived in the early phases of design.

In fact, it is not possible to duplicate actual conditions even with dynamic simulation. Moreover if one intends to begin modeling in the early phases of design process, one should be aware of the possible deviations in the results caused by assumptions.

Exploring accurate input value ranges for a specific parameter, a sensitivity analysis can be performed via simulation. The ESP-r building performance simulation program has been used to generate data for sensitivity analysis. As a dynamic simulation program ESP-r requires detailed input data all of which is not always fully available during early phases of design. This might be a handicap for end user who is not a simulation expert. Transforming complex input-output structure of detailed tools to best practice advices of guidelines will be more handily for designers in the early phases of design. Here the aim of using Esp-r for data acquiring is to explore a way of using detailed tools for developing design guidelines which will be served to non-experts.

Sensitivity Analysis

As a general definition, 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 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 uncertain analysis inputs to the uncertainty in analysis results (Helton et al, 2006)

There are several possible procedures to perform sensitivity analysis (SA). The most common SA is sampling-based. Several sampling strategies are available, including random sampling, importance sampling, and Latin hypercube sampling.

In general, a sampling-based sensitivity is one in which the model is executed repeatedly for combinations of values sampled from the distribution (assumed known) of the input factors. Other methods are based on the decomposition of the variance of the model output and are model independent.

In their reviews on sensitivity analysis in the scientific method, Saltelli (et al, 2006) emphasized that the works on sensitivity analysis highlight the importance of SA in corroborating or falsifying a model-based analysis. They stated that all sensitivity analyses were performed using a one-factor-at-a time (OAT) approach, so called as each factor is perturbed in turn while keeping all other factors fixed at their nominal value. On the other hand, it should be noted that when the purpose of SA is to assess the relative importance of input factors in the presence of factors uncertainty this approach is only justified if the model is proven to be linear.

There are several examples of the application of sensitivity analysis in building thermal modelling

(Spitler, 1989; Corson, 1992; Hui and Lam, 1996; Fülbringer and Roulet, 1999; Mc Donald, 2002; Westphal and Lamberts, 2005) 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) changed for particular increments of input values (Corson, 1992). In other words, for energy simulation models usually OAT approach is used.

For determining the results of sensitivity analysis, usually an influence coefficient is used. Basically this influence coefficient is calculated as follows:

$$IC = \frac{\text{Changes in output}}{\text{Changes in input}} = \frac{\Delta\, OP}{\Delta\, IP} \qquad (1)$$

where OP is output and IP is input. This is an equation of a ratio of simple difference. If only one step change is used, the influence coefficient in equation (1) will be determined as the ratio of difference between output results (OP_2-OP_1) to difference between input results (IP_2-IP_1). If more perturbations are used in the analysis, the influence coefficient can be determined from the slope of the regression straight line for the data (Lam and Hui, 1996)

In this study the general approach suggested by previous studies has been used. The procedure of the application of sensitivity analysis is as follows:

- Definition, calibration and simulation of a base case model
- Identification of the basic parameters of interest
- Identification of base case values for the parameters
- Introduction of perturbations to the selected parameters across their base case values one at a time. The change in the parameter should be large enough to cause a numerically significant change in the result.
- Analysis of the corresponding effects of the perturbation on simulation outputs.

The above procedure has been applied to four different degree day regions of Turkiye to catch the climatic influence on the same perturbed parameters.

CASE STUDY

Model Validation

For inter-model validation of the model, the calculation methodology of "*Standard for Heat Insulation in Buildings (TS825)"* is used. Based on TS 825, there are four degree day regions (DDR) in Turkiye and each of them has a u-value limit for external walls and windows (Table.1).

TS 825 has an annual heating energy consumption limit, which is calculated from the rate of building's total opaque surface area to its gross volume. The calculation considers steady-state conditions, and only takes into account the heat transfer mechanisms of conduction and convection. Building type (i.e. school, house or office) is not taken into account in the calculations. There are simple assumptions for internal heat gain rates (like occupancy, lighting, etc.), infiltration rate and climatic conditions. TS 825 considers only the heating season. Although the southern region of Turkiye has a higher number of cooling degree days than heating degree days, there is still no regulation for cooling. Note that lighting energy consumption has not been considered in any Turkish legislation yet.

Table.1. Four degree day regions (DDR) of Turkiye.

		1.st DDR	**2.nd DDR**	**3rd DDR**	**4th DDR**
Heating Degree Days*		512.5	1285.3	2676.9	3857.1
Cooling Degree Days**		1285.3	567.8	423.8	291.1
Acceptable U-value limits*** (W/m2K)	Ext. wall	0.80	0.60	0.50	0.40
	Grd.floor	0.80	0.60	0.45	0.40
	Roof	0.50	0.40	0.30	0.25
	Window	2.80	2.60	2.60	2.40

*Reference temperature 15ºC
**Reference temperature 18ºC
*** based on TS825.

Parametric study

In this study a simple school building scheme has been analysed. There are two main reasons for selecting school buildings. Firstly, there is the high energy consumption rate of school buildings in Turkiye; a report of the government (NECC, 2004) states that approximately 40% of saving can be achieved in this specific sector through the introduction of energy efficiency measures. The other reason is the construction policy of the government. Most school buildings in Turkiye are built for the government, which supplies an outline design only. Acquired projects are then realised in any region of the country, without taking into account local conditions. Yet each building has its unique context due to the site characteristics, leading to the fact that the government school buildings usually fail in energy savings and occupancy comfort (Ozturk, 2001).

The base case model studied in this project has five zones, four classrooms and a corridor. Of the four classrooms, two are placed at South (Figure.1). The input data of the model is listed in Table.2. The input values have been adapted to represent the acceptable values of TS 825. The U-values of the envelope components are listed in Appendix.1. The parameters considered for parametric study and their values are listed in the Appendix.2. The analysis has been done for each DDR.

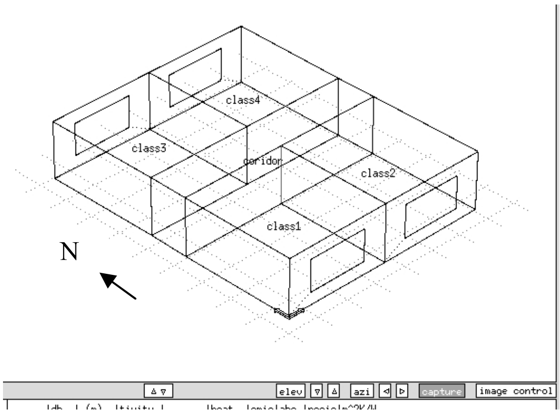

Figure.1. base case model

The results are evaluated in two ways. One is based on alteration percentage (AP) of the change of energy consumption depending on the change of input data values. The other evaluation is based on regression analysis (RA). To reveal the correlation between input and output variables, the slope of the regression straight line (if the relation is linear) is used for the data. The regression function is also used to determine the influence coefficient of the parametric study. If RA results are 1.00 or very close to 1.00, it means that there is a correlation (linear or parabolic). The analysis has been done with the input variables listed in Appendix.2 and AP results are shown in Table.3.

Table.2. Base case model input data.

Zone area of each classroom	47.52 m^2
Zone area of corridor	
Ceiling height	3.4m
Window area of each classroom	11.89 m^2
Window/wall ratio of each classroom	0.53
Transmittance of glazing	0.76
Metabolismic rates	5 W/m^2
Air Change Rate	1.0 ACH
Ventilation	N/A
Design temp. for heating	19ºC

Table.3. Based on degree day regions (DDR), the analysis results of alteration percentage of heating and cooling energy consumption.

Input Data (+) increase (-) decrease		**1st DDR** heating	**1st DDR** cooling	**2nd DDR** heating	**2nd DDR** cooling	**3rd DDR** heating	**3rd DDR** cooling	**4th DDR** heating	**4th DDR** cooling
U-value (+)	Ext.wall	%12,6 (+)	%2,4 (+)	%10,8(+)	%3,2 (-)	%11,1(+)	%8,1 (-)	%11,8(+)	%12,0 (-)
	floor	%53,6 (+)	%59,5(-)	%28,4(+)	%36,4(-)	%21,1(+)	%40,1(-)	%18,6(+)	%43,2 (-)
	roof	%29,5 (+)	%24,2 (+)	%28,7(+)	%13,4 (+)	%28,7(+)	%4,2 (+)	%31,2(+)	%5,3 (-)
Window / wall ratio (+)		%43,3(-)	%72,6 (+)	%12,9 (-)	%75,3 (+)	%8,5(-)	%82,8 (+)	%7,6 (-)	%87,6 (+)
Glazing U-value (+)		%24,1 (+)	%3,3(-)	%22,6(+)	%21,5(-)	%21,8(+)	%30,3(-)	%24,4(+)	%39,7(-)
Trans. of glazing (+)		%74,2 (-)	%54,7 (+)	%25,1 (-)	%86,9 (+)	%20,9(-)	%94,0 (+)	%21,4(-)	%97,8 (+)
Thermal mass (+)	Ext.wall	%1,9 (-)	%1,3(-)	%0,6 (-)	%3,2(-)	%0,2(-)	%3,8(-)	%0,2(-)	%6,2 (-)
	Floor	%6,1(-)	%4,5(-)	%3,1(-)	%8,2(-)	%1,4(-)	%14,2(-)	%1,1 (-)	%18,3(-)
Ceiling height (+)		%26,4 (+)	%6,6(-)	%23,9(+)	%9,5(-)	%19,9(+)	%16,7(-)	%19,9(+)	%23,6(-)
Zone depth (+)		%57,1 (+)	%18,6(-)	%46,8(+)	%44,3(-)	%44,1(+)	%52,4(-)	%43,4(+)	%62,3(-)
Air change rate (+)		%80 (+)	%11,7 (+)	%77,0(+)	%52,7(-)	%35,4(+)	%54,8(-)	%36,4(+)	%69,1(-)
Orientation (+)		%5,6	%38,1	%4,4	%55,4	%1,9	%21,4	%1,3	%69

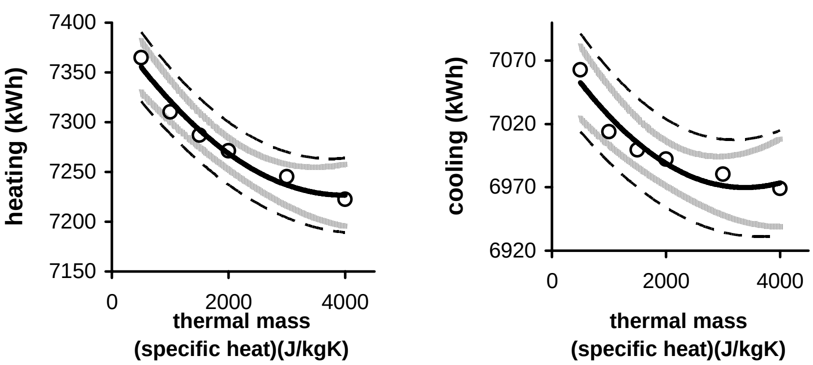

Figure.2. The relation graph of energy consumption of heating and cooling when thermal mass effect of external wall increase in 1st degree day region (DDR) where the "dots" are the observations of the sample, "bold black

line" is the fitted regression line, the" grey" lines are the confidence interval band and "dotted black lines" are the prediction interval band.

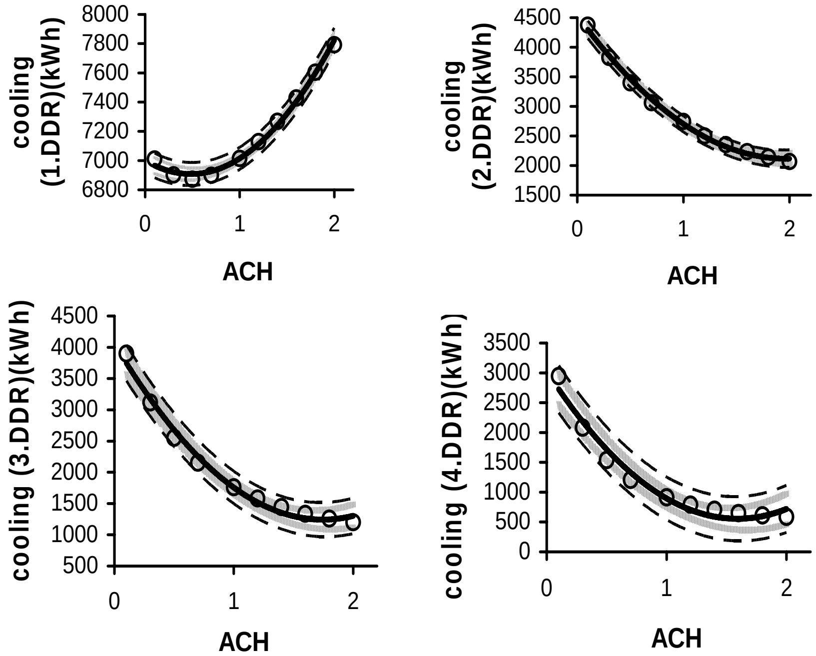

Figure3. The relation graphs of energy consumption of cooling when air change rate increase in each degree day region (DDR) where the "dots" are the observations of the sample, "bold black line" is the fitted regression line, the" grey" lines are the confidence interval band and "dotted black lines" are the prediction interval band.

Regarding the total heating and cooling energy consumptions, RA showed that the U-value of external walls and windows, thermal mass, window to wall ratio, total transmittance of glazing, ceiling height, zone depth and air change rate are significantly effective in all DDR as R^2 value of these parameters are 1.00 or very close to 1.00.

For the 1st DDR, which has a high cooling degree day value, high thermal mass in the external wall is not that much effective on both heating and cooling. As can be seen from Figure.2, a specific heat capacity of thermal mass above 2500-3000J/kgK does not lead to a significant reduction of energy consumption.

Another parameter with ambiguous findings is the air change rate. For all DDR, heating energy consumption increases with a higher air change rate. On the other hand, the input-output relation of cooling energy consumption is parabolic and decreases with lower ACH values (Figure.3). For the 2nd, 3rd and 4th DDR, when air change rate exceeds 1,0~1,2 ACH, the relative alteration of cooling energy consumption decreases. This becomes explicit in the DDR which has high heating degree day value. Contrarily to the 1st DDR, the cooling energy consumption begins to increase after the air change rate exceeds 0,5 ACH. As the 1st DDR has high cooling degree day values, the outside air temperature is higher than the inside air temperature. The air change rate from outside to inside increase the cooling load inside after a certain level. Consequently, reducing the air change rate is essential in order to decrease the cooling load for the 1st DDR and to decrease heating load for the rest of the DDRs.

In the parametric study, the AP values give an insight into the effect of input variables on output results. An alteration in the output exceeding 20% is accepted as a parameter with high impact, between 20%-5% are secondary parameters and below 5% is classified as negligible. Based on this categorisation, the gray cells in Table 3 show AP of high impact parameters. The (+) signs are for increase, the (-) ones are for decrease of consumption during values of input parameters increase.

TOWARDS A DESIGN GUIDELINE FOR THE DESIGN OF SCHOOL SCHEMES IN TURKIYE

Building design is an iterative process which includes different levels of detail. Meeting the requirements of each unique design therefore is only possible by being aware of the individual parameters. Each of them should be considered separately but the building should be assessed as a whole to find out the total integrated performance. One of the main issues taken into account when setting design parameters should be local conditions (ie. site environment, macro and micro climate, etc.). Although Turkiye has 4 DDR and regulations are organized regarding to these regions, there is no specifically defined guidance for special characteristics of each region.

Several countries in Europe and many states in the USA have design guidelines for different building types. The format of the guidelines differs but the aim is to provide guidance to designers on identifying and evaluating design alternatives and developing plans and specifications, and encourage integrated design decisions. The guidelines include roadmaps without any restriction to design freedom.

In this study, the outcomes listed below are the first steps towards a guideline for the design of school schemes in the four main climatic regions of Turkiye. The next stage towards the guideline will be the development of a list of energy efficiency design recommendations for each DDR based on these outcomes.

The results of this parametric study show that:

- External walls should be designed to have a minimum U-value for decreasing overall energy consumptions of all DDR. Particularly for the 1st DDR, energy savings of both cooling and heating could be reduced by a highly insulated wall.
- Depending on specific building type and internal gains, optimal U-value limits for the ground floor should be considered during design. For the buildings with high cooling load, high U-value will help to decrease energy consumption for cooling. Acceptable highest level of floor U-value could be selected.
- High U-value for the roof affects energy consumption positively for all DDR. High roof insulation measures should be taken for energy saving particularly for heating buildings in any DDR and for cooling in 1st and 2nd DDR.
- The energy consumption for cooling is highly sensitive to alteration of the window to wall ratio. The amount of heat gain from sun is directly related to the sizes of the windows. Bigger window sizes may cause high cooling loads due to relatively low energy saving for heating. The optimization of window to wall ratio for all DDR is essential.
- U-values for glazing should be the lowest for energy saving purposes, for the same reasons applying to the U-value of opaque surfaces.
- Total transmittance of glazing should be optimized for the buildings designed in the 1st DDR. For the other DDRs, this parameter is significantly effective on the energy consumption for cooling rather than heating. Total transmittance includes both visible and near IR parts of the solar spectrum. Decreasing the total transmittance value will decrease the cooling load but also affect daylighting level. Transmittance levels should be considered together with daylighting requirements and optimum values for both cooling and daylighting should be selected to design.
- Thermal mass is helpful for decreasing energy consumption for the buildings designed in any of the DDRs. For high heating DDRs, it is effective on cooling because it is easier to store cool. Contrarily, for high cooling DDRs, it is more effective on heating. Besides, thermal mass capacity significantly alters consumption when used in floor rather than in walls. This is because of easier thermal coupling of floors with solar radiation transmitted from glazing than walls since external walls have the insulation material outside and storage only possible with re-radiation.
- Designing high ceiling increases the heating energy consumption considerably for the buildings in 1st and 2nd DDRs and decrease energy consumption of cooling in 4th DDR.
- Increasing the zone depth significantly ipmacts on energy consumption. Depending on the degree day values of DDRs, heating-cooling energy consumption of each region should be optimised during design.
- Infiltration rate should not exceed 0,5-0,7 ACH for the buildings designed in any DDR, despite the fact that TS825 Turkish insulation Standard considers 1,0 ACH for tight buildings, 2,0 ACH for the others together with natural ventilation.

CONCLUSION

This study aims to reveal the importance of design decisions particularly taken in the early stages and to underline the effects of climatic differences on energy consumptions. Also, a particular building type has been evaluated. Although the representativeness of selected case model may cause discussions, it should be noted that the model was only used for revealing the sensitivity of each parameter. The applicability potential of the model will be explored by real building modeling which is going to be the case of future work. The design parameters evaluated in this study are not the only parameters of school buildings. It should be emphasized again 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 guideline to other building types. Considering only heating and cooling energy consumption as performance indicator may raise a contradiction with i.e. daylighting. Nevertheless the research is limited with only the effects of heating and cooling energy consumption. Similar analysis will be done for optimization of various contradictory indicators as a future work.

By this study a methodology searched to develop a design guideline for the unique characteristics of each degree day region (DDR) in Turkiye. Sensitivity analysis seems to be an option for evaluation of the priority of the parameters based on climate necessities. This is also a way of using simulation techniques for developing design guidelines. Nevertheless it should be noted that using sensitivity method needs to focus more on problem definitions, understanding of sensitivity theory, selection of appropriate tools and better interpretations of results. In most cases, the validation and verification of simulation tools used for analysis is not enough. There remains the issue of validation of user, which is a main source of uncertainties.

On the other hand due to large differences among the four DDRs, it becomes necessary to elaborately examine the region system of TS 825. In this study each DDR has been represented by a city (1^{st} DDR-Antalya; 2^{nd} DDR-Istanbul, 3^{rd} DDR-Ankara; 4^{th} DDR-Erzurum). Nevertheless there ought to be differences between two cities in the same DDR but separate geographical locations (ie. coastal city, forest city, etc.). One option is to make sensitively assessments according to the seven main geographical regions of Turkiye. See figure 4.

Figure.4. Seven geographical regions of Turkiye.

Another question remained in this study that whether the guidelines could support design decisions or not. This will be researched by applying the guidelines to real building projects. Therefore, as a work of next step, a test of the guideline be executed by making a comparison between the real building performances with best practice, and with those according to the guideline. The result of the comparison will show if the buildings were designed by the help of the guideline, how much the saving rate would have been. On the other hand, during this application, the role of performance simulations as a support tool of guidelines will be discussed.

REFERENCES

Berg FS, 1993, Acoustics and sound systems in schools. Singular Pub. Group San Diego, California.

Corson G. C., 1992, Input-Output Sensitivity of Building Energy Simulations, ASHRAE transactions, 98 (Part I),p. 618-626.

Daisey J. M., Angell W. J., Apte M. G., 2003, Indoor air quality, ventilation and health symptoms in schools: an analysis of existing information , Indoor Air 13 (1), 53–64.

De Wilde P. 2004, Computational Support for the Selection of Energy Saving Building Components, PhD thesis, Delft University of Technology, Faculty of Architecture, Building Physics Group, Delft, the Netherlands.

Fülbringer and Roulet, 1999; Confidence of Simulation Results: Put a Sensitivity Analysis Module in Your Model, Energy and Buildings, Volume 30, pp. 61-71.

Helton, J. C., Johnson, J. D., Sallaberry, C. J., Storlie, C. B., Survey of Sampling Based Methods for Uncertainity and Sensitivity Analysis, Reliability Engineering and System Safety, Volume 91, pp. 1175-1209.

Hensen, J. L. M. 2004, Towards more effective use of building performance simulation in design, in Proc. 7th International Conference on Design & Decision Support Systems in Architecture and Urban Planning, 2-5 July, Technische Universiteit Eindhoven.

Heschong, L., R. Wright, S. Okura, P. Klein, M. Simner, S. Berman and R. Clear, 2002, Daylighting impacts on human performance in school, Journal of the Illuminating Engineering Society (J. Illum. Eng. Soc.) 31(2), 101-114

Hopfe C. J., Struck C., Harputlugil G. U., Hensen J. L. M., De Wilde P., 2005, Exploration Of The Use Of Building Performance Simulation For Conceptual Design, IBPSA-NVL Conference, 20 October, Technische Universiteit Delft, Netherlands.

IEA, 2002, Energy Policies of IEA Countries; Turkey Review, OECD, IEA.

Judkoff, R., D. Wortman, B. O'Doherty, and J. Burch, 1983, A methodology for validating building energy analysis simulations. SERI/TR-254-1508. Golden, Colo.: Solar Energy Research Institute (now NREL).

Lam J. C. and Hui S. C., 1996, Sensitivity Analysis of Energy Performance of Office Buildings, Building and Environment, Vol.31 No.1, pp.27-39.

Mc Donald, 2002; Assessing the Significance of Design Changes when Simulating Building Performance Including the Effects of Uncertain Input Data, Proceedings of e-Sim'04, Vancouver.

Morbitzer C. A., 2003, Towards the Integration of Simulation into the Building Design Process", PhD Thesis, Strachclyde University, UK.

NECC, 2004, Energy Efficiency Strategy for Turkey, a report by MVV consultants, Germany.

Öztürk, S., 2001, Energy Efficiency Potential of School Buildings in Turkiye, NECC Report (in Turkish), Ankara.

Saltelli, A., Ratto, M., Tarantola, S., Campolongo, F., 2006, Sensitivity Analysis Practices: Strategies for Model Based Inference, Reliability Engineering and System Safety, Volume 91, pp. 1109-1125.

Spitler, J. D., Fisher, D. E., Zietlow, D. C., 1989; A Primer on the Use of Influence Coefficients in Building Simulation, Proceedings of Building Simulation'89 Conference, pp. 299-304, IBPSA, Vancouver, Belgium.

TSE, 2000, Heat Insulation Standard for Buildings: TS825, Turkish Standards Institution.

Westphal and Lamberts, 2005, Building Simulation Calibration Using Sensitiviy Analysis, Proceedings of Building Simulation'05 Conference, pp. 1331-1338, IBPSA, Montreal, Canada.

Wong N. H., and Jan W. L. S., 2003, Total building performance evaluation of academic institution in Singapore, Volume 38, Issue 1, January 2003, Pages 161-176.

APPENDIX.1

The materials and their thermophysical properties used in base model.

U-values of envelope components	**Degree Day Regions**			
	1st DDR (Antalya)	2nd DDR (İstanbul)	3rd DDR (Ankara)	4th DDR (Erzurum)
Ext. Wall U-value	0.74 W/m2K	0.56 W/m2K	0.48 W/m2K	0.38 W/m2K
Ground Floor U-value	0.79 W/m2K	0.59 W/m2K	0.44 W/m2K	0.39 W/m2K
Roof U-value	0.50 W/m2K	0.39 W/m2K	0.30 W/m2K	0.25 W/m2K
Window U-value	2.8 W/m2K	2.6 W/m2K	2.6 W/m2K	2.4 W/m2K

APPENDIX.2

The input parameters and perturbations used for sensitivity analysis.

Input		unit	Referance value	Perturbations		
				Min	Max	Nos.
U-value	External wall	W/m2K	RM1: 0.74 RM2: 0.56 RM3: 0.48 RM4: 0.38	0.33	0.74	6
	Floor	W/m2K	RM1: 0.79 RM2: 0.59 RM3: 0.44 RM4: 0.39	0.32	1.19	7
	Roof	W/m2K	RM1: 0.50 RM2: 0.39 RM3: 0.30 RM4: 0.25		1.18	7
Thermal Mass capacity (specific heat)	External wall	J/kgK	1000	500	4000	5
	Floor	J/kgK	1000	500	4000	5
Window to wall ratio		---	0.53	0.1	0.8	6
Optical Property of Transparent surface (direct transmittance)			0.76	0.15	0.76	4
U-value of Transparent surface		W/m2K	RM1: 2.75 RM2: 2.60 RM3: 2.60 RM4: 2.40	1.15	3.86	4
Zone depth		m	7.2	5	9	4
Ceiling height		m	3.4	3.0	4.0	6
Air change rate		ACH	1.0	0.1	1.2	5
Orientation (south facade)		-	0°	0°	180°	8