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UNCERTAINTY ANALYIS FOR CONCEPTUAL BUILDING DESIGN
A REVIEW OF INPUT DATA

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ABSTRACT

State of the art building performance simulation tools lack capabilities to support practitioners during the conceptual building design stage. [Hopfe et al, 2005]

It is hypothesized that risk assessment techniques dedicated to the analysis of uncertainties and sensitivities have the potential to provide a basis for objective decisions during the early design stages.

Concentrating on material properties, the paper presents preliminary results from a literature survey dedicated to locating appropriate input data for conducting risk assessments. Of specific interest are hereby the reliability of the source data as well as the method to obtain the mean value and standard deviation.

INTRODUCTION

The use of risk assessment techniques such as uncertainty and sensitivity analysis is not a new subject in building performance simulation (BPS). Publications indicate that at least one BPS – tool, ESP-r, has been subject to an implementation of appropriate algorithms to address the assessment of risks [Macdonald et al 1999]. Other efforts have been reported to address risk assessment methods, not tool integrated - but realized using UA tools coupled to BPS software externally, by Lomas and Eppel [1992], Breesch and Janssens [2005], and De Wit [2001] among others.

The aim of the past efforts was predominantly to address the accuracy of simulation results with respect to uncertainties. The current paper has a different perspective. It forms one step of an effort investigating measures to better service practitioners working in the earlier design stages using BPS-tools. Practitioners nowadays, take design decisions based on subjective design experience. The aim is to enrich numerical analysis results to provide valuable design information to achieve the goal to better serve practitioners needs.

It is hypothesized that results of risk analysis techniques have the potential to better educate design team members on critical design issues as, energy consumption, energy costs and thermal comfort.

De Wit [2001] identified four sources of uncertainties in BPS, which are: numerical -, scenario-, specification-, and modeling uncertainty. The latter two, specification and modeling uncertainties, introduced by the description of the building and its properties are addressed here.

METHODOLOGY

Two research methods were used. Firstly, a literature survey was conducted to identify relevant publications on the subject of material properties and associated standard deviations. Secondly, two potentially interesting techniques to obtain standard deviations were compared and assessed on practicability. Finally, recommendations were formulated and discussed.

UNCERTAINTY ANALYSIS (UA)

The probability theory allows conducting an uncertainty assessment of the simulation output based on the uncertainty of one or more input parameter.

A number of methods exist to conduct a UA such as Monte Carlo -, differential sensitivity (Morris) analysis -, and stochastic sensitivity analysis, among others.

UA techniques have in common that a number of input parameters are selected, which are used to generate a sample matrix based on specific sample distribution techniques as a starting point for output generation and result analysis. To generate the sample matrix, information about the mean value and standard deviation of each individual parameter is required.

The definition of a building model for performance simulation requires a great number of diverse input parameters such as, weather data, model dimensionality, casual gains, infiltration/ ventilation rates, and material properties among others. The current paper is dedicated to material properties only.

MATERIAL PROPERTIES

The literature survey revealed that it is particularly difficult to locate data describing their real on site performance. Standardized material property data sets, as prescribed in building codes, are sufficient to use for steady state design calculation to demonstrate code compliance. However, their characteristics do not suffice when used to simulate reality, as they do not allow for the representation of parameter variations.

Factors that can cause variations of material properties are:

- Temperature changes (external/internal);
- Moisture content variations (absorption / desorption);
- Aging, and;
- Material selection (Performance differences of one material within the same product family or across others).

When compiling a sample matrix to address the above variation one needs to consider the appropriate selection of problem specific input data, the type of sample distribution and sampling technique. Whilst the sampling technique (latin hypercube, Morris, random i.e.) to be used is dependent on the type of analysis, the choice of sample distribution (normal, logarithmic or uniform i.e.) depends on the characteristics of the data available.

To allow for the representation of heat/(mass) transfer phenomena in and around building elements, integrated BPS – tools require the definition of construction layers. Each layer is typically defined by material specific information as: specific heat capacity, conductivity, density, emissivity, solar absorbtance and vapor resistivity. The next section is dedicated to how to obtain material performance data to derive the standard deviation.

DATA PROVISION

There are three potential sources for the acquisition of material property data to represent material performance variations.

Material properties are typically provided by manufacturers based on measurements when introducing a product. Methods recommended by EN ISO 10456:1999 to obtain data for the conductivity are guarded hot plate -, heat flow meter – or hot box method i.e. Data provided by manufacturers are typically in "Design thermal value" format [EN ISO 10456:1999]. This value represent a typical performance of the material considered, under specific external and internal conditions, when incorporated in building elements, such as walls, flooring or roof constructions i.e. These value characteristics are not sufficient to support a UA. Material specific design thermal values can be found in Manufactures catalogues or building codes i.e.

Methods as documented in EN ISO 10456:1999 exists for deriving material properties for other than fixed standardized conditions, from "Declared thermal values". Declared thermal values represent the expected value of a thermal property of a material derived from measured data at reference conditions. This is particularly interesting if one wants to derive performance values for the compilation of a sample matrix using standard deviations. However, the methods can rarely be used due to inadequate information on test conditions, measurement sample size and limited test documentation.

The recognition of the importance of material performance values describing their real site behavior lead to data collecting efforts. One document repeatedly referenced, as milestone towards making data available for UA, is Clarke's et al [1991] report. The aim of compiling the document was to obtain data to describe variations of material properties as a function of temperature and/or moisture content. In due course of the project 14 international datasets were collected, classified, tabulated and published.

The authors identified a number of issues that limit the representativeness of the collected data, as follows:

- The sources of much of the data are not documented.
- Little information is provided on experimental conditions.
- Suspicion exists, that agreement between data sets can be attributed to historical borrowing.
- Quotation of values with missing indication to single or multiple measurements.

Based on the issues above it is doubtful that the data are representative for the full extend of potential variation of temperature and moisture content. Furthermore, the data available to not attempt to cover performance variations due to material aging processes. However, tabulated data sets are the easiest to access for research in the area of risk assessment.

UA FOR CONCEPTUAL DESIGN

Conceptual building design is characterized by a great number of concepts with little parametric detail to be evaluated; opposing the characteristics of the detailed design stage defined by a limited number of concepts with great parametric detail.

Parameter impact quantification during the early design is limited by the amount of design information available. However, the fact does not reduce the importance of the UA analysis but addresses the need for carefully chosen modeling abstraction levels. The risk for a designer to make a non-objective decision increases, the smaller the extend of information to base on design decision. To provide a starting point where only limited information is available one need to consider the largest possible search space. The search space will be gradually reduced during the design progress. By following this approach the risk is reduced missing out factors that cause big performance variation. Referring back to material properties it is important to decide which factors need to be considered during the concept design. It needs to be determined which of the factors mentioned earlier as moisture content, temperature variations, aging and material selection dominate the uncertainties for performance variations.

The following example demonstrates the identification of the factor dominating the uncertainty of the U-value for an external wall. The outwards facing layer was thereby the subject to parametric and material variations. A lightweight construction based on Judkoff and Neymark [1995] was chosen for the analysis (see Appendix A for details). The aim was to identify whether moisture content and temperature variations dominate over material selection.

Option 1 of 2, representing performance variations due to moisture content and temperature variations, was subject to the change of the thermal conductivity attributed to the external wall finish. The variation was based on a mean value (M) and standard deviation (STD) derived from Clarke et al [1991].

Table 1, Option 1 - Uncertainties attributed to moisture content and temperature variation

Conductivity plywood, M	0.16W/mK
Conductivity plywood, STD	0.04W/mK
U-value wall, M (300samples)	0.515W/m^{2}K
U-value wall, STD (300samples)	**0.0049**

Option 2, is characterized by performance variation due to the material selection. Two alternatives for wood siding as wall finish were selected to calculate U-values. Subsequently, the mean value and standard deviation were derived from the three samples.

Table 2, Uncertainties due to material selection

U-value wall, wood siding	0.517W/m^{2}K
U-value wall, brick finish	0.529W/m^{2}K
U-value wall, aluminum siding	0.532W/m^{2}K
U-value wall, M	0.526W/m^{2}K
U-value wall, STD	**0.0082**

It can be noticed that the uncertainty of the factor material selection dominates over the combined uncertainties of moisture content and temperature variation. In this particular case it appears appropriate to consider uncertainties introduced by the material selection prior considering factors moisture and temperature variations as it offers the larger search space.

CONCLUSION

The literature survey revealed that current datasets insufficiently represent on site performance variations of building materials. Numerical performance data derivation requires detailed information about test conditions which are rarely available and are therefore of limited use. Furthermore it can be concluded that previous efforts selecting material performance datasets, even so being limited in their coverage of potential performance variation factors are the most promising source to estimate material performance variations.

For concept design the most dominant performance variation factor should be used for UA. Following the approach of the maximized search space an example visualized that design thermal values can be chosen for the assessment of uncertainties attributed to material properties. However, UA for later design stages might require the primarily consideration of uncertainties attributed to moisture content and temperature variation to closely reflect reality.

Future work will be dedicated to expanding the presented example to cover more material properties to derive more generally applicable conclusions.

REFERENCES

Hopfe, C.J., Struck, C., Ulukavak Harputlugil, G. 2005. Exploration of the use of building performance simulation for conceptual design, IBPSA/NVL Symposium 2005, Delft Netherlands.

Macdonald I.A., Clarke J.A., Strachan P.A. 1999. Assessing uncertainties in building simulation, Proceedings of Building Simulation 1999, Paper B-21, Kyoto, Japan

Lomas K.J. and Eppel H. 1992. Sensitivity analysis techniques for building thermal simulation programs, Energy and Buildings, Vol.19, pp.21-44.

Breesch H. and Janssens A. 2005. Uncertainty and sensitivity of the performance of natural night ventilation, pp 3-8

De Wit M.S. 2001. Uncertainty in predictions of thermal comfort in buildings, PhD Thesis, Delft University

Pettersen T. D. 1994. Variation of energy consumption in dwellings due to climate, building and inhabitants, Energy and Buildings 21, pp 209-219

Clarke J.A., Yaneske P.P. and Pinney A.A. 1991. The harmonisation of thermal properties of building materials, Report TN91/6, BRE, Garston, Watford, UK

Judkoff, R. and Neymark, J. 1995. International energy agancy building energy simulation test (BESTEST) and diagnostic method, National Renewable Energy Laboratory, Golden, CO.

APPENDIX A

Table A1, Option 1 - wall construction

ELEMENT	CONDUCTIVITY (W/MK)	DENSITY (KG/M^3)	SPECIFIC HEAT CAPACITY (J/KG K)	THICKNESS (M)
Inside heat transfer coeff.	8.29W/m^{2}K			
Plasterboard	0.16	950	840	0.012
Fiberglass quilt	0.04	12	840	0.066
Wood siding	0.16	530	900	0.009
Outside heat transfer coeff.	29.3W/m^{2}K			

Table A2, Option 2 – Brick finish, wall construction

ELEMENT	CONDUCTIVITY (W/MK)	DENSITY (KG/M^3)	SPECIFIC HEAT CAPACITY (J/KG K)	THICKNESS (M)
Inside heat transfer coeff.	8.29W/m^{2}K			
Plasterboard	0.16	950	840	0.012
Fiberglass quilt	0.04	12	840	0.066
Brick, outer	0.96	0.011	900	0.011/
Outside heat transfer coeff.	29.3W/m^{2}K			

Table A3, Option 2 – Aluminum siding, wall construction

ELEMENT	CONDUCTIVITY (W/MK)	DENSITY (KG/M^3)	SPECIFIC HEAT CAPACITY (J/KG K)	THICKNESS (M)
Inside heat transfer coeff.	8.29W/m^{2}K			
Plasterboard	0.16	950	840	0.012/
Fiberglass quilt	0.04	12	840	0.066/
Aluminum siding	45	0.0007	900	0.0007/
Outside heat transfer coeff.	29.3W/m^{2}K			