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# UNCERTAINTY ANALYSIS FOR BUILDING PERFORMANCE SIMULATION – A COMPARISON OF FOUR TOOLS

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## ABSTRACT

Over the last three decades the use of building performance simulation (BPS) tools has increased but its ability to support building design is still limited.

State of the art BPS tools have the potential to be used more extensively during the entire design process if their current capabilities are expanded. It is hypothesized that by providing additional features supporting output accuracy assessments (uncertainty analysis) and parameter sensitivity studies BPS tools will provide more valuable design information.

Integrating techniques as uncertainty analysis (UA) and sensitivity analysis (SA) however requires not one but a large number of simulations of the same model to be conducted. Prototypes have been built automating the process for four software tools representing the modeling abstraction level from conceptual to detail design. The tools considered are LEA, IES VE, VA114 and HAMbase.

Potential sources for uncertainty variation of the results are discussed. The paper concludes with an indication of future work.

## KEYWORDS

Building performance, uncertainty analysis, sensitivity analysis, energy consumption, modeling abstraction level

## INTRODUCTION

During the early design stages, BPS is used occasionally, where design experience and guidelines are not sufficiently extensive, to evaluate the performance of design concepts. In the final design stage BPS is mostly confined to the demonstration of code compliance.

Efforts towards extending the use of building performance simulation were in the first instance dedicated to the study of uncertainties.

Uncertainty analysis is traditionally facilitated using the Monte Carlo analysis (MCA). The aim is to quantify the uncertainty of the simulation output caused by the uncertainty of the simulation input variables. Output parameters such as annual energy consumption for heating and cooling as well as corresponding peak loads are used for the result assessment. Furthermore, potential sources for the uncertainty variation of the results are discussed. The paper concludes with an indication of future work.

The paper presents results from a comparative study using four tools IESVE v5.5, VA114, HAMbase and LEA prerelease v0.9.1. The tools can be categorized in detailed design analysis (DDA) and conceptual design analysis (CDA) tools. CDA compared to DDA tools abstract the representation of the building and operation to most crucial parameter. IESVE v5.5, VA114, HAMbase represent DDA tools, whilst LEA represents a CDA tool.

The case study chosen is the BESTEST case 600. The input samples used were exactly the same for three tools, IES VE, VA114 and HAMbase.

The simulation output, annual energy consumption for heating and cooling as well as peak loads were used to compare the tool performance.

## METHODOLOGY

The BESTEST case 600 is used to study uncertainties. Uncertainties have been assigned to 48 input parameters describing the physical properties of the case and its operation. The input parameters used are exactly the same for three tools, IESVE, VA114 and HAMbase. Due to the higher modeling abstraction level of LEA, a number of parameters had to be excluded and others aggregated resulting in sample matrix containing only 26 out of 48 parameters for the UA analysis. For each tool a prototype was developed integrating the individual BPS tool with the statistical pre- and post processor, Simlab 2.2.

The model parameters are normally distributed using a fixed standard deviation of 5% for all variables. A standard deviation of 5% does not represent a realistic parameter uncertainty but defines a common base for the tool performance comparison. The input parameters are summarized in table 1. For each input parameter 200 samples were generated by latin hypercube sampling. The prototypes were deployed to generate simulation input files from the sample matrix and run the simulations.

*Table 1, Input parameter*

| VARIABLE | VARIED ON… |
|---|---|
| Specific heat capacity<br>Conductivity | every layer<br>every layer |
| Density<br>Thickness | every layer<br>every layer |
| Inside solar absorptivity<br>Outside solar absorptivity | every surface<br>every surface |
| Inside emissivity<br>Outside emissivity | every surface<br>every surface |
| Internal heat gains | zone |
| Infiltration rate | zone |

**Bestest**

The Bestest is a structured approach to evaluate the performance of building performance simulation tools. The evaluation is performed by comparing results of the tested tool relative to results by reference tools. The procedure requires simulating a number of predefined and hierarchal ordered cases. Firstly, a set of qualification cases have to be modeled and simulated. If the tool passes all qualification cases the tool is considered to perform Bestest compliant. In case of compliance failure the procedure suggests considering diagnostic cases to isolate its cause. Diagnostic cases are directly associated with the qualification cases (Judkoff and Neymark 1995). The first qualification case, case 600 (see figure 1) was used for the performance comparison.

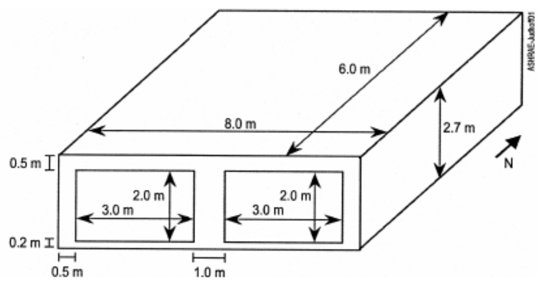


*Figure1. Bestest Case 600 - Geometry*

## TOOLS

**LEA**

LEA prerelease v0.9.1 (for beta testing) was specifically developed for Dutch professionals to predict instantaneous peak loads and annual energy demands, already, during the early design stages. Because it is meant to support early phase design, LEA reduces the representation of a building and its operation to the most crucial input variables. As an example, the building is modeled as one thermal zone and walls are defined by thermal resistances only. The current prerelease works without user interface, using XML input and output file.

**IES <VE>**

IESVE is a detailed integrated BPS tool addressing professionals worldwide. Its modular structure integrates features to predict building energy use and peak loads. The modules cover capabilities as lighting simulation, shadow cast, value engineering, life cycle costing, evacuation, component sizing and environmental CFD. The program is suited for the detailed design evaluation of buildings and systems, and provides an environment that enables the user to address a multitude of performance indicators i.e. energy use, thermal comfort and daylight availability. The output is visualized using a graphical interface suited for the data representation and interpretation.

**VA114**

VA114 is a detailed integrated BPS tools for Dutch professionals. It is an industry- strength and extensively used tool in the Netherlands. The tool is dedicated to the analysis of building energy use and thermal comfort. Furthermore it represents one tool among other in a toolbox, called Uniform environment. The toolbox includes tools for sizing building services components and systems, calculating heat gains and losses as well as assessing cold bridging. The results are stored and saved in text files. A separate tool, Uitvoerviz, is dedicated to the graphical presentation results.

**HAMbase**

HAMBASE (Heat Air and Moisture Building and Systems model) is a simulation model for heat and vapor flows in a building. With the model the indoor temperature, the indoor air humidity and energy use for heating and cooling of a multi-zone building can be simulated A first version of this model (ELAN) was published in 1987 (de Wit et al. 1987). Ever since, the model is continuously improved and expanded, i.e. integrating a model for predicting the indoor air humidity. (van Schijndel and de Wit 1999, de Wit 2006, ). The models are available under public domain licensing from the HAMLab website.

## RESULTS

The results are presented in the following figures and tables. The tables 1 to 4 show the maximum and minimum values alongside the standard deviation and mean value for 200 simulations. Values identified with “Case 600” indicate the result of the original Bestest case 600 without variation.

Figures 2 to 5 show the above values graphically for each tool individually.

The upper and lower BESTEST performance limits are visualized with dashed lines. They are used as an aide to assess the tool specific performance.

### Annual heating demand

Figure 2 show that LEA does not meet the Bestest criteria for the annual heating demand. The value lays well below the lower limit. The three remaining tools comply well with the Bestest limits.

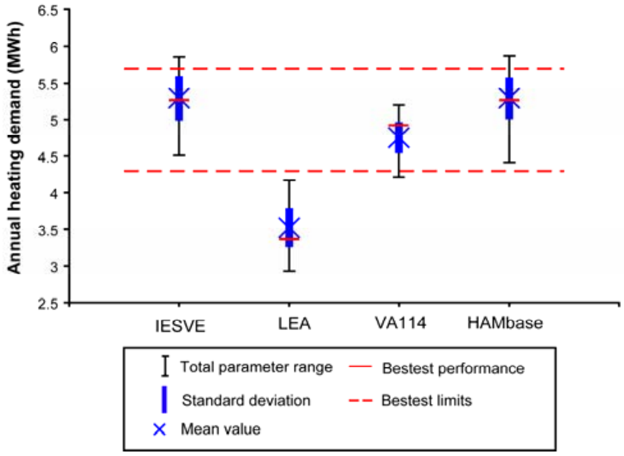


*Figure2, Tool performance comparison - Annual heating demand [MWh]*

Table 1 indicates the largest absolute range for HAMbase with 1.45MWh. The smallest range can be noticed for VA114 with 0.8MWh. The biggest uncertainty, using the standard deviation as uncertainty indicator, is caused by IES. The smallest uncertainty is calculated by VA114.

*Table 1, Annual heating*

| Annual heating [ MWh ] | | | | |
|---|---|---|---|---|
| | **IES** | **LEA** | **VA114** | **HamB.** |
| **Max.** | 5.85 | 4.17 | 5.19 | 5.87 |
| **Min.** | 4.51 | 2.93 | 4.21 | 4.41 |
| **Mean.** | 5.29 | 3.52 | 4.74 | 5.29 |
| **Stdev.** | 0.2508 | 0.2199 | 0.1612 | 0.2324 |
| **Case 600** | 5.259 | 3.36071 | 4.912 | 5.259 |

### Annual cooling demand

Figure 3 shows all four tools meet the Bestest criteria for annual cooling demand. However, it can be noticed that apart from VA114 the tools minimum values undershot the minimum performance limit.

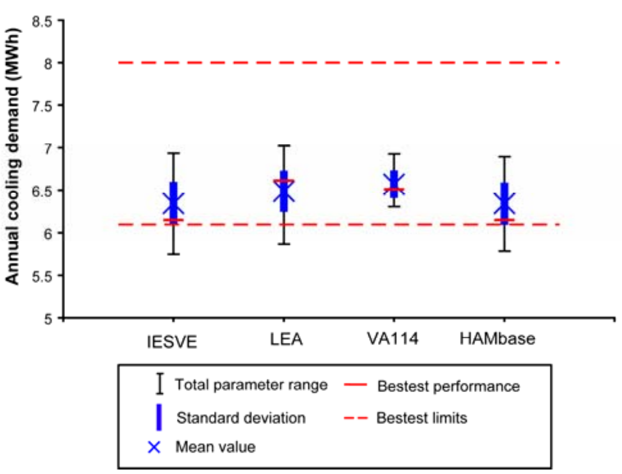


*Figure3, Tool performance comparison - Annual cooling demand [MWh]*

Table 2 indicates the largest absolute range for IES with 1.19MWh. The smallest range can be noticed for VA114 with 0.62MWh. The biggest uncertainty is caused by IES. The smallest uncertainty is calculated by VA114.

*Table 2, Annual cooling*

| Annual cooling [ MWh ] | | | | |
|---|---|---|---|---|
| | **IES** | **LEA** | **VA114** | **HamB.** |
| **Max.** | 6.94 | 7.02 | 6.93 | 6.89 |
| **Min.** | 5.74 | 5.87 | 6.29 | 5.78 |
| **Mean.** | 6.34 | 6.49 | 6.55 | 6.34 |
| **Stdev.** | 0.2105 | 0.1965 | 0.1131 | 0.2039 |
| **Case 600** | 6.1457 | 6.61031 | 6.509 | 6.1457 |

### Peak heating demand

Figure 4 shows all four tools meet the Bestest criteria for the peak heating load. It can be noticed that LEA's absolute maximum exceeds the upper Bestest performance limit.

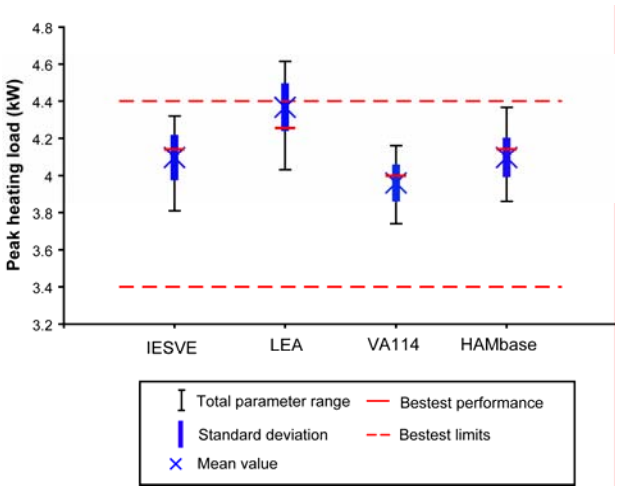


*Figure4, Peak heating load [kW]*

Table 3 indicates the largest absolute range for LEA with 0.56kW. The smallest range can be noticed for VA114 with 0.42kW. The biggest uncertainty is caused by LEA. The smallest uncertainty is calculated by VA114.

*Table 3, Peak heating*

| Peak heating [ kW ] | | | | |
|---|---|---|---|---|
| | IES | LEA | VA114 | HamB. |
| **Max.** | 4.32 | 4.62 | 4.16 | 4.37 |
| **Min.** | 3.81 | 4.03 | 3.74 | 3.86 |
| **Mean.** | 4.09 | 4.37 | 3.95 | 4.10 |
| **Stdev.** | 0.1009 | 0.1074 | 0.0788 | 0.0851 |
| **Case 600** | 6.3 | 6.75 | 6.29 | 6.3 |

### Peak cooling demand

Figure 5 shows that all four tools meet the Bestest criteria for the peak cooling load. It can be noticed that LEA's absolute maximum exceeds the upper Bestest performance limit.

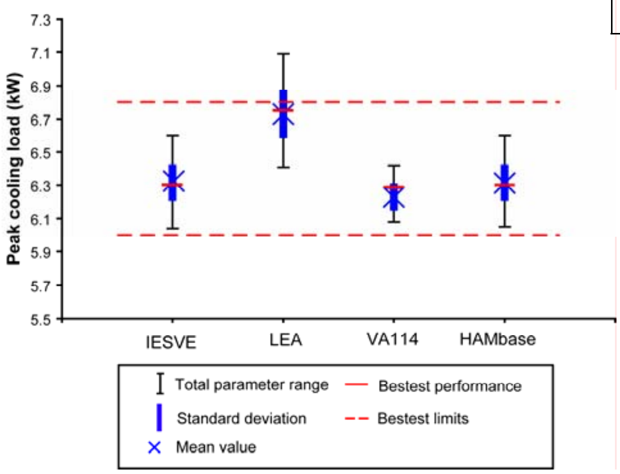


*Figure5, Peak cooling [kW]*

Table 4 indicates the largest absolute range for LEA with 0.68kW. The smallest range can be noticed for VA114 with 0.34kW. The biggest uncertainty is caused by LEA. The smallest uncertainty is calculated by VA114.

*Table 4, Peak cooling*

| Peak cooling [ kW ] | | | | |
|---|---|---|---|---|
| | IES | LEA | VA114 | HamB. |
| **Max.** | 6.6 | 7.09 | 6.42 | 6.6 |
| **Min.** | 6.04 | 6.41 | 6.08 | 6.05 |
| **Mean.** | 6.31 | 6.73 | 6.22 | 6.31 |
| **Stdev.** | 0.0879 | 0.1214 | 0.0607 | 0.0874 |
| **Case 600** | 6.3 | 6.75 | 6.29 | 6.3 |

## DISCUSSION

### Tool ranking

A rank analysis did show that the tools rank based on absolute value range and uncertainties are the same for the peak loads.

The smallest variation is shown by VA114 followed by HAMbase. The third place is taken by IES with LEA showing the biggest variations.

However no correlation of such kind can be noticed for the annual energy demand. However VA114 also shows the smallest variations for the annual loads in both cases.

### Range of uncertainties

The percentage different between the tools specific uncertainties are indicated in table 5.

*Table 5, Uncertainties,*
*Percentage difference across tools.*

| | Annual cooling | Annual heating | Peak heating | Peak cooling. |
|---|---|---|---|---|
| **Difference** | 45% | 10% | 27% | 50% |

Table 5 indicates that the peak and annual cooling energy is indicated with significantly larger differences across the tools than the peak and annual heating energy.

## CONCLUSION

A comparative study, addressing prediction uncertainties, for four tools IESVE v5.5, VA114, HAMbase and LEA prerelease v0.9.1 was conducted. Whilst LEA represents a conceptual design analysis tool, limited in its detail representing the model parametrically, the other three tools a detailed design analysis tools. It was found that the percentage difference of the predicted uncertainties is significantly higher for the peak and annual cooling demand than for the peak and annual heating demand.

Whilst IESVE shows the biggest uncertainties for the annual energy demand, LEA shows biggest uncertainties considering the peak loads.

VA114 indicated the smallest uncertainties across annual demands and peak loads.

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**Tools**

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## *Appendix A*

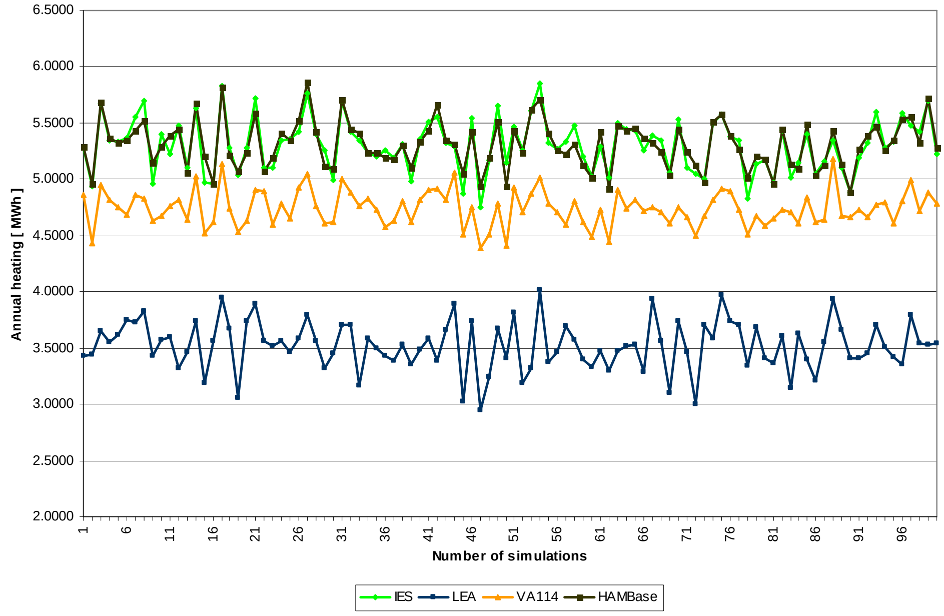


*Figure A1*
*Annual heating [MWh]*

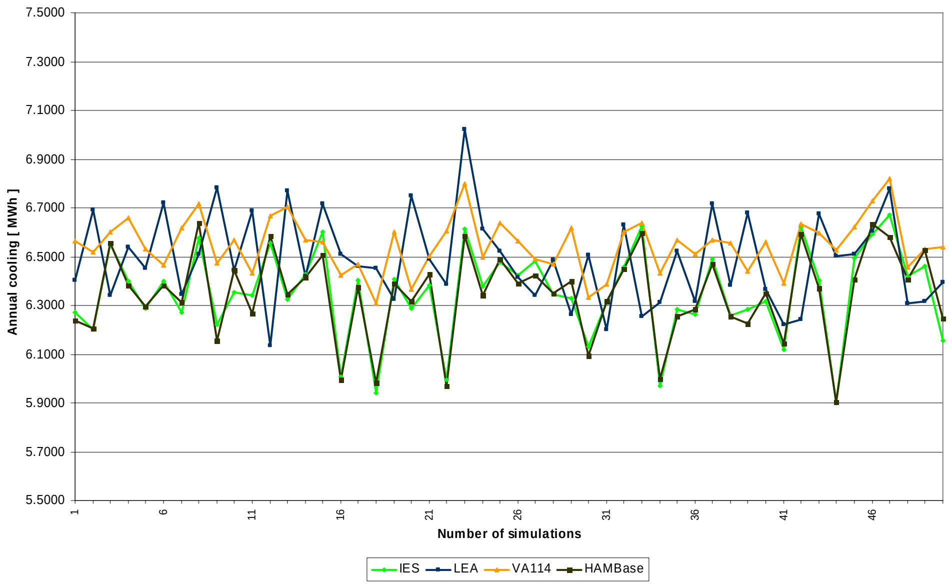


*Figure A2*
*Annual cooling [MWh]*