MSc SBDE Title Page

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Table of Contents

Introduction

Portfolio consists of three tasks done one after another with methodology, results and discussion written for each task. In the end of the project task 1 was reiterated due too human error.

The aim of the first task was to create two simple building models: base case 600 and free-floating case 600FF in two building simulation tools: EnergyPlus v8.9 and DesignBuilder v6.1. Comparison of the four models and their six outputs with each other and Building Energy Simulation Test (BESTEST) methodology results in order to demonstrate the ability of modelling and interpreting the inputs and outputs of both simulation tools.

In second task model from task one was used to create uncertainty and sensitivity analysis with the help of parametric tool to assess the impact of input parameters on the outputs. Finding sources of uncertainties is important part of an engineer's daily task. Model limitations, assumptions, missing information and input errors make up the overall design accuracy which impacts safety factors.

In third task multi-objective optimisation algorithm NSGA2 was used and several measures were incorporated to lower energy use for heating, cooling and lighting and improve the comfort of the design for the modelled building. Knowledge gained from previous tasks was used to narrow the range of parameters and two constraints were added. NSGA2 is a multi-objective algorithm that generates offsprings using a specific type of crossover and mutation and then selects the next generation according to nondominated-sorting and crowding distance comparison. [5]

Task 2 and 3 were created with the use of the tools JEPlus+EA v2.0 and its online portal.

Task 1 - Methodology

BESTEST Comparative Test Exercise

BESTEST Methodology "specifies test procedures for evaluating the technical capabilities and ranges of applicability of computer programs that calculate the thermal performance of buildings and their HVAC systems" specified by ASHRAE standard 140. [1]

EnergyPlus is a reach-based, dynamic whole-building energy performance simulation engine with text/form-based model editing tools. DesignBuilder is a commercial building simulation software package built on top of the EnergyPlus engine.

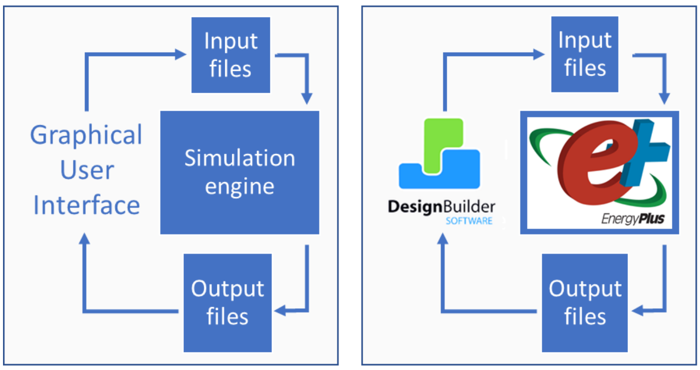


Figure 1 - Relation between DesignBuilder and EnergyPlus

All inputs in DesignBuilder go into EnergyPlus engine as the input. This means that if inputs for both tools are the same - output from these two simulation tools should be the same.

Simulation model is saved as .idf file which contains classes, objects and fields and is simulated with EnergyPlus weather data file (EP-BESTEST.epw provided with the brief). EnergyPlus runs single simulation and if successful gives many result files, but we will be mainly concerned about simulation output file (.eso).

Two separate models were created in both environments for two cases: 600 and 600FF. Case 600FF: simple box building with a single zone and south-facing windows, lightweight structure, fixed internal gain, free-floating temperature, i.e. no heat or cooling; Case 600: same building as Case 600FF, but including heating and cooling.

As a modelling starting point DesignBuilder was used to create case 600 model (DB600) as a simpler and more user-friendly tool. Graphical user interface is very well structured and easy to use.

Most of the inputs were taken from brief appendix 4 [6] which are ASHRAE standard 140 inputs in a good packed form. However, some additional assumptions and information were needed and later cross referenced with the original document [1]. To limit possibility of a human error simple window method was used. In brief table 11 floor construction layer lacked two material properties for insulation: density ρ and heat capacity Cp.

Case 600 is lightweight model and insulation is a lightweight material and any difference in these properties values should not have a significant impact on the output. Entered values for insulation layer (crossed) later changed for lightweight EPS values from DesignBuilder.

~~ρ = 0,01 kg/m3, Cp = 100 J/kgK~~ ρ = 10 kg/m3, Cp = 1400 J/kgK

According to EnergyPlus tests page 15 [2] ground reflectance was set to 0,2 [-].

Same base case model was created in EnergyPlus (EP600) and results were compared with DesignBuilder.

Comparative debugging – EP and DB

Results were different between DB and EP that said assumptions had to be checked if they are the same. IDF file was exported from the DesignBuilder to compare models. This iterative debugging process had to be done multiple times due to many differences or mistakes.

- **Frame and dividers** were modeled in DB as a default by they weren't modeled in EnergyPlus. That had to be removed from the DesignBuilder model as it is not should not be modelled in BESTEST case 600.
- **Mechanical Ventilation** was modelled in DB. Ventilation of 0,5 ach was specified in A4.4.1 case table in the brief. In total there was 1,0 ach (0,5 from ventilation and 0,5 from infiltration. Mechanical Ventilation was removed from DB and only infiltration was left in both models.
- **Location (altitude, latitude, longitude)** were different because they must be set inside .epw file and not in the EP object.
- **Internal gains 200W** were typed in the template with power input type but then transferred to the activity tab to power density type. This resulted in internal gains being 0W. DesignBuilder - Model options – gains data – equipment gain units were changed to absolute zone power and again 200W were entered.
- **Geometry Template - Area and Volume** were different in both tools, this impacts infiltration calculation as this is based on air changed per volume. Geometry template was changed in DesignBuilder to ASHRAE 90.1 template which means that volume is calculated by outer

surfaces. Same does EnergyPlus with auto calculate and this is methodology from ASHRAE standard 90.1

- **Thermal and Solar absorptance** in DesignBuilder for timber flooring layer wasn't the same. Value reentered in DB.

After all assumptions were checked and outputs were same, free-floating models were created and results exported. In total four model were created and six data frames were exported to .csv files.

DesignBuilder		EnergyPlus	
Case 600	Case 600FF	Case 600	Case 600FF
1.Annual heating and cooling load [kWh] 2.Hourly heating and cooling load [W]	3.Hourly internal zone air dry-bulb temperature [˚C]	4.Annual heating and cooling load [kWh] 5.Hourly heating and cooling load [W]	6.Hourly internal zone air dry-bulb temperature [˚C]

Figure 2 - Outputs for BESTEST comparative test exercise

Task 1 – Results and Discussion

To view 3D model from EnergyPlus .dxf was opened in Rhino 6. DesignBuilder has built-in viewer.

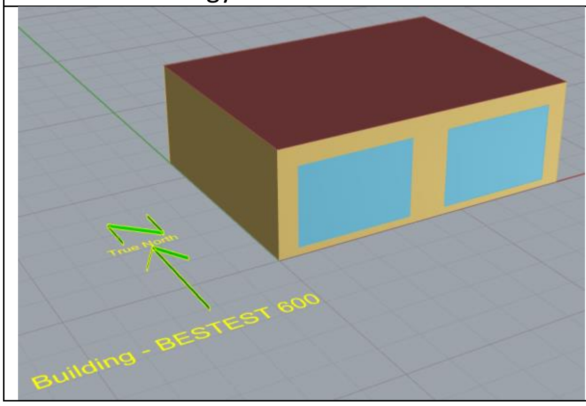
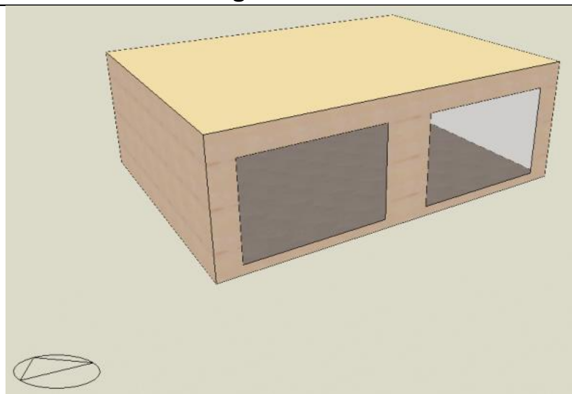
EnergyPlus v8.9 + Rhino 6	DesignBuilder v6.1
	

Figure 3 - Two 3D views of modelled geometries in both tools.

Results from EnergyPlus were in saved to .eso file. To view them "DesignBuilder Results Viewer" software was used. DesignBuilder has results viewer with built in preconfigured data display with many outputs on a single screen. However .eso files were usually opening faster in external viewer.

Comparative debugging – EP and DB

During modelling two uncertainties were discovered: insulation material properties (density and heat capacity) and geometry template.

Insulation material values were not given in the brief nor additional documents. Author chose to assume them as the typical lightweight EPS from DesignBuilder. However, by an error density was smaller by 1000 times and heat capacity around 14 times from typical lightweight EPS, that made floor layer even more lightweight. This error was spotted in the end of the project. Four models in task 1 were simulated again with new insulation material. Previous conclusion that insulation thermal mass does not have significant impact should be revised in the uncertainty analysis in task 2. In the end both tools give similar results with only 1kWh difference for heating and cooling annual loads.

Comparative evaluation – EP, DB and BESTEST

Results from exported .csv files were compared with values from and IES Testing Report [3].

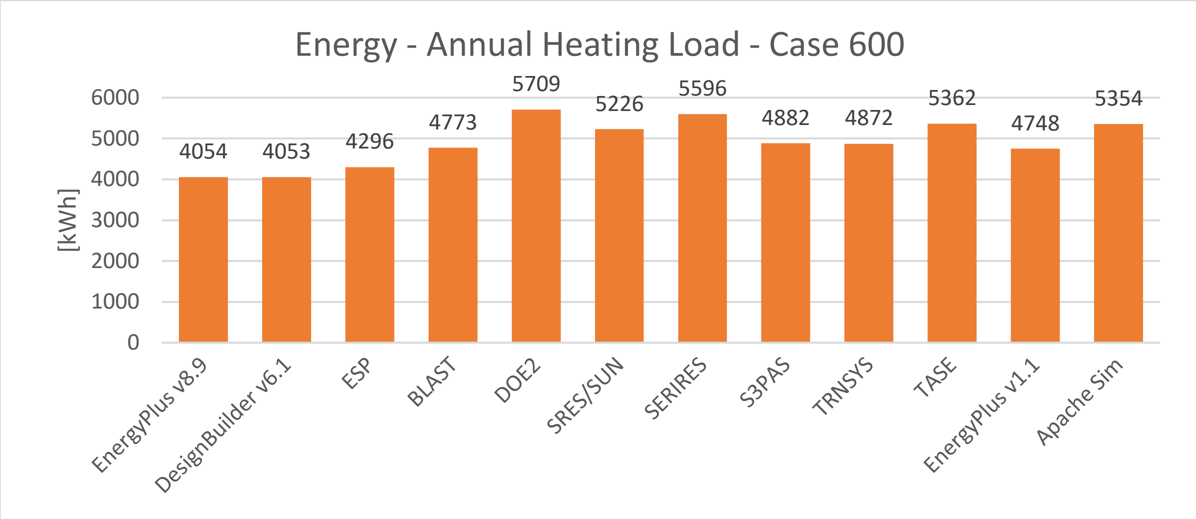


Figure 4 - Energy - Annual Heating Load - Case 600

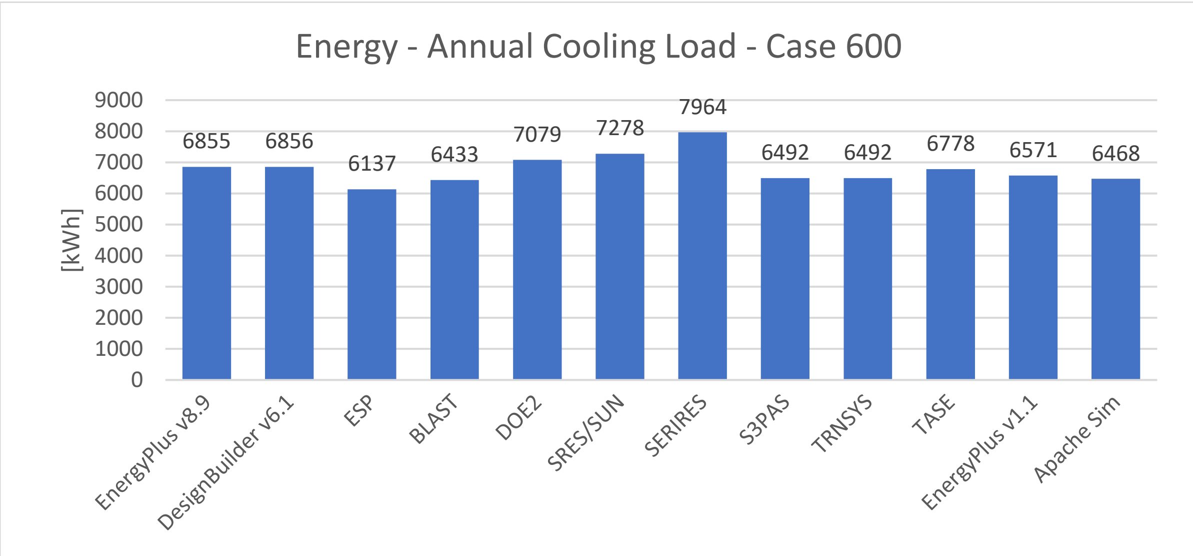


Figure 5 - Energy - Annual Cooling Load - Case 600

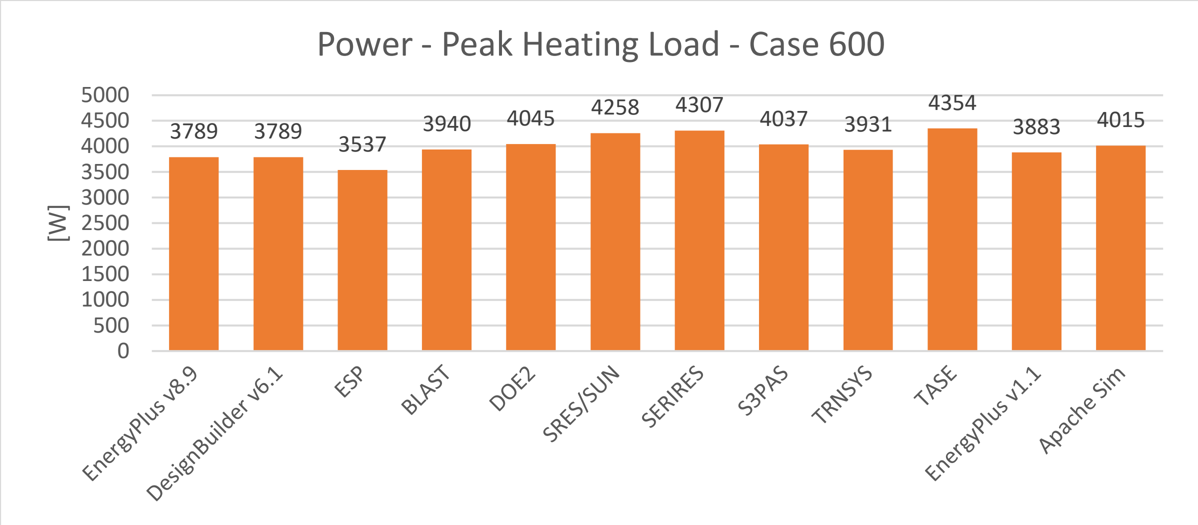


Figure 6 - Power - Peak Heating Load - Case 600

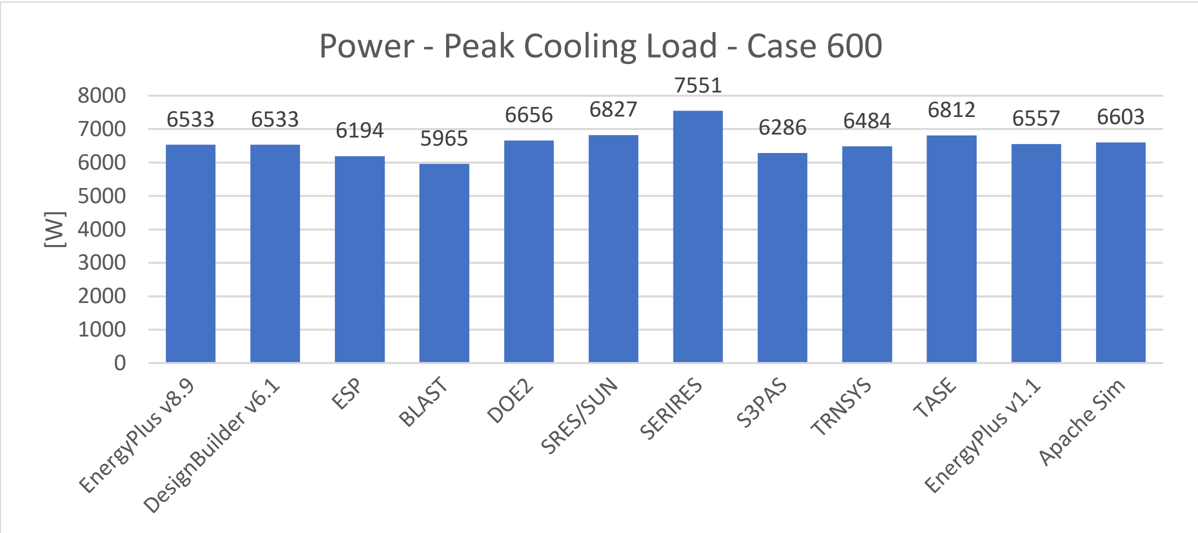


Figure 7 - Power - Peak Cooling Load - Case 600

	Annual Heating Load [kWh]	Anuual Cooling Load [kWh]	Peak Heating Load [W]	Peak Cooling Load [W]
EnergyPlus v8.9	4054	6855	3789	6533
DesignBuilder v6.1	4053	6856	3789	6533
BESTEST Average	5082	6769	4031	6594
BESTEST Min	4296	6137	3537	5965
BESTEST Max	5709	7964	4354	7551
Difference [%]	-20,2%	1,3%	-6,0%	-0,9%
within range	FALSE	TRUE	TRUE	TRUE

Table 1 - Comparative evaluation of EP, DB to BESTEST

EnergyPlus is out of the BESTEST range the results are not validated. Additionally, there is big difference in annual heating load between EnergyPlus versions: v1.1 – 4748 and v8.9 – 4054 [kWh]. This might mean that the uncertain inputs are far off from the BESTEST inputs or other assumptions are not correct. Zone temperatures in case 600FF are not far from the competition.

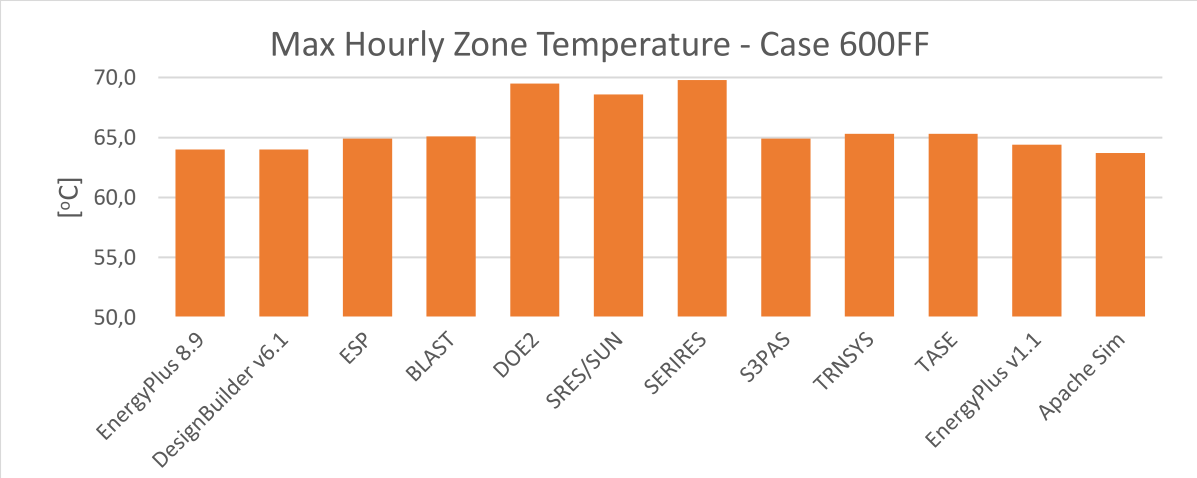


Figure 8 - Max Hourly Zone Temperature - Case 600FF

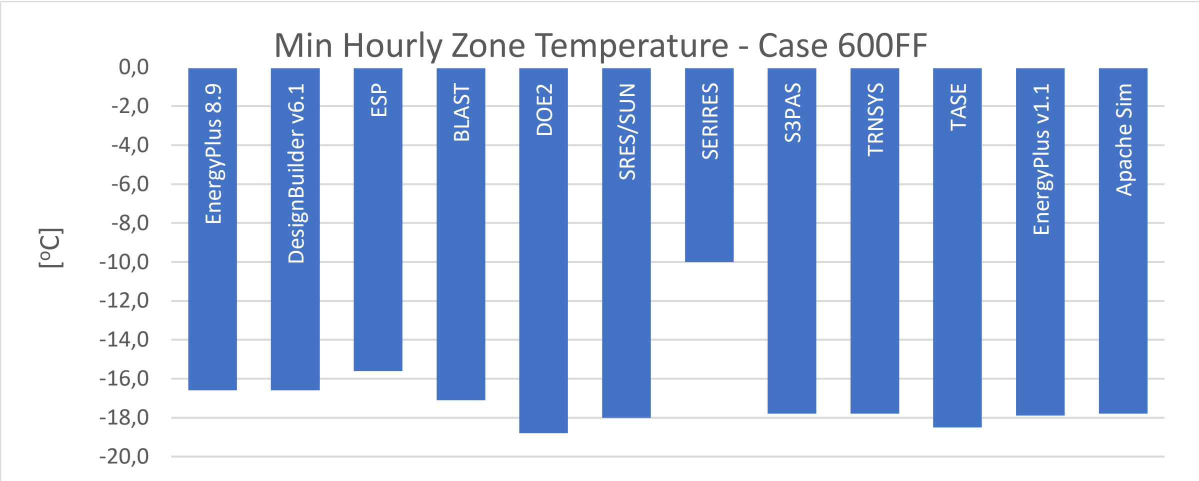


Figure 9 - Min Hourly Zone Temperature - Case 600FF

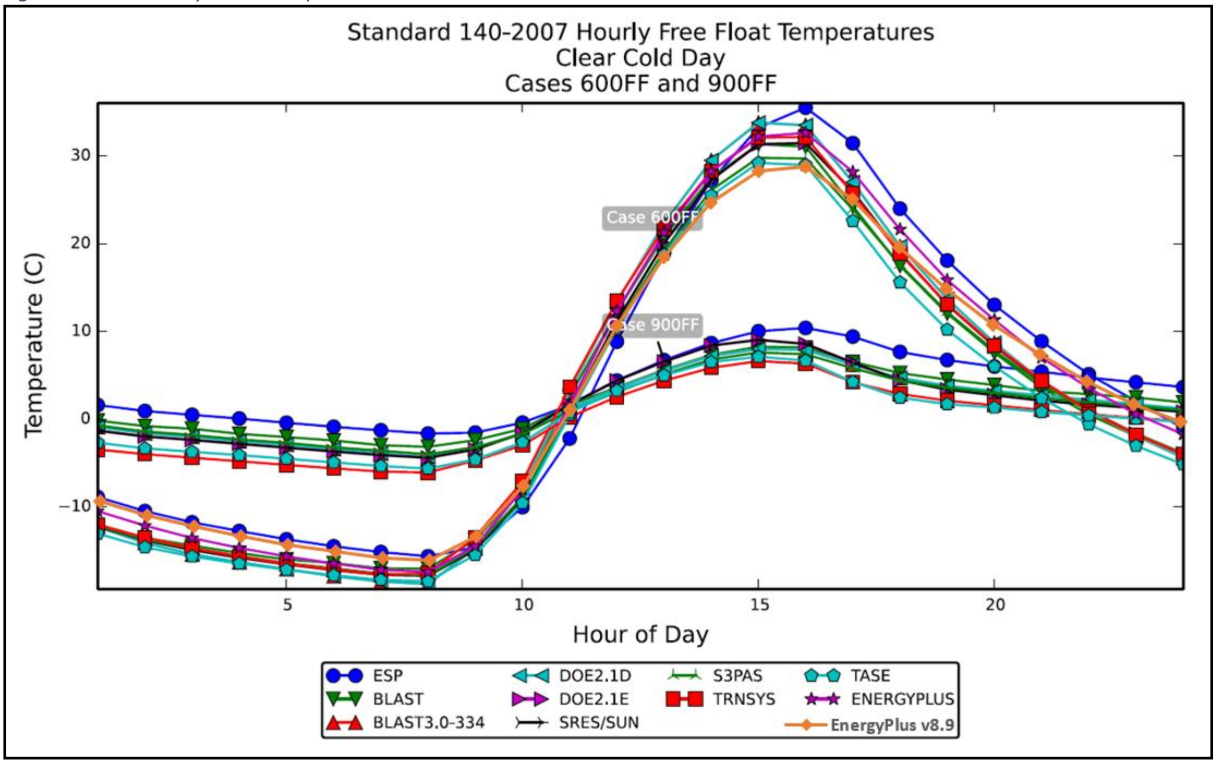


Figure 10 - Standard 140-2007 Hourly Free Float Temperatures for 4th of January - Cases 600FF and 900FF

Task 2 – Methodology

Note: bold text is the fields value in base case.

2A Parametric Analysis

Basis for uncertainty and sensitivity analysis is parametric analysis. However, if values in fields become variable and have a range of values then that would be parametric analysis and we would run multiple simulations to get more than one output.

The JEPLUS v2.0 simulation tool gives ability to create multiple simulations and is created for the purpose of parametric analysis. In a nutshell this tool takes .json file that has various parameters with ranges and output metrics, creates the list of job, runs multiple simulations with .idf and .epw file and once all the outputs are saved it takes all the results and produces aggregated spreadsheet files.

In the beginning of second task, single base case DesignBuilder model DB600 from first task was taken for further simulations, changed were appropriate and .idf files exported. In this task three parametric runs were created each with different variable fields in a single object. All simulation jobs were separately run for each object. Reported annual metrics: c0: Heating [kWh], c1: Cooling [kWh].

Object	Field	Range	N
Shadow Calculation	Calculation Method	{TimestepFrequency, **AverageOverDaysInFrequency**}	32
	Calculation Frequency	{5,10,15,**20**,25,30,35,40}	
	Sky Diffuse Modeling Algorithm	{**SimpleSkyDiffuseModeling**, DetailedSkyDiffuseModeling}	
Zone	Zone Inside Convection Algorithm	{**TARP**, Simple, CeilingDiffuser, TrombeWall AdaptiveConvectionAlgorithm}	25
	Zone Outside Convection Algorithm	{**DOE-2**, SimpleCombined, TARP, MoWiTT, AdaptiveConvectionAlgorithm}	
Timestep	Number of Timesteps per Hour	{2, **4**, 6, 8, 10, 12, 14, 16, 18, 20}	10

Table 2 - Three JEPlus parameters tables in one table for task 2A

2B Uncertainty Analysis

At the design stage input parameters are assumed to a certain degree and may contain high-level of uncertainty. Uncertainty analysis was done with the use of JEPLUS + EA v2.0 tool to simulate base case model with certain boundary conditions for these uncertain parameters. In total 2553 near-random jobs were simulated in the single run from 27225 possible jobs with the MORRIS sampling method in JEPlus + EA v2.0 tool. Reported annual metrics: c0: Heating [kWh], c1: Cooling [kWh].

Object	Field	Range	N
Building	P1. Terrain	{**Suburbs**, Country, Ocean, City, Urban}	5
Other Equipment	P2. Design Level	{100,120,140,160,180,**200**,220,240,260,280,300}	11
	P5. Fraction Radiant	{0.4, 0.5, **0.6**, 0.7, 0.8}	5
Site: Ground Temperature	P3. Monthly Ground Temperature	{6,7,8,9,**10**,11,12,13,14}	8
Site: Ground Reflectance	P4. Monthly Ground Reflectance	{0.1, 0.12, 0.14, 0.16, 0.18, **0.20**, 0.22, 0.24, 0.26, 0.28, 0.30}	11

Table 3 - JEPlus parameter table for task 2B

2C Sensitivity Analysis

Two additional metrics (output variables) were added: v3: Unmet Hours [hrs], v4: Lighting [kWh]. Unmet Hours is time not comfortable based on simple ASHRAE 55-2004 method calculated for a year.

Internal gains: People: occupancy 1 person, met = 99 W, winter clo = 1,0, summer clo = 0,7, scheduled 100% from 8 to 17, air velocity = 0,137, Lights: power 5 W/m2 with Daylighting control in the center of zone at 0,8m above floor, illuminance setpoint = 500 lux, lighting schedule same as for the occupancy. Shading: two horizontal overhangs for both windows with small 0,1m left and right extensions.

In total 5679 jobs were simulated in the single run from 896168448 possible jobs with the Morris method and sampling exploration in JEPlus + EA v2.0 tool.

Heating and Cooling hourly values (setpoints) had 0,5˚C step as this is the small typical step for controlling inside temperature on thermostat. Wall insulation thickness starts with the baseline value and ends with very thick insulation close to the Passive House standards. P11 with values from low as PUR insulation to high as glass wool. The parameters were chosen as the most probable ones to have a big impact on the outputs – the most sensitive ones.

Reported annual metrics: v1: Heating [kWh], v2: Cooling [kWh], v3: Unmet Hours [hrs], v4: Lighting [kWh]. To run the model in JEPlus + EA objectives are needed. Four objectives were created: t1: Heating [kWh], t2: Cooling [kWh], t3: Unmet Hours [hrs], t4: Total Energy [kWh]

Object	Field	Range	N
Building	P1. North Axis	{**0**, 30, 60, 90, 120, 150, 180, 210, 240, 270, 300, 330}	12
Schedule: Constant	P2. Heating Hourly Value	{18, 18.5, 19.0, 19.5, **20.0**, 20.5, 21.0, 21.5, 22.0}	9
	P3. Cooling Hourly Value	{23, 23.5, 24.0, 24.5, 25.0, 25.5, 26.0, 26.5, **27.0**}	9
WindowMaterial: SimpleGlazingSystem	P4. Solar Heat Gain Coefficient	{0.3, 0.4, 0.5, 0.6, 0.7, 0.8}	6
	P12. U-Factor	{0.6, 1.0, 1.4, 1.8, 2.2, 2.6, **3.0**}	7
Material	P5. Wall Insulation Thickness	{0.06, 0.10, 0.14, 0.18, 0.22, 0.26, 0.30}	7
	P10. Roof Insulation Thickness	{0.025, 0.030, 0.035, 0.040}	4
	P11. Wall and Roof Insulation Conductivity	{0.025, 0.030, 0.035, **0.040**}	4
Shading: Overhang	P6. Depth	{0.5, 0.9, 1.3, 1.7}	4
Window	P7. Length	{0.5, 1.0, 1.5, 2.0, 2.5, **3.0**, 3.5}	7
	P8. Window1 Surface Name	{**Wall_S**, Wall_E}	2
	P9. Window2 Surface Name	{**Wall_S**, Wall_N}	2

Table 4 - JEPlus parameters table for task 2C

Task 2 – Results and Discussion

2A Parametric Analysis

Labeled point is the base case. Shadow calculations give similar results with different algorithms, methods and frequencies.

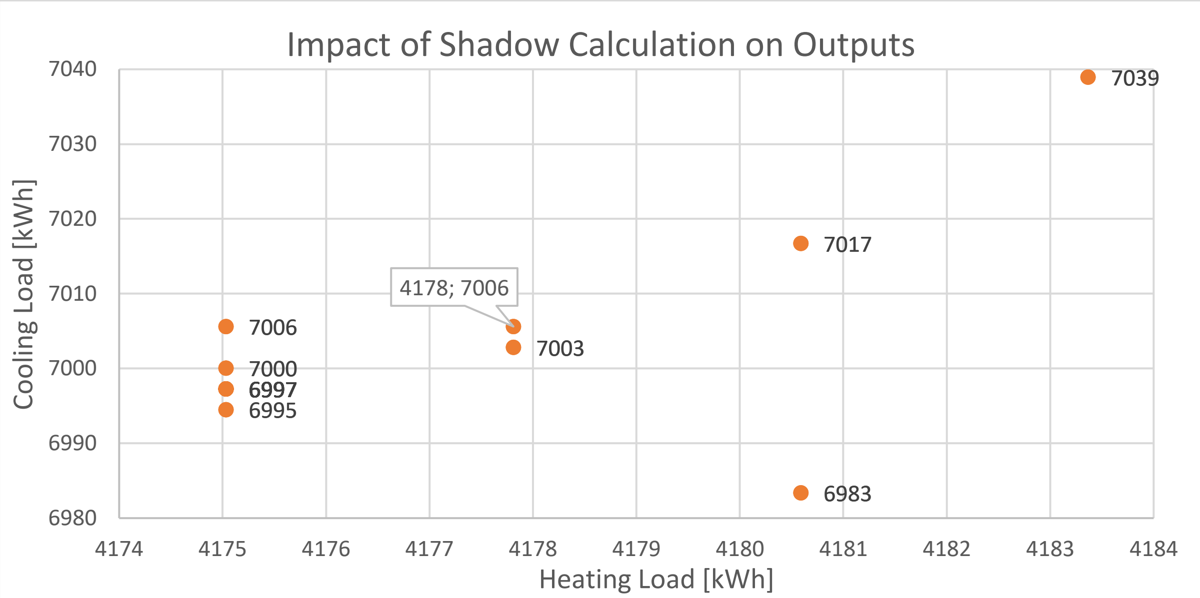


Figure 11 - Impact of Shadow Calculation on Outputs

Red points are the data points that should not be considered as the MoWiTT algorithm may not be appropriate for rough surfaces [X MoWiTT], analysed zone is not a Trombe wall nor it has ceiling diffuser. Labeled point is the base case with internal TARP and external DOE-2 algorithms. Even without red point the possible algorithms give very different results from the base case: 15,6% difference in annual heating load and 17,8% difference in annual cooling load.

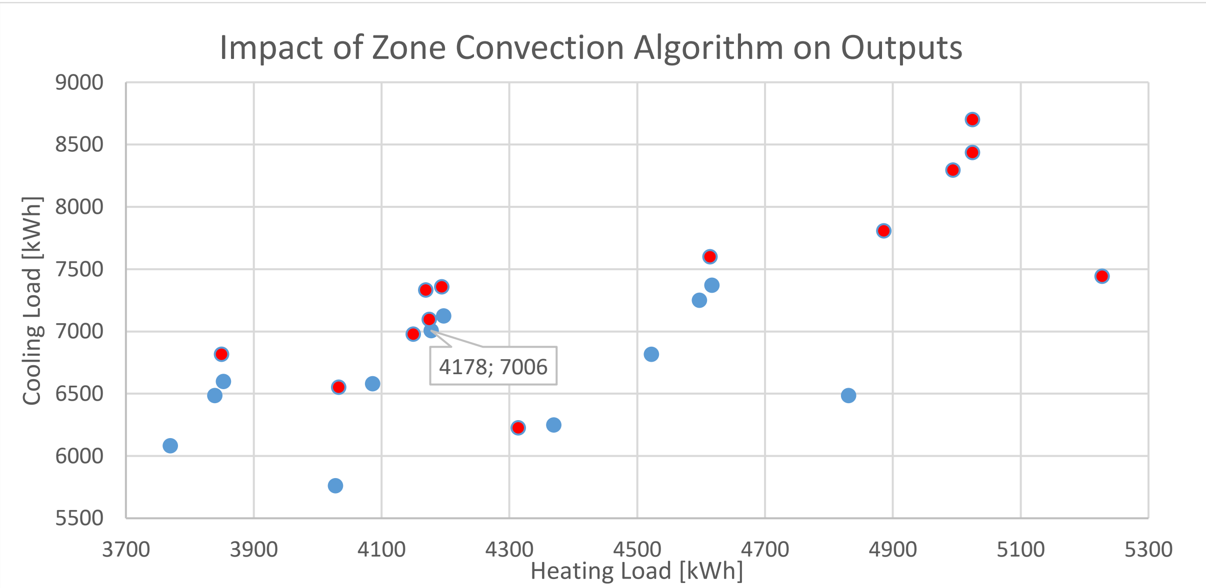


Figure 12 - Impact of Zone Convection Algorithm on Outputs

Timesteps higher than 4 give differences lower than 1,5 % in the outputs value compared to the last value with timestep = 20. It is interesting to note that with higher timesteps annual loads are also higher. Before simulating this parametric run I would assume that the results would be harmonious around the value.

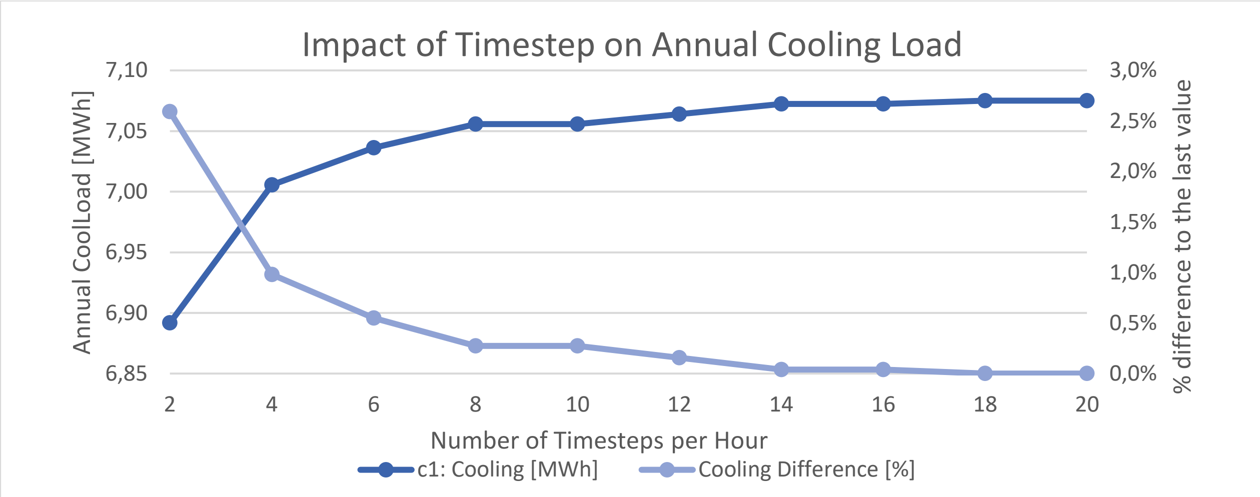


Figure 13 - Impact of Timestep on Annual Cooling Load

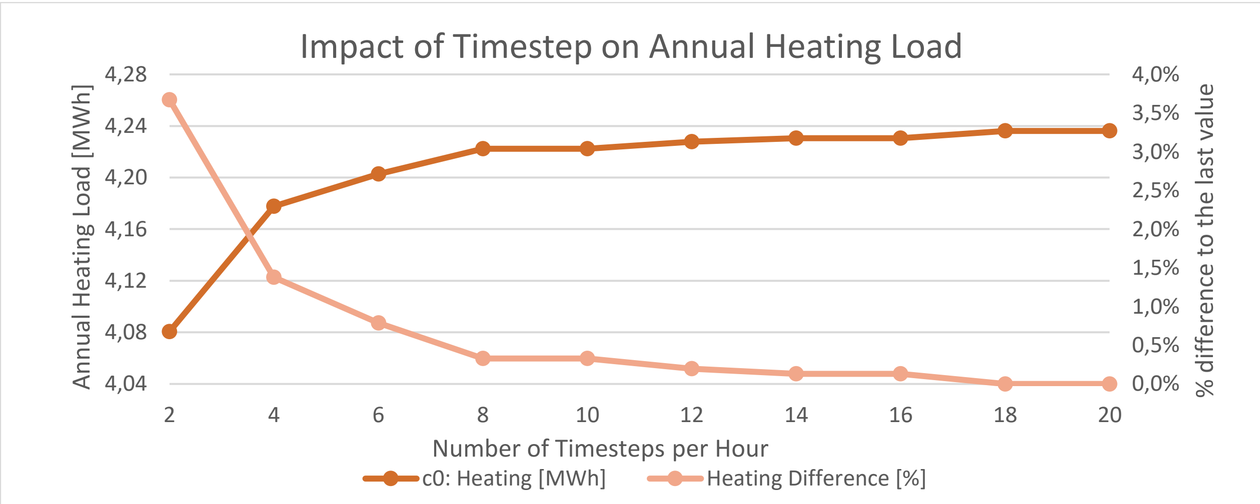


Figure 14 - Impact of Timestep on Annual Heating Load

2B Uncertainty Analysis

“Uncertainty analysis assesses the uncertainty in model outputs that derives from uncertainty in inputs.” [7] Biggest uncertainties come from P1(terrain) which affects how the wind hits the building [3] and P2(design level) of other gains that had big range of uncertainty <200;400> W. Changes of P3 (Monthly Ground Temperature) has lowest impact on outputs as the floor is very well insulated.

Parameter	Mu	Mu*	Sigma
P1	-22,85	115,2	88,11
P2	-708,2	708,2	27,02
P3	-50,16	50,16	1,721
P4	-85,09	85,09	6,994
P5	60,95	60,95	16,95

Table 5 - Contribution of the inputs on the objective t1 - Heating [kWh]

2C Sensitivity Analysis

"Sensitivity analysis assesses the contributions of the inputs to the total uncertainty in analysis outcomes." [7] JEA portal calculates three important statistical values based on the previously run simulations: Mu (mean of elementary effect), Mu* (mean of absolute elementary effect) and Sigma (standard deviation of elementary effect).

Parameter	Mu	Mu*	Sigma
P3 Cooling Setpoint	1047	1058	1009
P2 Heating Setpoint	-805	805	523
P1 Orientation	66	633	585
P7 Window width	142	445	396
P4 Window SHGC	27	406	371
P9 Window2 surface	-60	222	176
P12 Window U-value	132	170	138
P10 Roof ins. thicknesses	-160	165	163
P8 Window1 surface	-1	165	147
P5 Wall ins thickness	-130	138	127
P6 Shading depth	-73	125	165
P11 Insulation conductivity	89	91	63

Table 5 - Contribution of the inputs on the objective t3 - Unmet Hours [hrs]

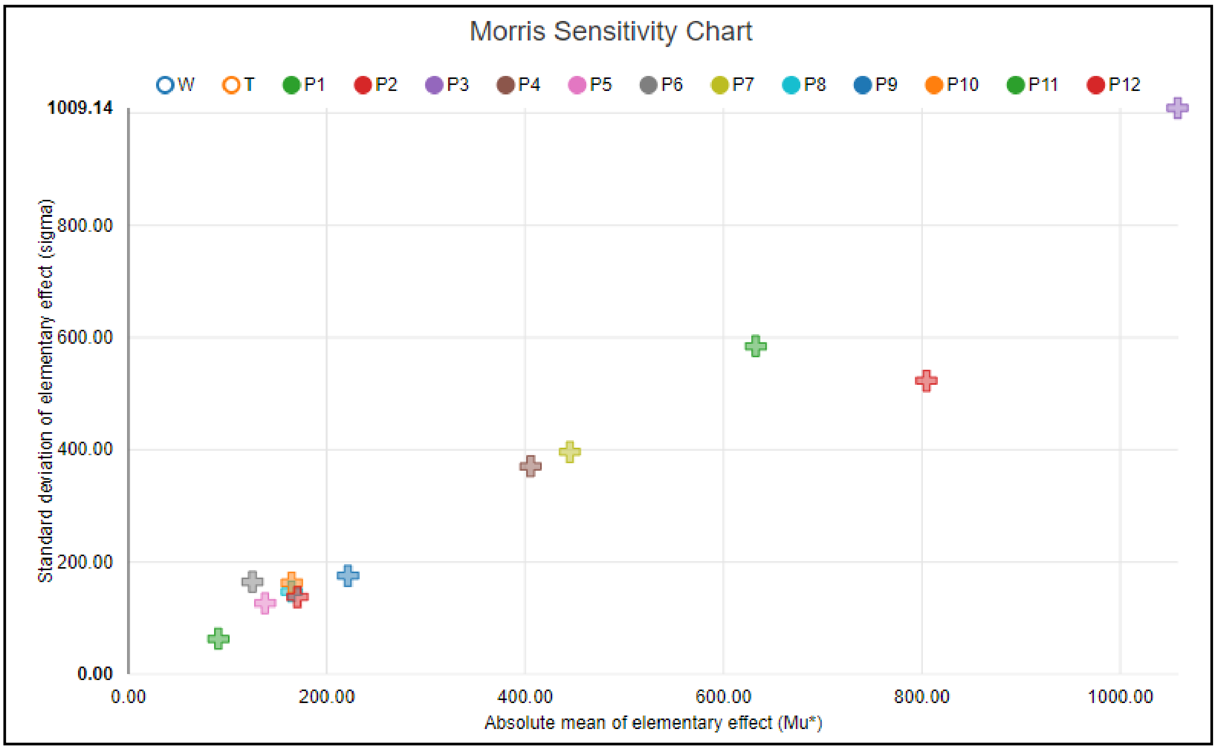


Figure 15 - Morris Sensitivity Chart for t3 - Unmet Hours [hrs]

Parameter	Mu	Mu*	Sigma
P7 Window width	2118	2127	1420
P5 Wall ins thickness	-1485	1485	1079
P2 Heating Setpoint	1374	1374	376
P10 Roof ins. thickness	-1326	1326	943
P3 Cooling Setpoint	-1176	1176	394
P4 Window SHGC	1029	1121	1414
P1 Orientation	-33	1049	1471
P11 Insulation conductivity	761	761	342
P12 Window U-value	719	719	410
P6 Shading depth	-438	481	678
P9 Window2 surface	-149	391	470
P8 Window1 surface	-44	253	317

Table 6 - Contribution of the inputs on the objective t4 - Total Energy [kWh]

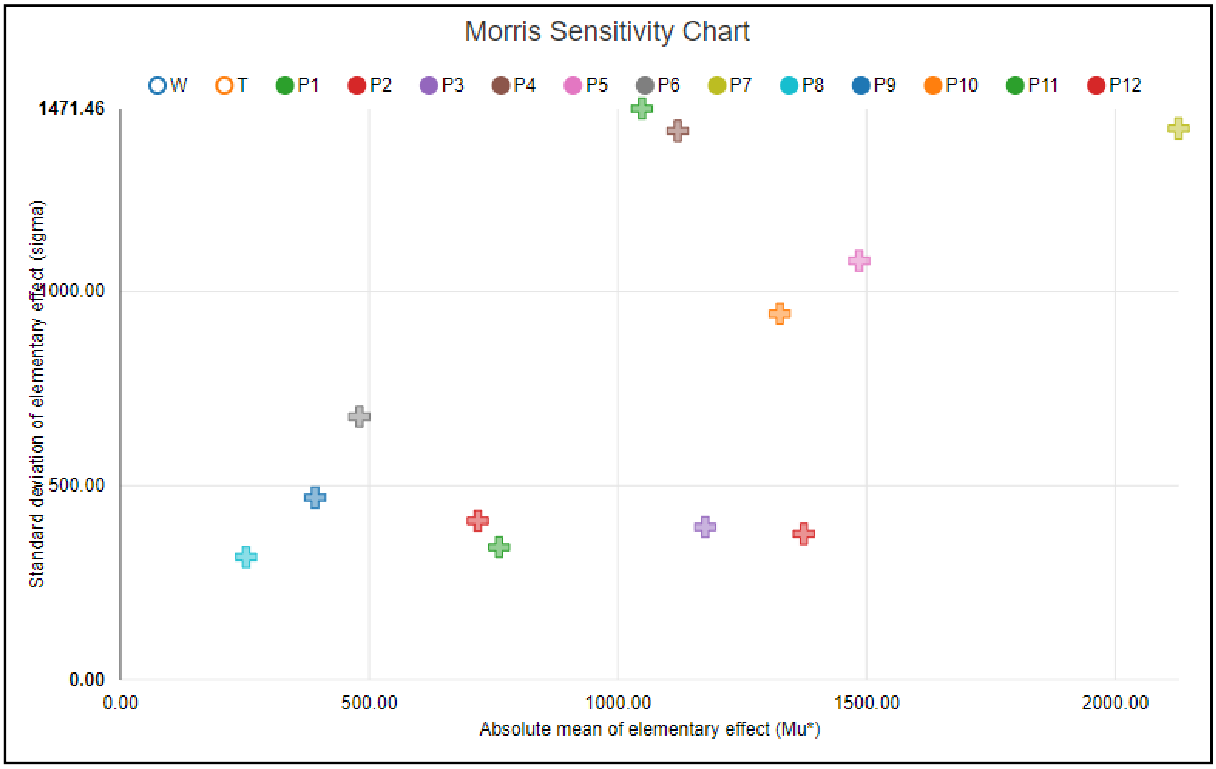


Figure 16 - Morris Sensitivity Chart for t4 - Total Energy [kWh]

Almost all parameters appeared to be very sensitive and model is impacted substantially by chosen parameters. Heating setpoint is a sensitive parameter for both objectives, bigger resolution would be beneficial for further analysis, additional chart (not presented) showed that it has local minimum in the upper range so range was moved into higher values. P7(Window width) has big impact on the total energy however high Sigma tells that the impact in not always high due to different parameters that change its impact such as P1(Orientation), P6(shading depth) or P12(Window U-value).

Task 3 – Methodology

Design Optimisation

Simple building model from task 2C was used as an input model for task 3. The design criteria include the same objectives as in task 2C. Parameter table was modified to incorporate findings from task 2C.

Inputs for design optimisation: EnergyPlus model from task 2C, 2C.json file with changes in parameter table (blue background) and additional two constraints in results collection. Upper bounds for objectives are targets for optimisation algorithm to achieve and they were set to very low values as the algorithm will try and run simulations indefinitely until it will reach these targets. Maximum values were set to high as I didn't want the algorithm to stay in local minimum.

Constraint	Upper bound	Maximum value
Total Energy [kWh]	1000	5000
Unmet Hours [hrs]	200	5000

Figure 17 - Constraints in design optimisation

Optimisation algorithm settings: exploration strategy NSGA2, sampling method random, 50 solutions per generation, feasibility relaxation 0, crossover rate 100%, mutation rate 20%, tournament size 2, feasibility first 0 and termination criteria set to 100 generations.

Object	Field	Range	N
Building	P1. North Axis	{0, 30, 60, 90, 120, 150, 180, 210, 240, 270, 300, 330}	12
Schedule: Constant	P2. Heating Hourly Value	{18, 18.5, 19.0, 19.5, 20.0, 20.5, 21.0, 21.5, 22.0, 22.5, 23.0, 23.5, 24.0}	13
	P3. Cooling Hourly Value	{25, 25.5, 26.0, 26.5, 27.0}	5
WindowMaterial: SimpleGlazingSystem	P4. Solar Heat Gain Coefficient	{0.5, 0.55, 0.60, 0.65, 0.70, 0.75, 0.80}	6
	P12. U-Factor	{0.6, 1.0, 1.4, 1.8, 2.2, 2.6, 3.0}	7
Material	P5. Wall Insulation Thickness	{0.06, 0.10, 0.14, 0.18, 0.22, 0.26, 0.30}	7
	P10. Roof Insulation Thickness	{0.16, 0.18, 0.20, 0.22, 0.24, 0.26, 0.28, 0.30}	4
	P11. Wall and Roof Insulation Conductivity	{0.024, 0.026, 0.028, 0.030}	4
Shading: Overhang	P6. Depth	{1.6, 1.8, 2.0, 2.2, 2.4, 2.6, 2.8, 3.0}	4
Window	P7. Length	{0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5}	7
	P8. Window1 Surface Name	{Wall_S, Wall_E, Wall_W, Wall_N}	2
	P9. Window2 Surface Name	{Wall_S, Wall_N}	2

Table 7 - JEPlus parameters table for task 3

Task 3 – Results and Discussion

Design Optimisation

Process was set to be terminated at 100 generations. All generations did run and 3861 cases were simulated. Convergence tab gave insight in the progress and range of results for objectives.

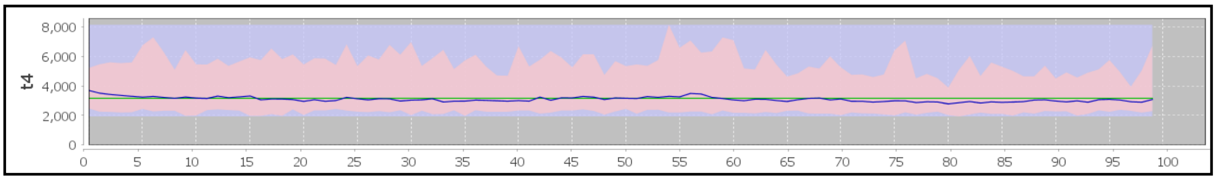


Figure 18 - Convergence lines for t4 objective

Although 100 generations might seem as too much and good solutions were already found in 10th and 15th, more generations were run to create more data points.

Figure 19 - Parameters histogram for all populations simulated in task 3

Parameter histograms for all populations show distribution of each parameter. This shows where algorithm went with its parameters to meet the objectives. Key findings from the optimisation process are the values that occurred most often.

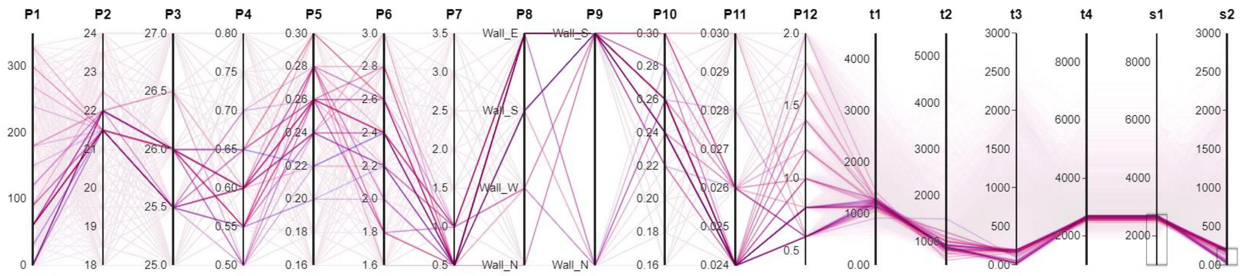


Figure 20 - Parallel Coordinates diagram with solutions that meet s1: Total Energy < 2700 kWh and s2: Unmet Hours < 200 hours constraints.

Parallel Coordinates diagram was filtered with: s1 < 2700 and s2 < 200 which shows 12 best solutions from the optimisation process. Each line is representing one case.

In the case of algorithm didn't find the solution that meets both constraints the best solution is the one that meet unmet hours constraint and has the lowest total energy use. In that case the best solution geometry, parameters and outputs from 3861 cases from design optimisation is presented below.

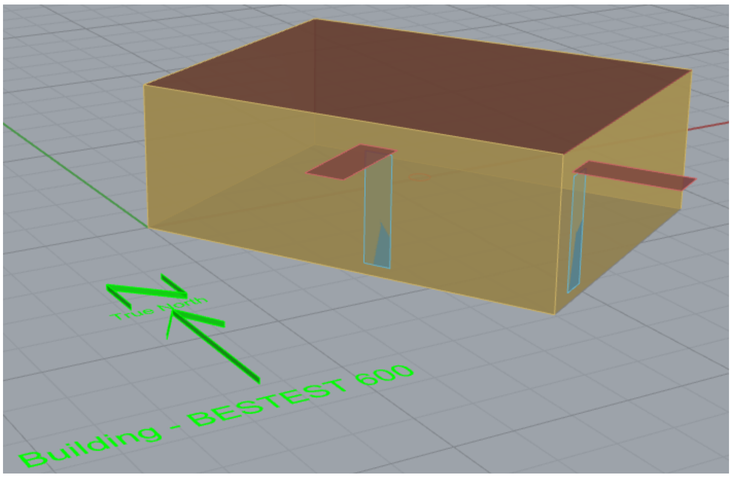


Figure 21 - Best solution geometry

Job ID:	**C-0_0_2_7_2_1_6_1_0_1_0_7_1_0**
P1:	**60**
P2:	**21.5**
P3:	**26.0**
P4:	**0.55**
P5:	**0.28**
P6:	**1.8**
P7:	**0.5**
P8:	**Wall_E**
P9:	**Wall_S**
P10:	**0.30**
P12:	**0.6**
P11:	**0.026**
T:	**JEP6002C.idf**
W:	**EP-BESTEST.epw**
t4	**2493.5**
v1	**1081.75**
v2	**839.14**
_s1	**0.373375**
v3	**174.25**
t1	**1081.75**
v4	**572.61**
s1	**2493.5**
t2	**839.14**
s2	**174.25**
_s2	**0.0**
t3	**174.25**
Is Feasible:	**false**
Is Selected:	**false**

Shading overhang is long and narrow as the extension width was contant 0,1m. Shading width or window height could have been another variable. Additional measures and new optimisation runs could yield even better solutions.

As anticipated after finished sensitivity analysis window width is lowest possible value from the range as window view is not an objective and 5 W/m2 is efficent lighting system. Algorithm went for small window size with lowers window U-value as it lowers heat losses, almost smallest SHGC which lowers heat gains and lowers radiative temperature which impact operative temperature so unmet hours stay low. That being said low window width minimizes both objectives.

Conclusions

It is possible to check every functionality of EnergyPlus. Each equation has references with how it was developed. [4] This is not always the case for other available commercial tools.

Design builder is commercial software that is very good tool for fast modelling as it has user friendly graphical user interface and it uses EnergyPlus as an engine which makes if very good simulation software both for energy analysts and researchers.

Results from both tools are not validated through BESTEST comparative evaluation as the values for Annual Heating Load were out of range. The model is imperfect and last flawed assumptions wasn't found.

JEPlus + EA tool helps explore many model variants with a simple and quick setup. Tool creates job list and runs many simulations in parallel which speeds up process immensely. JEA platform creates charts based on this data which leaves user with more time for data analysis.

Together all 3 tools are great for both practitioners and researchers.

In the end of the project insulation material properties error was reiterated in task 1 but wasn't in task 2 and 3. If spotted earlier insulation material properties and geometry templates would have been included in Task 2B.

Annual Load [kWh]	EP 600 before	EP 600 after reiteration
Cooling	7008	6855
Heating	4176	4054

Table 8 - EnergyPlus results for annual heating and cooling loads before and after error in insulation material properties

Uncertainty and sensitivity analysis play a vital role in understanding impact of each parameter on the results which translates to understanding of which parameter is important and which not as much. Knowledge gained from that exercise gives massive understanding of how the model behaves and which parameter to include to optimize the design.

Outputs with similar values formed clusters forming four groups. Group 1 had almost fixed range of setpoints with heating around 22,5 and cooling around 25,5 with narrow windows which resulted in very low unmet hours and aggregation in the bottom part of the chart. The most sensitive parameter calculated in task 2C was cooling setpoint and later heating setpoint. Most of the cases had one common denominator - heating setpoint. Most of the results in each group has heating setpoint equal to: group 1 (heating setpoint 22,5), group 2 (heating setpoint 22,0), group 3 (heating setpoint 21,5), group 4 (heating setpoint 21,0).

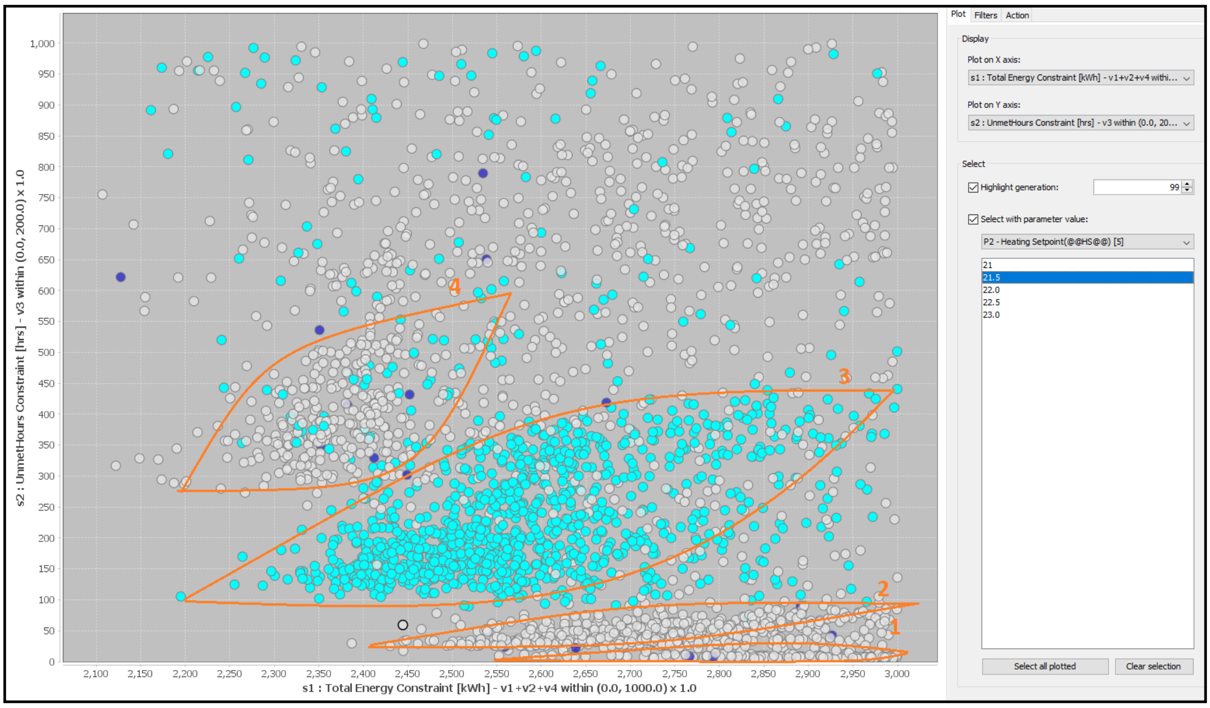


Figure 22 - Scatter plot with outputs from design optimisation, highlighted outputs have heating setpint at 21,5˚C

Most of the results in all 4 groups have cooling setpoint equal 25,5.

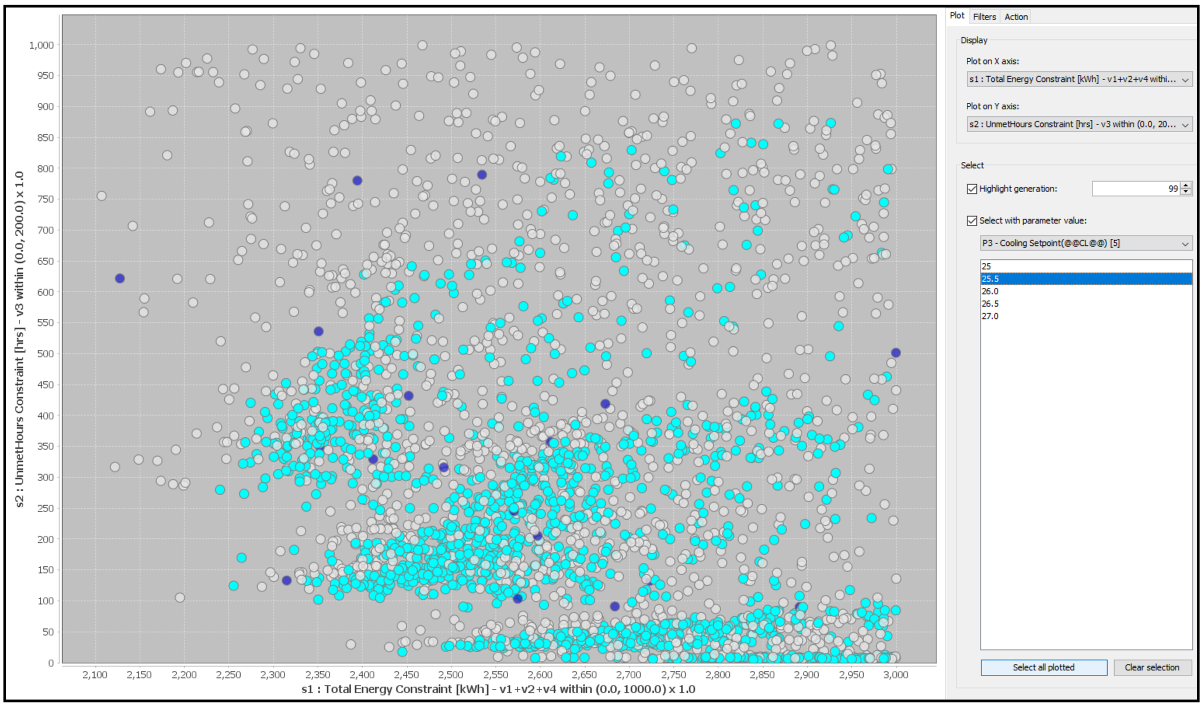


Figure 23 - Scatter plot with outputs from design optimisation, highlighted outputs have cooling setpoint at 25,5˚C

It would be interesting to have the ability to select area with a marker and then have parameter histograms for selected cases. Optimisation helped find best solutions faster than with just parametric design. NSGA2 algorithm helps to find optimal solutions for many objectives within constraint limits and set upper bounds. It might be interesting to see with which type of algorithm settings best solutions are discovered faster - statistically speaking.

References

1. ANSI/ASHRAE Standard 140-2007, Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs

2. Robert H. Henninger and Michael J. Witte GARD Analytics, Inc., EnergyPlus 8.4.0-832e4bb9cb Testing with Building Thermal Envelope and Fabric Load Tests from ANSI/ASHRAE Standard 140-2011, September 2015

3. Integrated Environmental Solutions, Building Envelope and Fabric Load Tests performed on ApacheSim in accordance with ANSI/ASHRAE Standard 140-2007, June 2015

4. https://bigladdersoftware.com/epx/docs/8-9/

5. Deb, K., Pratap, A., Agarwal, S., & Meyarivan, T. A. M. T. (2002). A fast and elitist multi-objective genetic algorithm: NSGA-II. IEEE transactions on evolutionary computation, 6(2), 182-197.

6. Appendix 4 from the BENV0086 Modelling Portfolio brief

7. https://ec.europa.eu/jrc/en/samo