1 Task 1

1.1 Introduction

The ANSI/ASHRAE Standard defines a series of test procedures that can be employed to evaluate the capability of programs. The purpose of tests is trying to identify the algorithmic differences, coding errors and modelling limitations of a tested software by comparing the predictions with its peer programs(ASHRAE, 2017). Aside from 8 official data provided by ASHRAE, this report will integrate extra three published result, namely EnergyPlus8.4, DesignBuilder4.2 and ApacheSim2015. The aim of this report is to validate two programs including EnergyPlus8.9 and DesignBuilder5.5 by referring to total 11 officially published results. Each program is tested with two cases, namely Base Case 600 and Free-float basic test Cases 600FF.

1.2 Methodology and assumptions

The universal input parameters are obtained from ASHRAE, however modifications are necessary due to the different algorithm of each program. A simple sensitivity analysis will be conducted to spot out the most influential factors for decision making. To confirm the validity of tested programs using Case 600, hourly heating and cooling loads are simulated. A comparative evaluation is performed to verify if the annual energy and peak loads are compatible with the official data. Additionally, the annual incident solar radiation is collected and compared to assess the program's capability of processing the site characteristics. Concerning the Case 600FF, the minimum, maximum and average free-floating temperature are comparatively evaluated. The temperature variation at 4th Jan. is plotted to understand how EnergyPlus8.9 and DesignBuilder5.5 cope with the large outside temperature variations. The global workflow is concisely documented and shown in the schematic.

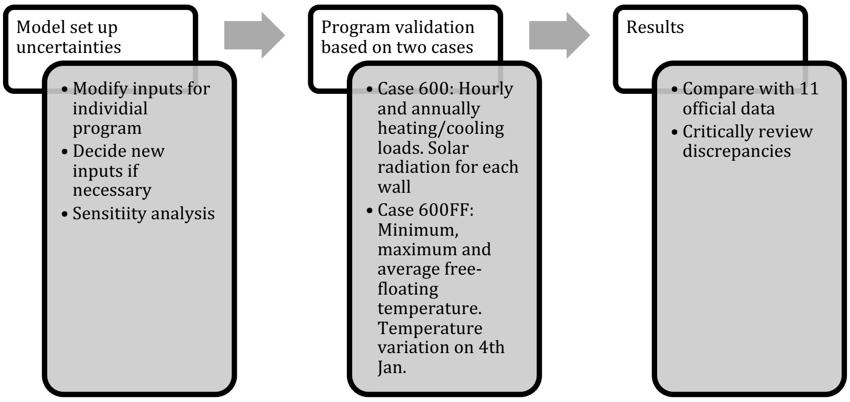


Figure 1 Schematic of workflow

1.2.1 Case 600(FF) Settings

Figure 2 illustrates the form of base case 600(FF), which is a single-zone rectangular building with no interior partitions. The dimension is 8x6x2.7m with two windows(3x2m) placed on the south exposure. The construction is lightweight, ideal HVAC system with 100% efficiency and infinite capacity limit. 200W internal gains and 0.5 ach infiltration is set to be always on, thermostat is introduced to keep the space between 20°C-27°C. The weather file informs a series of climate data at Denver-Stapleton (Latitude: 39.76°, Longitude: -104.86°). More construction characteristics and details are displayed in the following tables. Note that the green fill stands for No Uncertainty, yellow for Low Uncertainty, brown for Medium Uncertainty and red for High Uncertainty.

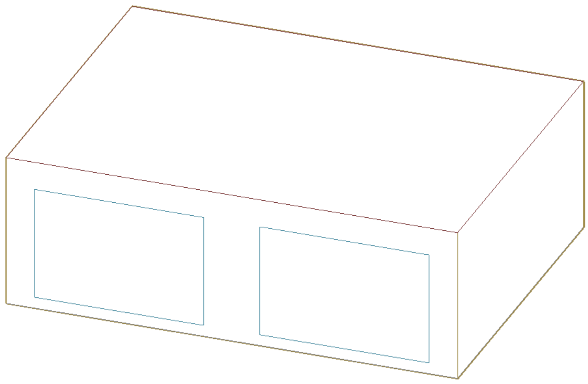


Figure 2-Case 600(FF) Geometry

Table 1- Opaque Elements Properties

Opaque Elements Properties									
	k (W/mK)	Thickness (m)	U (W/m^2K)	R (m^2K/W)	Density (kg/m^3)	Cp (J/ kg K)	Area (m^2)	Source	Notes
Exterior wall (inside to outside)							63.6	Coursework Brief	
Int surf coeff			8.29	0.121					Unused, See Note 1
Plasterboard	0.16	0.012	13.333	0.075	950	840			
Fiberglass quilt	0.04	0.066	0.606	1.65	12	840			
Wood siding	0.14	0.009	15.556	0.064	530	900			
Ext surf coeff			29.3	0.034					Unused, See Note 1
Total air+air			0.514	1.944					
Total surf surf			0.559	1.789					
Floor (inside to outside)							48		
Int surf coeff			8.29	0.121					Unused, See Note 1
Timber flooring	0.14	0.025	5.6	0.179	650	1200			
Insulation	0.04	1.003	0.04	25.075					Thermal Decouple, See Note 2
Total air+air			0.039	25.374					
Total surf surf			0.04	25.254					
Roof (inside to outside)							48		
Int surf coeff			8.29	0.121					Unused, See Note 1
Plasterboard	0.16	0.01	16	0.063	950	840			
Fiberglass quilt	0.04	0.1118	0.358	2.794	12	840			
Wood siding	0.14	0.019	7.368	0.136	530	900			
Ext surf coeff			29.3	0.034					Unused, See Note 1
Total air+air			0.318	3.147					
Total surf surf			0.334	2.992					

Note 1: The convective and radiative surface properties were not used in either in EnergyPlus nor DesingBuilder. Those surface properties could be neglected if the programs automatically account for air film effect (U.S. Department of Energy, 2015).

Note 2: The floor insulation has been made very thick to effectively decouple the floor thermally from the ground that helps to largely eliminate the uncertainty associated with heat transfer with ground(ASHRAE, 2017). EnergyPlus 8.9 treats floor as "NoMass" object that essentially reduce the uncertainty of the heat transfer with ground.

The detailed window properties can be found in Appendix A. Case 600FF is built based on Case 600 sharing the same parameters exhibited above. The only difference is that the heating and cooling system is switched off.

1.2.2 Case 600(FF) Modelling Notes

Table 2-EnergyPlus Modelling Information

EnergyPlus Modeling Notes			
Objects	**Value**	**Source**	**Comments**
Simulationcontrol	Run simulation for weather file run period	EDE_EnergyPlus_Guide_2018	HVACTemplate:Zone:IdealLoadsAirSystem is applied offering infite conditioning capacity, no sizing required and check simulation for weather only (EDE pp15)
Terrain	Country	Google Map	Flat, Open Country, observed from google map satllite using given coordinates
Loads Convergence Tolerance Value	0.039999999	EnergyPlus_ASHRAE140-Envelope-8.4.0	Default 0.04, no HVAC sizing required, the loads convergence is less important
Temperature Convergence Tolerance Value	0.0040000002	EnergyPlus_ASHRAE140-Envelope-8.4.0	Default 0.4 in two tested programs, marginal tolerences in this case (0.004) are allowed for max and min temperature convergence for better result accuracy, Medium uncertainty
Solar distribution	MinimalShadowing	EnergyPlus I/O	No exterior shadowing devices such as overhang in Case 600 (EnergyPlus ASHRAE use FullInteriorAndExterior)
ShawdowCalculation	AverageOverDaysInFrequency	EnergyPlus I/O	TimestepFrequency method is only chosen for dynamic fenestration and shades
SurfaceConvectionAlgorithm:Inside	TARP	EnergyPlus_ASHRAE140-Envelope-8.4.0	The TARP model correlates the heat transfer coefficient to the temperature difference for various orientations. Indeed, the temperature at different orientation is different due to the change of sun position and the amount of solar radiation entering due to fenestration arrangement
SurfaceConvectionAlgorithm:Outside	DOE-2	EnergyPlus_ASHRAE140-Envelope-8.4.0	DOE-2 can measure both rough (wall) and smooth (glass) surfaces. (Engineering reference pp96) Therefore, using DOE-2 is appropriate here
HeatBalanceAlgorithm	ConductionTransferFunction	EnergyPlus I/O	The specification provided does not indicate a moisture material property information and it is assumed to discount moisture storage or diffusion in construction element, choosing ConductionTransferFunction instead of MoisturePenetrationDepthConductionTransferFunction
Timestep	4	EnergyPlus_ASHRAE140-Envelope-8.4.0	Results are reported hourly, simulation is done every 15min
Internal Gains	OtherEquipment	/	Constant 200W, 100%sensible, 0% latent. 60%radiative, 40%convective, assume all internal gains are produced by otherequipment, which uses always on schedule. **Additionally, it does not follow the FAQ which spreads the gains to people and equiopment**

Table 3-DesingBuilder Modelling Information

DesignBuilder Modeling Notes			
Objects	**Value**	**Source**	**Comments**
Exposure to wind	3-Exposed	DesignBuilder_v4.2_ASHRAE140_2	Accounting for convection heat transfer for all external surfaces and hence the U-value of construction
Use daylight saving	Unchecked	DesignBuilder Help	The clock moves forward one hour in the summer months to model the daylighting, uncheck this to obtain more accurte data without savings
Ground and soil construction	Undefined	DesignBuilder_v4.2_ASHRAE140_2	It is defined in DB paper but not available in our version at Location tab, uncertainty
Geometry	8x6x2.7	ANSI/ASHRAE Standard 140-2017	8x6x2.7m was drawn for this report which is an uncertainty, because DesignBuilder draws the out envelop. To account fot the wall thickness, it is recommended to draw the geometry 8.2x6.2x2.7
Outside solar reflectance	0.075	DesignBuilder_v4.2_ASHRAE140_2	0.07846 in Energyplus, 0.075 for the DesingBuilder is instructed by the source. This difference will give rise to uncertainty to some extent
Inside solar reflectance	0.075	DesignBuilder_v4.2_ASHRAE140_2	0.07846 in Energyplus, same as above
Outside emissivity	0.9	DesignBuilder_v4.2_ASHRAE140_2	0.84 in Energyplus, same as above
Inside emissivity	0.9	DesignBuilder_v4.2_ASHRAE140_2	0.84 in Energyplus, same as above
HVAC	Simple HVAC system	DesignBuilder_v4.2_ASHRAE140_2	Simple HVAC is equivalent to ideal loads template where cooling and heating are infinite
Roughness	Rough	/	All assume to be rough
Process Gain	On	DesignBuilder_v4.2_ASHRAE140_2	Internal gain is expressed in form of process gain, given the floor area 48m2, the power density should be 4.16667w/m2.
Timestep	4	/	6 was used by DesignBuilder_Ashrae
Solar distribution	MinimalShadowing	/	FullInteriorAndExterior on DesignBuilder_Ashrae,Medium uncertainty
Loads Convergence Tolerance Value	0.039999999	/	0.04 on DesignBuilder_Ashrae
Temperature Convergence Tolerance	0.0040000002	/	0.4 on DesignBuilder_Ashrae

1.2.3 Sensitivity analysis

Table 4 shows a simple local sensitivity analysis to locate the most influential factor among those highlighted with medium to high uncertainties. The total energy is the reference point for comparison.

Table 4-Sensitivity analysis

Simple sensitivity analysis							
		x+	**x-**	**Total Energy + (MWh)**	**Total Energy - (MWh)**	**ΔEnergy**	**Rank**
EnergyPlus	**Temperature Convergence Tolerance Value**	0.4	0.004	11.276	11.276	0	2
	Solar distribution	FullInteriorAndExteriorWithReflections	MinimalShadowing	11.192	11.276	0.084	1
DesignBuilder	**Temperature Convergence Tolerance Value**	0.4	0.004	12.122	12.122	0	2
	Solar distribution	FullInteriorAndExterior	MinimalShadowing	12.106	12.122	0.016	1

1.3 Results and discussion

The results of EnergyPlus, DesignBuilder, and ApacheSim are graphically presented in Appendix B. It is noted that the Designbuider5.5(Figure6), tested by the modeler gives 6.039MWh while the official data from DesignBuilder4.2 indicates a cooling around 6.71MWh. The difference is likely associated with the "Groundandsoilconstruction" and the "Geometry". Although the former option is undefined and the connection to the cooling demand remains uncertain, the geometry does induce some influences on the cooling energy. DesignBuilder treats the geometry as outer layer, thus it underestimates the conditioned area leading to less cooling consumption. The similar deviation also happens to the peak cooling(Figure8). Regarding the Annual Incident Solar Radiation(Figure9), two tested programs perform consistently well. However, one discrepancy is observed on the West façade where two tested programs along with DesingBuilder4.2 give 1040kWh/m^2, but EnergyPlus8.4 shows 1000kWh/m^2. The difference is likely happened due to the "Solar distribution", this report selected "MinimalShadowing" but the input in the EnergyPlus8.4 is unavailable. One thing for certain is that that "Solar distribution" does have some influences on the energy consumption based on the sensitivity analysis. Furthermore, the temperature variation on 4th Jan. for Case 600FF(Figure13) worth interpretations. The temperature for all programs including the officially published results at 9am is approximate -14°C. However, the temperature at 4pm ranges from 28.97°C(TASE) to 35.51°C(ESP), averaged to 31.77°C. The examined program EnergyPlus8.9 shows 32.45°C while DesignBuilder5.5 gives 29.26°C. One interpretation is that different programs are computed differently to take account of the thermal mass. It has been observed that the diurnal range is large, thermal mass plays a crucial role to transfer the energy. Programs start with similar point at 9am, then after 7 hours to 4pm, the thermal mass effect is calculated by each individual program leading to different inside temperature.

1.4 Conclusion

Although the difference exists, they do not indicate any modelling limitations in the tested programs. A sensitivity analysis was conducted which is too simple to reflect the genuine uncertainties, for instance, two values are assigned to calculate the energy instead of using the statistical distribution. Generally, EnergyPlus8.9 performs better than DesignBuilder5.5, "Goundandsoilconstruction" and "Geometry" is responsible for that gap. Moreover, it remains unclear that the geometry affects the cooling energy, but why the heating is consistent? The official EnergyPlus8.4 yields 1000W/m2 on West façade, the detailed inputs for this should be investigated and prove the accuracy of hypothesis made. Finally, the input errors by modeler are not fully eliminated that may affect the quality of results.

2 Task 2

2.1 Introduction

Task 2 moves to the parametric analysis using jEPlus and sensitivity analysis with the aid of Simlab. jEPlus considerably increases the efficiency of simulation, achieved by setting a range for interested parameters that will be run automatically in EnergyPlus instead of adjusting each parameter manually. The result obtained can be sorted and help to identify the minimum energy consumption option. Moreover, the results from jEPlus could be processed in the Simlab, which is a powerful tool to analyse the sensitivity of inputs, such that the most sensitive input worth more careful evaluation.

jEPlus

2.2 Methodology and assumptions

The internal gain 200W, originally assumed in the "OtherEquipment" field, is transferred to the "Light" object. The intention of this reassignment ensures the integrity of Case 600 with constant 200W internal gains and creates a variation of electricity consumption profile, which is dominated by the availability of daylight. The maximum and minimum energy consumption for each type is tabulated and discussed accompany with the corresponding inputs. Additionally, multi-regression analysis is conducted to find the connection between the total energy and input parameters that can be employed to roughly estimate the total energy conveniently in the future.

2.3 Result and discussion

A full-factorial parametric simulation was performed accounting for the influences of Terrain, Building Orientation, Insulation Thickness, and the Overhang Depth. The Sensible heating and cooling loads, district energy and electricity consumption are computed.

Table 5-jEPlus simulation result

Types of Energy Consumption in Different Cases								
		Energy (J)	**Energy (MWh)**	**Terrain**	**Orientation (°)**	**Insulation thickness (m)**	**Overhang depth (m)**
Zone Sensible Cooling Energy	Max	1.07E+10	2.968	City	270	0.175	0.5
	Min	1.68E+09	0.467	Country	180	0.05	2
Zone Sensible Heating Energy	Max	2.41E+10	6.686	Country	180	0.025	2
	Min	4.2E+09	1.167	City	0	0.175	0.5
Electricity:Facility	Max	4.66E+09		/	180	/	2
	Min	4.3E+09		/	90	/	0.5
DistrictHeating:Facility	Max	2.41E+10		Country	180	0.025	2
	Min	4.2E+09		City	0	0.175	0.5
DistrictCooling:Facility	Max	1.09E+10		City	270	0.175	0.5
	Min	1.74E+09		Country	180	0.05	2
Total	Max	3.05E+10		Country	180	0.025	2
	Min	1.44E+10		Country	0	0.175	1.5

Table 5 is a truncated version of the summary table (Appendix C) since there are more than one max and min value for electricity consumption. The rationale behind is that the electricity, consumed by the lighting appliances, depends solely on the overhang depth, which affects the obtainability of daylight. Only four values, namely 0.5m, 1.0m, 1.5m, 2.0m for the overhang depth, the electric consumption keep repeating and create a bunch of max and min results. Besides, because only one zone exits, the district energy, and zone energy are pretty much the same. More explicitly, both max and min values are the same for the heating energy whilst the cooling part is not. Given that sensible energy is the energy used to change the temperature whereas the district energy is the sum of sensible and latent energy which accounts for both energy used to change the temperature and the phases. This means that the latent heating does not occur but latent cooling that is likely owing to the dehumidification of outside air that entering through windows or cracks to the inside conditioned room in summer. In terms of locating the min total energy consumption, the total energy contains just district heating, cooling and electricity consumption excluding the sensible energy to avoid repetition.

2.3.1 Multi-regression analysis

By learning from the existing inputs, the total energy can be explained and predicted using multi-regression analysis. In this case, the Terrain is excluded which affects the wind, hence affect the cooling and heating(Lawrence Berkeley National Laboratory, 2018). However, confirmed by the simulation results, the variation due to change of terrain is marginal and can be ignored. After implementing the regression analysis, the coefficient of determination R^2 indicates that 72% of response variable (total energy) can be explained. The P value of Orientation, Insulation Thickness and Overhang Depth are all less than 0.05, rejecting the null-hypothesis and they are all meaningful to predict the total energy(Frost, 2018). The function to estimate the total energy (J) is

$$\hat{E} = 2.56 \times 10^{10} + 2.14 \times 10^{7} Orientation - 4.86 \times 10^{10} InsulationThickness - 1.08 \times 10^{9} OverhangDepth.$$

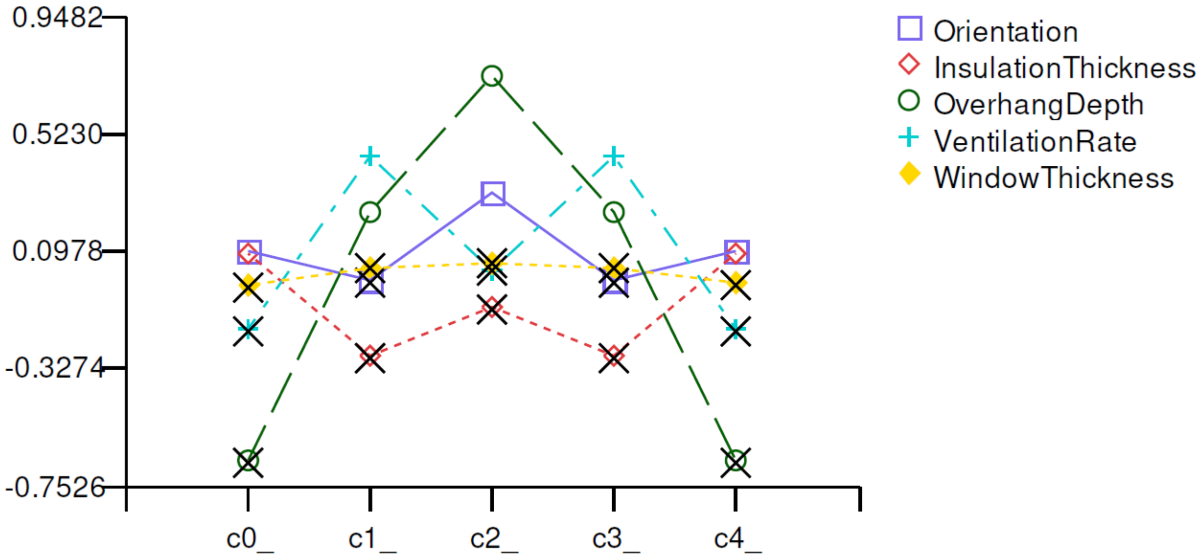
Generally, it can be summarised that increasing wall azimuth leads to larger energy consumption while the increase of insulation thickness and overhang depth reduces the overall energy use.

Simlab

2.4 Methodology and assumptions

It is instructed to set the terrain as city and add extra variables, namely the ventilation and window thickness. The statistical distribution and corresponding parameters are given which are used to configure jEPlus and Simlab. The Simlab for sensitivity analysis is performed twice with extra parameters, which is identified as important factors after first simulation. The most two influential parameters are tabulated and discussed.

2.5 Result and discussion



c0: ZONE 1 IDEAL LOADS AIR SYSTEM:Zone Ideal Loads Zone Sensible Cooling Energy [J](RunPeriod)
c1: ZONE 1 IDEAL LOADS AIR SYSTEM:Zone Ideal Loads Zone Sensible Heating Energy [J](RunPeriod)
c2: Electricity:Facility [J](RunPeriod)
c3: DistrictHeating:Facility [J](RunPeriod)
c4: DistrictCooling:Facility [J](RunPeriod)

Figure 3-Simlab analysis result

It is evident that the sensible energy and district energy is nearly the same and the later analysis will focus on the district energy and electricity consumption. Visually, the most influential factor is the overhang depth, followed by the orientation for the electricity consumption (c2). The ventilation rates and insulation thickness govern the district heating (c3). In terms of the district cooling (c4), the overhang depth is the dominating factor and ventilation also plays a role. The sensitivity result is summarised in the Table 6, the Pearson correlation coefficient is also displayed for better interpretation.

Table 6-Simlab analysis result for first two influential factors

Sensitivity analysis result				
Energy types	**Most influential factor**	**PEAR**	**Second Influential factor**	**PEAR**
c2: Electricity:Facility	Overhang dep.	0.7343	Orientation	0.3169
c3: DistrictHeating:Facility	Ventilation	0.4463	Insulation	-0.284
c4: DistrictCooling:Facility	Overhang dep.	-0.664	Ventilation	-0.187

As regards the electricity usage c2, which is primarily for the lighting appliances, it is reasonable that the overhang depth and orientation are significant since they affect the daylighting. About the heating, higher ventilation rate takes more heat away resulting in higher heating demand in winter while thicker insulation keeps the room warm with less heating requirements. Apart from constant 200W internal gains, the solar gain, affected by the overhang depth, is a crucial element affecting the district cooling. Ventilation rate as the second influential factor can take away heat and help reduce the cooling requirement in summer. Furthermore, in terms of electricity consumption, it is worth running another test for the visible transmittance of glazing, which has important implications on the admittance of light. Insulation conductivity and g-value are also considered as sensitive parameters for the heating and cooling consumption. The executions are increased to 800 times. The assumptions and sensitivity analysis result are tabulated in Table 7 and Table 8 respectively.

Table 7-Assumptions for second sensitivity analysis

Assumptions for the extra elements								
	Uniform distribution			Normal distribution			Uniform distribution	
g	Upper	0.9	**Insulation conductivity**	Mean	0.04	**Visible transmittance**	Upper	0.9
	Lower	0.1		Sd	0.01		Lower	0.1
	Weight	1					Weight	1

Table 8-Second sensitivity analysis result

New sensitivity analysis result				
Energy types	**Most influential factor**	**PEAR**	**Second Influential factor**	**PEAR**
c2: Electricity:Facility	Visible Trans.	-0.945	Overhang dep.	0.1911
c3: DistrictHeating:Facility	Ventilation	0.4711	g-value	-0.38
c4: DistrictCooling:Facility	g-value	0.627	Overhang dep.	-0.376

It is much more cost-effective to concentrate on the window properties, such as the visible transmittance and g-value. Overhang depth has significance to the electricity and cooling energy that should be carefully designed to meet both thermal comfort and lighting requirement. Last but not least, the ventilation operates constantly at the expense of heating energy in winter. It is strongly suggested to adjust the ventilation rate seasonally to take the most of it in practice.

2.6 Conclusion

This task gives an insight that insulation thickness, which is often regarded as the most important aspect to reduce energy, is less significant in this case. This information is valuable in practice to identify the most cost-effective way to design instead of blindly using the "common" knowledge. The statistical distributions are assumed with best knowledge, it is strongly recommended to refer to literature or in-situ data for more accurate distribution types in the future study.

3 Task 3

3.1 Introduction

Task 3 is split into two sections. The first part records the necessary modifications and assumptions for three cases, namely case controlled by daylighting, automated blinds and occupant's behaviour. The simulation results are compared and discussed. The second part focuses on the optimisation of window sizes, blinds setpoints, blind g-values, and slat angles. The Reinhard model is modified from the energy perspective, the best control mode is identified and discussed.

Subtask B – Simulation

3.2 Methodology and assumptions

Case600_DDLC puts emphasis on the lighting control with the sensor in the middle of the room. The internal gain, originally assumed in the "OtherEquipment" field is transferred to the "Lighting" object with the same constant 200W. This creates a varying electricity profile due to the availability of daylight. Case600_DDLC_OBM1 tends to simulate the automated blind, the assumed setpoints for activating the blinds are 14°C and 230W/m2. This is obtained by firstly ranking 8760 temperature and solar radiation data, and then averaging the central half data for each setpoint. The average annual data (9.7°C, 270W/m2) are not employed since they are less convincible owing to the dispersed distribution. Regarding to Case600_ DDLC_OBM2, the south windows are combined with the same area for the convenience of EnergyManagmentSystem, the "People" object is added.

3.3 Result and discussion

The simulation for each case was performed and the results were tabulated in Table 9.

Table 9-Simulation result for three cases

Simulation Models and Results				
Models	**Description**	**Annual heating demand per conditioned floor area (kWh/m2)**	**Annual cooling demand per conditioned floor area (kWh/m2)**	**Annual lighting electricity demand per conditioned floor area (kWh/m2)**
Case600_DD LC	Daylight-dimming lighting control	49.9	64.09	5.52
Case600_DD LC_OBM1	Automated blind with setpoints	55.15	23.91	5.67
Case600_ DDLC_OBM2	Reinhart model to represent occupancy behaviour	62.94	63.42	5.54

It is observed that the annual lighting demand is little and similar in each case. This brings about a thought that the setpoint 500 lux for lighting is consistently reached throughout the year, regardless existence of blinds. More explicitly, the sunlight is strong in the entire year and the blinds allow them to enter. The first hypothesis is confirmed by the solar radiation data in weather file that the radiation reaches 900W/m^2 in both summer and winter. Secondly, given the assumption that the slat is transparent, and the visible transmittance is 100% diffuse, irrespective of the solar incidence angle(Lawrence Berkeley National Laboratory, 2018). Therefore, the translucent slats allow visible light to light the room up with the constantly intense sunlight, reaching the setpoint 500 lux throughout the year.

In terms of the annual heating demand, Case 600_DDLC_OBM1 consumes more energy compared with the base case. This is likely because the blind is activated and hinder the solar gains when the setpoints are attained (14°C, 230W/m^2) while the interior temperature is lower than the heating setpoint 20°C. This reveals a drawback that setting the fixed setpoints for blind can hardly be considerate for both heating and cooling periods. Case 600_ DDLC_OBM2 creates the coldest winter and uses the most heating, a potential explanation is that the blind mainly keeps closing in the winter time leading to no useful solar gains. This theory is verified in Figure 4 by outputting the beam solar radiation at the work plane. It is noticed that the beam solar radiation on desk often exceeds 50W/m^2 in the winter time where occupants tend to close the blinds, hence consume more heating energy.

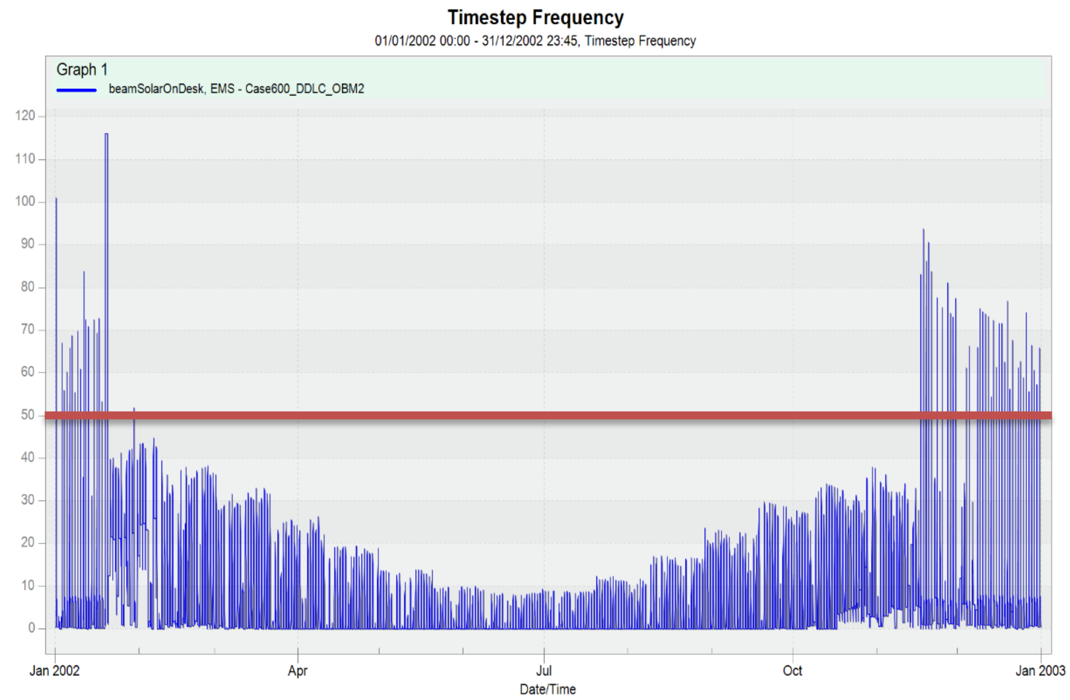


Figure 4-Annual BeamSolarOnDesk

In comparison with base case, the automated blinds considerably reduce the solar gains in summer, such that less cooling is required. Reinhart model requires similar amount of energy as base case which is potentially dictated by the overheating in the room due to the fact that blinds are opening all the summer (rarely exceed 50W/m^2), allowing unwanted solar heat entering the room. Reinhart model does not accurately represent occupant behaviour under the given climate, some modifications of the model are expected for the further work. Optimisation will be performed to find the optimal setpoints mainly for the automated blinds and appropriate size of windows. Moreover, some adjustments of Reinhart model and other relevant factors will be attempted.

Genopt

3.4 Methodology and assumptions

South windows are combined for the sake of optimisation process. Window size will be optimised for all three cases. Blind setpoints and blind slat angles will be optimised for Case 600_DDLC_OBM1. Moreover, there is an intention to modify the Reinhart model and calculate the optimal point where people are expected to close the blind from the perspective of energy saving. Optimisation settings for each case are tabulated in Table 10.

Table 10-Optimisation parameters in Genopt

Optimisation settings									
Optimisation parameter	**Settings**		**Optimisation parameter**	**Settings**		**Optimisation parameter**	**Settings**		**Notes**
Length of window (m)	Min	0.2	Width of window (m)	Min	0.2				The Z coordinate of window is fixed at 0.2m. Optimisation applies to all three cases
	Initial	0.2		Initial	0.2				
	Max	6.5		Max	2.2				
	Step	0.1		Step	0.1				
ShadingControl: Temperature setpoint (°C)	Min	5	ShadingControl: solar setpoint (W/m^2)	Min	100	Blind slat angle (°)	Min	10	Max temperature and solar radiation is obtained from weather file. Applied to Case 600_DDLC_OBM1
	Initial	5		Initial	100		Initial	10	
	Max	35		Max	980		Max	90	
	Step	0.5		Step	20		Step	5	
Beam solar on desk (W/m^2)	Min	5							Applied to Case 600_DDLC_OBM2
	Initial	5							
	Max	90							
	Step	5							

3.5 Result and discussion

Table 11-Optimised parameters for each case

Optimisation results			
	Opt_Case600_DDLC	Opt_Case600_DDLC_OBM1	Opt_Case600_ DDLC_OBM2
Optimised window length (m)	2.97	3.58	2.81
Optimised window width (m)	2.20	2.20	2.07
Optimised WWR	30.3%	36.4%	26.9%
Optimised Temperature setpoint (°C)		18.75	
Optimised solar setpoint (W/m^2)		237.50	
Optimised slat angle (°)		52.20	
Beam solar on desk (W/m^2)			27.50
Annual heating per conditioned area (kWh/m2)	59.45	56.52	56.51
Annual cooling per conditioned area (kWh/m2)	16.75	9.65	18.47
Annual lighting per conditioned area (kWh/m2)	5.67	5.73	5.76
Primary heating (kWh)	4565.60	4340.50	4339.98
Primary cooling (kWh)	884.30	509.60	975.31
Primary lighting (kWh)	897.40	907.60	912.02
Total primary energy (kWh)	6347.30	5757.70	6227.31

In terms of annual heating per conditioned area, there are not too many differences from the un-optimised model. On the contrary, the cooling energy has seen a substantial reduction, correctly use of blinds based on temperature and solar radiation is the most effective way to reduce energy consumption. Although lighting does not see a significant change and constitute a small amount of total energy consumption, the high conversion factor leads to high primary energy. Therefore, considering alternative energy source, such as cogeneration can effectively minimise the total primary energy consumption. The Reinhart model is optimised to 27.5 W/m2 instead of 50 W/m2. In general, the Case 600_DDLC_OBM1 is the most energy efficient model and it is suggested to have a varying setpoint programmed into an automated blind to boost the performance seasonally. However, it is not the best on in practice, because the frequent blind opening and closing mechanism may give rise to noise and high maintenance cost.

3.6 Conclusion

This work finds the optimal setting for each case and identified the best option among three. However, the optimised Reinhard, purely from the perspective of energy saving, does not necessarily means that is the point where people tend to close the blind. The occupant’s behaviour is greatly associated with many uncertainties, such as human comfort and psychological factors. More occupancy models should be tested to find the most representative behaviour in future work. It is also worth to work more on how the cogeneration will affect the overall performance as an alternative energy source. Furthermore, it is suggested to conduct a sensitivity analysis prior to the optimisation that greatly helps to identify the most influential factors for energy consumption and produce more convincible optimisation result.

Appendix A: Window properties

Window properties				
Properties	Value	Units	Source	Notes
Extinction coefficient	0.0196	/mm		
Number of panes	2			
Pane thickness	3.175	mm		
Air-gap thickness	13	mm		
Index of refraction	1.526			
Normal direct-beam transmittance through one pane	0.86156			
Thermal Conductivity of glass	1.06	W/m·K		
Conductance of each glass pane	333	W/m2·K		
Combined radiative and convective coefficient of air gap	6.297	W/m2·K	Coursework Brief	See Note 1
Exterior combined surface coefficient	21	W/m2·K		
Interior combined surface coefficient	8.29	W/m2·K		
U-value from interior air to ambient air	3	W/m2·K		
Hemispherical infrared emittance of ordinary uncoated glass	0.9			
Density of glass	2500	kg/m3		
Specific heat of glass	750	J/kg·K		
Interior shade devices	None			
Double-pane shading coefficient at normal incidence	0.907			
Double-pane solar heat gain coefficient at normal incidence	0.789			

Appendix B: Task 1 simulation result for Case 600 and Case 600FF

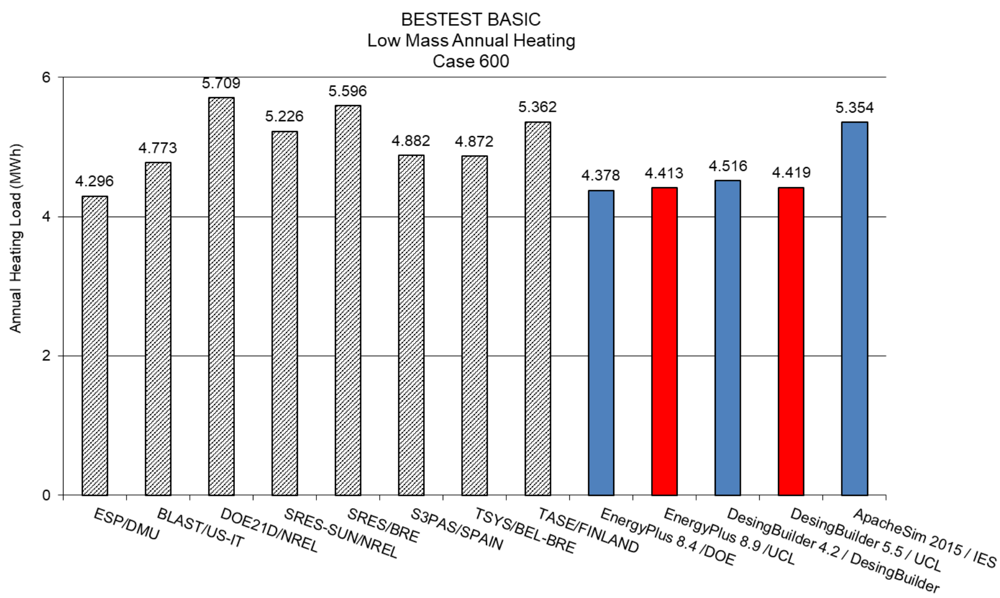


Figure 5-Annual Heating - Case 600

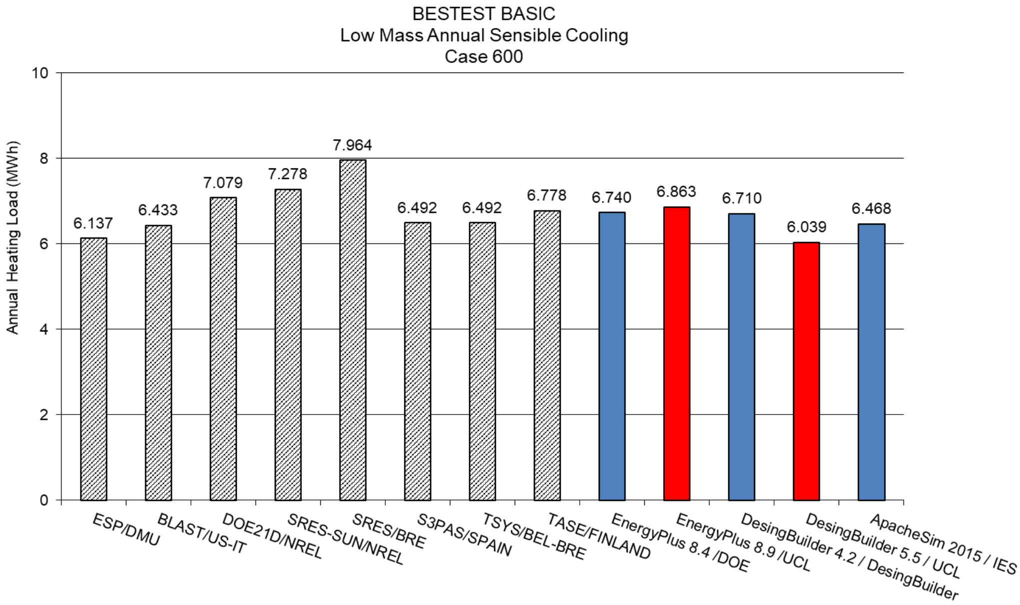


Figure 6-Annual Sensible Cooling -Case 600

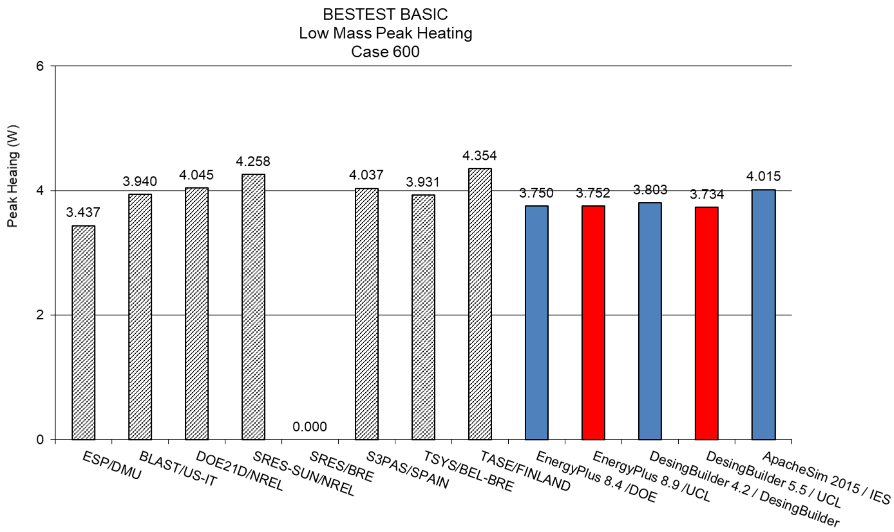


Figure 7-Peak Heating - Case 600

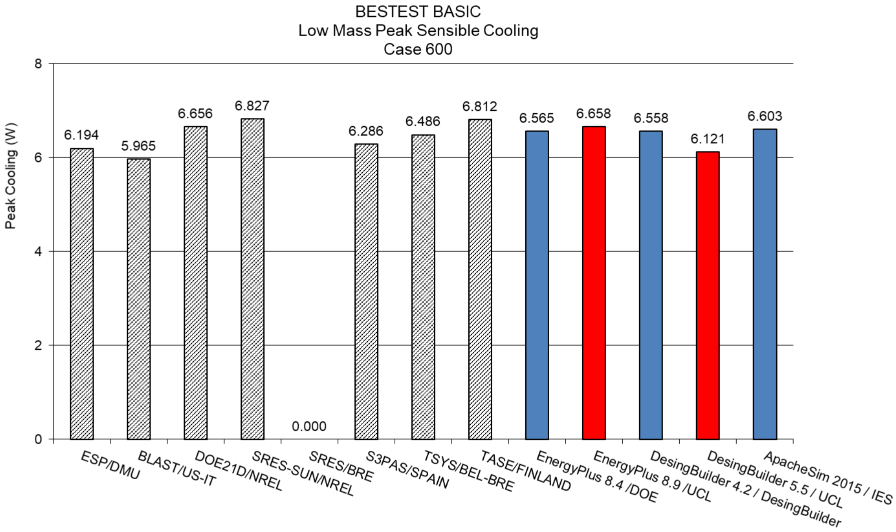


Figure 8-Peak Sensible Cooling - Case 600

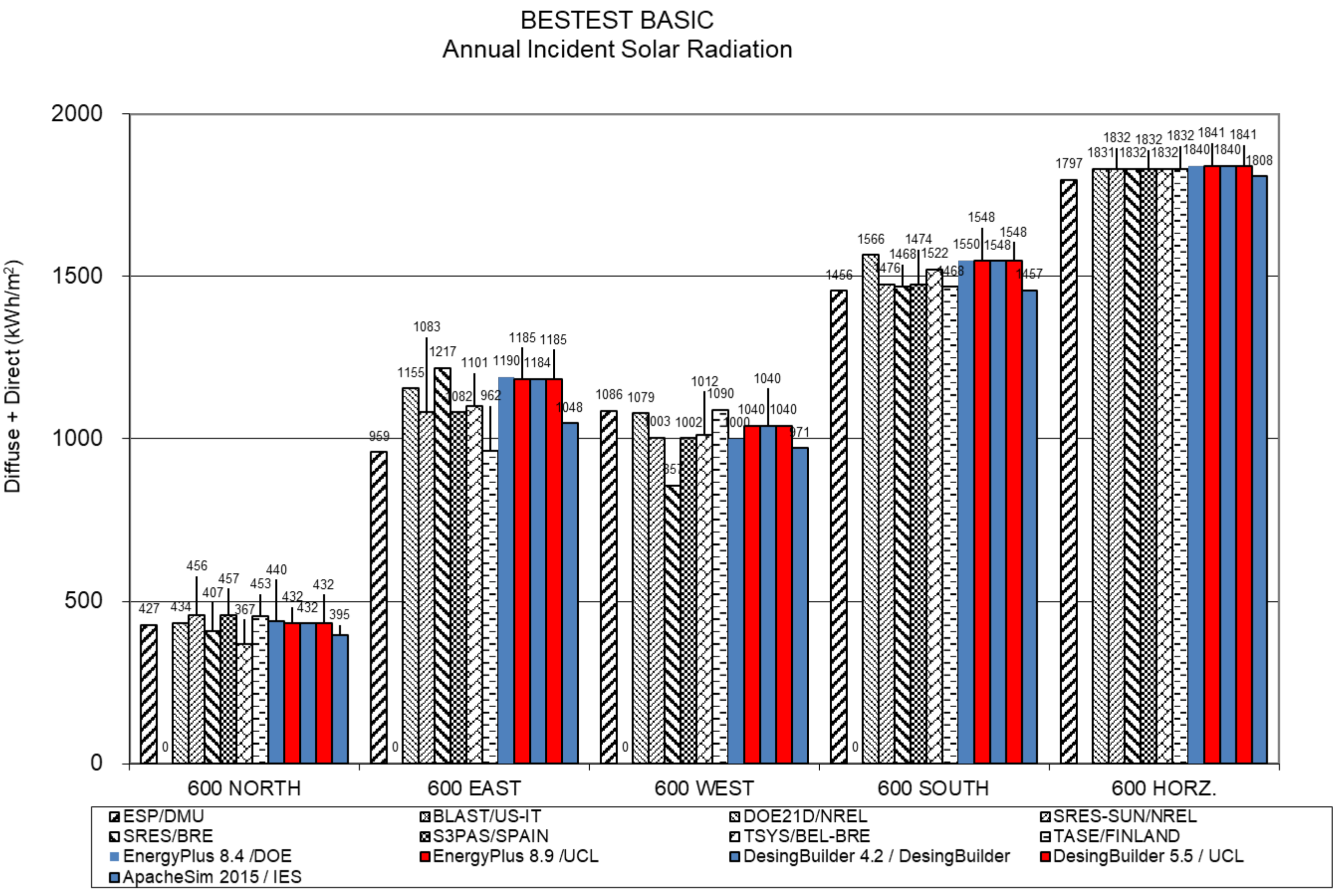


Figure 9-Annual Incident Solar Radiation at Different Orientation

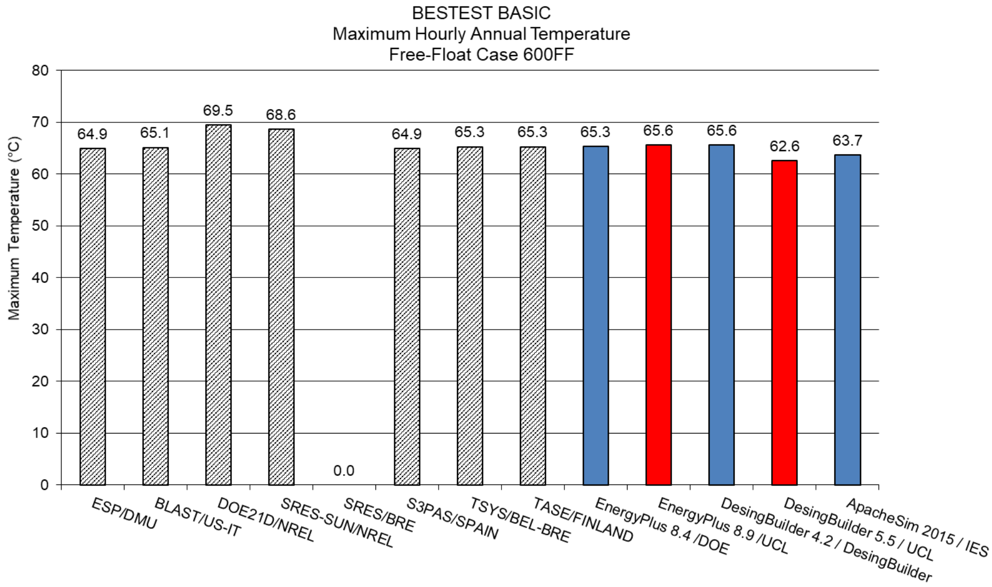


Figure 10-Maximum Hourly Temperature - Case 600FF

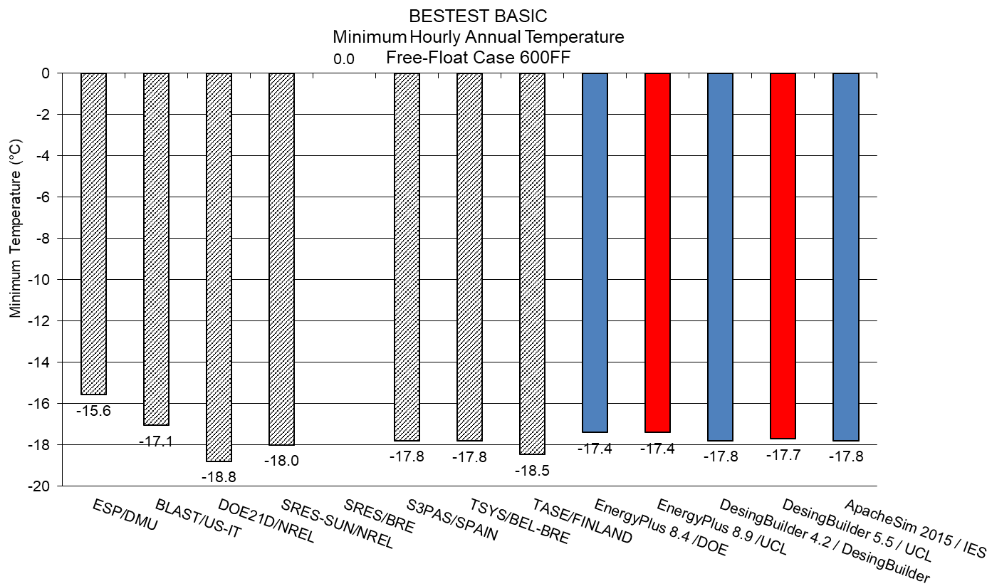


Figure 11-Minimum Hourly Temperature - Case 600FF

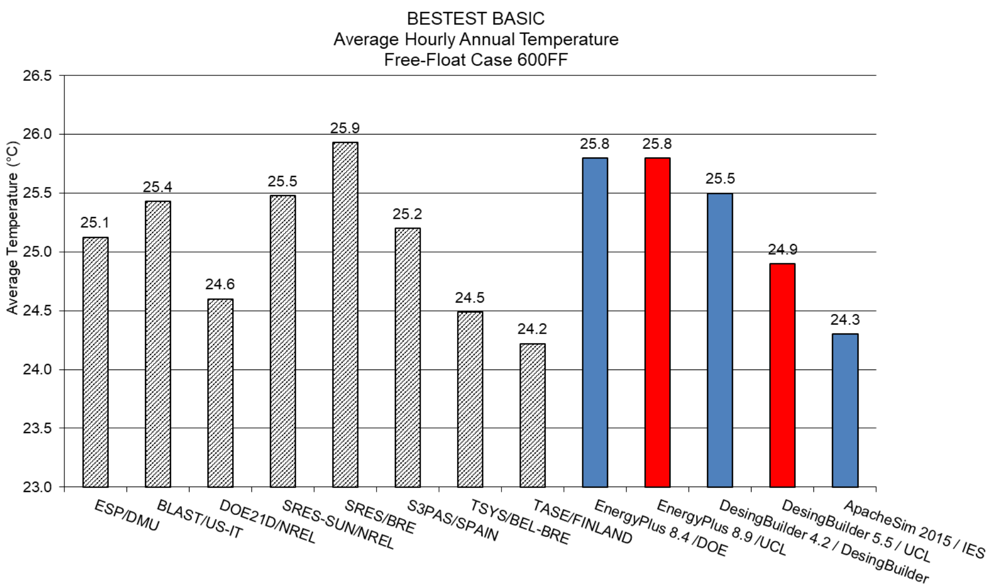


Figure 12-Average Hourly Temperature - Case 600FF

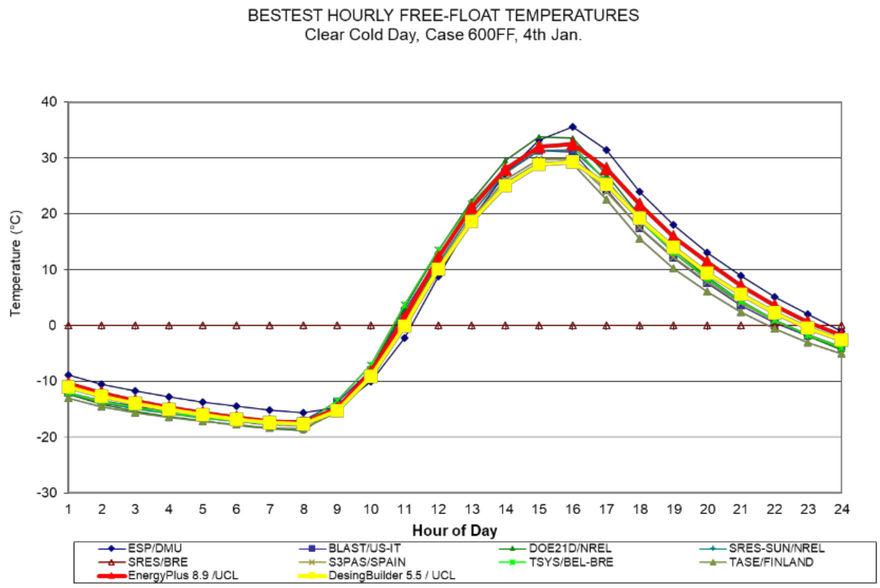


Figure 13-Temperature Variation at 4th JAN - Case 600FF

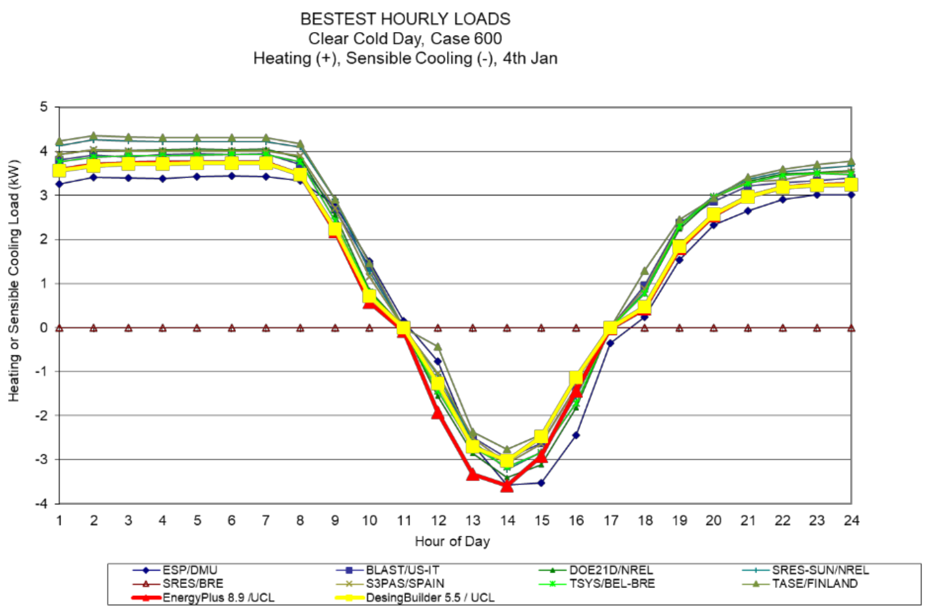


Figure 14-Heating/Cooling Load at 4th JAN - Case 600

Appendix C: Full jEPlus result

Types of Energy Consumption in Different Cases							
		Energy (J)	Energy (MWh)	Terrain	Orientation (°)	Insulation thickness (m)	Overhang depth (m)
Zone Sensible Cooling Energy	Max	1.07E+10	2.968	City	270	0.175	0.5
	Min	1.68E+09	0.467	Country	180	0.05	2
Zone Sensible Heating Energy	Max	2.41E+10	6.686	Country	180	0.025	2
	Min	4.2E+09	1.167	City	0	0.175	0.5
Electricity:Facility	Max	4.66E+09		Country	180	0.025	2
		4.66E+09		Country	180	0.05	2
		4.66E+09		Country	180	0.075	2
		4.66E+09		Country	180	0.1	2
		4.66E+09		Country	180	0.125	2
		4.66E+09		Country	180	0.15	2
		4.66E+09		Country	180	0.175	2
		4.66E+09		Suburbs	180	0.025	2
		4.66E+09		Suburbs	180	0.05	2
		4.66E+09		Suburbs	180	0.075	2
		4.66E+09		Suburbs	180	0.1	2
		4.66E+09		Suburbs	180	0.125	2
		4.66E+09		Suburbs	180	0.15	2
		4.66E+09		Suburbs	180	0.175	2
		4.66E+09		City	180	0.025	2
		4.66E+09		City	180	0.05	2
		4.66E+09		City	180	0.075	2
		4.66E+09		City	180	0.1	2
		4.66E+09		City	180	0.125	2
		4.66E+09		City	180	0.15	2
		4.66E+09		City	180	0.175	2
	Min	4.3E+09		Country	90	0.025	0.5
		4.3E+09		Country	90	0.05	0.5
		4.3E+09		Country	90	0.075	0.5
		4.3E+09		Country	90	0.1	0.5
		4.3E+09		Country	90	0.125	0.5
		4.3E+09		Country	90	0.15	0.5
		4.3E+09		Country	90	0.175	0.5
		4.3E+09		Suburbs	90	0.025	0.5
		4.3E+09		Suburbs	90	0.05	0.5
		4.3E+09		Suburbs	90	0.075	0.5
		4.3E+09		Suburbs	90	0.1	0.5
		4.3E+09		Suburbs	90	0.125	0.5
		4.3E+09		Suburbs	90	0.15	0.5
		4.3E+09		Suburbs	90	0.175	0.5
		4.3E+09		City	90	0.025	0.5
		4.3E+09		City	90	0.05	0.5
		4.3E+09		City	90	0.075	0.5
		4.3E+09		City	90	0.1	0.5
		4.3E+09		City	90	0.125	0.5
		4.3E+09		City	90	0.15	0.5
		4.3E+09		City	90	0.175	0.5
DistrictHeating:Facility	Max	2.41E+10		Country	180	0.025	2
	Min	4.2E+09		City	0	0.175	0.5
DistrictCooling:Facility	Max	1.09E+10		City	270	0.175	0.5
	Min	1.74E+09		Country	180	0.05	2
Total	Max	3.05E+10		Country	180	0.025	2
	Min	1.44E+10		Country	0	0.175	1.5

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