Master thesis : The effects of transparent adaptive façades on energy and comfort performances in office buildings

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Appendices

The effects of transparent adaptive façades on energy and comfort performances in office buildings

Electrochromic glazing, dynamic shading devices

and double-skin façades

Master's thesis in order to obtain a master degree in

« Architectural Civil Engineering », by **Stéphanie BERTRAND**

Promoter: Pr. Shady Attia

Jury members: Pr. Sigrid Reiter
Pr. Vincent Lemort

Appendices

Appendix A: Dynamic building envelopes review

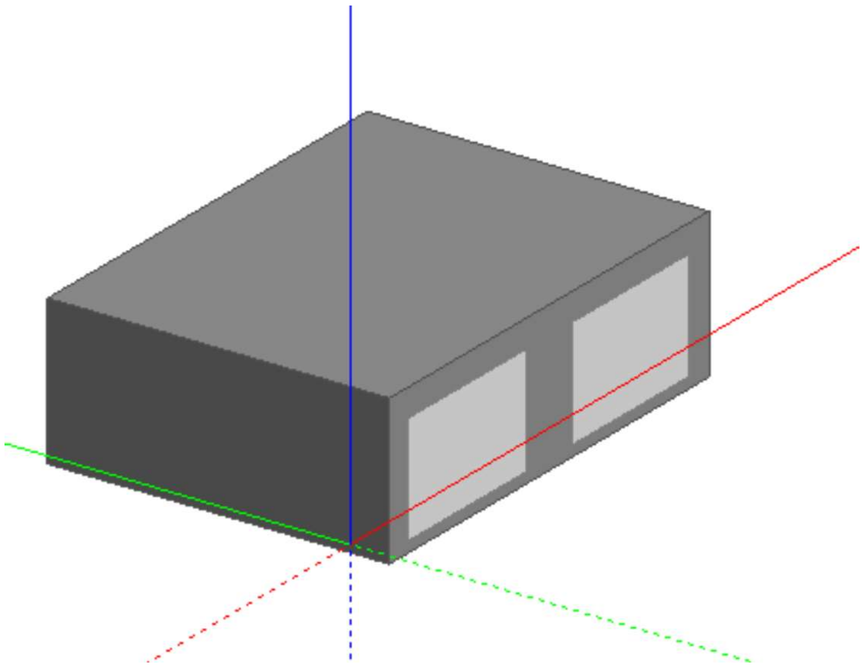
Dynamic envelopes

			What ?	Description	Controllable ?	Parameters: Energy consumption	Thermal comfort	Visual comfort	Energy generation	Acoustic perf.	Advantages	Inconvenients	References or study
Transparent	Switchable glazing	Intrinsic	**Photochromic glazing**	Tinting of the glazing when there is sun (solar radiation (UV)). There is a photochemical reaction between argent molecule contained into the glass and UV of the sun. Molecules come off and take their metallic form	No	X	X	X	/	/	- Improve visual and thermal comforts	- Less efficient than ECW - poor information from manufacturers - Autonomous	(Casini, 2018 ; Costanzo, Evola, & Marletta, 2016 ; Favoino F. , et al., 2018 ; Sibilio, Iavarone, Mastantuano, Mantova, & D'Ausilio, 2018 ;Tällberg, Petter Jelle, Loonen, Gao, & Hamdy, 2019)
Transparent	Switchable glazing	Intrinsic	**Thermochromic glazing**	Tinting of the glazing depending of the temperature. A suntuitive interlayer is placed between glass layers which will react with a variation of temperature.	No	X	X	X	/	/	- Improve visual and thermal comforts	- Less efficient than ECW - Autonomous	(Casini, 2018 ; Favoino F. , et al., 2018 ; Sibilio, Iavarone, Mastantuano, Mantova, & D'Ausilio, 2018 ; Fries, Fink-Straube, Menning, & Schmidt, 2011 ; Tällberg, Petter Jelle, Loonen, Gao, & Hamdy, 2019)
Transparent	Switchable glazing	Extrinsic	**Electrochromic glazing**	Tinting of the glazing by changing voltage. Need a low voltage to operate. Most known electrochromic glazing is based on WO_3 film. This chromogenic glazing is the most known and used on the market.	Yes	X	X	X	/	/	- The most suitable switchable glazing for building envelopes - Most used on the market - Since it is an extrinsic dynamic window, control strategies are allowed. - Improve energy performance, visual and thermal comfort.		(Aldawoud, 2013 ; Casini, 2018 ; Favoino F. , et al., 2018 ; Frattolillo, Loddo, Mastino, & Baccoli, 2019 ; Mäkitalo, 2013 ; Sibilio, Iavarone, Mastantuano, Mantova, & D'Ausilio, 2018 ; Tällberg, Petter Jelle, Loonen, Gao, & Hamdy, 2019)
Transparent	Switchable glazing	Extrinsic	**Nanocrystal-in-glass composite**	NC is composed by Indium oxide nanocrystal embedded in a matrix of niobium oxide. Need a low voltage to tint the glazing. NC operates by absorbing Li^+ ions and losing electrons from a donor layer. It exists the clear state where lighting and solar heat pass through the windows, then the cool state where solar heat is blocked and finally the dark state where solar heat and lighting are blocked.	Yes	X	X	X	/	/	- Supposed to provides better performances than ECW	- Quiet new technology that is still in an experimental phase	(Casini, 2018 ; Favoino F. , et al., 2018 ; Sibilio, Iavarone, Mastantuano, Mantova, & D'Ausilio, 2018)
Transparent	Switchable glazing	Extrinsic	**Gasochromic glazing**	Tinting of the glazing to mirror or bronze-color by changing voltage. The glass is tinting when hydrogen interacts with the active layer (usually a film of WO_3). The clear state is reverted by introducing O_2 in the cavity with the help of electrolyse reaction.	Yes	X	X	X	/	/	- GCW is less expensive than ECW due to its manufacturing process and to a simpler assembly. - GCW needs only one WO_3 layer compared to ECW which needs 5-layer configuration. - Improve energy performance, visual and thermal comfort. - Faster switching phase than ECW		(Casini, 2018 ; Favoino F. , et al., 2018 ; Sibilio, Iavarone, Mastantuano, Mantova, & D'Ausilio, 2018 ; Feng, et al., 2016)
Transparent	Switchable glazing	Extrinsic	**Liquid Crystal Device Windows**	Liquid crystals modulate the optical properties of the window by applying an electromagnetic field that align the liquid crystals allowing the sunlight to pass through it.	Yes	X	X	X	/	/		- This technology appears almost 15 years ago. However, its used is unfrequent in window device. - Poor investigations on it	(Casini, 2018 ; Favoino F. , et al., 2018 ; Gardiner, Morris, & Coles, 2009 ; Sibilio, Iavarone, Mastantuano, Mantova, & D'Ausilio, 2018 ; Seung-Won, Sang-Hyeok, Jong-Min, & Tae-Hoon, 2018)
Transparent	Switchable glazing	Extrinsic	**Suspended Particle Device (SPD) Windows**	Same than for le liquid crystals device but where microscopic particles are suspended. Need 100 volts to operate,	Yes	X	X	X	/	/		- This technology appears almost 15 years ago. However, its used is unfrequent in window device. - Poor investigations on it - Need higher voltage than LC	(Casini, 2018 ; Favoino F. , et al., 2018 ; Oltean, 2006 ; Sibilio, Iavarone, Mastantuano, Mantova, & D'Ausilio, 2018)
Transparent	Switchable glazing	Extrinsic	**electrokinetics pixels**	Electrokinetic pixel window can modulate the hue and the temperature that are coming from visible light. Two planar electrodes are controlling the electrophoretic dispersion of complementary colors are used (blue/yellow fexample).	Yes	X	X	X	/	/	- Can change and control the hue of the glazing which can be warmer or colder if blue yellow chosen, but also black and white opaque hue is black/white chosen. - due to its operation mode the production process should be easy and could be made for large are window	- Quiet new technology, very poor references about it - still in experimentation phase	(Casini, 2018 ; Sibilio, Iavarone, Mastantuano, Mantova, & D'Ausilio, 2018)
Transparent	Switchable glazing	Extrinsic	**elastomer-deformation tunable window,**	Can vary from a clear state to an opaque state by diffusing the light. It uses the geometric deformation of the glass surface to control the light diffusion. This is achieved by inserting a polymer pane between two elastomer layers that are transparent and dielectric. These are sprayed with electrically conducting silver nanowires. By applying a voltage, the nanowires turn to the electrodes which tend to deform the two elastomer layers. Their surfaces become rough and which decrease the light transmission while keeping a perfect neutral color.	Yes	X	X	X	/	/	- The production process should be cheaper because elastomer sheets are available in large format on the market - The main purpose is supposed to be the glare reduction while keeping a sufficient light transmission. - This technology can vary its transparency and thus control the view through the window	- Prototypal technology. Quiet new and thus very poor references about it. - The performances are still uncertain	(Casini, 2018 ; Sibilio, Iavarone, Mastantuano, Mantova, & D'Ausilio, 2018)
Transparent	Switchable glazing	Extrinsic	**Liquid infill tunable window**	This technology reduces the light transmission by pumping liquids in or out of a triple glazed insulated glass unit. Actually, a shading fluid is pumped from the bottom to up of the second cavity while the gas is extracted to a dedicated tank.	Yes	X	X	X	/	/	- Liquid height can vary and be controlled.	- Quiet new technology, very poor references about it - still in experimentation phase	(Casini, 2018 ; Sibilio, Iavarone, Mastantuano, Mantova, & D'Ausilio, 2018)
Transparent	Switchable glazing	Extrinsic	**Phase change materials**	Phase change materials increase the thermal storage capacity of the window. The aim of PCM is to absorb solar radiation. PCMs are able to change their phase (usually liquid-solid transition) and can use the latent heat of this transition for thermal energy storage purposes. typology: paraffin wax, salt hydrates, bio PCM,.. PCM can be used for opaque facade, shutters and glazing.	Yes	X	X	?	/	/	- Help to improve the energy, thermal and visual comfort performances but need a large PCM layer to show significant results - peak temperatures reduced	- Sometimes difficult to predict the effect (can be negative), can bu used in opaque surfaces - Very dependent of the climatic conditions and locations. - few manufacturers - Weak optical properties - Expensive	(Casini, 2018 ; Favoino F. , et al., 2018 ; Sibilio, Iavarone, Mastantuano, Mantova, & D'Ausilio, 2018 ; Vigna, Bianco, Goia, & Serra, 2018)
Transparent	Shadings	Active	**Motorized shading device**	These shading systems are the addition of shading device and motors that help to adjust these.	Yes	X	X	X	/	/	- Better than adjustable or fixed shading device. However, the dynamic part is poor.	- Costly while performances depend on the occupant's behavior	(Al-Masrani, Al-Obaidi, Zalin, & Aida Isma, 2018 ; Favoino F., et al., 2018).
Transparent	Shadings	Active	**Dynamic/automated shading device**	Shading devices dynamically controlled by algorithm. Most of the time depending of occupancy schedules and/or occupants preferences. Considered as the most usual smart façade technology. Thus many shapes and sizes are existing. The motion design can be simple (louvers, blinds, roller shades) or more complex (foldable origamis, parametric geometries,...)	Yes	X	X	X	/	/	- Many studies proved the advantages to add dynamic or automated aspect to shading devices	- Should be correctly studied before to be implemented (control strategies,..)	(Al-Masrani, Al-Obaidi, Zalin, & Aida Isma, 2018 ; De Luca, Voll, & Thalfeldt, 2018 ; Favoino F., et al., 2018 ; Henning Larsen Architects, 2020 ; Kyu Yi, Yin, & Tang, 2018 ; Mahmoud & Elghazi, 2016 ; Mostafa, et al., 2016)
Transparent	Shadings	Hybrid	**Hybrid shading device**	Dynamic shading devices that are more advanced in term of operation and shapes. These are based on biomimetism and are ablo to use the deformation of materials and systems to operate.	Yes	X	X	X	/	/	- Architectural - Better energy and comfort performances	- Many prototypal are studied because require a deep study to optimize their creation and implementation as shading device	(Al-Masrani, Al-Obaidi, Zalin, & Aida Isma, 2018 ; Attia, Favoino, Loonen, Petrovski, & Monge-Barrio, 2015 ; De Luca, Voll, & Thalfeldt, 2018 ; Favoino F., et al., 2018 ; LIFT Architects, 2020 ; Schleicher, Lienhard, Poppinga, Speck, & Knippers, 2015 ; Vergauwen, De Temmerman, & De Laet, 2014)
Transparent	Shadings	PV	**Dynamic photovoltaic shading**	Shading devices made of small photovoltaic panels which are dynamically controlled. In addition to save energy and to improve the visual comfort, such shading devices generate electricity on site due to the sun	Yes	X	X	X	X	/	- This type of dynamic shaidng device help to generate electricty in addition to save energy. - Dynamic side of photovoltaic shading help to decrease between 20 and 80% the energy consumption	- Difficult to simulate - Each case are supposed to be tailored (no standard)	(Energysage, 2018 ; Favoino F. , et al., 2018 ; Jayathissa, et al., 2017)

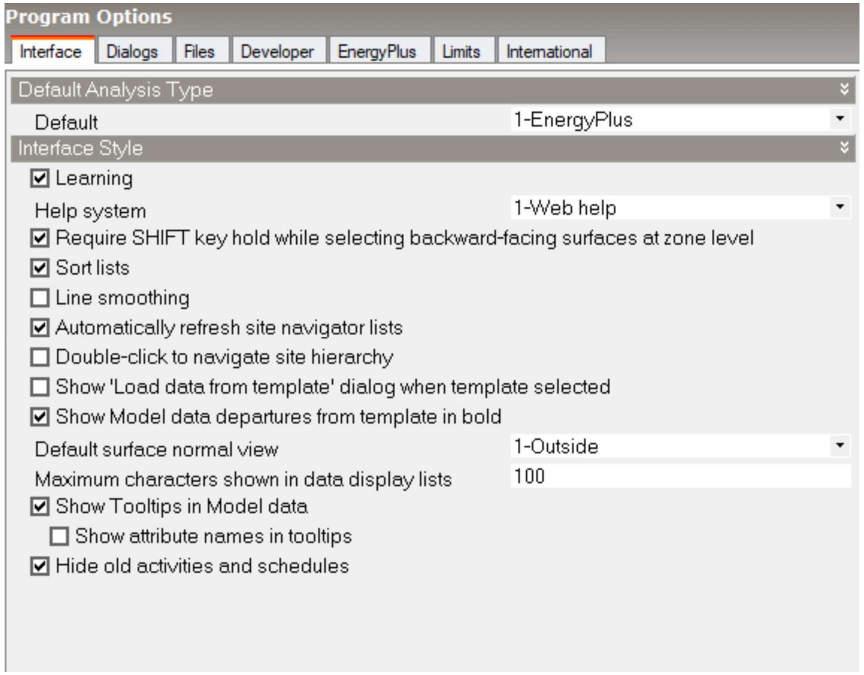
Opaque	Solar active facades	Double skin	**Double skin ventilated façade**	Typically a double curtain wall. Made of two glass wall layers separated by a gas cavity. This kind of facade can be (or not) ventilated, by natural, mechanical or mixed ventilation	**Yes**	**X**	**X**	**/**	**/**	**X**	- Higher window-to-wall ratio possible - Act as heat storage, so more efficient in cold climates - View to exterior kept - Good energy and thermal comfort performances - Acoustic and thermal insulation	- Less efficient in warm climate and unadvised in humid climate (condensation risk) - Costly in renovation - High maintenance if ventilated - Increased construciton weight	(Alberto, Ramos, & Almeida, 2017 ; Attia, Lioure, & Declaude, 2020 ; Favoino F. , et al., 2018 ; Pomponi, Piroozfar, Southall, Ashton, & Farr, 2016 ; Yazdizad, Rezaei, & Faizi, 2014 ; Zomorodian & Tahsildoost, 2018)
Opaque	Solar active facades	Double skin	**Double skin opaque ventilated facade**	Facade made with two layer separated by a gas cavity that can be from 2cm to more than 1m thick. One is a typical wall construction layer (opaque) and the other one can an opaque wall. This kind of facade can be (or not) ventilated, by natural, mechanical or mixed ventilation. An example is Trombe wall	**Yes**	**X**	**X**	**/**	**/**	**X**	- Less usual than transparent double-skin façade - Act as heat storage, so more efficient in cold climates - View to exterior kept - Acoustic and thermal insulation	- Less efficient in warm climate and unadvised in humid climate (condensation risk) - Costly in renovation - High maintenance if ventilated - Increased construction weight	(Alberto, Ramos, & Almeida, 2017 ; Attia, Lioure, & Declaude, 2020 ; Favoino F. , et al., 2018 ; Pomponi, Piroozfar, Southall, Ashton, & Farr, 2016 ; Yazdizad, Rezaei, & Faizi, 2014 ; Zomorodian & Tahsildoost, 2018)
Opaque	Solar active facades	Green	**Green façades**	Façades with growing plants	**No**	**X**	**X**	**/**	**/**	**X**	- Influence the thermal comfort and the energy performance - Regulation of heat transmitted to the building (radiation absorbed, evapotranspiration, transpiration) - Absoption of CO2 - High potential in urban environment - Part of the architectural aspect of the building	- Production of humidity	(Favoino F. , et al., 2018 ; Kalani & Lun Chow, 2017 ; Safikhani, Megat Abdullah, Remaz Ossen, & Baharvand, 2014)
Opaque	Solar active facades	Green	**Green roofs**	Roof with a vegetative layer	**No**	**X**	**X**	**/**	**/**	**/**	- Influence the thermal comfort and the energy performance - Regulation of heat transmitted to the building (radiation absorbed, evapotranspiration, transpiration) - Absoption of CO2 - High potential in urban environment - Part of the architectural aspect of the building	- Production of humidity	(Favoino F. , et al., 2018 ; Kalani & Lun Chow, 2017 ; Zhang, He, Zhu, & Dewancker, 2019)
Opaque	Solar active facades	PV	**Static photovoltaic panels**	Photovoltaic panels can be used as shading devices and thus electricity is produced due to the solar radiation	**No**	**X**	**X**	**/**	**X**	**/**	- Production of renewable electricity		(Attia, Lioure, & Declaude, 2020 ; Favoino F. , et al., 2018)
Opaque	Solar active facades	PCM	**Phase change materials**	PCMs are able to change their phase (usually liquid-solid transition) and can use the latent heat of this transition for thermal energy storage purposes. typology: paraffin wax, salt hydrates, bio PCM, etc. PCM can be used for opaque facade, shutters and glazing. But only opaque façade are considered in this family	**Yes**	**X**	**X**	**/**	**/**	**/**	- Help to improve the energy, thermal and visual comfort performances but need a large PCM layer to show significant results - peak temperatures reduced	- Sometimes difficult to predict the effect (can be negative), can bu used in opaque surfaces - Very dependent of the climatic conditions and locations. - few manufacturers - Weak optical properties - Expensive	(Attia, Lioure, & Declaude, 2020 ; Favoino F. , et al., 2018 ; Sibilio, Iavarone, Mastantuano, Mantova, & D'Ausilio, 2018)
Opaque	Active ventilative façades		**Closed cavity façade**	Advanced double-skin façade with a actively ventilated closed cavity. The air pulsed is dried before to enter in the cavity. Thereby, is allows less pollutant and particles to enter in.	**Yes**	**X**	**X**	**X**	**/**	**X**	- Less pollutant and particles in the cavity space - Less condensation's risks - Less maintenance needed - Longer durability - Smaller cavity needed compared to double-skin façade	- Very new technology, so very poor informaiton or studies made about it	(Attia, Lioure, & Declaude, 2020 ; Balog, 2019 ; Favoino F. , et al., 2018 ; Zani, Galante, & Ramming, 2020)
Opaque	Active ventilative façades		**Automated operable window**	Operable window controlled by a dynamic control strategy which controls the ventilation rate entering in the indoor space	**Yes**	**X**	**X**	**X**	**/**	**/**	- Better thermal performance and energy performance	- High investement for small impacts	(Attia, Lioure, & Declaude, 2020 ; Favoino F. , et al., 2018)
Opaque	Active ventilative façades		**Actively ventilated double-skin façade**	Considered as double-skin façade with mechanical or hybrid ventilation	**Yes**	**X**	**X**	**X**	**/**	**X**	- Shows better performance than naturally ventilated double-skin façade - Ventilation rate can be controlled - View kept - Act as a heat storage	- Less efficient in warm climate and unadvised in humid climate (condensation risk) - Costly in renovation - High maintenance if ventilated - Increased construction weight	(+E16:O27Alberto, Ramos, & Almeida, 2017 ; Attia, Lioure, & Declaude, 2020 ; Favoino F. , et al., 2018 ; Pomponi, Piroozfar, Southall, Ashton, & Farr, 2016 ; Yazdizad, Rezaei, & Faizi, 2014 ; Zomorodian & Tahsildoost, 2018)

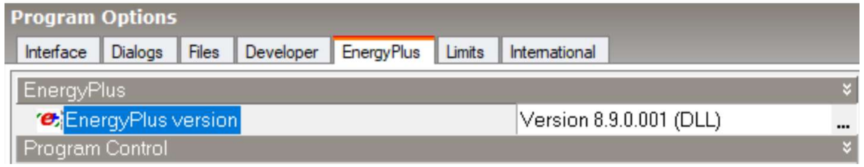
Appendix B: Screenshots of all steps made in DesignBuilder

Base case 600 Design Builder

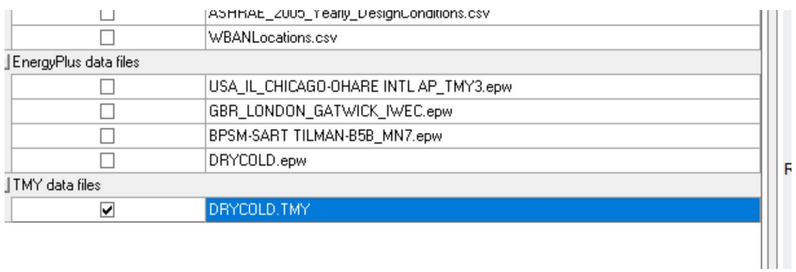


Site data

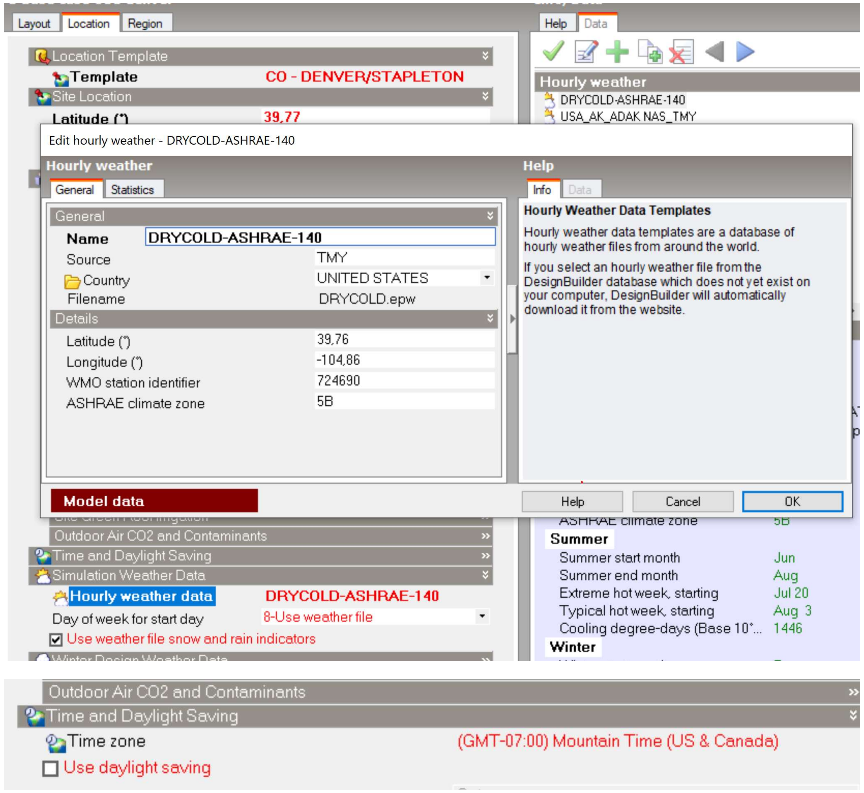




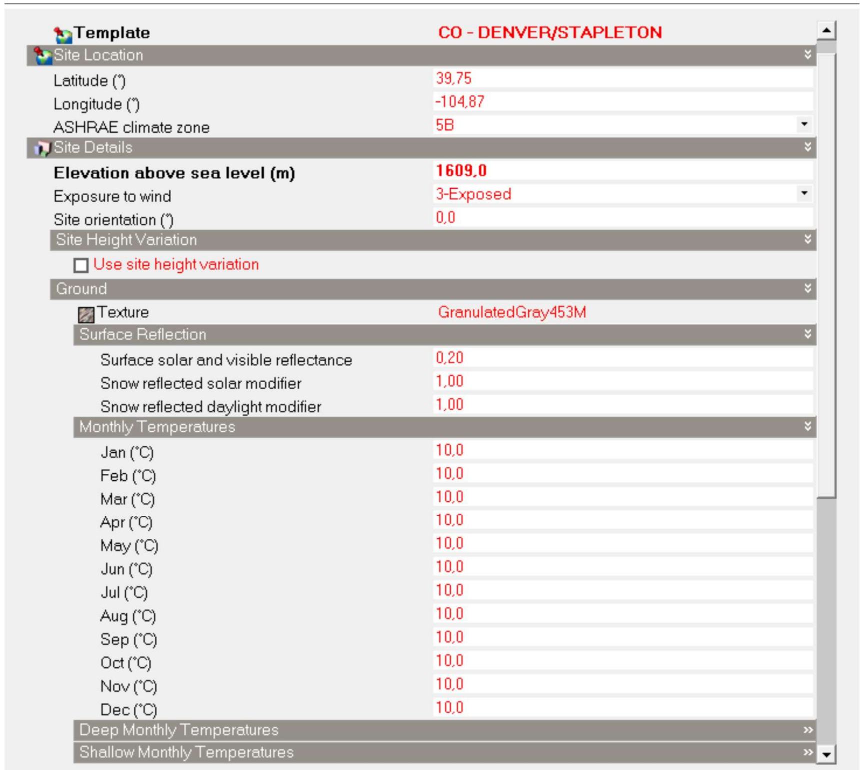
Different version than the one in the tutorial

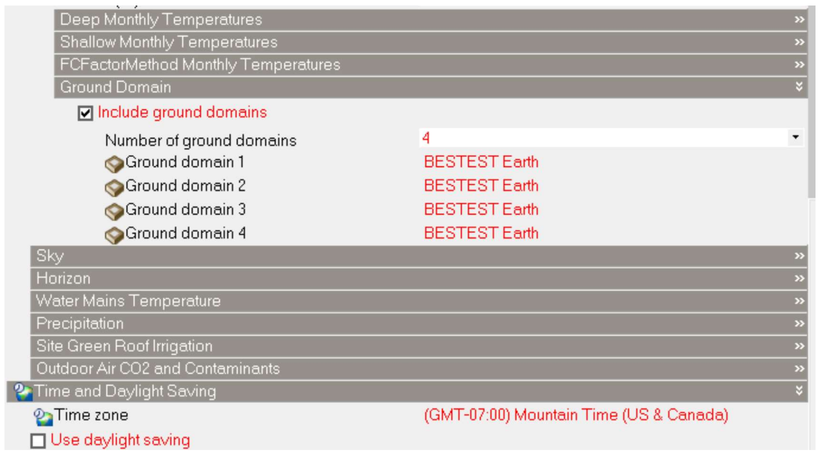


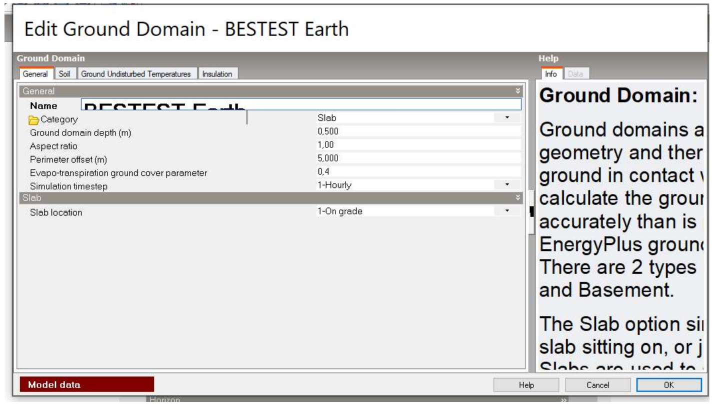
In **LOCATION tab it is possible to add the weather data file**



The Ground was changed into the location tab

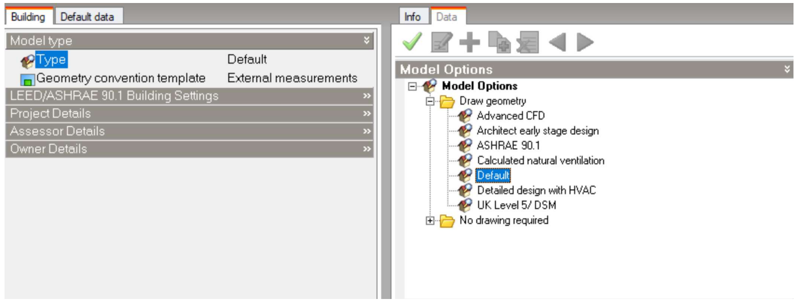






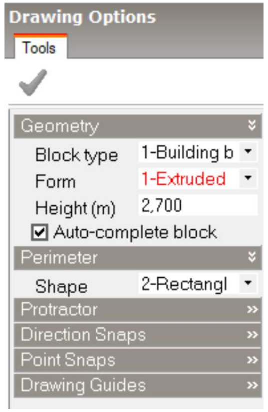
Selection of the hourly weather data files

Building

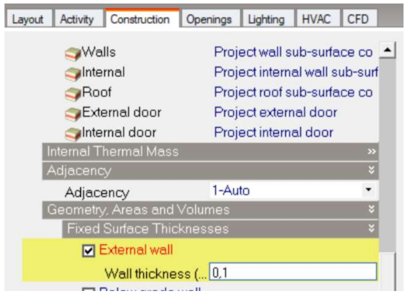


in layout tab, add building

we do not have "draw building+standard data", parametric

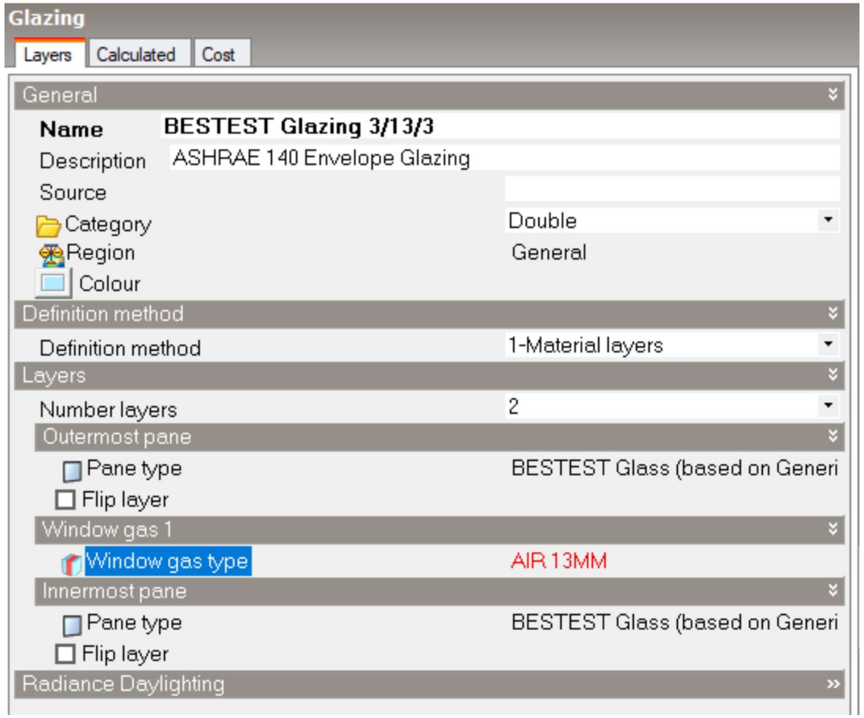


We cannot choose the wall thickness before to model.

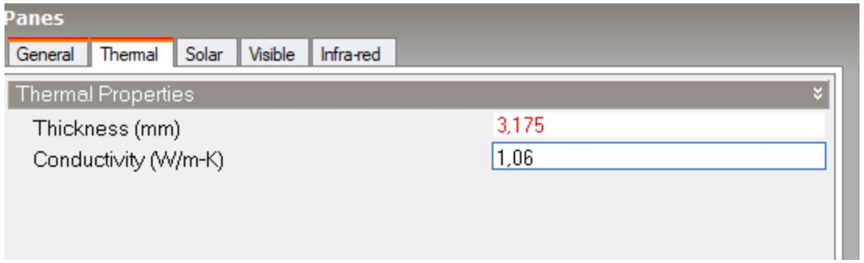


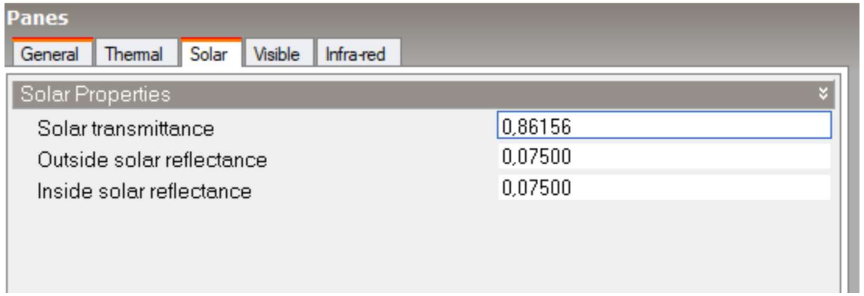
The building is modelled following the geometric data given.

Window

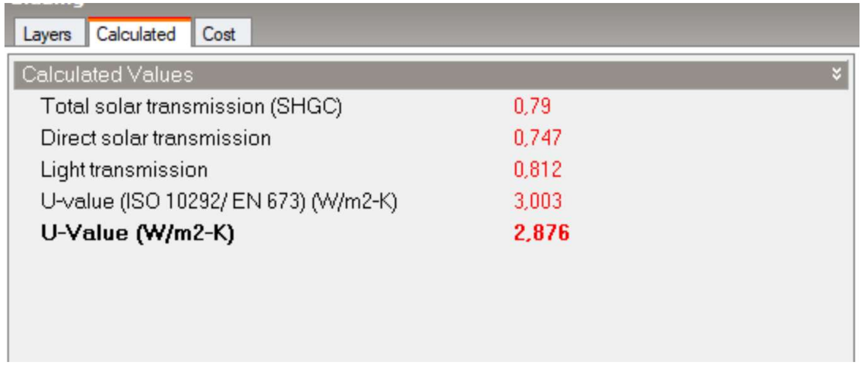


By clicking on the pane type, we created a new glass pane based on a Generic on : BESTEST Glass

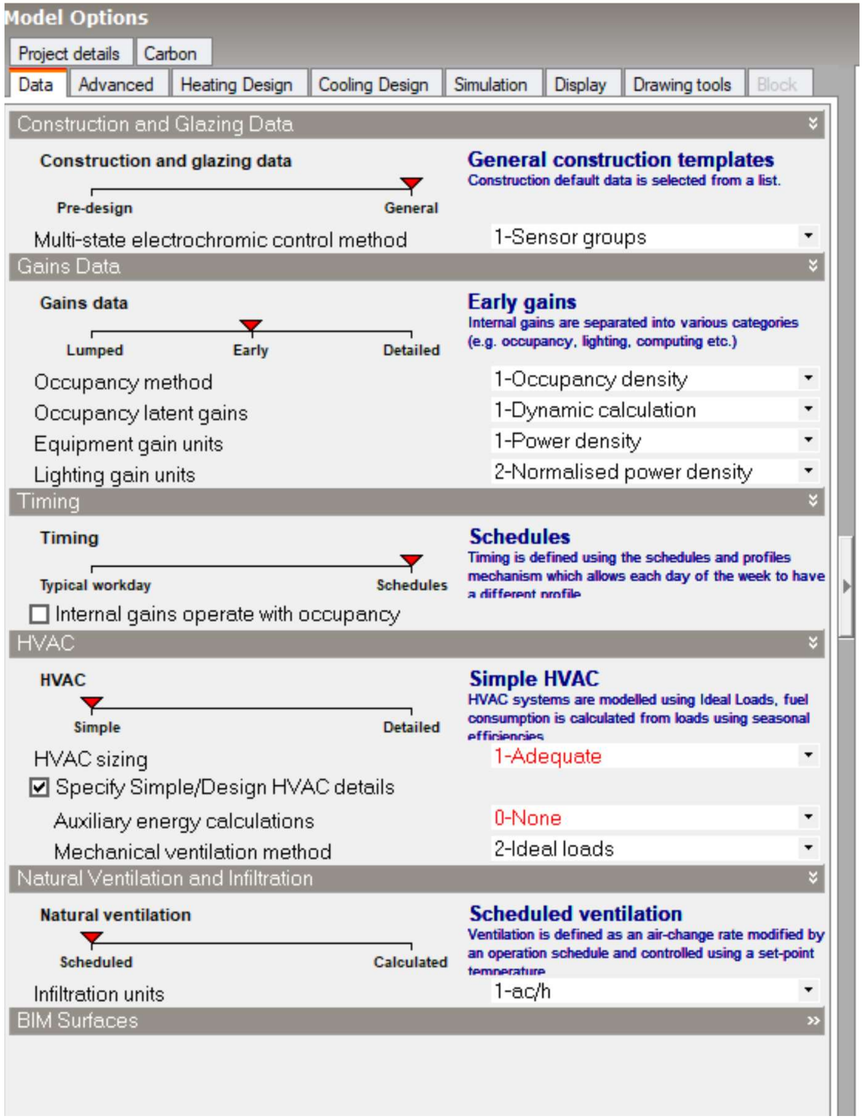


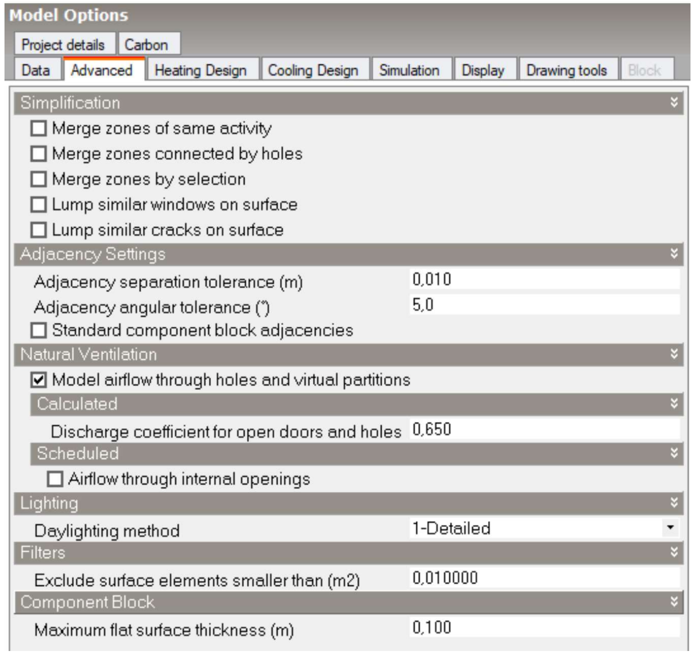


RESULTS TO have



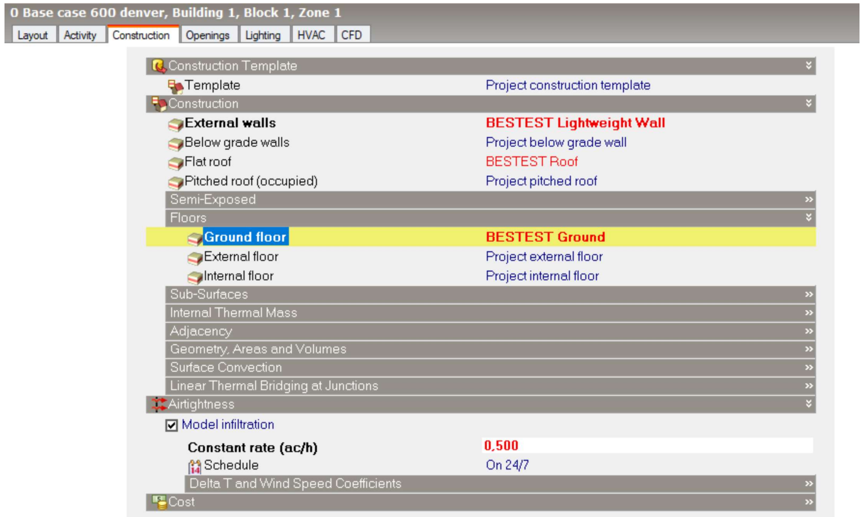
Model Option



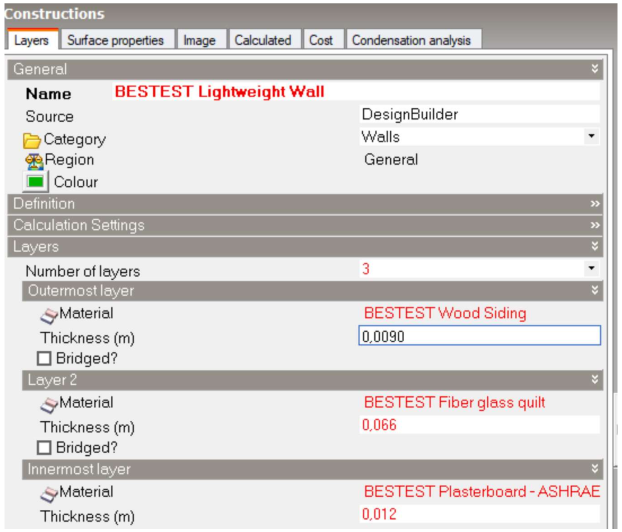


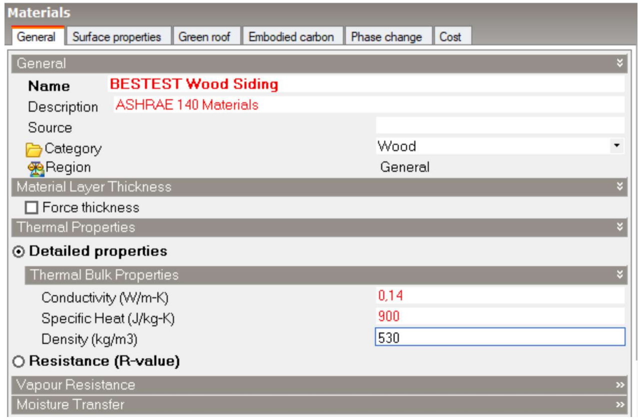
Construction tab

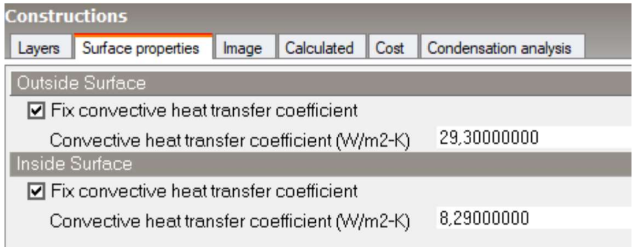
For each wall/floor/roof

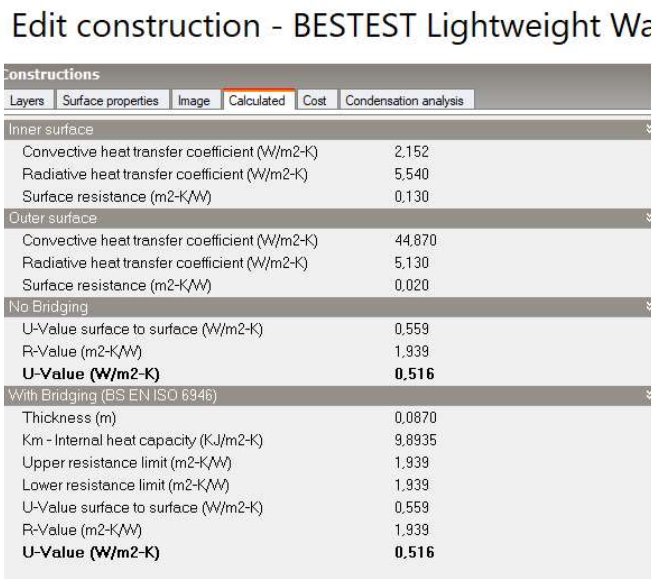


WALL









Now, do the same for the **ROOF**

Constructions

Layers | Surface properties | Image | Calculated | Cost | Condensation analysis

General	
Name	BESTEST Roof
Source	
Category	Roofs
Region	Colorado
Colour	
Definition	
Definition method	1-Layers
Calculation Settings	
Layers	
Number of layers	3
Outermost layer	
Material	BESTEST Roof deck
Thickness (m)	0,0190
☐ Bridged?	
Layer 2	
Material	BESTEST Fiber glass quilt
Thickness (m)	0,1118
☐ Bridged?	
Innermost layer	
Material	BESTEST Plasterboard
Thickness (m)	0,0100
☐ Bridged?	

Edit construction - BESTEST Roof

Constructions

Layers | Surface properties | Image | Calculated | Cost | Condensation analysis

Inner surface	
Convective heat transfer coefficient (W/m2-K)	4,460
Radiative heat transfer coefficient (W/m2-K)	5,540
Surface resistance (m2-K/W)	0,100
Outer surface	
Convective heat transfer coefficient (W/m2-K)	44,870
Radiative heat transfer coefficient (W/m2-K)	5,130
Surface resistance (m2-K/W)	0,020
No Bridging	
U-Value surface to surface (W/m2-K)	0,334
R-Value (m2-K/W)	3,113
U-Value (W/m2-K)	**0,321**
With Bridging (BS EN ISO 6946)	
Thickness (m)	0,1408
Km - Internal heat capacity (KJ/m2-K)	8,8872
Upper resistance limit (m2-K/W)	3,113
Lower resistance limit (m2-K/W)	3,113
U-Value surface to surface (W/m2-K)	0,334
R-Value (m2-K/W)	3,113
U-Value (W/m2-K)	**0,321**

And for the **FLOOR**

General	
Name	BESTEST Ground
Source	
Category	Floors (ground)
Region	Colorado
Colour	
Definition	
Definition method	1-Layers
Calculation Settings	
Layers	
Number of layers	2
Outermost layer	
Material	BESTEST Insulation
Thickness (not used in thermal calcs) (m)	1,0030
Innermost layer	
Material	BESTEST Timber flooring
Thickness (m)	0,0250
☐ Bridged?	

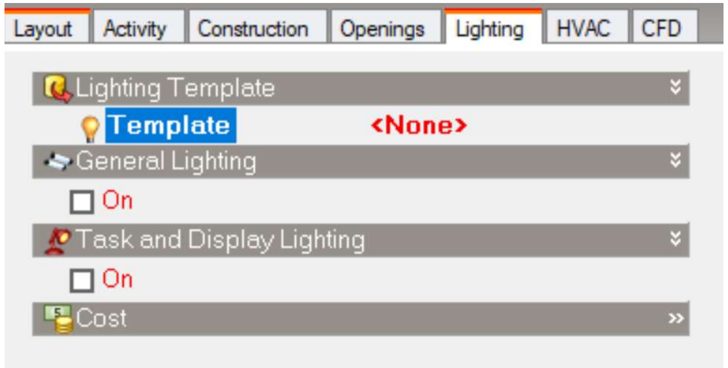
Edit construction - BESTEST Ground

Constructions

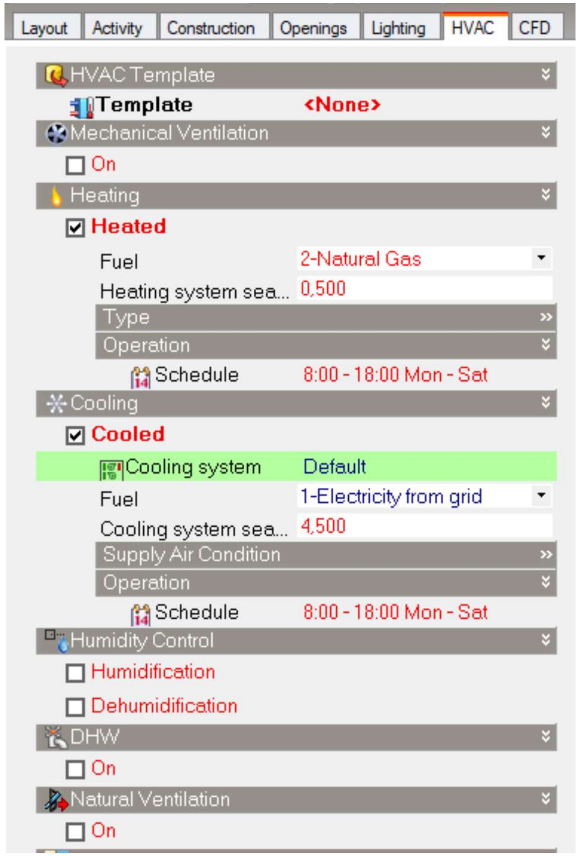
Layers | Surface properties | Image | Calculated | Cost | Condensation analysis

Inner surface	
Convective heat transfer coefficient (W/m2-K)	0,342
Radiative heat transfer coefficient (W/m2-K)	5,540
Surface resistance (m2-K/W)	0,170
Outer surface	
Convective heat transfer coefficient (W/m2-K)	44,870
Radiative heat transfer coefficient (W/m2-K)	5,130
Surface resistance (m2-K/W)	0,020
No Bridging	
U-Value surface to surface (W/m2-K)	0,040
R-Value (m2-K/W)	25,444
U-Value (W/m2-K)	**0,039**
With Bridging (BS EN ISO 6946)	
Thickness (m)	1,0280
Km - Internal heat capacity (KJ/m2-K)	19,5000
Upper resistance limit (m2-K/W)	25,444
Lower resistance limit (m2-K/W)	25,444
U-Value surface to surface (W/m2-K)	0,040
R-Value (m2-K/W)	25,444
U-Value (W/m2-K)	**0,039**

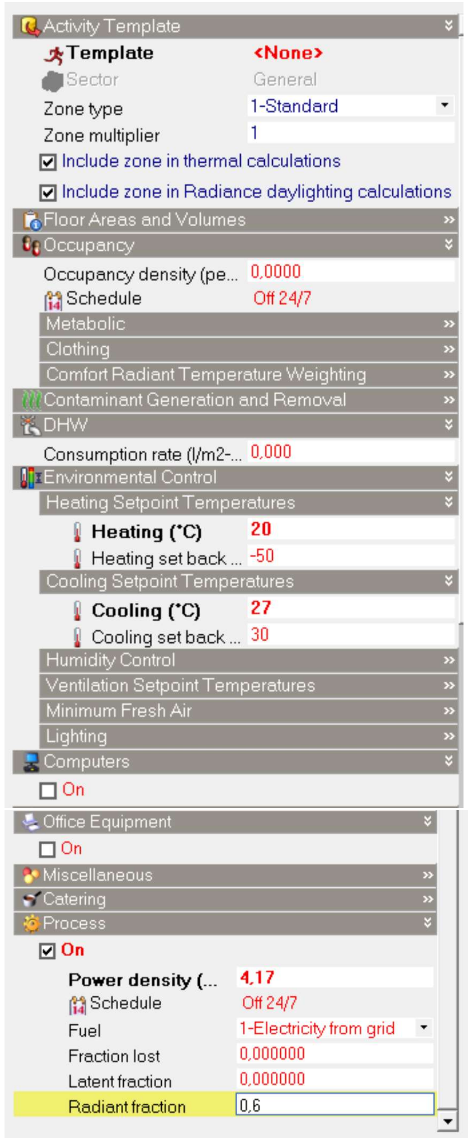
Lighting



HVAC Tab



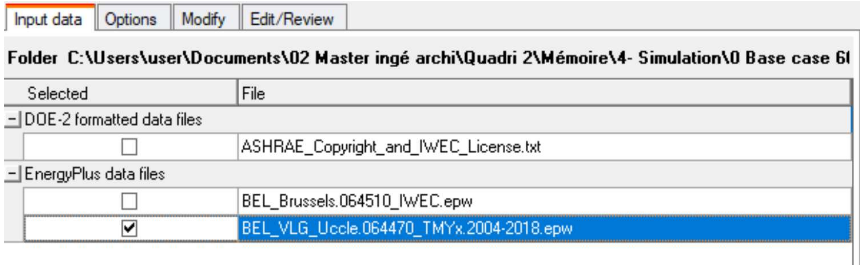
Activity

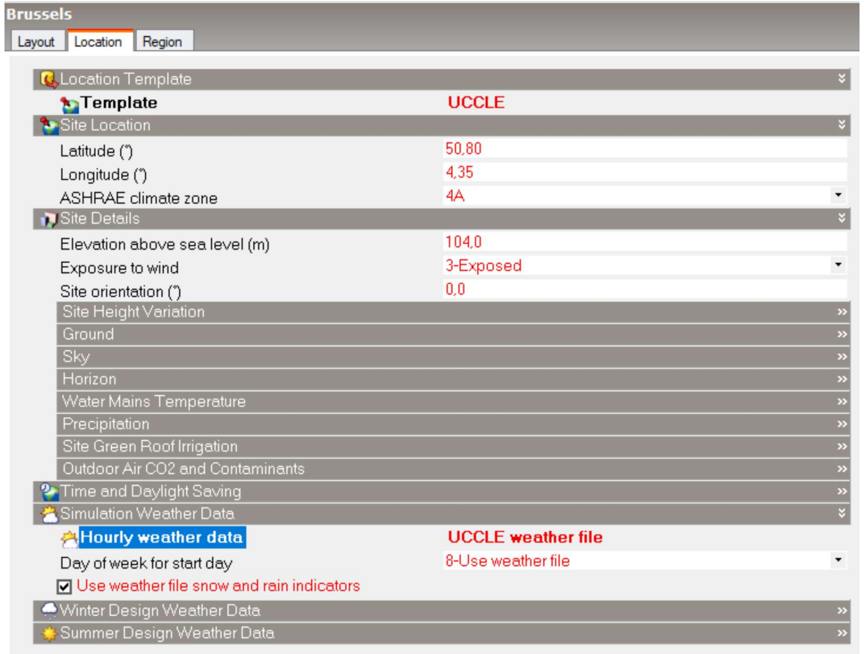


BRUSSELS BASE CASE 600

Changing location

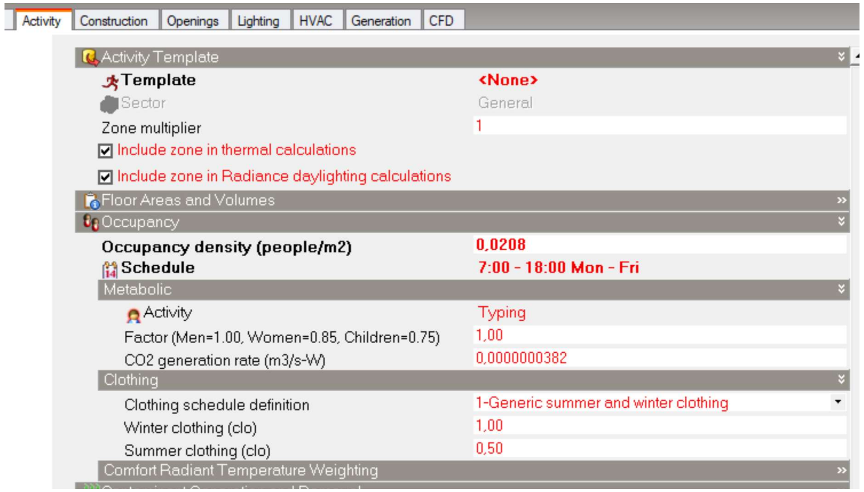
First we changed the location by BRUXELLES NATIONAL since it is the capital of the country.
Then, on download the weather data file from Energyplus





Location is set to Uccle since the most recent files are from this station.

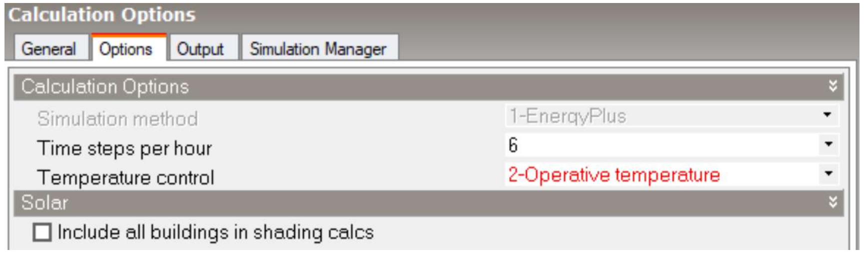
Activity tab



Occupancy has been change : 1person in the office during offices hours

Lighting put to 500lux

Equipment put to 150W (as Tällberg's study) = 3,125 W/m²

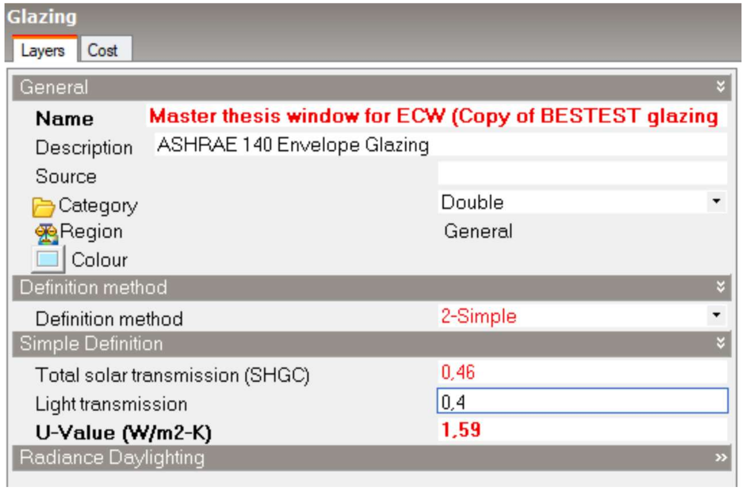


/!\ When simulating : **Operative temperature** have to be chosen

Chromogenic Glazing

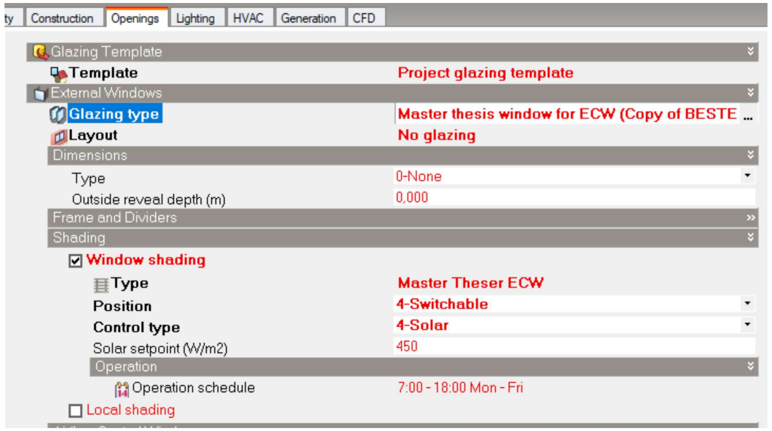
ECW

First we change the glazing type into the **clear state** of ECW

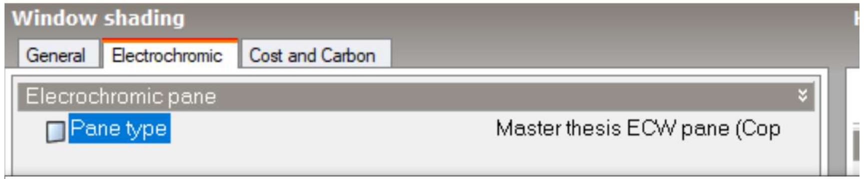


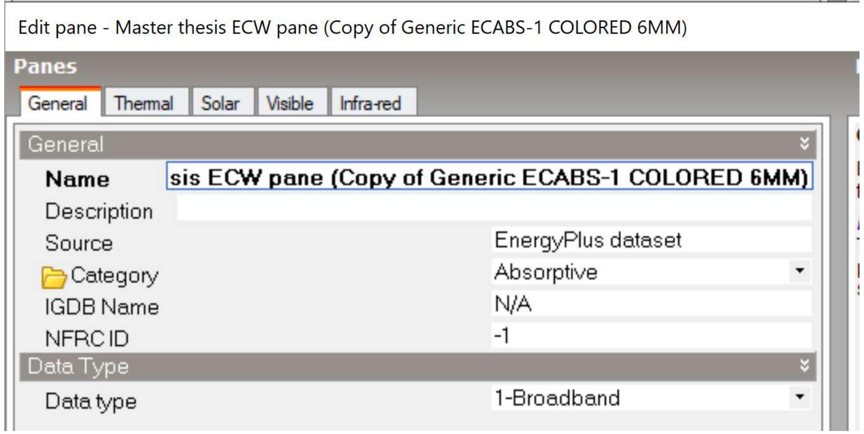
We choose definition method = 2-simple instead of 1- Material layers, to directly implement data given by Tällberg's study (NB : Light transmission = Visible transmittance)

Window shading box checked = **dark state**

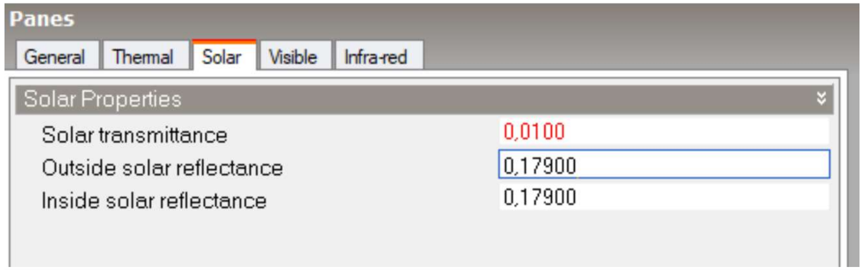


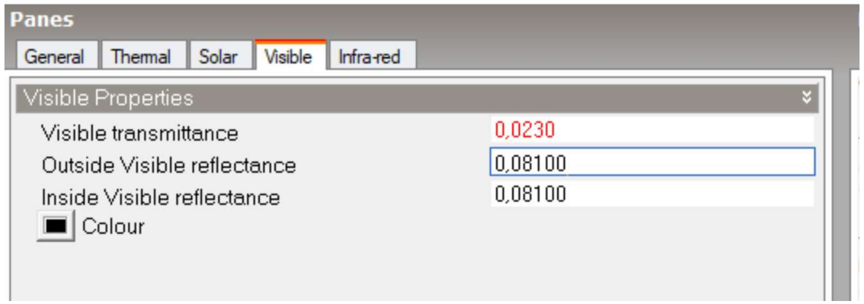
We change the Type of electrochromic glazing by clicking on the type and then the pane type :





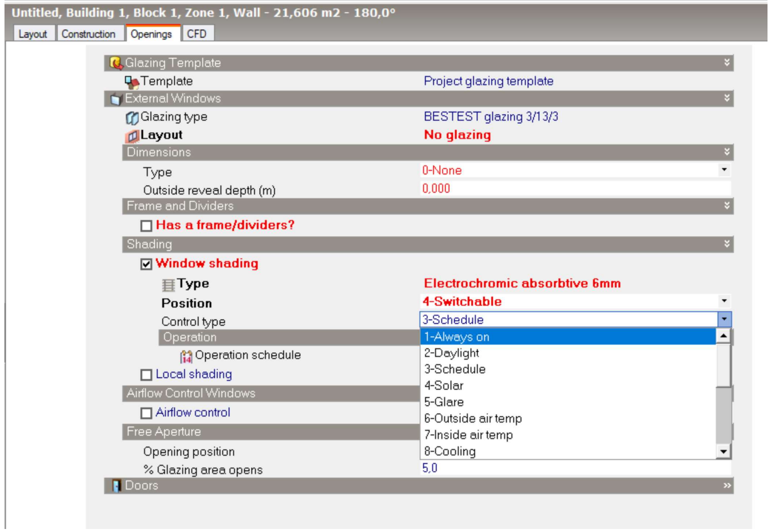
From Tällberg's study, we have T_vis, T_sol and g_value. Thus we will change solar and visible transmittance.

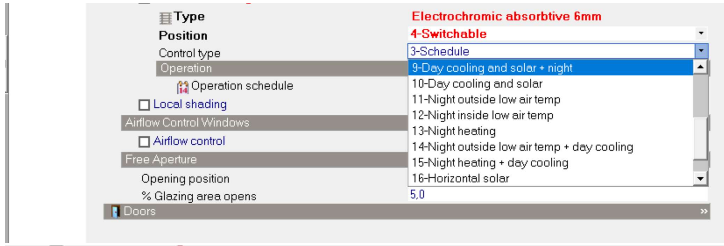


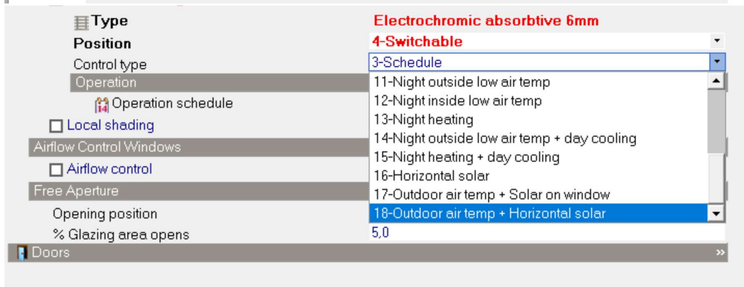


Control strategies

Then there is a lot of control type : Solar=Sun, daylight and operative temperature were made in the Tallberg study.

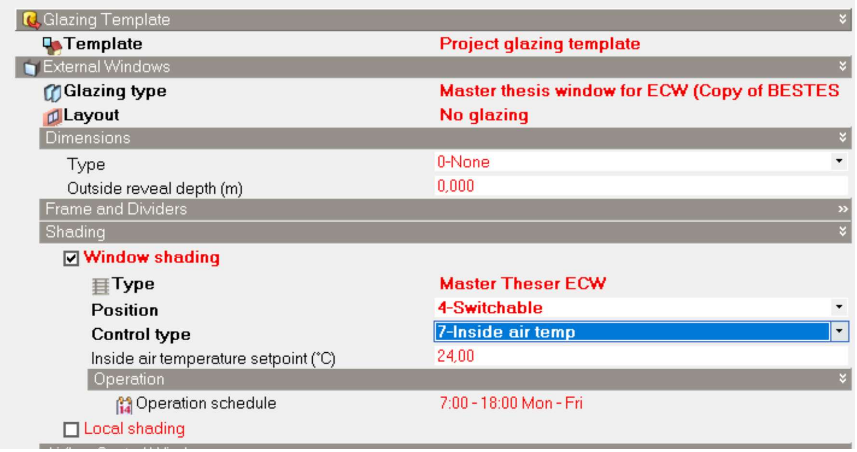




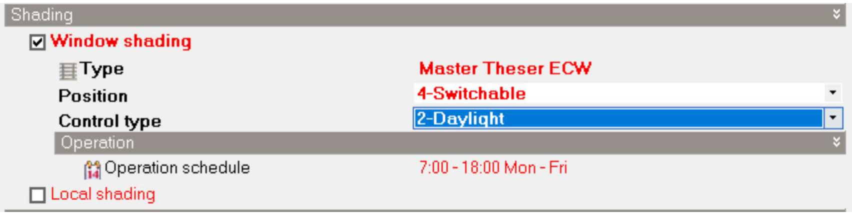


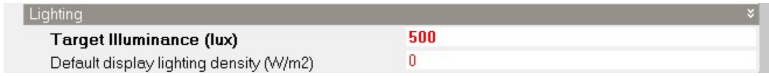
First choose : <4=solar : 450 W/m²

Second : 7=inside air temp : 24°C

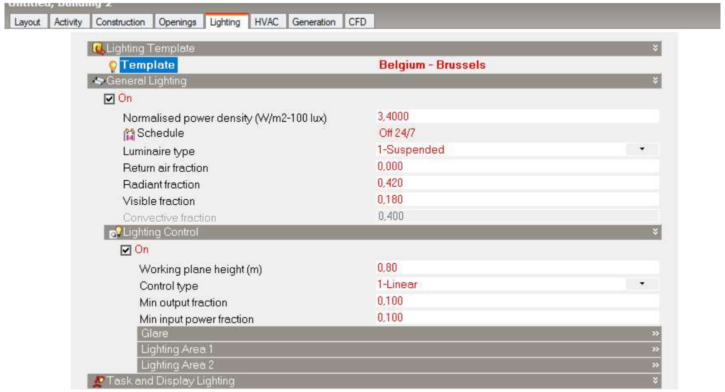


3th, 2 daylight, target put on 500 lux



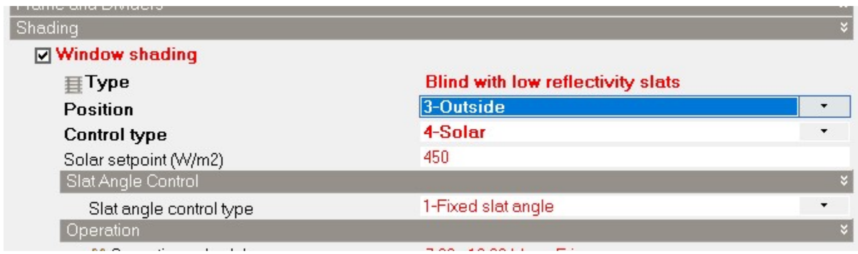


To operate, the lighting control have to be on

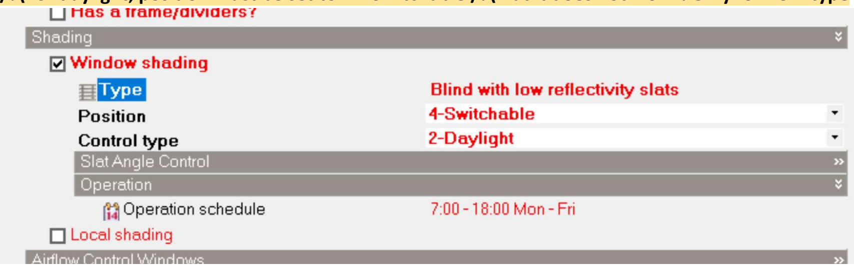


Dynamic shading

Control type are exactly **the same than for ECW** . We choose Blind low reflectivitity. To "normalize" results



/!\ for daylight, position must be set to 4 – Switchable /!\ But it does not work ! Only for ECW type

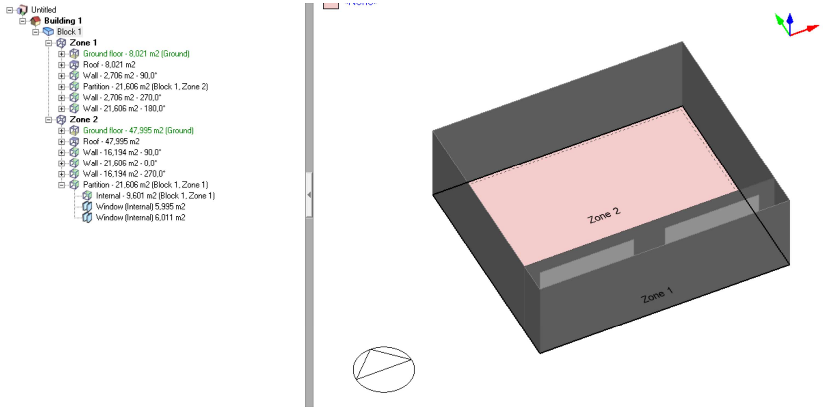


We try 5-Glare and it works. Thus this control strategy will be also studied.

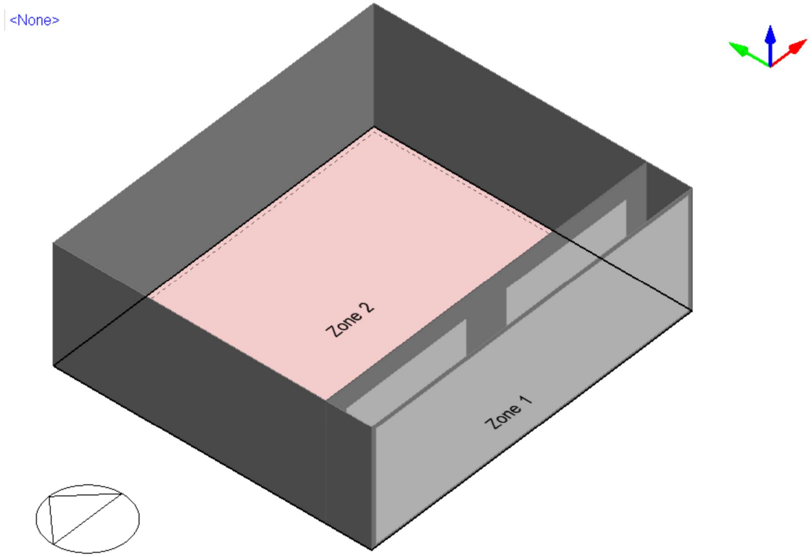
Double skin façade natural ventilated

A double layer has been modelled into the same block. We first extruded the south wall and deleted the initial windows. Then we made a partition of 1m layer.

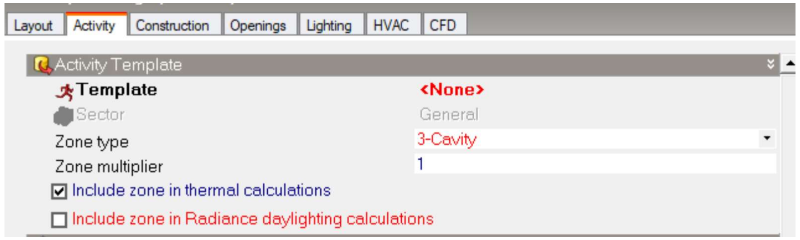
These windows (still from BESTEST) were redefined at surface level on the partition.



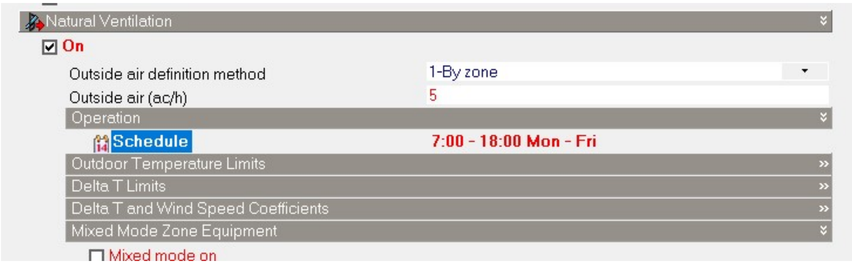
A big window was designed to represent a “curtain wall” with a Window-to-Wall ration of 91% (maximum allowed)



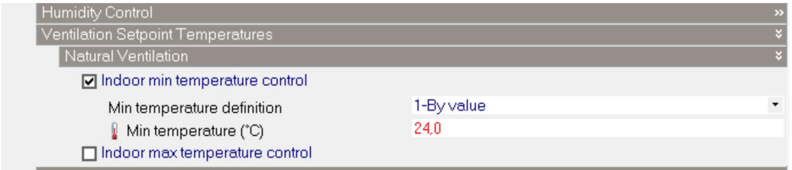
Activity where put to 3-Cavity



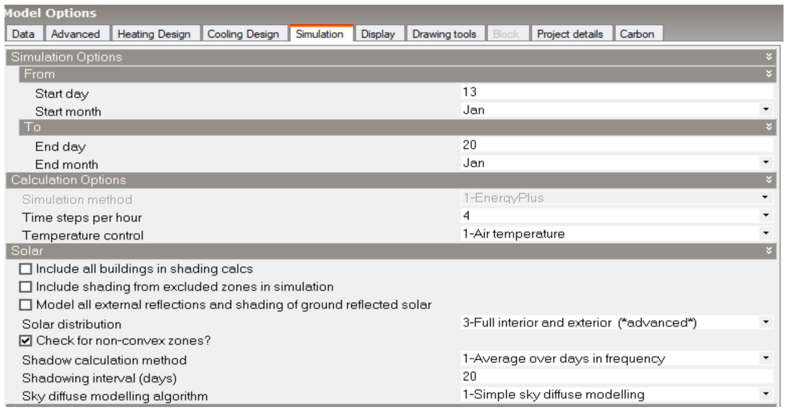
Firstly we assume no natural ventilation. Then we added it. At HVAC tab : default setting of DB but schedule only during offices hours



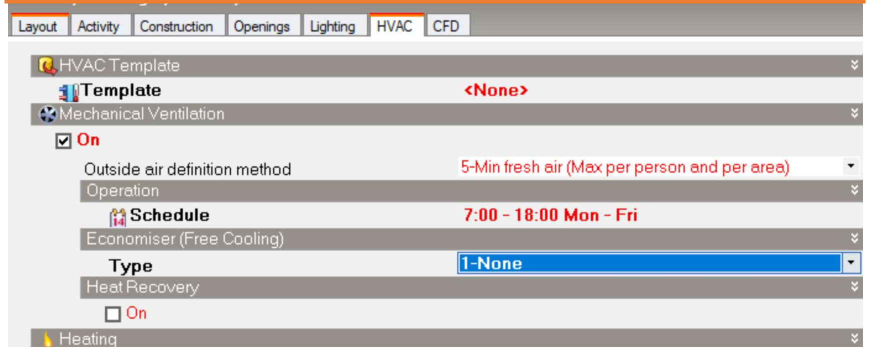
At activity tab



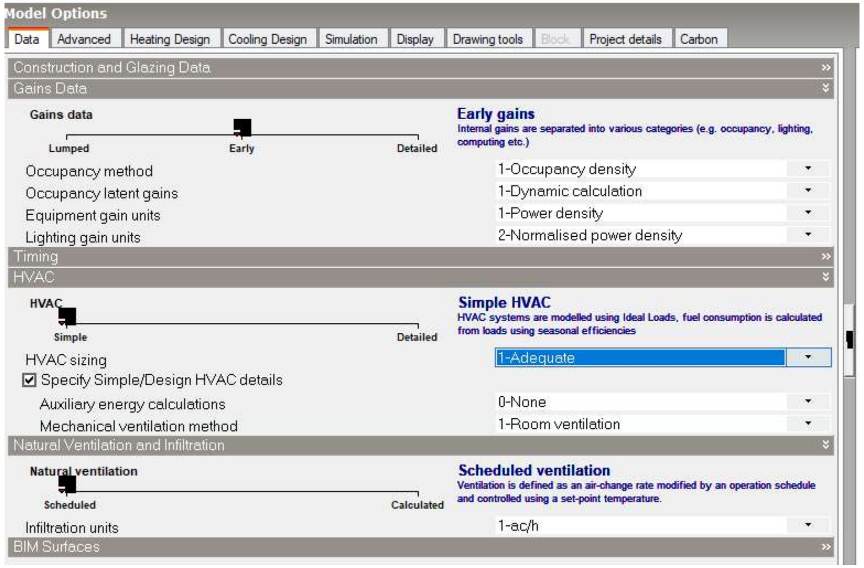
Because of the cavity, in model option, the solar distribution have to be 3-full exterior and interior



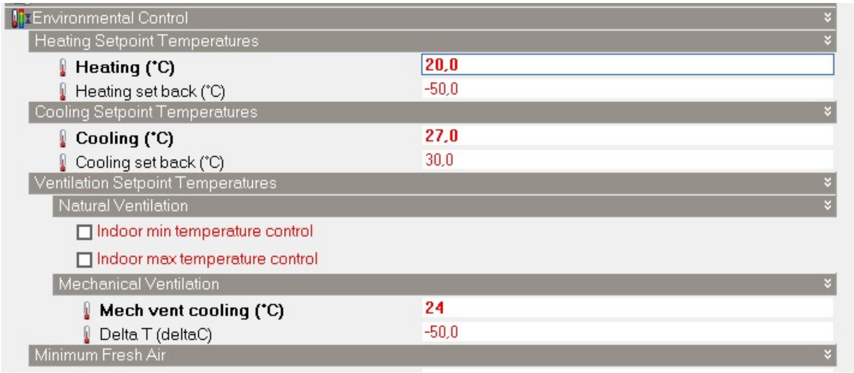
Double skin façade mechanically ventilated

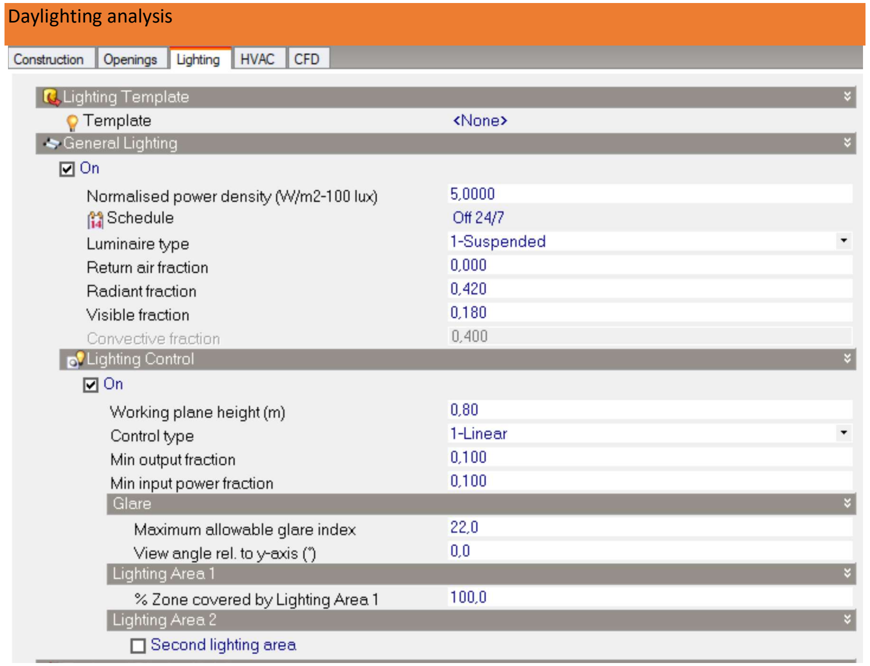


In model option, we have to put the mechanical ventilation method on 1-Room ventilation. By this way it is possible to control the mechanical ventilation with a temperature setpoint.

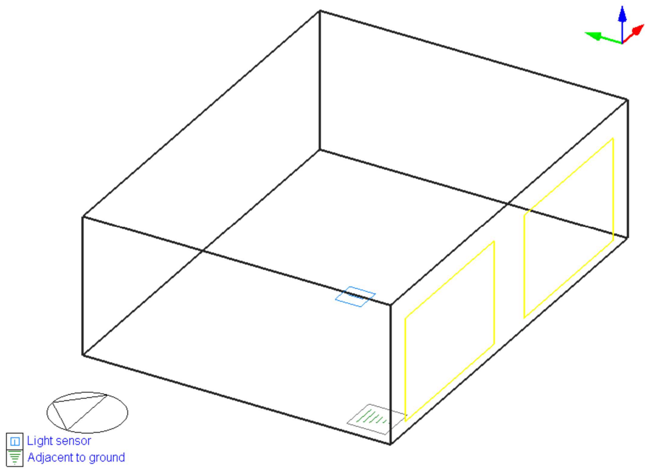


Mechanical ventilation cooling setpoint is the same than for natural ventilation

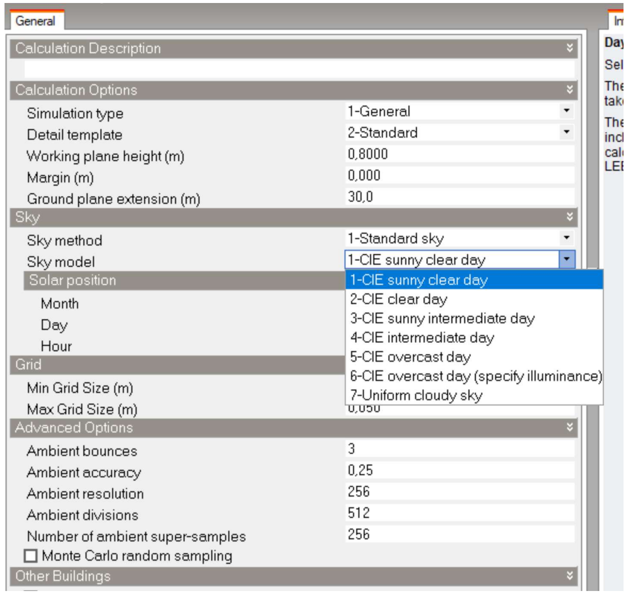




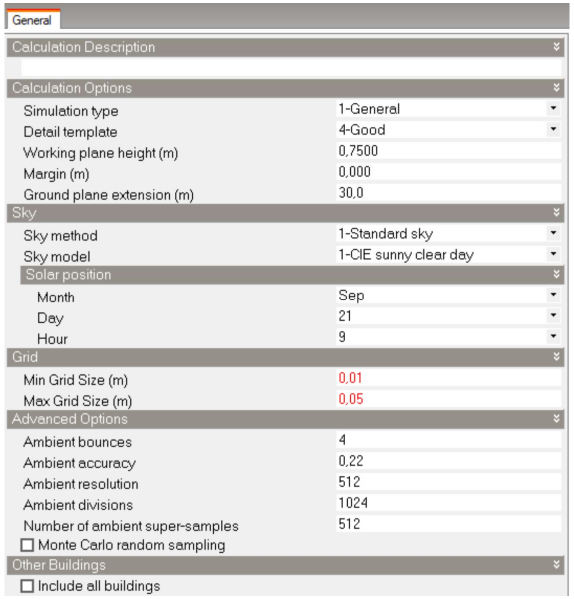
Control lighting on



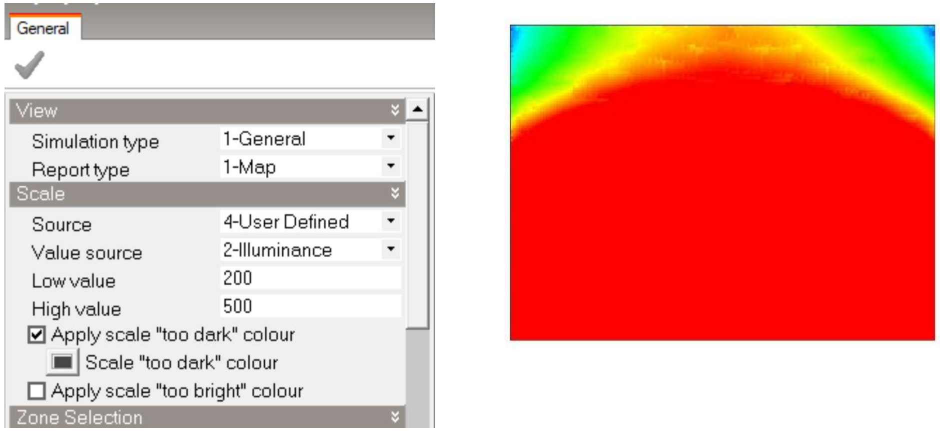
Light sensor is by default in the middle of the room



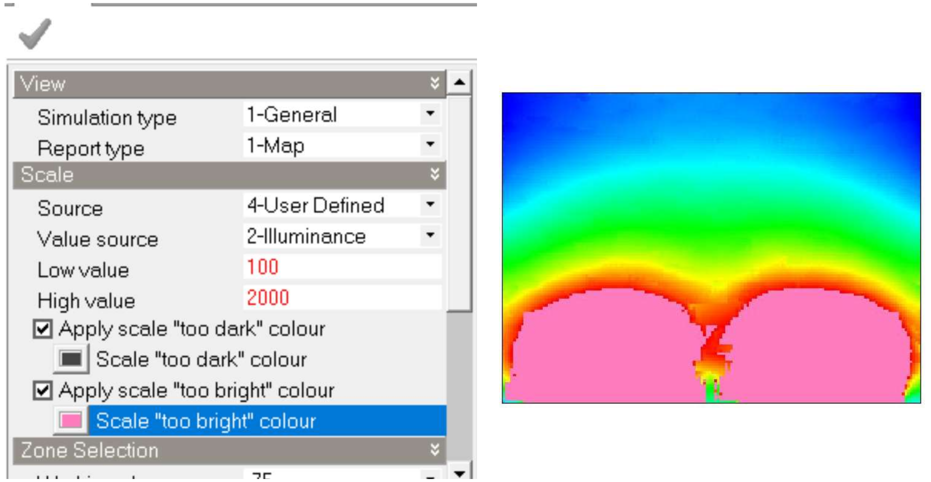
Sky model can be set for different type of day (cloudy, sunny,...)



Grid is changed to have more relevant results.



High value is changed to see illuminance below 500lux



Or Between 100 and 2000 lux for example

Appendix C: Hourly weather data file of Uccle.

Figures 1, 2 and 3 below show some of the climate data of epw file. Figure 1 presents the daily maximum and minimum temperature profile. It can be seen on the Figure 2 that solar radiation is higher in summer than in winter. Furthermore a second peak is visible in April. Regarding the Figure 3, the wind is mostly oriented South West which confirms what was said before. The windiest month is February which is shown on Figure 4.

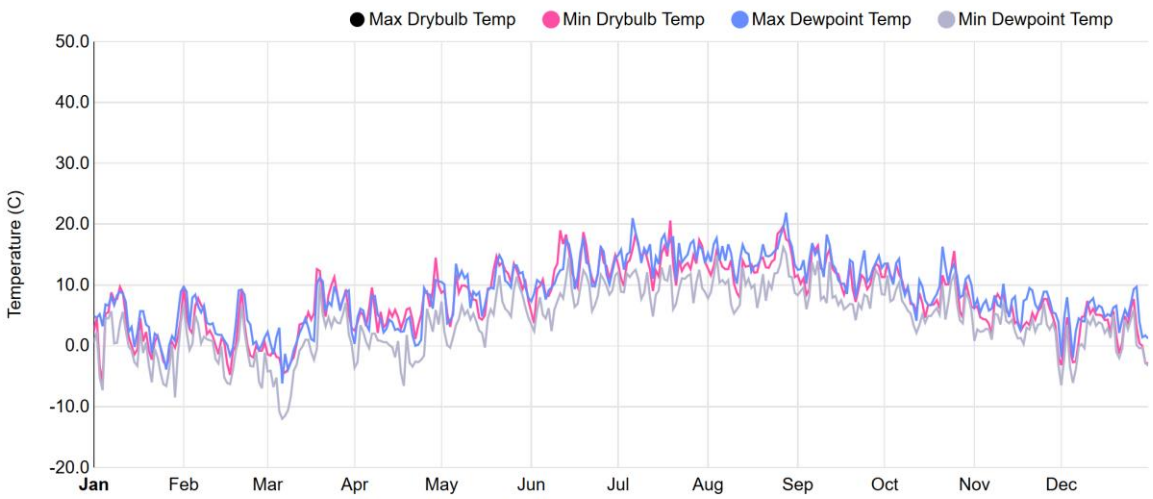


Figure 1 - Daily maximum and minimum temperature profile of the climate file (EnSimS, 2019)

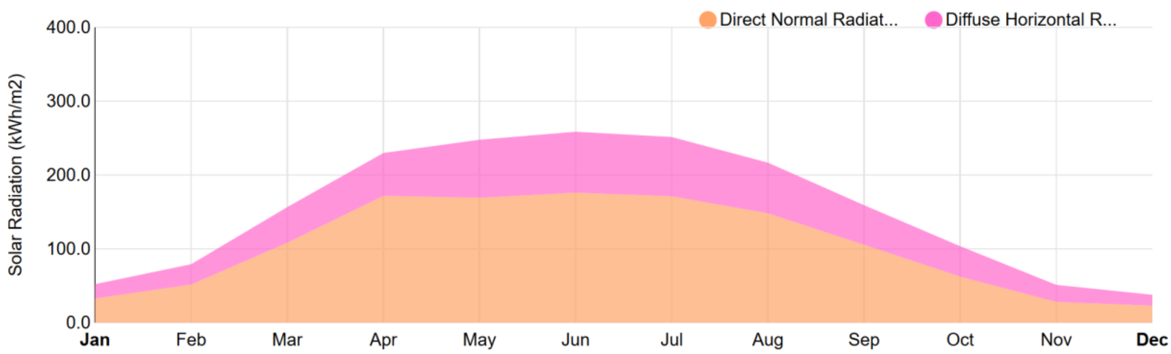


Figure 2 – Monthly total solar radiation profile of the climate file (EnSimS, 2019)

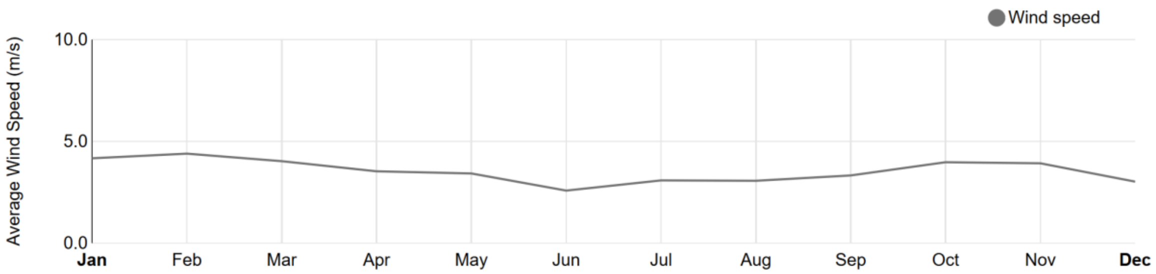


Figure 3 – Monthly total solar radiation profile of the climate file (EnSimS, 2019)

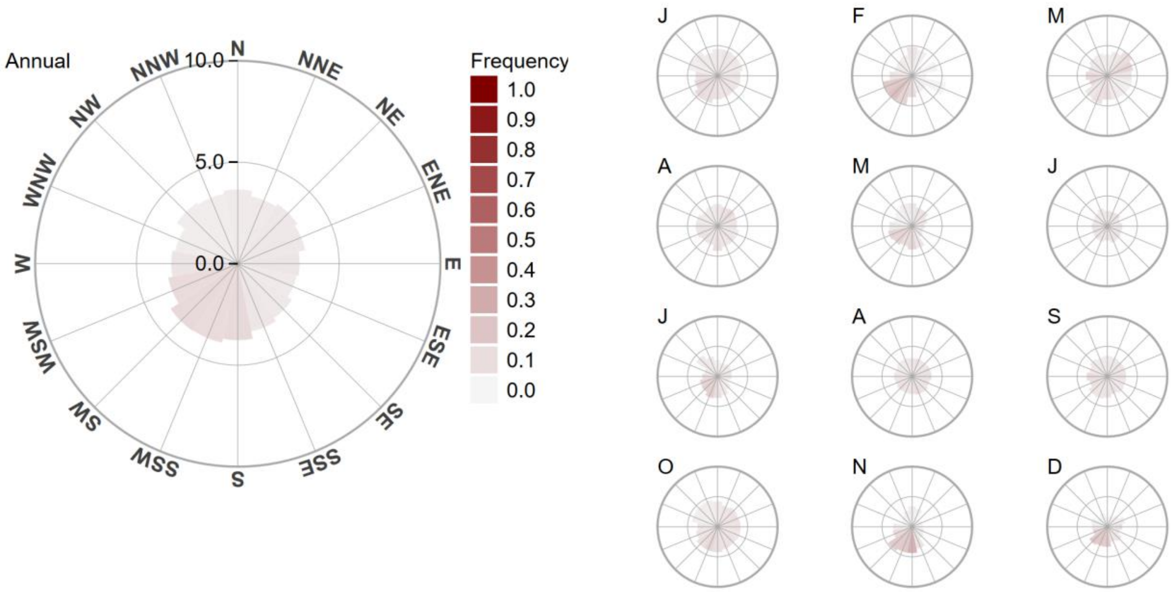
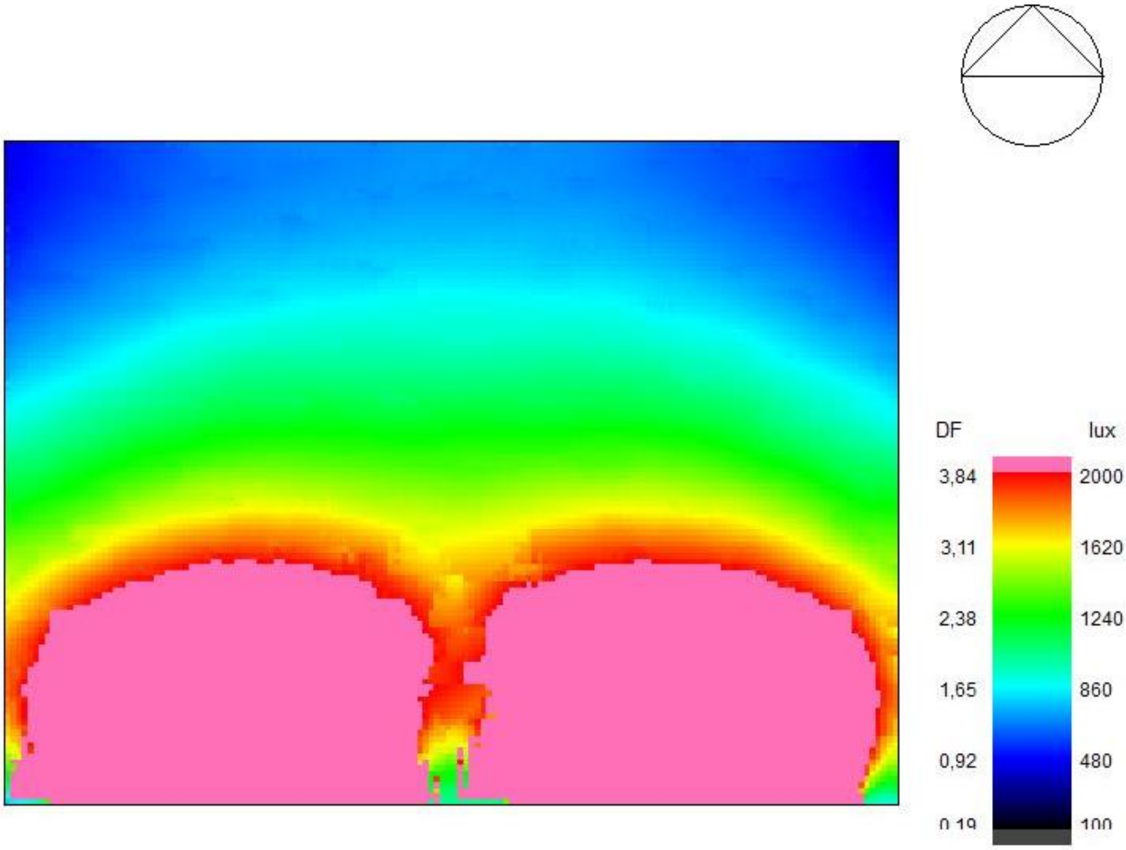
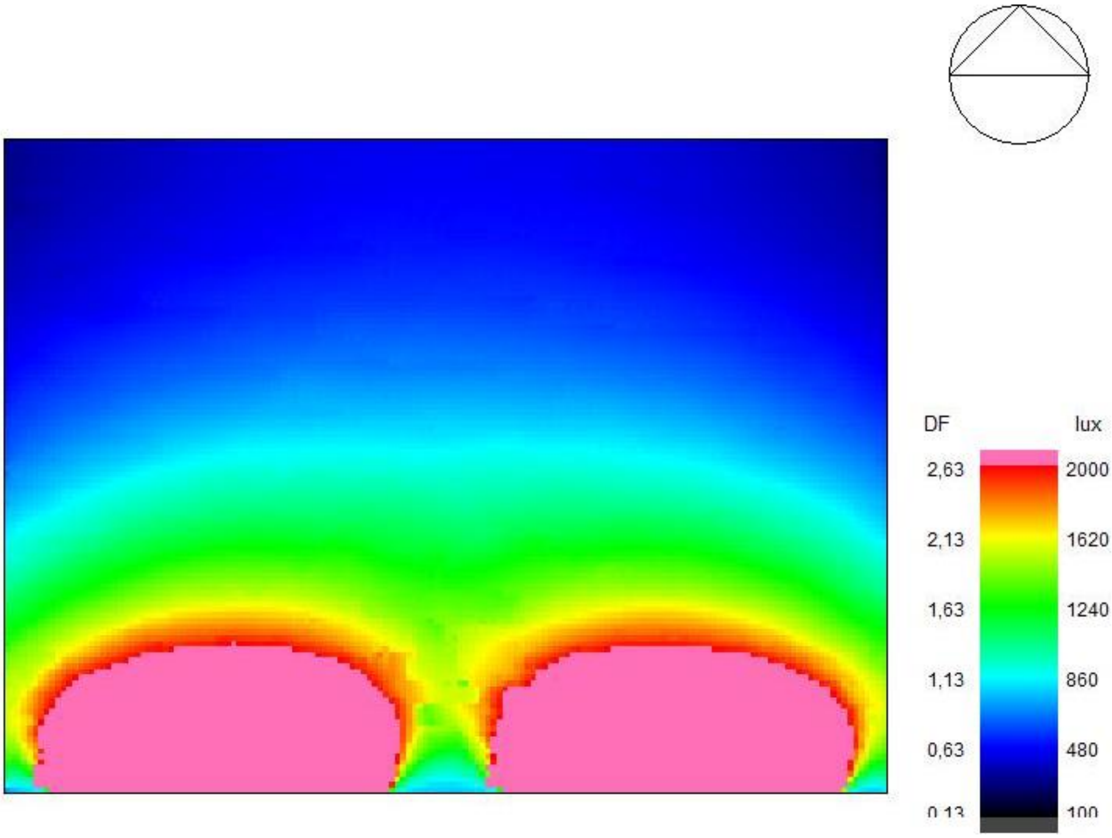


Figure 4 – Monthly wind direction of the climate file (EnSimS, 2019)

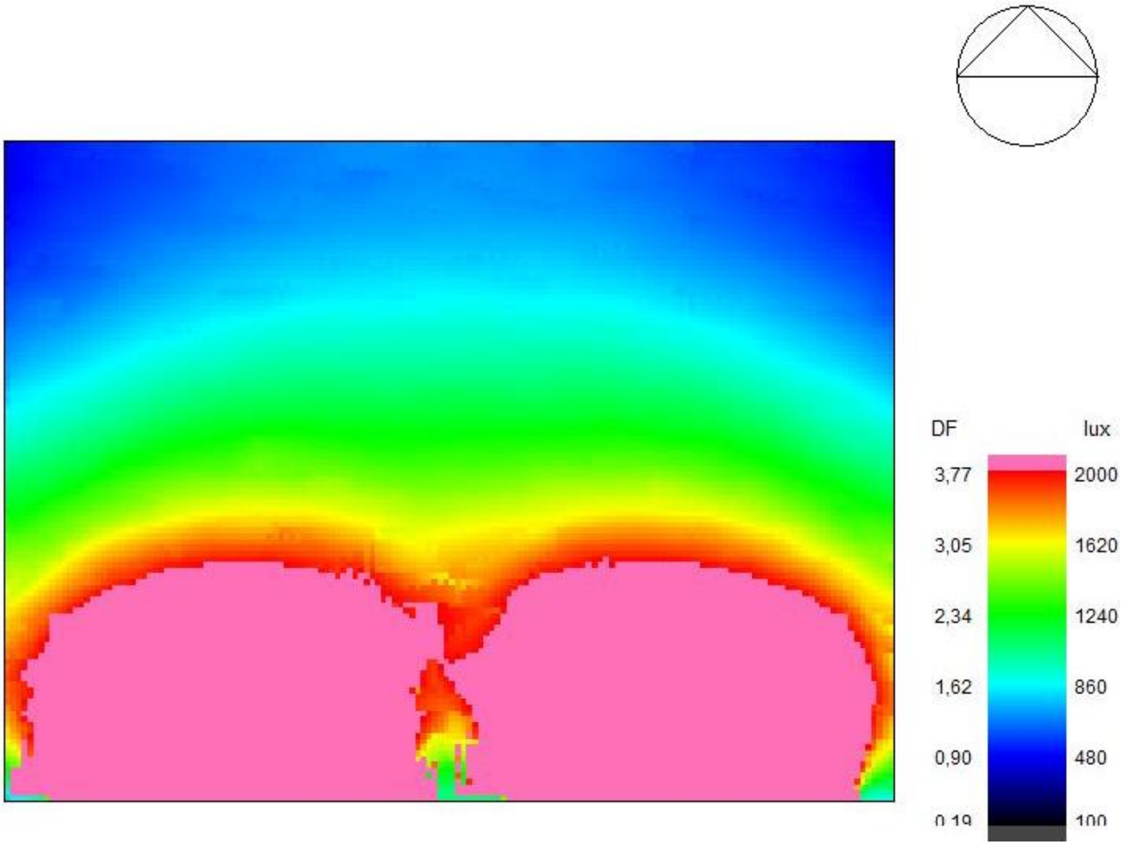
Appendix D: Daylighting results



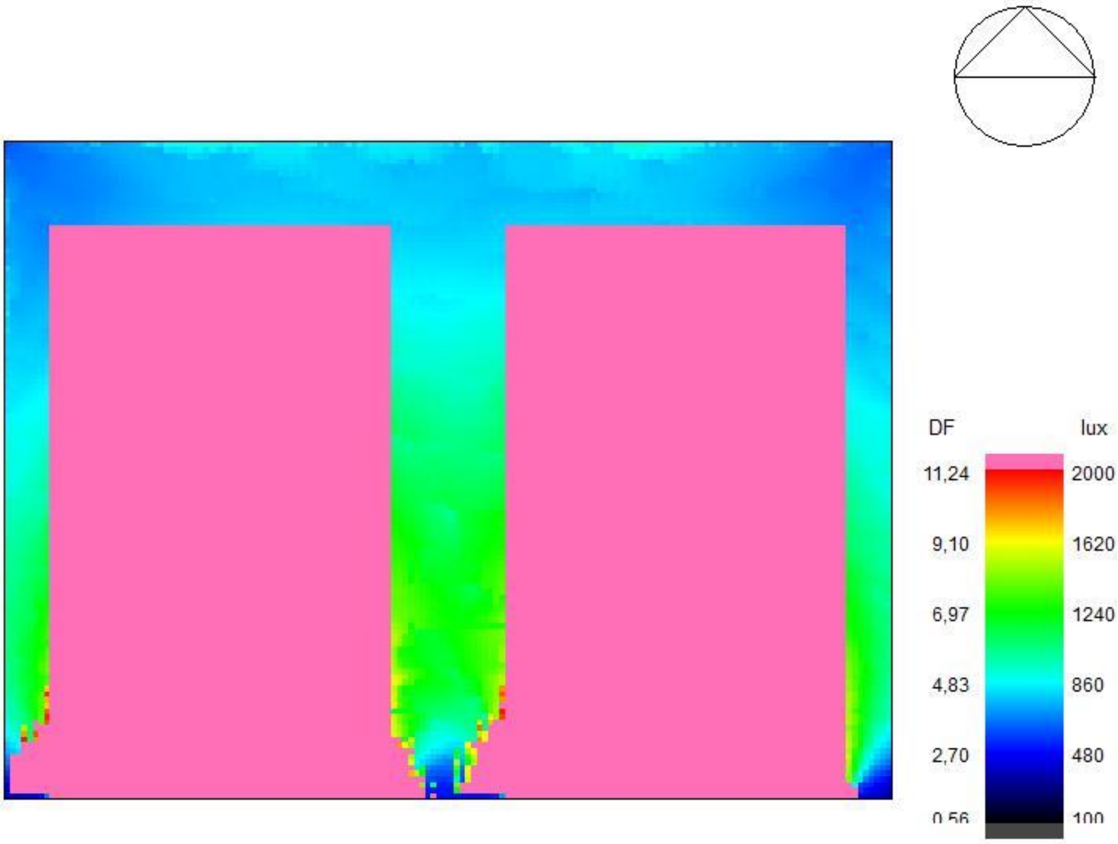
Base case, 21st March, 12 am



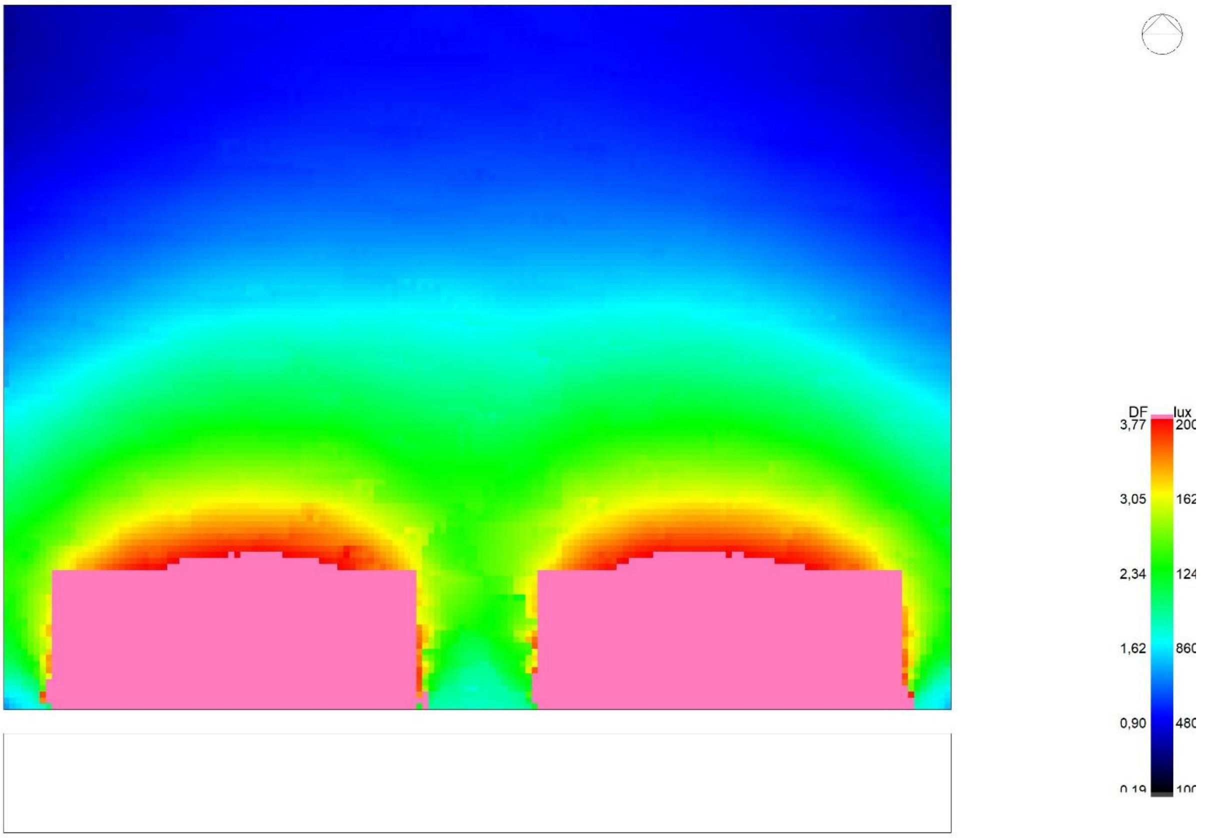
Base case, 21st June, 12 am



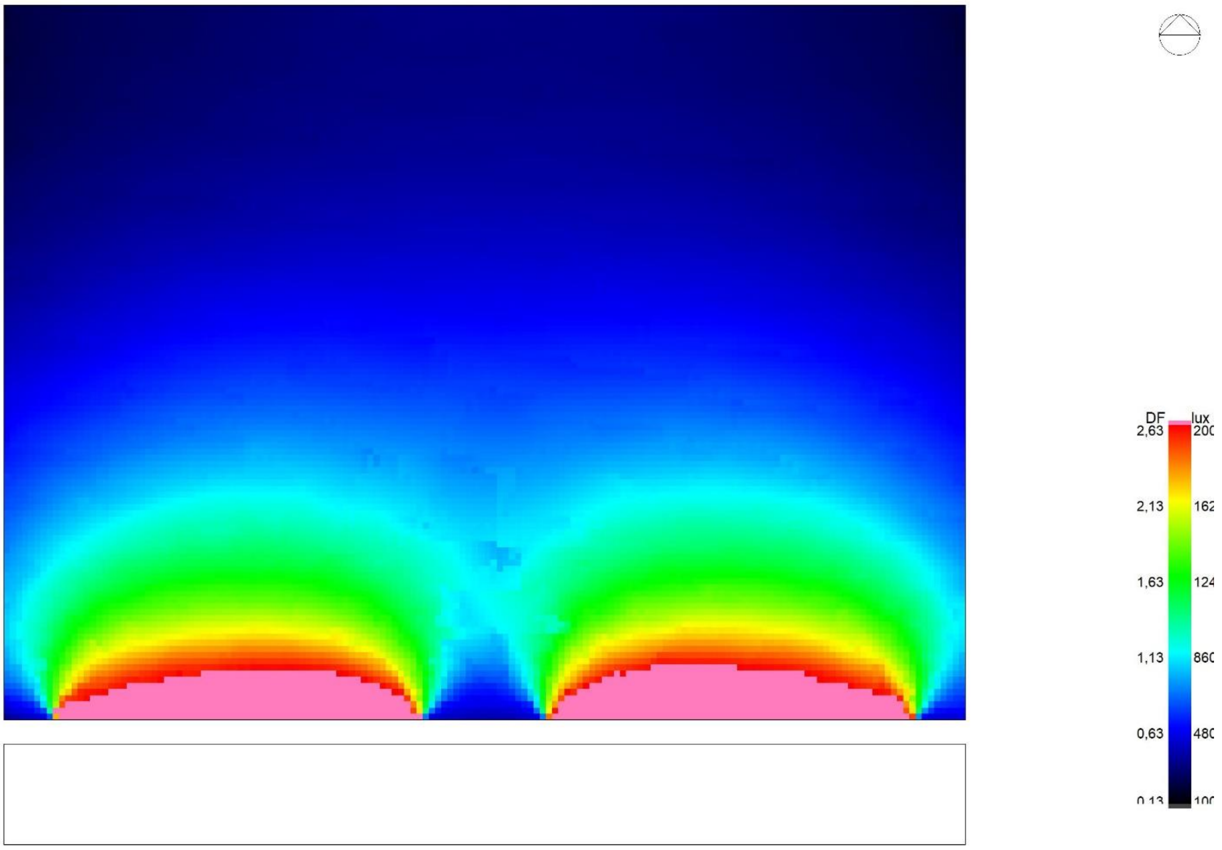
Base case, 21st September, 12 am



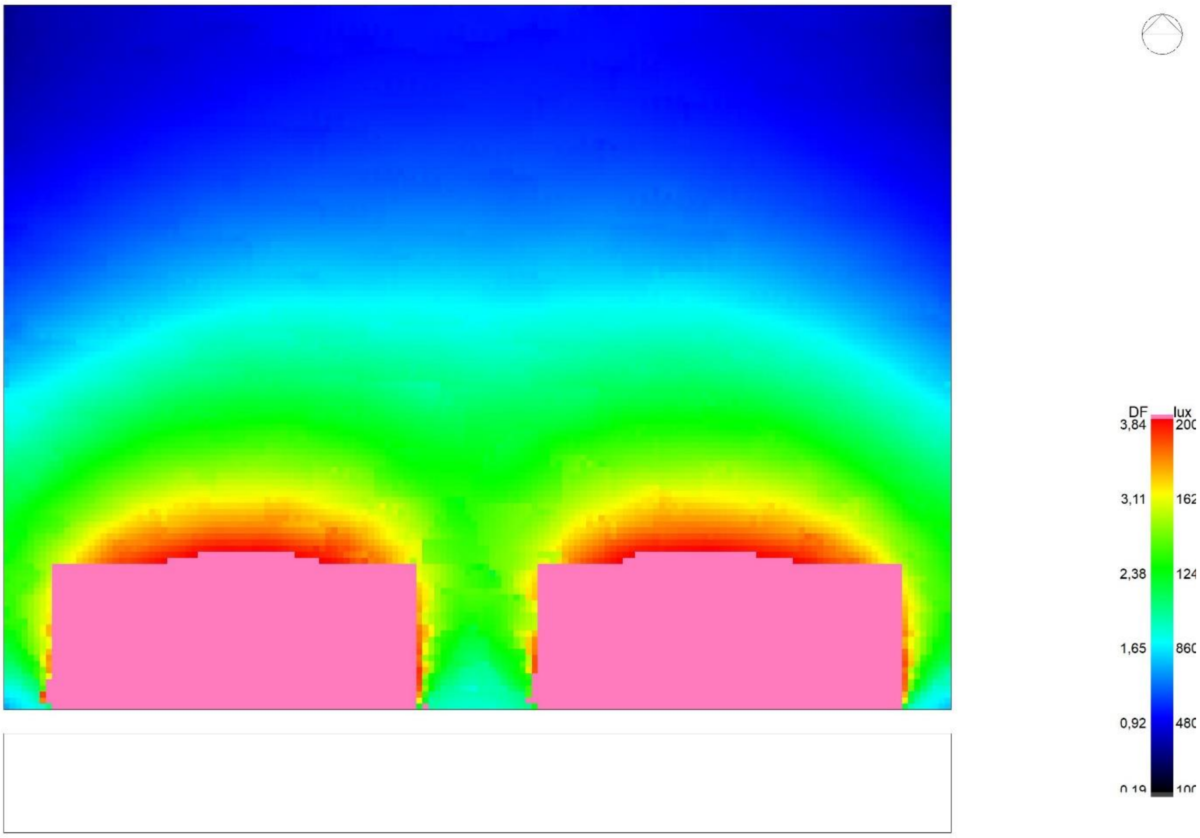
Base case, 21st December, 12 am



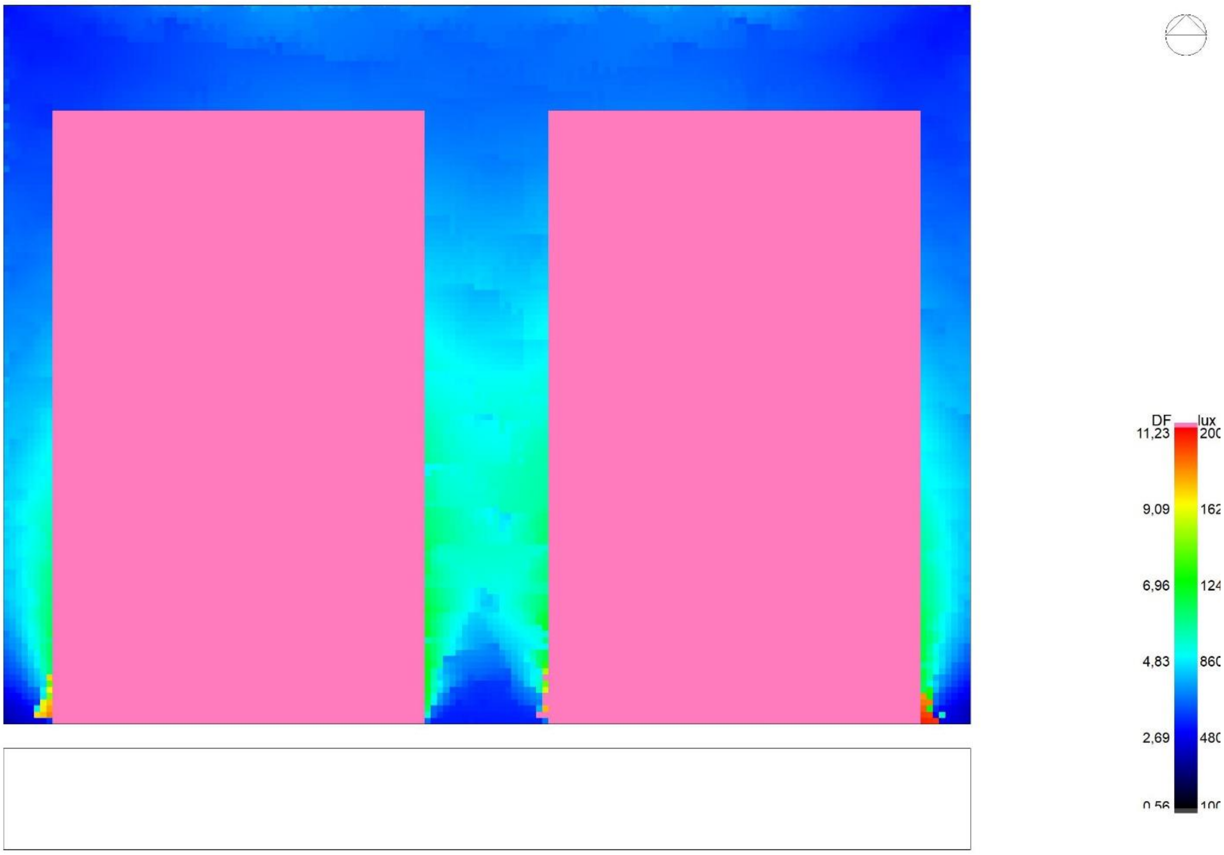
Double-skin façade case, 21st March, 12 am



Double-skin façade case, 21st June, 12 am



Double-skin façade case, 21st September, 12 am



Double-skin façade case, 21st December, 12 am

Appendix E: Summary of the annual results given by all simulations

					Energy						Thermal comfort				
Diminutive	**Case**	**Ventilation mode**	**Control strategy**	**Threshold**	**Heating demand (kWh/year)**	**Heating loads saving (%)**	**Cooling demand (kWh/year)**	**Cooling loads saving (%)**	**Annual loads (kWh)**	**Energy saving (%)**	**Hours of discomforts with winter clothes (hours)**	**Hours of discomforts with summer clothes (hr)**	**Hours of discomforts with winter or summer clothes (hr)**	**Total hours of discomfort (hr)**	**Improving of thermal comfort (%)**
Base case	Base	-	-	-	3804	100,0	5287	100,0	9091	100,0	2221	1282	704	4207	100,0
ECW0	Electrochromic	-	On during schedule	-	3824	100,5	2880	54,5	6704	73,7	1864	1555	655	4074	96,8
ECW1		-	Solar	450 W/m²-K	3969	104,3	2601	49,2	6570	72,3	1974	1664	862	4500	107,0
ECW2		-	Operative temp.	24°C	3845	101,1	2922	55,3	6767	74,4	2078	1360	702	4140	98,4
ECW3		-	Glare	22	3804	100,0	5287	100,0	9091	100,0	2221	1282	704	4207	100,0
ECW4		-	Daylight	500 lux	3969	104,3	2600	49,2	6569	72,3	1974	1664	862	4500	**107,0**
DS0	Dynamic shading	-	On during schedule		3834	100,8	2409	45,6	6243	68,7	1780	1667	692	4139	98,4
DS1		-	Solar	450 W/m²-K	3840	100,9	2886	54,6	6726	74,0	2029	1461	722	4212	100,1
DS2		-	Operative temp.	24°C	3858	101,4	2450	46,3	6308	69,4	1944	1477	706	4127	98,1
DS3		-	Glare	22	3804	100,0	5287	100,0	9091	100,0	2221	1282	704	4207	100,0
DSF0	Double skin facade	No vent.	-	-	2663	70,0	5710	108,0	8373	92,1	2202	1014	432	3648	86,7
DSF1		Natural	On during schedule	(5ac/h)	2788	73,3	5026	95,1	7814	86,0	2188	1071	458	3717	88,4
DSF2		Natural	Operative temp.	24°C ; 5ac/h	2704	71,1	5329	100,8	8033	88,4	2197	1015	432	3644	86,6
DSFV1	Double skin ventilated facade	Mechanical	Operative temp.	24°C ; 5ac/h	2705	71,1	5329	100,8	8034	88,4	2196	1014	431	3641	86,5
DSFV2		Hybrid	Operative temp.	24°C ; 5ac/h	2723	71,6	5100	96,5	7823	86,1	2196	1014	432	3642	86,6

Sensitivity analysis

		Diminutive	**Case**	**Ventilation mode**	**Fixed parameters**	**Parameter varied**	**Heating demand (kWh/year)**	**Heating loads saving (%)**	**Cooling demand (kWh/year)**	**Cooling loads saving (%)**	**Annual loads (kWh)**	**Energy saving (%)**	**Hours of discomforts with winter clothes (hours)**	**Hours of discomforts with summer clothes (hr)**	**Hours of discomforts with winter or summer clothes (hr)**	**Total hours of discomfort (hr)**	**Improving of thermal comfort (%)**
Electrochromic case	Control strategythresholds	Sensitivity analysis : electrochromic - Solar threshold															
		ECW1-s150	Electrochromic	-	Optical properties	150 W/m²-K	4057	106,7	2432	46,0	6489	71,4	1979	1783	978	4740	112,7
		ECW1-s300		-		300 W/m²-K	4015	105,5	2465,0	46,6	6480	71,3	1937	1765	909	4611	109,6
		ECW1		-		450 W/m²-K	3840	100,9	2886	54,6	6726	74,0	2029	1461	722	4212	100,1
		ECW1-s600		-		600 W/m²-K	3928	103,3	2944	55,7	6872	75,6	2080	1548	847	4475	106,4
		ECW1-s750		-		750 W/m²-K	3918	103,0	3295	62,3	7213	79,3	2139	1506	848	4493	106,8
		Sensitivity analysis : electrochromic - Operative temperature threshold															
		ECW2-t18	Electrochromic	-	Optical properties	18°C	3825	100,6	2880	54,5	6705	73,8	1864	1555	655	4074	96,8
		ECW2-t20		-		20°C	3824	100,5	2880	54,5	6704	73,7	1862	1555	653	4070	96,7
		ECW2-t22		-		22°C	3877	101,9	2864	54,2	6741	74,2	1932	1521	711	4164	99,0
		ECW2		-		24°C	3845	101,1	2922	55,3	6767	74,4	2078	1360	702	4140	98,4
		ECW2-t26		-		26°C	3823	100,5	3334	63,1	7157	78,7	2186	1289	702	4177	99,3
c shading	Control strategythresholds	Sensitivity analysis : dynamic shading - solar threshold															
		DS1-s150	Dynamic shading	-	Slat properties	150 W/m²-K	3970	104,4	2324	44,0	6294	69,2	1885	1751	866	4502	107,0
		DS1-s300		-		300 W/m²-K	3910	102,8	2412	45,6	6322	69,5	1906	1644	787	4337	103,1
		DS1		-		450 W/m²-K	3840	100,9	2886	54,6	6726	74,0	2029	1461	722	4212	100,1
		DS1-s600		-		600 W/m²-K	3807	100,1	4051	76,6	7858	86,4	2175	1324	715	4214	100,2
		DS1-s750		-		750 W/m²-K	3805	100,0	5096	96,4	8901	97,9	2221	1284	705	4210	100,1
		Sensitivity analysis : electrochromic - Operative temperature threshold															
		DS2-t18	Dynamic shading	-	Slat properties	18°C	3834	100,8	2408	45,5	6242	68,7	1780	1667	692	4139	98,4
		DS2-t20		-		20°C	3834	100,8	2409	45,6	6243	68,7	1780	1667	693	4140	98,4
		DS2-t22		-		22°C	3898	102,5	2393	45,3	6291	69,2	1799	1672	716	4187	99,5
		DS2		-		24°C	3858	101,4	2450	46,3	6308	69,4	1944	1477	706	4127	98,1
		DS2-t26		-		26°C	3823	100,5	2563	48,5	6386	70,2	2190	1293	702	4185	99,5
		Sensitivity analysis : dynamic shading - slat angle															
		DS2-a15	Dynamic shading	-	OT - Threshold = 24°C, BtG = 0,05 m, slat width = 0,025 m, slat separation = 0,01875 m	15	3857	101,4	2452	46,4	6309	69,4	1946	1461	705	4112	97,7
		DS2-a30		-		30	3857	101,4	2460	46,5	6317	69,5	1946	1464	706	4116	97,8
		DS2		-		45°	3858	101,4	2450	46,3	6308	69,4	1944	1477	706	4127	98,1
		DS2-a60		-		60	3862	101,5	2439	46,1	6301	69,3	1935	1499	706	4140	98,4
		DS2-a75		-		75	3864	101,6	2434	46,0	6298	69,3	1920	1479	705	4104	97,6
		Sensitivity analysis : dynamic shading - slat separation															
		DS2-p005		-		0,005 m	3855	101,3	2470	46,7	6325	69,6	1954	1451	705	4110	97,7

Dynam	Slat properties	DS2-p010	Dynamic shading	-	OT - Threshold = 24°C, S_a = 45°, BtG = 0,05 m, slat width = 0,025 m,	0,01 m	3856	101,4	2465	46,6	6321	69,5	1950	1457	706	4113	97,8
		DS2		-		0,01875 m	3858	101,4	2450	46,3	6308	69,4	1944	1477	706	4127	98,1
		DS2-p025		-		0,025 m	3868	101,7	2440	46,2	6308	69,4	1894	1516	706	4116	97,8
		DS2-p0375		-		0,0375 m	3836	100,8	2495	47,2	6331	69,6	2040	1390	703	4133	98,2
		DS2-p050		-		0,05 m	3816	100,3	2822	53,4	6638	73,0	2118	1350	703	4171	99,1
		Sensitivity analysis : dynamic shading - slat width															
		DS2-w0,5	Dynamic shading	-	OT - Threshold = 24°C, S_a = 45°, BtG = 0,05 m, slat separation = 0,01875 m	0,5 cm	3799	99,9	3890	73,6	7689	84,6	2183	1302	700	4185	99,5
		DS2-w0,875				0,875 cm	3814	100,3	2926	55,3	6740	74,1	2128	1343	702	4173	99,2
		DS2-w1,25		-		1,25 cm	3837	100,9	2492	47,1	6329	69,6	2038	1391	703	4132	98,2
		DS2		-		2,50 cm	3858	101,4	2450	46,3	6308	69,4	1944	1477	706	4127	98,1
		DS2-w3,75		-		3,75 cm	3856	101,4	2461	46,5	6317	69,5	1948	1458	706	4112	97,7
		DS2-w5,00		-		5,00 cm	3855	101,3	2467	46,7	6322	69,5	1920	1479	705	4104	97,6
		Sensitivity analysis : dynamic shading - Blind-to-glass distance															
		DS2-b02	Dynamic shading	-	OT - Threshold = 24°C, S_a = 45°, slat width = 0,025 m, slat separation = 0,01875 m	0,02 m	3850	101,2	2542	48,1	6392	70,3	1970	1432	704	4106	97,6
		DS2-b035				0,035 m	3855	101,3	2477	46,9	6332	69,7	1950	1457	705	4112	97,7
		DS2		-		0,05 m	3858	101,4	2450	46,3	6308	69,4	1944	1477	706	4127	98,1
		DS2-b10		-		0,10 m	3861	101,5	2419	45,8	6280	69,1	1935	1494	706	4135	98,3
		DS2-b15				0,15 m	3861	101,5	2410	45,6	6271	69,0	1933	1494	707	4134	98,3
		DS2-b20		-		0,20 m	3862	101,5	2405	45,5	6267	68,9	1931	1495	707	4133	98,2
Double-skin façade	DB properties	Sensitivity analysis : Double skin facade - natural ventilation - cavity depth															
		DSF2	Double skin facade	Natural	T_n=24°C; 5ac/h	1	2704	71,1	5329	100,8	8033	88,4	2197	1015	432	3644	86,6
		DSF2-c0,75		Natural		0,75	2734	71,9	5600	105,9	8334	91,7	2217	995	423	3635	86,4
		DSF2-c0,5		Natural		0,5	2747	72,2	6118	115,7	8865	97,5	2236	977	419	3632	86,3
		DSF2-c0,25		Natural		0,25	2758	72,5	6620	125,2	9378	103,2	2248	961	409	3618	86,0
	Threshold	Sensitivity analysis : Double-skin facade - temperature threshold															
		DSF2-t18	Double skin facade	Natural	Cavity depth 1m,	18	2717	71,4	5305	100,3	8022	88,2	2187	1029	433	3649	86,7
		DSF2-t20		Natural		20	2712	71,3	5311	100,5	8023	88,3	2191	1022	433	3646	86,7
		DSF2-t22		Natural		22	2709	71,2	5319	100,6	8028	88,3	2194	1018	432	3644	86,6
		DSF2		Natural		24	2704	71,1	5329	100,8	8033	88,4	2197	1015	432	3644	86,6
		DSF2-t26		Natural		26	2701	71,0	5341	101,0	8042	88,5	2198	1015	432	3645	86,6
Double-skin ventilated façade	Mechanical ventilation	Sensitivity analysis : mechanical ventilation - mechanical flow ventilation															
		DSFV1-f3	Double skin ventilated facade	Mechanical	Cavity depth 1m, T_m=24°C	3	2693	70,8	5454	103,2	8147	89,6	2198	1016	432	3646	86,7
		DSFV1		Mechanical		5	2705	71,1	5329	100,8	8034	88,4	2196	1014	431	3641	86,5
		DSFV1-f10		Mechanical		10	2723	71,6	5100	96,5	7823	86,1	2196	1014	431	3641	86,5
		DSFV1-f15		Mechanical		15	2733	71,8	4943	93,5	7676	84,4	2196	1017	432	3645	86,6
		DSFV1-f20		Mechanical		20	2739	72,0	4832	91,4	7571	83,3	2196	1017	432	3645	86,6
		DSFV1-f25		Mechanical		25	2742	72,1	4753	89,9	7495	82,4	2196	1017	431	3644	86,6
		Sensitivity analysis : mechanical ventilation - temperature threshold															
		DSFV1-t18	Double skin ventilated facade	Mechanical	Cavity depth 1m, 5ac/h	18	2718	71,5	5305	100,3	8023	88,3	2187	1029	433	3649	86,7
		DSFV1-t20		Mechanical		20	2713	71,3	5311	100,5	8024	88,3	2191	1022	433	3646	86,7
		DSFV1-t22		Mechanical		22	2709	71,2	5319	100,6	8028	88,3	2195	1017	432	3644	86,6
		DSFV1		Mechanical		24	2705	71,1	5329	100,8	8034	88,4	2196	1014	431	3641	86,5
		DSFV1-t26		Mechanical		26	2702	71,0	5341	101,0	8043	88,5	2199	1015	432	3646	86,7
	Hybrid ventilation	Sensitivity analysis : hybrid ventilation - temperature threshold															
		DSFV2-t18	Double skin ventilated facade	Hybrid	Cavity depth 1m, 5ac/h	18	2745	72,2	5054	95,6	7799	85,8	2180	1032	432	3644	86,6
		DSFV2-t20		Hybrid		20	2736	71,9	5066	95,8	7802	85,8	2187	1023	432	3642	86,6
		DSFV2-t22		Hybrid		22	2729	71,7	5082	96,1	7811	85,9	2194	1018	432	3644	86,6
		DSFV2		Hybrid		24	2723	71,6	5100	96,5	7823	86,1	2196	1014	432	3642	86,6
		DSFV2-t26		Hybrid		26	2719	71,5	5119	96,8	7838	86,2	2198	1015	432	3645	86,6
		Sensitivity analysis : mechanical ventilation - mechanical flow ventilation															
		DSFV2-f3	Double skin ventilated facade	Hybrid	Cavity depth 1m, T_m=24°C	3	2718	71,5	5181	98,0	7899	86,9	2197	1015	432	3644	86,6
		DSFV2		Hybrid		5	2723	71,6	5100	96,5	7823	86,1	2196	1014	432	3642	86,6
		DSFV2-f10		Hybrid		10	2733	71,8	4943	93,5	7676	84,4	2196	1017	431	3644	86,6
		DSFV2-f15		Hybrid		15	2739	72,0	4832	91,4	7571	83,3	2196	1017	432	3645	86,6
		DSFV2-f20		Hybrid		20	2742	72,1	4753	89,9	7495	82,4	2195	1017	431	3643	86,6
		DSFV2-f25		Hybrid		25	2744	72,1	4694	88,8	7438	81,8	2194	1018	432	3644	86,6

Final comparative analysis															
Diminutive	Case	Ventilation mode	Control strategy	Threshold	Heating demand (kWh/year)	Heating loads saving (%)	Cooling demand (kWh/year)	Cooling loads saving (%)	Annual loads (kWh)	Energy saving (%)	Hours of discomforts with winter clothes (%)	Hours of discomforts with summer clothes (%)	Hours of discomforts with winter or summer clothes (%)	Total hours of discomfort (%)	Improving of thermal comfort (%)
Base case	Base	-	-	-	3804	100,0	5287	100,0	9091	100,0	2221	1282	704	4207	100,0
ECW0	Electrochromic	-	Schedule	-	3824	100,5	2880	54,5	6704	73,7	1864	1555	655	4074	96,8
ECW1		-	Solar	450 W/m²-K	3969	104,3	2601	49,2	6570	72,3	1974	1664	862	4500	107,0
ECW2		-	Operative temp.	24°C	3845	101,1	2922	55,3	6767	74,4	2078	1360	702	4140	98,4
ECW3		-	Glare	22	3804	100,0	5287	100,0	9091	100,0	2221	1282	704	4207	100,0
DS0	Dynamic shading	-	Schedule		3834	100,8	2409	45,6	6243	68,7	1780	1667	692	4139	98,4
DS1-s300		-	Solar	300 W/m²-K	3910	102,8	2412	45,6	6322	69,5	1906	1644	787	4337	103,1
DS2		-	Operative temp.	24°C	3858	101,4	2450	46,3	6308	69,4	1944	1477	706	4127	98,1
DS3		-	Glare	22	3804	100,0	5287	100,0	9091	100,0	2221	1282	704	4207	100,0
DSF0	Double skin facade	No vent.	-	-	2663	70,0	5710	108,0	8373	92,1	2202	1014	432	3648	86,7
DSF1		Natural	Schedule		2788	73,3	5027	95,1	7815	86,0	2188	1071	458	3717	88,4
DSF2		Natural	Operative temp.	24°C ; 5ac/h	2704	71,1	5329	100,8	8033	88,4	2197	1015	432	3644	86,6
DSFV1-f25	Double skin ventilated facade	Mechanical	Operative temp.	24°C ; 25ac/h	2742	72,1	4753	89,9	7495	82,4	2196	1017	431	3644	86,6
DSFV2-f25		Hybrid	Operative temp.	24°C ; 25ac/h	2744	72,1	4694	88,8	7438	81,8	2194	1018	432	3644	86,6

Appendix E.1: Results of the base case

Base case results								
	Heating demand (kWh)	Cooling demand (kWh)		Inside Surface Temp (°C)	Ext Surface Temp (°C)		Solar Incident (kWh)	Solar Trans (kWh)
Jan	783,5	82,8	Jan	15,2	7,1	Jan	310,6	343,8
Feb	625,1	215,8	Feb	15,9	8,0	Feb	424,0	474,7
Mar	509,8	468,3	Mar	17,5	9,8	Mar	712,4	762,4
Apr	311,1	667,4	Apr	19,5	13,2	Apr	838,6	840,3
May	164,7	522,9	May	20,6	15,5	May	725,0	620,3
Jun	69,6	576,2	Jun	22,5	18,8	Jun	669,1	533,5
Jul	27,1	663,2	Jul	23,3	20,1	Jul	696,8	575,5
Aug	45,1	756,3	Aug	23,0	19,8	Aug	739,2	690,1
Sep	127,4	611,3	Sep	21,2	16,9	Sep	667,9	679,7
Oct	269,0	370,1	Oct	19,3	13,9	Oct	530,1	561,7
Nov	544,3	86,9	Nov	16,5	10,0	Nov	289,1	305,9
Dec	795,3	56,5	Dec	15,4	8,1	Dec	227,9	251,6

Appendix E.2: Results of electrochromic cases

ECW results

	Heating demand (kWh)				
	Base case	ECW 0 - On during schedule	ECW 1 - solar	ECW 2 - OT	ECW 3 - Glare
Jan	783,5	692,2	684,3	689,9	783,5
Feb	625,1	567,7	563,8	571,0	625,1
Mar	509,8	485,2	485,9	485,7	509,8
Apr	311,1	299,0	305,4	305,7	311,1
May	164,7	164,4	163,1	164,3	164,7
Jun	69,6	69,8	69,6	69,8	69,6
Jul	27,1	27,2	27,0	27,2	27,1
Aug	45,1	45,0	44,9	45,0	45,1
Sep	127,4	120,3	120,4	119,7	127,4
Oct	269,0	238,5	238,6	238,2	269,0
Nov	544,3	454,8	455,1	460,2	544,3
Dec	795,3	660,5	665,0	668,8	795,3

	Cooling demand (kWh)				
	Base case	ECW 0 - On during schedule	ECW 1 - solar	ECW 2 - OT	ECW 3 - Glare
Jan	82,8	6,3	16,2	6,6	82,8
Feb	215,8	50,3	55,4	52,8	215,8
Mar	468,3	217,2	245,2	227,2	468,3
Apr	667,4	320,3	357,2	339,4	667,4
May	522,9	307,3	357,1	311,5	522,9
Jun	576,2	430,4	471,3	427,7	576,2
Jul	663,2	480,9	528,7	475,0	663,2
Aug	756,3	504,5	548,9	501,9	756,3
Sep	611,3	339,3	379,2	344,0	611,3
Oct	370,1	165,9	233,6	176,4	370,1
Nov	86,9	30,4	38,9	32,1	86,9
Dec	56,5	28,1	32,6	28,1	56,5

	Surface temperatures (°C)							
	Temp - Base case	Temp - Base case	Inside Surface Temp - ECW0	Ext Surface Temp - ECW0	Inside Surface Temp - ECW1	Ext Surface Temp - ECW1	Inside Surface Temp - ECW2	Ext Surface Temp - ECW2
Jan	15,2	7,1	15,5	8,9	15,3	7,9	15,4	8,2
Feb	15,9	8,0	16,6	10,7	16,4	9,6	16,4	9,9
Mar	17,5	9,8	18,5	13,3	18,2	12,0	18,3	12,4
Apr	19,5	13,2	21,2	18,1	20,7	16,7	21,0	17,3
May	20,6	15,5	21,9	19,3	21,3	17,5	21,7	18,6
Jun	22,5	18,8	23,9	22,4	23,2	20,6	23,7	22,1
Jul	23,3	20,1	24,8	24,0	23,9	22,0	24,6	23,6
Aug	23,0	19,8	24,6	24,1	23,9	22,4	24,4	23,7
Sep	21,2	16,9	22,6	20,8	22,1	19,5	22,4	20,4
Oct	19,3	13,9	20,3	16,9	19,8	15,3	20,1	16,3
Nov	16,5	10,0	16,9	11,5	16,6	10,4	16,7	10,8
Dec	15,4	8,1	15,7	9,4	15,5	8,4	15,5	8,7

	Solar radiation (kWh)				
	Solar Incident	Solar Trans - Base case	Solar Trans - ECW0	Solar Trans - ECW1	Solar Trans - ECW2
Jan	310,6	343,8	83,8	223,6	185,1
Feb	424,0	474,7	132,3	243,0	213,1
Mar	712,4	762,4	298,4	437,4	392,6
Apr	838,6	840,3	256,8	390,6	330,8
May	725,0	620,3	194,5	359,6	245,4
Jun	669,1	533,5	199,2	342,8	223,0
Jul	696,8	575,5	181,1	346,9	208,5
Aug	739,2	690,1	213,3	361,2	243,3
Sep	667,9	679,7	193,4	332,6	238,7
Oct	530,1	561,7	165,0	348,6	232,6
Nov	289,1	305,9	118,5	234,8	189,3
Dec	227,9	251,6	100,4	204,3	173,4

Appendix E.3: Results of dynamic shading cases

DS results

	Heating demand (kWh)				
	Base case	DS 0 - Schedule	DS 1 - solar	DS 2 - OT	DS 3 - Glare
Jan	783,5	686,7	686,6	691,6	783,5
Feb	625,1	574,2	571,3	577,2	625,1
Mar	509,8	495,4	491,2	491,0	509,8
Apr	311,1	302,0	305,5	306,3	311,1
May	164,7	162,4	163,1	162,5	164,7
Jun	69,6	69,8	69,6	69,8	69,6
Jul	27,1	27,1	27,0	27,1	27,1
Aug	45,1	44,9	44,9	44,9	45,1
Sep	127,4	120,1	120,4	119,4	127,4
Oct	269,0	239,0	238,6	237,9	269,0
Nov	544,3	453,2	455,4	459,8	544,3
Dec	795,3	659,6	666,9	671,0	795,3

	Cooling demand (kWh)				
	Base case	DS 0 - Schedule	DS 1 - solar	DS 2 - OT	DS 3 - Glare
Jan	82,8	6,3	15,3	6,3	82,8
Feb	215,8	50,3	54,1	50,3	215,8
Mar	468,3	192,6	217,0	199,6	468,3
Apr	667,4	252,2	290,1	266,0	667,4
May	522,9	246,7	314,0	254,2	522,9
Jun	576,2	369,6	431,3	368,9	576,2
Jul	663,2	412,5	486,4	409,5	663,2
Aug	756,3	418,0	485,2	418,8	756,3
Sep	611,3	268,4	318,5	275,6	611,3
Oct	370,1	133,7	205,6	142,6	370,1
Nov	86,9	30,4	36,7	30,4	86,9
Dec	56,5	28,1	32,0	28,1	56,5

	Surface temperatures (°C)							
	Inside Surface Temp - Base case	Ext Surface Temp - Base case	Inside Surface Temp - DS 0	Ext Surface Temp - DS 0	Inside Surface Temp - DS 1	Ext Surface Temp - DS 1	Inside Surface Temp - DS 2	Ext Surface Temp - DS 2
Jan	15,2	7,1	15,1	7,9	15,0	7,6	15,4	8,2
Feb	15,9	8,0	15,7	9,3	15,6	9,0	16,4	9,9
Mar	17,5	9,8	17,3	11,9	17,3	11,3	18,3	12,4
Apr	19,5	13,2	19,4	16,5	19,4	15,6	21,0	17,3
May	20,6	15,5	20,7	18,2	20,6	17,0	21,7	18,6
Jun	22,5	18,8	22,7	21,7	22,5	20,2	23,7	22,1
Jul	23,3	20,1	23,5	23,1	23,3	21,5	24,6	23,6
Aug	23,0	19,8	23,1	23,1	23,0	21,8	24,4	23,7
Sep	21,2	16,9	21,3	19,8	21,1	18,8	22,4	20,4
Oct	19,3	13,9	19,3	15,8	19,2	14,9	20,1	16,3
Nov	16,5	10,0	16,6	10,6	16,4	10,3	16,7	10,8
Dec	15,4	8,1	15,5	8,4	15,3	8,3	15,5	8,7

	Solar radiation (kWh)				
	Solar Incident	Solar Trans - Base case	Solar Trans - DS 0	Solar Trans - DS 1	Solar Trans - DS 2
Jan	310,6	343,8	88,5	225,1	185,1
Feb	424,0	474,7	139,3	246,6	213,1
Mar	712,4	762,4	310,8	444,4	392,6
Apr	838,6	840,3	277,4	403,9	330,8
May	725,0	620,3	218,2	370,5	245,4
Jun	669,1	533,5	221,6	352,3	223,0
Jul	696,8	575,5	205,2	357,3	208,5
Aug	739,2	690,1	234,1	372,5	243,3
Sep	667,9	679,7	208,3	341,3	238,7
Oct	530,1	561,7	174,8	352,7	232,6
Nov	289,1	305,9	122,8	235,8	189,3
Dec	227,9	251,6	103,5	204,9	173,4

Appendix E.4: Results of the double-skin façades

	Heating demand (kWh)			
	Base case	DSF 1 - Schedule	DSF 2 - OT	DSF 0 - No vent
Jan	783,5	530,2	511,5	508,0
Feb	625,1	430,1	418,2	413,3
Mar	509,8	348,3	338,7	332,0
Apr	311,1	209,1	205,1	197,9
May	164,7	103,9	101,2	96,6
Jun	69,6	41,5	40,7	39,1
Jul	27,1	10,0	9,5	8,8
Aug	45,1	16,8	15,9	14,6
Sep	127,4	68,9	67,0	64,4
Oct	269,0	161,7	157,9	153,6
Nov	544,3	341,3	330,2	328,2
Dec	795,3	527,0	508,9	506,7

	Cooling demand (kWh)			
	Base case	DSF 1 - Schedule	DSF 2 - OT	DSF 0 - No vent
Jan	82,8	114,8	130,1	142,7
Feb	215,8	227,4	247,9	268,4
Mar	468,3	427,9	456,3	488,4
Apr	667,4	591,2	629,9	680,0
May	522,9	495,2	528,7	574,1
Jun	576,2	564,9	592,2	632,6
Jul	663,2	660,3	690,9	737,1
Aug	756,3	731,1	762,8	811,3
Sep	611,3	611,7	641,0	681,2
Oct	370,1	427,5	453,6	482,0
Nov	86,9	109,4	122,5	132,9
Dec	56,5	64,3	73,5	79,8

	Surface temperatures (°C)													
	Inside Surface Temp -	Ext Surface Temp -	I.R temp - DSF 1	E.R temp - DSF 1	I.C temp - DSF 1	E.C temp - DSF 1	I.R temp - DSF 2	E.R temp - DSF 2	I.C temp - DSF 2	E.C temp - DSF 2	I.R temp - DSF 0	E.R temp - DSF 0	I.C temp - DSF 0	E.C temp - DSF 0
Jan	15,2	7,1	18,9	15,7	10,7	5,7	19,3	16,5	11,4	5,9	19,5	17,0	11,9	6,1
Feb	15,9	8,0	20,0	17,6	12,9	7,0	20,4	18,2	13,4	7,2	20,8	19,1	14,3	7,4
Mar	17,5	9,8	22,3	21,4	17,0	9,7	22,5	21,8	17,4	9,8	23,2	23,1	18,6	10,2
Apr	19,5	13,2	24,3	24,8	21,4	13,9	24,4	25,0	21,6	13,9	25,3	27,0	23,4	14,6
May	20,6	15,5	24,8	25,5	22,6	16,2	24,8	25,6	22,7	16,2	25,7	27,3	24,2	16,8
Jun	22,5	18,8	26,1	27,6	25,5	19,9	26,2	27,6	25,6	20,0	26,9	29,0	26,9	20,4
Jul	23,3	20,1	26,8	28,4	26,6	21,3	26,8	28,4	26,7	21,3	27,5	29,9	28,1	21,8
Aug	23,0	19,8	26,5	28,3	26,6	21,1	26,6	28,3	26,7	21,1	27,3	29,9	28,1	21,7
Sep	21,2	16,9	24,9	25,7	23,3	17,7	25,0	25,8	23,5	17,7	25,7	27,3	24,8	18,2
Oct	19,3	13,9	22,8	22,2	19,0	13,8	23,0	22,4	19,2	13,9	23,6	23,6	20,3	14,3
Nov	16,5	10,0	20,0	17,6	13,4	8,9	20,3	18,2	14,0	9,1	20,5	18,6	14,3	9,2
Dec	15,4	8,1	18,7	15,5	10,8	6,5	19,1	16,3	11,5	6,7	19,3	16,6	11,8	6,8

	Solar radiation (kWh)					
	Solar Incident - Base case	Solar Trans - Base case	Solar Incident - DSF	Solar Trans - DSF 1	Solar Trans - DSF 2	Solar Trans - DSF 0
Jan	310,6	343,8	310,5	343,6	343,6	343,6
Feb	424,0	474,7	423,8	474,5	474,5	474,5
Mar	712,4	762,4	712,1	762,2	762,2	762,2
Apr	838,6	840,3	838,2	840,0	840,0	840,0
May	725,0	620,3	724,7	620,1	620,1	620,1
Jun	669,1	533,5	668,8	533,3	533,3	533,3
Jul	696,8	575,5	696,5	575,3	575,3	575,3
Aug	739,2	690,1	738,9	689,8	689,8	689,8
Sep	667,9	679,7	667,7	679,4	679,4	679,4
Oct	530,1	561,7	529,9	561,5	561,5	561,5
Nov	289,1	305,9	289,0	305,8	305,8	305,8
Dec	227,9	251,6	227,9	251,5	251,5	251,5

Appendix E.5: Results of the double-skin ventilated cases

	Heating demand (kWh)		
	Base case	DSFV 1 - Only mech	DSFV 2 - hybrid
Jan	783,5	511,6	512,7
Feb	625,1	418,3	420,2
Mar	509,8	338,8	341,5
Apr	311,1	205,2	208,8
May	164,7	101,2	103,7
Jun	69,6	40,7	41,5
Jul	27,1	9,5	10,0
Aug	45,1	15,9	16,7
Sep	127,4	67,1	68,4
Oct	269,0	158,0	159,7
Nov	544,3	330,3	330,9
Dec	795,3	509,1	509,7

	Cooling demand (kWh)		
	Base case	DSFV 1 - Only mech	DSFV 2 - hybrid
Jan	82,8	130,1	123,4
Feb	215,8	247,9	235,6
Mar	468,3	456,3	437,0
Apr	667,4	629,9	598,6
May	522,9	528,7	501,4
Jun	576,2	592,2	567,8
Jul	663,2	690,9	663,3
Aug	756,3	762,8	734,0
Sep	611,3	641,0	616,3
Oct	370,1	453,6	435,4
Nov	86,9	122,5	117,3
Dec	56,5	73,5	70,5

	Surface temperatures (°C)									
	Inside Surface Temp - Base case	Ext Surface Temp - Base case	I.R temp - DSFV 1	E.R temp - DSFV 1	I.C temp - DSFV 1	E.C temp - DSFV 1	I.R temp - DSFV 2	E.R temp - DSFV 2	I.C temp - DSFV 2	E.C temp - DSFV 2
Jan	15,2	7,1	19,3	16,5	11,4	5,9	19,2	16,3	11,3	5,9
Feb	15,9	8,0	20,4	18,2	13,4	7,2	20,2	17,9	13,1	7,1
Mar	17,5	9,8	22,5	21,8	17,4	9,8	22,3	21,3	16,9	9,7
Apr	19,5	13,2	24,4	25,0	21,6	13,9	23,9	24,2	20,8	13,7
May	20,6	15,5	24,8	25,6	22,7	16,2	24,5	24,9	22,0	16,0
Jun	22,5	18,8	26,2	27,6	25,6	20,0	25,9	27,0	25,0	19,8
Jul	23,3	20,1	26,8	28,4	26,7	21,3	26,5	27,8	26,0	21,1
Aug	23,0	19,8	26,6	28,3	26,7	21,1	26,2	27,6	26,0	20,9
Sep	21,2	16,9	25,0	25,8	23,5	17,7	24,6	25,2	22,8	17,5
Oct	19,3	13,9	23,0	22,4	19,2	13,9	22,8	22,0	18,8	13,8
Nov	16,5	10,0	20,3	18,2	14,0	9,1	20,3	18,1	13,9	9,1
Dec	15,4	8,1	19,1	16,3	11,5	6,7	19,1	16,2	11,4	6,7

	Solar radiation (kWh)				
	Solar Incident - Base case	Solar Trans - Base case	Solar Incident - DSF	Solar Trans - DSFV 1	Solar Trans - DSFV 2
Jan	310,6	343,8	310,5	343,6	343,6
Feb	424,0	474,7	423,8	474,5	474,5
Mar	712,4	762,4	712,1	762,2	762,2
Apr	838,6	840,3	838,2	840,0	840,0
May	725,0	620,3	724,7	620,1	620,1
Jun	669,1	533,5	668,8	533,3	533,3
Jul	696,8	575,5	696,5	575,3	575,3
Aug	739,2	690,1	738,9	689,8	689,8
Sep	667,9	679,7	667,7	679,4	679,4
Oct	530,1	561,7	529,9	561,5	561,5
Nov	289,1	305,9	289,0	305,8	305,8
Dec	227,9	251,6	227,9	251,5	251,5