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Thermal Comfort and Lighting Analysis and Simulation	
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1. Introduction

SEEMPubS specifically addresses reduction in energy usage and CO_2 footprint in existing public buildings by implementing an intelligent ICT-based building monitoring and managing system.

WP1 has been mainly devoted to analyse the demonstrator characteristics and its energy saving potential.
In particular, after a first phase that was aimed at studying the buildings' architectural features, energy consumptions and usage (Energy audit), the potential in saving energy of the control solutions proposed in WP2 has been assessed by means of building performance simulations. The procedure adopted has been as follow:
- analysis of available software and selection of the most appropriate with respect to the simulation goal;
- monitoring of environmental condition in the selected rooms (illuminance, air temperature, relative humidity);
- buildings' modelling and simulation of environmental conditions;
- comparison between monitored data and simulated results (models' validation);
- further set up of rooms' models;
- estimation of rooms performance in terms of energy consumption and environmental conditions when applying the new control strategies.

A further goal of WP1 was to compare the simulated buildings energy performance with the data achieved during the monitoring activity carried out after installing the control and monitoring system designed in the project.

The results obtained in the different phases of this research activity has been presented step by step in previous project Deliverables (D1.1; D1.2; D2.3.1; D2.3.2) and are in this Deliverable summarised and completed with new results.
The document is organised in two main sections: one related to the heating and cooling simulations (section 2) and one referred to the lighting simulations (section 3). For each section all information concerning the software used for the analysis, the input data assumed for each pair of modelled rooms, the control strategies and the obtained results are reported. Furthermore, in each section, some first considerations concerning the comparison between simulated performances and monitored data are reported and commented.

2. Modeling and simulation for HVAC

1.1 Geometric model - Choice of TRNSYS (thermal simulation)

TRNSYS is a internationally recognized software dedicated to the simulation of dynamic systems, developed by the Solar Energy Laboratory (SEL), University of Madison in the United States. It allows performing dynamic simulations of the thermal behaviour of a mono or multi-zone building. It can also follow hourly consumption (heating, air conditioning) or production (solar panels) annual energy facilities of a building.

TRNSYS is in fact a software which compiles different modules (called "types") and allows to link them one to the other to create a realistic model of the building (or the room) tested. Each type has its own part in the simulation. For example, three types are used to create meteorological data of the simulated place, and a special type to model the building (walls and their compositions, windows...).

The new version of TRNSYS (v17) was used to perform those simulations. The new 3D plug-in of this version was used on several cases of the project to go further in the interoperability between parametric architectural software (Revit) and energy simulation software (TRNSYS; Daysim, etc.)

The figure below presents the TRNSYS simulation diagram used to simulate the buildings with the different types to model all the specifications of the Politecnico campus (fan coils or AHU...).
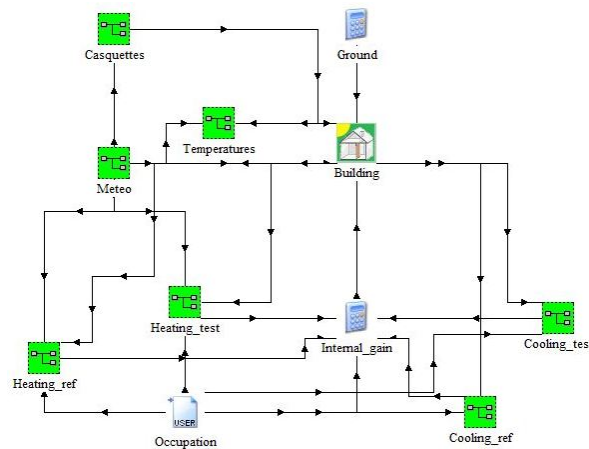

Figure 1 : Global TRNSYS simulation model

1.2 Interoperability between building information modeling and thermal simulation software

The interoperability between software described in this paragraph is an important issue of the SEEMPubS project, and permits to optimize the data exchange among architecture and energy simulations.

Interoperability between the 3D model (on Revit Architecture) and TRNSYS is made possible from July 2010 due to the last version of the software that for the first time integrates a 3D plug-in called TRNSYS3D.
It consists mainly in the importation of the tridimensional model in TRNSYS and in its use for the creation of tridimensional thermal zones to which apply the thermal simulation. In the SEEMPubS project this procedure has been applied to 6 different buildings for testing and optimizing the data flow from the architectural to the thermal model.

The interoperability test starts with the construction of the building model using the last release of Autodesk Revit Building (release 2011 at the beginning of the experiment). TRNSYS 17 operates by using a Plug-in in SketchUp 7 Pro (that is a common 3D modeling software). Since it is not possible to import directly the Revit file in SketchUp, it was necessary to use a .dxf file as a bridge: the Revit model was exported as a .dxf file that was subsequently imported in SketchUp 7 Pro.
The building model imported in SketchUp is not directly usable for the radiation calculations. It is necessary to build a new model of the building that contains the 3D information of the building surfaces and, moreover, the different thermal zones of the building. The thermal zones are created ex-novo using TRNSYS3D; in fact it is not possible to transform SketchUp volumes or surfaces in TRNSYS thermal zones.

The thermal zones are used to simulate the dynamic flow of energy. For this reason the imported 3D model was useful as a layout to build correctly and quickly the TRNSYS volumes. But in the interoperable process it was necessary to take a particular attention to some critical points, such as the orientation of the 3D model, and the connectivity of the thermal zones. Finally, after these important checks, it was necessary to verify the wall type created and assign the correct type for every wall (external wall, internal wall, ceiling, floor, etc.) before the exportation on TRNSYS software. After exportation, no changes about orientation and wall type can be done.

The procedure described maintains the exact geometry of the building components (walls, floors, windows, doors) and detailed 3D solar gains (not possible to get on TRNSYS) in the importation from Revit to TRNSYS. This is of fundamental importance, because the geometric correctness and congruence of the wall surfaces is necessary for the creation of the thermal zones. In fact the vertexes of the interior and exterior surfaces of the geometrical model are used as inference points for the creation of thermal zones.
Since the windows in Revit are parametric objects, it is possible to calculate the exact area of the frame and of the glass surface for each window; then this value is used in TRNSYS to improve the accuracy of the simulation results

But with this procedure, thermal zoning still needs to be done after importation on TRNSYS, so interoperability is not complete. Simplification for thermal zone is an attitude of mind, depending on wall composition, wall direction, wall dimension, occupancy of each room modeled.

The other risk is to get a lot of walls for one room, and therefore long simulation times, with results similar as from a simplified model.

We can say that there is the possibility of interoperability between the Building Information Model and the dynamical thermal simulation, for simple buildings with small wall thickness. The main benefit of this method is that the Areas, exact orientation of the wall and floor surfaces doesn't change significantly during the importation of the model from Revit to TRNSYS. We can also get solar gains which are not calculated on TRNSYS.
No difference are noticed with this method and classical method (TRNSYS 2D) in terms of results.
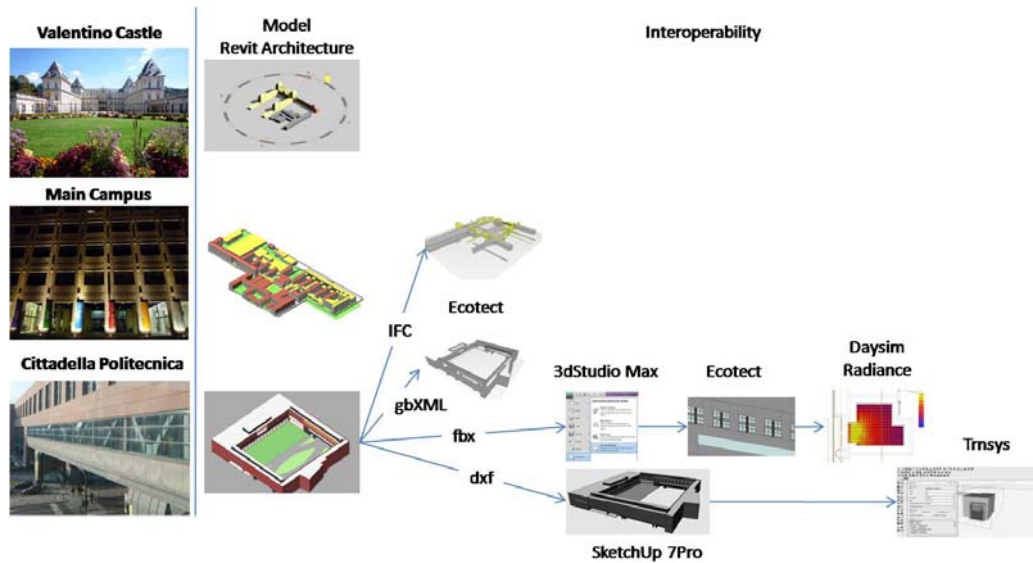
1.3 Buildings and Systems simulations

In the field of building performance simulation, results (outputs) given by a model depend on its accuracy and on input data used to run the model. Thus, it is important to describe inputs as precisely as possible. In the SEEMPubS project, most of the inputs have been provided by the *Politecnico di Torino* (Polito) during task 1.2. Some input data are the result of bibliographical reviews and calculations performed at *UCBL* and others are the result of assumptions made by *UCBL* and validated by the Polito.

The following pages summarize input data currently used in the project. Some data are used by all the simulations (meteorological data), others are specific to each model.

1.3.1 Input data common to all simulations

1.3.1.1 Temperature

Meteorological data used in the project comes from the Meteonorm database. Temperature, wind direction, wind speed, relative humidity, beam radiation on horizontal (W/m), total radiation on horizontal (W/m) are available in hourly values over one year.
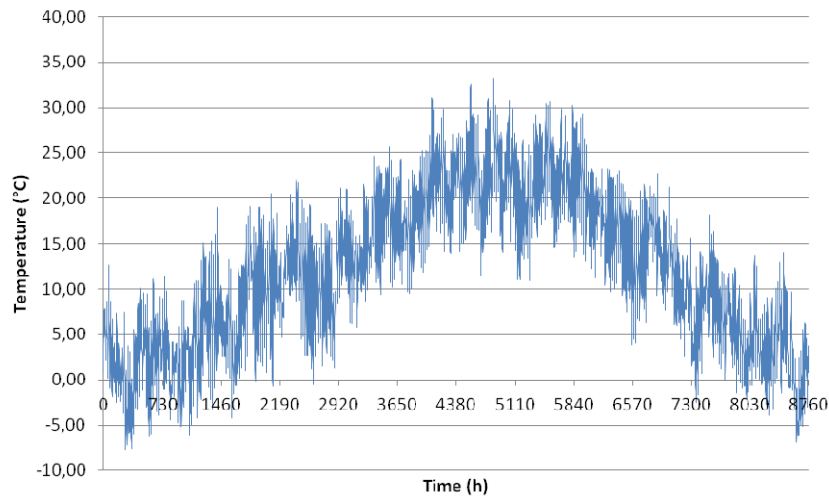
Figure 2 : Temperature as a function of time in Turin (Meteo datas, 2010)

1.3.1.2 Occupancy schedules

Occupancy is defined by a typical week reported during the 52 weeks of a year.

In real life, because of days off and vacations on the following days, occupancy should be lower.

Heating and cooling devices are turned off during holidays, so Occupancy and lighting loads are set to 0 during these no occupancy periods.

There are no savings on these periods.

1.3.1.3 Simulation Time Step

Simulation Time step is 4 minutes.

1.3.1.4 Implementation of system

On TRNSYS, each module represents a part of the environment or the building, by connecting them one to each other an accurate model of the rooms and of the fan coil used in Politecnico.

For example, in Figure 3, two different parts (one left and one right) which represent a fan coil (one for the test room and one for the reference room) are described.
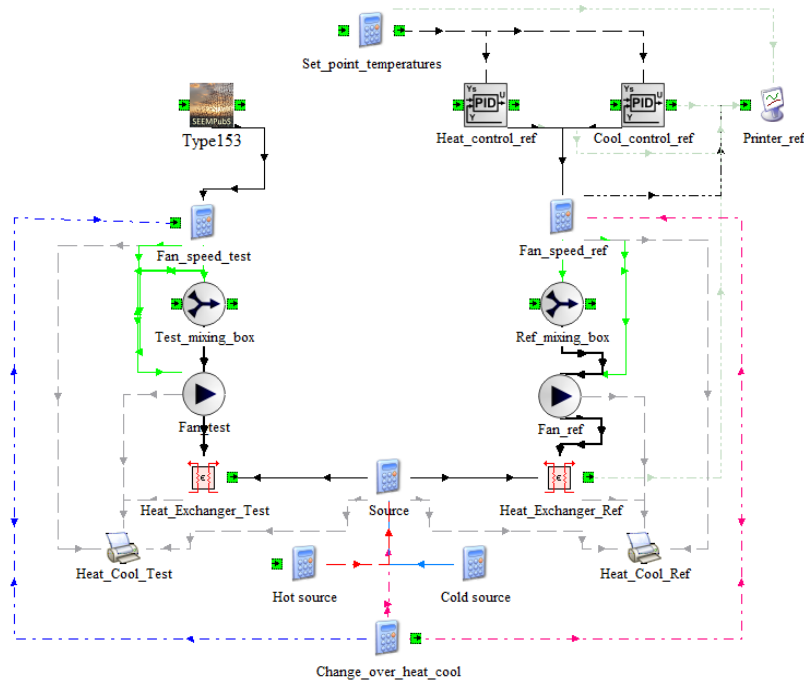
Figure 3 : Detail of the fan coil model (reference and test)

Each part, is composed of two controllers (one for heating and one for cooling) or one for test room, which controls both, a calculator in which we calculate the fan speed according to the selected speed, a valve not used for now but which can allow to add fresh air, a fan to have flow rate of air in the system and finally a heat exchanger between the air of the room (moved by the fan) and the hot water.

To approach more precisely the reality of the Politecnico campus, two special types were used to simulate fan coils (present in nearly all the rooms of the SEEMPubS project). Those types use the hot water temperature and the flow rate of the fan to calculate the exact energy consumption of the system.

1.3.2 **Input data used for Rooms 1&2 (Student offices in Valentino Castle)**

1.3.2.1 Geometry of the model

The test room and the reference room are part of the Valentino Castle which is not entirely simulated. Two rooms were selected in task 1.1 and data were collected in task 1.2. These data are used as inputs of the thermal simulation.
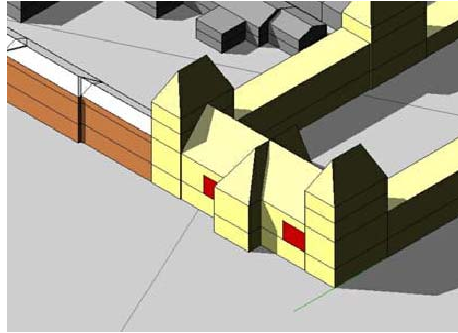
Figure 4 : Insertion of the model in the entire building

The model has been split into four zones whose names, areas and volumes are displayed in the following table.

Table 1 : Numbering and denomination of thermal zones

Zones		Volume (m³)	Area (m²)	Number of nodes	Occupancy
1	Reference room	385	59.3	1	Yes
2	Test room	385	59.3	1	Yes
3	Attic of reference room	704	133.4	1	None
4	Attic of test room	704	133.4	1	None

The hall, corridor and adjacent offices are not included in the model as shown in Figure 5 below. An adiabatic boundary condition is set for boundary walls that are adjacent to a heated area.
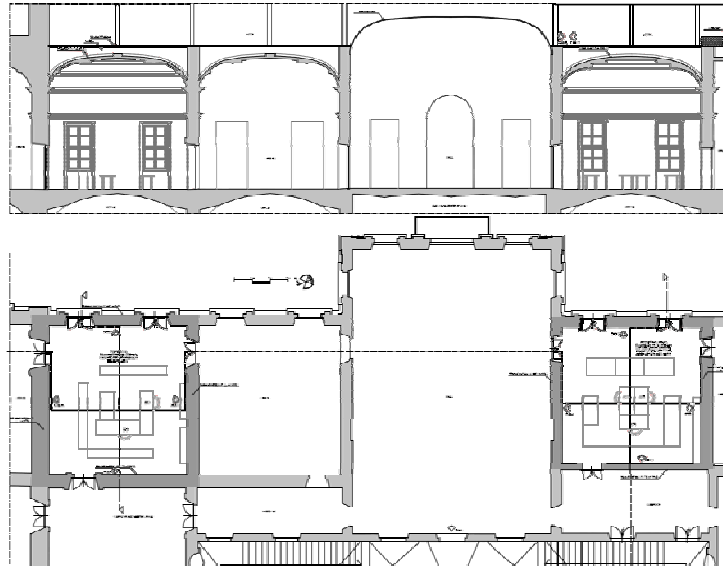
Figure 5: Plan and section of the premises included in the model (in red)

1.3.2.2 Building Envelop description

1.3.2.2.1 Walls

External Wall 1		Density (kg.m^{-3})	Thickness (mm)	C$_p$ (kJ.kg^{-1}.K^{-1})	k (kJ.h^{-1}.m^{-1}.K^{-1})
A	Gypsum	1 000	30	0.9	1.500
B	Brick	1 700	570	0.8	3.863

External Wall 2		Density (kg.m^{-3})	Thickness (mm)	C$_p$ (kJ.kg^{-1}.K^{-1})	k (kJ.h^{-1}.m^{-1}.K^{-1})
A	Gypsum	1 000	30	0.9	1.500
B	Brick	1 700	170	0.8	3.863

Floor		Density (kg.m^{-3})	Thickness (mm)	C$_p$ (kJ.kg^{-1}.K^{-1})	k (kJ.h^{-1}.m^{-1}.K^{-1})
A	Wood	500	20	1.2	0.542
B	Subfloor	500	200	1.2	0.542
C	Brick	1 700	350	0.8	3.863
D	Gypsum	1 000	30	0.9	1.500

Roof		Density (kg.m^{-3})	Thickness (mm)	C$_p$ (kJ.kg^{-1}.K^{-1})	k (kJ.h^{-1}.m^{-1}.K^{-1})
A	Slate	2 700	50	0.75	7.581

Adjacent Ceiling (Office)		Density (kg.m^{-3})	Thickness (mm)	C$_p$ (kJ.kg^{-1}.K^{-1})	k (kJ.h^{-1}.m^{-1}.K^{-1})
A	Wood	500	50	1.2	0.542

Adjacent Ceiling (Office)		**Density** *(kg.m⁻³)*	**Thickness** *(mm)*	**C$_p$** *(kJ.kg⁻¹.K⁻¹)*	**k** *(kJ.h⁻¹.m⁻¹.K⁻¹)*
B	Air layer	80	**30**	1.44	0.18
C	Brick	1 700	120	0.8	3.863

Adjacent Ceiling		**Density** *(kg.m⁻³)*	**Thickness** *(mm)*	**C$_p$** *(kJ.kg⁻¹.K⁻¹)*	**k** *(kJ.h⁻¹.m⁻¹.K⁻¹)*
A	Wood	500	120	1.2	0.542

Adjacent Wall (Corridor)		**Density** *(kg.m⁻³)*	**Thickness** *(mm)*	**C$_p$** *(kJ.kg⁻¹.K⁻¹)*	**k** *(kJ.h⁻¹.m⁻¹.K⁻¹)*
A	Gypsum	1 000	30	0.9	1.500
B	Brick	1 700	280	0.8	3.863
C	Gypsum	1 000	30	0.9	1.500

Adjacent Wall (Hall)		**Density** *(kg.m⁻³)*	**Thickness** *(mm)*	**C$_p$** *(kJ.kg⁻¹.K⁻¹)*	**k** *(kJ.h⁻¹.m⁻¹.K⁻¹)*
A	Gypsum	1 000	30	0.9	1.500
B	Brick	1 700	520	0.8	3.863
C	Gypsum	1 000	30	0.9	1.500
Adjacent Wall (Office)		Density *(kg.m⁻³)*	Thickness *(mm)*	C$_p$ *(kJ.kg⁻¹.K⁻¹)*	k *(kJ.h⁻¹.m⁻¹.K⁻¹)*
A	Gypsum	1 000	30	0.9	1.500
B	Brick	1 700	670	0.8	3.863
C	Gypsum	1 000	30	0.9	1.500

Internal Wall		**Density** *(kg.m⁻³)*	**Thickness** *(mm)*	**C$_p$** *(kJ.kg⁻¹.K⁻¹)*	**k** *(kJ.h⁻¹.m⁻¹.K⁻¹)*
A	Concrete	2 300	200	0.92	6.318

1.3.2.2.2 Windows

Single pane windows are implemented with the following characteristics:
      ID Number: 1001 (TRNSYS Windows Library)
      Simple pane window
      Design : 2.5
      U-Value = 5.74 W/m².K - g-Value = 0.87 W/m².K

1.3.2.3 Building loads and occupancy

At the moment, the simulation time step is set to 15 minutes.

1.3.2.3.1 Occupancy

Occupancy loads are defined in two zones: *reference office* and *test office*:
One person produces a heat flux of 70W (half convective, half radiative). Occupancy loads are defined as follow:

Occupancy	
Reference office	From 8:00 to 18:00 5/7
Test office	Mon, Fri from 8:00 to 18:00 Tue, Wed from 8:00 to 10:00, from 13:00 to 14:00, from 16:00 to 18:00 Thu : no occupation

1.3.2.3.2 Lighting

Lighting loads are defined in two zones: *reference room* and *test room*:

Lighting loads are first arbitrary set to 10 W/m² and follow the occupancy schedule. It means that lights are always turned on when someone is inside the room and are always turned off if not.

Lighting	
Reference office	From 8:00 to 18:00 5/7
Test office	Mon, Fri from 8:00 to 18:00 Tue, Wed from 8:00 to 10:00, from 13:00 to 14:00, from 16:00 to 18:00 Thu : no occupation

Lighting loads are extracted from lighting simulation carried out through Daysim and then integrated in thermal models.

1.3.2.3.3 Heating

Heating loads are defined in two zones: *reference room* and *test room*. Each room is equipped with a fan coil with variable speed (3 speeds) and an effectiveness of heat exchanger of 65 %.

The fan speed of fan coil units is controlled by a command law based on temperature difference between the set point temperature (21°C) and air temperature in the room as shown on Figure 6 and Table 2 below.
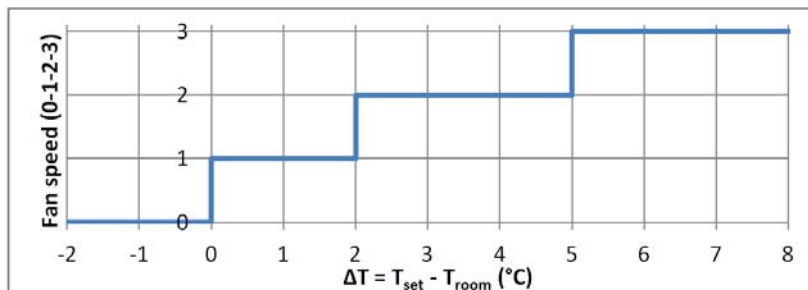
Figure 6: Fan speed command law of fan coil units

Fan speed	Flow rate *(kg/h)*
0	0
1	1987
2	2510
3	3137

Table 2: Fancoil flow rate

The hot side fluid (water) is preheated at temperature function of outside temperature as shown on Figure 7 below. The mass flow rate is set to a constant value of 760 kg/h
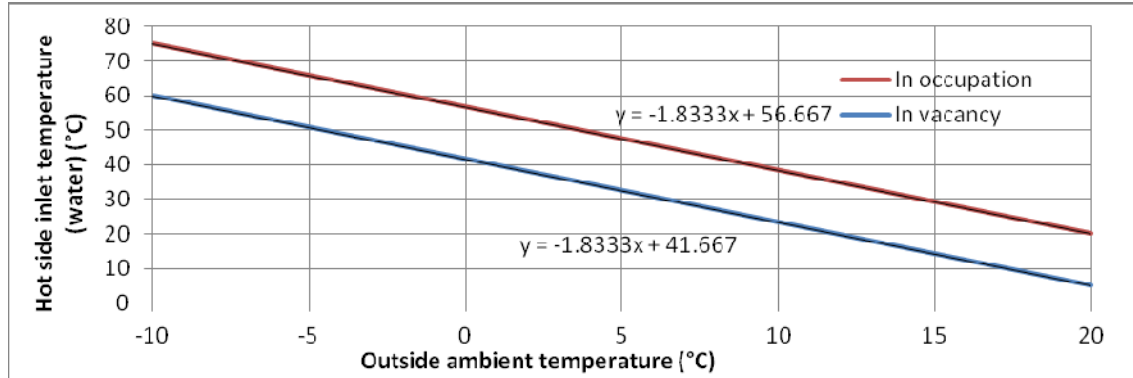
Figure 7: Fan coil hot side inlet temperature as a function of outside ambient temperature

1.3.2.3.4 Cooling

No Cooling devices are defined in theses rooms.

1.3.2.3.5 Ventilation

No sanitary ventilation rate is defined in addition to ventilation rates of fan coil units or auxiliary air conditioner.

1.3.2.3.6 Infiltration and natural ventilation

Infiltration is set to 0.4 air change rate per hour (ACH) in offices and to 0.7 ACH in attic spaces. Natural ventilation is not taken into account in the model.

1.3.3   Input data used for (DITER offices in Valentino Castle)

1.3.3.1.1 Geometry of the model

The test room and the reference room are part of the Valentino Castle which is not entirely simulated. Two rooms were selected in task 1.1 and data were collected in task 1.2. These data are used as inputs of the thermal simulation.
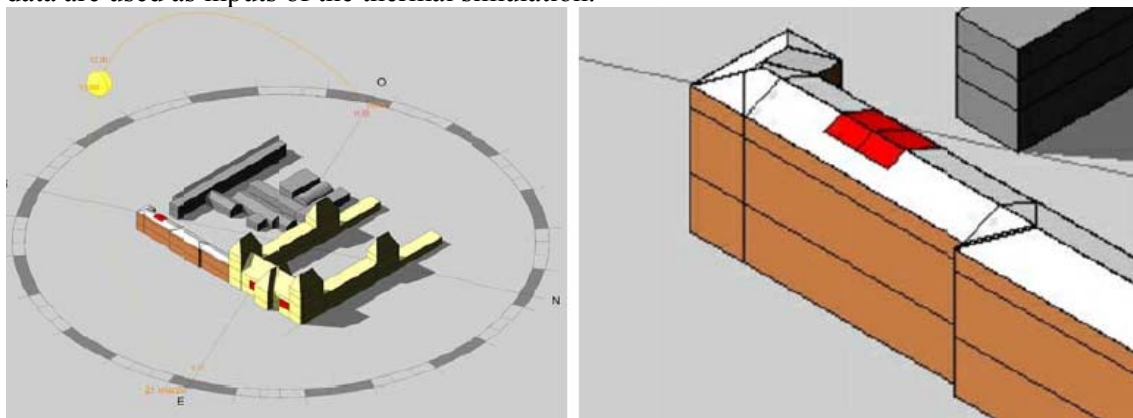
Figure 8 : Insertion of the model in the entire building

The model has been split into four zones whose names, areas and volumes are displayed in the following table.

Table 3 : Numbering and denomination of thermal zones

	Zones	Volume (m^3)	Area (m^2)	Number of nodes	Occupancy
1	Reference room north	58	17.0	1	Yes
2	Test room	58	17.0	1	Yes
3	Reference room south	58	17.0	1	Yes
4	Corridor	51	18.7	1	None

Adjacent offices are not included in the model as shown in Figure 9 below. An adiabatic boundary condition is set for boundary walls that are adjacent to a heated area.
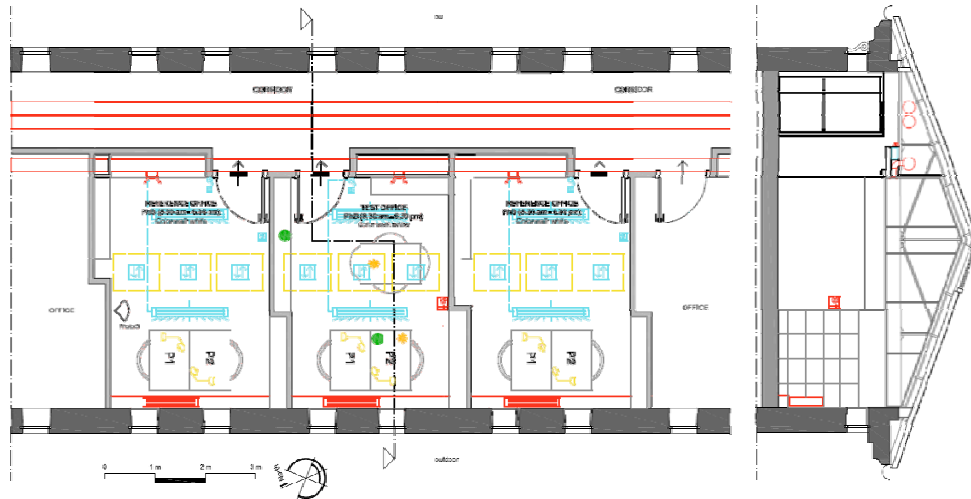
Figure 9: Plan and section of the premises included in the model (in red)

1.3.3.2 Building Envelop description

1.3.3.2.1 Walls

	External Wall	Density $(kg.m^{-3})$	Thickness (mm)	C_p $(kJ.kg^{-1}.K^{-1})$	k $(kJ.h^{-1}.m^{-1}.K^{-1})$
A	Gypsum	1 200	30	0.9	1.500
B	Brick	1 700	470	0.8	3.863

	Floor	Density $(kg.m^{-3})$	Thickness (mm)	C_p $(kJ.kg^{-1}.K^{-1})$	k $(kJ.h^{-1}.m^{-1}.K^{-1})$
A	Wood	500	5	1.2	0.542
B	Subfloor	500	95	1.2	0.542
C	Brick	1 700	200	0.8	3.863
D	Gypsum	1 000	20	0.9	1.500

	Roof	Density $(kg.m^{-3})$	Thickness (mm)	C_p $(kJ.kg^{-1}.K^{-1})$	k $(kJ.h^{-1}.m^{-1}.K^{-1})$
A	Slate	2 700	50	0.75	7.581

Adjacent Wall, Type 1		Density $(kg.m^{-3})$	Thickness (mm)	C_p $(kJ.kg^{-1}.K^{-1})$	k $(kJ.h^{-1}.m^{-1}.K^{-1})$

Adjacent Wall, Type 1		Density $(kg.m^{-3})$	Thickness (mm)	C_p $(kJ.kg^{-1}.K^{-1})$	k $(kJ.h^{-1}.m^{-1}.K^{-1})$
A	Gypsum	1 000	100	0.9	1.500

Adjacent Wall, Type 2		Density $(kg.m^{-3})$	Thickness (mm)	C_p $(kJ.kg^{-1}.K^{-1})$	k $(kJ.h^{-1}.m^{-1}.K^{-1})$
A	Glass	2 490	20	0.83	4.188

1.3.3.2.2 Windows

Single pane windows are implemented on vertical walls with the following characteristics:
> ID Number: 1001 (TRNSYS Windows Library)
> Simple pane aluminium window
> U-Value = 5.74 W/m².K
> g-Value = 0.87 W/m².K

Double pane windows are implemented on tilted surfaces (roof) with the following characteristics:
> ID Number: 15008 (Basic TRNSYS Windows Library)
> Double panes wood window
> Design: 6/16/4
> U-Value = 2.54 W/m².K
> g-Value = 0.44 W/m².K

1.3.3.3 Building loads and occupancy

At the moment, the simulation time step is set to 60 minutes. It could be lowered to 15 minutes.

1.3.3.3.1 Occupancy

Occupancy loads are defined in three zones: *reference room north*, *test room and reference room south*.

One person produces a heat flux of 70W (half convective, half radiative). Occupancy loads are defined as follow:

Occupancy	Time step : 60 minutes
Reference office	From 8:00 to 18:00 5/7: 2
Test office	Mon, Fri from 8:00 to 18:00 : 2 Tue, Wed from 8:00 to 10:00, from 13:00 to 14:00, from 16:00 to 18:00 : 2 Thu : no occupation

1.3.3.3.2 Lighting

Lighting loads are defined in four zones (reference offices north and south, test office and corridor) and are arbitrary set to 10 W/m². In offices, lights schedule follows occupancy and meteorological data (total radiation IT) in order to properly simulate the behavior of

occupants. Lights are manually controlled in 1 group (ON/OFF switch). Manual control of lights is modelled by the following equation:

$$Q_l(t) = \begin{cases} if\ IT \leq 200\ \frac{W}{m^2} : k * S * occ \\ if\ 200 < IT \leq 400\ \frac{W}{m^2} : Q_l(t-1) \\ if\ IT > 400\ \frac{W}{m^2} : 0 \end{cases}$$

1.3.3.3.3 Shading system

Internal venetian blinds are installed and manually controlled. Occupant's behaviour is never easy to model but the fairest way to model the manual use of a sunscreen is to base the value of the shading factor on the values of beam radiation (IB) and solar zenith angle (SZA) in order to isolate potential periods of glare. The internal shading factor (ISF) is then controlled with the following equation:

$$ISF = \begin{cases} if\ \begin{cases} IB > 100\ ^W/_{m^2} \\ and\ 30° > SZA > 60° \end{cases} then\ ISF = (1 - ISF_{max}) \\ else\ ISF = (1 - ISF_{min}) \end{cases} \quad where\ \begin{cases} ISF_{min} = [0;1](=0) \\ ISF_{max} = [0;1](=0.6) \end{cases}$$

1.3.3.3.4 Heating

Heating loads are defined in three zones: *reference office north*, *reference office south* and *test office*. Each room is equipped with a fan coil with variable speed (3 speeds) and an effectiveness of heat exchanger of 65 %.

The fan speed of fan coil units is controlled by a command law based on temperature difference between the set point temperature (21°C) and air temperature in the room as shown on Figure 10 and Table 4 below.
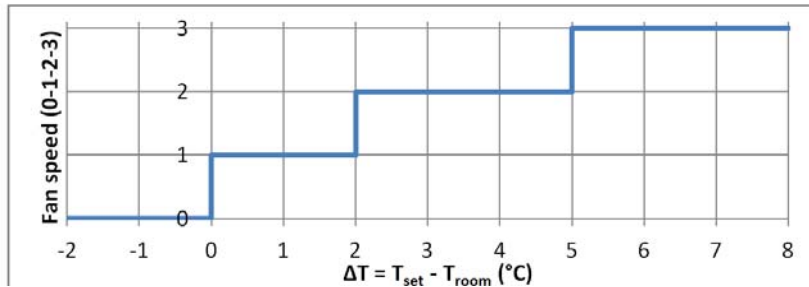
Figure 10: Fan air speed command law of fan coil units

Table 4: Fan coil flow rate

Fan speed	Flow rate (kg/h)
0	0
1	618
2	780
3	975

The hot side fluid (water) is preheated at temperature function of outside temperature as shown on Figure 7 above. The mass flow rate is set to a constant value of 300 kg/h.

Heating and cooling devices are modelled and controlled as shown on Figure 11

Figure 11 : Heating and cooling Modeling

below (see later)
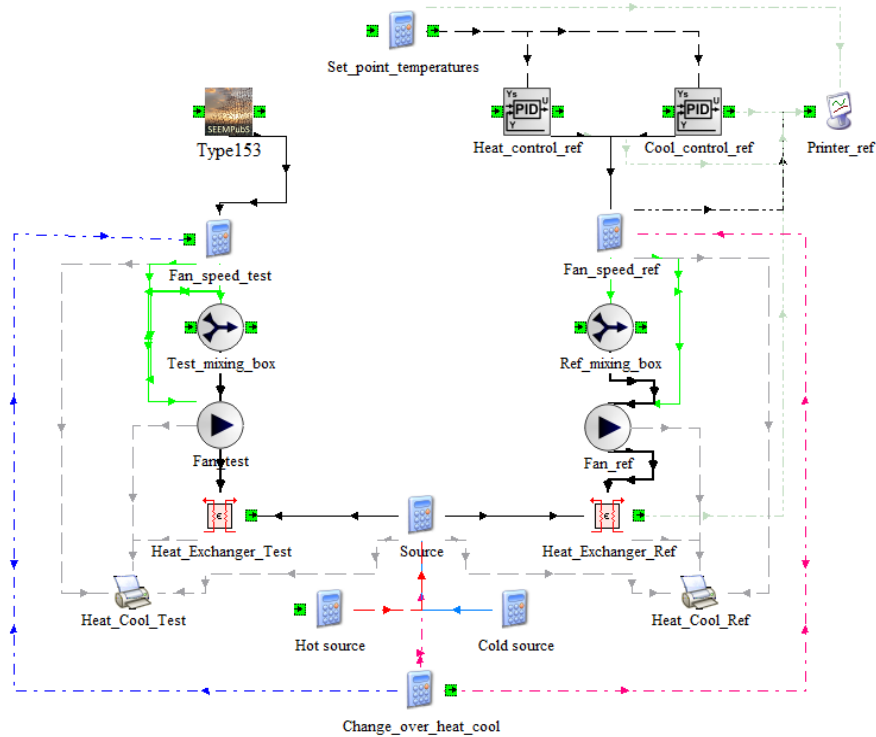
Figure 11 : Heating and cooling Modeling

1.3.3.3.5 Cooling

Cooling devices are described in Figure 11

Figure 11 : Heating and cooling Modeling

above. Cooling loads are defined in three zones: *reference office north*, *reference office south* and *test office*. Each room is equipped with a fan coil with variable speed (3 speeds) and an effectiveness of heat exchanger of 65 %.

The fan speed of fan coil units is controlled by a command law based on temperature difference between the set point temperature (21°C) and air temperature in the room as shown on Figure 10 and Table 4 above.

The cold side fluid (water) is cold at a constant temperature (5°C). The mass flow rate is set to a constant value of 60 kg/h.

1.3.3.3.6 Other loads – Electronic devices

A computer is set to produce a heat flux of 100W (convective). Two computers run on a schedule based on occupancy.

1.3.3.4 Ventilation

No sanitary ventilation rate is defined in addition to ventilation rates of fan coil units or auxiliary air conditioner.

1.3.3.4.1 Infiltration and natural ventilation

Infiltration is set to 0.4 air change rate per hour (ACH) in offices and to 0.6 ACH in the corridor.
Natural ventilation is not taken into account in the model.

1.3.4   Input data specifics to Rooms 6 & 7 (Classroom)

These rooms were not equipped with control and monitoring systems for budget problems. They were considered only in the simulation phase.

1.3.4.1 Geometry of the model

The test room and the reference room are part of a bigger building which is not entirely simulated. Two rooms were selected in task 1.1 and data were collected in task 1.2. These data are used as inputs of the thermal simulation.
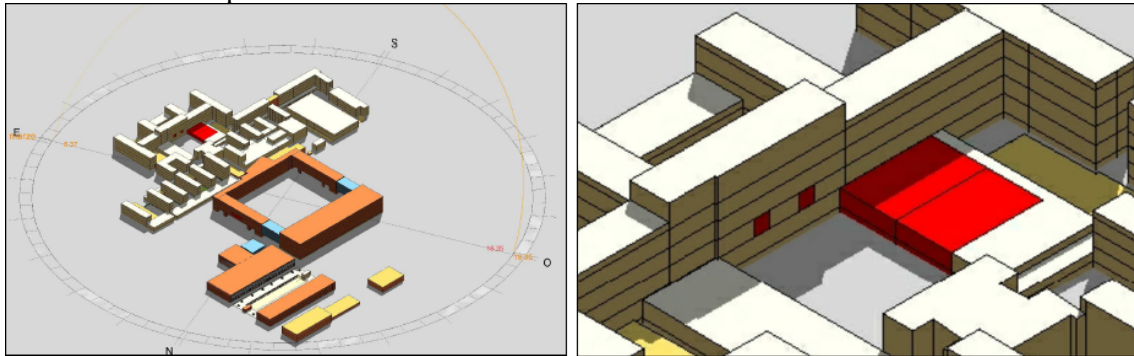
Figure 12 : Insertion of the model in the entire building

The model has been split into six zones whose names, areas and volumes are displayed in the following table.

Table 5 : Numbering and denomination of thermal zones

Zones		Volume (m³)	Area (m²)	Number of nodes	Occupancy
1	Reference Up Ceiling	675	145	1	Yes
2	Reference Up Floor				
3	Reference Down Ceiling	877	173	1	Yes
4	Reference Down Floor				
5	Test Up Ceiling				
6	Test Up Floor	675	145	1	Yes
7	Test Down Ceiling				
8	Test Down Floor	877	173	1	Yes
9	Corridor Up	846	186	1	None
10	Corridor Down	407	109	1	None
11	Basement	2 990	983	1	None

Adjacent rooms are not included in the model as shown in Figure 13 below. An adiabatic boundary condition is set for boundary walls that are adjacent to a heated area.
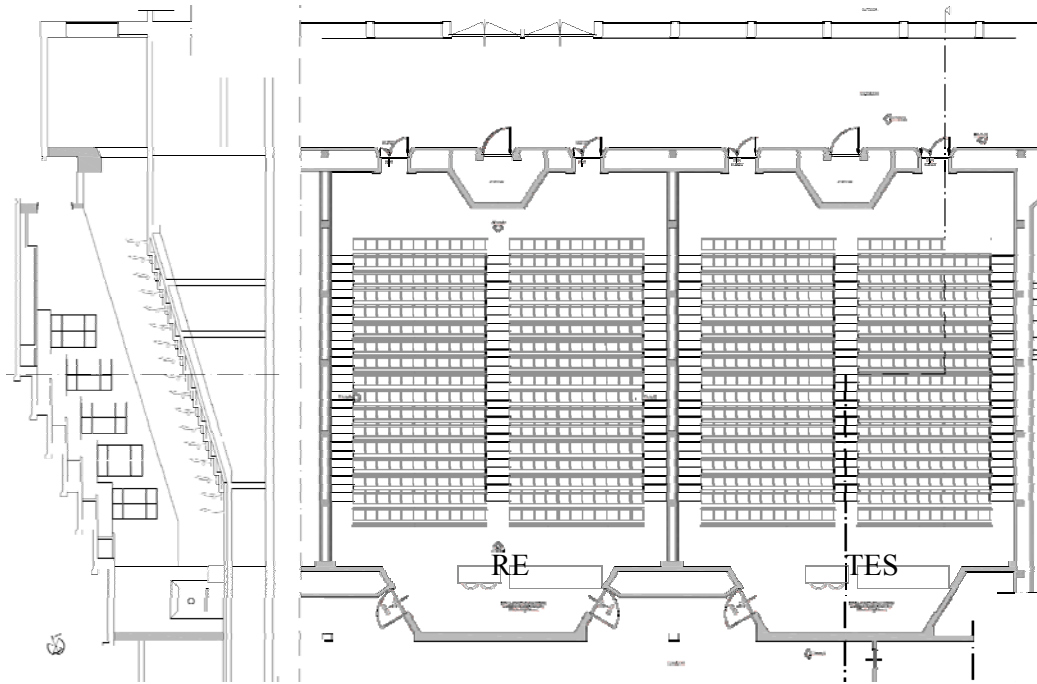
Figure 13: Plan and section of the premises included in the model (in red)

1.3.4.2 Building Envelop description

1.3.4.2.1 Walls

External Wall		Density (kg.m⁻³)	Thickness (mm)	C_p (kJ.kg⁻¹.K⁻¹)	k (kJ.h⁻¹.m⁻¹.K⁻¹)
A	Plaster	950	15	0.84	0.58
B	Brick	1 700	100	0.79	4.22
C	Equivalent layer A	1 780	122	0.805	1.80
D	Brick	1 700	100	0.79	4.22
E	Plaster	950	15	0.84	0.58
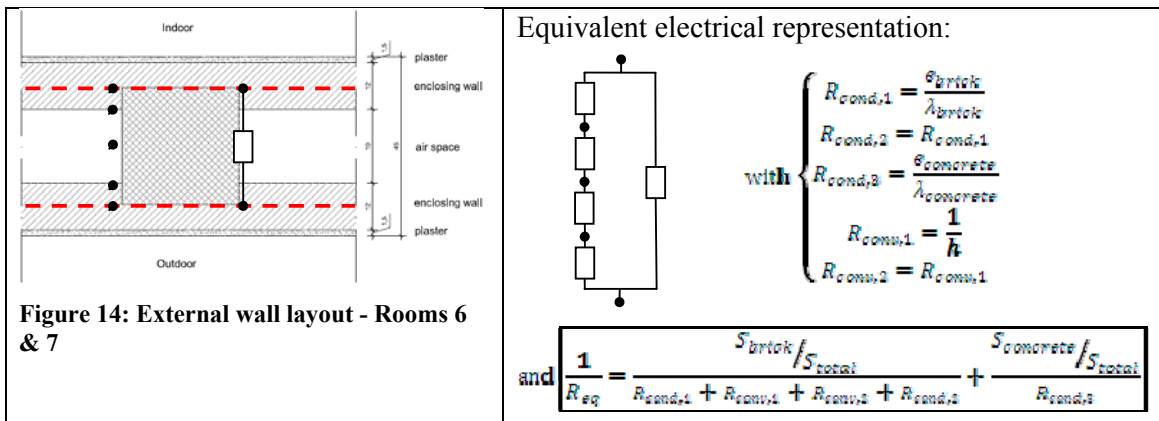
Figure 14: External wall layout - Rooms 6 & 7

Equivalent electrical representation:

$$\text{with} \begin{cases} R_{cond,1} = \dfrac{e_{brick}}{\lambda_{brick}} \\ R_{cond,2} = R_{cond,1} \\ R_{cond,3} = \dfrac{e_{concrete}}{\lambda_{concrete}} \\ R_{conv,1} = \dfrac{1}{h} \\ R_{conv,2} = R_{conv,1} \end{cases}$$

$$\text{and } \frac{1}{R_{eq}} = \frac{S_{brick}/S_{total}}{R_{cond,1} + R_{conv,1} + R_{conv,2} + R_{cond,2}} + \frac{S_{concrete}/S_{total}}{R_{cond,3}}$$

Adjacent Wall, Type 1		Density (kg.m⁻³)	Thickness (mm)	C_p (kJ.kg⁻¹.K⁻¹)	k (kJ.h⁻¹.m⁻¹.K⁻¹)
A	Plaster	950	15	0.84	0.58
B	Brick	1 700	100	0.8	3.863
C	Equivalent layer B	1 780	131	0.805	1.847
D	Brick	1 700	100	0.8	3.863
E	Plaster	950	15	0.84	0.58

Note: It is the same calculation process than for external wall but with an air layer of 270 mm instead of 190 mm and a concrete layer 80 mm thicker.

Adjacent Wall, Type 2		Density (kg.m⁻³)	Thickness (mm)	C_p (kJ.kg⁻¹.K⁻¹)	k (kJ.h⁻¹.m⁻¹.K⁻¹)
A	Plaster	950	15	0.84	0.58
B	Brick	1 700	120	0.8	3.863
C	Plaster	950	15	0.84	0.58

Adjacent Wall, Type 3		Density (kg.m⁻³)	Thickness (mm)	C_p (kJ.kg⁻¹.K⁻¹)	k (kJ.h⁻¹.m⁻¹.K⁻¹)
A	Plaster	950	15	0.84	0.58
B	Brick	1 700	250	0.8	3.863
C	Plaster	950	15	0.84	0.58

Adjacent Wall, Type 4		Density (kg.m⁻³)	Thickness (mm)	C_p (kJ.kg⁻¹.K⁻¹)	k (kJ.h⁻¹.m⁻¹.K⁻¹)
A	Plaster	950	15	0.84	0.58
B	Brick	1 700	120	0.8	3.863
C	Plaster	950	15	0.84	0.58
D	Airlayer	Massless	830	R_{eq} = 0.05 h.m².K/kJ	
E	Plaster	950	15	0.84	0.58
F	Brick	1 700	120	0.8	3.863
G	Plaster	950	15	0.84	0.58

Floor (horizontal)		Density (kg.m⁻³)	Thickness (mm)	C_p (kJ.kg⁻¹.K⁻¹)	k (kJ.h⁻¹.m⁻¹.K⁻¹)
A	Marble	2 800	15	1.00	12.6
B	Mortar subfloor	1 800	10	0.84	3.13
C	Incline cement mortar	2 000	45	1.00	5.04
D	Hollow brick	1 000	180	0.84	1.44
E	Plaster	950	15	0.84	0.58

Tilted floor		Density (kg.m⁻³)	Thickness (mm)	C_p (kJ.kg⁻¹.K⁻¹)	k (kJ.h⁻¹.m⁻¹.K⁻¹)
A	Marble	2 800	20	1.00	12.6
B	Brick	1 700	110	0.8	3.863
C	Equivalent layer C	255	110	0.12	3.04

Tilted floor		**Density** *(kg.m⁻³)*	**Thickness** *(mm)*	**Cₚ** *(kJ.kg⁻¹.K⁻¹)*	**k** *(kJ.h⁻¹.m⁻¹.K⁻¹)*
D	Reinforced concrete	2 400	70	0.84	7.92
E	Equivalent layer D	1 074	237	0.84	3.379
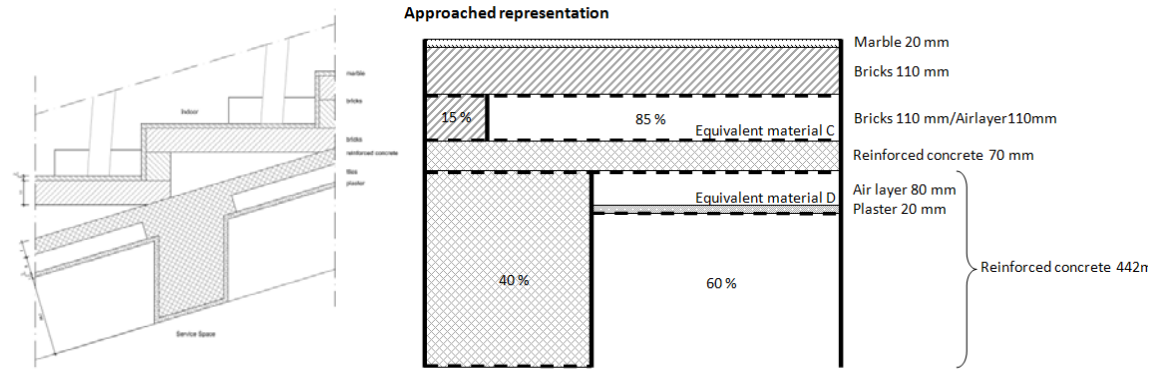
Figure 15: Approached representation of tilted floor layout

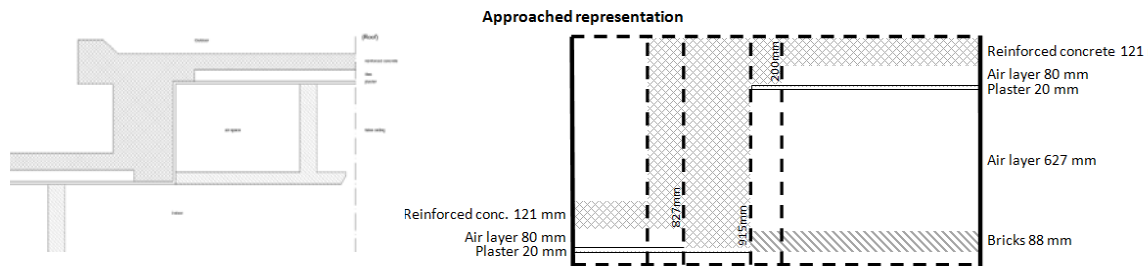| **Roof**		**Density** *(kg.m⁻³)*	**Thickness** *(mm)*	**Cₚ** *(kJ.kg⁻¹.K⁻¹)*	**k** *(kJ.h⁻¹.m⁻¹.K⁻¹)*
A	Equivalent layer E	1 690	388	0.84	3.87

Figure 16: Approached representation of roof layout

1.3.4.2.2 Windows

Single pane windows are implemented on vertical walls with the following characteristics:
ID Number: 1001 (TRNSYS Windows Library)
Simple pane aluminium window
U-Value = 5.74 W/m².K
g-Value = 0.87 W/m².K

1.3.4.3 Building loads and occupancy

At the moment, the simulation time step is set to 60 minutes. It could be lowered to 15 minutes.

1.3.4.3.1 Occupancy

Occupancy loads are defined in four zones: *reference classroom (up and down)* and *test classroom (up and down)*, apart from vacations, holidays and weekends, as follows:

One person produces a heat flux of 70W (half convective, half radiative). There are 374 seats in each classroom but the real occupancy is probably less. Occupancy loads are *arbitrary* defined as follow:

Occupancy	Time step : 60 minutes
Reference classroom up	From 8:00 to 10:00: 50 From 10:00 to 12:00: 80 From 12:00 to 14:00: 0 From 14:00 to 16:00: 80 From 16:00 to 18:00: 80
Reference classroom down	From 8:00 to 10:00: 80 From 10:00 to 12:00: 100 From 12:00 to 14:00: 0 From 14:00 to 16:00: 100 From 16:00 to 18:00: 100
Test classroom up **Test classroom down**	Same occupation as reference classroom.

1.3.4.3.2 Lighting

Lighting loads are defined in all classrooms and corridors zones (6) and are arbitrary set to 10 W/m². In classrooms, lights schedule follows occupancy as there is no natural light. The down corridor looks dark despite the windows. Therefore, the lights are probably used all the time between classes. Lighting loads are displayed in the following table.

Lighting	Time step : 60 minutes
Classrooms	From 8:00 to 12:00 5/7: 10 W/m² From 14:00 to 18:00 5/7: 10 W/m²
Corridor Down	From 8:00 to 9:00: 5 W/m² From 10:00 to 11:00: 5 W/m² From 12:00 to 13:00: 5 W/m² From 14:00 to 15:00: 5 W/m² From 16:00 to 17:00: 5 W/m² From 18:00 to 19:00: 5 W/m²
Corridor Up	From 8:00 to 9:00: 5 W/m² From 10:00 to 11:00: 2 W/m² From 12:00 to 13:00: 2 W/m² From 14:00 to 15:00: 2 W/m² From 16:00 to 17:00: 2 W/m² From 18:00 to 19:00: 5 W/m²

1.3.4.3.3 Heating

Heating systems are defined are defined as explained previously.

Fan speed of fan coil units is controlled by a command law based on temperature difference between the set point temperature (21°C) and air temperature in the room as shown on Table 6 below.

Table 6: Fan coil flow rate

Fan speed	Flow rate *(kg/h)*
0	0
1	2027
2	2560
3	3200

The hot side fluid (water) is preheated at temperature function of outside temperature as shown on Figure 7. The mass flow rate of water is set to a constant value of **1200** kg/h.

1.3.4.3.4 Cooling

Cooling systems are defined as explained previously.

The cold side fluid (water) is cold at a constant temperature (5°C). The mass flow rate is set to a constant value of 600 kg/h.

1.3.4.3.5 Other loads – Electronic devices

Others loads are defined in two zones: *reference classroom* down and *test classroom down*. A computer is set to produce a heat flux of 100W (convective). One computer in each zone run on a schedule based on occupancy.

1.3.4.4 Ventilation, infiltration, airflow model

1.3.4.4.1 Ventilation

No sanitary ventilation rate is defined in addition to ventilation rates of fan coil units or auxiliary air conditioner.

1.3.4.4.2 Infiltration and natural ventilation

Infiltration is not set in classrooms yet and is set to 0.6 air change rate per hour (ACH) in corridors.
Natural ventilation is not taken into account in the model.

1.3.5   Input data specifics to Rooms 8 & 9 (Administrative offices)

1.3.5.1 Geometry of the model

The test room and the reference room are part of a bigger building which is not entirely simulated. Two rooms were selected in task 1.1 and data were collected in task 1.2. These data are used as inputs of the thermal simulation.
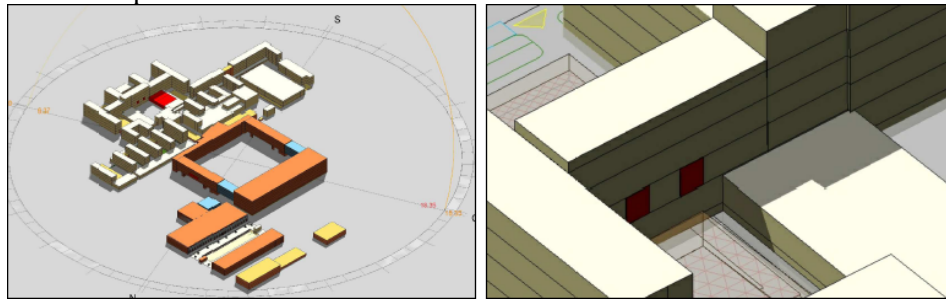

Figure 17 : Insertion of the model in the entire building

The model has been split into four zones whose names, areas and volumes are displayed in the following table.

Table 7 : Numbering and denomination of thermal zones

Zones		Volume (m³)	Area (m²)	Number of nodes	Occupancy
1	Reference	135	35.9	1	Yes
2	Intermediate	161	43.0	1	Yes
3	Test	122	32.4	1	Yes
4	Corridor	76	20.3	1	None

Adjacent rooms are not included in the model as shown in Figure 18 below. An adiabatic boundary condition is set for boundary walls that are adjacent to a heated area. TRNSYS3d was used to define masks and to calculate the shading and insulation matrices.
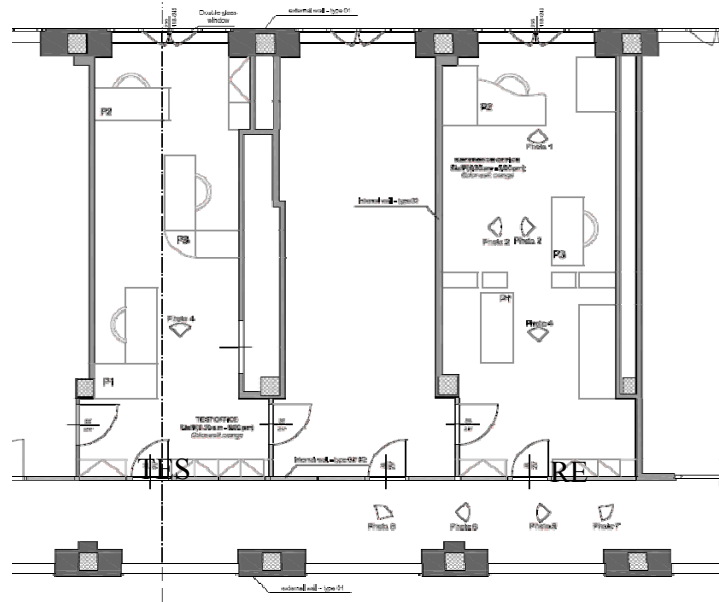
Figure 18: Plan and section of the premises included in the model (in red)

1.3.5.2 Building Envelop description

1.3.5.2.1 Walls

External Wall, Type 1		Density (kg.m⁻³)	Thickness (mm)	C_p (kJ.kg⁻¹.K⁻¹)	k (kJ.h⁻¹.m⁻¹.K⁻¹)
A	Plaster	950	15	0.84	0.58
B	Brick	1 700	120	0.80	3.863
C	Air layer 270 mm	Massless. Req.			
D	Brick	1 700	120	0.80	3.863
E	Stone	1 700	45	0.80	3.791

External Wall, Type 2		Density (kg.m⁻³)	Thickness (mm)	C_p (kJ.kg⁻¹.K⁻¹)	k (kJ.h⁻¹.m⁻¹.K⁻¹)
A	Plaster	950	15	0.84	0.58
B	Brick	1 700	120	0.80	3.863
C	Air layer	80	20	1.44	0.180
D	Brick	1 700	120	0.80	3.863
E	Stone	1 700	45	0.80	3.791

Boundary floor/ceiling		Density (kg.m⁻³)	Thickness (mm)	C_p (kJ.kg⁻¹.K⁻¹)	k (kJ.h⁻¹.m⁻¹.K⁻¹)
A	Marble	2 800	20	1.00	12.6
B	Mortar subfloor	1 800	80	1.00	3.13
C	Thermal insulation	2 000	60	1.00	5.04
D	Hollow block-floor	1 000	250	0.84	1.44
E	Plaster	950	20	0.84	0.58

Adjacent Wall, Type 1		Density (kg.m⁻³)	Thickness (mm)	C_p (kJ.kg⁻¹.K⁻¹)	k (kJ.h⁻¹.m⁻¹.K⁻¹)
A	Plaster	950	15	0.84	0.58
B	Brick	1 700	120	0.8	3.863
C	Plaster	950	15	0.84	0.58

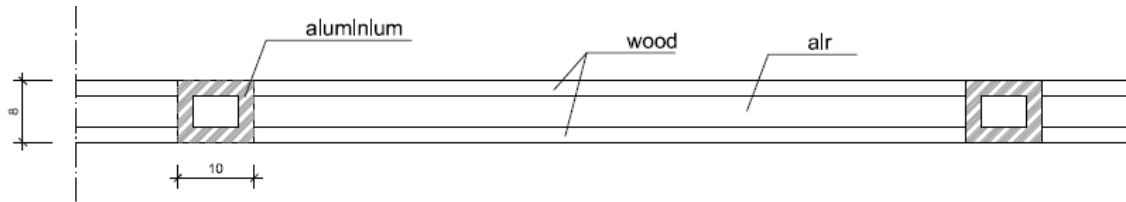| Adjacent Wall, Type 2		Density (kg.m⁻³)	Thickness (mm)	C_p (kJ.kg⁻¹.K⁻¹)	k (kJ.h⁻¹.m⁻¹.K⁻¹)
A	Massless: Equivalent thermal resistance R_{eq}				

Figure 19: Internal wall 2 layout (administrative offices)

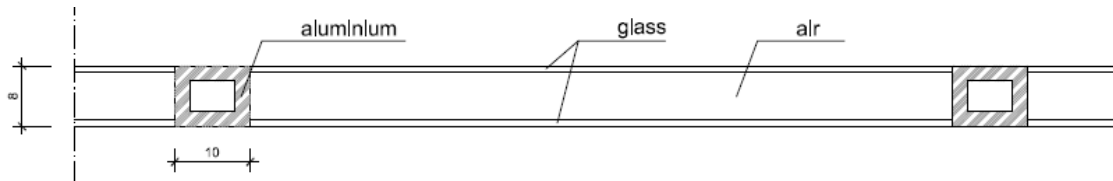| Adjacent Wall, Type 3		Density (kg.m⁻³)	Thickness (mm)	C_p (kJ.kg⁻¹.K⁻¹)	k (kJ.h⁻¹.m⁻¹.K⁻¹)
A	Massless: Equivalent thermal resistance R_{eq}				

Figure 20: Internal wall 3 layout (administrative offices)

1.3.5.2.2 Windows

Double panes windows are implemented on vertical walls with the following characteristics:
ID Number: 2001 (TRNSYS Windows Library)
Double panes aluminium window without thermal break
Design: 2.5/12.7/2.5
U-Value = 2.95 W/m².K
g-Value = 0.78 W/m².K

1.3.5.3 Building loads and occupancy

1.3.5.3.1 Occupancy

Occupancy loads are defined in three zones: *reference office, intermediate office* and *test office*.
One person produces a heat flux of 70W (half convective, half radiative). There are three workstations in each office. Occupancy loads are defined as follow:

Occupancy	Time step : 60 minutes
Reference office	From 8:00 to 12:00: 3 From 12:00 to 13:00: 0 From 13:00 to 17:00: 3
Intermediate office	Id.
Test office	Id.

1.3.5.3.2 Lighting

Lighting loads are defined in all zones (4) and are arbitrary set to 10 W/m². In offices, lights schedule follows occupancy and meteorological data (total radiation IT) in order to properly simulate the behavior of occupants. Lights are manually controlled in 1 group (ON/OFF switch). Manual control of lights is modelled by the following equation:

$$Q_l(t) = \begin{cases} if\ IT \leq 200\,\frac{W}{m^2}: k * S * occ \\ if\ 200 < IT \leq 400\,\frac{W}{m^2}: Q_l(t-1) \\ if\ IT > 400\,\frac{W}{m^2}: 0 \end{cases}$$

1.3.5.3.3 Shading system

Internal vertical bands are installed and manually controlled. Occupant's behaviour is never easy to model but the fairest way to model the manual use of a sunscreen is to base the value of the shading factor on the values of beam radiation (IB) and angle of incidence (AI) in order to isolate potential periods of glare. The internal shading factor (ISF) is then controlled with the following equation:

$$ISF = \begin{cases} if\ \begin{Bmatrix} IB > 100\ ^W/_{m^2} \\ and\ AI > 45° \end{Bmatrix} then\ ISF = (1 - ISF_{max}) \\ else\ ISF = (1 - ISF_{min}) \end{cases} \quad where \quad \begin{cases} ISF_{min} = [0;1] \\ ISF_{max} = [0;1] \end{cases}$$

1.3.5.3.4 Heating

Heating loads are defined in two zones: *reference room* and *test room*. Each room is equipped with a fan coil with variable speed (3 speeds) and an effectiveness of heat exchanger of 65 %, as explained previously.

Fan speed of fan coil units is controlled by a command law based on temperature difference between the set point temperature (21°C) and air temperature in the room as shown below. The hot side fluid (water) is preheated at temperature function of outside temperature. The mass flow rate is set to a constant value of **100** kg/h.

Table 8: Fan coil flow rate

Fan speed	Flow rate *(kg/h)*
0	0
1	618
2	780
3	975

1.3.5.3.5 Cooling

Cooling systems are defined as explained previously. The cold side fluid (water) is cold at a constant temperature (5°C). The mass flow rate is set to a constant value of 100 kg/h.

1.3.5.3.6 Other loads – Electronic devices

Others loads are defined in three zones: *reference room, intermediate room and test room.* A computer is set to produce a heat flux of 100W (convective). One computer in each zone run on a schedule based on occupancy.

1.3.5.4 Ventilation, infiltration, airflow model

1.3.5.4.1 Ventilation

No sanitary ventilation rate is defined in addition to ventilation rates of fan coil units or auxiliary air conditioner.

1.3.5.4.2 Infiltration and natural ventilation

Infiltration is set to 0.5 in the corridor and to 0.2 in offices. No natural ventilation network is defined in the simulation.

1.3.6   Input data specifics to Room 10&11 (DAUIN Laboratories)

1.3.6.1 Geometry of the model

The test room and the reference room are part of a bigger building that is not entirely simulated. TRNSYS3d has been used to define the corridor, the two monitored rooms and the two double skin façades as shown on Figure 21 below.
An adiabatic boundary condition is set for boundary walls that are adjacent to a heated area.
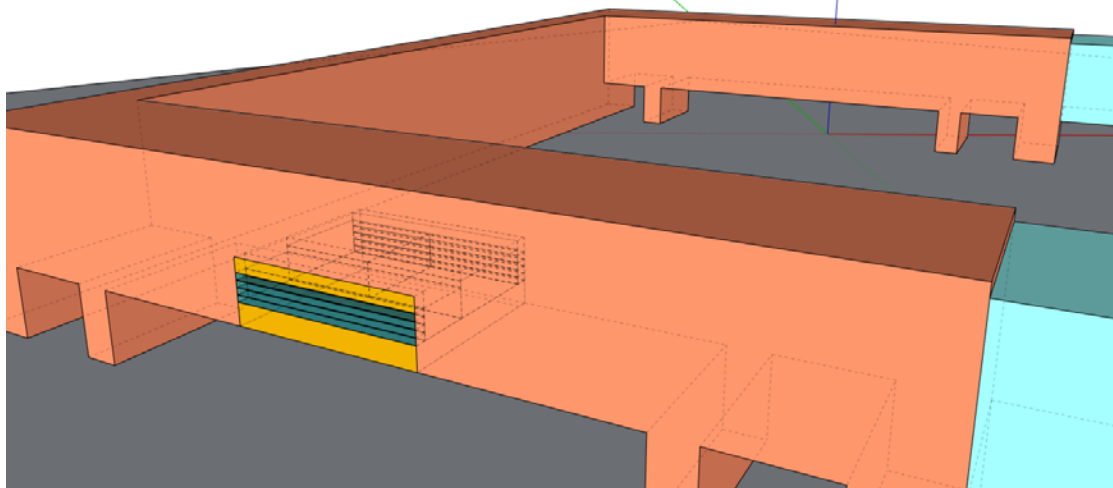

Figure 21 : Insertion of the model in the entire building

The model has been split into ten convex zones in order to perform the detailed radiation mode in TRNSYS. It explains why the attic space is split into four different zones. The following table shows the names, areas and volumes of each zone.

Table 9 : Numbering and denomination of thermal zones

Zones		Volume (m^3)	Area (m^2)	Number of nodes	Occupancy
1	Test lab	304	89.5	1	Yes
2	Ref lab	317	93.2	1	Yes
3	Corridor	287	102.5	1	Yes
4	Double-Skin South-West	66	23.5	4	None
5	Double-Skin North-East	66	23.5	4	None
6	Service Space	764	332.2	1	None
7	Lab attic	153	182.7	1	None
8	Corridor attic	287	102.5	1	None
9	Above double-skin South-West	34	23.5	1	None
10	Above double-skin North-East	34	23.5	1	None

Zones 4 and 5 have four air-nodes vertically distributed (there is 0.7 m between each air-node). It is a way to take thermal stratification into account in the model. The associated airflow model is also split into four 0.7-meter high level.

1.3.6.2 Building Envelop description

1.3.6.2.1 Walls

External Floor (Below Service Space)		Density $(kg.m^{-3})$	Thickness (mm)	C_p $(kJ.kg^{-1}.K^{-1})$	k $(kJ.h^{-1}.m^{-1}.K^{-1})$
A	Concrete	2 300	200	1.0	6.30

External Wall		Density $(kg.m^{-3})$	Thickness (mm)	C_p $(kJ.kg^{-1}.K^{-1})$	k $(kJ.h^{-1}.m^{-1}.K^{-1})$
A	Gypsum	1 000	13	0.9	1.50
B	Coating of mortar	2 000	20	1.0	4.14
C	Concrete	2 300	180	1.0	6.30
D	Thermal insulation	20	150	1.0	0.126

False Ceiling (between lower space and attic space)		Density $(kg.m^{-3})$	Thickness (mm)	C_p $(kJ.kg^{-1}.K^{-1})$	k $(kJ.h^{-1}.m^{-1}.K^{-1})$
A	Ceiling plate	35	50	1.19	0.108

Adjacent Ceiling (between attic space and upper space)		Density $(kg.m^{-3})$	Thickness (mm)	C_p $(kJ.kg^{-1}.K^{-1})$	k $(kJ.h^{-1}.m^{-1}.K^{-1})$
A	Plasterboard	950	40	0.84	0.58
B	Air layer	massless	117	R = 0.047 h.m².K/kJ	
C	Concrete	2 300	200	1.00	6.30

Boundary Ceiling (between attic space and out of model upper space)	Density *(kg.m⁻³)*	Thickness *(mm)*	Cₚ *(kJ.kg⁻¹.K⁻¹)*	k *(kJ.h⁻¹.m⁻¹.K⁻¹)*
A	Plasterboard	950	40	0.84	0.58
B	Air layer	massless	117	R = 0.047 h.m².K/kJ	
C	Concrete	2 300	200	1.00	6.30

Adjacent Wall (between two inside spaces)	Density *(kg.m⁻³)*	Thickness *(mm)*	Cₚ *(kJ.kg⁻¹.K⁻¹)*	k *(kJ.h⁻¹.m⁻¹.K⁻¹)*
A	Plasterboard	790	30	0.80	1.37
B	Expanded Polystyrene (EPS)	25	40	1.38	0.14
C	Air layer	massless	80	R = 0.047 h.m².K/kJ	
D	Expanded Polystyrene (EPS)	25	40	1.38	0.14
E	Plasterboard	790	30	0.80	1.37

Boundary Wall (between two inside spaces on the edge of the model)	Density *(kg.m⁻³)*	Thickness *(mm)*	Cₚ *(kJ.kg⁻¹.K⁻¹)*	k *(kJ.h⁻¹.m⁻¹.K⁻¹)*
A	Plasterboard	790	30	0.80	1.37
B	Expanded Polystyrene (EPS)	25	40	1.38	0.14
C	Air layer	massless	80	R = 0.047 h.m².K/kJ	
D	Expanded Polystyrene (EPS)	25	40	1.38	0.141
E	Plasterboard	790	30	0.801	1.372

1.3.6.2.2 Windows

Double panes windows on both sides (interior and exterior) of the double-skin façade are implemented with the following characteristics:

ID Number: 4001 (TRNSYS Windows Library)
Double pane window, low-e
Design: 3/12.7/2.5
U-Value = 1.76 W/m².K
g-Value = 0.597 W/m².K

1.3.6.3 Building loads and occupancy

At the moment, the simulation time step is set to 60 minutes. It will be lowered to 15 minutes.

1.3.6.3.1 Occupancy

Occupancy loads are defined in three zones: *corridor*, *reference lab* and *test lab*:
One person produces a heat flux of 75W (half convective, half radiative).

Occupancy	Time step : 60 minutes
Corridor	From 8:00 to 9:00 : 10 From 12:00 to 13:00 : 10 From 14:00 to 15:00 : 10 From 18:00 to 19:00 : 10

Occupancy	Time step : 60 minutes
Ref Lab	From 8:00 to 12:00 : 10 From 14:00 to 18:00 : 10
Test Lab	We have to define what is the real occupancy.

1.3.6.3.2 Lighting

Lighting loads are defined in three zones (reference lab, test lab and corridor) and are arbitrary set to 10 W/m². In laboratories, lights schedule follows occupancy and meteorological data (total radiation IT) in order to properly simulate the behaviour of occupants. Lights are manually controlled in 1 group (ON/OFF switch). Manual control of lights is modelled by the following equation:

$$Q_l(t) = \begin{cases} if\ IT \leq 200\,\frac{W}{m^2} : k * S * occ \\ if\ 200 < IT \leq 400\,\frac{W}{m^2} : Q_l(t-1) \\ if\ IT > 400\,\frac{W}{m^2} : 0 \end{cases}$$

1.3.6.4 Shading system

Internal venetian blinds are installed and manually controlled. Occupant's behaviour is never easy to model but the fairest way to model the manual use of a sunscreen is to base the value of the shading factor on the values of beam radiation (IB) and solar zenith angle (SZA) in order to isolate potential periods of glare. Since the double skin façade is divided into four nodes, it is easy to define five positions of the internal shading device based on IB and SZA values:

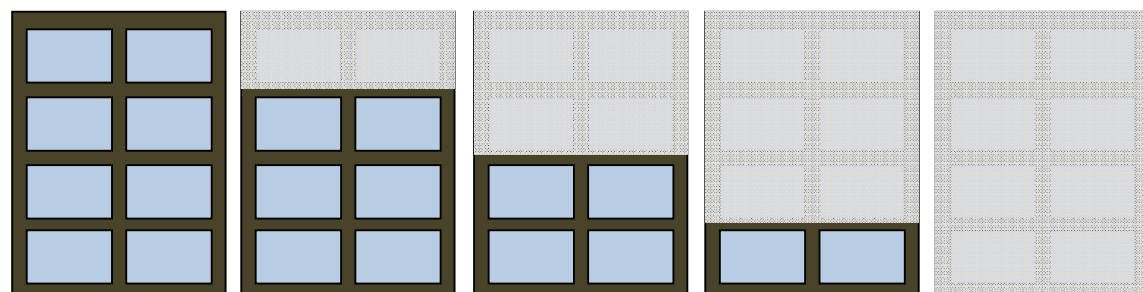If $IB < 100\,W/m^2$ or $SZA > 70°$ or $SZA < 30°$ then *no shading device* (1)
Else

    If $SZA > 60°$ then *Shading device in front of the upper quarter of the window* (2)
    If $SZA > 50°$ then *Shading device in front of the upper half part of the window* (3)
    If $SZA > 40°$ then *Shading device in front of the three upper quarters of the window* (4)
    If $SZA < 40°$ then *Shading device in front of the entire window* (5)

The following picture summarizes the different positions and conditions used to reproduce occupant's behaviour regarding to shading device control.

Configuration 1	Configuration 2	Configuration 3	Configuration 4	Configuration 5
$IB < 100\,W/m^2$ or $SZA > 70°$	$IB > 100\,W/m^2$ and $SZA \leq 70°$	and $SZA \leq 60°$	and $SZA \leq 50°$	and $SZA < 40°$

or $SZA < 30°$	and $SZA > 60°$	and $SZA > 50°$	and $SZA > 40°$	and $SZA > 30°$

1.3.6.4.1 Heating

Heating loads are defined in three zones: *corridor*, *reference lab* and *test lab*:
Heating loads are calculated by TRNSYS based on a setting temperature defined as follow:

Heating	
Corridor	From 5:00 to 7:00 : pre-heating From 7:00 to 19:00 : 21°C From 19:00 to 5:00 : no heating
Ref Lab	From 5:00 to 7:00 : pre-heating From 7:00 to 19:00 : 21°C From 19:00 to 5:00 : no heating
Test Lab	We have to define what is the real occupancy and base the heating loads on the reflab schedule and the occupancy

1.3.6.4.2 Cooling

Cooling loads are defined in three zones: *corridor*, *reference lab* and *test lab*:
Cooling loads are calculated by TRNSYS based on a setting temperature defined as follow:

Cooling	Time step : 60 minutes
Corridor	From 6:00 to 19:00 : 26°C From 19:00 to 5:00 : no cooling
Ref Lab	From 6:00 to 19:00 : 26°C From 19:00 to 5:00 : no cooling
Test Lab	From 6:00 to 19:00 : 26°C From 19:00 to 5:00 : no cooling

1.3.6.4.3 Other loads – Electronic devices

Others loads are defined in two zones: *reference lab* and *test lab*:
A computer is set to produce a heat flux of 150W (radiative). Additional loads are defined as follow:

| Occupancy	Time step : 60 minutes
Ref Lab	From 8:00 to 18:00 : 10 computers
Test Lab	From 8:00 to 18:00 : 10 computers

1.3.6.5 Ventilation, infiltration, airflow model

1.3.6.5.1 Ventilation

No sanitary ventilation rate is defined in addition to ventilation rates of fan coil units or auxiliary air conditioner.

1.3.6.5.2 Airflow model (natural ventilation, infiltration, coupling between zones)

Infiltration values are calculated by the airflow model set in Contam and linked step by step to the thermal model by type 97.

Figure 22: 3D-view of the airflow model
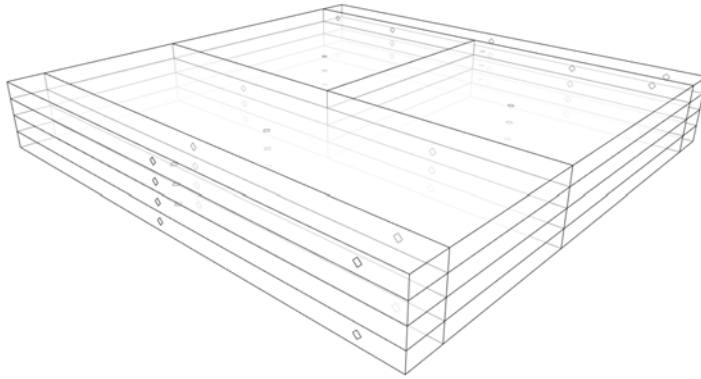
Double skin façades, corridor, reference lab and test lab are split into four 0.7-meter high zones as shown in Figure 22.

Attic spaces and service space are not taken into account in the model which means that no convective coupling is defined in the thermal simulation from or to these spaces.

Each diamond in Figure 22 represents an airflow element more precisely defined in Figure 24 below.

To run properly, this model needs a description of each airflow elements. These data will be used in conjunction with meteorological data (temperature, pressure, but also wind properties) in order to incorporate the effects of wind pressure and stack effect on the building. Therefore, wind properties have to be known correctly.

1.3.6.5.3 Wind properties

Wind properties are only used in the simulation of the DAUIN laboratories since it is the only room where airflow values strongly influence the results. The airflow model is defined in CONTAM. It enables incorporating the effects of weather on a building. Besides ambient temperature and barometric pressure, wind speed and wind direction are used to calculate wind pressure, which can be a significant driving force for air infiltration through a building envelope (Walton & Dols, NISTIR 7251, 2008, p. 127).

Chapter 16, Airflow around buildings, in the 2005 ASHRAE Fundamentals Handbook (ASHRAE, Airflow Around Buildings, 2005, p. 16.3 to 16.5) gives a general introduction to the effects of wind pressure on buildings.

The equation for wind pressure on the building surface is

$$P_w = C_p \frac{\rho_a \cdot V_H^2}{2} \qquad \text{(Eq. 1)}$$

where

V_H Approach wind speed at the upwind wall height (usually the height of the building)

C_p Wind pressure coefficient

The local wind speed V_H at the top of the building is estimated by applying terrain and height corrections to the hourly wind speed V_{met} from a nearby meteorological station.

CONTAM actually uses the following equation when calculating wind pressures on the building.

$$P_w = \frac{\rho_a \cdot V_{met}^2}{2} C_h \cdot f(\theta) \qquad\qquad\qquad\qquad \text{(Eq. 2)}$$

where

ρ_a	Ambient outdoor air density
V_{met}	Wind speed measured at meteorological station
C_h	Wind speed modifier coefficient accounting for terrain and elevation effects
$f(\theta)$	Coefficient that is a function of the relative wind direction. CONTAM refers to this function as the *wind pressure profile*.

Three sets of data are consequently required: wind speed, wind direction and wind pressure profile.

1.3.6.5.3.1   *Wind speed and wind direction*

Wind speed and wind direction are displayed on the following wind roses (Figure 23 and Table 10). Note that wind blows from the indicated direction.

Wind direction is equally distributed on every direction except North and South.

Wind blows more often from South than from any else direction and blows almost never from North.

As shown on Table 10, wind direction is similar during fall and winter on the one hand, and during spring and summer on the other hand when wind speed can be higher. Wind distribution over a season is important to know in order to understand airflow values in the double-skin façade.
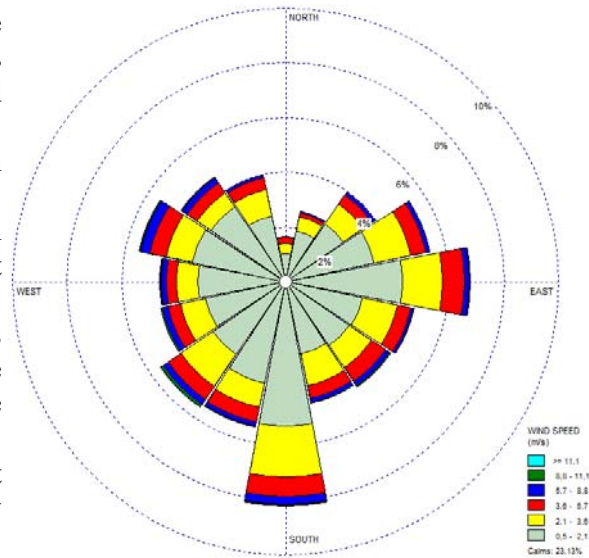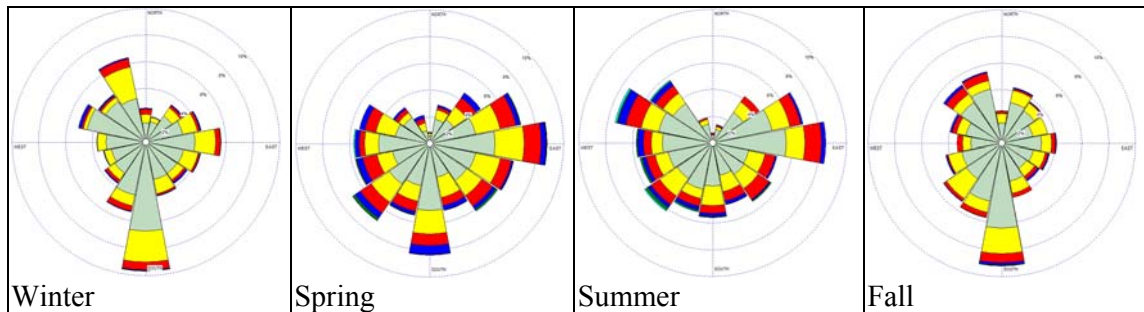
Figure 23 : Wind rose for the entire year

Table 10 : Wind roses season by season

Winter	Spring	Summer	Fall

1.3.6.5.3.2   *Wind pressure profiles*

Wind pressure coefficient C_p has been defined in (Eq. 1) above. It is nearly impossible to calculate accurate wind pressure coefficients without resorting to wind-tunnel experiment which would be too time-consuming and above all too expensive to do in this project.

Moreover, the geometry of the building is very particular in this case since it is raised above the ground in an opened courtyard formed with three others buildings. The wind pressure profile is then hard to calculate.

A sensibility study could be done on the project to see if the wind pressure profile has a strong influence or not on the results.
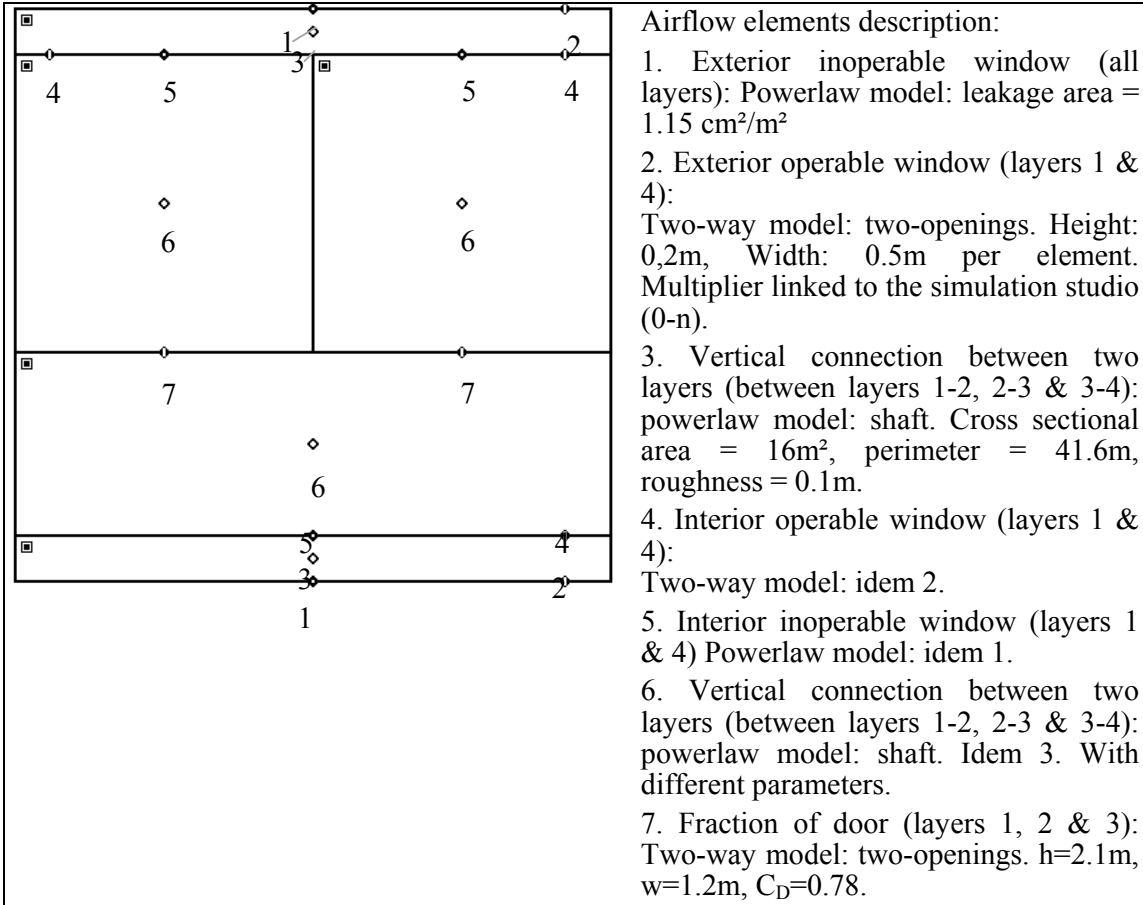
1.3.6.5.4 Airflow elements description

[diagram of airflow elements]	Airflow elements description:
	1. Exterior inoperable window (all layers): Powerlaw model: leakage area = 1.15 cm²/m²
	2. Exterior operable window (layers 1 & 4):
	Two-way model: two-openings. Height: 0,2m, Width: 0.5m per element. Multiplier linked to the simulation studio (0-n).
	3. Vertical connection between two layers (between layers 1-2, 2-3 & 3-4): powerlaw model: shaft. Cross sectional area = 16m², perimeter = 41.6m, roughness = 0.1m.
	4. Interior operable window (layers 1 & 4):
	Two-way model: idem 2.
	5. Interior inoperable window (layers 1 & 4) Powerlaw model: idem 1.
	6. Vertical connection between two layers (between layers 1-2, 2-3 & 3-4): powerlaw model: shaft. Idem 3. With different parameters.
	7. Fraction of door (layers 1, 2 & 3): Two-way model: two-openings. h=2.1m, w=1.2m, C_D=0.78.

Figure 24 : List and position of airflow elements used in the airflow network model

Elements 2 and 4 are closed by default but their opening can be done on request.

1.3.7 **Input data specifics to Rooms 12 & 13 (DAUIN offices)**

1.3.7.1 Geometry of the model

The test room and the reference room are part of a bigger building which is not entirely simulated. Two rooms were selected in task 1.1 and data were collected in task 1.2. These data are used as inputs of the thermal simulation.
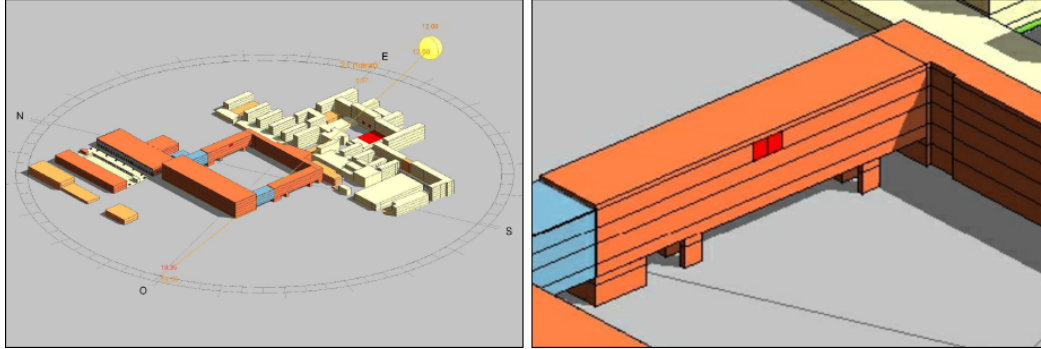
Figure 25 : Insertion of the model in the entire building

The model has been split into seven zones whose displayed in the following table.

Table 11 : Numbering and denomination of thermal zones

Zones		Volume (m³)	Area (m²)	Number of nodes	Occupancy
1	Reference office	48	15.6	1	Yes
2	Test office	48	15.6	1	Yes
3	Corridor	65	27.1	1	None
4	Attic Office	22	31	1	None
5	Attic Corridor	40	27.1	1	None
6	Vertical Service Space	8	3.4	1	None
7	Service Space Roof	65	27.1	1	None

Adjacent rooms are not included in the model as shown in Figure 26 below. An adiabatic boundary condition is set for boundary walls that are adjacent to a heated area. TRNSYS3d was used to define masks and to calculate the shading and insulation matrices.
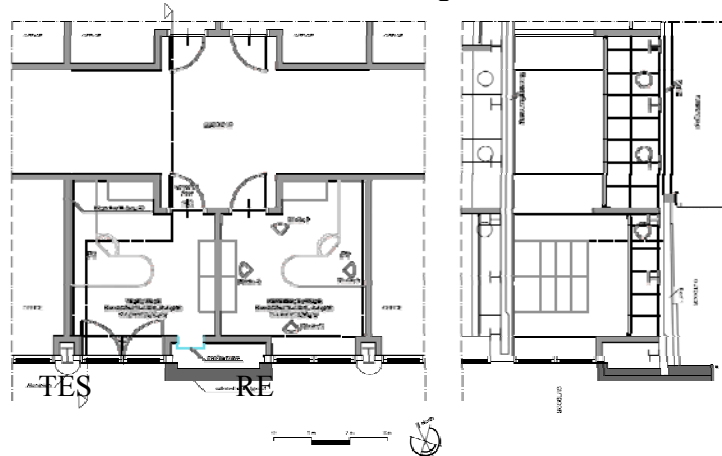
Figure 26: Plan and section of the premises included in the model (in red)

1.3.7.2 Building Envelop description

1.3.7.2.1 Walls

Adjacent Floor/Ceiling (between attic space and upper space)		Density (kg.m⁻³)	Thickness (mm)	C_p (kJ.kg⁻¹.K⁻¹)	k (kJ.h⁻¹.m⁻¹.K⁻¹)
A	Plasterboard	950	40	0.84	0.58
B	Air layer	massless	117	R = 0.047 h.m².K/kJ	
C	Concrete	2 300	120	1.00	6.30

False Ceiling (between lower space and attic space)		Density (kg.m⁻³)	Thickness (mm)	C_p (kJ.kg⁻¹.K⁻¹)	k (kJ.h⁻¹.m⁻¹.K⁻¹)
A	Ceiling plate	35	50	1.19	0.108

Roof, Type 1		Density (kg.m⁻³)	Thickness (mm)	C_p (kJ.kg⁻¹.K⁻¹)	k (kJ.h⁻¹.m⁻¹.K⁻¹)
A	Reinforced concrete	2 400	120	0.84	7.92
B	Concrete	2 300	111	1.00	6.30
C	Polystyrene insulation	25	60	1.38	0.14
D	Water proof layer	1800	60	1	7.2

Roof, Type 2		Density (kg.m⁻³)	Thickness (mm)	C_p (kJ.kg⁻¹.K⁻¹)	k (kJ.h⁻¹.m⁻¹.K⁻¹)
A	Reinforced concrete	2 400	70	0.84	7.92
B	Bitumen	1 100	27	0.61	0.61
C	Polystyrene insulation	25	40	1.38	0.14
D	Clay tiling	1 700	91	0.84	3.00
E	Concrete	2 300	60	1.00	6.30
-	Self locking floating floor	-	10	-	-

External Wall		Density (kg.m⁻³)	Thickness (mm)	C_p (kJ.kg⁻¹.K⁻¹)	k (kJ.h⁻¹.m⁻¹.K⁻¹)
A	Hollow clay block	1 500	190	1.8	5.4
B	Cement rendering	1 700	6	1.00	4.15
C	Polystyrene insulation	25	50	1.38	0.14
D	Air layer	Massless	64	R_{eq} = 0.050 h.m².K/kJ	
E	Stone wall covering	1 700	20	0.80	3.791

Adjacent Wall		Density (kg.m⁻³)	Thickness (mm)	C_p (kJ.kg⁻¹.K⁻¹)	k (kJ.h⁻¹.m⁻¹.K⁻¹)
A	Plasterboard	950	30	0.84	0.58
C	Air layer	Massless	60	R_{eq} = 0.050 h.m².K/kJ	
C	Sound and thermal insulation	25	40	1.38	0.14
D	Plasterboard	950	30	0.84	0.58

1.3.7.2.2 Windows

Double panes windows on both sides (interior and exterior) of the double-skin façade are implemented with the following characteristics:

> ID Number: 4001 (TRSYS Windows Library)
> Double pane window, low-e
> Design: 3/12.7/2.5
> U-Value = 1.76 W/m².K
> g-Value = 0.597 W/m².K

1.3.7.3 Building loads and occupancy

1.3.7.3.1 Occupancy

Occupancy loads are defined in two zones: *reference office* and *test office*.

One person produces a heat flux of 70W (half convective, half radiative). There is a single workstation in each office. Occupancy loads are defined as follow:

Occupancy	Time step : 60 minutes
Reference office	From 8:00 to 12:00: 1 From 12:00 to 13:00: 0 From 13:00 to 18:00: 1
Test office	Id.

1.3.7.3.2 Lighting

Lighting loads are defined in three zones (reference office, test office and corridor) and are arbitrary set to 10 W/m². In offices, lights schedule follows occupancy and meteorological data (total radiation IT) in order to properly simulate the behaviour of occupants. Lights are manually controlled in 1 group (ON/OFF switch). Manual control of lights is modelled by the following equation:

$$Q_l(t) = \begin{cases} if\ IT \le 200\,\dfrac{W}{m^2} : k * S * occ \\ if\ 200 < IT \le 400\,\dfrac{W}{m^2} : Q_l(t-1) \\ if\ IT > 400\,\dfrac{W}{m^2} : 0 \end{cases}$$

1.3.7.3.3 Shading system

Internal venetian blinds are installed and manually controlled. Occupant's behaviour is never easy to model but the fairest way to model the manual use of a sunscreen is to base the value of the shading factor on the values of beam radiation (IB) and solar zenith angle (SZA) in order to isolate potential periods of glare. The internal shading factor (ISF) is then controlled with the following equation:

$$ISF = \begin{cases} If \begin{cases} IB > 100\ ^W/_{m^2} \\ and\ 30° > SZA > 60° \end{cases} then\ ISF = (1 - ISF_{max}) \\ else\ ISF = (1 - ISF_{min}) \end{cases} \quad where \begin{cases} ISF_{min} = [0;1](=0) \\ ISF_{max} = [0;1](=0.6) \end{cases}$$

1.3.7.3.4 Heating

Heating loads are defined in three zones: reference office, test office and corridor.
Heating loads are defined in two zones: *reference room* and *test room*. Each room is equipped with a fan coil with variable speed (3 speeds) and an effectiveness of heat exchanger of 65 %.

Fan speed of fan coil units is controlled by a command law based on temperature difference between the set point temperature (21°C) and air temperature in the room as shown below. The hot side fluid (water) is preheated at temperature function of outside temperature. The mass flow rate is set to a constant value of **150** kg/h.

Table 12: Fan coil flow rate

Fan speed	Flow rate *(kg/h)*
0	0
1	144
2	192
3	240

The fan speed of fan coil units is controlled by a command law based on temperature difference between the set point temperature (21°C) and air temperature in the room as shown on Figure 6 and Table 2 above.

1.3.7.3.5 Cooling

Cooling systems are defined as explained previously.

The cold side fluid (water) is cold at a constant temperature (5°C). The mass flow rate is set to a constant value of 500 kg/h.

1.3.7.3.6 Other loads – Electronic devices

Others loads are defined in two zones: *reference room and test room*.
A computer is set to produce a heat flux of 100W (convective). One computer in each zone run on a schedule based on occupancy.

1.3.7.4 Ventilation, infiltration, airflow model

1.3.7.4.1 Ventilation

No sanitary ventilation rate is defined in addition to ventilation rates of fan coil units or auxiliary air conditioner.

1.3.7.4.2 Infiltration and natural ventilation

Infiltration is set to 0.5 in the corridor, 0.2 in offices and 0.5 in other spaces (attic spaces and service spaces). All hypothesis about building and systems would be verified in validation part. Some parameters are missing and would be validate thereafter, using monitored data: fan coil power, water temperature, exact air flow.

1.4   Updated Control strategy for HVAC

In this section, a final improvement of this strategy is proposed, updating deliverable 2.3.1 and 2.3.2. Only Control Strategy updates calculations are presented thereafter.

1.4.1   Presence prediction and planning in all rooms

We have combined occupancy detection with schedule-based control: presence prediction and planning. In the following we describe the concepts that have been built into our HVAC control strategy for simulation. Three types of occupancy estimation were included:

Planned Presence: For each room we define a basic occupancy schedule to assure a minimum temperature level. During scheduled occupancy a room will be heated to this basic temperature level. If occupancy is detected, the room will be heated up to the defined Tsp (Set Point Temperature)
Presence Detection: Presence is known with a presence detector. Heating can be cut or slowed down when the room is unoccupied after a brief delay. Set point temperature of fan coil is set in a period of occupation.
Presence Prediction: more fine-grained control and higher energy savings can be achieved by predicting presence: heating can be anticipated to get better comfort when user arrived.

We have included presence prediction in the simulations to experiment with it, however, for the sake of simplicity we have not deployed it in the real-world deployment.
HVAC strategy applied is the same on each room, presented on Figure 27.
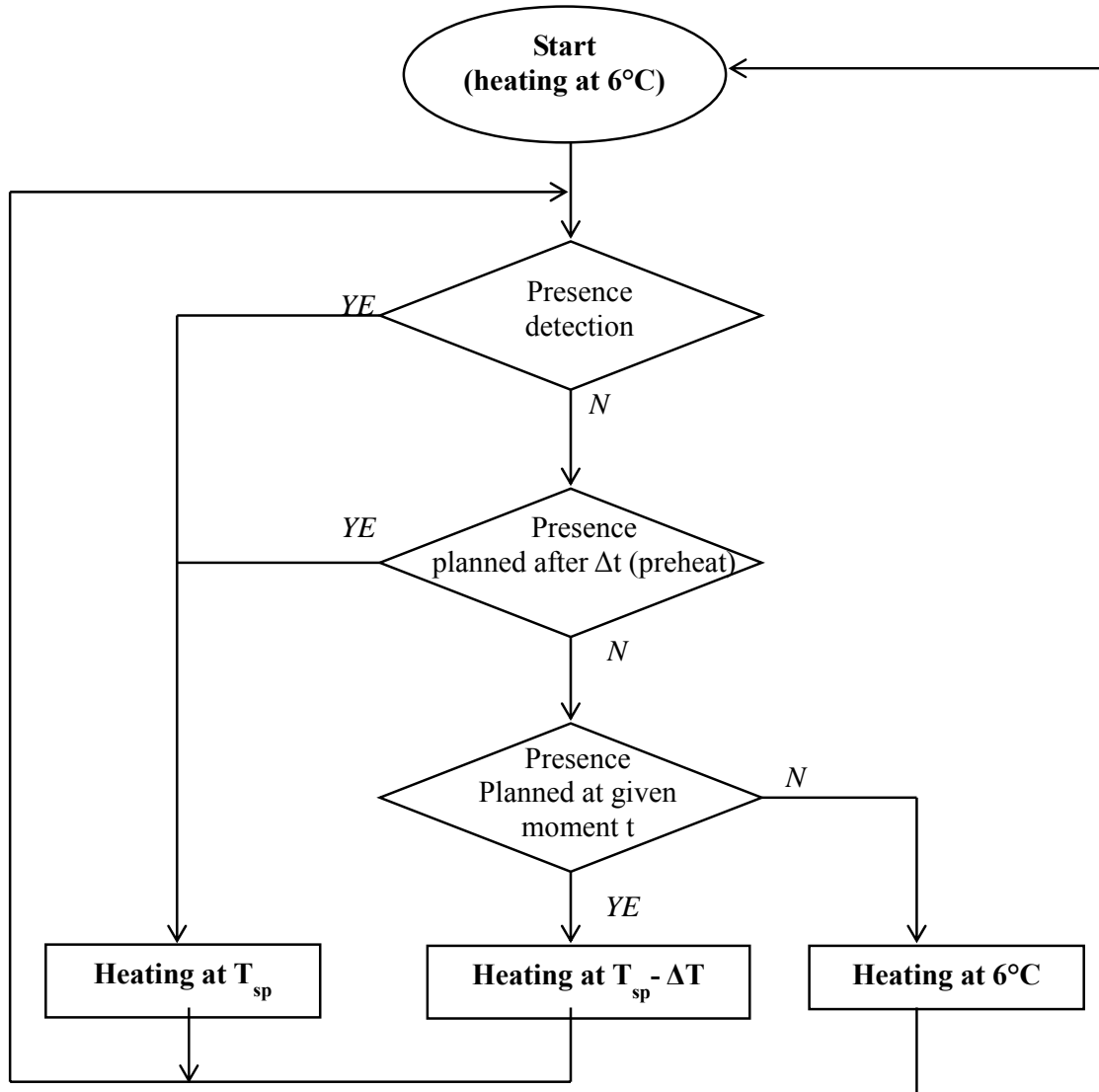
Figure 27 : heating strategy

The more occupancy planning is known, the more comfort can be ensure, especially at the beginning of occupancy period.

1.4.2   Recovery Time Optimization

The recovery time Δt is the time that the system needs to reach the set point temperature after a period of inactivity (e.g. during night). Correlations have been found between the recovery time and temperature difference ΔT between the set point temperature and the indoor temperature when the heating system is turned on.

However, correlations are not the same on a whole winter period, because the link between heating time and temperature difference changes with temperature difference. The optimal recovery time depends on the outside temperature.

We therefore calculate this recovery time on each day, based on a history of past periods of heating. This history is divided into two parts: Monday mornings (history of 8 values) and the

rest of the week (history of 15 values, 3 weeks). The reason why Monday mornings are treated separately is that a long period without heating (due to week-end) leads to a longer preheating period on Monday than for the other days of the week. The thermal behaviour of the building is different.

This allows us to create a pre-heating phase for each room, taking into account the features of the room itself but also environmental parameters as outdoor temperature.

For each preheating period, one of the two arrays is filled with the recovery time dt_{rec} and the temperature difference dT between the initial interior temperature and the set point temperature.

When a new value has to be stored, the oldest value is replaced by what is the new oldest value, etc. The first line in the table is always the most recent value.

dt_{rec} is calculated with the following formula: $dtrec = \beta_1 * (T_{spow} - T_i) + \beta_0$, where β_0 and β_1 are the coefficient of the linear regression:

$$\beta_1 = \frac{\sum_{k=1}^{n} dT_k \cdot \sum_{k=1}^{n} dt_{rec_k} - n \cdot \sum_{k=1}^{n} \left(dT_k \cdot dt_{rec_k} \right)}{\left(\sum_{k=1}^{n} dT_k \right)^2 - n \cdot \sum_{k=1}^{n} dT_k^2} \text{ and } \beta_0 = \frac{\sum_{k=1}^{n} dt_{rec_k} - \beta_1 \cdot \sum_{k=1}^{n} dT_k}{}$$

Figure 28 above show correlation variation function of external climate.
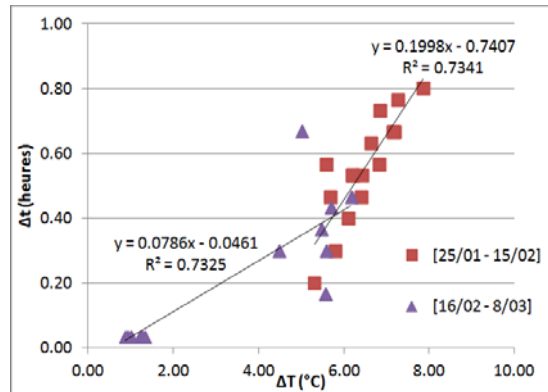
Figure 28: Correlations used for the restart time according to season (two periods are represented)

1.4.3   Timers

To avoid turning on the fan coil in case of a very short period of presence (e.g. a person just entering and leaving an office very quickly) or a false positive presence detection event, we have included a system of timers. Occupancy will only be confirmed if a certain number of occupancy events have been detected during a timer period. Similarly, non occupancy will only be confirmed after a certain period of time without any presence detection.

1.4.4   Updating Savings Results for different strategies

Results for DITER Office and for three test cases are presented on table 13 below.:
Test case 1 (D2.3.2): presence detection with two set point temperatures (21°C and 18°C

Test case 2 (D2.3.2): presence detection with two set point temperatures (21°C and 18°C) and optimization of the recovery time (fixed correlations)
Test case 3 (update): presence detection with two set point temperatures (21°C and 18°C) and optimization of the recovery time (auto adaptive optimization § 5.4)

Table 13 : savings result for different test case, Diter Offices

kWh/m².year,	Reference	Test Case 1 -	Test case 2 –	Test case 3
Heating	57.35	46.3	50.3	43.6
Savings	-	19.3%	12.4%	24.0%

Comfort in Auto Adaptive strategies is quite the same as fixed correlation strategy (test case 2). Some discomforts can be observed when high climatic variation is detected, because optimization of pre heating time is made on two previous weeks.
More, with system, regulation system automatically fit with thermal characteristics of building where it is implemented, with no more results differences.
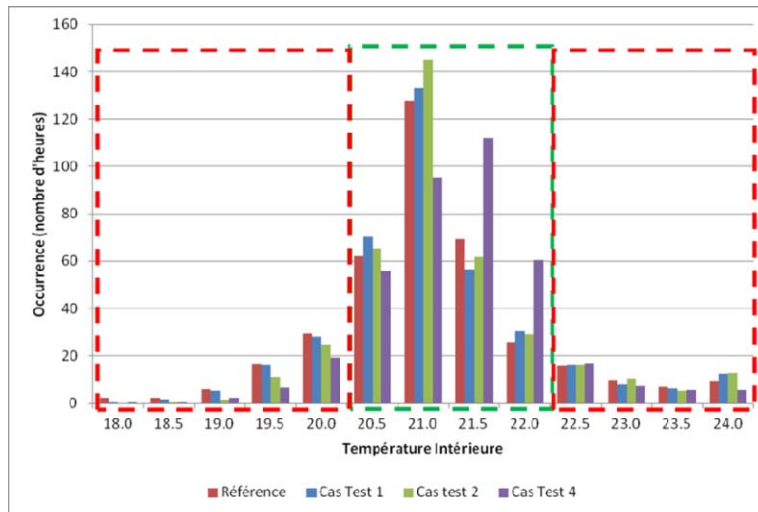
Figure 29 : Internal air temperature distribution from January 1st to April 15 (typical winter) for occupancy between 8AM to 6PM (DITER Offices) for 3 test cases and the reference case.

1.4.5 Adaptative comfort

1.4.5.1 Description

Instead of having fixed set point temperatures, variable set point temperatures could lead to an improvement of user comfort and a reduction of energy consumption in the meantime. In fact, a too high temperature difference between inside and outside can lead to user discomfort. In summer for instance, if it is very hot outside (40°C for example) and the set point temperature is 26°C, the user will experience a 14°C temperature difference when he comes in or leaves the building whereas the set point temperature could be higher (it would lead to better comfort and energy savings).

If adaptative comfort is chosen, the set point temperature will be calculated based on the reference outside temperature $T_{e,ref}$.

$$T_{e,ref} = \frac{T_{e,24h,1} + 0.8 * T_{e,24h,2} + 0.4 * T_{e,24h,3} + 0.2 * T_{e,24h,4}}{2.4}$$

Where

$T_{□↓}$

And

$$\begin{cases} T_{spos} = 0.534 * T_{e,ref} + 11.9 \\ T_{spow} = 0.310 * T_{e,ref} + 17.8 \\ T_{spot} = T_i \text{ during interseason} \end{cases}$$

$$\begin{cases} T_{spvs} = T_{spos} - 3 \\ T_{spvw} = T_{spos} - 3 \\ T_{spvt} = T_i \text{ during interseason} \end{cases}$$

Adaptative comfort could create discomfort for user because set point temperature will change.

On the project, Adaptative comfort is not used because on test rooms we need do guaranty comfort for user at the same level as in reference rooms. So, Set point temperature needs to be fixed on winter and in summer and not changing with climate.

Adaptative comfort will not be implemented on monitored system to guaranty same previous set point temperature on test and reference room.

Based on the simulated control strategy we have a context for each room, modeling all important environmental variables of a room. Among others these are fan speed, current temperature, temperature set point, and occupancy. The logic for evaluating the right set point and fan speed based on these parameters is implemented in the rules:

1.4.5.2 Comparison with no use of adaptative comfort

Set point temperature with and without adaptative temperature were compared. Results are presented on the following figure 30:
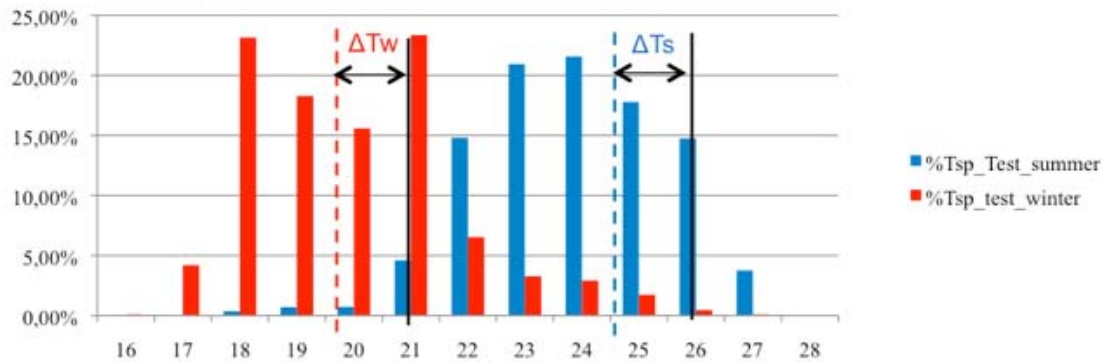
Figure 30 : Set point temperature accuracy in occupancy periods, with adaptative comfort, on two seasons

It can be conclude that on Winter: average $T_{sp\text{-}test}$ is 19.8 °C. With no adaptative comfort, $T_{sp\text{-}ref}$ is 21 °C. So $\Delta T_w = -1.2$ °C, which implies less consumptions

On Summer: average $T_{sp\text{-}test}$ is 24.8 °C. With no adaptative comfort: $T_{sp\text{-}ref} = 26$°C.
So ΔT_s is -1.2 °C which implies more consumptions, but also more comfort.

One of the constraints of the project was to ensure comfort or a minima not to degraded it, so not change set point temperature on test room, regarding reference room. Adaptive comfort was so not used in final system and simulations, because laws could leads to coldest temperature, particularly in winter.

Adaptative comfort could be interesting on hotter climates on the south of Europe.

1.5   Validation of simulation

Simulation were validated comparing simulation results with monitored data. Two validations were made:

First one on February march 2011, to validate building properties (thermal composition of wall, windows, solar gains influence), physical global behavior on non-occupancy period.
Second one with system implemented, fan coil characteristics, to validate how change temperature and others parameters on monitored building, for a small time step and efficiency of control strategy on real life; on January – March 2013.

No validations were made during summer.

1.5.1   First validation :

This validation was made during monitored campaign on February 2011. Temperature in all 6 pairs of room was monitored, with no new heating or cooling strategy implemented.
The goal was to validate thermal models and our simulated buildings.
The Following figure show results for DITER Offices.
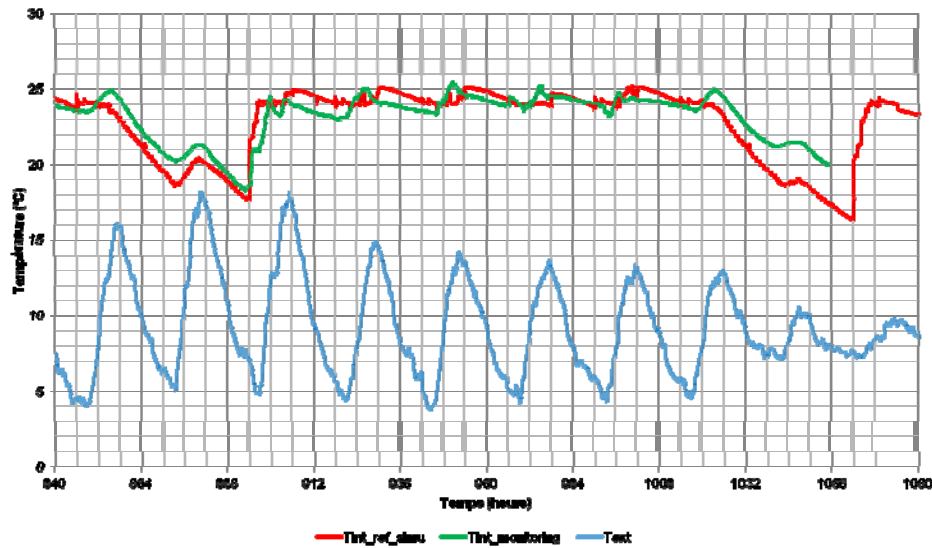
Figure 31 : comparison between monitored and simulated indoor temperature in Diter Office

A zoom on weekend and on weekday night shows that **temperature decreases as fast in the simulation as in reality**. It means that **buildings properties are correctly set** in the simulation.

Focusing on $T_{ref\text{-}monitored}$ (in green), pikes of temperature can be observe at the beginning of the days. Simulation seems to depend less on radiation than monitoring values. Two tracks can be investigated together to explain results differences. On simulation, **Beam radiation values are unknown** (values used in the simulation are recreated from global radiation values and

relative values of direct radiation taken from a TMY2 weather data file for Turin). The absolute **comparison** between simulation results and monitoring values **is then biased**.

1.5.2 Second validation

Second validation was fulfilled with monitored campaign on February March 2013.
Heating strategy was implemented on buildings and results from some individual days have been obtained.
The aim was to validate characteristics of fan coils (water temperature, supply air flow, water flow, power) and microscopic comportment of building with a regulation with short time step (inertia of buildings); to have a same building comportment when heating (temperature variation) in simulation and in monitored data, after second validation.

Because of problems in monitoring system, only results on Valentino Castle are available. On this building, validation is only partial because, only a few days are exploitable.
One more monitored campaign should be necessary to validate simulation on others buildings and have Savings results.

1.5.2.1 Water temperature

Water temperature in heating period changes considering outside temperature.
Relation between outside temperature and supply air temperature can be put in evidence, in occupation, with valentine Castle monitored data from February and June 2013.
Only steady are used, when water fan coil temperature can be considered as the same as supply air temperature.
Results are presented on the following figure.

This figure shows that for a same fan speed, supply air temperature change. Correlation seems to be the same for fan speed 1 and 2. We don't have enough data on fan speed 3
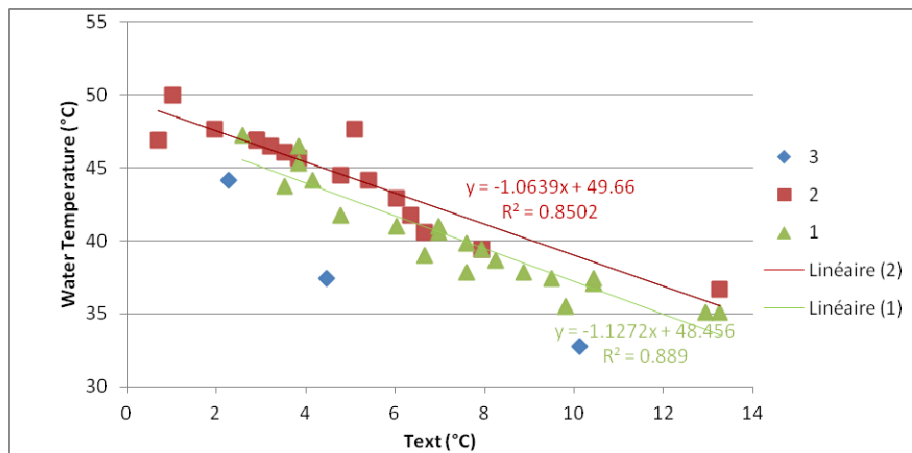
Figure 32 : Water temperature and External temperature in Valentino Castle

Considering unknown parameters, a simplified Relation is then used there in all buildings:
$$T_{water} = -T_{ext} + 50$$

1.5.2.2 Other Fan coil Parameters

Supply air flow supply, supply air temperature and fan coil power are linked in the same formula (see later) so even there are not known, relative savings result comparison could be done between reference and test room.

Air Flow is first set to value given from technical documents.

Set point temperature is more 23 degrees for DITER office and Valentino Castle (air temperature). The same temperature would be applied on the same way.

1.5.2.3 Inertia validation

We focus on inertia validation thereafter, because TRSYS and type 56 (multi-zone building model) are not adapted to small time step simulation, particularly for heavy walls buildings.

Time Step of simulation is 4 minutes, to permit regulation, but time base of heavy walls could be lower than 1 hour.

Because time step and timebase are not equal, the simulation will converge to a limit value between each timebase, as shown in the figure below, where time step is 4 minutes and timbase is 1 hour. Then, regulation is impossible because internal temperature change for several degrees on short time, as shown on figure 33.
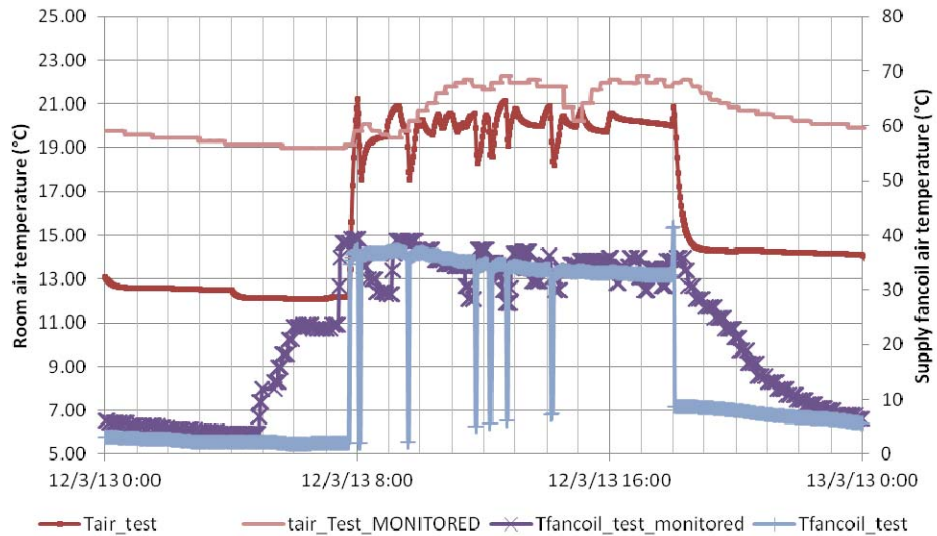
Figure 33 : internal Air and Fan coil Air temperature for monitored and simulation data - room 12, before second validation

Inertia was artificially added on fan coil, out of Type56, to have a greater regulation from presence and to have a better correlation between simulated and monitored air temperature, which guaranty a simulated regulation with more accuracy.

With this artificial add of inertia, consummations doesn't change because it only consist on averaging over time supply air temperature values, then used on simulation.

Results are presented on figure 34.
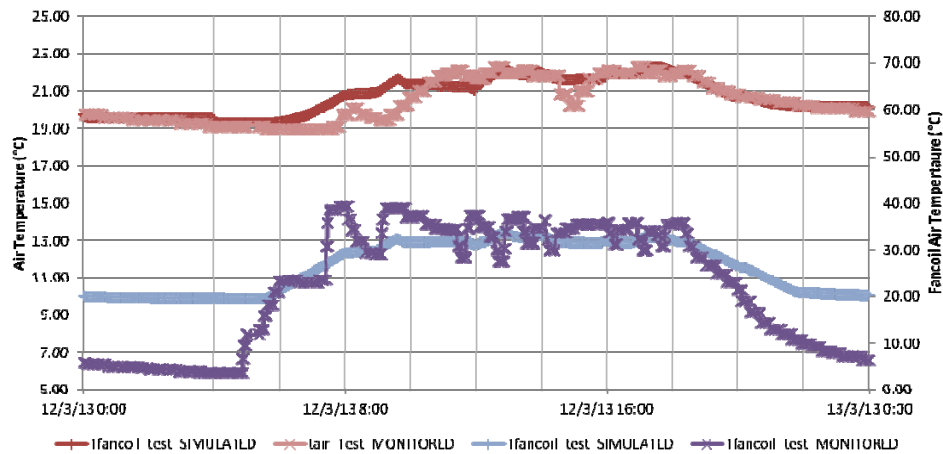
Figure 34 : Internal and Fan coil Air temperature for monitored and simulation data - room 12, adding 2 hours of inertia

Temperature difference during night (no occupancy period) is not a problem because these data are not used for savings calculations.

This second validation leads to the fact that comparison of simulation and monitored results is biased.

1.5.2.4 Gap between simulation and reality

It is quite obvious that there is a gap between simulation and real-world operation of a complex HVAC control system.
First, sending rate of sensors used in the real world is not as accurate as in simulation. Sensors doesn't respond at the same time, so regulation is not perfect. There are time gaps between two presence detection, then to wait fan speed value changing, then in transient working of fan coil between two fan speed; so a gaps of 15 to 20 minutes needs to be considered to have practically a regulation whereas it's instant in simulation. Another issue is the difference between available data in simulation and reality. Of course, in simulation we can model an almost complete system while in the real world we simply don't have all information available.
We lack exact data about water temperature, water flow, air flow and efficiency of the heating exchanger. On meteorological data, beam radiation values are not known.

Finally, no natural ventilation network is defined in the simulation.
Our simulation results could have signification only in comparing reference and test room savings, in percentages.

1.6 Simulation Results

For each building, consummations, savings and Comfort results are presented.

Occupancy planning are different for all rooms. To get a comparison, we decided to apply the same planning in all simulation. It is given on the following table.

Table 14: detected occupancy for 6 simulations

Detected Occupancy	
Reference office	Monday-Friday : 6:00-18 :00 Saturday 6:00 – 12:00
Test office	Monday-Friday : 8:00-12:00 & 13:00-18:00 Saturday : 8:00-12:00 ; 90 % of theoretical occupancy

Table 15 : planned occupancy for 6 simulations

Planned Occupancy	
Reference office	Monday-Friday : 8:00-18 :00 Saturday 8:00 – 12:00

Set point is set to 23 °C and simulation time Step is 4 minutes.

Results with this "full occupancy planning" will be used as reference for comparison with parametric studies thereafter.

1.6.1 Secretariat Offices

Table 16 : Heating and Cooling consumptions and Savings – Secretariat Office

Month	Heating				Cooling			
	Ref.	Test.	Save (Kwh)	Save (%)	Ref.	Test.	Save (Kwh)	Save (%)
January	2650	2469	181	7%				
February	2227	2096	131	6%				
March	1945	1758	188	10%				
April	666	569	96	14%				
May					-	-	-	-
June					-	-	-	-
July					-	-	-	-
August					-	-	-	-
September					-	-	-	-
October	860	765	95	11%				
November	1851	1680	171	9%				
December	2527	2357	170	7%				
Total (kWh)	12726	11694	1031	*8.1 %*	-	-	-	-
Total(kWh /m²/y)	212	195	*17*		-	-	-	-
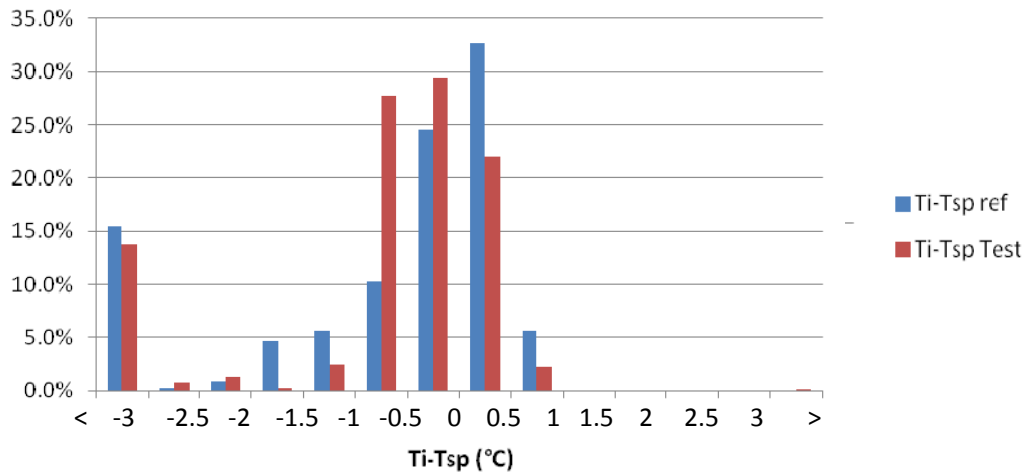
Figure 35 : Comfort Study for Secretariat Offices: Ti-Tsp distribution in occupancy periods

1.6.2 DITER Office

Table 17 : Heating and Cooling consumptions and Savings – DITER Offices occ at 8AM

Month	Heating				Cooling			
	Ref.	Test.	Save (Kwh)	Save (%)	Ref.	Test.	Save (Kwh)	Save (%)
January	587	519	68	12%				
February	448	387	61	14%				
March	348	284	63	18%				
April	106	65	40	38%				
May					29	25	5	15%
June					78	64	14	18%
July					715	538	177	25%
August					410	372	37	9%
September					62	43	19	31%
October	305	234	71	23%				
November	734	619	115	16%				
December	1171	981	190	16%				
Total (kWh)	3699	3090	609	**16.5 %**	1294	1043	251	**19.4 %**
Total(kWh /m² /y)	218	182	36		76	61	15	
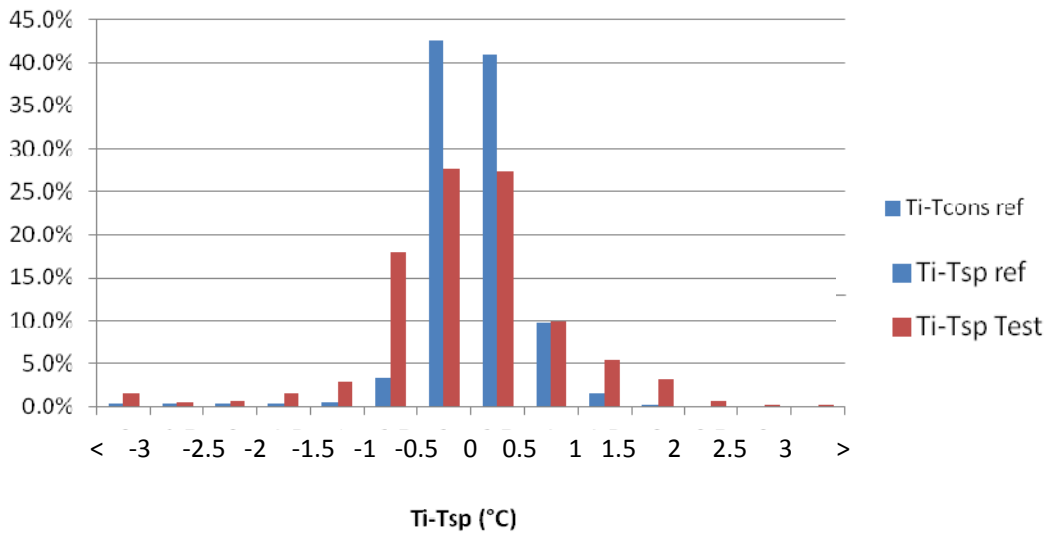
Figure 36 : Comfort Study for DITER offices: Ti-Tsp distribution in occupancy periods

1.6.3   Administrative Offices

Table 18 : Heating and Cooling consumptions and Savings – Administrative offices

Month	Heating				Cooling			
	Ref.	Test.	Save (Kwh)	Save (%)	Ref.	Test.	Save (Kwh)	Save (%)
January	700	623	78	11%				
February	515	455	60	12%				
March	396	344	53	13%				
April	133	108	25	19%				
May					22	13	9	40%
June					70	53	17	24%
July					301	223	78	26%
August					151	103	48	32%
September					43	33	10	23%
October	176	150	26	15%				
November	379	342	38	10%				
December	617	561	56	9%				
Total (kWh)	2917	2582	335	*11.5 %*	590	429	161.3	*27.4 %*
Total(kWh /m²/y)	81	72	9		16	12	*4*	
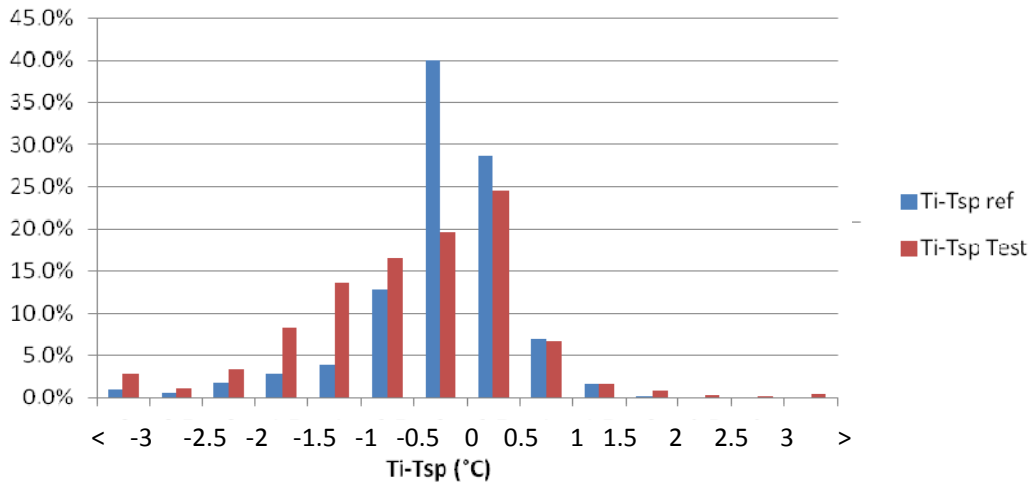
Figure 37 : Comfort Study for Administrative offices: Ti-Tsp distribution in occupancy periods

1.6.4 Classrooms

Table 19 : Heating and Cooling consumptions and Savings – Classrooms

Month	Heating				Cooling			
	Ref.	Test.	Save (Kwh)	Save (%)	Ref.	Test.	Save (Kwh)	Save (%)
January	22918	20727	2191	10%				
February	17923	16360	1563	9%				
March	14605	13093	1512	10%				
April	4919	4054	865	18%				
May					725	705	21	3%
June					2289	2105	184	8%
July					4858	4043	815	17%
August					3061	2757	304	10%
September					575	569	6	1%
October	6457	5171	1286	20%	4	3		
November	14179	13150	1030	7%	0	0		
December	21354	20748	606	3%				
Total (kWh)	102356	93303	9052	*8.8 %*	11567	10231	1330	*11.6 %*
Total(kWh /m²/y)	325	296	29		37	32	4	
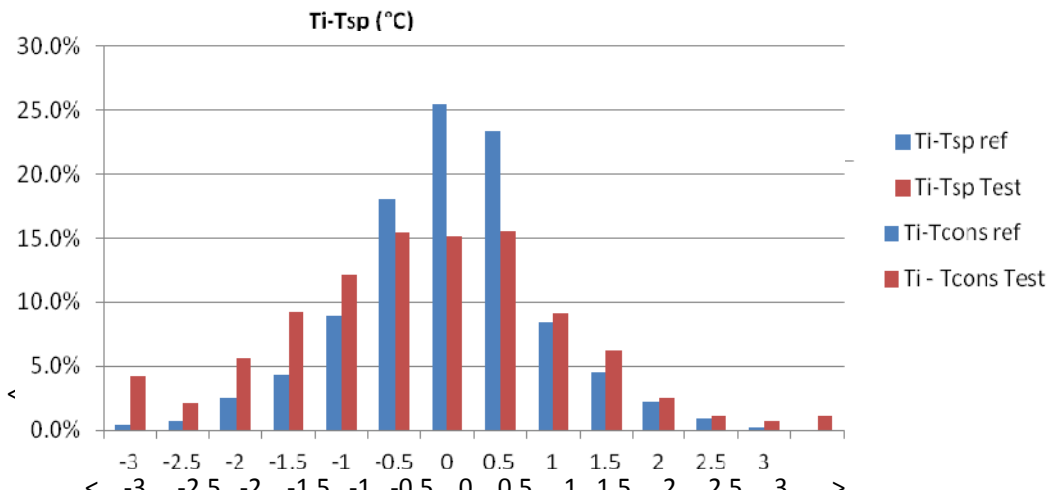
Figure 38 : Comfort Study for Classrooms : Ti-Tsp distribution in occupancy periods

1.6.5　　　　　　　　DAUIN Offices

Table 20 : Heating and Cooling consumptions and Savings – DAUIN Offices

Month	Heating				Cooling			
	Ref.	Test.	Save (Kwh)	Save (%)	Ref.	Test.	Save (Kwh)	Save (%)
January	272	193	79	29%				
February	192	128	65	34%				
March	118	50	67	57%				
April	15	0	15	100%				
May					46	49	-3	-6%
June					136	111	25	19%
July					210	165	45	21%
August					187	148	40	21%
September					72	66	6	8%
October	2	0	2	100%				
November	124	75	49	39%				
December	229	160	69	30%				
Total (kWh)	951	607	345	*36.2 %*	651	538	146	*17.4 %*
Total(kWh /m^2/y)	59	38	21		41	34	7	
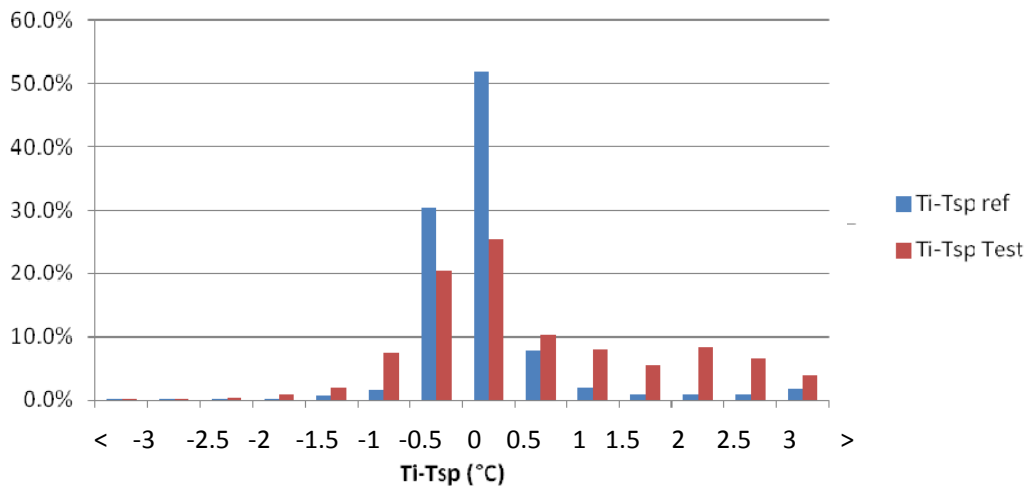
Figure 40 : Comfort Study for DAUIN Office: Ti-Tsp distribution in occupancy periods

1.6.6   DAUIN Lab (Double Skin Models)

Table 21 : Heating and Cooling consumptions and Savings – DAUIN Lab

Month	Heating				Cooling			
	Ref.	Test.	Save (Kwh)	Save (%)	Ref.	Test.	Save (Kwh)	Save (%)
January	2633	2132	501	19%				
February	2042	1568	474	23%				
March	1829	1300	529	29%				
April	695	434	261	38%				
May					-	-	-	-
June					125	175	-50	-40%
July					578	509	69	12%
August					511	515	-4	-1%
September					78	112	-34	-44%
October	896	667	229	26%				
November	1772	1325	447	25%				
December	2324	1775	549	24%				
Total (kWh)	12191	9201	2990	*24.5 %*	1292	1323	-19	*-2.4 %*
Total(kWh /m²/y)	135	102	*33*		14	15	0	
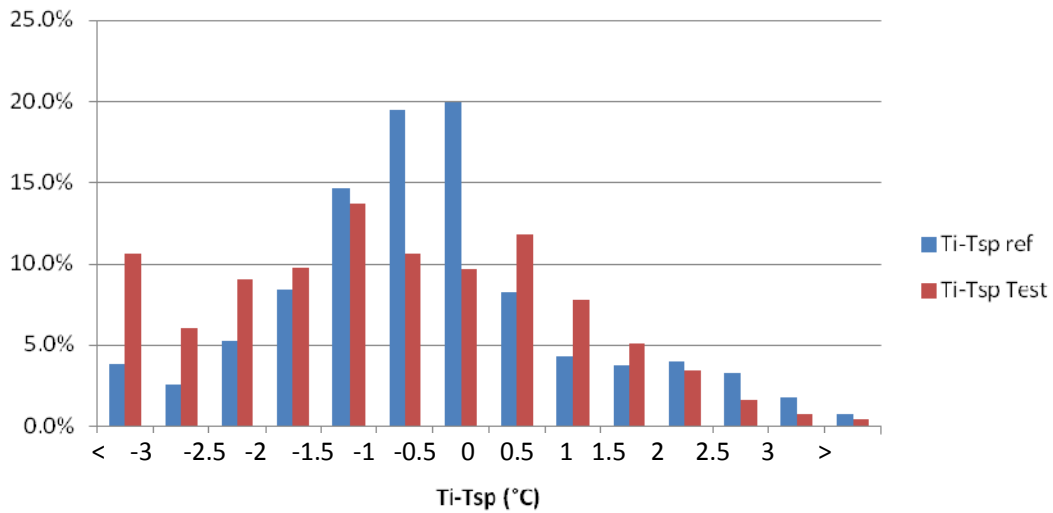
Figure 41 : Comfort Study for DAUIN Lab: Ti-Tsp distribution in occupancy periods

1.6.7   Comparison of savings in different rooms

This savings only come from auto adaptative preheating time, shorter than on reference room, and from midday pause.
They are given in the followig table:

Table 22 : Cooling and heating savings in different buildings

	Secretariat offices	Diter Offices	Administrative offices	ClassRooms	Dauin Lab (double skin)	Dauin Offices
Savings Ref/test Heating	8.1 %	16.5 %	11.5 %	8.8%	24.5%	36.2 %
Savings Ref/Test Cooling	-	19.4 %	27.4%	11.6%	-2.4%	17.4 %

Table 23 : Thermal characteristics of buildings

	Surface (m)	Insulation	Inertia	Orientation of principal facade	Heigh of the floor (m)	Surface of windows
Secretariat offices	65	low	high	South-East	7.3	5.8
Administrative Offices	32	Low	medium	North	3.75-4.56	6.2
Dauin Lab	15.6	high	medium	South-West	3.1	4.84
Diter Offices	17	low	high	North-West	(2.3 to 3.6)	23.7
Dauin Offices	15.6	high	medium	South-West	3.1	4.84
ClassRooms	315	Low	medium	-	5.2	43

      On heating periods, savings are more important in the best insulated buildings (DAUIN Offices and DAUIN Lab) and on small rooms (DITER offices, administrative offices, DAUIN offices).
      On cooling periods savings are quite the same for Classrooms, DITER offices and DAUIN offices. DAUIN lab, and Administrative offices have very weak consumptions of cooling so comparison of saving results will leads to errors.

      Comfort is less good on high inertia and no insulated buildings (DITER offices, secretariat offices) because more time is necessary to heat the rooms after a no occupancy period than in recent buildings.
      Comfort is quite the same between reference and test rooms. Difference of 0,5 to 1 degrees can be shown between temperature in reference and test room, in occupancy.
Consumptions and potential absolute savings are more important on Heavy winter (January-February; November – December) and on heavy summer (June-August).

      On inter-seasons (March-May and September-October), savings are less important and depends on external conditions, and quickly changes during days (cold or hot days with required little heating or little cooling).

1.6.8   **Savings in high intermittent occupancy rooms**

We compare the two rooms DITER Offices and DAUIN Offices, with different characteristics. Presence is not predicted on test room, only presence detection is used.

Occupancy	
Reference office – theoretical occupancy	Monday-Friday : 6:00-18 :00 Saturday 6:00 – 12:00
Test office Real Occupancy + adaptive preheating time	Mondays & Fridays : 8:00 to 12:00 and 13:00 to 18:00 Tuesdays & Wednesdays : 8:00-10:00, 13:00-14:00 and 16:00-18:00 Thursdays : no occupancy Saturdays : 8:00 to 12:00 56 % of theoretical occupancy

Additional savings, due to less occupancy comparing to first test case, are presented on the following table.

Table 24 : Additional Heating and Cooling consumptions and Savings – DITER Offices

	Heating		Cooling	
	Ref.	**Test.**	**Ref.**	**Test.**
Classical Occupancy (90 % of th. occ)	3699	3090	1294	1043
Real Occupancy Office (56 % of th. occ)	3754	2883	1232	929
Savings kWh	-55	207	62	114
Savings %	-1.4	+ 6.7	+ 4.8	+ 10.9
Global additionnal savings	**+5.3 %**		**+15.7 %**	

heating	Mondays		Tuesdays/ wednesday		Thursdays		Friday		Saturdays	
	Ref.	**Test**	**Ref.**	**Test**	**Ref.**	**Test**	**Ref.**	**Test**	**Ref.**	**Test**
ClassicOcc	464	463	934	766	443	371	426	358	254	177
Real Occ	466	480	958	606	470	178	428	425	255	177
Savings kWh	-2	-17	-24	160	-27	193	-2	-67	0	0
Add Savings %	-0.4	-3.6	-2.5	+ 20	-6.1	+52	-0.5	-18.7	0	0
Global add savings	**-4%**		**+17.6%**		**+45.9%**		**-19.2%**		**0%**	

Table 25: Additionnal Heating and Cooling consumptions day per day

We have savings particularly on days where occupancy is weak. The day after weak occupancy, consummations are more important because temperature at the beginning of heating is lower; high inertia buildins and weak insulation enforced this problem.
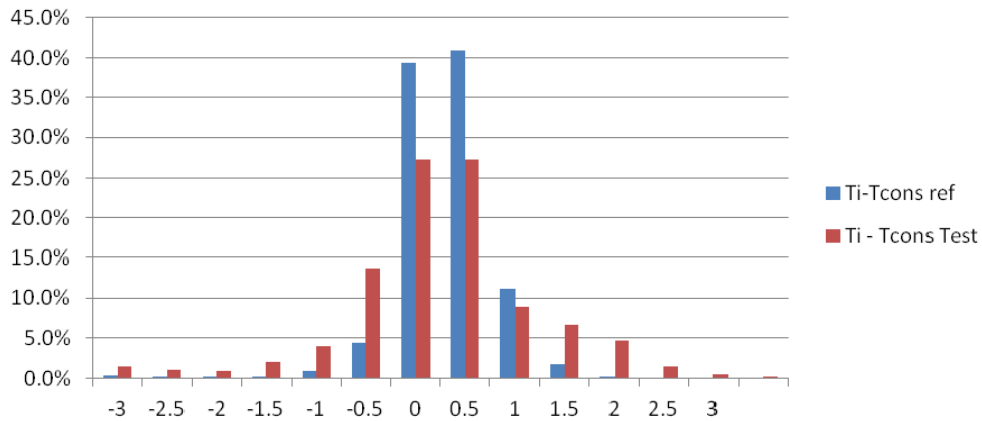
Figure 42 : Comfort Study for DITER offices : Ti-Tsp distribution in occupancy periods
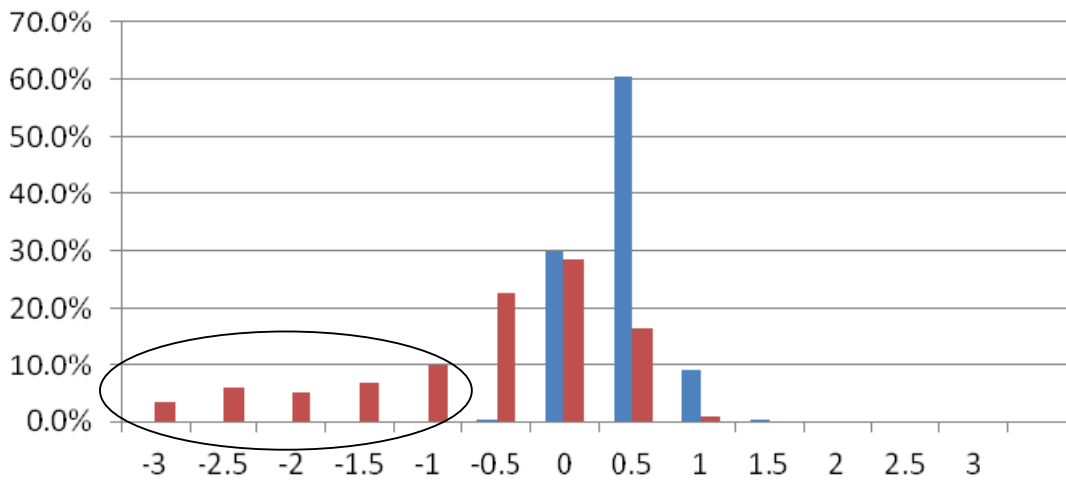
Figure 43 : Comfort Study for DITER offices, Tuesdays/Wednesdays

Confort is not a problem except for Thursdays/Wednesdays (figure 43) and our control system seems to be not well adapted for a good comfort, on small no occupancy periods. Long no occupancy periods (half a day…) leads to more savings in a good comfort.

1.6.9   **Comparison of savings between occupancy detection and prediction**

For Class Rooms, we can study how change savings when occupancy is well predicted or not. Set point temperature is 23 °C. Comfort is the same.
Occupancy profile and savings are given on the following table:

Occupancy Planning detected	
Fancoil Planning (Ref. Room)	Monday-Friday : 6:00-18 :00 Saturday 6:00 – 12:00
Real Occupancy (Test Room)	Monday, Wednesday, Friday : 8:00-12:00 and 13:00-18:00 Tuesday : 13:00-18:00; Thursday : 8:00-12:00 ; Saturday : 8:00-12:00

Theoretical occupancy
Theoretical occupancy A on test office   Monday, Wednesday, Friday : 8:00-12:00 and 13:00-18:00   Tuesday : 13:00-18:00 ; Thursday : 8:00-12:00 ; Saturday : 8:00-12:00
Theoretical occupancy B on Test Office   Monday, Wednesday, Friday : 8:00-12:00 and 13:00-18:00   Tuesday : 13:00-18:00 ; Thursday : 8:00-12:00 ; Saturday : 8:00-12:00

Savings results are given on the following table:

Table 26 : Heating and Cooling consummations and Savings – Classrooms Offices:

	Heating		Cooling	
	Ref.	**Test.**	**Ref.**	**Test.**
Classical Occupancy (90 % of th. occ)	*102356*	*93303*	11567	10231
Theoretical occupancy A	104324	94364	10313	8216
Savings kWh	-1968	-1061	1254	2015
Savings %	-1.9	- 1.1	+ 10.8	+ 19.7
Global additional savings	**-3 %**		**+30.5 %**	
Theoretical occupancy A	104509	78733	10311	8137
Savings kWh	-2153	14570	1256	2094
Savings %	-2.1	+15.6	+10.8	+ 20.5
Global additional savings	**+13.5 %**		**+31.3**	

This study shows the importance of presence prevision. Savings could be really improved if occupancy planning is planned, particularly in winter, set point temperature is 6 °C in that case whereas it's 18°C when it's not planned. Savings in this last case are very weak.
Phenomena is less important in summer because set point temperature on summer is easier to reach than in winter (gap between external temperature and set point is more important in winter).

1.7   Validation of System with Monitored results

In this section we discuss results from the real-world deployment of the integrated HVAC control system and the relation to the simulation results. The installation of the middleware-based BEMS has started in December 2012 with monitoring only. Gradually, we added technologies and rooms and first experiments of HVAC control in January.
2013. The deployment of the control strategies started on February 19th only in Room 12 (Secretariat Office) and on March, 4th on DITER offices. Results on Others buildings are not available for Winter due to problems of collecting data (see work package 4).

Between simulation and deployment we encountered some problems due to network issues in the historical buildings that prevented the HVAC control system to communicate properly, so we used results on individual days.

On summer, deployment of control strategies was available from July 10th on DITER Office, Administrative office and DAUIN offices. We will compare results in term of occupancy.

We have to notice that Auto adaptive Strategy for calculating preheating time has not been implemented for this monitored data campaign.

1.7.1   Runtime Observations and work of system

First we discuss RunTime Observations to show if our regulation system is working or not.
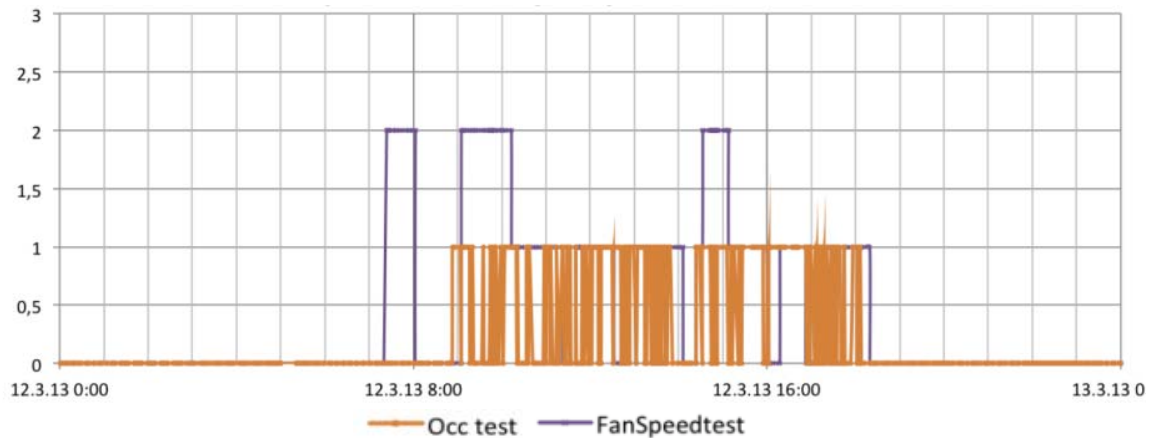
Figure 44 : Fan Speed and Occupancy in Test Room on March, 12th
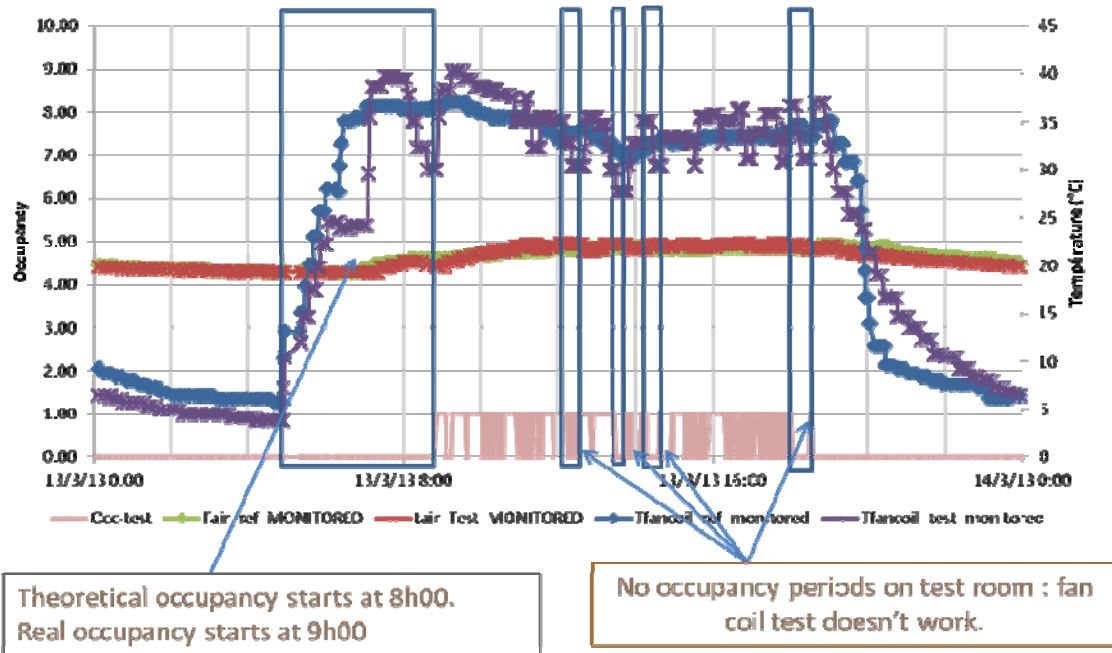
Figure 45 : Monitored and FanCoil Temperature on Room12 reference and Test Room

Figure 44 and Figure 46 show observations and differences between a reference room and a test room (Royal Rooms) on 12th March 2013.

Figure 44 shows the fan speed and occupancy pattern for one day in the test room. We can clearly observe preheating phase in the morning, setting the fan speed to 2, and then another heating phase after presence has been detected for the first time. We can also see that occupancy changes a lot during the day. The occupancy data shown in Figure 5 comes from the motion sensor, so it does not yet include the occupancy detection based on Timer-based Occupancy Confirmation. The high rate with which the sensor switches from occupied to not occupied shows that the Timer-based
Occupancy Confirmation is quite important; otherwise we would have many unnecessary fan coil activations.

Figure 45 shows the different patterns of fan coil activity in the reference and test room (expressed in fan coil temperature). While the fan coil in the reference room stays at the same speed during the whole day, we can see the changes based on our control strategy in the test room. The comparison indicates the energy savings potential at the start and the end of a day and during non-occupied periods throughout the day, thanks to the combination of occupancy schedule and occupancy detection

Figure also show that air temperature in reference and Test room are the same, so there is no difference of comfort between reference and test room.

1.7.2   **Monitored Savings Calculations**

1.7.2.1 Methodology

First, we need to calculate the air flow $Q_{v,i}$ of the fan coil for each speed i with the formula:

$$Q_{v,i} = Q_v \cdot p_i$$

with Q_v the maximum air flow of the fan coil in kg=s and p_i the air flow in % in relation to fan speed (cf. Table 27)

Fan Speed (i)	Air Flow (pi)
3	100 %
2	80 %
1	60 %

Table 28 : Air Flow for different Fan Speed

Now, to calculate savings, we know the following parameters: fan coil temperature, fan speed, fan coil air flow, indoor temperature, and air heat capacity (fixed number). Using these parameters we can estimate the instantaneous power at each time step of the fan coil with the following formula:

$$P(t) = Q_{v,i} \cdot C_p \cdot (T_f(t) - T_i(t))$$

with P(t) power of fan coil in Watts, Qv; i the air flow at each time step in kg=s, Cp the air heat capacity in J=kg=K, Tf the fan coil temperature, and Ti the indoor temperature at each time step. We can finally estimate relative energy savings using theses formulas:

$$Cons = \sum_{day} P(t) \quad \text{with} \quad GS = \frac{Cons_{ref} - Cons_{test}}{Cons_{ref}}$$

1.7.2.2 Monitored results from Room12 - Potential Energy Savings

Due to the gap between the very detailed model in simulation and the available data in real world, a complete comparison between simulation and experiment is very hard to achieve. We would need extensive sensor deployments and still, we might not be able to exclude external influences as described before. Nevertheless, we can make some assumption on missing variables and calculate relative energy savings between reference and test rooms.

Results for three selected days are presented in the following table. Fan speed has been on 1 in the reference room all day long.

Room 12	Conso in ref room (kWh)	Conso in Test room (kWh)	Global Savings (%)	Average T_{ref}-T_{test} in occ. (°C°)
05/02/2013	46.52	39.98	14%	0.22
12/03/2013	31.73	24.61	22%	- 0.05
12/03/2013	0.33	0.00	100%	0.33

Table 29 : Monitored Results – secretariat offices

We have selected these three days based on an analysis of our data. Due to the aforementioned issues with networks, restarts and several re-configurations during the beginning of the deployment, we chose to look at some single days for which we have the most complete data.

If we compare these results to relative results between the two rooms in simulation, we get numbers pointing in the same direction, depending on the occupancy profiles. For example if we choose a working day of 8 hours with a 1 hour break during lunch, simulation results in 16% energy savings for March.

In terms of Comfort, absolute value of T_{ref} - T_{test} difference is lower than 1 °C so comfort is not deteriorate.

Although, we can't give absolute numbers on energy savings, our simulations and samples from the real data indicate that energy savings can already be achieved by implementing an intermittent HVAC control based on input from a just a single motion sensor.

1.7.2.3 Monitored results from DITER Offices – Potential Energy Savings - Heating

We proceed on the same way on DITER Offices Data. Because monitored campaign was realized on March, when heating consumptions are lower and solar gains are more important; it's difficult to exploit results:

Table 30 : Monitored Results - DITER Offices

Days	Cons. on ref. room (kWh)	Cons. on test. room (kWh)	Global Savings (%)	Absolute Savings (kWh)	Average [Tref-Ttest] in occ
07/03/2013	0.14	0.00	100%	0.15	-1.12
08/03/2013	0.01	0.00	100%	0.00	-1.51
12/03/2013	0.33	0.00	100%	0.33	-0.64
13/03/2013	0.19	1.20	-518%	-1.01	-0.13
14/03/2013	0.98	0.432	57%	0.56	-0.14

We cannot conclude if our system works on March on DITER Office.
We can confirm that our system is more interesting in heavy winter (from December to February) when savings potential are important.

Monitored data were collected during 3 days in July for DITER offices and administrative offices, during cooling period.

1.7.2.1 Monitored results from DITER Offices – Potential Energy Savings - Cooling

Figure show great work of regulation on presence. On July, 17th, we can see that presence in the room was weak. Temperature in reference and test room is the same, and it can be noticed that it's quite the same on a whole day, despite high augmentation of external temperature; big inertia is responsible for this stability.
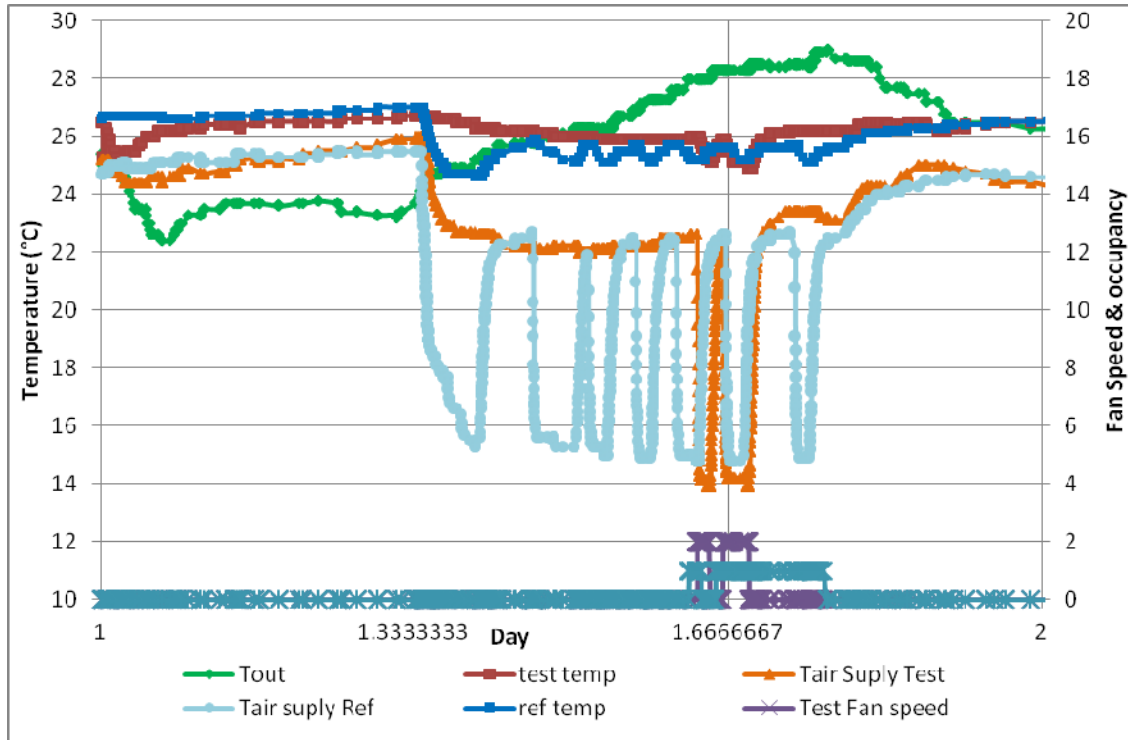
Figure 47 :Monitored room and fan coil temperature on July 17th in DITER offices

Following table show that in test room cooling consummations are not important regarding reference room:

Table 31: Cooling savings on DITER offices, for 3 days

Days	Cons. ref (kWh)	Cons. test (kWh)	Global Savings (%)	Average Tref-Ttest en occ
17/07/2013	7.53	1.60	79%	-0.29
18/07/2013	2.38	1.14	52%	-0.43
19/07/2013	0.94	0.17	82%	-0.13

1.7.2.2 Monitored results from Administrative offices – Potential Energy Savings - Cooling

Occupancy on administrative office is on the whole day. Savings are less important and confirm the way that our system doesn't permits a lot of gains if occupancy is on full day.
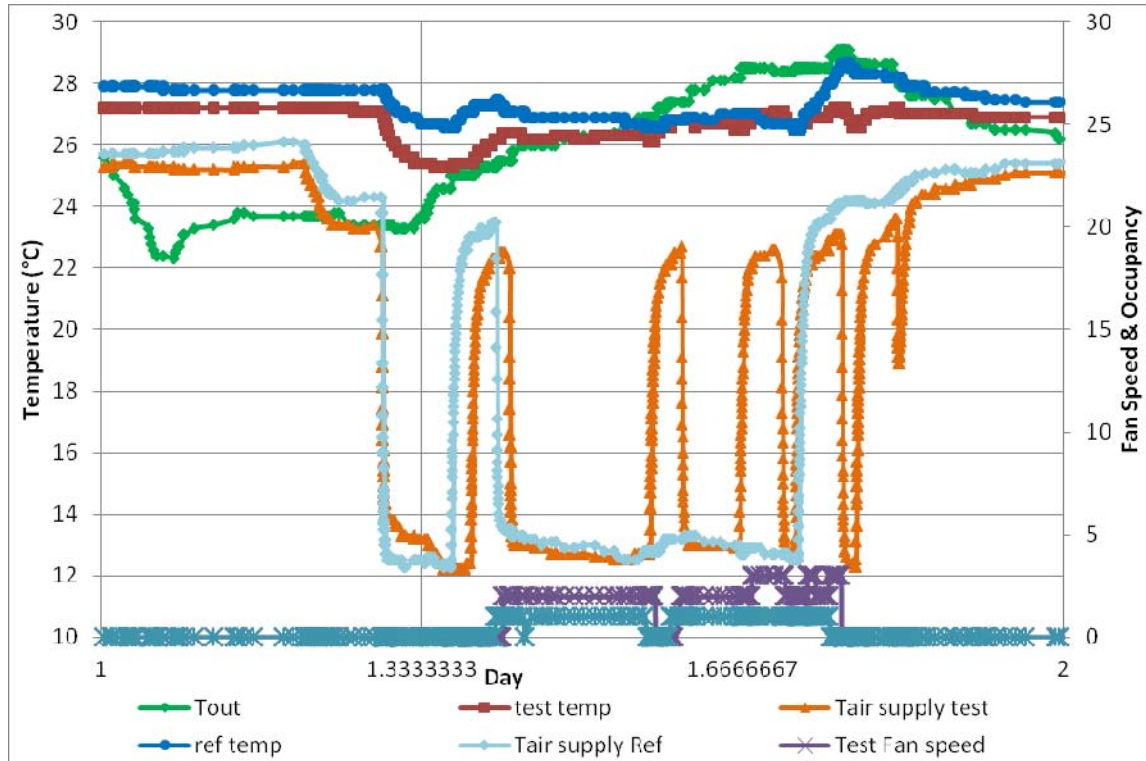
Figure 48: Monitored room and fan coil temperature on July, 17th in Administrative offices

Table 32: Cooling savings on Administrative offices

Days	Cons. ref (kWh)	Cons. test (kWh)	Global Savings (%)	Average Tref-Ttest en occ
17/07/2013	19.53	15.88	19%	0.29
18/07/2013	6.04	9.63	-59%	0.27

Heating planning is not the same on reference and test room, so it's difficult to compare the two consumptions.

This leads to the conclusion that our system is not very adapted to high occupancy rooms.

3. Modeling and simulation for Lighting

As already described in previous deliverables (D2.3.1 and D2.3.2) lighting simulation has been carried out with the aim of estimating and comparing the electric lighting energy demand of Reference rooms (rooms with existing, and manually controlled lighting systems) and Test rooms (rooms where the control systems and control strategies planned in the SEEMPubS project have been implemented). The simulation results have been used to define the saving potential achievable through the application of lighting controls and to optimize the control strategy on the basis of the specific room characteristics.

Lighting simulations were not carried out for Classrooms 1&3 (because, for budget limits and technical difficulties, it was decided to exclude these rooms from the demonstrator project) and for the Student Offices in the Valentino Castle (because for the particular features of these historically painted rooms it was not possible to apply any lighting control to the existing general lighting plant – crf. D2.3.1).

In the following sections the main steps of the simulation process and the obtained results are presented. In the sections, information already included in previous deliverables and new results are presented to provide an overall view of the activity carried out on this topic.

1.8 Choice of the software for lighting simulation

The total annual energy used for lighting depends on different aspects, mainly related to:
− indoor daylight availability
− building usage, in terms of target illuminance and occupancy profile
− user behaviour, in terms of interaction with the lighting plant and the shading devices
− lighting plant characteristics, such as the installed electric power density and the adopted lighting control system.

The software adopted to calculate the energy demand for electric lighting is Daysim. This is, in fact, a Radiance-based software that calculates daylight through a dynamic climate-based annual simulation, and, as a consequence, it estimates the energy demand for lighting taking into account the lighting power installed in the room, the type of lighting control system, the occupancy profile, the lighting requirements (the target illuminance value), and the user behavior.

A more detailed description of the software characteristics has been already included in Deliverable 2.3.2.

1.9 Interoperability between building information modeling and lighting simulations

To test the interoperability between architectural modeling and lighting simulations it was necessary to realize the 3D models of the real rooms and their external environment. The 3D models were used to run energy simulations, which were validated through the monitored data and then used to estimate the building energy demand.

In order to run the lighting simulations, it was not possible to import the parametric model from Revit into Daysim directly. The software Ecotect Analysis was hence used as interface to launch Daysim. As a result, Revit was imported into Ecotect using different procedures, with the aim of finding the most appropriate.

The first trial adopted the traditional approach based on the exporting in IFC (Industry Foundation Classes) format, but it did not succeed because some elements, such as the

window frames, were not exported or were displaced.

The second trial was based on the exporting from Revit by a gbXML file, but some geometrical discrepancies in the surfaces generated from the solid elements made the model unsuitable for the lighting simulation. In fact, this type of exporting involved some model simplifications that turned out to be incorrect for lighting simulations, even if the model was correctly generated and all the elements had maintained their reciprocal positions.

The third procedure was the most appropriate, both concerning modeling in Revit Architecture environment and for the analyses with Daysim (thanks to Ecotect as a software interface), through the use of 3DStudioMax as an intermediate software (to convert the .fbx file exported from Revit in a .3ds file imported into Ecotect) which gave good results in terms of geometrical consistency of the exported model. Nevertheless, also with this procedure it was necessary to check the 3D models imported in Ecotect before starting the lighting simulations in Daysim, to prevent some trivial mistakes connected to an oversight or elimination by the operator (for instance the disappearance of some parametric elements).

1.10 Input data for lighting simulation

After importing the rooms' architectural models into Daysim, some other input concerning the site, the room's architectural features, the lighting systems characteristics, the users' behavior and the lighting requirements were defined for each room.

The weather file describing the annual external daylighting conditions and the user behavior (a mix of active and passive behavior) were the common input for all rooms, whereas the other inputs were defined taking into account the actual characteristics of each room.

In the following sections the most relevant input data used are summarized.

1.10.1 DITER offices

Modeling of room characteristics
- visible reflectance and transmittance values assumed for opaque components and for glazing to model the space

component	visible reflectance ρ_{vis} [%]	component	visible transmittance τ_{vis} [%]
floor	22	glass of the skylight	64
walls	76	glass of the skylight with the blind	25
ceiling	76	glass of vertical windows	86
desks	63		
office cabinet – type 1	16		
office cabinet – type 2	25		
door	13		
chair	5		
frames	20		

Modeling of room usage and installed lighting and shading systems
- occupancy profile: Monday through Friday, from 9 am until 6 pm, with one hour break for lunch (noon to 1 pm) and two 30 minute coffee breaks (10-10.30 am and 3.30-4 pm)
- occupant behavior: equal mix of active and passive users
                                    active blind control
- installed lighting power density LPD: 8.835 W/m^2
- ballast loss factor : 10%
- sensors' stand-by power: 0

- delay time (for automatic switching off): 10 minutes
- blind control: Reference room: manual
                          Test room: manual (a)
                                            automatic (skylight only) (b)
- target illuminance   500 lux

Calculation grid

- working plane (desks): the calculation grid was set in correspondence of the actual position of the desks in the room, at an height of 80 cm above the floor
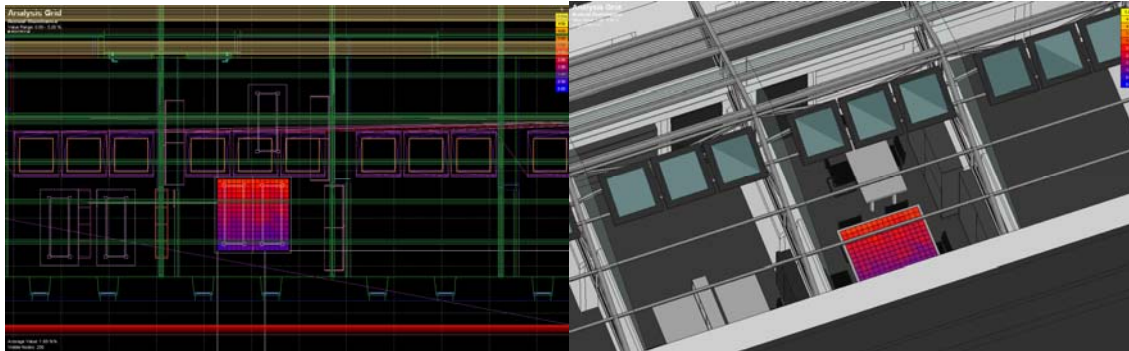
1.10.2   ADMINISTRATIVE offices

Modeling of room characteristics
- visible reflectance and transmittance values assumed for opaque components and for glazing to model the space

component	visible reflectance ρ_{vis} [%]	component	visible transmittance τ_{vis} [%]
floor	28	glass of vertical windows	82
walls	47		
ceiling	70		
desks	57		
chairs	7		
office cabinet	57		
door	56		
frames	61		

Modeling of room usage and installed lighting and shading systems
- occupancy profile: Monday through Friday, from 9 am until 5.15 pm, with one hour break for lunch (noon to 1 pm) and two 30 minute coffee breaks (10-10.30 am and 3.30-4 pm)
- occupant behavior: equal mix of active and passive users
                        active blind control
- installed lighting power density LPD: 6.73 W/m^2 (Reference Room) ; 6,54 W/m^2 (Test Room)
- ballast loss factor: 10%
- sensors stand-by power: 0,085 W/m^2 (Test room)
- delay time (for automatic switching off): 10 minutes
- blind control: Reference room: manual
                          Test room: manual
- target illuminance   500 lux (a)
                          300 lux (b)

Calculation grid
- whole room: the calculation grid was set at a height of 80 cm above the floor (thus being aligned with the working plane) so as to cover the whole room minus a peripheral stripe of 60 cm (which was considered a clearance space for furniture)
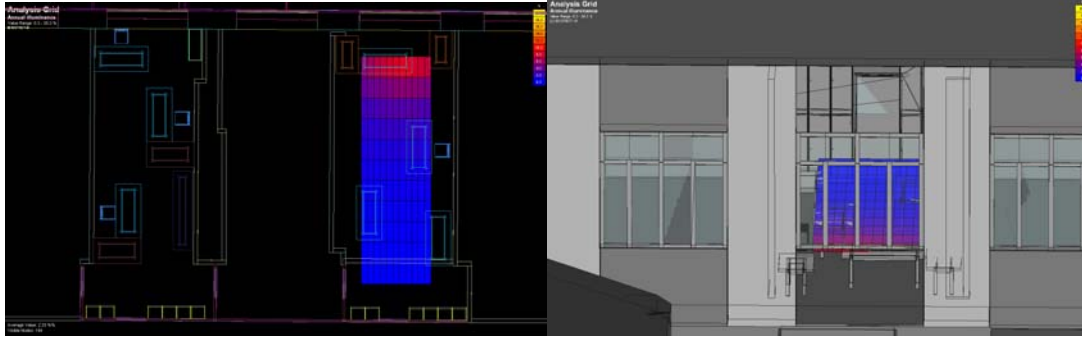
1.10.3 DAUIN laboratories

Modeling of room characteristics
- visible reflectance and transmittance values assumed for opaque components and for glazing to model the space

component	visible reflectance ρ_{vis} [%]	component	visible transmittance τ_{vis} [%]
floor	19	glass of internal vertical windows	66
walls	77	glass of external vertical windows	50
ceiling	70		
desks	35		
office cabinet	35		
door	25		
frames	20		

Modeling of room usage and installed lighting and shading systems
- occupancy profile: Monday through Friday, from 9 am until 6 pm, with one hour break for lunch (noon to 1 pm) and two 30 minute coffee breaks (10-10.30 am and 3.30-4 pm)
- occupant behavior: equal mix of active and passive users
                        active blind control
- installed lighting power density LPD: 7.96 W/m^2
- ballast loss factor: 10%
- sensors' stand-by power: 0.07 W/m^2 (Test laboratory)
- delay time (for automatic switching off): 10 minutes
- blind control: Reference room: manual
                        Test room: manual

Calculation grids
- whole room: the calculation grid was set at a height of 80 cm above the floor (thus being aligned with the working plane) so as to cover the whole room minus a peripheral stripe of 60 cm (which was considered a clearance space for furniture)
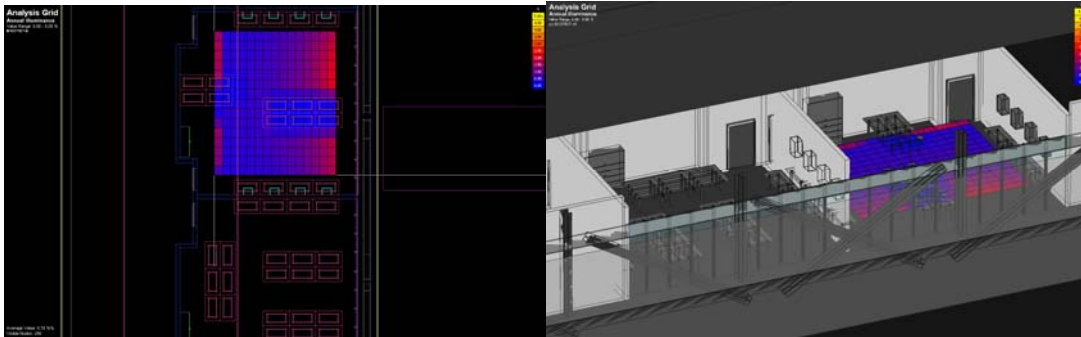
1.10.4 DAUIN offices

Modeling of room characteristics
- visible reflectance and transmittance values assumed for opaque components and for glazing to model the space

component	visible reflectance ρ_{vis} [%]	component	visible transmittance τ_{vis} [%]
floor	40	glass of vertical windows	66
walls	53		
ceiling	70		
desks	21		
office cabinet	21		
door	8		
frames	10		

Modeling of room usage and installed lighting and shading systems
- occupancy profile: Monday through Friday, from 9 am until 6 pm, with one hour break for lunch (noon to 1 pm) and two 30 minute coffee breaks (10-10.30 am and 3.30-4 pm)
- occupant behavior: equal mix of active and passive users
  active blind control
- installed lighting power density LPD: 10.15 W/m^2
- ballast loss factor: 10%
- sensors' stand-by power: 0.1 W/m^2 (Test room)
- delay time (for automatic switching off): 10 minutes
- blind control: Reference room: manual
  Test room: manual

Calculation grid

- working plane (desks): the calculation grid was set in correspondence of the actual position of the desks in the room, at an height of 80 cm above the floor
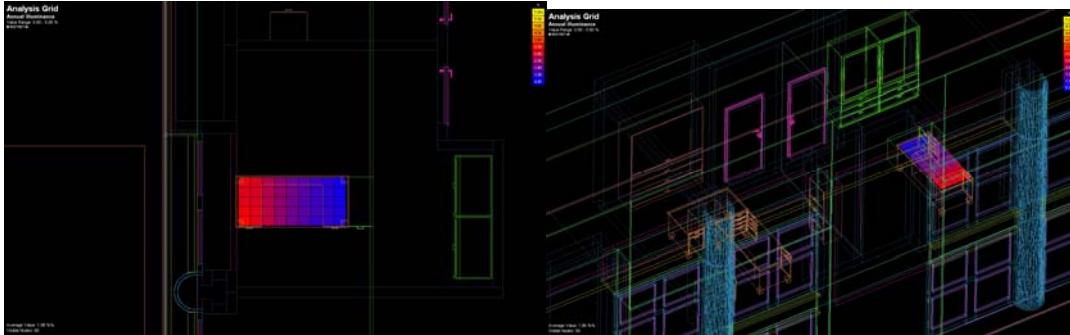
1.11 Lighting control strategies

The lighting control strategies used in the simulations have been described and explained in Deliverable 2.3.1 and 2.3.2.

Reference rooms were always simulated considering a manual control of both lighting systems and blinds; for Test rooms the simulation was repeated changing the lighting control rules in order to find the most effective solution in terms of energy savings. In particular two different switching on/off strategies were compared:
- TEST CASE 0: lights are switched on and off by the occupancy sensor
- TEST CASE 1: lights are switched on manually and switched off by the occupancy sensor

From the simulation results, two type of control strategies, corresponding to CASE 1, resulted, at the end, to be the most effective:
- Manual switch on; switch off based on presence detection, dimming based on daylight availability and target illuminance; (Figure 49): in rooms with sufficient daylight availability (DITER offices, ADMINISTRATIVE offices and DAUIN single offices)
- Manual switch on and switch off based on presence detection (Figure 50): in rooms with low daylight availability (DAUIN laboratories).
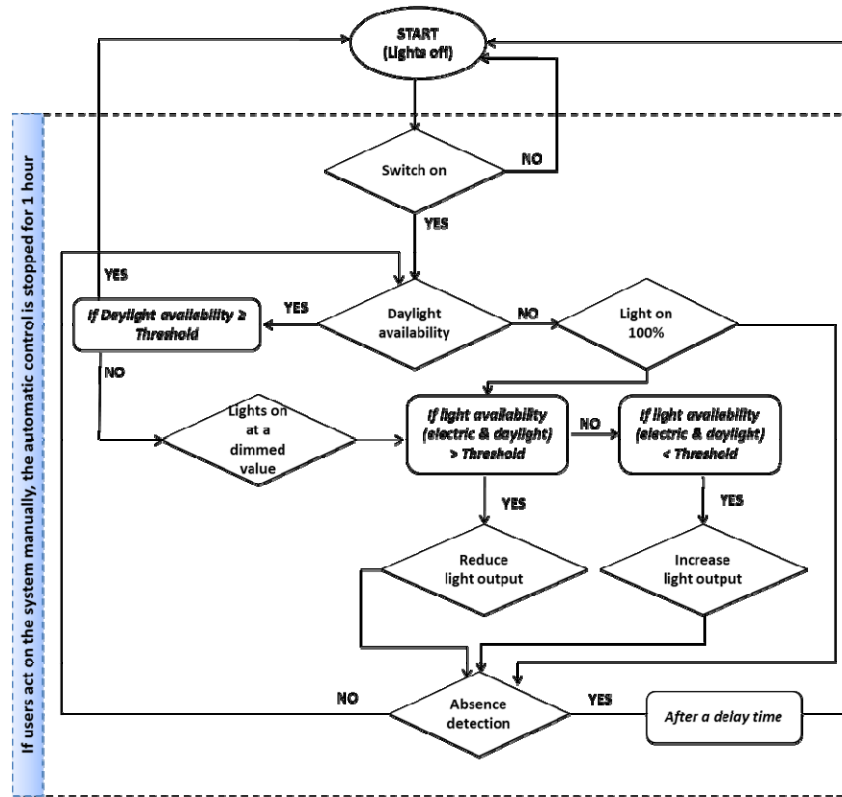
Figure 49: lighting control strategy for room with sufficient daylight availability
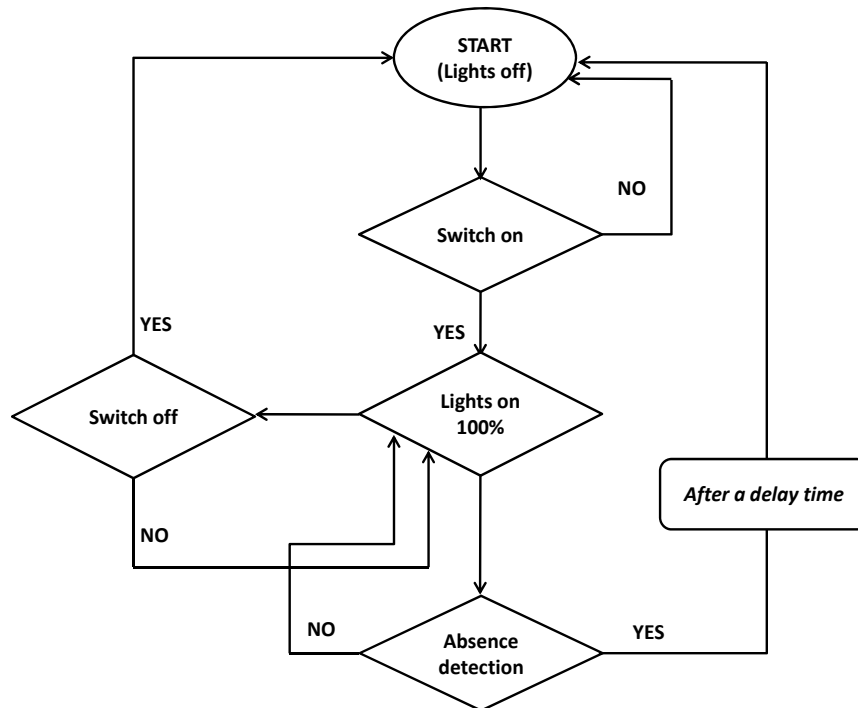
Figure 50: lighting control strategy for room with low daylight availability

1.12 Lighting simulation results

In this section the energy demands for lighting, resulting from the lighting simulations carried out for each couple of room (Reference and Test) are summarized. Besides the annual electric lighting energy demands and savings, which were already reported in Deliverable 2.3.2, the monthly values are here included.

1.12.1   DITER offices

Lighting control strategies:
Test CASE 0: automatic switch on/off by occupancy sensor; automatic dimming.
Test CASE 1: manual switch on; automatic switch off by occupancy sensor; automatic dimming.
For the DITER Test Office simulations were repeated considering both a manual and an automatic control of the blinds installed on the skylights.
In Table 33 the annual value of the energy demands and savings for the different control strategies are reported, while in Table 34 the monthly energy demands and savings for the control solution that was actually implemented are presented. This corresponds to Test CASE1 with manual blind control, as, for technical problems, it was not possible to install the devices that were necessary to realize an automatic blind control.

Table 33: DITER offices annual Lighting energy demands and savings for different control strategies

	Reference room [KWh/m^{2}y]	Test room CASE 0 [KWh/m^{2}y]		Savings [%]		Test room CASE 1 [KWh/m^{2}y]		Savings [%]	
	Manual blind	Manual blind	Automatic blind	Manual blind	Automatic blind	Manual blind	Automatic blind	Manual blind	Automatic blind
Year	18.10	15.60	12.70	14	29	12.80	9.50	29	48

Table 34: DITER offices monthly lighting energy demand and savings

	Reference room [KWh/m²]	Test Room CASE 1 [KWh/m²]	Saving CASE 1 [%]
January	**1.707**	**1.309**	**23.3**
February	**1.455**	**1.036**	**28.8**
March	**1.839**	**0.973**	**47.1**
April	**1.305**	**0.960**	**26.4**
May	**1.468**	**1.014**	**30.9**
June	**1.432**	**0.881**	**38.5**
July	**1.390**	**1.007**	**27.5**
August	**1.478**	**1.049**	**29.0**
September	**1.233**	**0.950**	**23.0**
October	**1.620**	**1.193**	**26.4**
November	**1.623**	**1.182**	**27.2**

December	**1.531**	**1.198**	**21.8**

1.12.2 ADMINISTRATIVE offices

Lighting control strategies:
Test CASE 0: automatic switch on/off by occupancy sensor; automatic dimming.
Test CASE 1: manual switch on; automatic switch off by occupancy sensor; automatic dimming.

For ADMINISTRATIVE offices simulations were repeated considering two different target illuminances: 500 lux (target value for offices as reported in international standards) and 300 lux (target value required by the occupants of the offices)
In Table 35 the annual value of the energy demands and savings for the different testes control strategies are reported, while in Table 36 the monthly energy demands and savings for the control solution that was actually implemented are presented. This corresponds to Test CASE 1 with a target illuminance of 300 lux.

Table 35: ADMINISTRATIVE office annual Lighting energy demands and savings for different control strategies

	Reference room [KWh/m^{2}y]	Test room CASE 0 [KWh/m^{2}y]		Savings [%]		Test room CASE 1 [KWh/m^{2}y]		Savings [%]	
	300 lux	500 lux	300 lux	500 lux	300 lux	500 lux	300 lux	500 lux	300 lux
Year	11.80	11.50	10.60	2	10	8.90	8.30	25	30

Table 36: ADMINISTRATIVE office monthly lighting energy demand and savings

	Reference room [KWh/m²]	Test Room CASE 1 [KWh/m²]	Saving CASE 1 [%]
January	**1.159**	**0.896**	**22.7**
February	**0.987**	**0.711**	**28.0**
March	**0.987**	**0.705**	**28.6**
April	**0.959**	**0.593**	**38.2**
May	**0.889**	**0.641**	**27.9**
June	**0.975**	**0.561**	**42.4**
July	**0.938**	**0.597**	**36.4**
August	**0.943**	**0.634**	**32.8**
September	**0.835**	**0.575**	**31.1**
October	**1.045**	**0.810**	**22.5**
November	**1.077**	**0.838**	**22.2**
December	**1.046**	**0.828**	**20.9**

1.12.3 DAUIN laboratories

Lighting control strategies:
Test CASE 0: automatic switch on/off by occupancy sensor.

Test CASE 1: manual switch on; automatic switch off by occupancy sensor.

In Table 37 the annual value of the energy demands and savings for the different testes control strategies are reported, while in Table 38 the monthly energy demands and savings for the control solution that was actually implemented are presented. This corresponds to Test CASE 1.

Table 37: DAUIN laboratories annual Lighting energy demands and savings for different control strategies

	Reference room [KWh/m²y]	Test room CASE 0 [KWh/m²y]	Savings [%]	Test room CASE 1 [KWh/m²y]	Savings [%]
Year	18.00	17.10	5	15.50	14

Table 38: DAUIN laboratories monthly lighting energy demand and savings

	Reference room [KWh/m²]	Test Room CASE 1 [KWh/m²]	Saving CASE 1 [%]
January	1.554	1.357	10.0
February	1.380	1.194	11.1
March	1.511	1.321	10.1
April	1.415	1.249	9.8
May	1.622	1.355	13.1
June	1.416	1.187	9.7
July	1.450	1.273	8.0
August	1.592	1.364	11.3
September	1.364	1.183	10.4
October	1.568	1.386	9.2
November	1.575	1.310	14.6
December	1.455	1.252	11.6

1.12.4   DAUIN offices

Lighting control strategies:

Test CASE 0: automatic switch on/off by occupancy sensor; automatic dimming.

Test CASE 1: manual switch on; automatic switch off by occupancy sensor; automatic dimming.

In Table 39 the annual value of the energy demands and savings for the different testes control strategies are reported, while in Table 40 the monthly energy demands and savings for the control solution that was actually implemented are presented. This corresponds to Test CASE 1.

Table 39: DAUIN offices annual Lighting energy demands and savings for different control strategies

	Reference room [KWh/m²y]	Test room CASE 0 [KWh/m²y]	Savings [%]	Test room CASE 1 [KWh/m²y]	Savings [%]

Year	18.50	15.50	16	11.30	39

Table 40: DAUIN offices monthly lighting energy demand and savings

	Reference room [KWh/m²]	Test Room CASE 1 [KWh/m²]	Saving CASE 1 [%]
January	1.884	1.315	30.2
February	1.581	0.993	37.2
March	1.598	0.890	44.3
April	1.243	0.772	37.9
May	1.255	0.814	35.1
June	1.196	0.723	39.5
July	1.201	0.775	35.5
August	1.450	0.862	40.6
September	1.589	0.763	52.0
October	2.068	1.073	48.1
November	1.730	1.158	33.0
December	1.697	1.165	31.4

1.13 Comparison between simulation results and monitored data

In this section we try to provide some comparison between monthly simulation results and the data of energy consumptions for lighting monitored in some rooms.

In this regard, Figure 51 and Figure 52 show an example of the comparison of simulated and measured in-the-field data for two months, March and May 2013. From both figures it can be observed that the two series of data are comparable in terms of absolute values, but this is limited to some specific time-steps, and in contrast show a discrepancy if the whole month is considered and the total monthly energy consumption is calculated: this is equal to 0.973 kWh/m^2 from the simulations versus 0.279 kWh/m^2 from the field monitoring for March 2013 and equal to 1.014 kWh/m^2 versus 0.094 kWh/m^2 for May 2013. This discrepancy, which highlights that the actual energy consumed in the real rooms is substantially lower than what predicted through the simulations, seems to be due mainly to the following factors:

- The occupancy profile, that is the actual presence of the users in the space throughout the considered month. For this reason, the two occupancy profiles assumed by Daysim for the simulations and monitored through the sensors installed in the real spaces are plotted as well in figures 50 and 51 for the two considered months. Daysim assumes that users are in

the space from 9 am to 6 pm every day but with three breaks: a one hour break for lunch and two thirty minute coffee breaks, one in the morning and one in the afternoon. In contrast, the actual presence of real users of the space is more random as a consequence of the type of work carried out by researchers, which includes lectures or meetings in other rooms. It should be noted that for the simulations run in Daysim, an annual climate file with a time-step of five minutes was used, while the graphs shown in figure 50b and 51b, are plotted for a time-step of 1 hours. Therefore, the average of the occupancy profile values (0 = vacancy of the room; 1 = presence of occupants in the room) was calculated for each hour: this explains why intermediate values between 0 and 1 for the occupancy profile calculated by Daysim are visualized in the graphs.

- The behaviour the users have towards the use of both the shading system and the electric lights during their presence in the space. In the first simulations it was assumed a user behaviour corresponding to an equal mix of active and passive, but from personal communications with the users of both the test and the reference DITER offices, it was noticed that the users tend to turn on the ceiling-mounted lights very rarely, preferring to use instead a task-lighting. In any case, the quantity of daylight is judged to be sufficient for a large amount of moments (with the consequence that electric lighting remains off) for which in simulations it was assumed that electric lights are on, even though with a dimmed setting. In a second set of simulations the user was considered to have an active behaviour for the use of lights, and in this case the monthly energy demand for lighting dropped down to 0.601 kWh/m^2 for March and 0.652 kWh/m^2 for May.

- The differences between the actual climatic condition in the month of March and May 2013 with respect to the standardised climatic data included in the file used for the simulation.

monthly energy demand for lighting from simulations: 0.973 kWh/m^2
monthly energy demand for lighting from field measurements: 0.279 kWh/m^2

b)
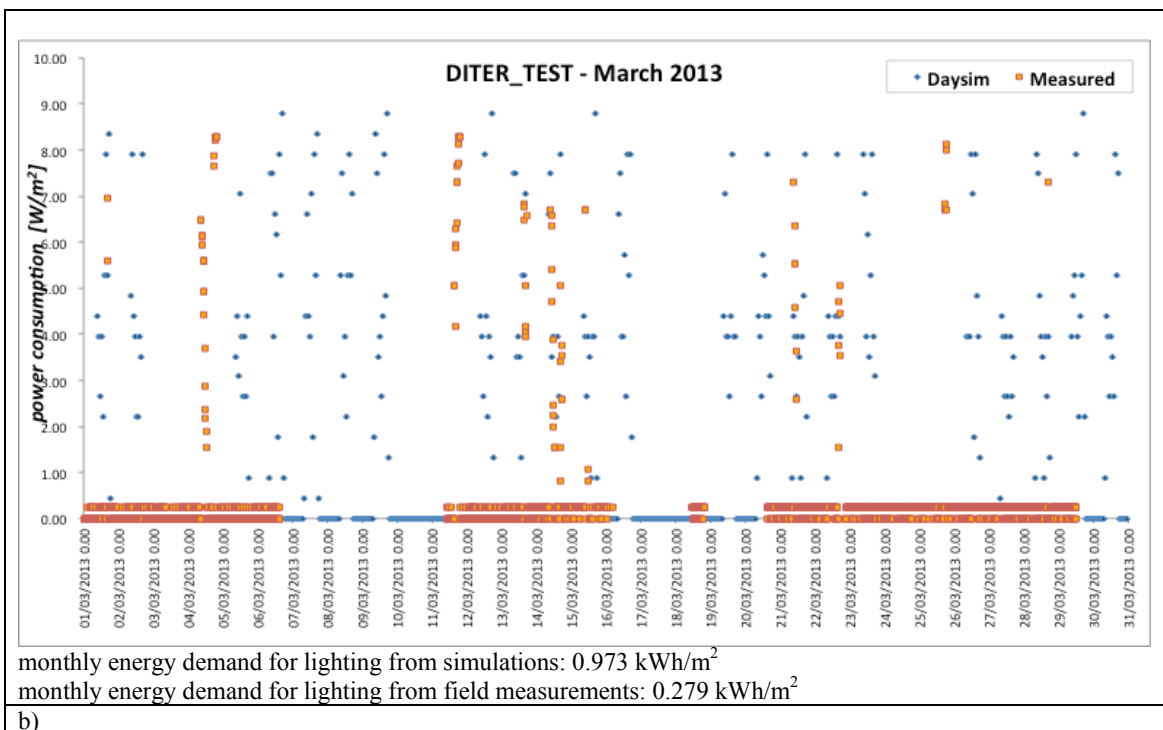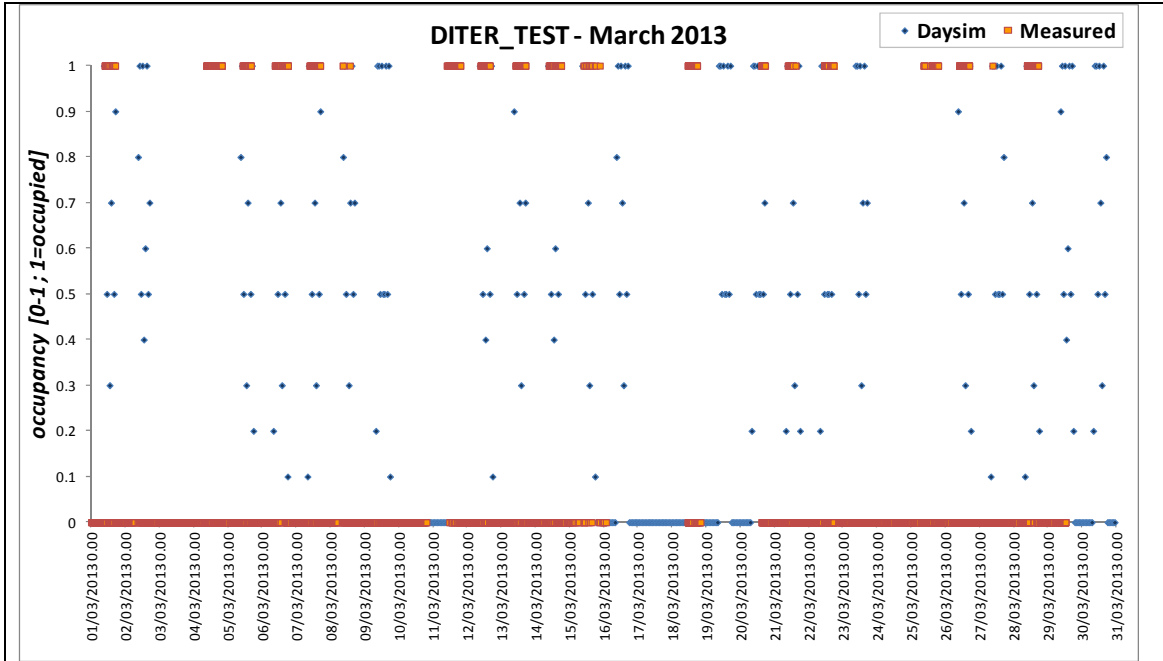
Figure 51: comparison of simulated and measured in-the-field data for the DITER_TEST room and for the month of March 2013: power use (a) and occupancy profile (b).

a)
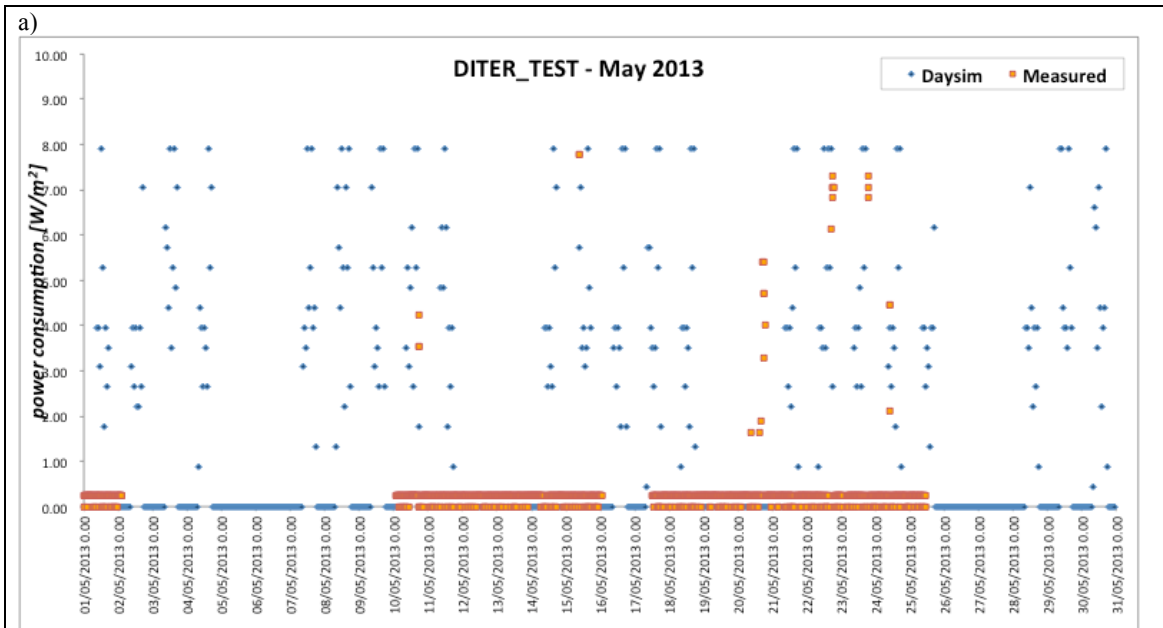
monthly energy demand for lighting from simulations: 1.014 kWh/m²
monthly energy demand for lighting from field measurements: 0.094 kWh/m²

b)
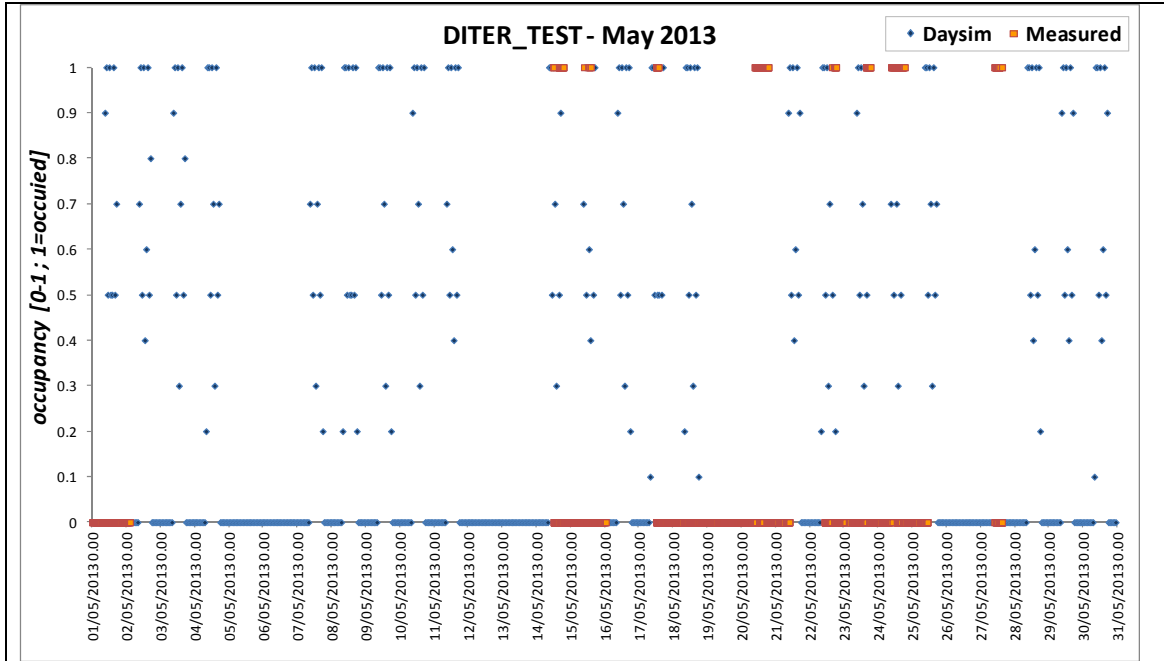
Figure 52: comparison of simulated and measured in-the-field data for the DITER_TEST room and for the month of May 2013: power use (a) and occupancy profile (b).

Besides the analysis concerned with the comparison of simulated and field monitored energy consumption data, which was explained above and which described the discrepancies which occurred between the two series of data, further considerations can be drawn through a comparison of the *real* energy consumption of a pair of reference-test rooms, in which the same typologies of sensors are installed. Actually, field monitored data can be used for this purpose, for both the reference and the homologous test room. **Table 41** shows, for example, the energy consumption which have been measured for the period from March to the end of June, for the DITER offices, and the corresponding energy savings.

Table 41: comparison of monthly lighting energy demand for the reference and the test DITER offices. Both data from simulations and field monitoring are shown.

	simulations			field monitoring		
	Reference room [KWh/m^2]	Test Room CASE 1 [KWh/m^2]	Saving CASE 1 [%]	Reference room [KWh/m^2]	Test Room CASE 1 [KWh/m^2]	Saving CASE 1 [%]
March to June	6.044	3.828	36.6	1.778	1.015	42.9

4. Conclusion

This deliverable consisted in making a recap of all simulated results for HVAC and for lighting in terms of energy saving potential. Some experimental results have been available during this last year and it has been possible to validate again the models and also to compare the predictions results to the monitored one.

We remember that for the evaluation of the achievable energy savings, the rooms selected for the project (six pairs of similar rooms for which the characteristics of the envelope and of the systems have been modelled and data tuned for having a good representation) were simulated as they are now, with the existing plants and control systems (Reference rooms) and after applying the proposed control strategies (Test rooms). The updated control strategies are presented here again for HVAC and lighting.

For HVAC, we can confirm that our control system, based on an optimization of recovery time and presence detection, is more interesting in heavy winter (from December to February) when savings potential are important. The complete control strategy (auto-learning calculation of recovery time) has not been uploaded on the system and more efficiency in terms of comfort and energy savings can be obtained. We have observed that, even when presence is complete during the week, it is possible to have energy gains due to the good determination of the restart time. So, thermal comfort is good during all the days. When it is possible to save also energy during absence of the occupant the strategy becomes more interesting. It is also important to anticipate the absence knowing the schedule of occupancy because in this case we can lower the set-point higher than 3°C (case of absence detection) and have more energy gains. The 3°C lowering decreases thermal comfort when the occupant enters again the room. This is prejudicial for high inertia buildings because it is necessary more time to reach the set point temperature.

If we summarize the energy gains, we can give a range from 10% to 30%. 10% when inertia is high and absence is low; 30% when inertia is low and absence is high.

For cooling, we had very few experimental results during last months of monitoring to have complete conclusions. We have verified that the general behaviour obtained with simulations was obtained and that the system is running well. The monitoring and control continue and in the next months (after the end of the project) it will be possible to have better conclusions on thermal comfort and on the energy gains.

Control based on adaptative comfort is not suitable with the actual law of calculation of the set point temperature (to low temperatures in very cold winter). The persons are not used to have so low temperatures in rooms and there is an education to do on this point.

For lighting, the simulation results reported in the document highlight the potential savings achievable by applying the control strategies defined for this project (from 14% to 39% depending on the room's characteristics and the type of lighting control). On the other hand, they also emphasize the large discrepancies between the absolute values of electric lighting power consumptions monitored in the rooms and the ones calculated with Daysim. Comparing the monitored to the simulated data, this seems to be mainly ascribable to the differences between the simulated and the actual occupancy profile and to the users' behaviour towards the control of lights.

Beside the different absolute values, the monitored data for the period from March to June, for the DITER offices, seem to confirm the saving potentials of the new lighting control system.

These data have been presented as an example, and will have to be confirmed after a whole year of monitored data will be available. To compare the monitored data and the simulated results using the data recorded during a whole year should also reduce the error caused by the differences between 'actual' daily climatic data and the corresponding weather data in the climatic file used for the simulation.

5. References

6. References

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7. List of figures

8. List of Tables