Universitat Politécinica de Valencia
Escuela Técnica Superior de Ingeniería de Edificación
Camino de Vera Valencia

Master of Science in Engineering Technology: Construction

Passive house standard in a warm climate. Analysis of closures with tests in a university building. Passive house modelling with advanced computer tools.

Promotor: Dr. Carolina Aparicio Fernández

Thesis submitted to obtain the degree of
Master of Science in Engineering Technology Construction

Olivier Deboo
Edouard Bertrand

Academic year: 2013 - 2014

ACKNOWLEDGEMENTS

We would like to thank Kaho Sint-Lieven, Universitat Politechnica de Valencia (Spain) and the European Union to give us the opportunity to go on Erasmus. We would like to express the deepest appreciation to Javier Calvo Diaz, who welcomed and helped us a lot when we arrived at UPV and during our stay. In addition, a thanks to Professor Guido Kips who helped us with the preparation and the paperwork in Belgium.

We would also like to express our gratitude to our promoter lecturer Carolina Sabina Fernández for the useful comments, remarks and engagement through the learning process of this master thesis. A special thanks to José Luis Vivancos Bon and Rafael Royo Pastor for their time and help with the writing of this paper.

This was a great experience for us to learn new things, different approaches and to meet new people who were very helpful. We will never forget this.

ABSTRACT

The title of the thesis is "Passive house standard in a warm climate. Analysis of closures with tests in a university building. Passive house modelling with advanced computer tools."

The objective of the thesis is to create a digital model of an existing university building with TRNSYS, an advanced simulation program, and modify it to lower the cooling and heating demand to meet the passive house standard.

TRNSYS generates the temperatures as well as the heating and cooling demand that are expected in the building during one year. Therefore measurements with a weather station combined with the data from the official weather station at UPV helped obtaining annual weather data as input for TRNSYS.

The C_p generator was used to calculate the wind pressure coefficients, which affect the air infiltration into the building. Also the thermal bridges in the thermal envelope were calculated using THERM as input for TRNSYS. The model is validated to check its correctness and precision by comparing it with the actual temperatures in the building. Therefore the temperatures on 2 places in the building were measured while obtaining the outside weather data.

Finally modifications are imported into the model and their effect on the cooling and heating demand is analysed. The fact that the building is located in a warm climate makes the application of the passive house standard complicated. Also this fact has important influences on which modifications to apply and how to analyse them.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF GRAPHS

List of tables

1. INTRODUCTION

Before we arrived at UPV we had to choose a title of a thesis out of a list. We both preferred the thesis: “Passive house standard in a warm climate. Analysis of closures with tests in a university building. Passive house modelling with advanced computer tools.” We are both interested in building physics and we both don’t dislike working with a new computer program. This was one of the many reasons we choose for Valencia to go on Erasmus.

As in the title of this thesis is shown, one part is modelling a building using an advanced simulation program and comparing the outputs of the program with data obtained by measurements in the building. At the end we made improvements on the building model. The program simulates the conditions inside the building with all the changes we implemented in the program and in accordance with the weather data we obtained. The results will be analysed and conclusions about the model and improvements will be taken. We had to take into account that the building is situated in a warm climate. So the corrections have different influences depending on the season. This was a difficult issue for us, because we really had to change our way of thinking. In Belgium we primarily focus on the heating demand of a building and not so much on the cooling demand. In a climate like here in Valencia it’s the other way around.

With the prospects of adapting, renovating or even rebuilding the faculty of building management, this thesis can have some importance. In time of economic crisis and increasing environmental awareness, a high quality design in terms of energy demands and consumption is indispensable. That’s why improvements such as insulation, renewable energy, better equipment for cooling/heating, ventilation etc. are important to achieve this quality design. A passive house is the example of such a design. A passive house is a building with comfortable indoor conditions throughout the year, achieved with minimum energy input. The design and construction are very important in this matter.

Before we started with the computer program and doing the measurements we did some research about this subject. We read some articles that our promoter in Spain, Lecturer Carolina Sabina Fernández and our Professor Hilde Breesh in Belgium suggested. We also read the manuals of TRNSYS (TRNSYS, TRNFlow and Multi-zone Building).

The building that we are evaluating is a university building. This means that this is a non-residential building. The following criteria have to be obtained to receive a passive house certificate (www.passivehouse-international.org):

- Specific space heating demand: ≤ 15 kWh/(m^{2}a)
- Specific useful cooling demand: ≤ 15 kWh/(m^{2}a)
- Total specific primary energy demand: ≤ 120 kWh/(m^{2}a)
- Airtightness: ≤ 0.6/h

These criteria will be used to implement modifications to the model and in this way reaching the Passive House standard.

2. CONCEPTS

2.1. BUILDING SIMULATION WITH TRNSYS

"TRNSYS is the abbreviation of **Tran**sient **Sy**stem **S**imulation Tool. It is a complete and extensible simulation environment for the transient simulation of systems, including multi-zone buildings. It is used by engineers and researchers around the world to validate new energy concepts, from simple domestic hot water systems to the design and simulation of buildings and their equipment, including control strategies, occupant behaviour, alternative energy systems (wind, solar, photovoltaic, hydrogen systems), etc." (Klein S.A. et al, 2012, p8)

TRNSYS contains two parts. The first is an engine that reads and processes the input file, iteratively solves the system, determines convergence, and plots system variables. The kernel also provides utilities that (among other things) determine thermophysical properties, invert matrices, perform linear regressions, and interpolate external data files.

The second part of TRNSYS is an extensive library of components, each of which models the performance of one part of the system. The standard library includes approximately 150 models ranging from pumps to multizone buildings, wind turbines to electrolyzers, weather data processors to economics routines, and basic HVAC equipment to cutting edge emerging technologies. The user has the possibility to modify existing components or write their own, extending the capabilities of the environment.

TRNSYS is very successful due to its open, modular structure. The source code of the kernel as well as the component models, is delivered to the end users. This simplifies extending existing models to make them fit the user's specific needs.

The DLL-based architecture allows users and third-party developers to easily add custom component models, using all common programming languages (C, C++, PASCAL, FORTRAN, etc.). In addition, TRNSYS can be easily connected to many other applications, for pre- or post-processing or through interactive calls during the simulation (e.g. Microsoft Excel, Matlab, COMIS, etc.). TRNSYS applications include:

- Solar systems (solar thermal and PV)
- Low energy buildings and HVAC systems with advanced design features (natural ventilation, slab heating/cooling, double façade, etc.)
- Renewable energy systems
- Cogeneration, fuel cells
- Anything that requires dynamic simulation

2.1.1. TRNSYS Simulation studio with TRNBUILD

"Simulation Studio is a complete simulation package containing several tools, from simulation engine programs and graphical connection programs to plotting and spreadsheet software. It is an integrated tool which can be used from the design of a project to its simulation." (Klein S.A. et al, 2012, p.12)

The simulation studio contains 3 main steps to become a valid result:

- Inputs
- Calculation: Type 56 – Multizone Building
  ➔ Interaction with TRNBUILD and TRNFLOW
- Outputs

2.1.1.1. Inputs

The main inputs are:

- The TRNBUILD file.
- The Weather Data Reading and Processing (Type 15).

The TRNBUILD file

You have the choice to import a 3D construction made in Google Sketch-up by using the TRNSYS3d-plugin or you can design the building in TRNSBUILD yourself. When there are no defaults, you can import this to TRNSYS.

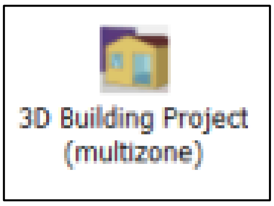


FIGURE 2 - SYMBOL OF 3D BUILDING PROJECT

FIGURE 1 - SYMBOL OF BUILDING PROJECT

Eventually the type56 will be changed to type 56: Multi-Zone Building with Airflow (TRNFLow). This way it will be able to do the calculations and simulations in combination with TRNFlow.

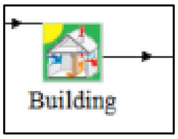


FIGURE 3 - SYMBOL OF TYPE 56 WITH AIRFLOW (TRNFLOW)

"This component models the thermal behaviour of a building divided into different thermal zones. In order to use this component, a separate pre-processing program must first be executed." (Klein S.A. et al, 2012,p.8) The TRNBUILD program reads in and processes a file containing the building description and generates two files that will be used by the TYPE 56 component during a TRNSYS simulation. The file containing the building description processed by TRNBUILD can be generated by the user with any text editor or with the interactive program TRNBUILD. The required notation is described fully in the TRNBUILD documentation in the following section.

The Weather Data Reading and Processing - Type 15

"This component serves the purpose of reading data at regular time intervals from an external weather data file, interpolating the data (including solar radiation for tilted surfaces) at time steps of less than one hour, and making it available to other TRNSYS components." (Klein S.A. et al, 2012, p.98) The model also calculates several useful terms including the mains water temperature, the effective sky temperature, and the heating and cooling season forcing functions.

2.1.1.2. CALCULATION

It is in the Simulation Studio that the calculation takes place. It is possible to pick any type out of the TRNSYS Library or take any option needed out of the toolbar.

All the different inputs and outputs can be connected by the link tool. Now the program can do the calculations and simulations. The obtained results can be compared and judged with result obtained in real life experiments.

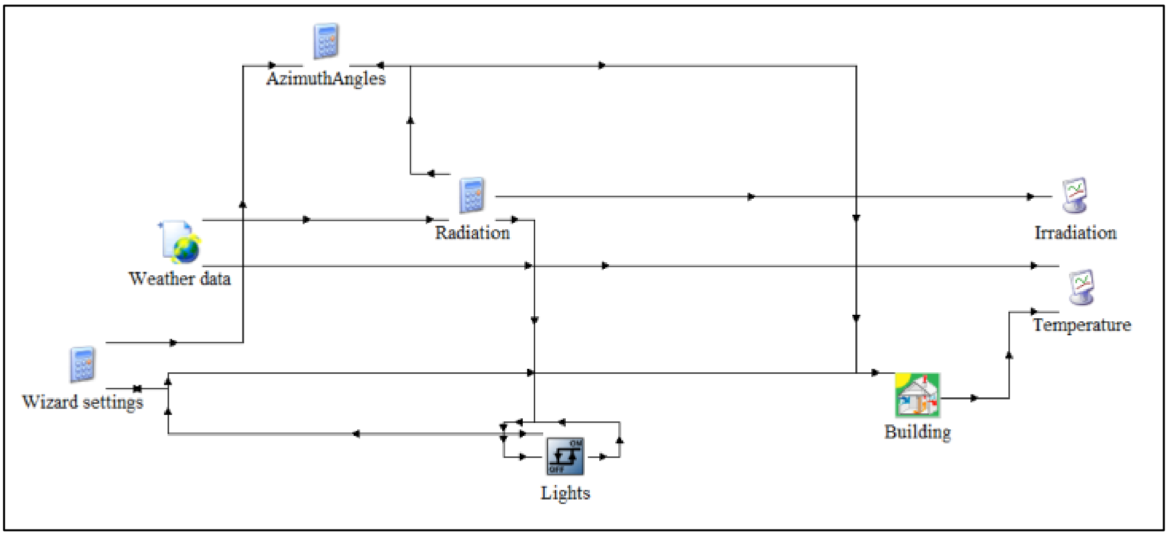


FIGURE 4 - SYSTEM IN THE SIMULATION STUDIO

Creating Links

Links allows to exchange information between two component models. In this way the outputs from the first model can be used as inputs in the second model. When the mouse is in the area of the first model, 8 ports appaer around the icon. When you choose one and click, you will see the same at the second model. A line will be drawn between the two components to indicate information flow between them. This line will initially be empty (blue). When the variable is specified in the link, it will turn black.

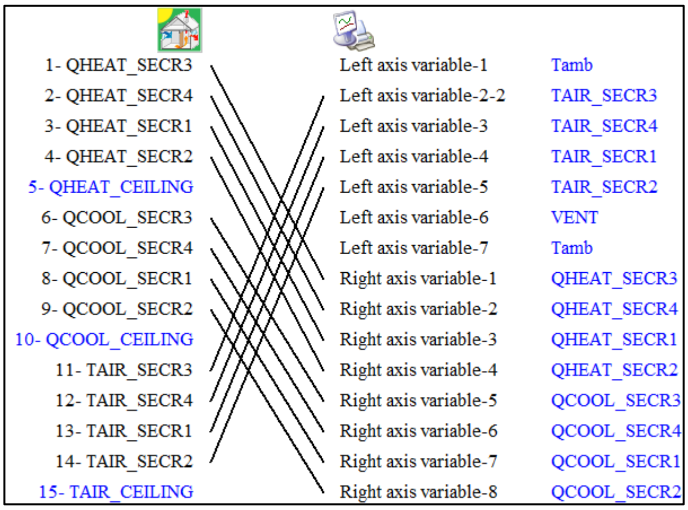


FIGURE 5 - LINKS

Equations

A very useful feature in TRNSYS is the ability to define equations within the input file. These are not integrated in a component. These equations can be: functions of outputs of other components, numerical values, previously defined equations... They can then be used as: inputs to other components, parameters, initial values of inputs… The use of equations is most easily accomplished by using a special equations component. This equations component can be placed in an assembly or saved like any other component.

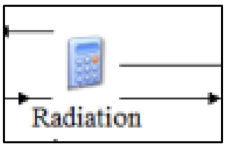


FIGURE 6 - SYMBOL FOR EQUATIONS

The equation component will not be represented in the generated input file by a UNIT, TYPE statement. Rather, the information contained in this component will be placed in an EQUATIONS statement within the TRNSYS input file. The user can specify the location of the equations in the Control Cards window. Different blocks of equations can be placed anywhere within the input file and are arranged just like different components.

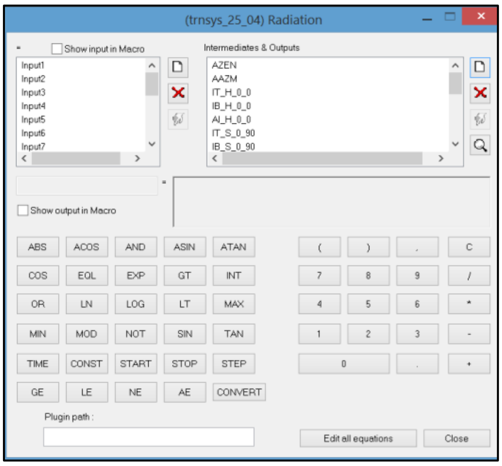


FIGURE 7 - WINDOW FOR EQUATIONS

2.1.1.3. OUTPUTS

In TRNSYS Simulation Studio the user can choose out of several output methods, such as:

- Economics
- Online plotter
- Histogram plotter
- Printegrator
- Printer
- Scope
- Simulation summary
- TRNSYS Plugin for SketchUp Printer

Online Plotter (no units) – type 65c

"The online graphics component is used to display selected system variables while the simulation is progressing. This component is used a lot because it provides valuable variable information and allows users to immediately see if the system is not performing as desired." (Klein S.A. et al, 2012, p.62) The selected variables will be displayed in a separate plot window on the screen. In this instance of the Type65 online plotter, data sent to the online plotter is automatically printed, once per time step to external file which has been defined by the user.

FIGURE 8 - SYMBOL OF ONLINE PLOTTER

2.1.2. TRNBUILD

In TRNBUILD there are 3 main windows:

- Project
- The zone window
- Definition of the airflow network for detailed calculation with TRNFlow

It is possible to model the thermal behaviour of a building which is divided into different thermal zones. The TRNBUILD program reads in and processes a file containing the building description and generates two files that will be used by the TYPE 56 component during a TRNSYS simulation.

The parameters of TYPE 56 are not defined directly in the TRNSYS input file because a multizone building is very complex. Instead, a file building file (*.BUI) is assigned containing the required information.

“TRNBUILD has been developed to provide an easy-to-use tool for creating the BUI file. Starting with some basic project data, the user describes each thermal zone. Finally, the desired outputs are selected. All data entered are saved in the so-called building file (*.BUI).” (Klein S.A. et al, 2012, p.9)

2.1.2.1. PROJECT

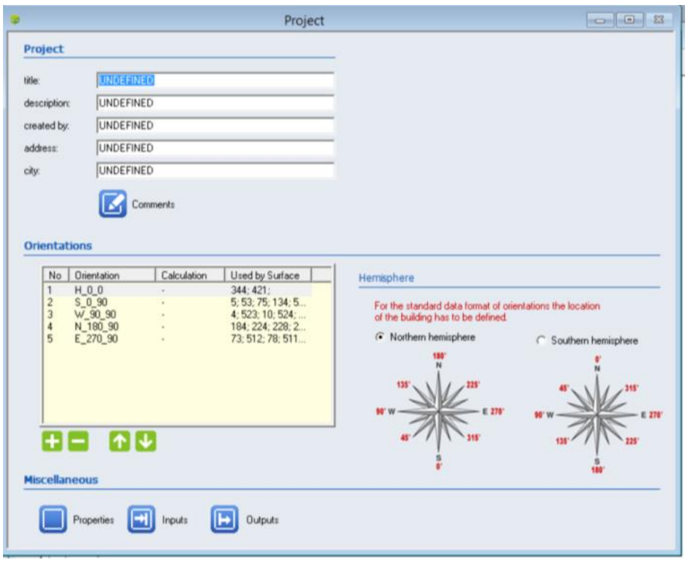


FIGURE 9 - THE PROJECT INITIALIZATION WINDOW

In this window the user has the possibility to enter general information about the project, the orientation of the required walls, basic material properties, view a list of required inputs to type 56 and selects the desired outputs of type 56.

Inputs

The user can link components from TRNSYS Simulation Studio with TRNBuild.

Outputs

The user may adjust the time base of the transfer function if necessary. The default value of 1 is adequate for most cases and 0.5 for light walls.

The user can edit, add or delete outputs of TYPE 56, so-called NTYPES. The results give the simulated results back to the Simulation Studio.

2.1.2.2. THE ZONE WINDOW

This window contains all the information of a thermal zone of the building. All the different zones are listed in the TRNBuild Navigator. In TRNSYS 17 it's possible to have more than one airnode in a thermal zone. They can be moved from one zone to another (multi-airnode zone).

The 4 main parts to describe the data for an airnode are:

a) The required REGIME DATA
b) The WALLS of the airnode
c) The WINDOWS of the airnode
d) Optional equipment data and operating specifications including INFILTRATION, VENTILATION, COOLING, HEATING, GAINS and COMFORT.

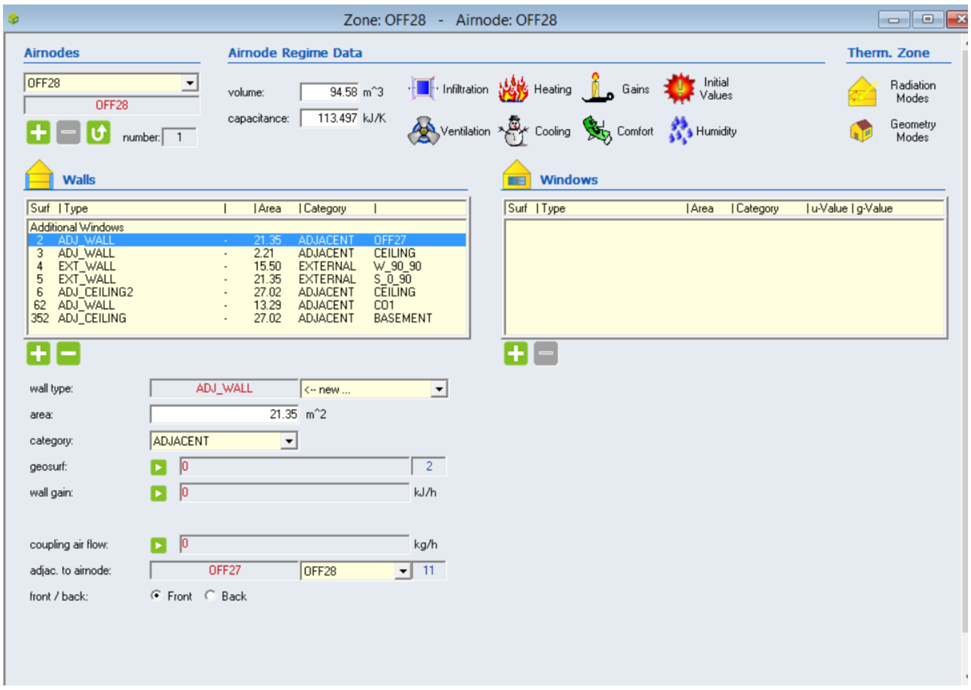


FIGURE 10 - THE ZONE WINDOW

a) The required REGIME DATA

Data	Description	unit
volume	Volume of air within airnode	m^3
Capacitance	Total thermal capacitance of airnode plus that of any mass not considered as wall	kJ/K
Init. Temperature	Initial temperature of the airnode air	°C
Init. Rel. humidity	Initial relative humidity of the airnode air	%
Humidity model	A simple (capacitance) detailed (buffer storage) model	-

TABLE 1 - REGIME DATA

b) The WALLS of the airnode

In this part he user can add, delete or edit the walls of an airnode. It gives an overview off all the different walls. Their properties (wall type, area, category, geosurf, surface number and wall gain) can be defined. With the Wall Type Manager and Layer Type Manager it is possible to create respectively new walls and new materials. The program will calculate the U-value of the wall. It needs the thickness of every layer and its properties (conductivity, capacity and density).

c) The WINDOWS of the airnode

This is very similar to the previous option. The user has the possibility to add more parameters such as the shaded area, the g-value …

d) Optional equipment data and operating specifications

There are 6 optional equipment data or operating specifications that can be defined:

- Infiltration: an airflow into the zone from outside the zone
- Ventilation: an airflow e.g. from heating and/or cooling equipment into the airnode. The user can add, delete or edit a previous defined type.
- Heating: the user can add, delete or edit a previous defined type. For each heating system the set temperature (= maximum heating temperature) has to be added.
- Cooling: the user can add, delete or edit a previous defined type. For each cooling system the set temperature (= minimum heating temperature) has to be added.
- Gains: these are internal gains (persons, electrical devices, etc.)
- Comfort: the user can define the clothing factor, metabolic rate, external work, and the relative air velocity

2.1.2.3. DEFINITION OF THE AIRFLOW NETWORK FOR DETAILED CALCULATION WITH TRNFLOW

When we changed the "type 56 - Multi-Zone Building" to "type 56 - Multi-Zone Building with Airflow (TRNFLow)", we obtained the possibility to add an airflow network in TRNBuild.

2.1.3. TRNFLOW

"TRNFLOW is the integration of the multizone airflow model COMIS (Conjunction of Multizone Infiltration Specialists) into the thermal building module of TRNSYS (Type 56). With TRNFLOW the airflows between airnodes (coupling), from outside into the building (infiltration) and from the ventilation system (ventilation) can be calculated." (Klein S.A. et al, 2012, p.4)

Figure 11 – workingscheme of trnflow shows us that the airflow- and thermal model are linked with each other. In this picture the information flow between the 2 models is represented by one air temperature node and one airflow. The model starts with the input node temperature $\vartheta_{in,1}$. The corresponding airflow $\dot{m}$ is calculated and used in the thermal model. Here the output room temperature $\vartheta_{out,1}$ is calculated. With an iterative solver algorithm, the input temperatures set is found which matches the output temperatures set.

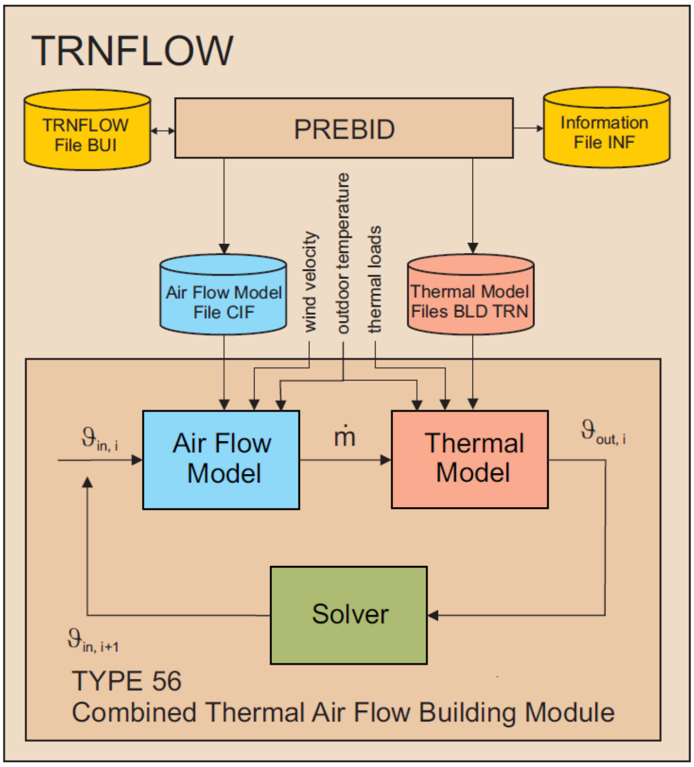


FIGURE 11 – WORKINGSCHEME OF TRNFLOW

An airflow model is based on the network model of the building. The network is a collection of connected air nodes. They are connected with air links.

2.1.3.1. AIRFLOW NODES

There are 4 possible classes of nodes to build an airflow network:

- **Constant pressure nodes**: fixed pressure of the building
- **Thermal airnodes**: corresponds to the airnodes in the thermal model. They have a homogenous temperature and can be represented by a node with single values for temperature, humidity and pressure.
- **Auxiliary nodes**: used to define a ductwork of a ventilation system.
- **External nodes**: represents the wind pressure at the outside of a building. The pressure coefficients (C_p) can be added to the external nodes for several wind directions.

2.1.3.2. AIR LINK

There are 4 different air link types:

- **Crack**: component (small opening/ group of small openings) that uses the power law form to express the leakage characteristic of cracks.
- **Duct**: in a straight duct the flow is defined by the friction loss and the dynamic losses due to fittings.
- **Fan**: used to define its flow characteristic at a certain fan speed.
- **Large vertical opening**: a large opening with a vertical velocity profile. The flow in this model is strictly horizontal.

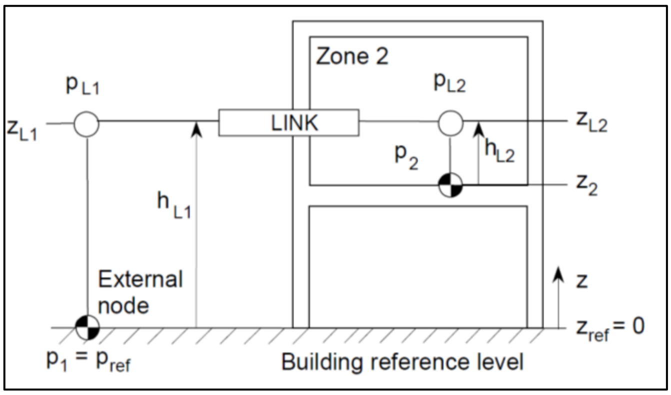


FIGURE 12 – DEFINITION OF AIRNODE AND LINK PRESSURE

2.2. WIND PRESSURE SIMULATION WITH C_P GENERATOR

2.2.1. WIND PRESSURE COEFFICIENTS C_P

The pressure on a building façade is given by:

$P_{total} = P_{atm} + P_w$

Where: P_{total} = pressure on the façade (Pa)

P_{atm} = atmospheric pressure (Pa)

P_w = pressure due to the wind effect (Pa)

The wind-effect is caused by the wind pressure P_w and can be estimated by the equation:

$P_w = 0.5\ \rho\ C_p\ V^2$ (Pa)

Where: ρ = air density (kg/m^3)

C_p = wind pressure coefficient (-)

V = local wind velocity at a specified reference height (m/s)

From the previous equation it appears that the wind pressure coefficient C_p can be understood as a dimensionless description of the dynamic wind pressure at a specific point of the building envelop. It depends on four parameters: the spatial location on the building envelope, the building shape, the surroundings and the wind direction. It can also be influenced by large openings in facades. As wind is a major actuator for natural ventilation, C_p-values are used as input in natural ventilation simulation programs which is in our case TRNSYS.

As it is practically impossible to take into account the full complexity of pressure coefficient variation some analytical programs have been developed over the years. Some methods to evaluate C_p-values are briefly discussed below:

- **Tabulated values** (e.g. AIVC tables) are very easy to use but have a limited range of applications. They give an average value for each building facade, under different assumptions (low-rise building, exposition to wind etc.).

- On the opposite site, the **wind tunnel** technique can give C_p-values under any circumstances. But this requires a lot of efforts and technology. Therefore, it can only be used in the design process of big projects.

- Simulations tools include **Computational Fluid Dynamic** (CFD) calculations, which is also time- consuming and expensive.

- Specific **C_p-generators** (TNO model) have been developed as a trade-off between accuracy and complexity. We used the C_p-generator in our project.

2.2.2. TNO C_P-GENERATOR

A computer program has been developed in the Netherlands to predict the Cp-values on facades and roofs of block-shaped buildings. This program is based on fits of experiments in a wind tunnel:

- on typical block-shaped buildings,
- in different terrain roughness,
- with and without obstacles on systematically varying distances.

The calculation process takes three steps.

Step 1: the pressure at the **centre of the building facades** is calculated as function of the wind direction, the terrain roughness, and the building dimension, but in an **exposed environment** (no local obstacles). Those two assumptions will be dropped in the next steps.

Step 2: a first correction is calculated for **other points** of the facades, as function of ratios of the building dimensions, wind attack angle and terrain roughness.

Step 3: a second correction is calculated for **local obstacles**, according to their size, distance, orientation and azimuth.

The main advantage of this tool is that only a small amount of data is required.

2.2.2.1. THE INPUTS

The input for the C_p Generator is simple. On the website you find a ".txt"-file as an example and they recommend you to work in (a copy of) this file by adjusting the file to your own specific situation. The different inputs are:

- Title
- Wind.Zo
- North arrow
- Obstacles
- C_p positions

To get more details about the input, see Appendix A.

2.2.2.2. THE OUTPUTS

After preparing the input ".txt"-file we let the web application do the calculation in four easy steps where we declare the name and the format of the output file. The web application calculates a C_p-value per wind direction for each defined point. We put these values in a polar graph to see if the calculations meet the reality. The C_p simulation program is based on fits of earlier measured data of on-site tests and systematic performed wind tunnel tests. It still is a simulation program, which means that the results have to be used with great care and at our own risk. The accuracy of the predicted wind pressures for a simple environment is good. This is shown by several validations. However, complex building and obstacle shapes have to be dealt with more care, as well as small passages. That is the reason why we narrowed most of the problem down to basic shapes. Also we neglected the shapes that we didn't reckon to be important in our case.

2.3. THERMAL BRIDGE CALCULATION WITH THERM 7.2

THERM® is a state-of-the-art, Microsoft Windows™-based computer program developed at Lawrence Berkeley National Laboratory (LBNL) for use by building component manufacturers, engineers, educators, students, architects, and others interested in heat transfer. Using THERM, you can model two-dimensional heat-transfer effects in building components such as windows, walls, foundations, roofs, and doors; appliances; and other products where thermal bridges are of concern. THERM's heat-transfer analysis allows you to evaluate a product's energy efficiency and local temperature patterns, which may relate directly to problems with condensation, moisture damage, and structural integrity. THERM's two-dimensional conduction heat-transfer analysis is based on the finite-element method, which can model the complicated geometries of building products. THERM has three basic components:

- **Graphic User Interface:** It allows you to draw a cross section of the product or component for which you are performing thermal calculations.

- **Heat Transfer Analysis:** It includes: an automatic mesh generator to create the elements for the finite-element analysis, a finite-element solver, an optional error estimator and adaptive mesh generator, and an optional view-factor radiation model.

- **Results:** The results from THERM's finite-element analysis of a building component can be viewed in various ways: U-factors, isotherms, colour-flooded isotherms, heat-flux vector plots, colour-flooded lines of constant flux and temperatures (local and average, maximum and minimum).

The features of THERM have been used to calculate the thermal bridges in the building and particularly for the linear thermal transmittance in the 2 dimensional construction knots. With this value the heat flow through the connection of two construction elements is calculated per meter of the thermal bridge and per Kelvin.

3. Case study

The case study involves gathering information and gathering indoor and outdoor air parameters such as temperature and humidity in the secretariat of the school of building engineering at Universitat Politecnica de Valencia. The gathered information can be compared with the output of TRNSYS. To make the calculations with TRNSYS, we considered not only the secretariat but a whole thermal zone. The whole thermal zone was introduced into TRNSYS to make the calculations more veracious, because the secretariat is not an isolated building but a part of the faculty building. The offices and corridors that surround the secretariat have a big influence on the secretariat's inside conditions.

3.1. Location

The secretariat is housed at the Universitat Politecnica de Valencia, Campus de Vera. It is located in building 1B: ETS d'Enginyeria d'Edificacio, this is the red part on the picture below (Figure 13). The campus is on the northern boundary between the city of Valencia and the countryside (Figure 14). It is surrounded by open areas on the north and by buildings up to 20m high in the other directions. The distance to the sea is approximately 2km.

FIGURE 13 - LOCATION OF BUILDING 1B AT UPV

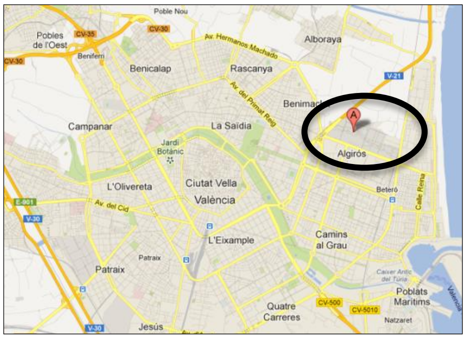


FIGURE 14 - LOCATION UPV IN VALENCIA

The position of the thermal zone in the faculty of building engineering and the secretariat within it can be seen on the picture below in blue and red respectively (Figure 15). This case study only analyses the secretariat area considering a useful area of 204m^2. It’s a large open room in which the administrative staff is working. The small adjacent offices that are also used by the administrative staff are not considered as secretariat area in the model.

In the secretariat we measured the temperature and the humidity of the room and the false ceiling. On the roof of the secretariat we placed the weather station.

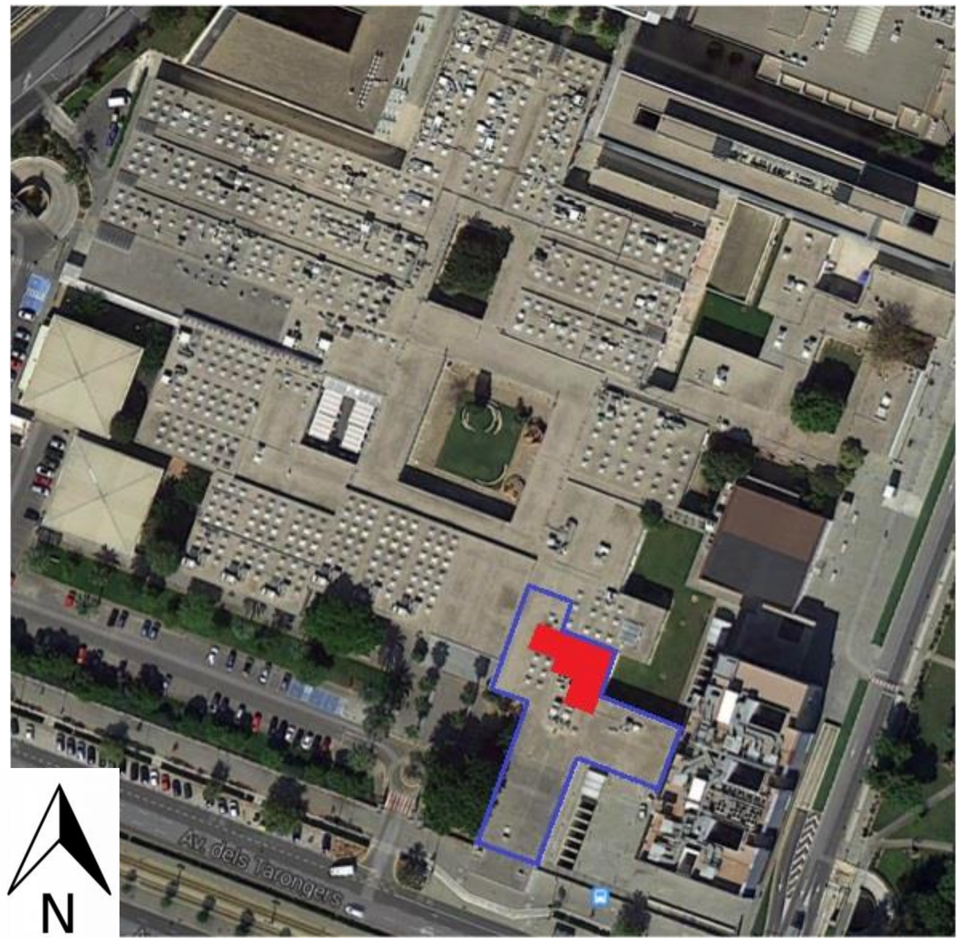


FIGURE 15 - LOCATION OF THE THERMAL ZONE AND THE SECRETARY

3.2. ELEMENTS OF THE THERMAL ENVELOPE

The building has been constructed in a single storey and the floor has an elevation of approximately 0.50m compared to the ground level. Also underneath the floor there is a low ventilated basement with an average height of 0.80m and a false ceiling between the roof and the working area with a height of 1.00m. Different from the working area, these two volumes are not confined by separating elements and are spread over the whole surface of the thermal zone. The working area is 3.50m high. The building is more than 40 years old and was built on a provisional base, therefore a lot of simple prefabricated construction materials were used in the floor, the roof and the walls.

The values of total thermal resistance and overall heat transfer coefficient of the different elements of the building envelope were calculated below.

3.2.1. THE WALLS

The walls are made out of prefabricated panels. The dimensions of the panels are: 1.50m length by 0.50m height. The thickness depends on whether it's an inside wall (7cm) or an outside wall (10cm). The panels are made out of a main layer of wood fibre between 2 layers of cement mortar. The panels don't have any structural function whatsoever they just are used as partitioning walls. A steel frame fulfils the structural balance of the building. Steel U-profiles are used for the frame. As mentioned earlier the building was constructed on a provisional base, so the cost of the building and the way of constructing it had to be as low and as easy as possible. Therefore all the U-profiles have the same section and only differ in length. The steel profiles are welded together per two so they get a rectangular shape and are hollow inside. The composition of the walls and the calculation of the heat transfer coefficients of the two walls are represented below (Figure 16)(Table 2 and Table 3). The steel column is located at the inside of the building. The wall has been recalculated to count in the influence of the steel profiles, this can be seen in section 4.3.2.

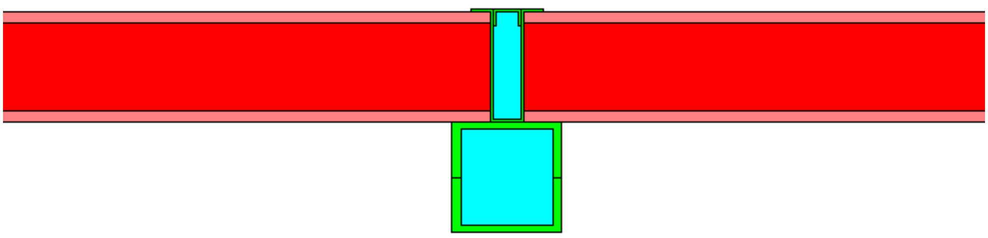


FIGURE 16 - SECTION OF THE VERTICAL WALLS

Outside

Layer	Thickness [m]	Conductivity [W/mK]	Thermal Resistance [m^2K/W]
Exterior			0.04
Cement mortar	0.01	1.30	0.08
Wood fibre	0.08	0.16	0.5
Cement mortar	0.01	1.30	0.08
Interior			0.13
Total Thickness (m)	**0.10**	**R_t (m^2K/W):**	**0.69**

TABLE 2 - TOTAL THERMAL RESISTANCE OF THE OUTSIDE WALL

Inside

Layer	Thickness [m]	Conductivity [W/mK]	Thermal Resistance [m^2K/W]
Interior			0.13
Cement mortar	0.01	1.30	0.08
Wood fibre	0.05	0.16	0.31
Cement mortar	0.01	1.30	0.014
Interior			0.13
Total Thickness (m)	**0.07**	**R_t (m^2K/W):**	**0.63**

TABLE 3 - TOTAL THERMAL RESISTANCE OF THE INSIDE WALL

The overall heat transfer coefficient of the considered enclosures including the thermal resistance of the surfaces is **1.46 W/m^2K** for the outside and **1.59 W/m^2K** for the inside wall. Here we didn't consider the influence of the steel profiles in the calculation of the U-values of the wall nevertheless these have a big influence on the thermal characteristics of the wall. This will be implemented further in this paper when thermal bridges are added.

3.2.2. THE FLOOR

The floor has an elevation of approximately 0.50m compared to the ground level. Underneath the floor slab there is a ventilated low basement of 0.80m high. Because it's a ventilated basement we assumed outside conditions at the bottom of the floor slab. The calculation of the total thermal resistance of the slab is represented below (Table 4).

Layer	Thickness m	Conductivity W/mK	Thermal Resistance m^2K/W
Interior			0.17
Tiles (Terrazo)	0.03	1.30	0.023
Mortar (Mortero)	0.03	0.80	0.038
Sand (Arena)	0.03	2.00	0.015
Reinforced concrete (Hormigón)	0.30	1.43	0.21
Exterior			0.04
Total Thickness (m)	**0.39**	**R_t (m^2K/W):**	**0.50**

TABLE 4 - TOTAL THERMAL RESISTANCE OF THE FLOOR

The overall heat transfer coefficient for the floor including the thermal resistance of the surfaces is **2.02 W/m^2K**.

3.2.3. THE ROOF

The total concrete slab of the roof has a total thickness of 0.30m, which is very thick for a roof that has to be supported by a steel frame. The packed sand ensures the slope of 3cm/m to drain the roof. We took an intermediate value for the thickness of the packed sand layer. The stones on top of the impermeable layer have multiple purposes, as there are the protection of the underlying layers against the influences of the wind and the sun. The calculation of the total thermal resistance of the slab is represented below (Table 5).

Layer	Thickness [m]	Conductivity [W/mK]	Thermal Resistance [m²K/W]
Exterior			0.04
Gravel (Grava)	0.05	2.00	0.025
Bitumen (Bétun)	0.01	0.17	0.059
Packed sand (Arena)	0.15	2.00	0.075
Reinforced concrete (Hormigón armado)	0.15	0.55	0.27
Prefabricated concrete slab (Losa)	0.15	1.15	0.13
Interior			0.10
Total Thickness (m)	**0.51**	**R_t (m²K/W):**	**0.70**

TABLE 5 - TOTAL THERMAL RESISTANCE OF THE ROOF

The overall heat transfer coefficient for the roof including the thermal resistance of the surfaces is **1.42 W/m²K**.

3.2.4. THE FALSE CEILING

Tiles of synthetic fibre are used to compose the false ceiling. The dimensions of the tiles are 150x50x3 cm. The layout of the false ceiling is a web of U-profiles every one and a half metre with in-between the synthetic tiles. The calculation of the total thermal resistance of the slab is represented below (Table 6). The false ceiling is the barrier between the working zone, where we wish to have a comfortable temperature, and the zone with the pipes. This needs to have a good isolating capacity because we only want to heat up the working zone. If this is not the case than the zone that has to be heated up becomes much bigger.

Layer	Thickness [m]	Conductivity [W/mK]	Thermal Resistance [m²K/W]
Interior			0.10
Fibre (Falso techno fibro)	0.03	0.03	1
Interior			0.10
Total Thickness (m)	**0.39**	**R_t (m²K/W):**	**1.20**

TABLE 6 - TOTAL THERMAL RESISTANCE OF THE FALSE CEILING

The overall heat transfer coefficient for the floor including the thermal resistance of the surfaces is **0.83 W/m²K**. This is a reasonable value.

3.2.5. THE WINDOWS

The windows are made out of a stainless steel frame. The glass used in the windows is clear single glass of 6mm thick with a heat transfer coefficient (U-value) of **5.68 W/m²K** and a window solar factor (g-value) of **0.91**. Also worth mentioning are the blinds in front of every window (Figure 17). Every window disregarding the orientation is equipped with permanent adjustable outdoor blinds. The type of shading is Venetian blinds. They allow controlling the light flow that enters the secretariat, protect the windows from external influences and prevent heating of the glass. The blades are made out of PVC and the dimension of each blade is 70x15x1.5 cm. The distance between the blades is 15 cm and each column counts 15 blades. The inclination of each column of blades can be manually adjusted on the outside. The blinds already are very old, a lot of them can't be adjusted anymore because they are rusted.

FIGURE 17 - VENETIAN BLINDS IN FRONT OF WINDOWS

3.2.6. THE SKYLIGHTS

The skylights are composed out of polyester resin reinforced with plates of glass fibre. They are double plated, i.e. two overlapping plates stacked together, forming an isolation room that gives a high thermal insulation. We don't know the U-value of the skylights that are used but if we look for some reference values we find U-values of 2.68 W/m^2K (http://www.walbers.be).

We neglected the skylights in the TRNSYS-file because it was not possible for us to make the connection with the working area because the false ceiling area is in-between. If we wanted to put the skylights into the TRNSYS-file we had to add a zone between every skylight and the working area, which would lead to another 13 extra thermal zones and multiple connections to make. In theory this is perfectly possible but we think that the small extra zones would make the model less precise. This has definitely an effect on our result, because we didn't consider their share in the solar heat gains or in the risk of overheating. But on the other hand the effect of the skylights has to be put in perspective. Firstly there is the heat transfer coefficient of the skylights that is less than half of the value for the windows, which means that they insulate better. Also the skylights are not clear and have a light colour so the solar factor will be small. This is positive in summer when the risk of overheating is higher. Nevertheless we cannot forget this neglect in the interpretation of the results especially if the U-value of the roof is being improved.

3.3. BUILDING CHARACTERISTICS

3.3.1. HEATING, COOLING AND VENTILATION

The school of building engineering is heated, cooled and ventilated with the same installations and same pipe networks. Thereby it's really difficult to estimate these units for the secretariat alone. Also we have no information about the present installations placed on the faculty's roof. Fresh air is conditioned and then blown into the different spaces. The reference value for the ventilation is 1.4 volumes per hour during business hours. The conditioned fresh air is blown into the secretariat by 8 conical diffusers in the false ceiling (Figure 19). The set points for the heating and cooling installation are 20°C and 26°C respectively. These temperatures should ensure comfortable working conditions during business hours. Business hours in the secretariat and practically the whole department are from 8 a.m. to 8 p.m. from Monday until Friday. This schedule is considered the same for all active conditioning devices that are used in the building. By night all the devices are switched off.

The secretariat has 2 extra heating and cooling devices installed on the ceiling and also some electrical heaters are used (Figure 18). These devices ensure that the comfort temperature demands in the secretariat are answered. But it also makes us believe that the conditioning installation leaves much to be desired.

FIGURE 18 - EXTRA HEATING DEVICE

FIGURE 19 - CONICAL CEILING DIFFUSER

3.3.2. INFILTRATION

The airtightness of the thermal envelope leaves much to be desired. A lot of infiltration is expected through the windows and trough every joint and connection. The most important ones are the joints between the steel frame and the prefabricated panels, between two panels, between the wall and the connections with floor and roof and between the panels and the windows.

To know the airtightness of the thermal envelope we performed a BlowerDoor test in one of the offices (see 4.1.3). Unfortunately it was not possible to obtain good results for the airtightness so this is still an unknown factor.

3.3.3. INTERNAL HEAT GAINS

The internal heat gains are composed out of the different loads in the secretariat. There are only heat gains when the faculty is open. The same time schedule as for the heating, cooling and ventilation devices is assumed, which is from Monday to Friday from 8 a.m. until 8 p.m. There are three factors that define the quantity of the heat gains, namely the number of persons, the number of computers or other electronic devices and the number of artificial lights in the room. These units could be empirically determined and we found the following quantities:

- Number of persons: 6
- Number of computers or other electronic devices: 10
- Number of artificial lights: 27 luminaires with each 3 fluorescent lamps
  → 106 fluorescent lamps

4. METHODOLOGY

4.1. THE MEASUREMENTS

4.1.1. WATCHDOG 2000 SERIES WEATHER STATION

The watchdog 2000 series (Figure 20 - Watchdog 2000 series) is a full weather station from Spectrum Technologies. It is completely weather proof and features a 12-bit resolution for higher accuracy.

FIGURE 20 - WATCHDOG 2000 SERIES

The weather station should be located in an open and unobstructed area to ensure accurate measurement. That's why it was installed on the roof above the secretariat (Figure 21 - Watchdog 2000 series on roof). This way an accurate measuring for the temperature, solar irradiance, humidity, rainfall, wind speeds and direction and dew point is obtained on the exact location of the secretariat.

FIGURE 21 - WATCHDOG 2000 SERIES ON ROOF

SpecWare 9 Professional

Specware 9 Professional software is used to transfer data to the computer. We can connect the Watchdog 2000 series with a USB connection.

This software is used to transfer the data and gives you the possibility to obtain a graphical display or in tables (Figure 22 - Data of watchdog 2000 series). In our research we only need tables in Microsoft Excel or saved as a ".txt" file.

VIEWDATA - Kladblok

Bestand Bewerken Opmaak Beeld Help

m2700sSecretariaat

	Temperature (*C)			Temperature (*C)			Temperature (*C)			Temperature (*C)			Temperature (*C)
	*C	*C	*C	*C	*C	wat/m2	%	*C	mm	Deg	km/h	km/h	*C
Date and Time	TMPA	TMPB	TMPC	TMPD	TMPE	SRD	HMD	TMP	RNF	WND	WNG	WNS	DEW
2014-03-10 13:10						1,0	32,4	20,3	0,2	183	3	0	3,1
2014-03-10 13:20						1,0	34,1	19,9	0,0	183	0	0	3,5
2014-03-10 13:30						1,0	35,2	19,7	0,0	183	0	0	3,8
2014-03-10 13:40						1,0	32,9	19,6	0,2	337	1	0	2,7
2014-03-10 13:50						483,0	25,4	20,3	0,0	235	11	4	-0,2
2014-03-10 14:00						307,0	21,3	20,8	0,0	333	4	0	-2,2
2014-03-10 14:10						517,0	18,8	20,6	0,0	201	8	3	-4,0
2014-03-10 14:20						168,0	16,3	20,5	0,0	278	9	4	-6,0
2014-03-10 14:30						98,0	16,3	20,6	0,0	242	8	1	-5,9
2014-03-10 14:40						109,0	18,8	20,8	0,0	204	8	1	-3,8
2014-03-10 14:50						153,0	21,3	20,7	0,0	225	6	0	-2,3

FIGURE 22 - DATA OF WATCHDOG 2000 SERIES

TRNSYS gives the opportunity to implement these files in TRNSYS. Figure 23 shows the window that appears where the preferred weather data can be chosen.

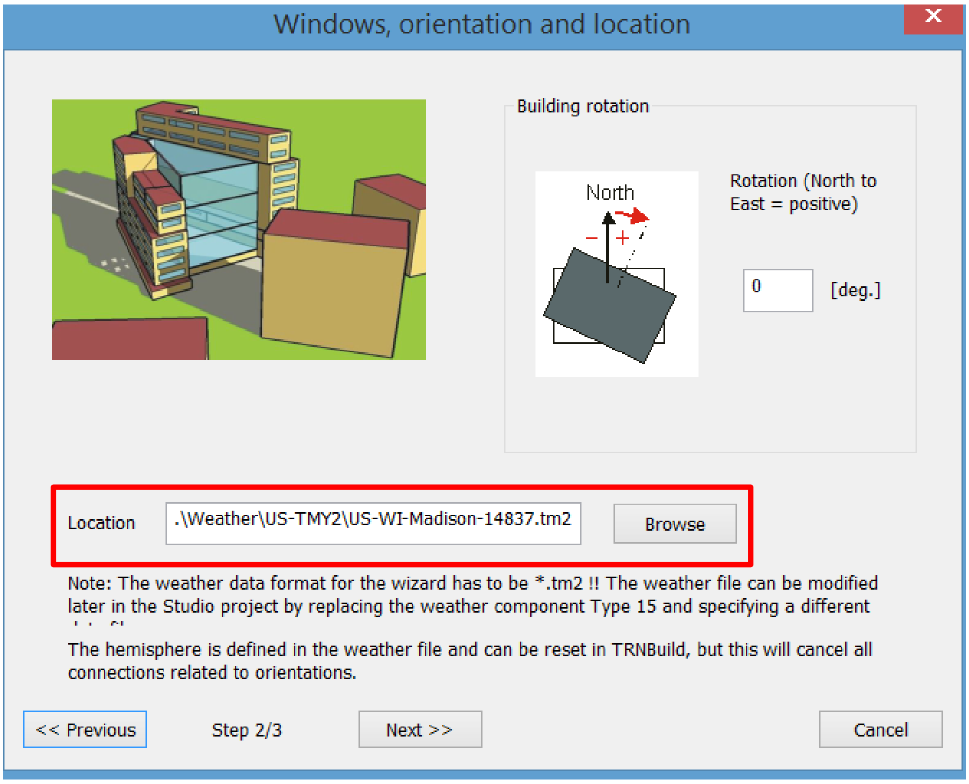


FIGURE 23 - IMPLEMENT OF WEATHER DATA

4.1.2. TESTO 435 – 2

The Testo 435-2 (Figure 25 - Testo 435-2) is a measuring instrument for ambient air conditions, for assessment of Indoor Air Quality and adjusting and testing VAC systems. We used the humidity probe (Figure 24 - Humidity probe). This is used to measure the air moisture and the air temperature. Clear analysis and archiving ensure practical PC documentation. There is the possibility to connect additional temperature and humidity probes (up to 3 probes)(http://www.testo-international.com).

The probe has following specifications: Meas. range -20 to +70 °C / Meas. Range 0 to +100 %RH

FIGURE 25 - TESTO 435-2

FIGURE 24 - HUMIDITY PROBE

Comfort Software X35

We need this software to transfer the obtained data to a computer. It is also possible to analyse separate measurement values and measurement series. This involves in letting the date been showed in a graphic display but we only used it to transform it to tables in Microsoft Excel. The transfer of a Testo instrument to the PC happens via USB. When the instrument is connected, it plots a proper table with all the measurements as shown in following figure. (Instruction Manual Comfort Sorftware x35 Professional)

01 Metin...	Datum	Tijd	%RV	°C
1	27/03/2014	10:46:24	25,8	22,9
2	27/03/2014	10:56:24	25,1	23,1
3	27/03/2014	11:06:24	24,6	23,3
4	27/03/2014	11:16:24	24,6	23,3
5	27/03/2014	11:26:24	24,2	23,4
6	27/03/2014	11:36:24	26,0	23,2
7	27/03/2014	11:46:24	24,1	23,3
8	27/03/2014	11:56:24	24,3	23,5
9	27/03/2014	12:06:24	24,5	23,5
10	27/03/2014	12:16:24	25,2	23,2
11	27/03/2014	12:26:24	24,0	23,5
12	27/03/2014	12:36:24	24,3	23,3
13	27/03/2014	12:46:24	24,3	23,4
14	27/03/2014	12:56:24	26,2	23,2
15	27/03/2014	13:06:24	26,3	23,1
16	27/03/2014	13:16:24	26,1	23,1
17	27/03/2014	13:26:24	25,5	22,9
18	27/03/2014	13:36:24	27,1	22,7
19	27/03/2014	13:46:24	26,7	22,6

FIGURE 26 - DATA OF TESTO 435-2

4.1.3. BLOWERDOOR TEST

4.1.3.1. DEFINITION

Windows, doors or ventilation systems are provided to ventilate buildings. Unfortunately air exchange also occurs trough openings caused by poorly designed thermal bridges in the joints and connections. Uncontrolled air exchange trough the thermal envelope causes higher heating and cooling demand and can cause feelings of discomfort.

The BlowerDoor test is a way to examine uncontrolled air exchange, locate leakages in the thermal envelope and determine the rate of air exchange. By measuring the differential pressure the airtightness of a building is determined. Both under and overpressure of 50 Pa are used.

By performing a BlowerDoor test many disadvantages can be eliminated or prevented, such as: draughts, poor sound insulation and living comfort, high energy consumption, condensation build-up, moisture damage and mould formation.

4.1.3.2. EQUIPMENT FOR THE BLOWERDOOR TEST

DM-2 Series 2 Channel Digital Pressure Gauge (Figure 28)

Retrotec's DM-2, dual channel, digital manometer puts the operator in command of virtually every parameter of interest to the BlowerDoor tester. The DM-2 represents a huge advance in building and envelope diagnostic instrumentation. It calculates:

- The pressure on two channels
- The airflow
- The equivalent leakage area
- The air-changes per hour

The 2000-Serie calibrated fan (Figure 27)
Software Retrotec FanTestic version 5.2.116

FIGURE 28 - DM-2 DIGITAL MANOMETER

FIGURE 27 - THE 2200 SERIE CALIBRATED FAN

4.1.3.3. CONCLUSION OF THE TEST

The BlowerDoor test was performed in a smaller office in the close surrounding of the secretariat and has the same structural composition as the secretariat. The test setup was done and the fan was powered to put the office in an under pressure. The pressure wasn't decreased at all in the building, so it became clear that there was a big problem. The built up pressure by the fan was built up so low that it couldn't be just some small air leak. We tried to make the volume much smaller by closing inside doors, but the pressure didn't change a lot. We had to conclude that the bad airtightness of the office is caused by the air coming through the false ceiling. As we mentioned before the space between the false ceiling and the roof slab of the whole thermal zone is connected with each other. So in fact, all the separate offices are connected with each other, because the false ceiling is not really a separating construction. This is exactly why we chose this office to perform the test, and not the secretariat, because it was semidetached from the other offices and was assumed to be a closed entity. Unfortunately it became clear during the test that this was definitely not the case. We had to conclude that it is impossible to perform a BlowerDoor test in this building, so that we are not able to obtain a value for the airtightness of the building.

The result of the failure of this test is that there is another unknown parameter about the building. The airtightness of the building has a very big influence on the energy demand of the building. Because this parameter is unknown, we can't compare it with the results of the wind pressure coefficients to validate the model.

4.2. CALCULATION OF THE CP-VALUES WITH CP GENERATOR

The ground plan of the department of the school of building management has a difficult shape to define the obstacles. Therefore we simplified the plan in rectangular shaped blocks and only considered the parts which are in directly surrounding of the thermal zone which the secretariat is part of. These parts have the biggest influence on the magnitude of the C_p-values. Also when there are too many separate obstacles close to each other, the result of the C_p prediction only is reduced. We divided the energy zone into three parts and made a separate C_p-value calculation for each part. A visualization of the simplified model of the building can be seen below (Figure 29).

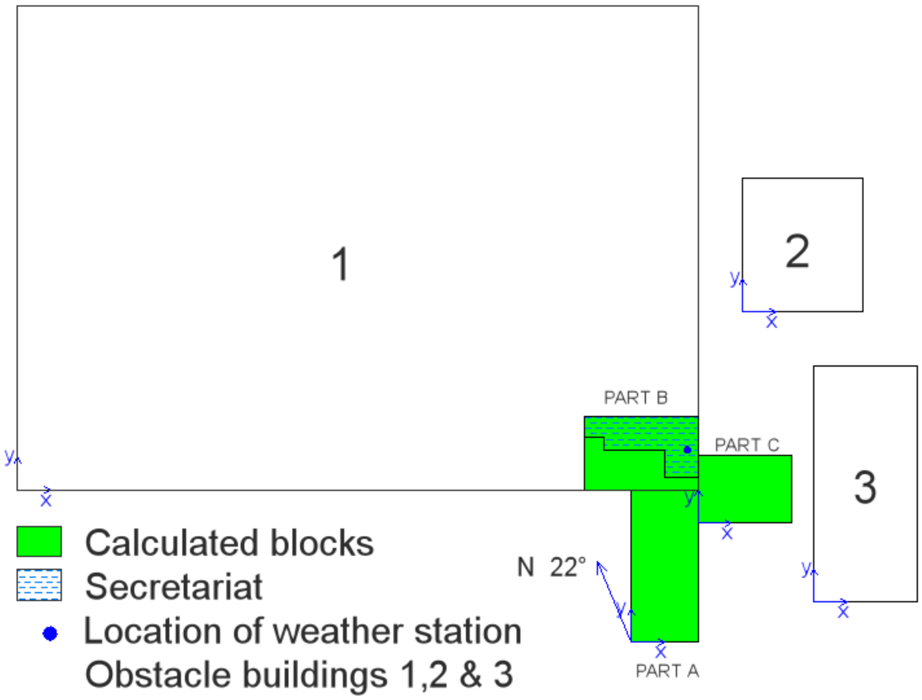


FIGURE 29 - VISUALIZATION OF THE C_P MODEL

To visualize the results we made a polar graph per part and per façade. Thus we can easily see if the C_p-values meet the real situation. Also a visualization of the location of the points where the C_p-values were calculated per façade is added (Figures 30,31 and 32). The points are numbered according to the façade its local coordinate system. Some similarities can be perceived on each graph. For example the magnitude and the sign of each C_p-value depend on the orientation of the façade and the presence of an obstacle in the direct surrounding of the façade. The north arrow has an angle of 22° counter clockwise. This angle has not been taken into account in the C_p generator's output.

The inputs and outputs of the C_p Generator are added in Appendix A.

4.2.1. RESULTS OF PART A

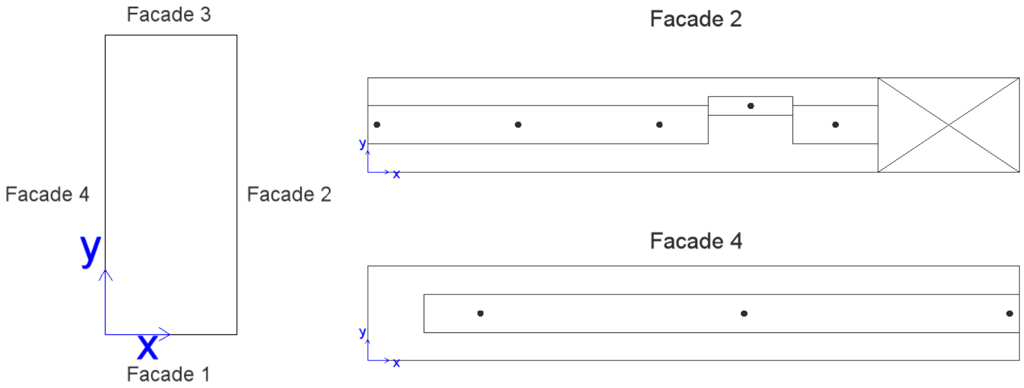
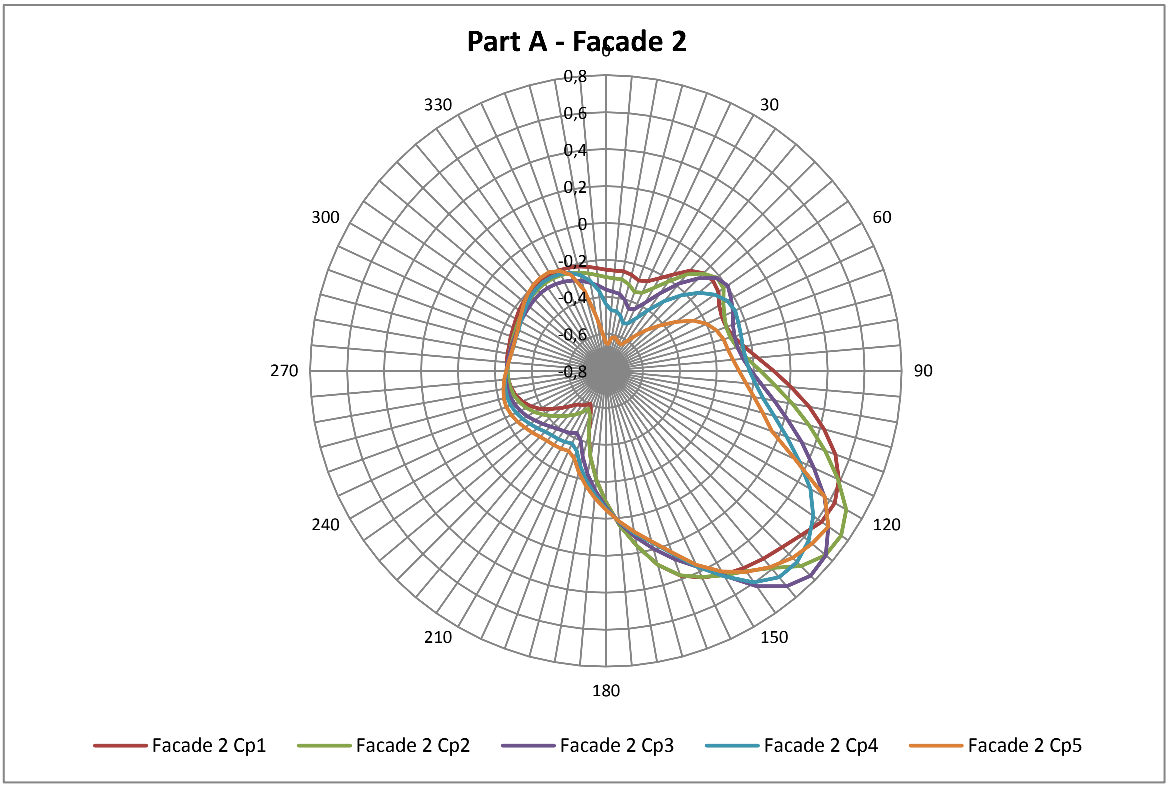


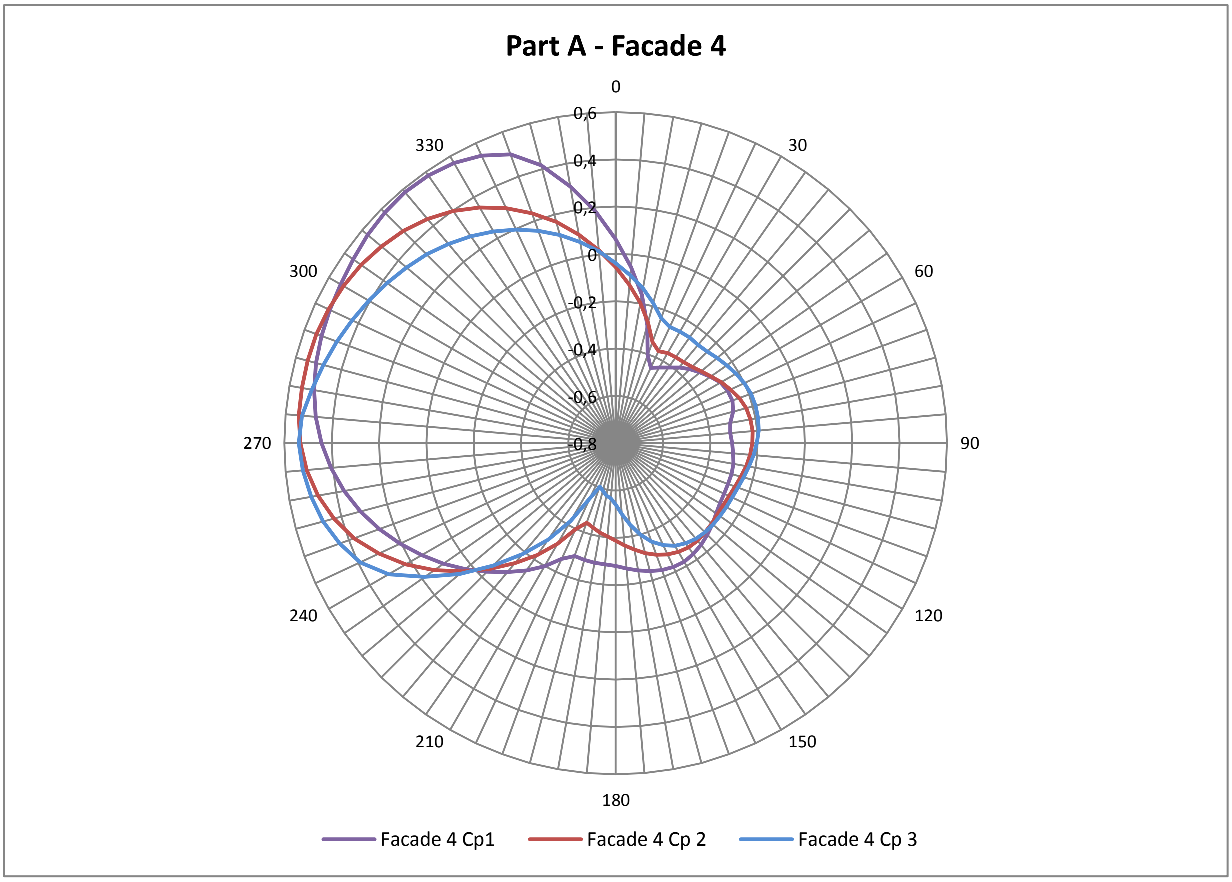
FIGURE 30 - LOCATION OF THE PRESSURE POINTS IN PART A

On Graph 1 the result of the C_p-values for façade 2 can be seen. It is oriented to the East. The C_p points reach their maximum value between 120 and 150 degrees. In addition only between 80° and 180° there are positive values, which mean an overpressure on the wall. Everywhere else there are negative values or an under pressure. An extreme negative value is reached by curves 1 and 2 on 210° and by 4 and 5 between 10° and 30°. In the middle of the façade the highest value is reached.

Graph 2 shows the results of the C_p-values for façade 4. The façade has similar conditions but 180° turned. The curves reach their maximum value between 260° and 330°. These values are wider spread possibly because of the absence of an obstacle in this direction. Also the maximum values are smaller.



GRAPH 1 - C_P VALUES ON FAÇADE 2 IN PART A



GRAPH 2 - C_P VALUES ON FAÇADE 4 IN PART A

4.2.2. Results of zone B

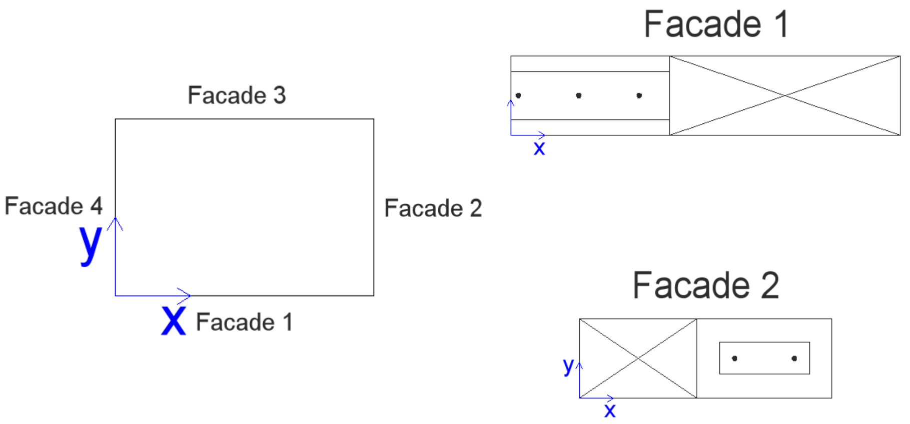
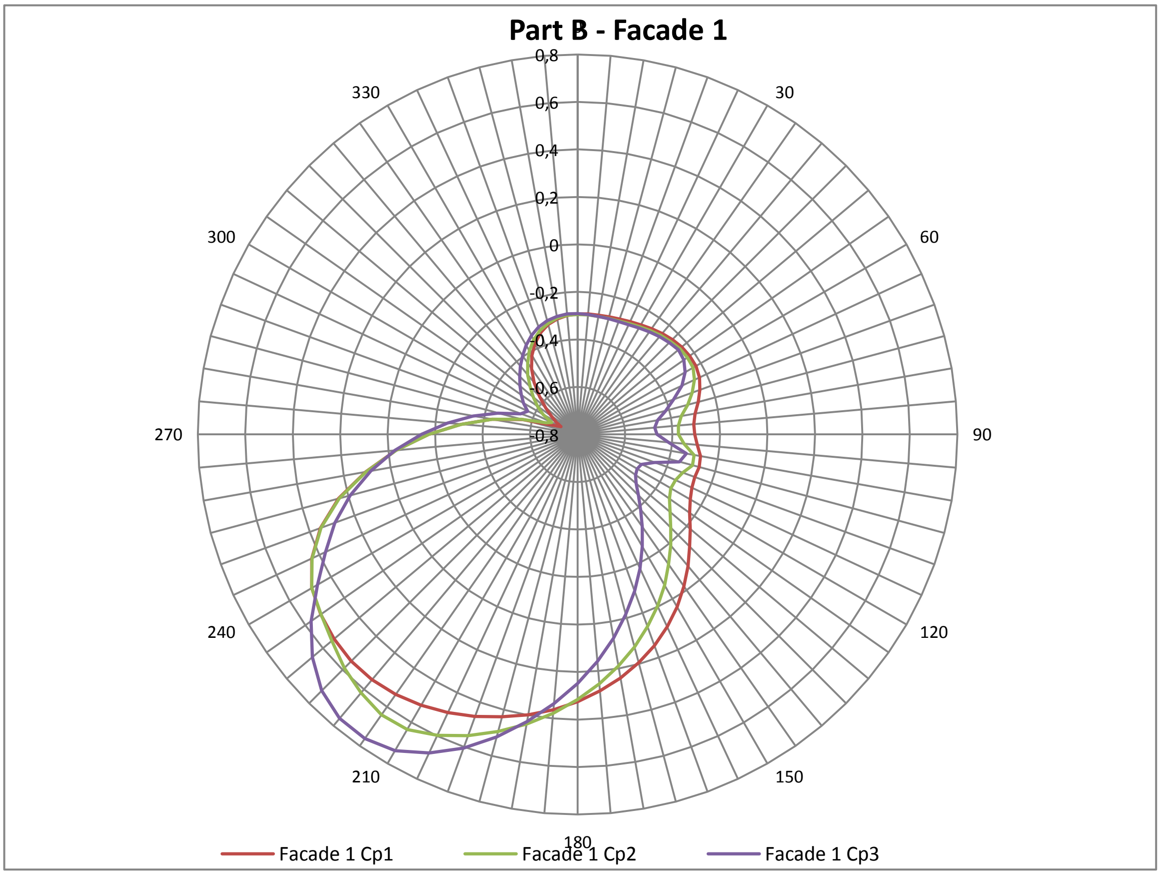
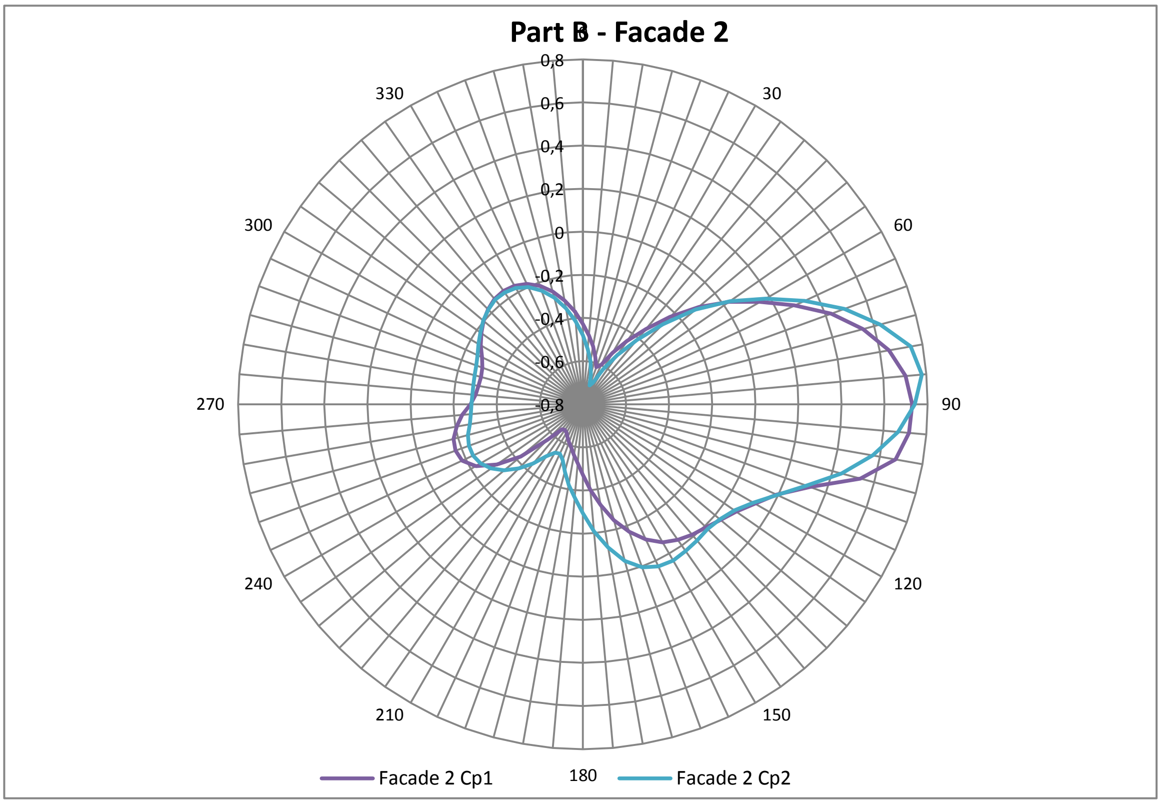


FIGURE 31 – LOCATION OF C_P-POINTS IN PART B



GRAPH 3 - C_P VALUES ON FAÇADE 1 IN PART B



GRAPH 4 - C_P VALUES ON FAÇADE 2 IN PART B

4.2.3. Results of zone C

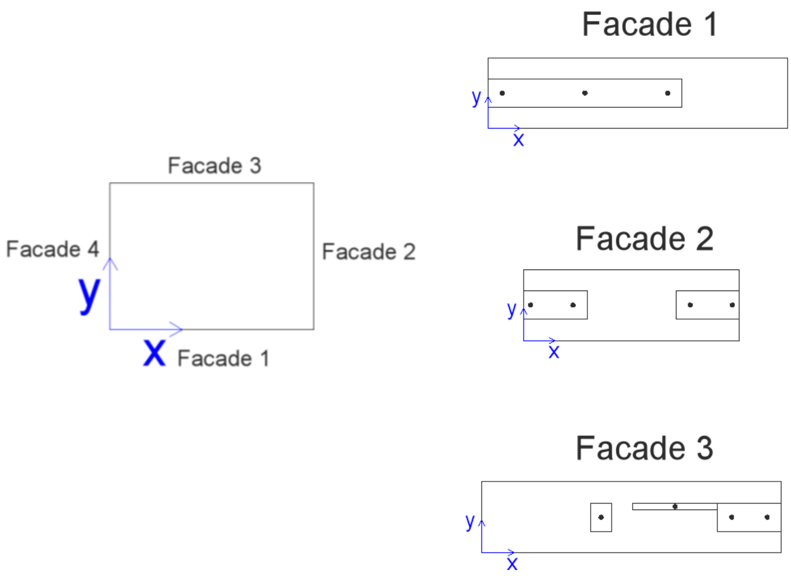
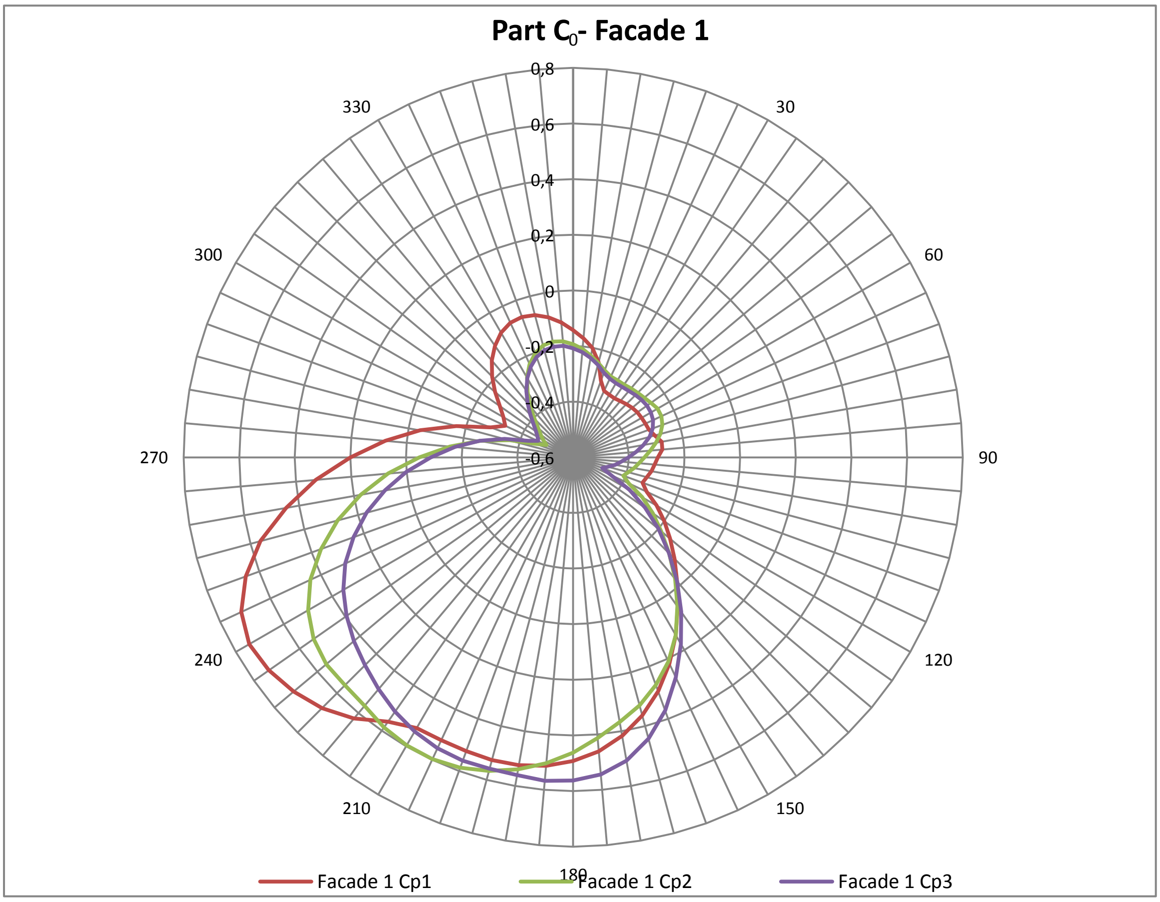
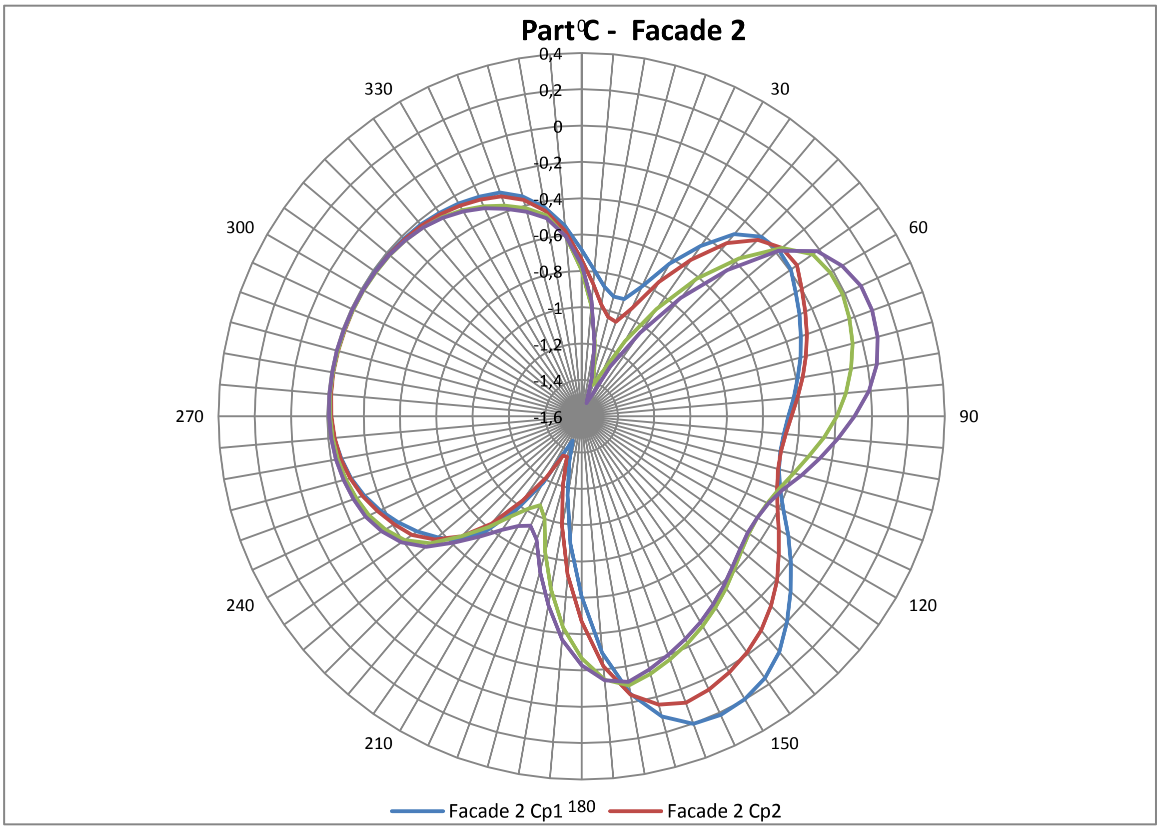


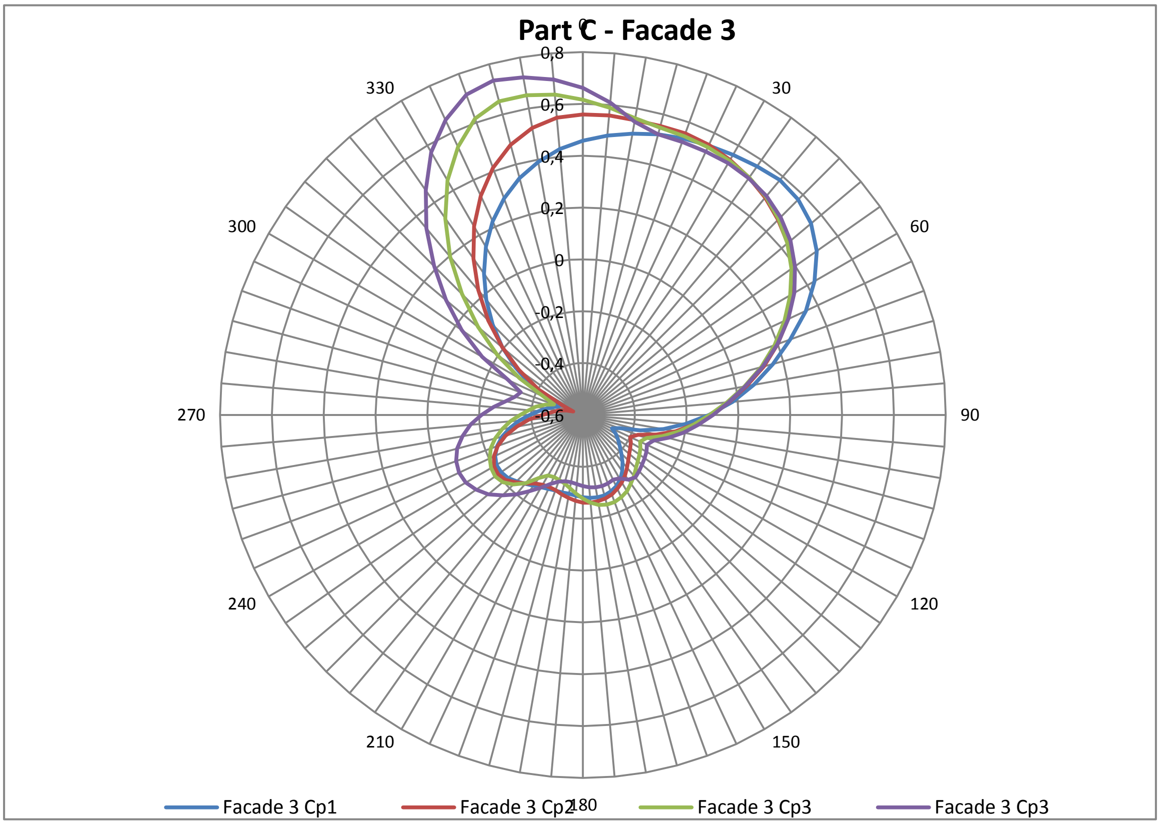
FIGURE 32 - LOCATION OF C_P-POINTS IN PART C



GRAPH 5 - - C_P VALUES ON FAÇADE 1 IN PART C



GRAPH 6 - C_P VALUES ON FAÇADE 2 IN PART C



GRAPH 7 - C_P VALUES ON FAÇADE 3 IN PART C

4.3. THERMAL BRIDGE CALCULATION WITH THERM 7.2

We used the features of THERM to calculate the linear thermal transmittance values, Ψ, of the thermal bridges, which are then introduced into TRNSYS. The three kinds of outer slabs have the same composition everywhere in the building. We calculated three thermal bridges namely the connections of the vertical outer wall with both the floor and the roof slabs and the vertical wall with the steel profiles.

4.3.1. CALCULATION METHODOLOGY

THERM was used to calculate the 2 dimensional U-values of the thermal bridges but also the U-values of the separate slabs were calculated. The different steps for introducing and a thermal bridge into THERM and calculating the 2 dimensional U-value are:

- Drawing of the thermal bridge with a CAD based software program.
- Introduction of the CAD-file in THERM as an “Underlay”. Then the contours can be overdrawn with the polygon drawing tools of THERM.
- Putting the “Gravity arrow” in the right direction. Through this the program knows the direction and the sense of the heat flow.
- Definition of the different U-values that have to be calculated. For every thermal bridge we calculated three U-values, namely one for every slab separately and for the 2D U-value.
- Definition of the materials in “Material definitions”. Here the name, colour and conductivity (λ) value of each material are introduced (Figure 33) and allocated to the right polygon.

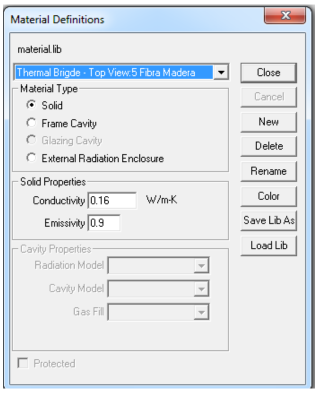


FIGURE 33 - MATERIAL DEFINITIONS IN THERM

- Definition of the “Boundary Conditions” of the outer borders of the thermal bridge drawing (Figure 34). The boundary conditions ensure that defined borders surround the thermal bridge. Three different boundary conditions were used, namely:
  - “Inside conditions” have a temperature of **20°C** and are allocated to all the inside borders of the thermal bride.
  - “Outside Conditions” have a temperature of **10°C** and are allocated to all the outside borders.
  - “Adiabatic” conditions are used to connect the outside and inside conditions and to close the chain of boundary conditions.

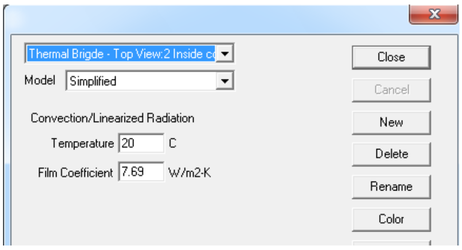


FIGURE 34 - DEFINING BOUNDARY CONDITIONS IN THERM

- Connection of the boundary conditions to the different U-values that need to be calculated with "Boundary Condition Type" (Figure 35). This step makes the program clear over which distance the thermal bridge has to calculated by allocating a boundary condition to a specific U-value calculation.

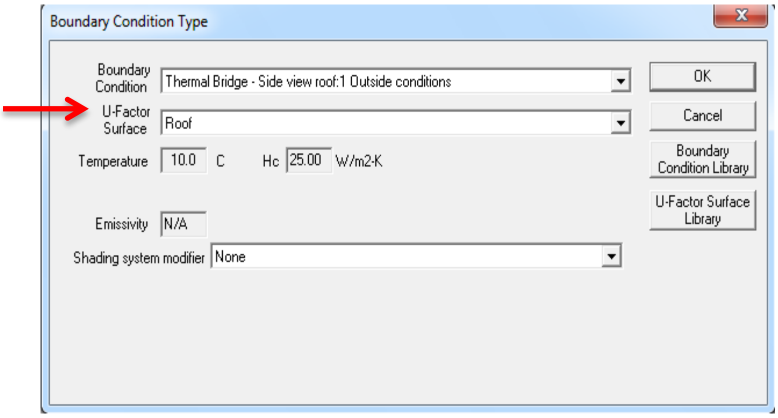


FIGURE 35 - BOUNDARY CONDITION TYPE IN THERM

- Calculation of the U-values. Depending on the orientation of the desire U-value the length over which the U-value is calculated can be changed to "Total Length", "Projected X" or "Projected Y" (Figure 36).

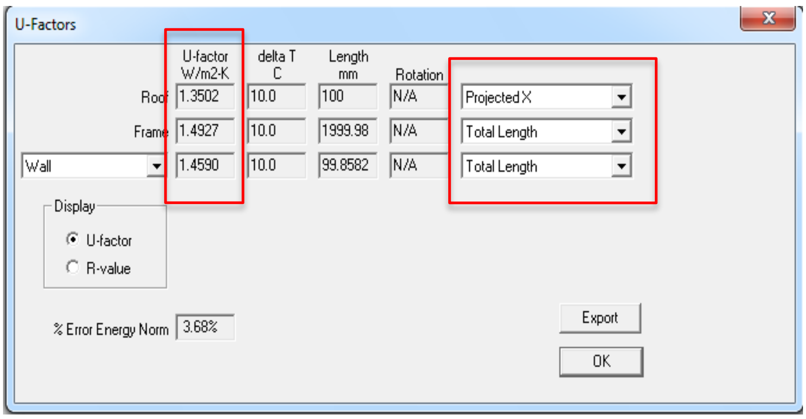


FIGURE 36 - CALCULATED U-VALUES IN THERM

With the calculated 2 dimensional U-values, the linear thermal transmittance construction knots can be calculated for the connections between the outer wall en both the floor and the roof. The general formula for the linear thermal transmittance, Ψ [W/mK], of a linear thermal bridge separating the two environments being considered in defined as (Werkgroep PaThB2010, 2009, p.22) :

$$\Psi = \frac{\Phi_{2D} - \Phi_{1D}}{L\ (\theta_i - \theta_e)}\ [\frac{W}{m\ K}]$$

With:

- **Φ_{2D}:** The total heat flux that is lost from the indoor environment, calculated on basis of a two-dimensional, validated numerical calculation [W]. This is the heat flux that we want to calculate with THERM.

- **Φ_{1D}:** The total heat flux that is lost from the indoor environment, calculated according to the reference. The reference calculation of the heat transport is characterized by the U-values U_i and surfaces A_i of the partitions of the losing surface, which occur in the construction node. The following applies: $\Phi_{1D} = \sum U_i A_i (\theta_i - \theta_e)\ [W]$.

- **L:** The length over which the construction node occurs.

- **$(\theta_i - \theta_e)$:** The temperature difference between the indoor and outdoor environment.

This formula can be simplified to become a value for the linear thermal transmittance per meter:

$$\Psi = U_t L_t - \sum U_i L_i\ \ [\frac{W}{mK}]$$

With

- **U_t:** Is the total U-value of the 2 dimensional construction node that is calculated by THERM.
- **L_t:** The total length of the 2 dimensional construction node over which the total U-value is calculated.
- **$\sum U_i L_i$:** The product of the U-value and length of each partitions of the losing surface, which occur in the construction node.

We also checked the risk of condensation and therefore mold growth on the inner surface of the thermal bridges. The risk of mold formation compares the temperature drop across the building fabric, with the total temperature drop between the inside and outside air. It is a critical calculation, as the consequences of condensation and mould growth are likely to be more serious for building occupiers than any local heat loss. If low internal surface temperatures in the area of a thermal bridge are below the dew point of the air, condensation is almost certain to form. This in turn is likely to result in structural integrity problems with absorbent materials such as insulation products or plasterboard and of even greater concern, the occurrence of mould growth. This risk is expressed by the temperature factor f_{Rsi} and has to be greater than a minimum value, which depends on the purpose of the considered building. For office buildings the temperature factor has to be greater than 0.5 (http://www.schoeck.co.uk/en_gb/press/the-surface-temperature-factor-frsi--434). The formula for the temperature factor is:

$$f_{Rsi} = \frac{\theta_{s,i,min} - \theta_e}{\theta_i - \theta_e}$$

With:

- $\theta_{s,i,min}$: The minimum inside temperature of the evaluated surface. The minimum temperature in this case is the temperature in winter, this way the worst situation is considered.
- θ_e: The outside temperature (10°C)
- θ_i: The inside temperature (20°C)

4.3.2. THE OUTER WALL WITH STEEL PROFILE

The section of the outside wall and the steel profiles can be seen on Figure 37. The connection between the prefabricated wall panels and the steel profiles is clearly a thermal bridge. Steel has a really bad thermal conductivity value of 50 W/mK and the wood fibre layer, which in this building is the thermal insulator, is interrupted. The steel profiles are hollow so inside there is stationary air, which is a good insulator but the steel offsets this effect. The result of the calculation is presented with infrared temperatures, which can be seen on Figure 38. The temperatures in the prefabricated panels evolve gradually, but the closer to the steel profiles the more the colours are deflected. The inside surface temperatures of the steel profile is much higher than the one of the panels. Also conversely the outside surface steel temperature is much higher than the panel's temperature. This makes clear that the thermal steel profile inertia is much smaller and therefore a poorly designed thermal bridge. This thermal bridge was calculated over a total length of 1,5m because that's the centre-to-centre distance of the profiles. Therefore the result of THERM could be introduced into TRNSYS as the U-value of the outer wall per meter. The overall heat transfer coefficient of this wall is **1.946 W/m²K**.

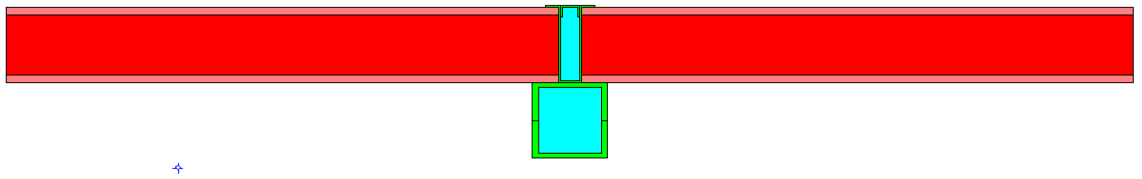


FIGURE 37 – SECTION OF THE THERMAL BRIDE IN THE OUTER WALL

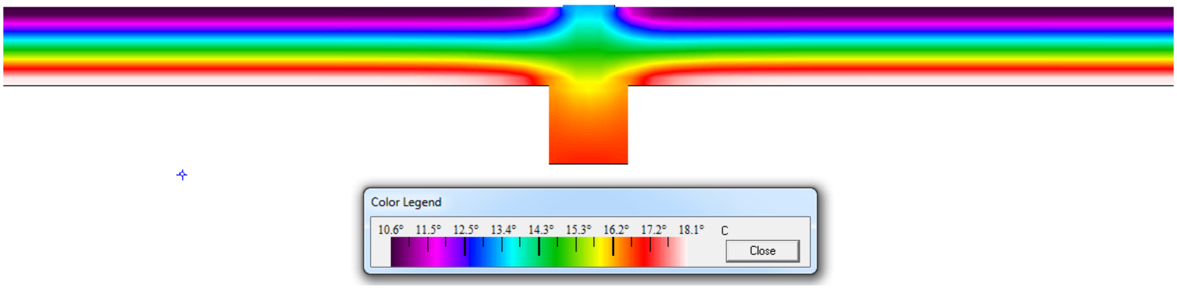


FIGURE 38 – INFRARED TEMPERATURES IN OUTER WALL BY THERM

The lowest inside surface temperature is on the steel profile and amounts **16,5°C.** The temperature factor is:

$$f_{Rsi} = \frac{\theta_{s,i,min} - \theta_e}{\theta_i - \theta_e} = \frac{16.5\ - 10}{20\ - 10} = 0.65\ \geq 0.5$$

We can conclude that there is no big risk of mold growth on the vertical walls nevertheless this is a poorly designed thermal bridge.

4.3.3. THE ROOF-WALL CONNECTION

The section of the connection between the roof slab and the wall can be seen on Figure 39. The result of the calculation is presented with infrared temperatures, which can be seen on Figure 40. The temperatures in the prefabricated panels as well as in the roof slab evolve gradually, but the closer to the corner the more the colours are deflected. The inside corner temperature is much higher than on the other inside surfaces. The calculated U-values and the lengths to make the linear thermal transmittance calculation are represented in Table 7 and Figure 40 respectively. The Ψ-value amounts:

$$\Psi = U_t L_t - \sum U_i L_i = 1.493 * 2 - 1.46 * 1 - 1.42 * 1 = \mathbf{0.106}\ \frac{\boldsymbol{W}}{\boldsymbol{mK}}$$

This makes clear that this thermal bridge is not that poorly designed, knowing that to be a good design the Ψ-value should be around 0 W/mK. For the connection the Ψ-value is still acceptable, but there may not be forgotten that the U-values for the two construction entities are quite high.

The lowest inside surface temperature can be found in the corner and amounts **17.3°C.** The temperature factor is:

$$f_{Rsi} = \frac{\theta_{s,i,min} - \theta_e}{\theta_i - \theta_e} = \frac{17.3\ - 10}{20\ - 10} = 0.73\ \geq 0.5$$

We can conclude that there is no big risk of mold growth on the vertical walls nevertheless this is a poorly designed thermal bridge.

	U-value [W/m²K]
Outer wall	1.46
Roof slab	1.42
Thermal bridge (2D)	1.493

TABLE 7 - U-VALUES ROOF-WALL CONNECTION BY THERM

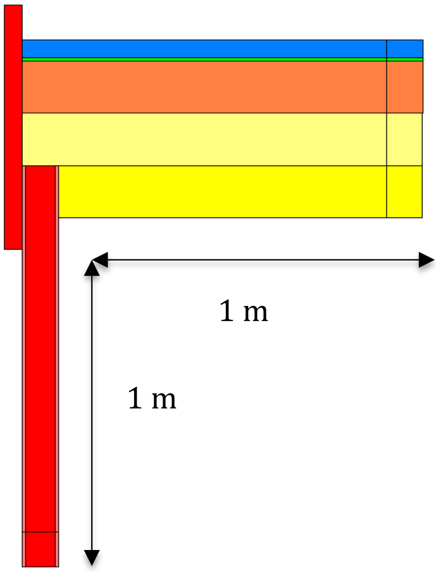


FIGURE 39 – SECTION ROOF-WALL CONNECTION THERMAL BRIDGE

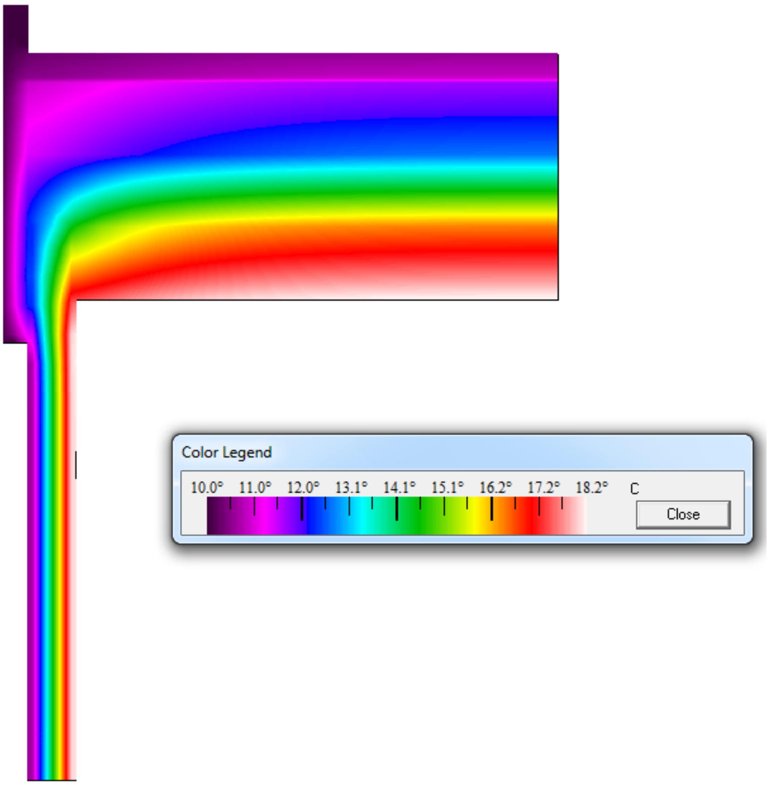


FIGURE 40 – INFRARED TEMPERATURES IN ROOF-WALL CONNECTION BY THERM

4.3.4. THE FLOOR-WALL CONNECTION

The section of the connection between the floor slab and the wall can be seen on Figure 41. The result of the calculation is presented with infrared temperatures, which can be seen on Figure 42. The temperatures in the prefabricated panels as well as in the floor slab evolve gradually, but the closer to the corner the more the colours are deflected. The inside corner temperature is much higher than on the other inside surfaces. The calculated U-values and the lengths to make the linear thermal transmittance calculation are represented in Table 8 and Figure 41 respectively. The Ψ-value amounts:

$$\Psi = U_t L_t - \sum U_i L_i = 1.959 * 2 - 1.46 * 1 - 2.02 * 1 = \mathbf{0.438} \ \frac{\boldsymbol{W}}{\boldsymbol{mK}}$$

This makes clear that this thermal bridge is really poorly designed, knowing that to be a good design the Ψ-value should to be around 0.05 W/mK. This is mainly because the floor has a high U-value with no insulating layers of any kind. This leads to a high 2 dimensional U-value and therefor a poorly designed thermal bridge.

The lowest inside surface temperature is on the steel profile and amounts **16°C.** The temperature factor is:

$$f_{Rsi} = \frac{\theta_{s,i,min} - \theta_e}{\theta_i - \theta_e} = \frac{16 \ - 10}{20 \ - 10} = 0.60 \ \geq 0.5$$

We can conclude that there is no big risk of mold growth on the vertical walls nevertheless this is a poorly designed thermal bridge.

	U-value [W/m²K]
Outer wall	1.46
Floor slab	2.02
Thermal bridge (2D)	1.959

TABLE 8 - U-VALUES FLOOR-WALL CONNECTION BY THERM

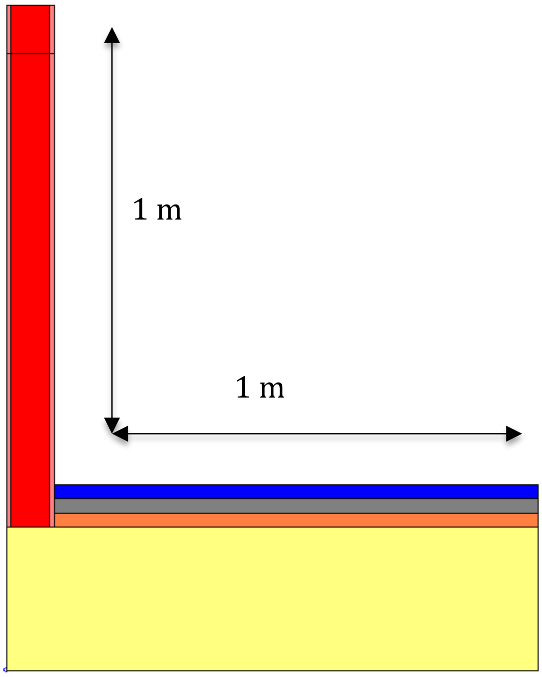


FIGURE 41 - SECTION FLOOR-WALL CONNECTION THERMAL BRIDGE

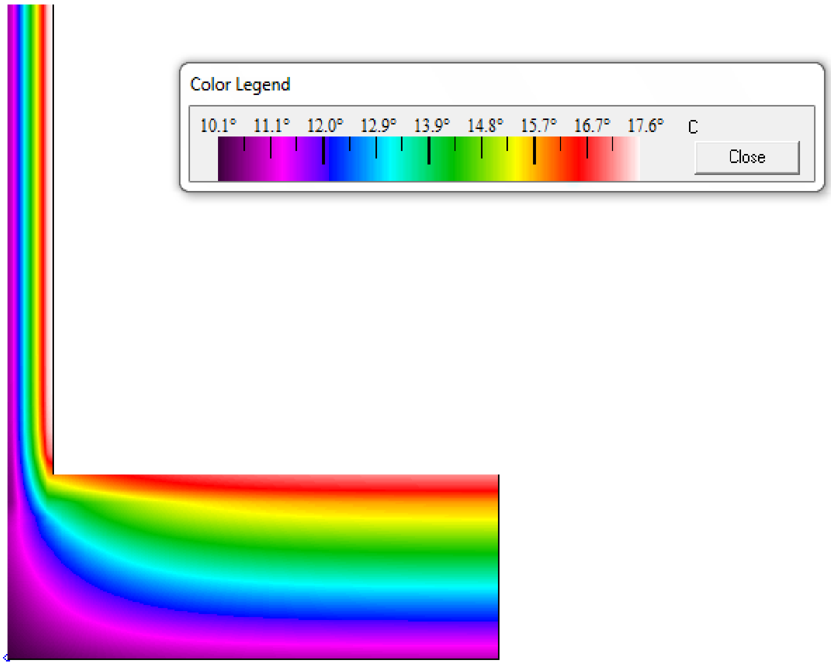


FIGURE 42 – INFRARED TEMPERATURES IN FLOOR-WALL CONNECTION BY THERM

4.4. TRNSYS-FILE

4.4.1. MODEL IN SKETCH-UP

Google Sketch-Up is a computer program that is used to draw buildings in 3D and there is a connection with TRNSYS to create a multi-zone building. There is a TRNSYS3d plugin where the file can be saved as an ".idf" file (Identification file), which can be implemented in TRNSYS. Another way is by inserting the volumes by putting all the different surfaces off each room directly into TRNSYS. Sketch-Up makes this easier and gives a visual control. The ".idf"-file is the file where the dimensions are saved.

So first the building was drawn. Normally each room has 3 different storeys: basement, the room and the ceiling. For each volume, a new thermal area had to be made. We had to define the surfaces which are in contact with a different thermal zone. So if there is a wall, then the surfaces have to be defined in both directions.

FIGURE 43 - TOOLBAR FOR TRNSYS3D IN SKETCH-UP

Some problems occurred when we tried to load the file into TRNSYS 17. That's why only on storey was drawn. Later the basement and ceiling was inserted manually in TRNSBuild.

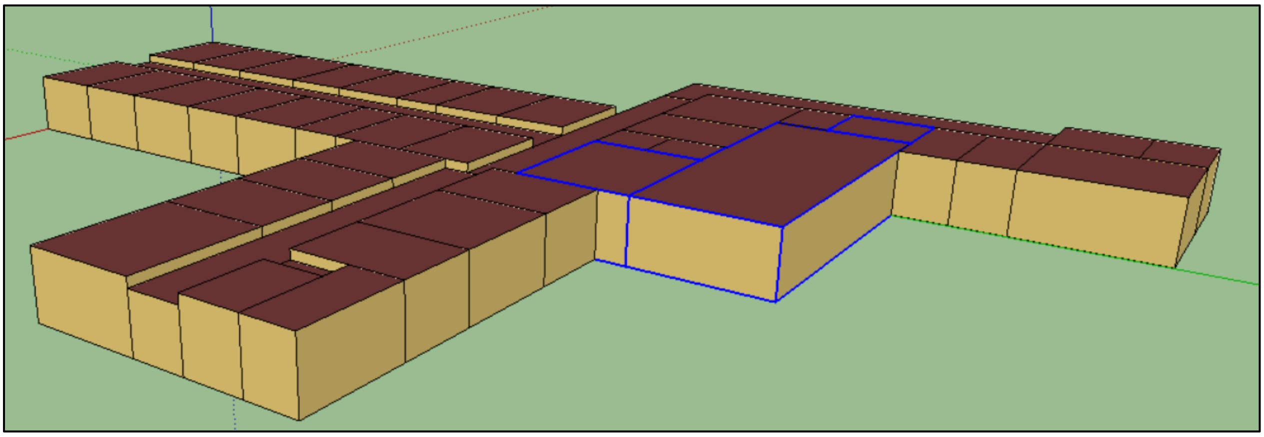


FIGURE 44 - RESULT IN GOOGLE SKETCH-UP WITH THE SECRETARIAT IN BLUE

In the secretariat thermal zone there are in fact no internal walls, but when the ".idf"-file has to be introduced in TRNSYS, we have to divide the secretariat into different thermal zones. A Trnsys3d thermal zone must be convex. This means that the connecting line between every point in the zone to another point in the zone can't cross any surface of the zone (Figure 45).

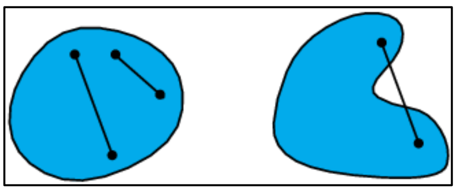


FIGURE 45 - CONVEX AND CONCAVE SURFACE

4.4.2. INSERTING THE MODEL IN TRNSYS

When this ".idf" file is created, a new 3D Building Project (Multizone) – type 56 can be created.

"This component models the thermal behaviour of a building having multiple thermal zones. The building description is read by this component from a set of external files having the extensions *.bui, *.bld, and *.trn. The files can be generated based on user supplied information by running the pre-processor program called TRNBuild." (KLEIN S.A. et al, 2012)

When the specific weatherdata and ".idf" file is selected, TRNSYS will make a standard system off types which are combined with several links. This system can be changed by using the types and creating equations .

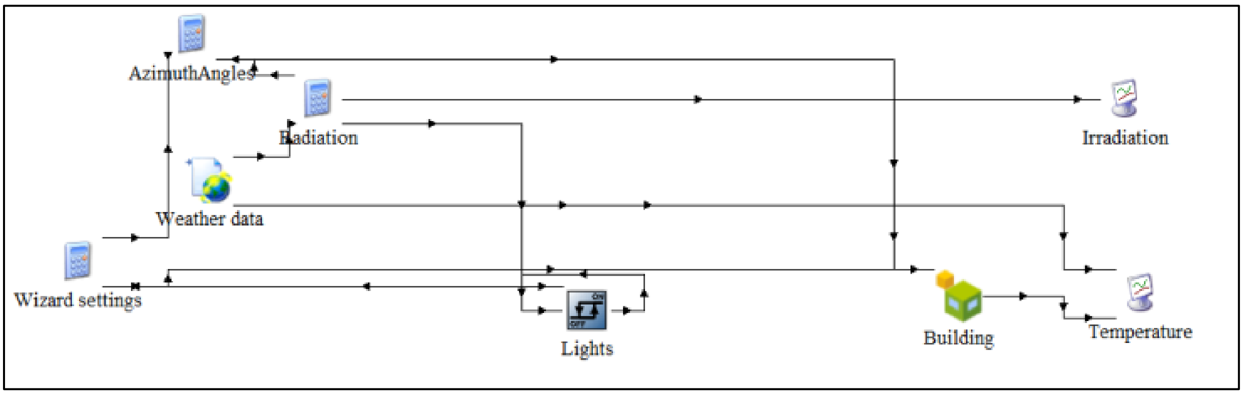


FIGURE 46 - SYSTEM OF TYPES AND LINKS FOR A MULTIZONE BUILDING

Tthe Multizone building (Loads and Structures)had to be replaced into a multizone building with AirFlow (TRNFlow). This will give the possibility to know the heat flow in the different room/layers and windows.

The type for the weather data has to be changed as well. It I changed into type 99. "This component serves the main purpose of reading weather data at regular time intervals from a data file, converting it to a desired system of units and processing the solar radiation data to obtain tilted surface radiation and angle of incidence for an arbitrary number of surfaces." (Klein S.A. et al, 2012, p.101)

The weather data that we obtained will be supplemented with the weather data of another weather station. They are joined together in a txt-file and has to be saved as an ".99" file.

4.4.3. ADJUSTMENTS IN TRNBUILD

By right-clicking on the symbol of the TRNBuild file and choosing "Edit Building", the building can be adjusted. Now the walls (thickness and materials), rooms, windows ... can be defined. The ceiling and basement are defined in TRNBuild. But first the Geometry Modes of every volume had to be changed to "manual (without 3D data)" (Figure 47).

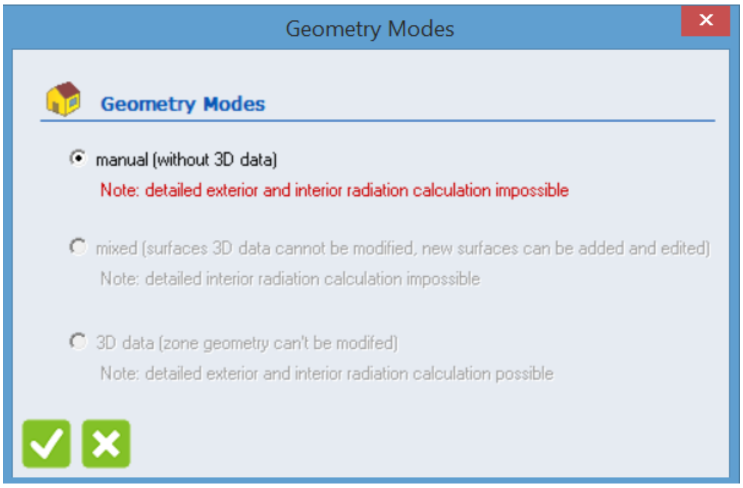


FIGURE 47 – GEOMETRY MODES

4.4.3.3. WALLS

First the different kinds of materials had to be defined in the Layer Type Manager (Figure 48). For each material we need:

- Conductivity [kJ/hmK]
- Capacity [kJ/kgK]
- Density [kg/m^3]

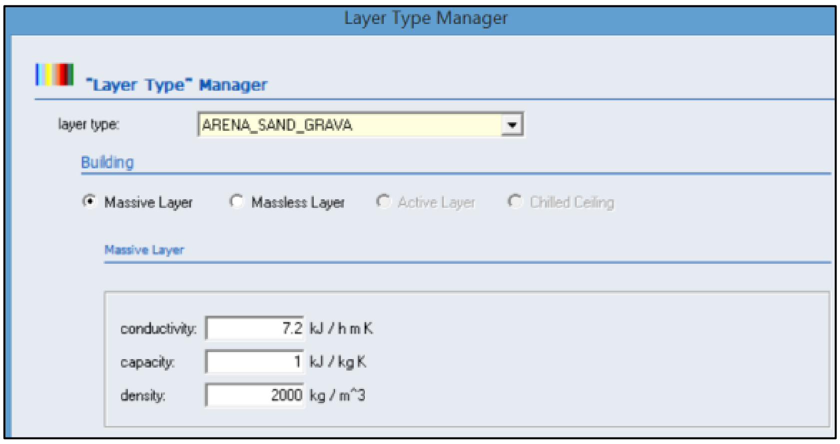


FIGURE 48 - LAYER TYPE MANAGER

After declaring every necessary layer, the different kind of walls could be defined. There are 5 different kinds off wall types:

- Adj_ceiling: the floor between the basement and the room
- Adj_ceiling 2: the ceiling between the room and the ext_roof
- Adj_wall: the wall between adjacent rooms
- Ground_floor: the floor between the basement and the soil
- Ext_roof: the ceiling between the top layer and the outside

These walls have to be introduced in the Wall Type Manager. Every different material/layer was added to the specific wall type in order from “front/inside” to “back”. This has its influence on the values of the Convective Heat Transfer Coefficient of the Wall.

Position of wall and heat flow	Rse [m²K/W]	Rsi [m²K/W]	Rse [kJ/hm²K]	Rsi [kJ/hm²K]
Vertical walls or >60° and horizontal heat flow	0.04	0.13	90.00	27.70
Horizontal wall or <60° and flow going up	0.04	0.10	90.00	36.00
Horizontal wall and flow going down	0.04	0.17	90.00	21.18

TABLE 9 - THERMAL RESISTANCE AT THE SURFACE IN CONTACT WITH EXTERNAL AIR

To know exact composition for each type off wall, see 3.2.1.

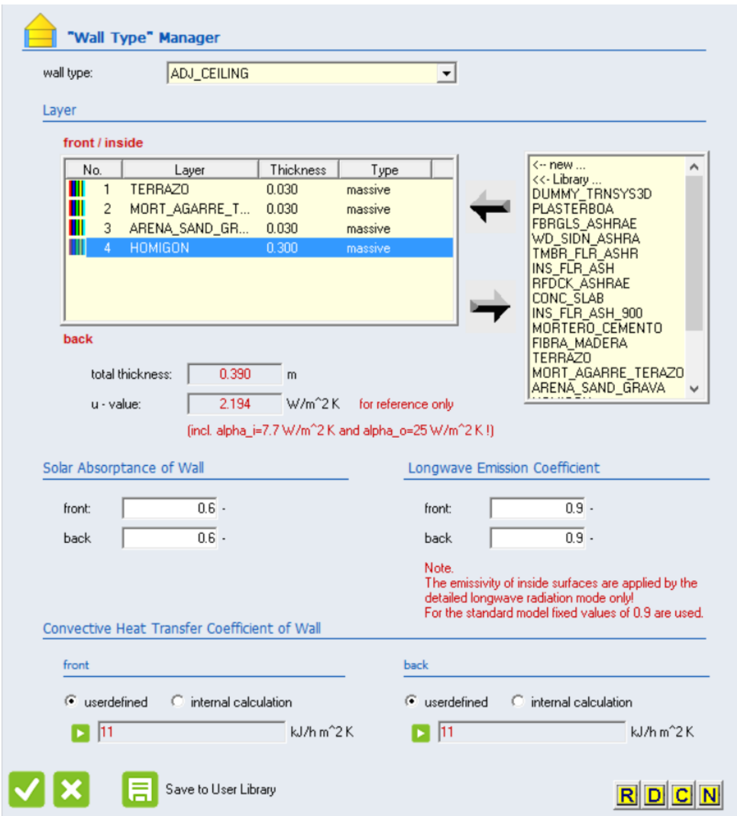


FIGURE 49 - WALL TYPE MANAGER

In EXT_WALL and EXT_ROOF the presence off several thermal bridges needed to be added:

- Thermal bridge of the columns (of steel) in the wall
- Thermal bridge of the wall with the roof
- Thermal bridge of the wall with the floor

There are two ways to introduce these changes in TRNBuild:

- Introduce the thermal bridges by hand in every Airnode Manager
- Calculate (with another program: THERM 7.2, see 0) the U-value and make a new layer. This layer will be introduced as the material in a new wall in Wall Type Manager.

It is easier to introduce the thermal bridges of the columns in the wall as a new layer/wall and the ones for the wall/floor and wall/roof manually in the airnodes.

a) <u>Introducing in airnode manager</u>

Every thermal bridge needed to be introduced and TRNBuild will keep it in its library.

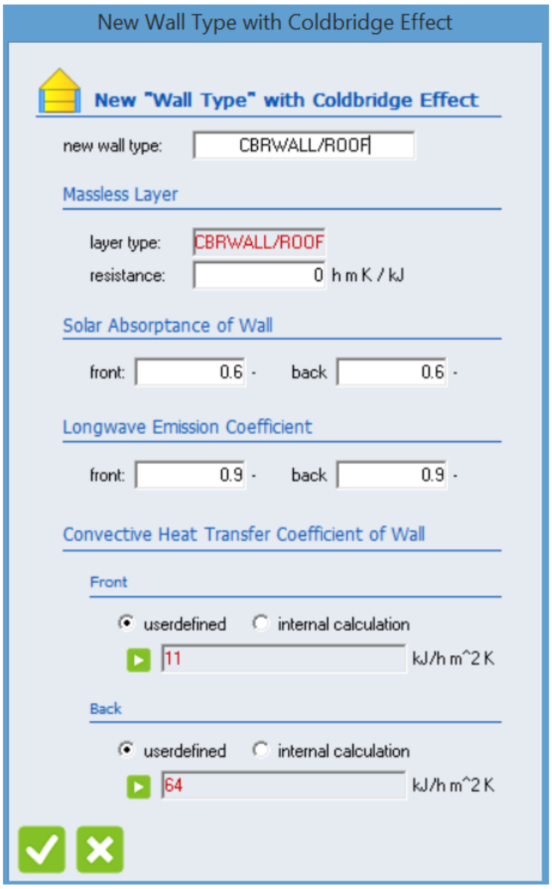


FIGURE 50 - INSERTING A THERMAL BRIDGE MANUALLY

- Wall/roof:
  - Ψ = 0.106 W/mK = 2.621 mKh/kJ
  - Rsi = 27.7 kJ/hm^{2}K
  - Rse = 90 kJ/hm^{2}K

- Wall/floor:
  - Ψ = 0.841 W/mK = 0.330 mKh/kJ
  - Rsi = 27.7 kJ/hm^{2}K
  - Rse = 90 kJ/hm^{2}K

After adding the needed thermal bridges, select the one necessary in each airnode and define the total distance this thermal bridges has influence on.

b) <u>Introducing as a layer</u>

As calculated in paragraph 4.3.2 the U-value of the wall with the thermal bridge is: 1.946 W/m^{2}K. So instead of using EXT_WALL, a new layer " EXT_WALL_COLD " is made in the Layer Type Manager with following properties:

- Conductivity: 1.05 kJ/hmK
- Capacity: 1.56 kJ/kgK
- Density: 760 kg/m^3

<u>Conductivity</u>:

$U = 1 / (R_{si} + R_{wall} + R_{se})$ with R_{si} = 0.13 m^{2}K/W and R_{se} = 0.04 m^{2}K/W

⇨ R_{wall} = 0.344 m^{2}K/W

$R_{wall} = d/ \lambda$ with d = 0.1 m

⇨ λ = 0.291 W/mK
⇨ λ = 1.05 kJ/hmK

To calculate the capacity and the density the weighted average is taken by using the thickness and properties of the used materials.

<u>Capacity</u> = (2*1 + 8*1.7) / 10

= 1.56 kJ/kgK

<u>Density</u> = (8*500 + 2*1800) / 10

= 760 kg/m^3

4.4.3.5. HEATING

In the Heating Type Manager the maximum temperature and the minimum humidity in a room can be defined. We set the maximum temperature to 20°C and an unlimited humidity just to get started.

FIGURE 51 - HEATING TYPE MANAGER

4.4.3.6. VENTILATION

In the Ventilation Type Manager all the parameters (air change rate, temperature of airflow and humidity of airflow), which have influence on the ventilation system are defined. The air change rate was set to 0.8 changes per hour.

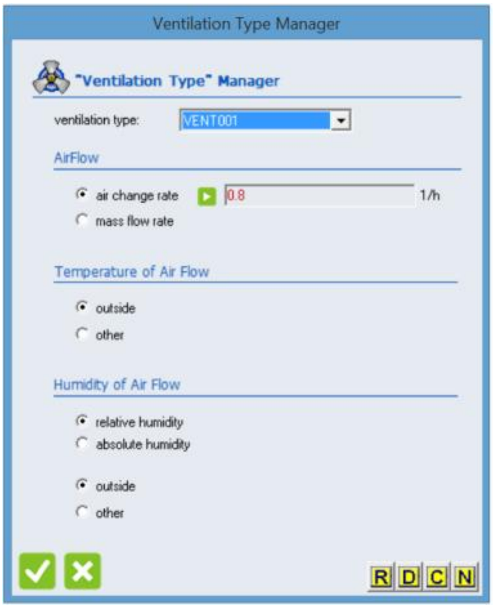


FIGURE 52 - VENTILATION TYPE MANAGER

4.4.3.7. COOLING

In the Cooling Type Manager the opportunity is given to change the set temperature for a room, the control of the cooling power and if you want dehumidication. We only set the temperature to 26°C.

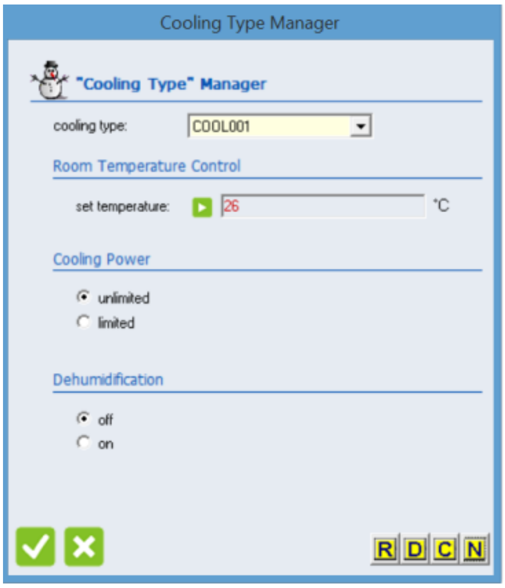


FIGURE 53 - COOLING TYPE MANAGER

4.4.3.8. WINDOWS

There is the possibility to add different kinds of windows in The Window Type Manager. The actual windows in the building have following properties:

- g-value (Solar factor): 0.91 %/100
- U-value (Thermal Transmittance): 5.68 W / m^{2}K
- Single glass (6 mm)
- Stainless steel framework

We took a window type that was already in the WinID-library with the following properties (Figure 54):

- g-value (Solar factor): 0.837 %/100
- U-value (Thermal Transmittance): 5.73 W / m^{2}K
- Single glass (6 mm)
- Stainless steel framework

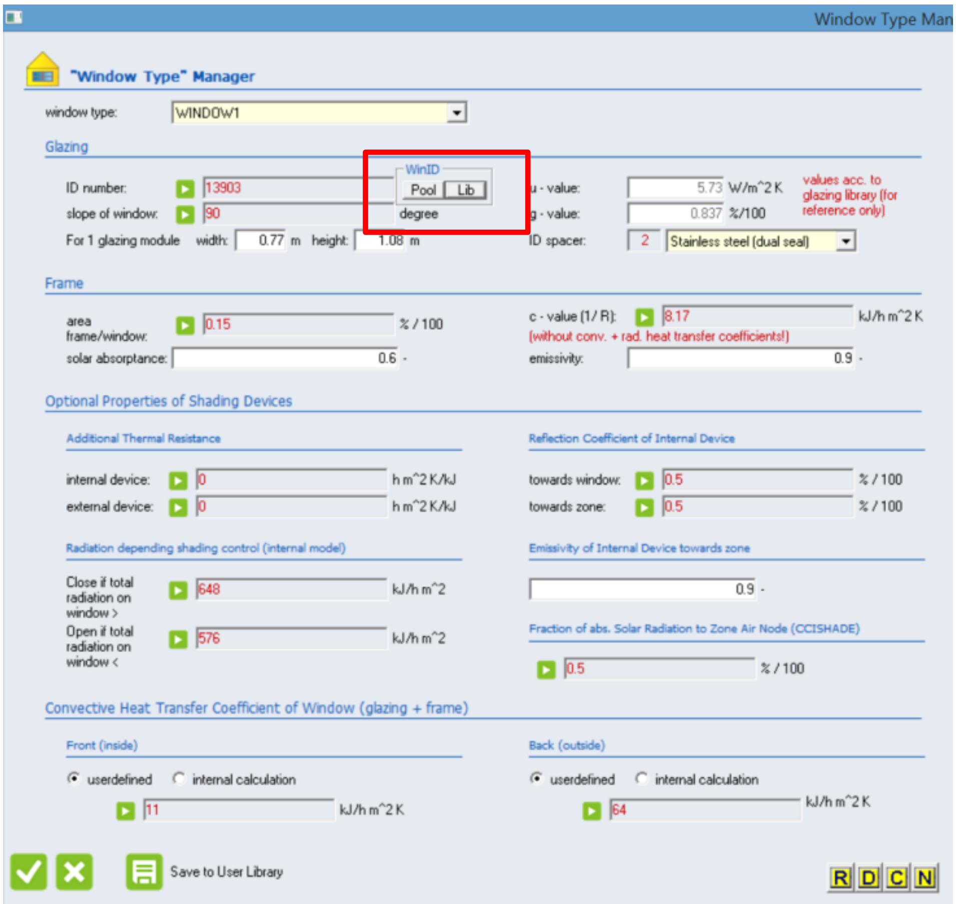


FIGURE 54 - WINDOW TYPE MANAGER

Table 10 shows the areas of the windows in every office. The location of every office can be found in Appendix B.

OFFICE	AREA [m^2]	OFFICE	AREA [m^2]
Off21	3	Off38	8.86
Off22	9	Off11	9.1
Off23	6	Off12	2.945
Off24	9.2	Off13	3
Off25	8	Off14	5.6
Off26	9.6	Off15	6.4
Off27	8.9	Off16	8.68
Off28	8.86	Off17	9
Off32	2.6	Off18	9.12
Off33	6	Off19	12
Off34	4.6	Secr2	15
Off35	8	Secr3	5
Off36	9.6	Co2	18.5
Off37	8.9	Co3	13

TABLE 10 - AREAS OF THE WINDOWS FOR EACH OFFICE

The shading devices are on the outside of the windows. They used venetian blinds, as described in paragraph 3.2.5. They are very old and for most off them it's impossible to change their angle. That is why the angle was generalised for all the blinds and an average angle of 30° with the horizontal was supposed. To insert this in TRNSYS a new equation had to be made in the Simulation Studio. When the zenith angle is 0°, there is a minimal shading on the window:

Min_shad = 15*0.15*sin(30°) = 1.125 m

➔ 1.125m of 2m is shaded, so this makes 56.25%

The zenith angle "alfa" has to be known to know how much the whole window is shaded.

- $AB^2 = 15^2 + 15^2 - 2*15*15*\cos(60°)$
  ➔ AB = 15cm
- $15^2 = 15^2 + 15^2 - 2*15*15*\cos(30+alfa)$
  ➔ **alfa = 30°**

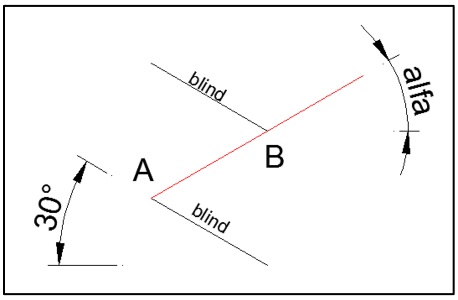


FIGURE 55 – SKETCH FOR CALCULATING SHADING

These numbers were inserted in the equation with the value 0 for no shading and 1 for zero transmission.

➔ Shading = min(max(min_shad + z_angle/alfa*(1-min_shad),0) ,1)

The min and max is to avoid that the number for shading is not more then 1 and less then 0. After this we have to add the shading to every window in TRNBuild (Figure 56). This equation doesn't take the diffusion radiatioon in account and the shading doesn't depend on the azimuth angle.

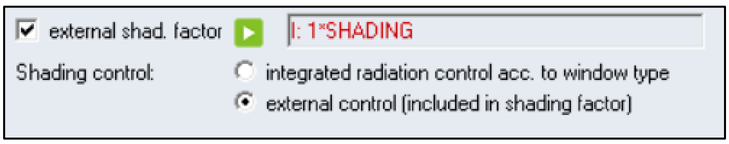


FIGURE 56 – ACTIVATING SHADING IN TRNBUILD

4.4.4. ADJUSTMENTS IN TRNFLOW

When TRNFLOW is turned on in the main window, the defined TRNFLOW data is displayed and more links can be added to the airflow network. In the simulation the defined infiltrations, ventilations and links will be changed by the calculated airflows.

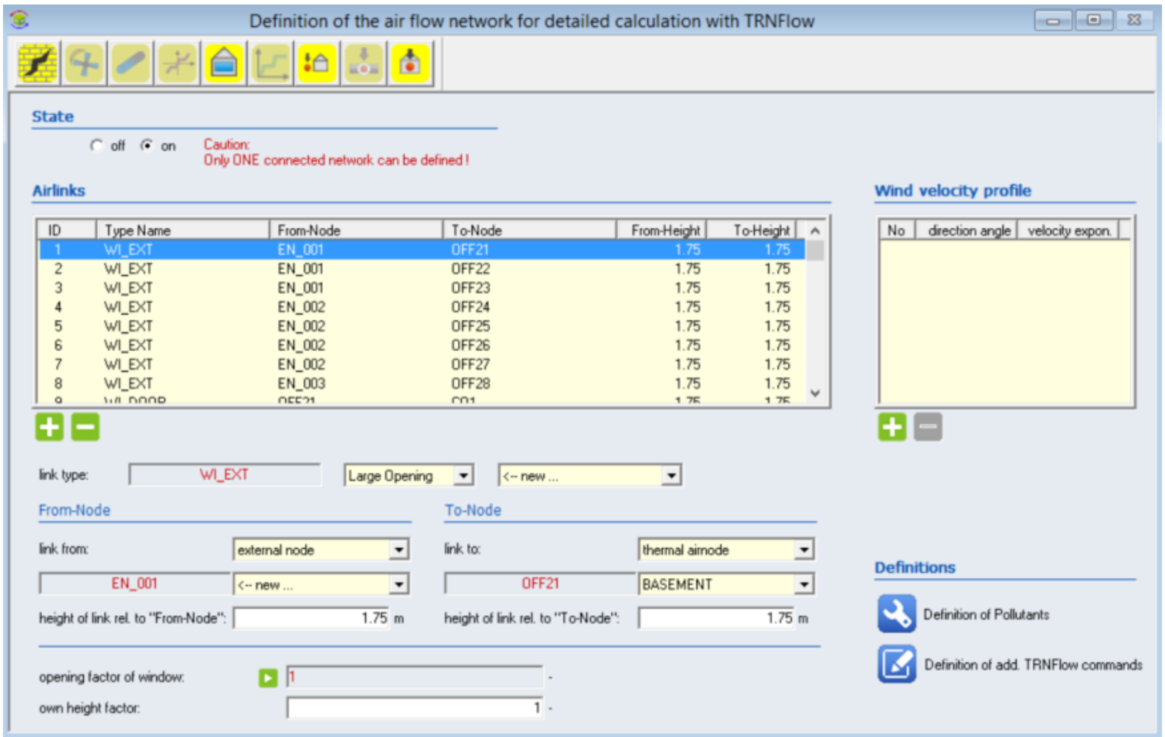


FIGURE 57 - MAIN WINDOW OF TRNFLOW

The left part of the window of Figure 57 gives the opportunity to add or erase data of the airflow network. For adding a part of the network, the following has to be defined:

- Link type → we will only use “large opening” and “crack”
- “From node” and “to node” → we will only use “external node” and “thermal airnode”

4.4.4.1. LINK TYPE

We use the large opening when we connect the external airnode with the inside through a window and other situations . When this option in the window is selected, a new type of large opening can be created and the Large Opening Type Manager appears (Figure 58).

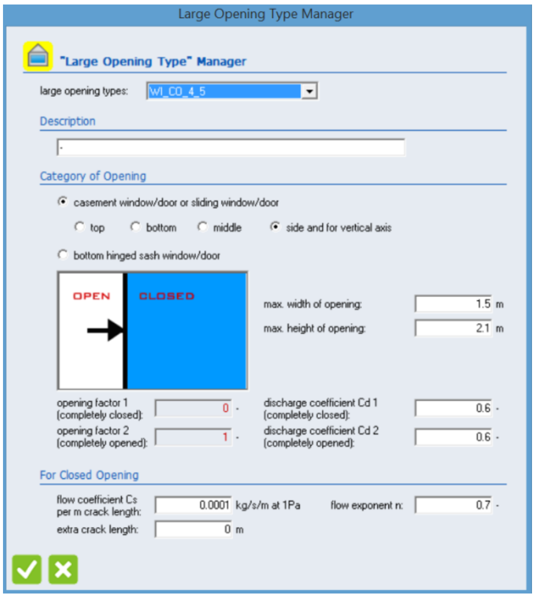


FIGURE 58 - LARGE OPENING TYPE MANAGER

In Table 11 different types of large openings are listed with their description, maximum width and maximum height of the opening.

Name	Description	Max. width [m]	Max. height [m]
WI_CO_4_5	Opening corridor 4-5	1.5	2.1
WI_CO1_2	Opening corridor 1-2	3	3
WI_CO2_4	Opening corridor 2-4	1.5	3
WI_CO3_2	Opening corridor 2-3	3	3
WI_DOOR	Opening door	1	2.1
WI_EXT	Opening in external wall	0.1	0.1
WI_SESCR2_3	Opening between secr 2-3	7.46	3.5
WI_SECR4_3	Opening between secr 3-4	3.05	3.5
WI_SECR1_2	Opening between secr 1-2	4.6	3.5

TABLE 11 – LIST WITH LARGE OPENINGS

For the normal walls inside the building, the crack-type was used. When a crack is defined the air mass flow coefficient C_S and the airflow exponent n needs to be known. The air mass flow coefficient is typical for different types of walls, based on its materials. The exact value of this coefficient is obtained by doing experiments. This wasn't possible, that's why the value of a plastered brick wall out of Table 12 was used.

Component	C [kg/s/m@1Pa]	n
window new weather stripped	$\leq 3.33 \cdot 10^{-5}$	0.6
window old weather stripped	$6.67 \cdot 10^{-5} – 2 \cdot 10^{-4}$	0.6
external doors weather stripped	$1.0 \cdot 10^{-4} – 1.0 \cdot 10^{-3}$	0.6
internal doors	$1.3 \cdot 10^{-3} – 2.4 \cdot 10^{-3}$	0.6
brick wall plastered [kg/s/m^2@1Pa]	$2.0 \cdot 10^{-5} – 2.5 \cdot 10^{-5}$	0.85
wall/ceiling joint caulked (masonry/concrete)	$8.0 \cdot 10^{-6} – 1.8 \cdot 10^{-5}$	0.6

TABLE 12 - EXAMPLES OF MASS FLOW COEFFICIENT CS AND AIRFLOW EXPONENT N

The standard value of 0.65 for the airflow exponent is not changed because most cracks have a mixed flow regime with a flow exponent of 0.6 to 0.7. In Table 13, all different types of cracks are listed, each with there name, length, height, Cs and n. We use 2.0 * 10^(-5) as value for the air mass flow coefficient Cs.

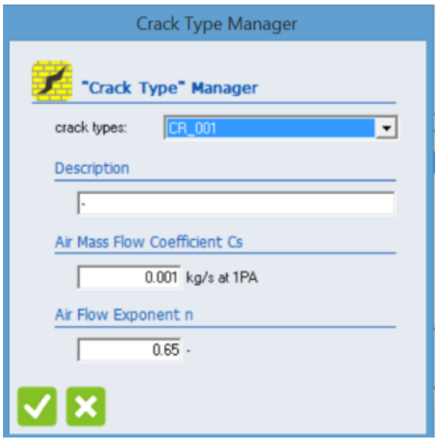


FIGURE 59 - CRACK TYPE MANAGER

NAME	LENGTH [m]	HEIGHT [m]	Cs [kg*10^(-4)/s at 1Pa]	n
CR_6M	6	3.5	4.2	0.65
CR_31_16	3.05	3.5	2.135	0.65
CR_32_16	2.95	3.5	2.065	0.65
CR_CO4_15	4.59	3	2.754	0.65
CR_15_14	4.59	3.5	3.213	0.65
CR_13_14	2.8	3.5	1.96	0.65
CR_CO5_13	3.2	3	1.92	0.65
CR_CO2_11	1.5	3	0.9	0.65
CR_CO2_SECR3	7.56	3	4.536	0.65
CR_3M	3	3.5	2.1	0.65
CR_03_SECR2	4.71	3.5	3.297	0.65
CR_02_SECR2	1.93	3.5	1.351	0.65
CR_02_01	4.17	3.5	2.919	0.65
CR_RECR2_1	3.1	3.5	2.17	0.65
CR_CO3_LOBBY	4.46	3	2.676	0.65

TABLE 13 - LIST WITH ALL THE DIFFERENT CRACK-TYPES

4.4.4.2. "From-node" to "To-node"

When the airflow network is made, all the thermal zones could be connected with each other. If thermal zones, which are adjacent with outside, are made then they are connected with the external node. Never forget that only 1 connected network can be defined. The direction of the from-node to the to-node is defined as the positive flow direction.

First the "Thermal Airnode" has to be defined. The reference height measured from ground plane to the top edge of the floor, the airnode height (inside) and the airnode depth (inside) has to be inserted. Last-mentioned is the distance from the external wall to the opposite internal wall (Figure 60).

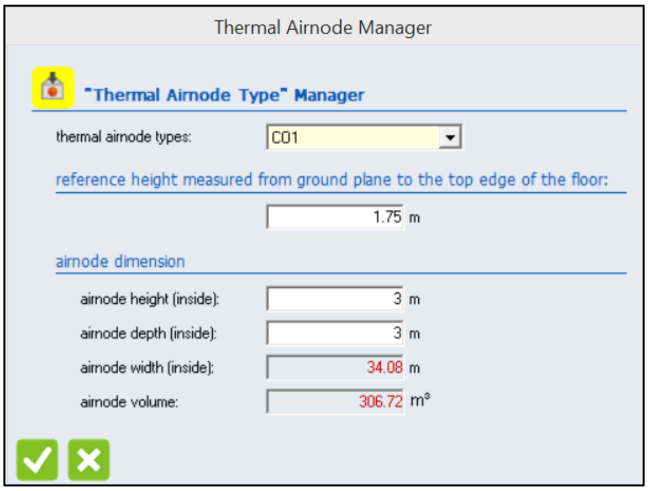


FIGURE 60 - THERMAL AIRNODE MANAGER

The reference height measured from plane to the top edge of the floor, the height of link relatively to "From-node" and the height of link relatively to "To-node" are 1.75m in every case. We have to use the C_p values obtained in paragraph 4.2, when we have to connect a thermal zone with an external zone. They are added in the "External Node Manager", where all the different necessary external nodes are made. The reference height of the C_p values is 1m75 as well.

No valid result was obtained when the ceiling and the basement were connected with the rooms. It is not possible to connect them with large openings because the link height have to be the same (KLEIN S.A. et al, 2012). The results with the cracks or with ducts gave bad results as well. This is because the ceiling and basement are 2 big zones for the whole model. In reallity ther are sometimes separating walls and ducts in the ceiling and basement.

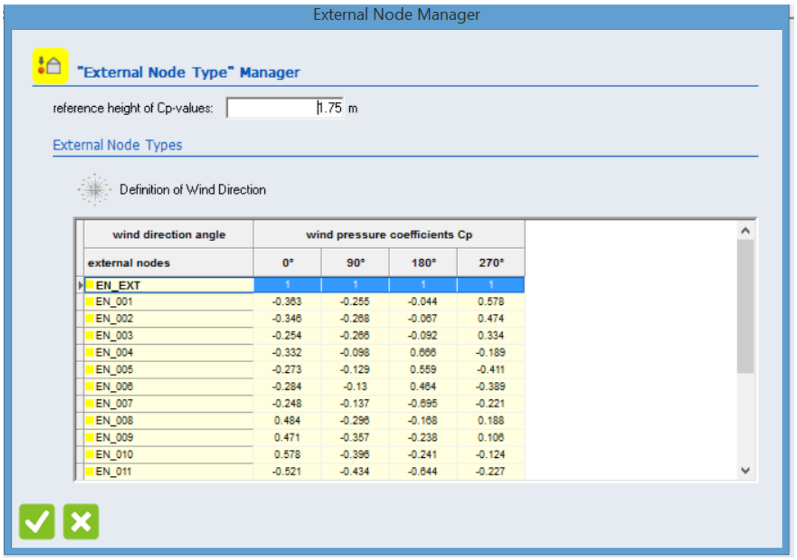


FIGURE 61 - EXTERNAL NODE MANAGER

In Table 14 all the external nodes and their C_p values (per 90°) for each office its external wall are shown. To see the location of the offices, see Appendix B.

OFFICE	NAME	0°	90°	180°	270°
11	EN_008	0.458	-0.114	-0.283	-0.395
12	EN_009	0.616	0.111	0.277	0.358
13	EN_010	0.661	0.098	-0.326	-0.209
14	EN_011	-0.764	-0.097	-0.229	-0.210
15	EN_012	-0.797	-0.194	-0.267	-0.216
16	EN_004	-0.143	-0.295	0.492	0.201
17	EN_005	-0.194	-0.344	0.462	-0.047
18	EN_006	-0.208	-0.401	0.562	-0.088
19	EN_007	-0.683	-0.461	-0.608	-0.221
21	EN_001	0.063	-0.308	-0.281	0.443
22	EN_001	0.063	-0.308	-0.281	0.443
23	EN_001	-0.056	-0.222	-0.388	0.533
24	EN_002	-0.056	-0.222	-0.388	0.533
25	EN_002	-0.056	-0.222	-0.388	0.533
26	EN_002	-0.056	-0.222	-0.388	0.533
27	EN_002	-0.039	-0.203	-0.540	0.540
28	EN_003	-0.039	-0.203	-0.540	0.540
32	EN_017	-0.647	-0.079	-0.049	-0.261
33	EN_017	-0.647	-0.079	-0.049	-0.261
34	EN_018	-0.438	-0.022	-0.055	-0.263
35	EN_019	-0.359	-0.014	-0.065	-0.261
36	EN_020	-0.293	0.036	-0.090	-0.269
37	EN_020	-0.293	0.036	-0.090	-0.269
38	EN_021	-0.252	0.108	-0.092	-0.266
SECR_2	EN_014	-0.480	0.740	-0.294	-0.283
SECR_3	EN_013	-0.427	0.728	-0.472	-0.278
CO2	EN_015	-0.291	-0.465	0.248	-0.142
CO3	EN_016	-0.293	-0.306	0.325	-0.174

TABLE 14 - LIST WITH CP-VALUES

4.4.5. MODIFICATIONS TO THE MODEL TO ACHIEVE A PASSIVE HOUSE

We will make some changes to the model to achieve the goal of developing a passive house. The modifications that are made:

- Insulation in the walls, roof and floor
- Different angle for shading devices
- Different types of windows and framework
- Infiltration
- Ventilation
- Internal gains

4.4.5.1. WALLS, ROOF AND FLOOR

Depending on the results of the initial model, some changes are made to the compositions of the walls, roof and floor. The insulation is added to the structure in steps from 3cm, 6cm and 9cm. Afterwards conclusions are drawn which improvements are the best to accomplish the conditions for a passive house. The used insulation is PUR (RECTICEL EUROWALL):

- Conductivity = 0.0828 kJ/hmK
- Capacity = 1.4 kJ/kgK
- Density = 30 kg/m^3

The position of the insulation in the roof is between the stones and the waterproofing. The position of the insulation in the floor is between the concrete and the dry concrete.

4.4.5.2. WINDOWS AND SHADING

The windows are changed to see which influence they have on the heating and cooling demand for the secretariat. A different type of glass and framework is used.

The influence of the angle of the blinds on the energy demand is analyzed as well. The analyzed angles, their percent of minimal shading and angle for maximal shading are presented in Table 15. These numbers are the values used in the equation in the simulation studio that is connected with the TRNBuild file for the shading on the windows.

Angle from the blinds [°]	Minimal shading area [%]	Angle maximum shading [°]
0	11.25	45
30	56.25	30
45	79.55	22.5
60	97.43	15

TABLE 15 – ANALYZED ANGLES AND SHADES

4.4.5.3. INFILTRATION

The influence of the infiltration can be obtained in 2 different ways in TRNSYS. One way is by introducing a fixed air change rate and activate this in every room of the building. The strategy we used is by using TRNFlow. The area where the air flows through (leakage) can be calculated with following formula:

$$A = \frac{Q}{C_d} \sqrt{\frac{\rho}{2\, \Delta p}}$$

With:

- Q the airflow through the opening
- C_d the discharge coefficient of the opening
- ρ the density of air
- Δp air pressure difference between outside and inside

The only unknown parameter is Q [m^3/s] and is calculated by multiplying the volume of the secretariat by the considered air change rate. The results for this calculation are presented in Table 16 – area for openings depending ons air change rate. Square openings are assumed, so the maximum height and width of the opening is the square root of the area.

Air change rate [h^{-1}]	Area [m^2]	Max. height/width in TRNFLOW [m]
10	0.415	0.6439
4	0.166	0.4072
0.6	0.025	0.1577
original	0.010	0.1000

TABLE 16 – AREA FOR OPENINGS DEPENDING ONS AIR CHANGE RATE

4.4.5.4. VENTILATION

A new system of ventilation is introduced that uses passive ventilation to cool and refresh our building. The ventilation is activated when certain conditions are obtained. When the ventilation is working, the cooling is inactive.

Conditions for ventilation:

- This system works only during the summer and can be active on every moment of the day.
- The system is only activate when the outside temperature is less than 25°C.
- The temperature outside has to be lower than the temperature inside.

This way the building is cooled down mostly by the night.

This system is introduced in TRNFlow. The large openings are becoming bigger when the ventilation is on. That is why the large openings have to be controlled by an input-formula. When the ventilation is not working, the normal infiltration is active. When it is active, a bigger opening is obtained. To accomplish this, an opening (when it is completely open) of 2m^2 for every type of infiltration is considered. The input-formula is based on the percentage of the leak area (depending on the infiltration) to the total of 2m^2.

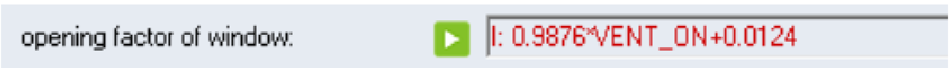


FIGURE 62 – INPUT FORMULA

The right part is for the present infiltration and when VENT_ON (output from equation) is 1 (ventilation active) the whole large opening is open.

Following table contains the percentage of the 2m^2 depending on the infiltration rate:

Infiltration rate [h^{-1}]	Percentage for infiltration [%]	Percentage for total opening [%]
10	20.73	79.27
4	8.29	91.71
0.6	1.245	98.755
0.24 (original)	0.5	99.5

TABLE 17 – PERCENTAGES FOR VENTILATION/INFILTRATION

4.4.5.5. INTERNAL GAINS

The lights where originally set on 55W/m^2. The difference will be compared for 19 and 10 W/m^2.

5. RESULTS

5.1. RESULTS OF THE MEASUREMENTS

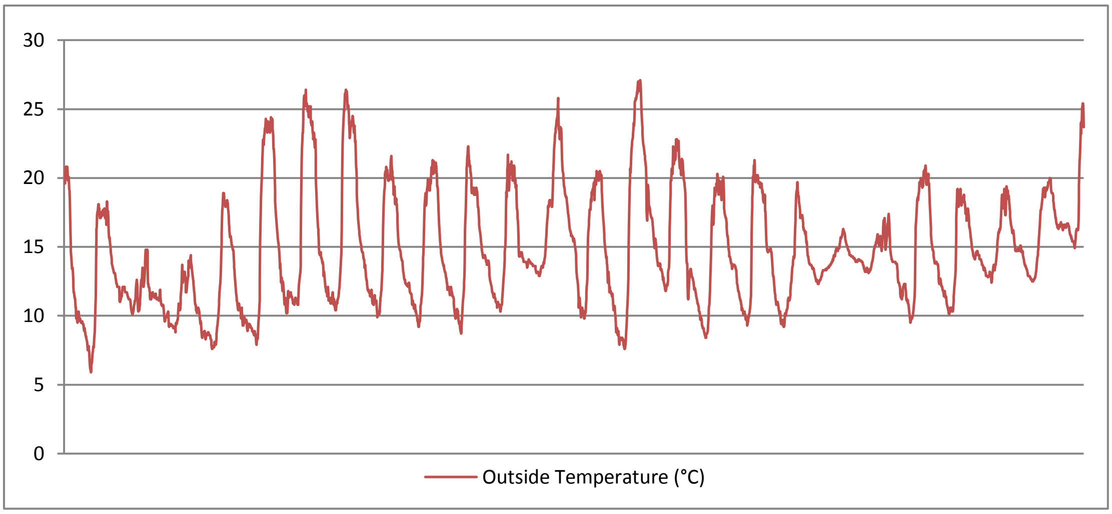
The analyzed measurements are the weatherdata obtained by the Watchdog® weatherstation and the secretariat's inside air temperatures obtained by the Testo® heat sensors. There have also been made some combinations of parameters to watch their mutual influence. The measurements were taken during a period where the temperatures are quite moderate, so no extreme conditions were determined. Thereby we cannot take any determinations for the whole year or every season. But analysing these measurements is important to understand the behaviour of the different parameters over time and their influence on the air conditions in buildings.

5.1.1. ANALYSIS OF THE OUTSIDE WEATHER DATA

The weatherstation was located on the roof of the secretariat and collected the temperature, the humidity, the solar irradiation, the wind speed, wind gusts and wind direction and the rainfall and the dew point. The outside weatherdata were collected every 10 minutes starting from 10th of march on 13:10 until 4th of april on 10:20. These parameters are used as input for the TRNSYS model. They are an important basis to compare the inside temperatures with.

5.1.1.1. TEMPERATURE

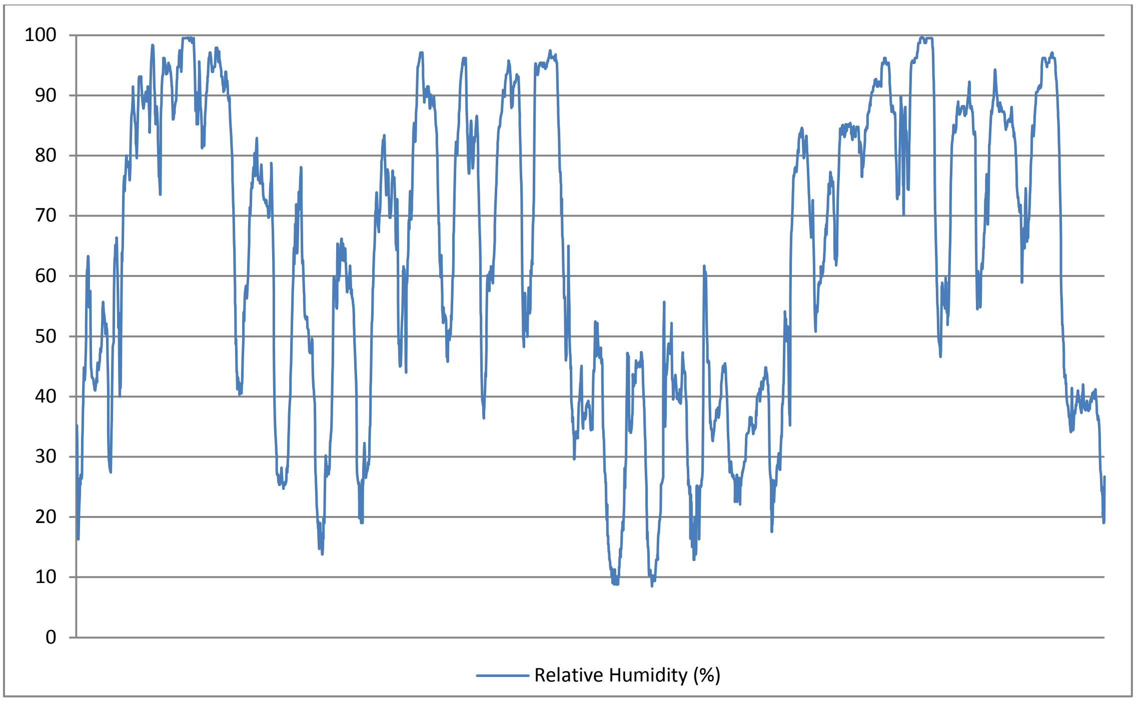
The outside temperatures for the measuring period are presented on Graph 8. The mainly difference between minima and maxima are around 15°C. The maxima differ from less than 15°C to more than 25°C. The minima have a smaller dispersion from around 7°C to 15°C.



GRAPH 8 - MEASURED OUTSIDE TEMPERATURE

5.1.1.2. Humidity

The relative humidity of the outside air is presented on Graph 9. A wide spread over time can be determined.



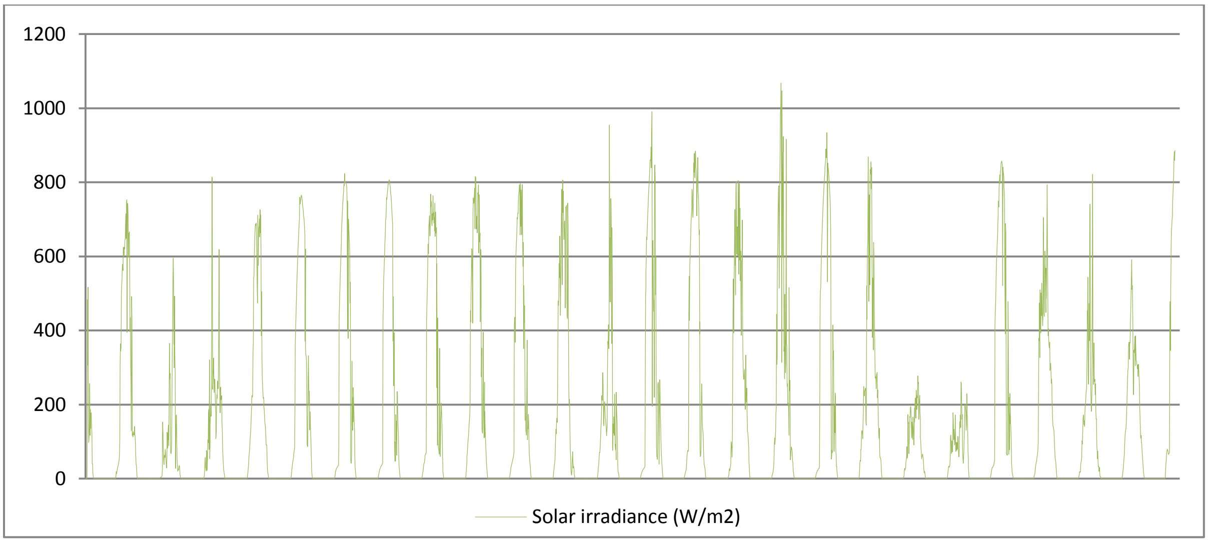
GRAPH 9 - MEASURED OUTSIDE RELATIVE HUMIDITY

5.1.1.3. Solar irradiance

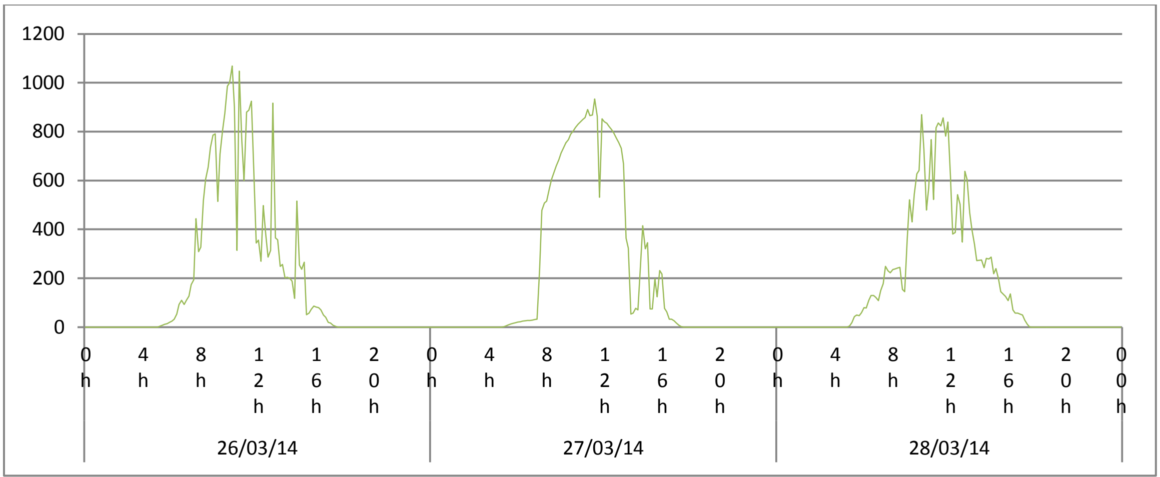
The solar irradiance is defined as the solar radiation energy per unit area. The unit is W/m^2. The outside temperatures as well as the surface temperatures are highly influenced by the solar irradiance. Therefore it has a big influence on the heating and cooling demand. The solar irradiance received by the weather station during the whole measuring period is presented on Graph 10 and Graph 11. The different days can be clearly seen and are divided by pieces with 0 irradiance, which represent the nights. The time data on the x-axis have been left out to keep the graph clear. The average daily maximum value for a sunny day is around 800 W/m^2 of solar irradiance. There are also 2 very cloudy days, represented on peaks 20 and 21, with almost no sun reaching the earth's surface. Still these days have a solar irradiance peak of more than 200 W/m^2. The peak value is reached on the 26th of March. Also can be concluded that the weather station doesn't have any shade from surrounding buildings. This would lead to a daily relapse of the solar irradiance at the same time. This is not the case in this graph.

To view the solar irradiance on different parts of the day, a magnification of 3 days was made on Graph 11. On this graph the influence of clouds can be seen very clearly. Clouds can cause a differentiation of the solar irradiance from a few units to more than 600 W/m^2. The 27th of March seems to be very sunny day until around 3 p.m. Sunrise can be determined at around 5 a.m. and the sun directly reaches the device at

7:30 a.m., when the graph raises sharply. Around 4:30 p.m. the sun sets to become night one hour later at around 5:30 p.m.



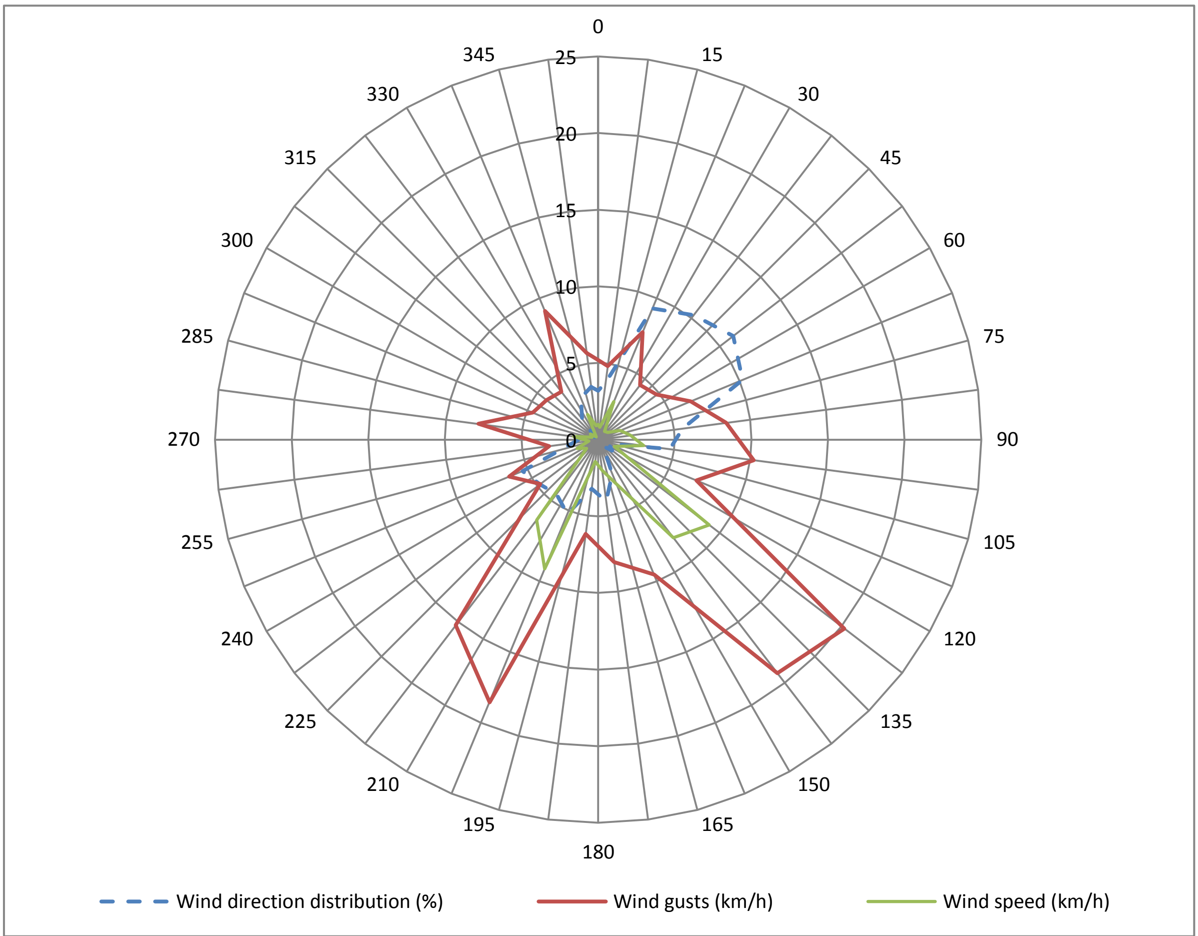
GRAPH 10 - MEASURED SOLAR IRRADIANCE OUTSIDE



GRAPH 11 - ZOOM OF MEASURED SOLAR IRRADIANCE OUTSIDE

5.1.1.4. WIND

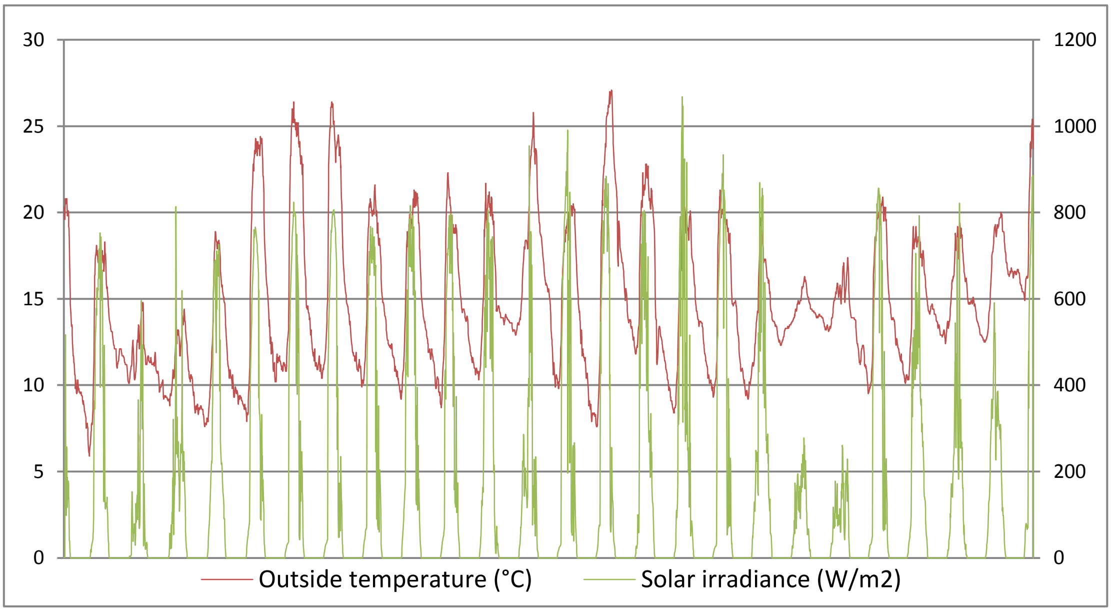
The wind measurements have been converted to relative values to make a proper analysing of the data. The data have been simplified into direction interval with a range of 15 degree (so 1° to 15°, 16° to 30°…) to make it clearer. Also data with only a wind direction and 0 km/h for wind speed and gusts have been deleted, because when there is no wind, the wind doesn't have a direction. The result of this calculation can be seen on Graph 12. The wind direction correlation means how many times the wind came from a certain direction in comparison with the other directions. The average wind speeds and gusts are the average speeds per interval. The wind gusts are clearly a lot bigger than the normal wind speeds, the higher the wind gust the bigger the difference between speed and gust speed. The wind speed has nearly the same shape as the wind gusts. The graph determines the directions with the highest wind speeds, which are southeast and between south and southwest. The most directions that are most frequent are northeast and to a lesser extent southwest. So the most frequent direction is the one with low wind speeds from the northeast. The wind is influenced a lot by the different obstacles. And because we have a high building in the close vicinity of the secretariat these values are really specific for this location.



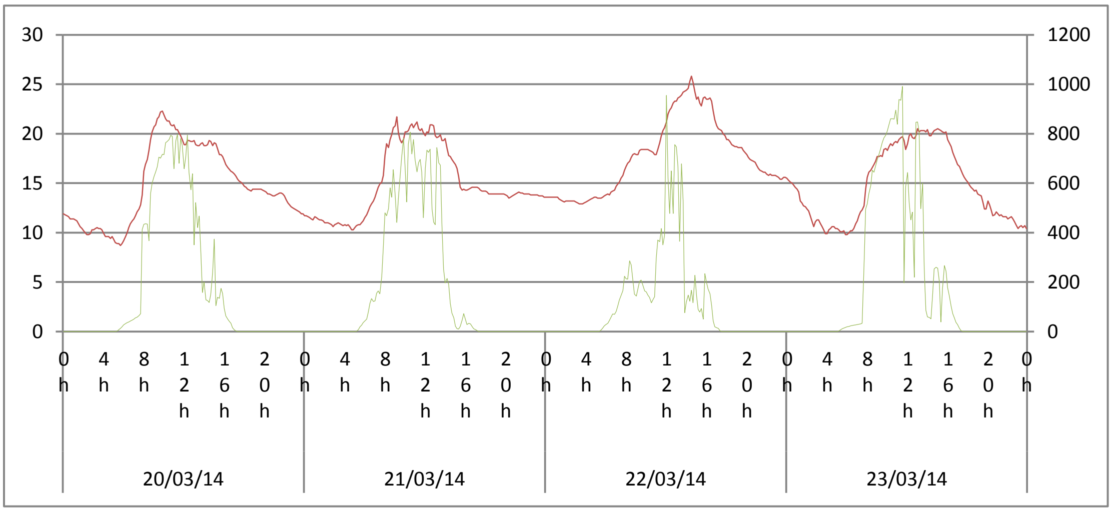
GRAPH 12 - MEASURED OUTSIDE WIND DATA

5.1.1.5. COMPARISON OF TEMPERATURE AND SOLAR IRRADIANCE

The influence of the solar irradiation on the outside temperatures can be determined on Graph 13 and more in detail on Graph 14. These two parameters are directly related to each other. When there is a lot of solar irradiation reaching the earth's surface we can determine higher temperatures and vice versa. So when there is sun, it's warm. When there are a lot of clouds, and thereby little solar irradiance the outside temperatures are lower. On the other hand there are some days with higher value of solar irradiance than others but don't have a higher temperature. This contradicts with our previous determination. This can be caused by the time when the maximum solar irradiance appears and how long the high solar irradiance is maintained.



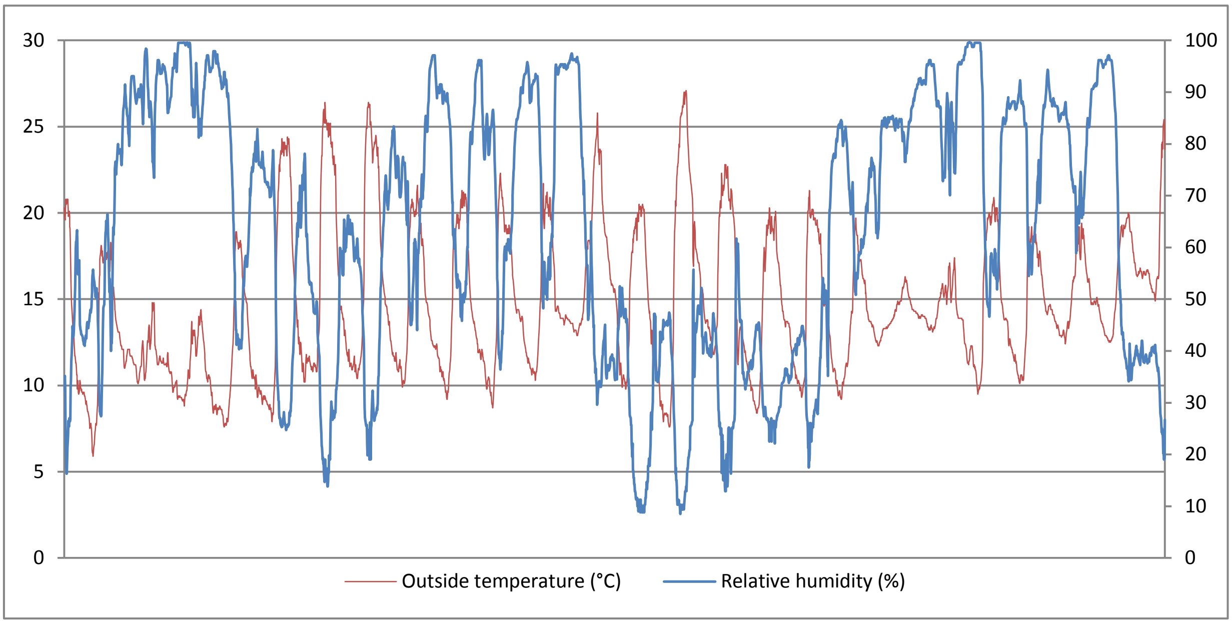
GRAPH 13 - COMPARISON OUTSIDE TEMPERATURE-SOLAR IRRADIATION



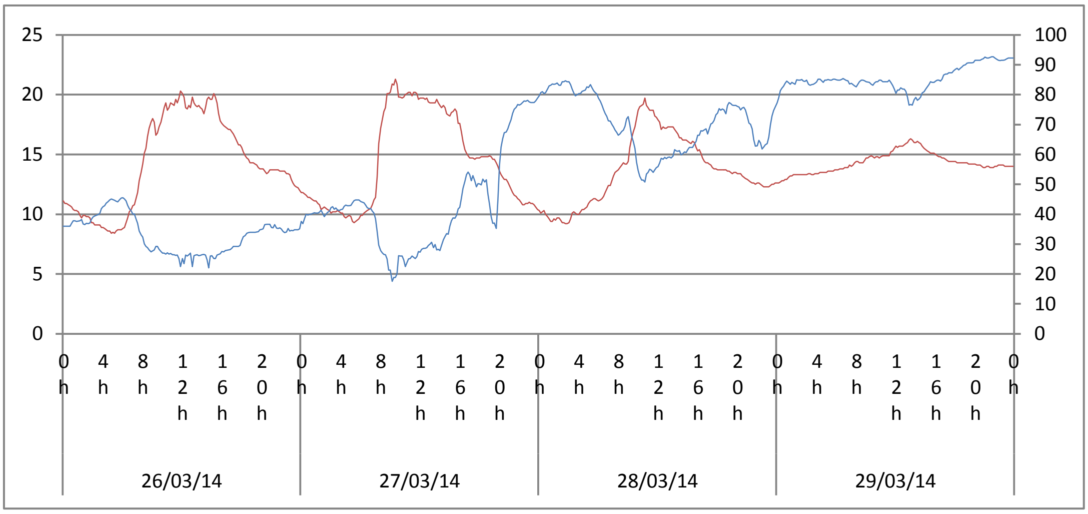
GRAPH 14 - ZOOM OUTSIDE TEMPERATURE-SOLAR IRRADIATION

5.1.1.6. COMPARISON OF TEMPERATURE AND HUMIDITY

The combination of outside temperature and relative humidity are presented on Graph 15 and more in detail for four consecutive days on Graph 16. A reversed relation can be determined between the two parameters. When temperatures peak during day humidity rates reach their minima and vice versa. We can see a clear difference between days when it was probably raining or threatening to rain with lower temperatures, and bright days with higher temperatures and low humidity rates.



GRAPH 15 - COMPARISON OUTSIDE TEMPERATURE-RELATIVE HUMIDITY



GRAPH 16 - ZOOM OUTSIDE TEMPERATURE-REALTIVE HUMIDITY

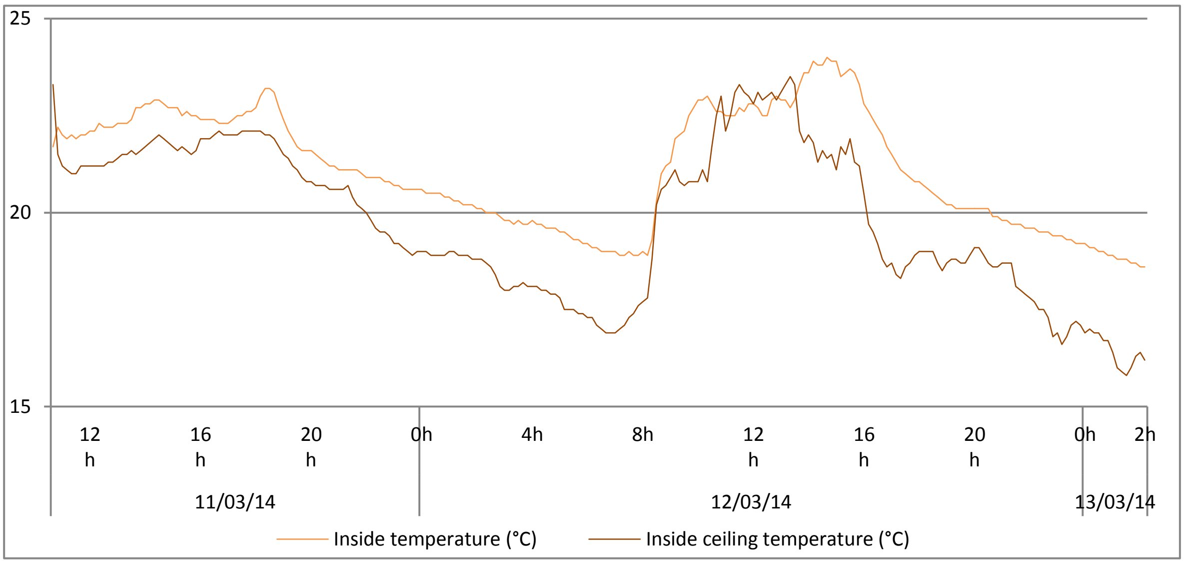
5.1.2. ANALYSIS OF THE INSIDE MEASUREMENTS

The inside temperatures and humidity rates were measured over a period of one moth. These measurements are important to evaluate the level of air comfort in the secretariat. Unfortunately we had some setbacks with obtaining the measurements from the heat sensors. The sensors had to collect temperatures 24 hours a day and therefore the batteries of the only lasted for maximum three days. Together with the opening hours of the secretariat that had to be respected and the malfunctioning of the sensors sometimes, the final result is rather poor. There are a lot of dateless gaps in the graphs. Nevertheless we tried to analyse and compare the measurements as good as possible by only plotting the periods where every parameter is known. We obtained measurements of the thermal sensors for 4 separate periods:

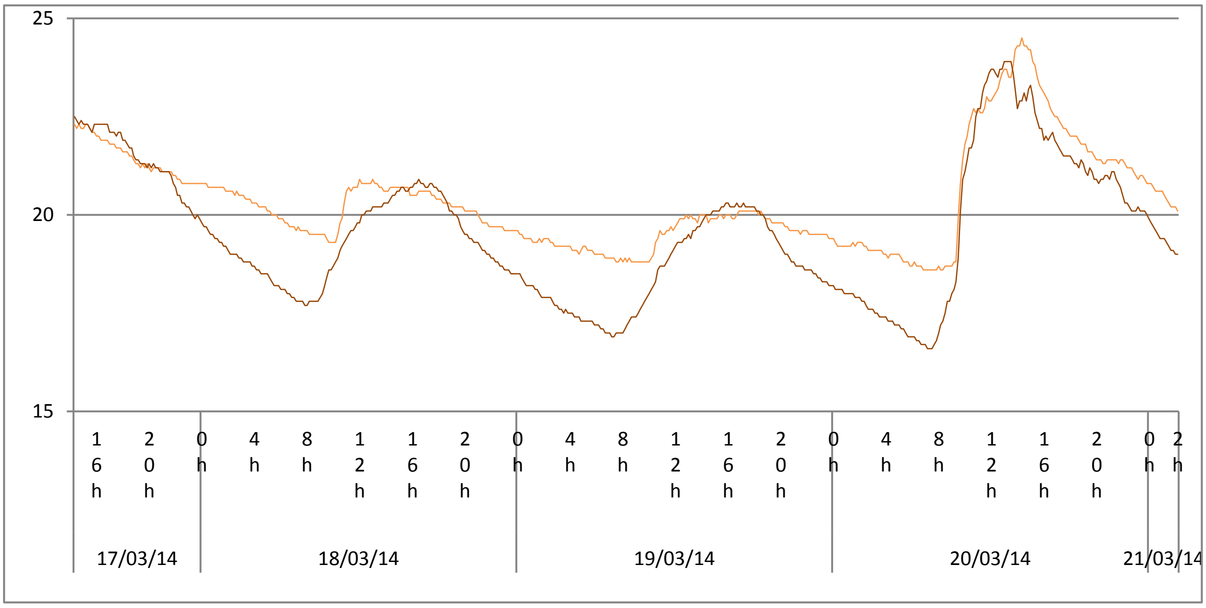
- 11/03/2012 (11:40) → 13/03/2014 (2:10)
- 17/03/2014 (14:20) → 21/03/2014 (2:10)
- 24/03/2014 (13:10) → 25/03/2014 (18:00)
- 27/03/2014 (15:00) → 31/03/2014 (00:40)

5.1.2.1. TEMPERATURE

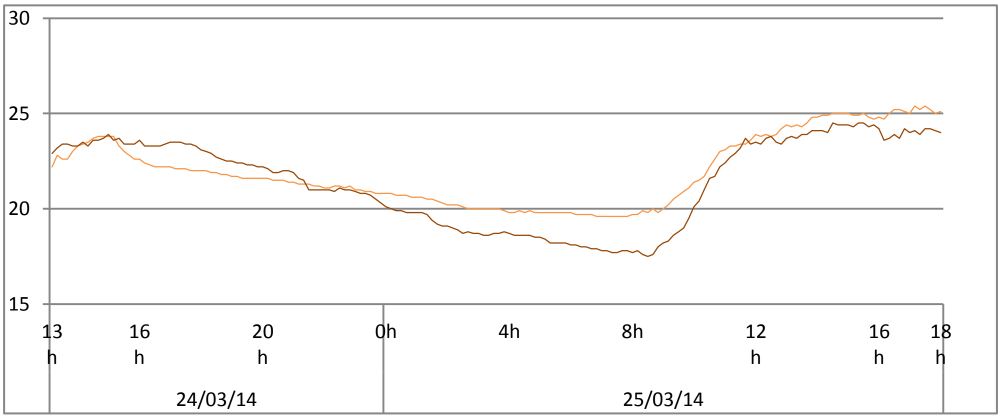
The curves of the room temperature and the temperature in the false ceiling are presented in four graphs representing the consecutive periods of data collection (Graph 17,18,19 and 20). There can be seen a clear difference between the periods when the heating devices are switched on and off during daytime, which are during weekends (29th and 30th of March) and holidays (17th,18th and 19th of March). The reached temperatures are much lower when devices are switched of. Also the slopes of the temperature curves are much smaller. The temperature curves are similar to each other. The ceiling temperatures are mostly lower than the inside temperatures. This is probably because the room has a more direct effect of the heating devices. Also the heat is faster lost through the roof slab, which has a big surface, causing lower minima in the ceiling. The ceiling temperature curve reaches its minimum always one or two hours before the temperature in the secretariat. This wasn't expected, because the curves have a very similar progression when the heating devices are switched. This difference in minimum temperatures can also be ascribed to the higher influence of the outside temperature and the solar irradiance on the ceiling temperature. The inside temperature curve peaks always at around 16h during working days. This makes us suspect that the time during which the heating devices are switched on much shorter than assumed. The secretary is heated during working houres which are from 8 a.m. until 8 p.m. But if we look to the temperature curves, we can see that this is probably not the case.



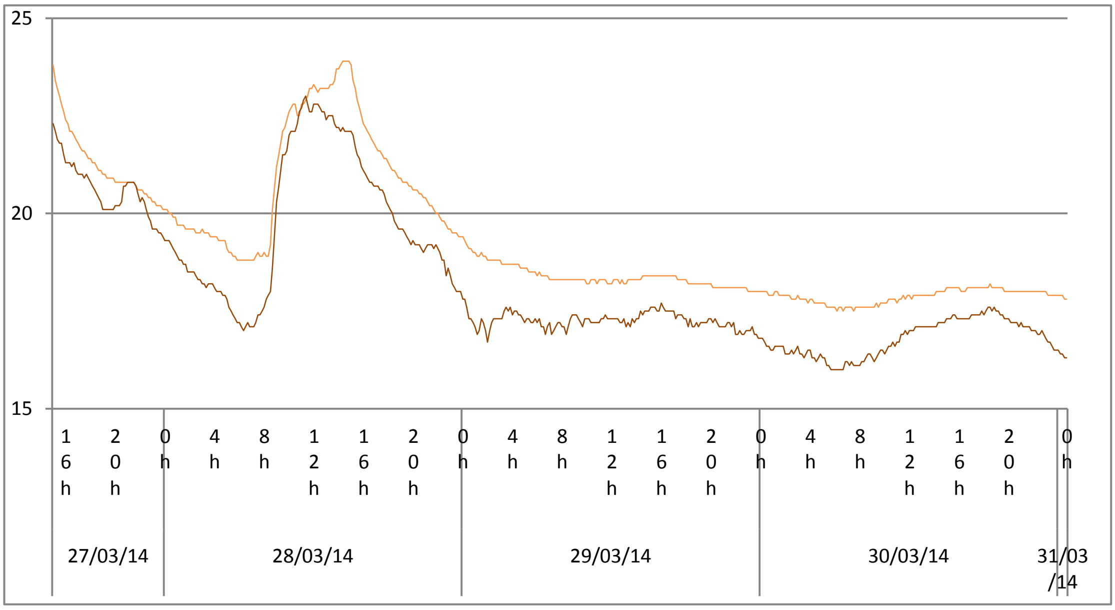
GRAPH 17 – TEMPERATURES MEASURED BETWEEN 11-13/03



GRAPH 18 – TEMPERATURES MEASURED BETWEEN 17-21/03



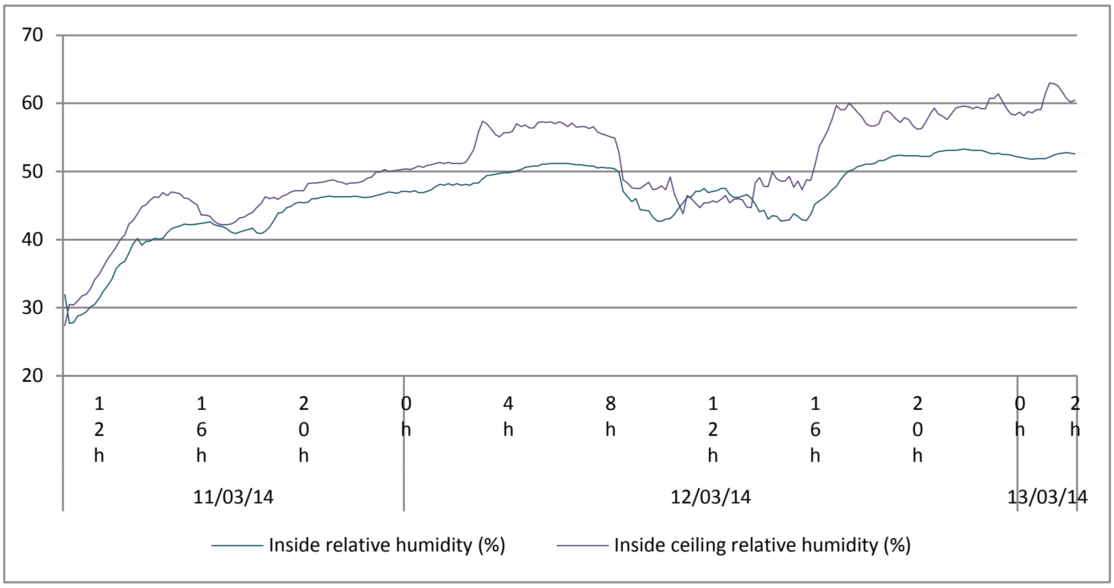
GRAPH 19 – TEMPERATURES MEASURED BETWEEN 24-25/03



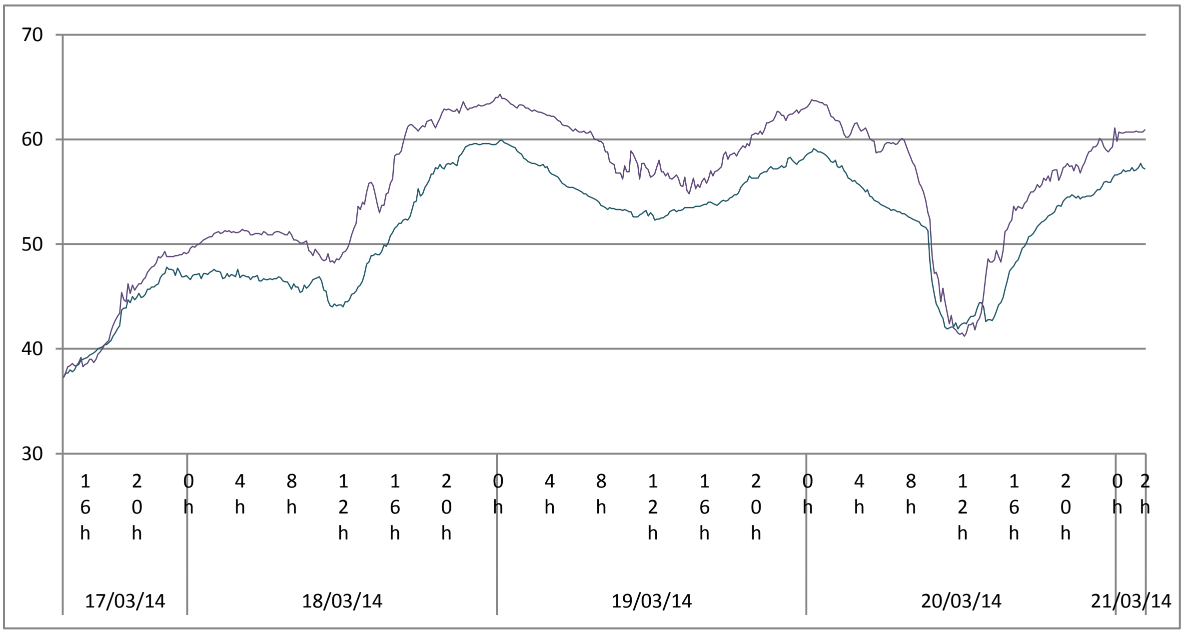
GRAPH 20 – TEMPERATURES MEASURED BETWEEN 27-31/03

5.1.2.2. HUMIDITY RATES

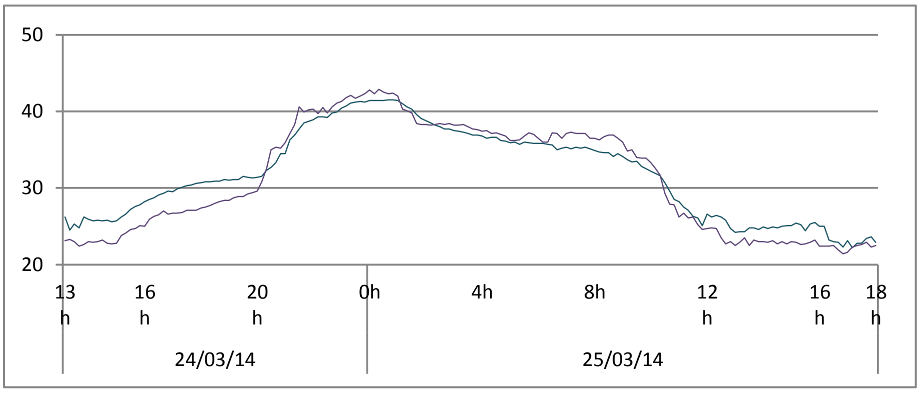
The curves of the relative humidity in the room and the false ceiling are presented in four graphs representing the consecutive periods of data collection (Graph 21, Graph 22, Graph 23 and Graph 24). The humidity rate in the working area is always lower than the humidity rate in the false ceiling. This can be related with the absence of ventilation in the false ceiling. The air is not refreshed that fast, so the humid air is less fast drained. The amounts of relative humidity differ a lot from day till day.



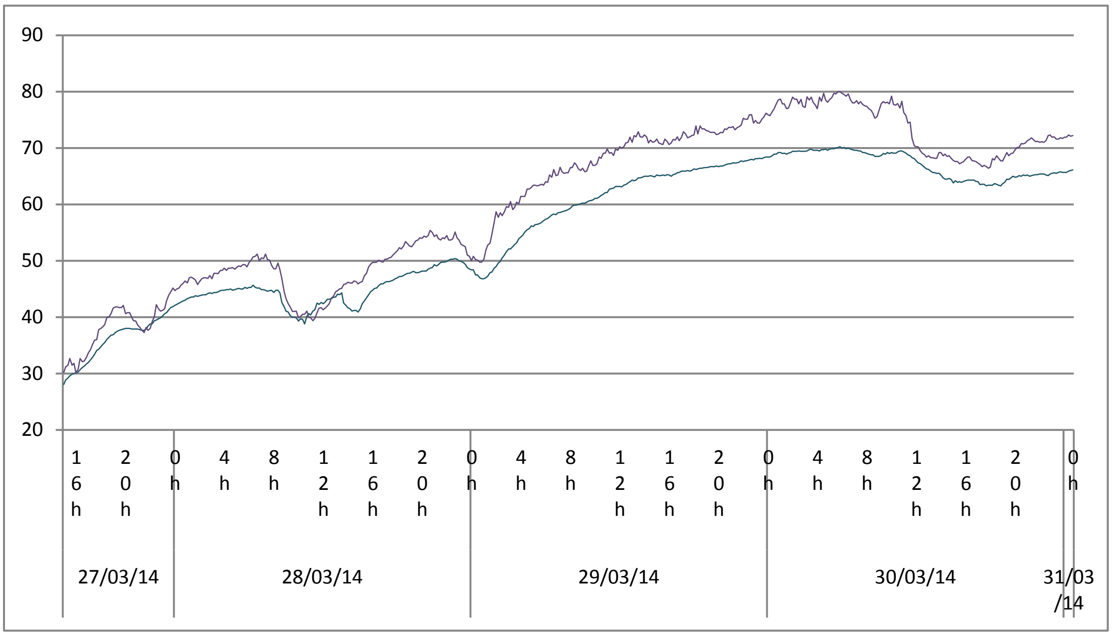
GRAPH 21 - MEASURED INSIDE RELATIVE HUMIDITY 11-13/03



GRAPH 22 - MEASURED INSIDE HUMIDITY 17-21/03

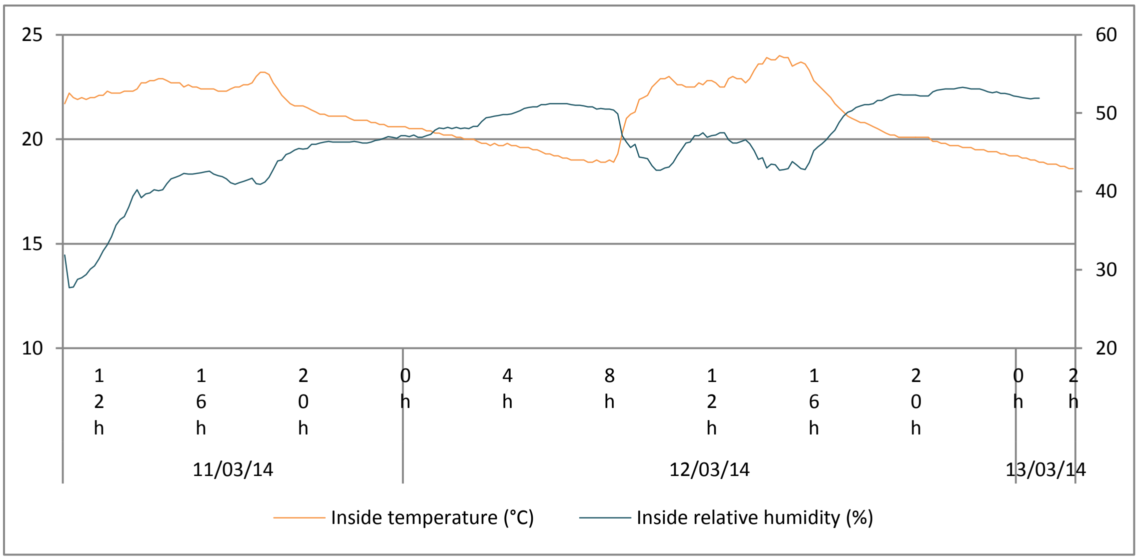


GRAPH 23 - MEASURED INSIDE HUMIDITY 24-25/03

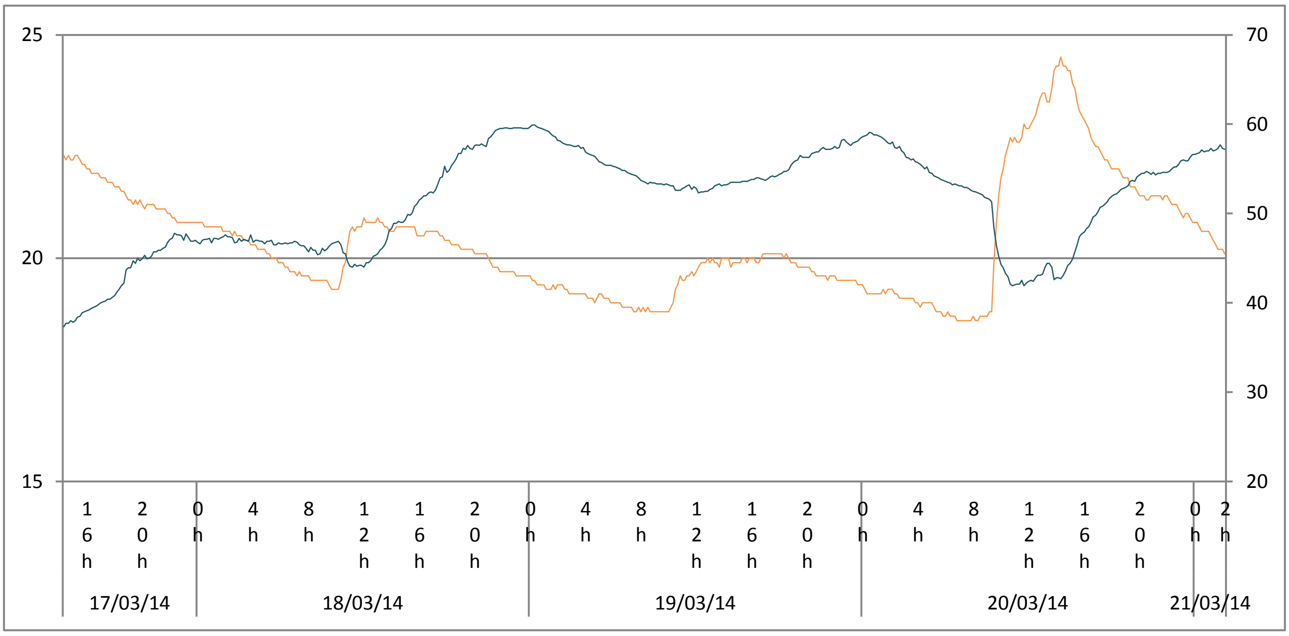


GRAPH 24 - MEASURED INSIDE HUMIDITY 27-31/03

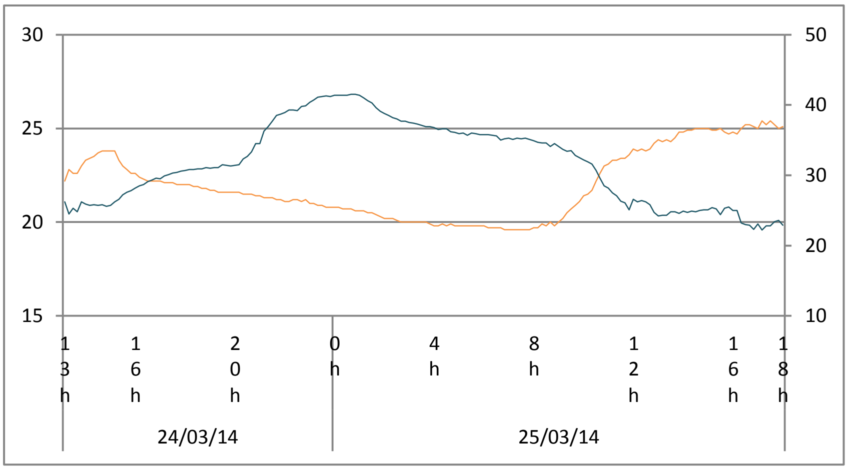
Comparing the temperatures and the humidity rates in the secretariat (Graph 25, Graph 26, Graph 27 and Graph 28) we can see some similarities with Graph 15. During the day when temperatures are higher, the humidity is lower and vice versa. There can also be seen a clear difference between working days and weekends or holidays, because during these last ones the air conditioning devices are switched of. It can be clearly seen that humidity rates are much higher when ventilation is switched of.



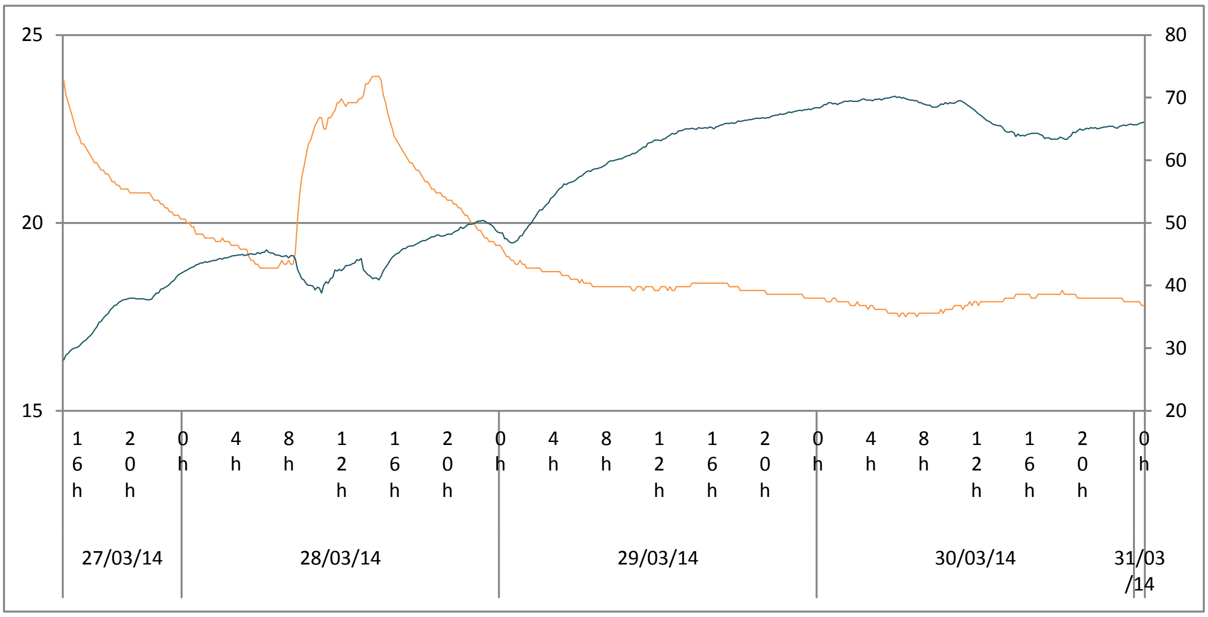
GRAPH 25 - COMPARISON INSIDE TEMPERATURE-RELATIVE HUMIDITY 11-13/03



GRAPH 26 - COMPARISON INSIDE TEMPERATURE-RELATIVE HUMIDITY 17-21/03



GRAPH 27 - COMPARISON INSIDE TEMPERATURE-RELATIVE HUMIDITY 24-25/03



GRAPH 28 - COMPARISON INSIDE TEMPERATURE-RELATIVE HUMIDITY 27-31/03

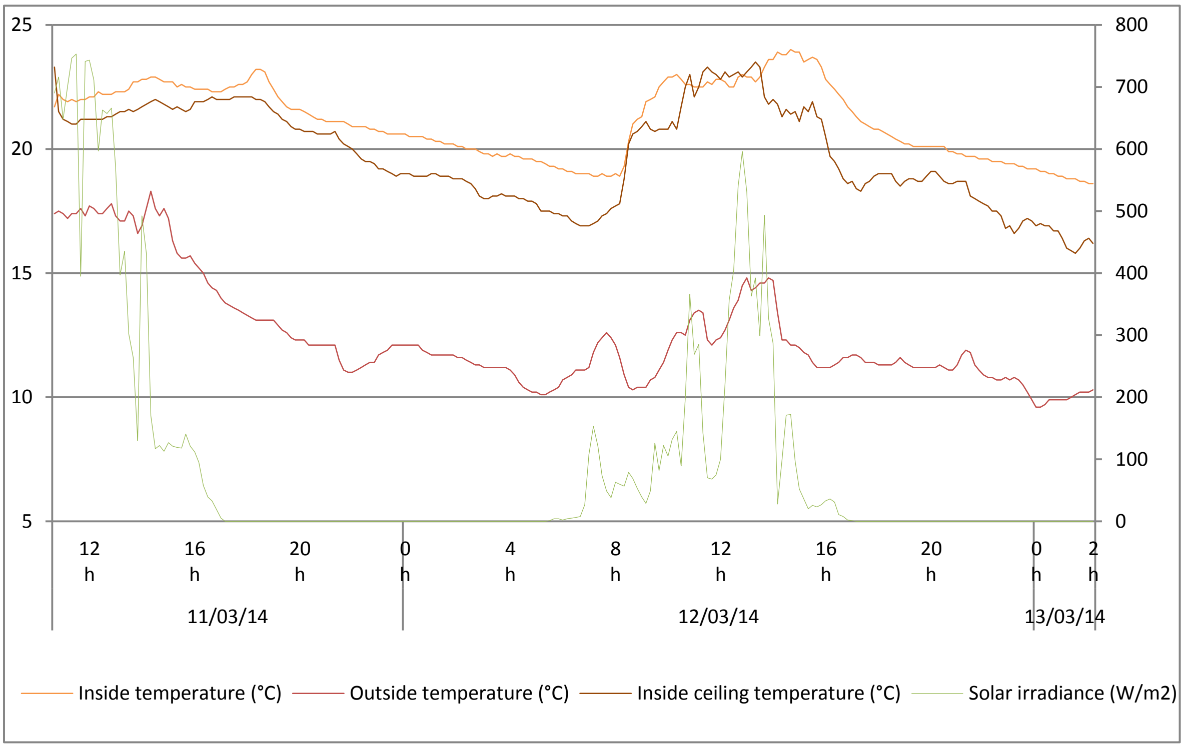
5.1.2.4. TEMPERATURES AND HUMIDITY RATES OF FALSE CEILING

The comparison of temperatures and humidity rates in the false ceiling are similar to the paragraph the previous paragraphs and therefore not added to the paper.

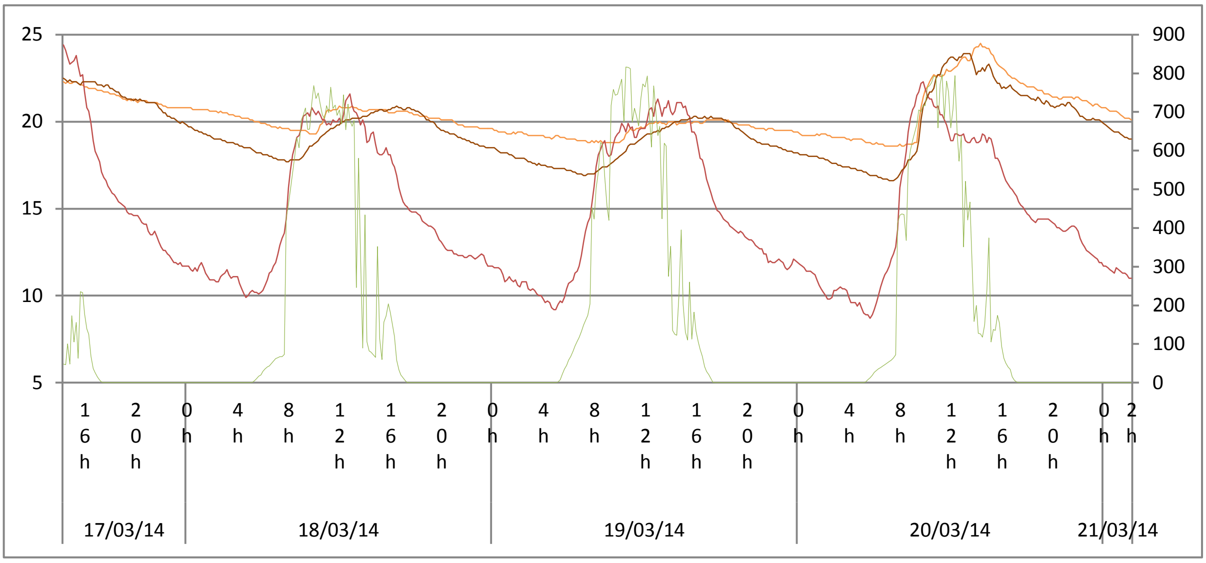
5.1.3. Comparing inside and outside measurements

5.1.3.1. Temperatures and solar irradiance

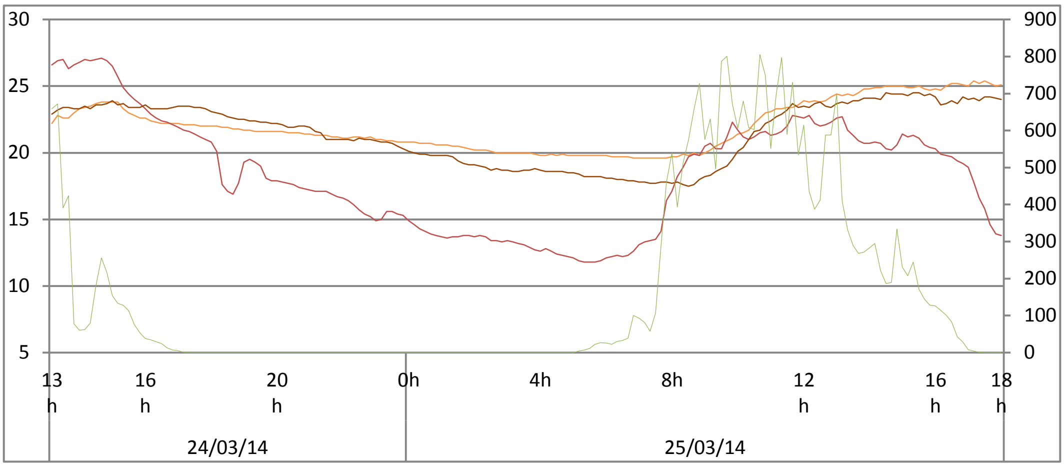
The measured in- and outside temperatures are compared and presented in Graph 29,graph 3 , graph 31 and **Fout! Verwijzingsbron niet gevonden.**There can be made a difference between working days and weekends or holidays. During weekends or holidays the inside temperatures depend much more on the outside weather conditions. On warm, sunny days comfortable inside temperatures are reached and the difference between outside and inside maxima is small. On colder, cloudy days the inside temperatures are more levelled. If we compare a holiday (19th) and a working day (20th) with similar outside temperatures next to the obvious difference in inside temperatures the difference in the slope of the curves in the beginning and the end of the day indicates the beginning and ending of the period during which the heating is switched on. During working hours, the inside temperatures are more independent from the outside weather conditions. The temperatures are kept higher than 20°C. There is never any risk of overheating during the measuring period. Taking into account the period of collecting the measurements this is quite normal, but this is certainly not the case the whole year round.



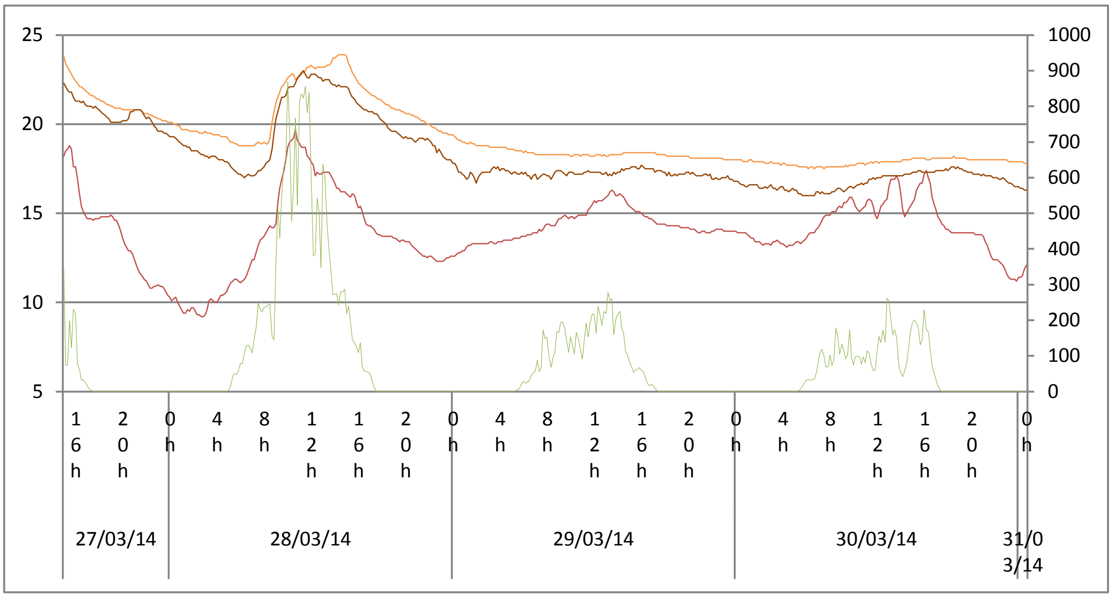
GRAPH 29 – COMPARISON TEMPERTURES-SOLAR IRRADIANCE 11-13/03



GRAPH 32 – COMPARISON TEMPERATURES-SOLAR IRRADIANCE 17-21/03



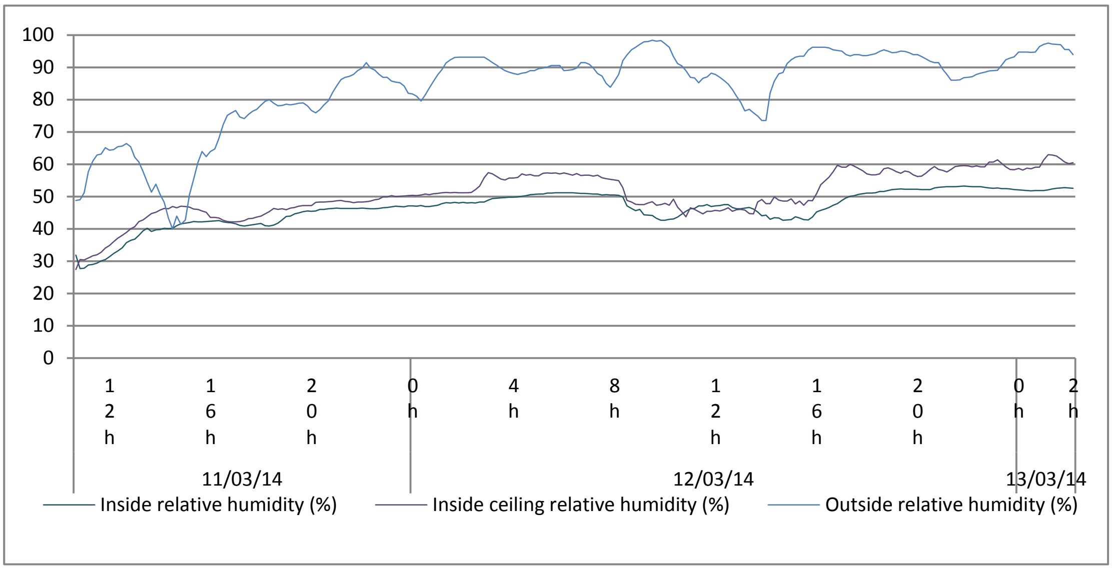
GRAPH 31 – COMPARISON TEMPERATURES-SOLAR IRRADIANCE 24-25/03



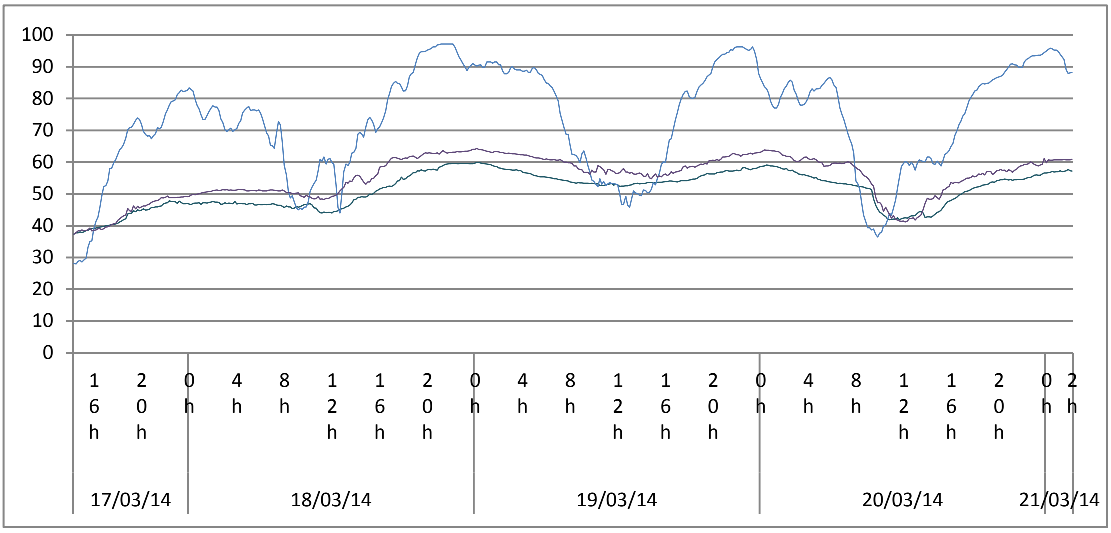
GRAPH 300 – COMPARISON TEMPERATURES-SOLAR IRRADIANCE 27-31/03

5.1.3.2. Humidity rates

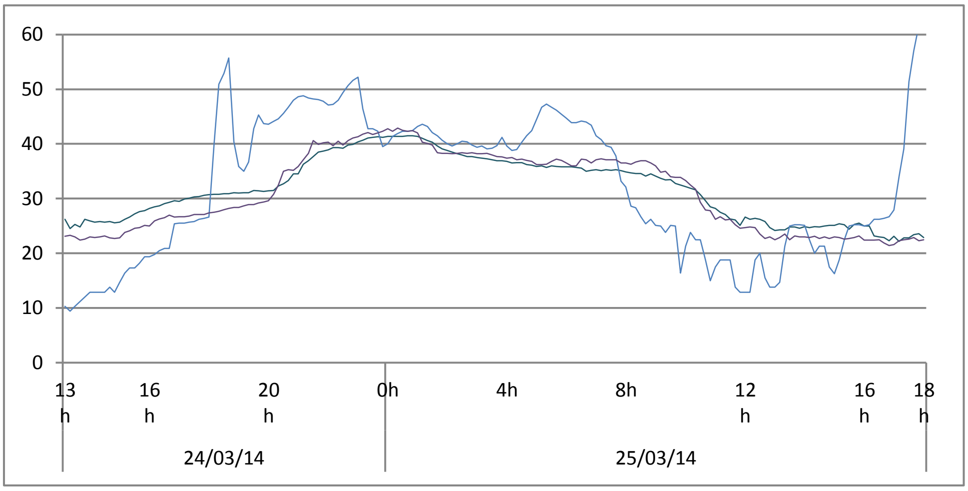
The in- and outside humidity rates are compared and presented on Graph 33, Graph 34, Graph 35 and Graph 36. The inside humidity rates is the secretariat and the false ceiling follow approximately the same path. During a big part of the data-collecting period the outside humidity rates are rather high. On Graph 33 and Graph 34 there can be seen two contradictory periods. On the first graph the outside humidity stays high during several days, this can also be seen on Graph 36. On the second graph the outside humidity meats the inside humidity rates during daytime. This has something to do with the time during which it was raining. There can be concluded that during weekends or holidays the inside humidity rates follow the outside humidity rates with ceiling humidity can mount up higher than the secretariat's humidity rate. During working days on the other hand the inside humidity rates are kept within bounds by the air conditioning.



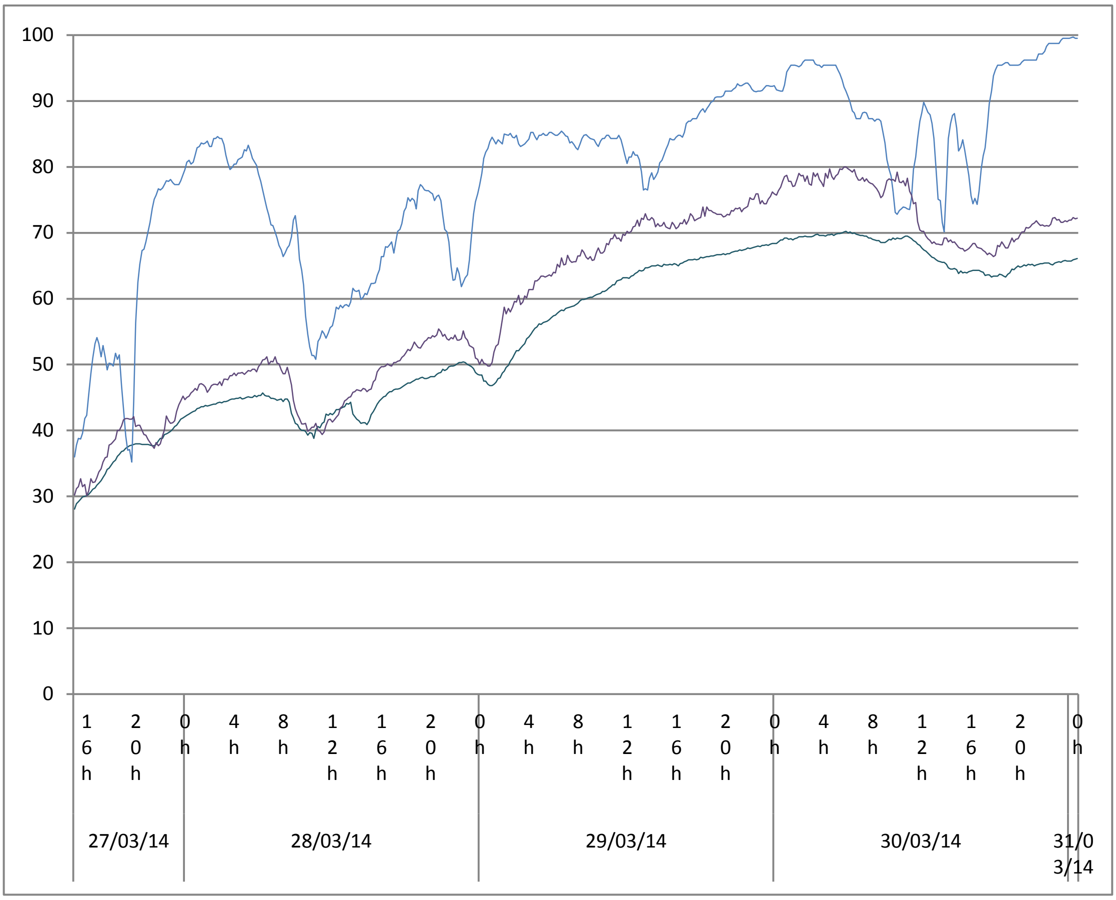
GRAPH 33 – COMPARISON INSIDE-OUTSIDE HUMIDITY RATES 11-13/03



GRAPH 34 - COMPARISON INSIDE-OUTSIDE HUMIDITY RATES 17-21/03



GRAPH 35 - COMPARISON INSIDE-OUTSIDE HUMIDITY RATES 24-25/03



GRAPH 36 - COMPARISON INSIDE-OUTSIDE HUMIDITY RATES 27-31/03

5.1.4. CONCLUSION

By this making this comparison it has become clear that the outside weather conditions have influence on the inside air conditions. But it's not that simple, because a lot of different parameters have to be considered to make a conclusion. A general conclusion cannot be made, but it can be separated into working days and weekends or holidays. During working days the inside temperatures and humidity rates are less independent from the outside parameters. This is due to the air conditioning devices inside. During holidays and weekends the opposite is determined.

The weather data are taken in a month with very moderate conditions. It would have been better to measure extreme weather conditions during winter and summer. They have the biggest influence on the energy demand of the building. Hot temperatures to determine the amount over overheating and thereby the effect on the cooling demand and on the other hand cold temperatures to determine the effect on the heating demand. Unfortunately our time scope was too small to do so. Nevertheless some insights were created to understand the mutual influences of the different parameters. Lastly, there no information known about the low basement between the ground and the floor slab. It may have been a good idea to put a heat sensor there as well.

5.2. VALIDATING THE TRNSYS MODEL

The TRNSYS model has to be checked on its correctness and precision of the outputs before making modifications or improvements. The model's accurateness can be revised by comparing the measured inside temperatures with the output temperatures from TRNSYS. Also the energy demand of the model is analysed.

5.2.1. COMPARING TEMPERATURE MEASUREMENTS WITH OUTPUTS TRNSYS

The inside temperature measurements are very important parameters for the validation of the TRNSYS model. They are the connection between reality and the virtual air conditions created in the model. To compare them, the output of TRNSYS has to be fitted to the measured data. We obtained the secretariat's temperature measurements for 5 separate periods:

- 11/03/2012 (11:40) → 13/03/2014 (2:10)
- 17/03/2014 (14:20) → 21/03/2014 (2:10)
- 24/03/2014 (13:10) → 25/03/2014 (18:00)
- 27/03/2014 (15:00) → 31/03/2014 (00:40)
- 31/03/2014 (13:30) → 04/04/2014 (11:40) (no ceiling temperature)

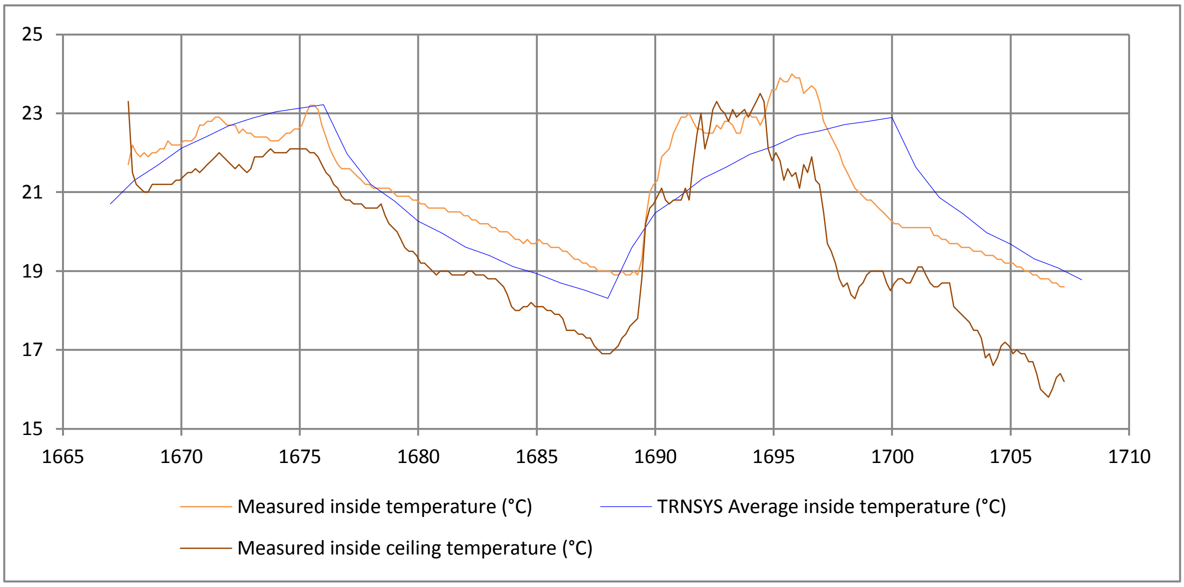
First of all the minimum and maximum temperature in the room (during a workday) had to be checked. The initial set temperature of the heating and cooling had to be the same as the one in reality. The set temperature in reality was around 20°C for the heating. This corresponds with the initial estimated value in TRNSYS. It's more difficult to check the set temperature of the cooling. The maximum temperatures inside the secretariat were never reached like in summer. But the initial temperature of 25°C that we supposed in TRNSYS was never exceeded, so this value could be retained.

A problem occurred while designing the connection between the suspended ceiling and the room. When the airflow connections were made, the temperatures were not following the measured ones. That's why heating and cooling in the ceiling was introduced to obtain a similar curve for these temperatures.

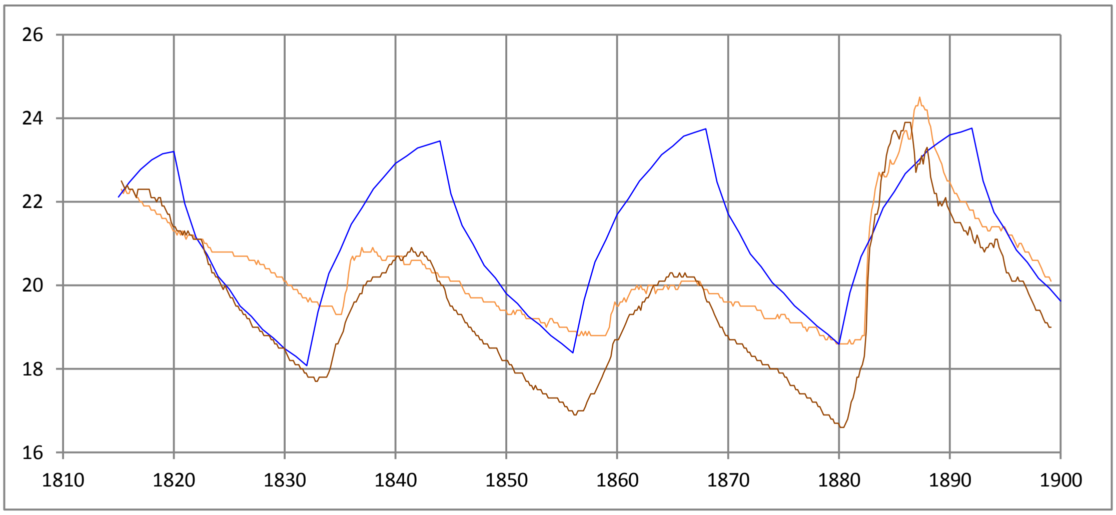
In reality the temperature curves of the ceiling and room are close to each other. So by conditioning the ceiling the influence of the ceiling can be minimalized, but not equalized. The big difference is that the temperature raise caused by the heat gains doesn't have influence on the temperatures in ceiling. As result we have a temperature curve of the ceiling the follows the temperature in the secretariat but without the irregular shape.

5.2.1.1. COMPARISON OF THE INSIDE TEMPERATURES

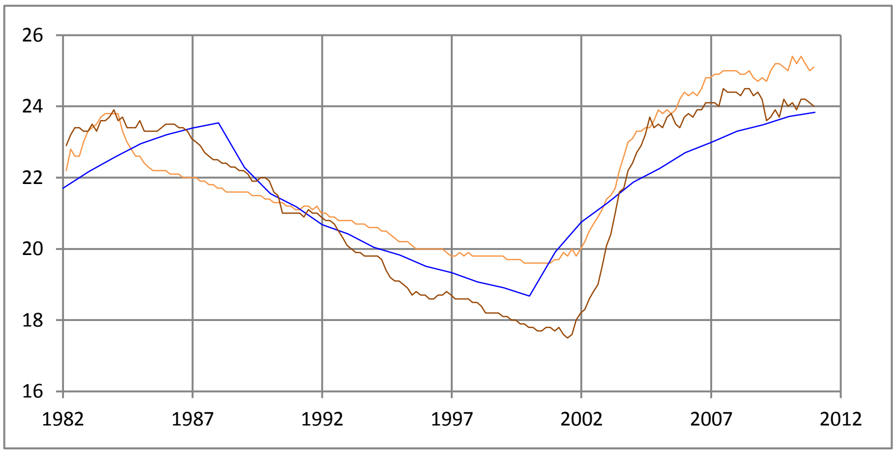
On the following graphs the measured inside temperature curve is compared with the temperature curve that is given by TRNSYS (Graph 37, Graph 38, Graph 39, Graph 40 and Graph 41). The difference in volatility between the two curves immediately stands out. This is because the TRNSYS model is a computer simulation, which is not the same as real time data collection. The curve of the TRNSYS model follows the inside temperatures roughly. Differences can be determined in the time and values of the peaks and troughts. The difference in the values are acceptable never exceeding 1°C and the amplitude of the curves is largely the same. Between the hours 1815 and 1875 there is a big difference, this is because these were holidays and are not taken into account by TRNSYS. The time difference between peaks and troughts is a more difficult issue to understand. We see that the heating periods of the TRNSYS curve starts earlier and continues longer. This confirms the insecurity about the time during which the heating devices are switched on in reality. For TRNSYS the temperatures during a working day have to be between 20°C and 26°C. This is a big difference with the real temperature data. The slope of the temperature curves are different as well. This can be due to the absence of some issues in the TRNSYS model. First of all we have the two extra air heating and cooling devices and the electrical heaters in the secretariat that haven't been taken into account in the model. Also we have to keep in mind that in reality the furniture holds an amount of heat. So the room reaches the requested temperature faster, due to this extra heat load. TRNSYS assumes and empty secretariat with the only heating gains are the internal and internal heating gains which we put in. Moreover, in reality there can be more or less persons present or more or less computers and lights switched on.



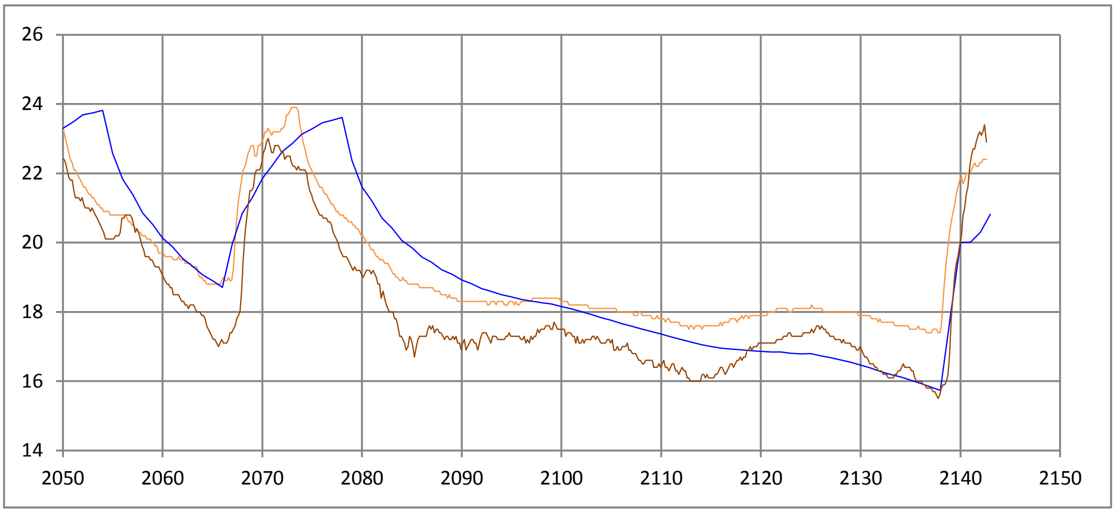
GRAPH 37 – COMPARISON INSIDE TEMPERATURES 11-13/03



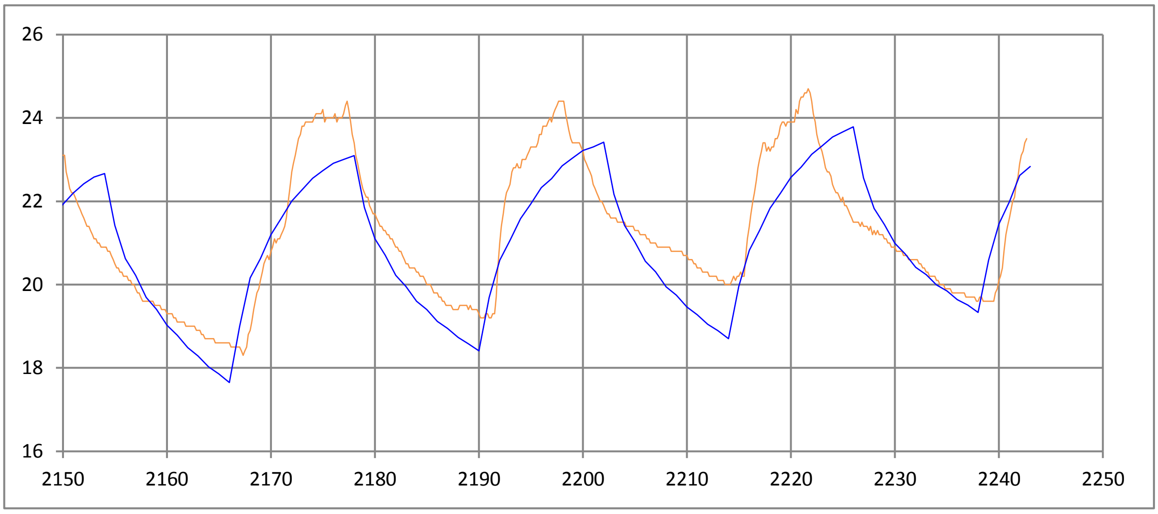
GRAPH 38 - COMPARISON INSIDE TEMPERATURES 17-21/03



GRAPH 39 - COMPARISON INSIDE TEMPERATURES 24-25/03



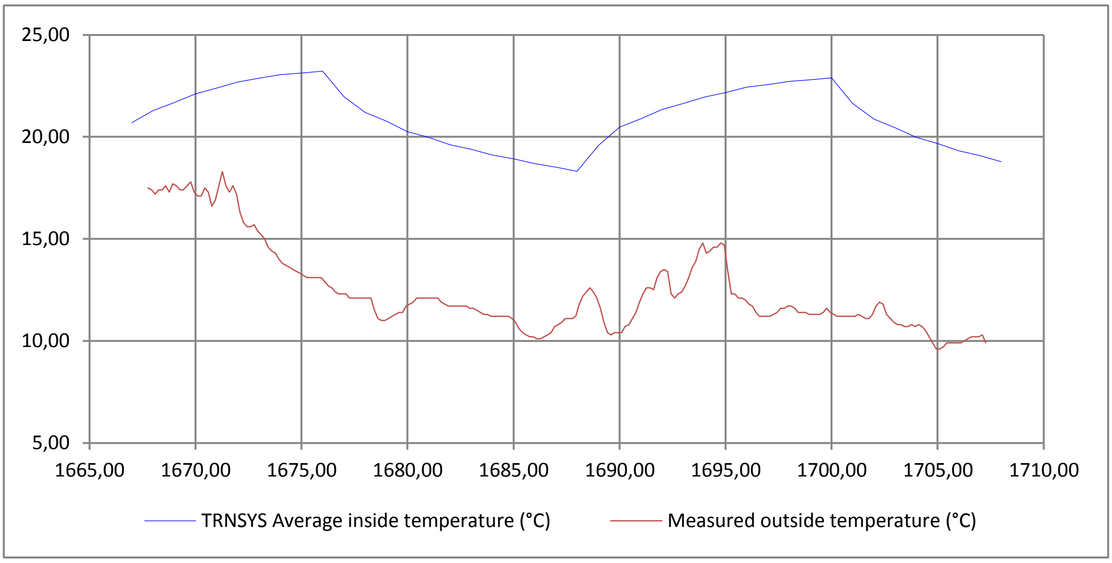
GRAPH 41 – COMPARISON INSIDE TEMPERATURES 27-31/03



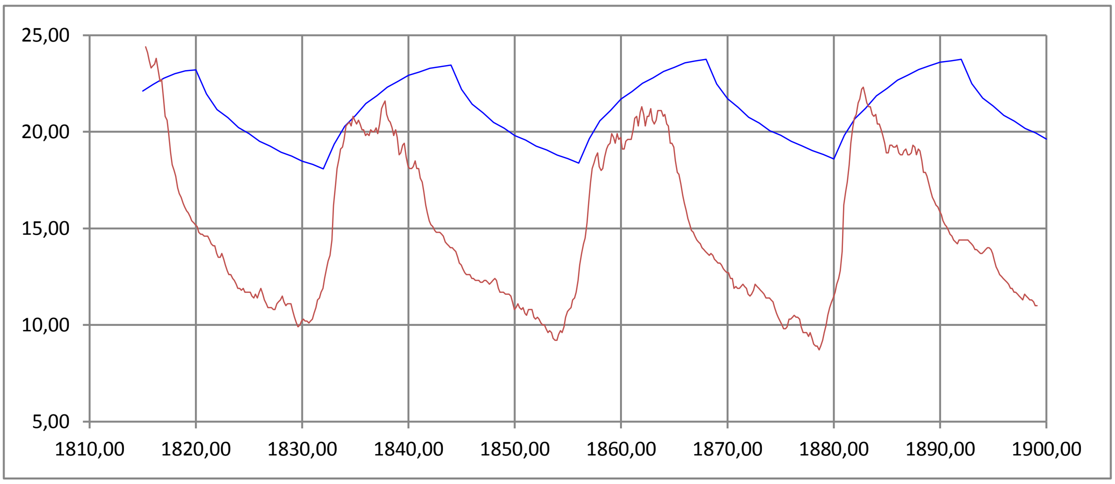
GRAPH 40 – COMPARISON INSIDE TEMPERATURES 31/03-04/04

5.2.1.2. Comparing inside and outside temperature

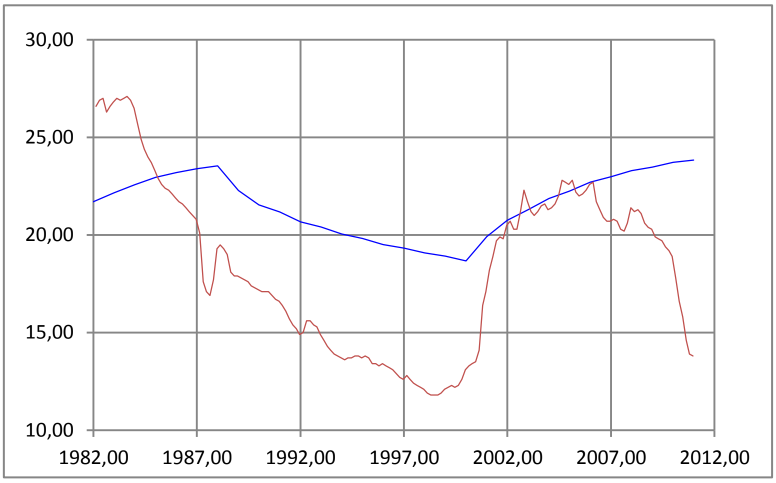
If the TRNSYS output temperature is compared with the outside temperature (Graph 42, Graph 43, Graph 44, Graph 45 and Graph 46) we can determine some similarities and some differences with the measured inside temperatures. During working days, when the conditioning devices are switched on, there can be no real influence on the inside temperature determined. This is in line with the measurements. On the other hand during weekends the outside weather conditions don't have an influence on the inside temperature. This different from reality where inside temperatures are evolving with the outside ones. This makes us believe that there are some differences in the performance of the structural elements and the physical aspects of the building and the TRNSYS model. As there are for example the heat, air and solar transfer trough the thermal envelope of the building. A lot of these parameters were made on assumptions because of the lack the real data.



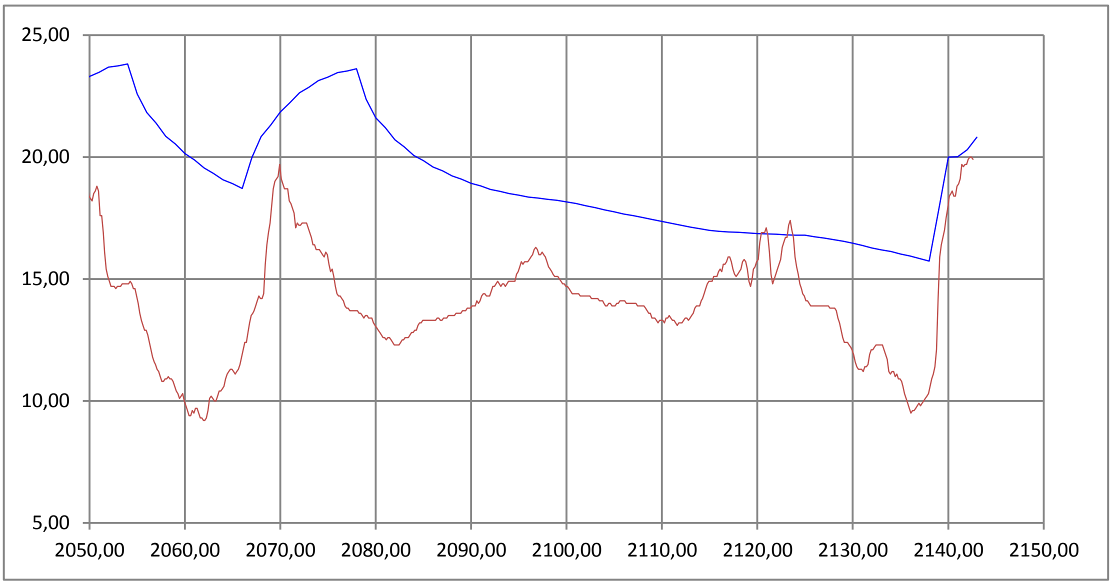
GRAPH 42 – COMPARISON OUTSIDE –TRNSYS TEMPERATURE 11-13/03



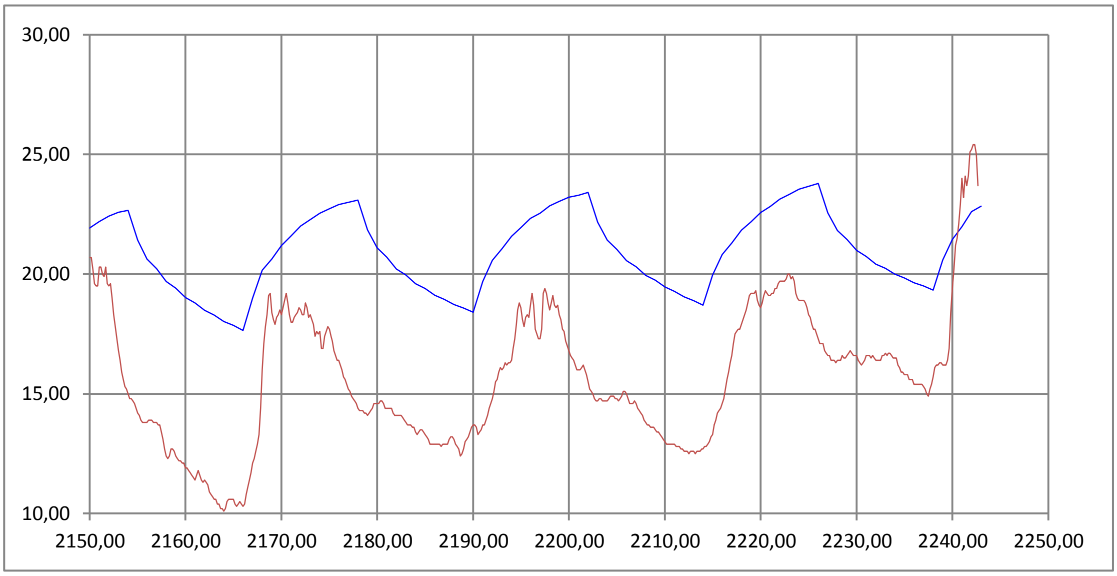
GRAPH 43 - COMPARISON OUTSIDE –TRNSYS TEMPERATURE 17-21/03



GRAPH 44 - COMPARISON OUTSIDE –TRNSYS TEMPERATURE 24-25/03



GRAPH 45 - COMPARISON OUTSIDE –TRNSYS TEMPERATURE 27-31/03



GRAPH 46 - COMPARISON OUTSIDE –TRNSYS TEMPERATURE 31/03-4/04

5.2.1.3. CONCLUSION

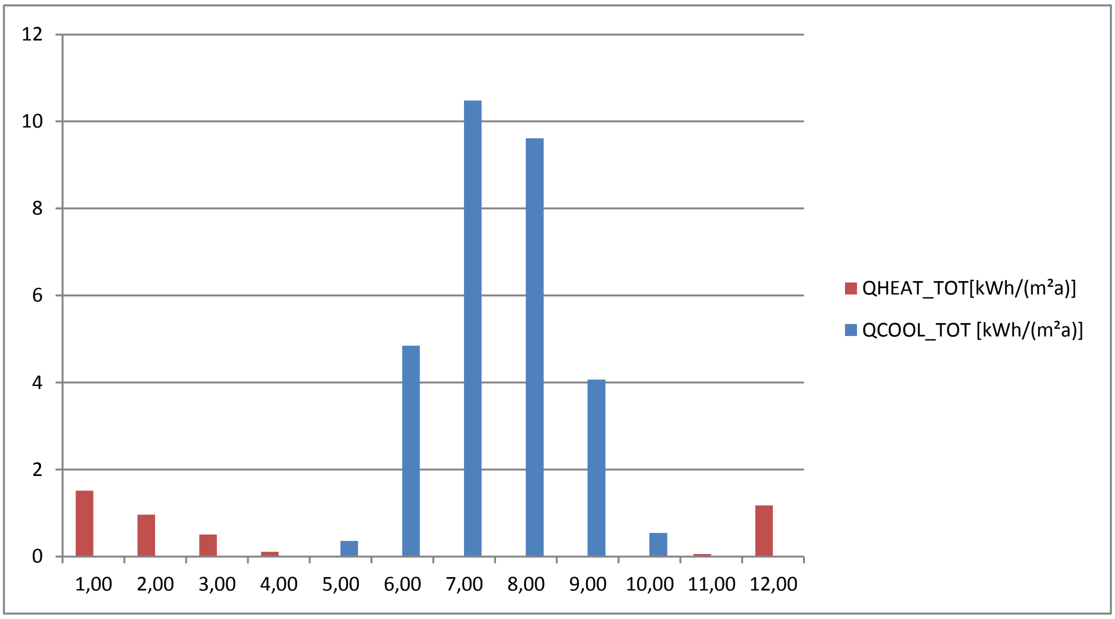
We conclude that the output of TRNSYS is acceptable considering the big amount of assumption that had to be made. This model could of course be finetuned to have an even better correspondence with the real situation. Unfortunatly this exceeds our knowledge about TRNSYS and about the building.

5.2.2. ANALYZING THE ENERGY DEMAND

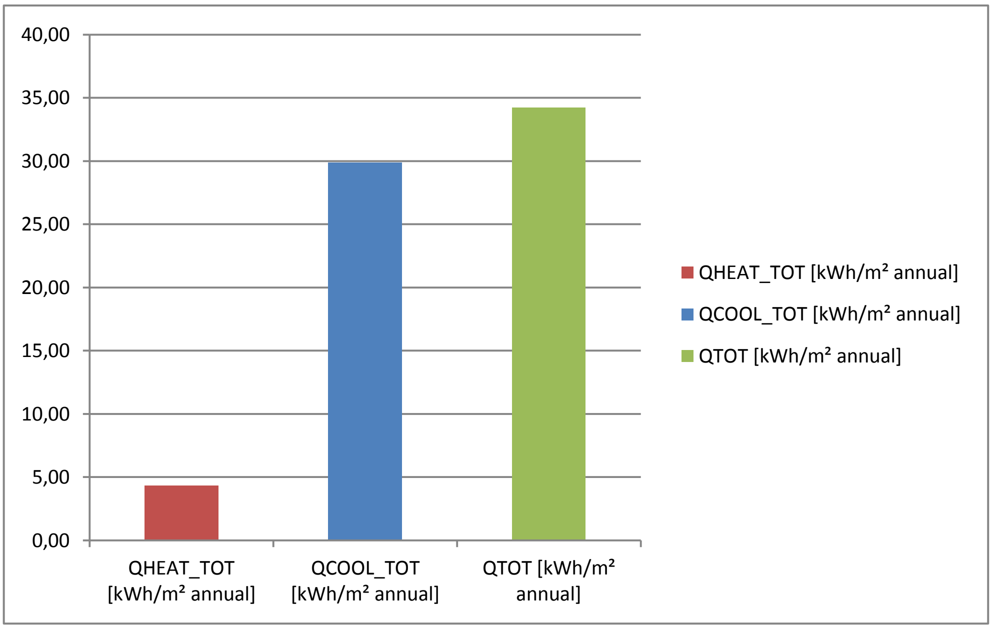
To obtain the total annual cooling and hetaing demand of the secretariat the simulation is runned for one year. The results of the calculation are presented in Table 18 and in Graph 47 and Graph 48, which present the monthly and annual total heating demands respectively. The first conclusion is that the energy demand for cooling is much bigger than the energy demand for heating. Also during one year there are 6 months when cooling is needed and 7 months where heating is needed. The total energy demand for the secretariat is 43.22 kWh/m^2 for one year. This value is very small and much smaller than expected. It was expected that the cooling demand would be bigger than the heating demand, because of the Mediterrenean climate with mild winters and hot summers but was not expected to be that low. If we compare with the main total annual energy demand for Valencia that amounts around 45 kWh/m^2 according to Boletin Oficial de Estado for Valencia. (http://www.boe.es/boe/dias/2013/09/12/pdfs/BOE-A-2013-9511.pdf, p.9). But this building is very old and has poor thermal envelope conditions, so the energy demand was expected to be even higher than this value. On the other hand it has to be meantioned that this is the energy demand for the secretariat alone. Because the secretariat is surrounded by areas that are conditioned as well and there is only contact with outside over a small piece of wall, this energy demand has to be put in perspective. Obtaining the energy demand for the whole thermal zone, would be a good way to watch if this value is acceptable. Unfortunately we were not capable to calculate this value due to errors we couldn't resolve. Classifying this result as good or bad is really hard because we can't compare it with any previous studies. There had to be made a lot of assumptions that could cause a big difference in the secretariat's energy demand that we were unable to define properly. This result has to be considered and put more into perspective in the follow-up of this paper when modifying the building characteristics.

	QHEAT_TOT[kWh/(m^{2}a)]	QCOOL_TOT [kWh/(m^{2}a)]
January	1,514	0,000
February	0,963	0,000
March	0,503	0,000
April	0,110	0,000
May	0,000	0,355
June	0,000	4,845
July	0,000	10,478
August	0,000	9,614
September	0,000	4,067
October	0,007	0,538
November	0,052	0,000
December	1,176	0,000
Total year	4,33	29,9
Global energy demand:	**34.22 [kWh/(m^{2}a)]**	

TABLE 18 – PRESENT ENERGY DEMANDS MONTHLY AND ANNUAL



GRAPH 47 - PRESENT MONTHLY HEATING AND COOLING DEMAND



GRAPH 48 - PRESENT ANNUAL ENERGY DEMANDS

To meet the passive house standard the requirements for energy demand have to be fullfilled by the building. The standard requires heating and cooling demands to be 15 kWh/(m^2a) or less. The secretariat's heating demand meets the objective, but the cooling demand doesn't meet the target value. The heating demand doesn't have to be reduced to meet the passive house standard, but some modifications are still made to evaluate their effect on both the cooling and heating demand. Also the modifications can effect the other rooms which can in their turn have an effect on the secretariat.

It was impossible to know if the primary energy demands is 120 kWh/(m^{2}a) or less. There was not enough information about the machines used in this zone to calculate this value. There is no hot water in the building and there is no specific data about the heating, cooling and extra electrical devices. So without knowing the energy needed to obtain the 15 kWh/(m^{2}a) for cooling and heating, it is impossible to compare them.

5.3. MODIFICATION OF THE BUILDING

Modifications are done to the secretariat's building components to decrease the energy demand. The modifications are all implemented and analysed separately to see their individual influence on the energy demand.

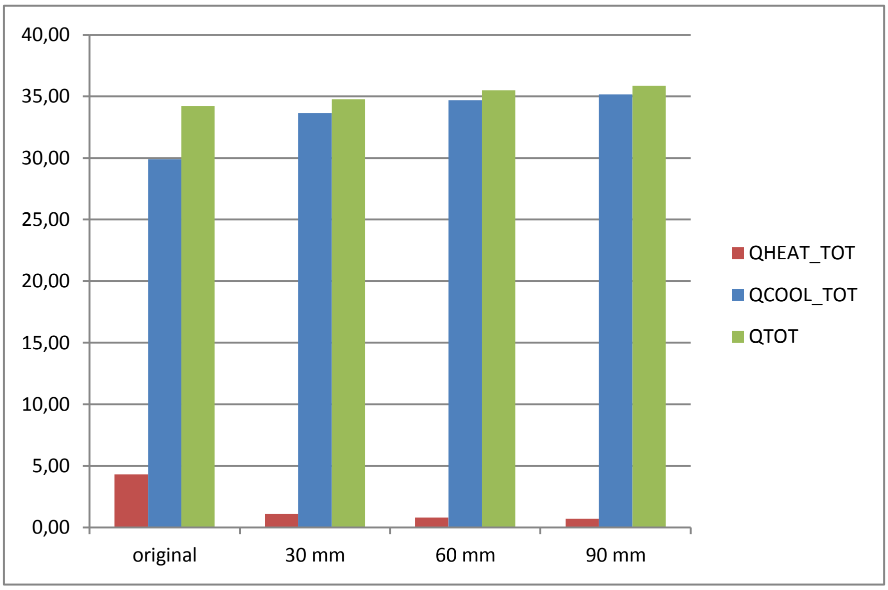
5.3.1. MODIFICATION OF THE THERMAL INSULATION

5.3.1.1. WALL INSULATION

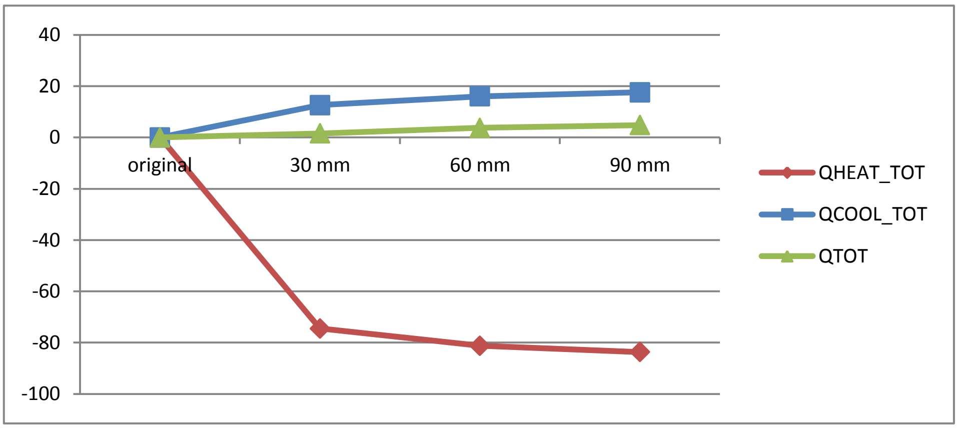
The effect of improving the U-value of the outer wall on the energy demand of the secretary by adding different thicknesses of insulation is analysed and represented in Table 19 and in Graph 49 and Graph 50. The secretariat has only a small part of outside wall, the main part is of the vertical walls are next to interior spaces. The outer wall has a surface of 32.09m^2 out of the total surface for the thermal zone of 776.23 m^2 that is analysed. The present U-value of the wall is 1.950 W/(m^{2}K).

	QHEAT_TOT [kWh/(m^{2}a)]	QCOOL_TOT [kWh/(m^{2}a)]	QTOT [kWh/(m^{2}a)]
Original	4,33	29,90	34,22
30 mm	1,10	33,66	34,76
60 mm	0,81	34,70	35,51
90 mm	0,71	35,17	35,87

TABLE 19 - ENERGY DEMANDS FOR MODIFICATION OF THE WALL INSULATION



GRAPH 49 - ENERGY DEMANDS FOR MODIFICATION OF THE WALL INSULATION



GRAPH 50 – VARIATION OF ENERGY DEMANDS FOR MODIFICATION OF THE WALL INSULATION

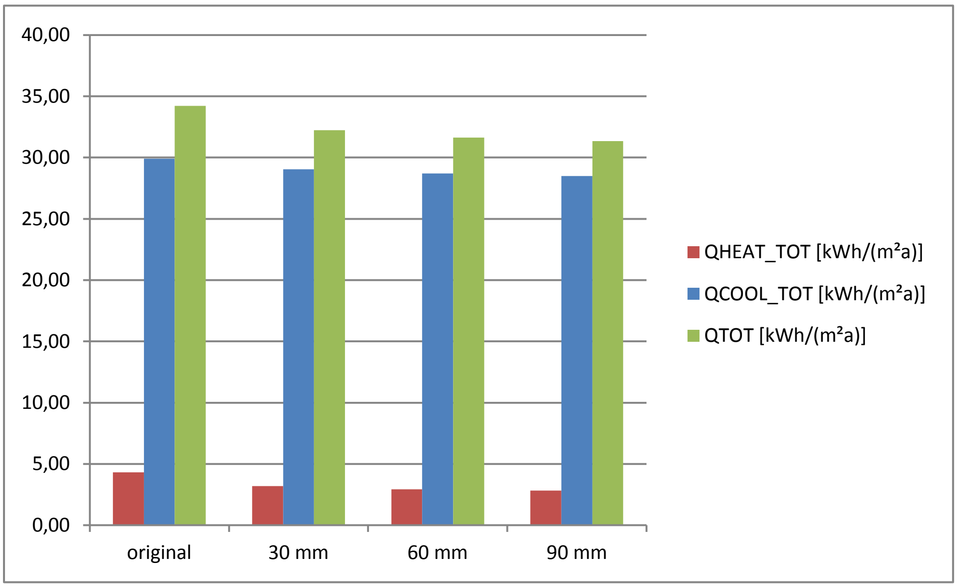
Adding thermal insulation to the outer wall has a positive influence on the heating demand and a negative effect on the cooling demand. The thermal insulation decreases the heat transfer trough the wall. So conditions inside are less influenced by the outside weather conditions in winter and summer. To that extent a decrease of both heating and cooling demand is expected. The insulation has a negative effect on the cooling demand because the internal heat gains ensure an increase of the temperature but the temperature is less transmitted to the outside. Also during summer nights for example when the temperature outside has decreased, the inside temperature doesn't decrease automatically because of the higher thermal resistance of the wall. A positive effect could have been expected when the outer wall was oriented to the south, so it has more influence on the chance of overheating of the secretariat. This is not the case for the secretariat. This leads to a faster overheating of the building and a higher cooling demand. The result is also a higher total energy demand because the cooling demand is dominant to the heating demand. This is normal in warm climates where the reason of insulation in the winter has a reverse effect in the summer.

5.3.1.2. ROOF INSULATION

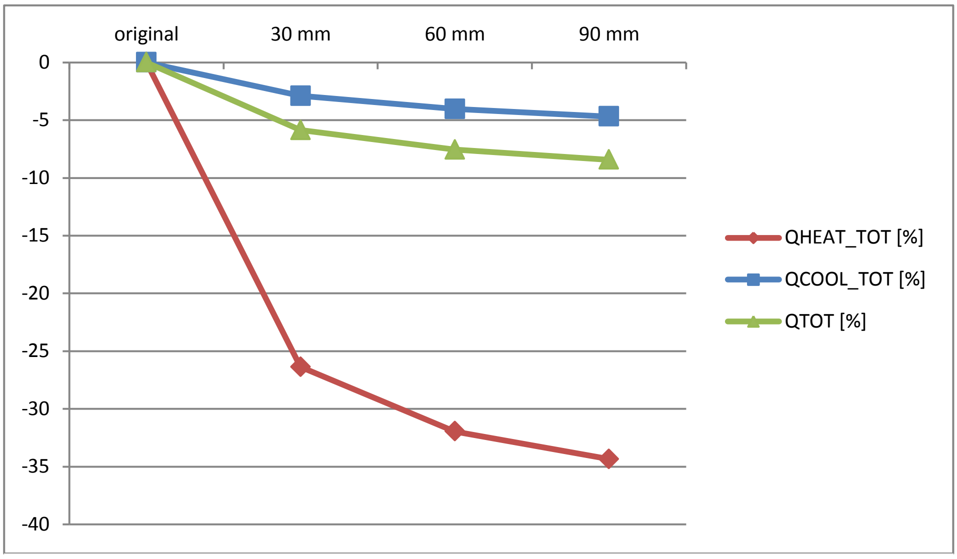
The effect of improving the U-value of the roof slab on the energy demand of the secretary by adding different thicknesses of insulation is analysed and represented in Table 20 and in Graph 51 and Graph 52. In comparison with the outside wall the roof of the secretariat has a much larger contact area with outside. The roof's contact area is 204.39m^2 of the total 1501.68m^2 of the thermal zone. The present U-value of the roof is 1.42 W/(m^{2}K). The insulation is placed between the waterproofing and the gravel.

	QHEAT_TOT [kWh/(m²a)]	QCOOL_TOT [kWh/(m²a)]	QTOT [kWh/(m²a)]
Present case	4,33	29,90	34,22
30 mm	3,19	29,03	32,22
60 mm	2,94	28,69	31,64
90 mm	2,84	28,50	31,34

TABLE 20 - ENERGY DEMANDS FOR MODIFICATION OF THE ROOF INSULATION



GRAPH 51 - ENERGY DEMANDS FOR MODIFICATION OF THE ROOF INSULATION



GRAPH 52 – VARIATION OF ENERGY DEMANDS FOR MODIFICATION OF THE ROOF INSULATION

Adding thermal insulation to the roof slab has a positive influence on both the heating and cooling demand. The thermal insulation decreases the heat transfer through the roof slab. This positive effect on the heating demand is the same as for the wall insulation. Less heat is lost in winter. The positive effect on the cooling demand is smaller because there are two opposite effects. The building can't lose their heat that easy but on the other hand it's also more difficult for the heat to enter the building when the sun is shining on the roof and the surface temperature becomes really high. The positive effect on the heating demand is much lower than the effect of the wall insulation. This is due to bigger exposure of the roof to the sun in comparison with the wall. That's why the effect on the heating demand is smaller. We can conclude that this is a good improvement for the energy demand of the secretariat.

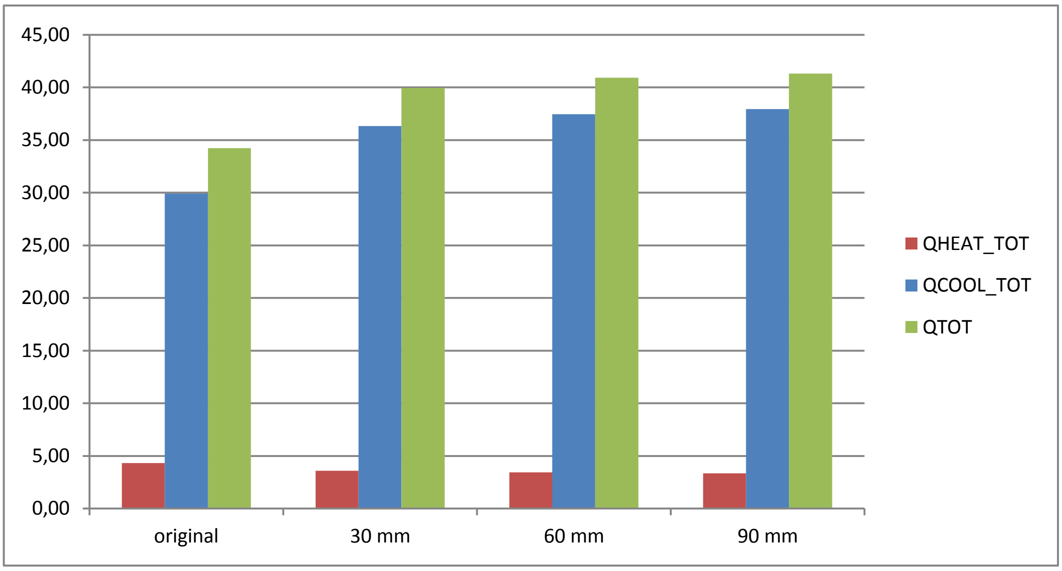
5.3.1.3. Floor insulation

The effect of improving the U-value of the floor slab on the energy demand of the secretary by adding different thicknesses of insulation is analysed and represented in

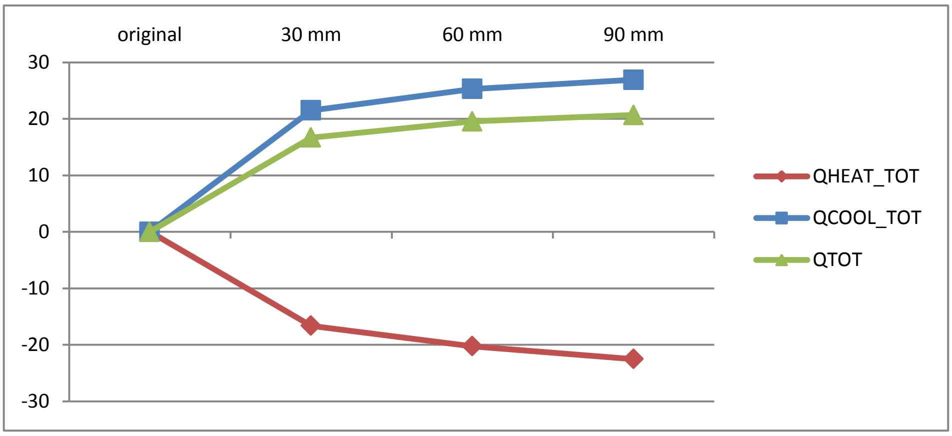
Table 21 and in Graph 53 and Graph 54. The floor has a present U-value of 2.02 W/(m²K). The area is 204.39m², which is the same as the area of the roof.

	QHEAT_TOT [kWh/(m²a)]	QCOOL_TOT [kWh/(m²a)]	QTOT [kWh/(m²a)]
original	4,326	29,899	34,224
30 mm	3,606	36,331	39,937
60 mm	3,450	37,466	40,916
90 mm	3,351	37,947	41,299

TABLE 21 - ENERGY DEMANDS FOR MODIFICATION OF THE FLOOR INSULATION



GRAPH 53 - ENERGY DEMANDS FOR MODIFICATION OF THE FLOOR INSULATION



GRAPH 54 – VARIATION OF ENERGY DEMANDS FOR MODIFICATION OF THE FLOOR INSULATION

Adding thermal insulation to the outer wall has a positive influence on the heating demand and a negative effect on the cooling demand. During winter the colder soil temperature will cool down the air in the basement. This will affect the temperature in the room due to the heat stream from the rooms to the basement. This means that the heating has to do an effort to keep the temperature on level. When we insert insulation, this will be reduced. In summer the opposite will occur.

Normally the cooler air in the basement, due to the colder soil, will lead to a natural cooling effect of the secretariat. When we put insulation in between, this will not happen and an increase off the cooling demand is inevitable. The thermal insulation decreases the heat transfer through the floor.

5.3.2. CHANGING THE WINDOWS

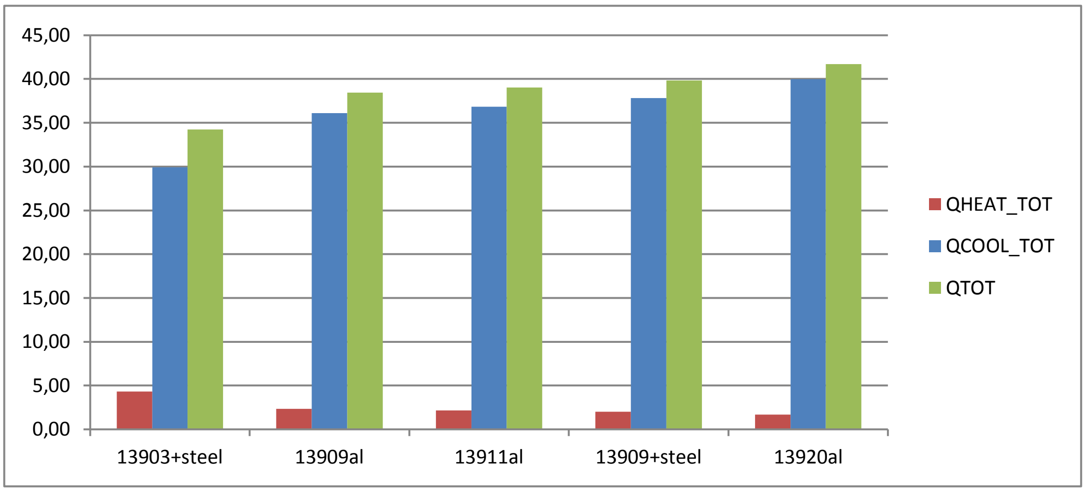
The present windows are in clear single glass of 6mm with framework in painted stainless steel. The windows are changed to analyse their effect on the energy demand. The new windows are choosen out of the library in TRNSYS. In Table 22 the different types off windows and their specifications that we used to evaluate their influence are listed. We chose to only consider double glass windows with a frame either in steel or aluminium.

types	Glass	ID Window	Solar factor $g_{\perp}$ [%/100]	U_{glass} [W/m²K]	Window frame	U_{frame} [W/m²K]
Initial	Clear 4mm	13903	0.84	5.73	Steel	5.7
4/6/4	Clear 4/6/4	13909	0.76	3.44	Al	3
6/8/6	Clear 6/8/6	13911	0.72	3.21	Al	3
4/6/4	Clear 4/6/4	13909	0.76	3.44	Steel	5.7
4/8/4	Double emis. 4/8/4	13920	0.76	2.48	Al	3

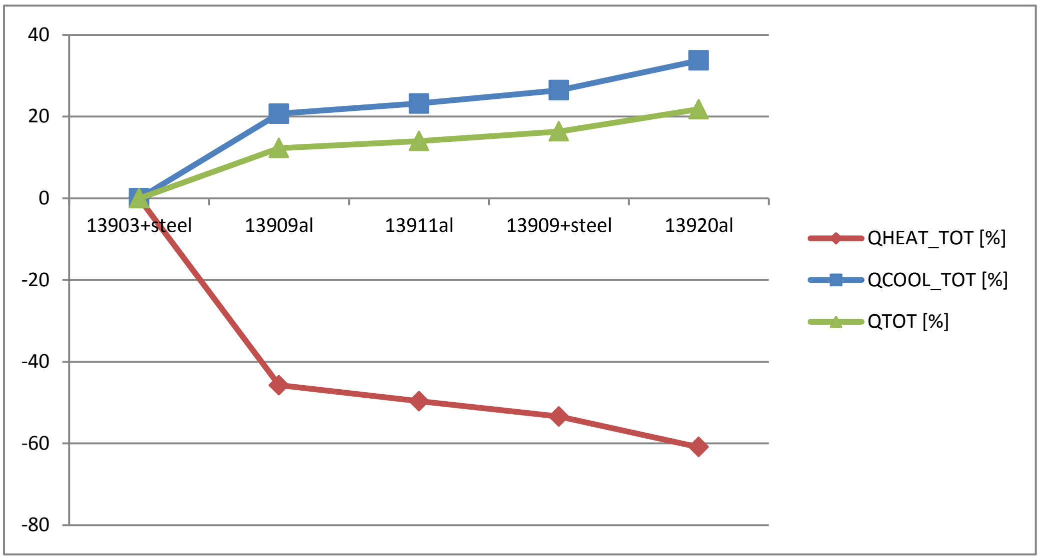
TABLE 22 – TYPES AND SPECIFICATIONS OF THE WINDOWS

	QHEAT_TOT [kWh/(m²a)]	QCOOL_TOT [kWh/(m²a)]	QTOT [kWh/(m²a)]
13903+steel	4,32	29,90	34,23
13909al	2,34	36,09	38,43
13911al	2,18	36,84	39,01
13909+steel	2,01	37,81	39,82
13920al	1,69	39,99	41,68

TABLE 23 - ENERGY DEMANDS FOR CHANGES OF THE WINDOWS



GRAPH 55 - ENERGY DEMANDS FOR CHANGES OF THE WINDOWS



GRAPH 56 – VARIATION OF ENERGY DEMANDS FOR CHANGES OF THE WINDOWS

The results of these modifications are presented in Table 23 and in Graph 55 and Graph 56. To analyse these results two influences have to be considered. First of all there is the improvement of the insulating capacity of the windows caused by the air (or sometimes gas) between the two glass plates and by the bigger thermal resistance of the framework. Also the airtightness of the windows is improved. Secondly the solar energy transmittance (g-factor) of the glass is decreased. These two factors cause less influence of the outside weather conditions on the inside ones. With single glass the heat flows very easily to the colder volume. The heating demand decreases when the single glass is changed by double glass. The cooling demand on the other hand increases quite a lot depending on the type of window. This has the same explanation as the previous modifications where the insulating capacity of the components is improved. The better the insulating part the more the heat transfer is decreased. This has positive effect on the heating demand and a negative effect on the cooling demand. The magnitude of the effect depends on the quantity of the two previous explained values.

There must not be forgotten that the blinds are still in front of the windows. The effect of the shading will be analysed below.

5.3.3. ADJUSTMENT OF THE OUTER BLINDS

The effect of the shading factor on the secretariat's energy demand is evaluated by changing the angle "alfa" (Figure 63) of the blinds. The higher the angle of the blinds the bigger is the shading on the windows. The effect of the blind adjustments on the energy demand of the secretariat is shown in Table 24 and in Graph 57 and Graph 58.

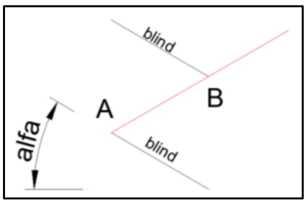


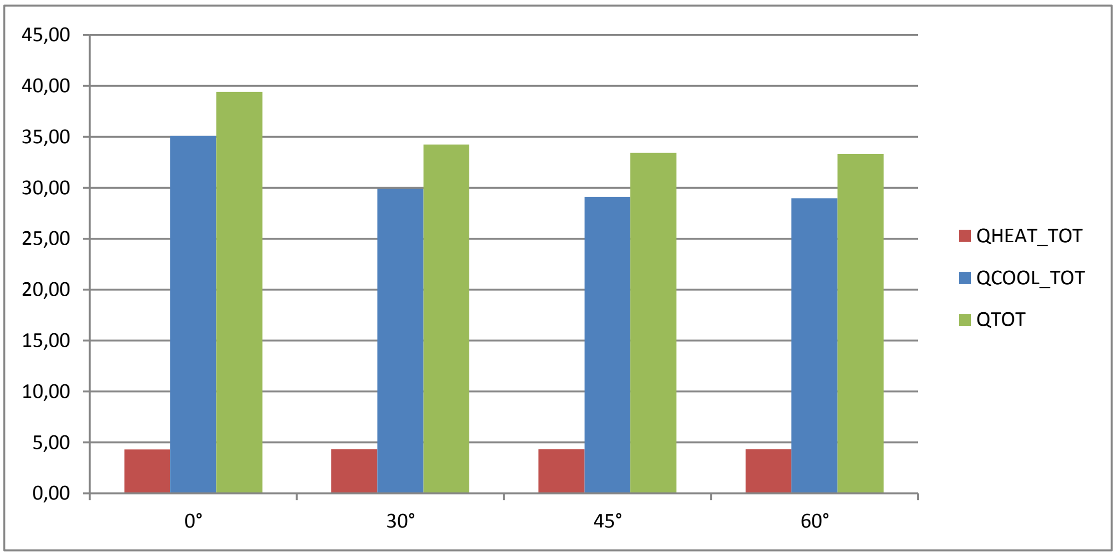
FIGURE 63 - SKETCH OF THE ANGLE OF BLINDS

In the equation in the simulation studio we only took the direct radiation into account. The diffuse radiation is important to have natural light into the building but it doesn't have a lot of influence on the cooling and heating demand.

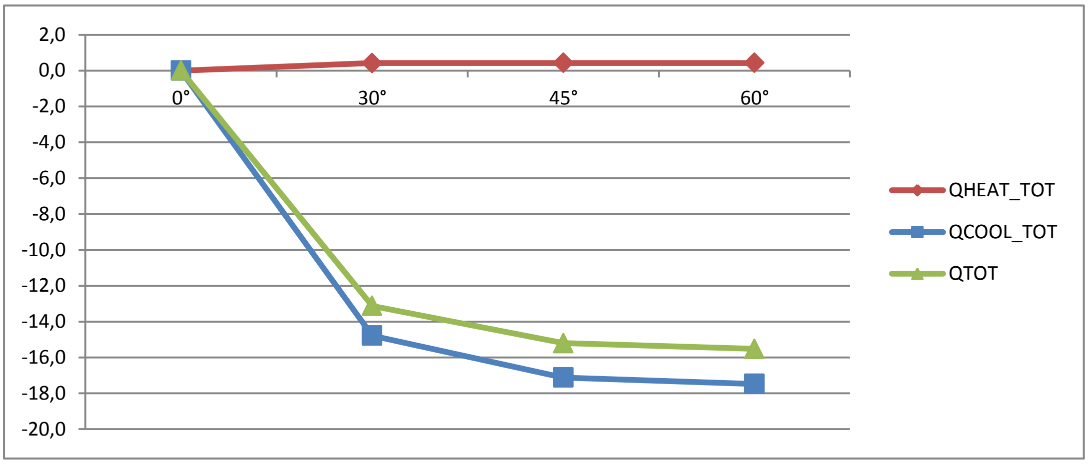
As expected the lowest cooling demand is when the angle is the biggest. This is the angle with the biggest shaded area on the window. The effect on the heating demand is almost nothing. It increases just a little bit because in winter, when the azitmuth of the sun is lower, the secretariat will gain more heat from the sun for 0° than with 60°, so the heat demand at 60° will be a little bit bigger. As can be deducted from Graph 58 this is a important modicifaction to reduce the cooling demand of the building because the heating demand is almost not affected.

alfa	QHEAT_TOT [kWh/(m²a)]	QCOOL_TOT [kWh/(m²a)]	QTOT [kWh/(m²a)]
0°	4,31	35,08	39,39
30°	4,33	29,90	34,22
45°	4,33	29,08	33,40
60°	4,33	28,95	33,28

TABLE 24 - ENERGY DEMANDS FOR ADJUSTMENTING THE BLINDS



GRAPH 57 - ENERGY DEMANDS FOR ADJUSTMENTING THE BLINDS



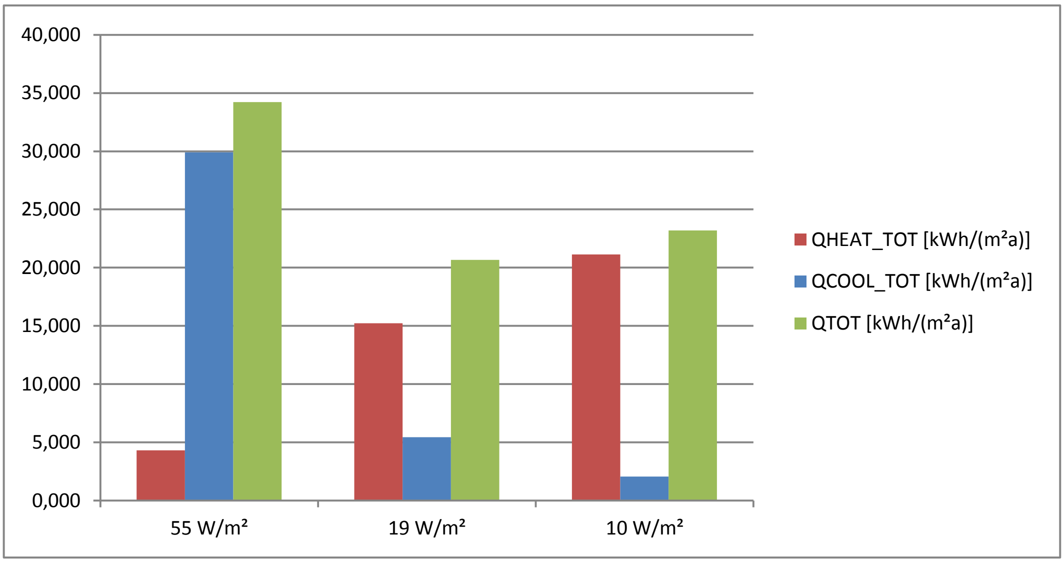
GRAPH 58 – VARIATION OF THE ENERGY DEMANDS FOR ADJUSTING THE BLINDS

5.3.4. CHANGING THE INTERNAL HEAT GAINS

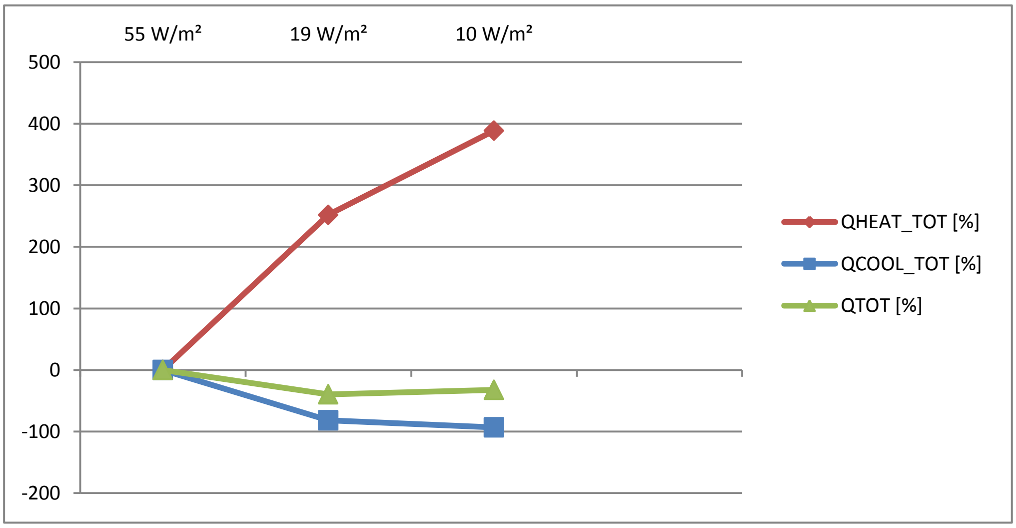
Only a decrease of the heat gains by the lights was considered because it wouldn't be realistic to reduce the number of persons or the number of electronic devices in the secretariat. The energy gains from the lights were changed gradually changed from 55 W/m² to 19 W/m² and 10 W/m². Changing the internal heat gains means less heat production by the internal components, which will have it's effect on the energy demands. The results are represented in Table 25 and in Graph 59 and Graph 60.

	QHEAT_TOT [kWh/(m²a)]	QCOOL_TOT [kWh/(m²a)]	QTOT [kWh/(m²a)]
55 W/m²	4,326	29,899	34,224
19 W/m²	15,227	5,443	20,670
10 W/m²	21,137	2,053	23,190

TABLE 25 - ENERGY DEMANDS OF CHANGING INTERNAL HEAT GAINS



GRAPH 59 - ENERGY DEMANDS OF CHANGING INTERNAL HEAT GAINS



GRAPH 60 – VARIATION OF ENERGY DEMANDS OF CHANGING INTERNAL HEAT GAINS

As expected, the influence of a reduction of the lighting energy has a big influence on both energy demands. When using lights with 10 W/m² , which is 5.5 times less than initially, the heating demand is almost quadrupled. The cooling demand on the other hand is only reduced by almost 100%. The global result for this modification is still good, because of the stake of the cooling demand in the total energy demand. In any case this is an important improvement because not only the energy demand of the building is reduced. Heat producting by the lights is a very inefficient way of producing heat. It is not the purpose of lights. This emprovement will therefore probably have a big influence in the total primary energy of the building. This item is not considered in this paper, but this doesn't make it less important.

5.3.5. Influence of infiltration

The effect of changing the air infiltration into the building by fixed air change rates is represented in Table 26 and in Graph 61 and Graph 62. The initial model was designed with openings of 10 on 10cm. This was randomly chosen to get started. Also there was no bases to deduct a value for the airtightness of the building because of the impossibility of the BlowerDoor test. While making improvements on the model it turned out that the size of the openings was a bad choice, according to airtightness of the actual building. A passive house building has an air change rate of maximum 0.6 times the volume per hour. In older buildings with single glass windows, this value is located somewhere between 8 and 10 volumes per hour. If the output of the initial model is compared with the models where a fixed air change rate is introduced, the influence of the assumption becomes clear.

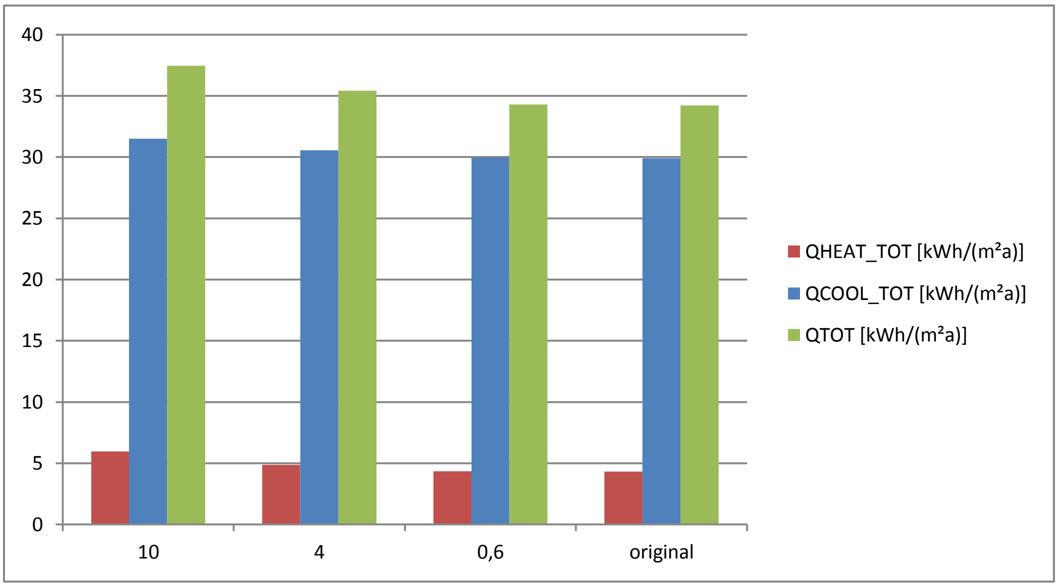
As Graph 61 and Graph 62 are observed, there can be seen that our initial model has a smaller energy demand than any other case. This means that the infiltration of the initial model is smaller than 0.6 volumes per hour, which is the requirement to meet the passive house standard. This is off course not the case in practice. Altough the actual airtightness value is unknown, it's impossible that this building has this level of airtightness. There are a lot of airleaks present in the building whereof the windows and the outside walls with the steel profiles and prefabricated panels are the most important ones. Unfortunately we have to conclude that the model contains some assumptions that turn out to be wrong. This was expected considering the low energy demands that were obtained in paragraph 5.2.2.

Making a building airtight has possitive influence on both heating and cooling demand. The effect is bigger on the heating demand. What is striking is the small differences between the various airtightnesses. Much bigger values and differences between the values for cooling and heating demand were expected. So here there also has to be concluded that this part of the model contains some malfunctions that are not representable.

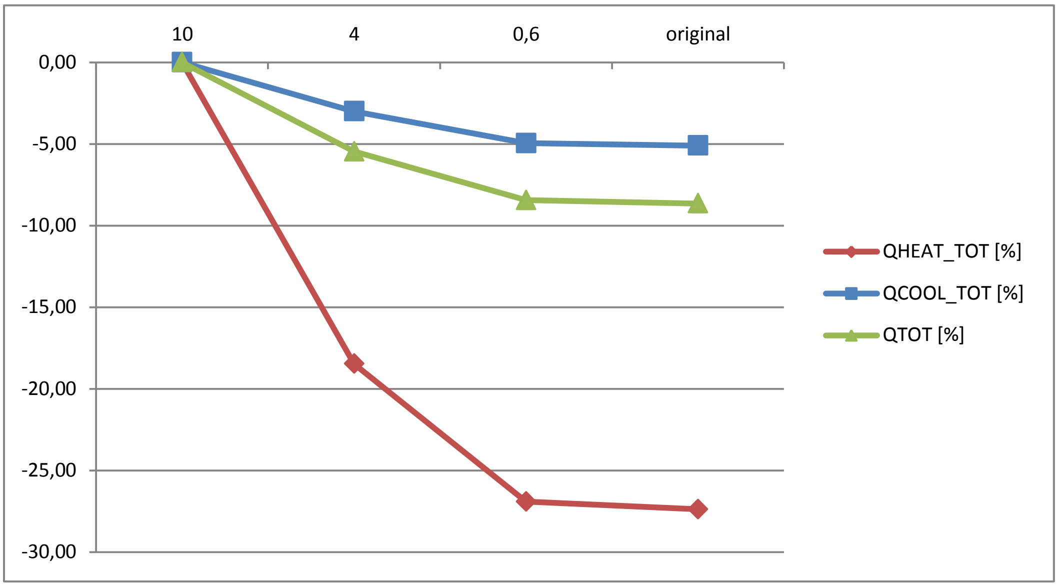
Lastly we want to remark that TRNSYS doesn't consider any practical way of reaching these levels of airtightness. The size of the infiltration opening is introduced and the rest of the building is considered as airtight. This is off course not how it is in reality.

	QHEAT_TOT [kWh/(m²a)]	QCOOL_TOT [kWh/(m²a)]	QTOT [kWh/(m²a)]
10	5,956	31,505	37,461
4	4,856	30,560	35,416
0,6	4,353	29,947	34,300
original	4,326	29,899	34,224

TABLE 26 – ENERGY DEMANDS OF MODIFICATION OF THE INFLILTRATION



GRAPH 61 - ENERGY DEMANDS OF MODIFICATION OF THE INFLILTRATION



GRAPH 62 – VARIATION OF ENERGY DEMANDS OF MODIFICATION OF THE INFLILTRATION

5.3.6. THE EFFECT OF NATURAL VENTILATION

The analysis of the effect of natural ventilation in the building is based on the previous models with the various infiltration rates. This is because ventilation and infiltration are connected with each other in TRNSYS, so it's impossible to analyse the effect of ventilation separately. The effect of natural ventilation into the building in represented below per air change rate. The opening where the air flows through is set on $2m^2$ when the ventilation switches on. Making the infiltration opening bigger is a way to simulate the natural ventilation for example trough a ventilation opening or a window. When the ventilation is switched on, the cooling doesn't work. On the other hand when the natural ventilation switches off, the normal infiltration rate is working. When the ventilation is on, the infiltration opening becomes $2m^2$. The criteria for which this system is activated are:

- The system can only be activated in summer
- The temperatures outside has to be lower than 25
- The temperature inside has to be higher than outside.

We assume that the criteria will mostly be fulfilled during nightfall or by night. So this type of ventilation can be seen as intensive night ventilation. The way this is introduced in TRNSYS, see 4.4.5.4.

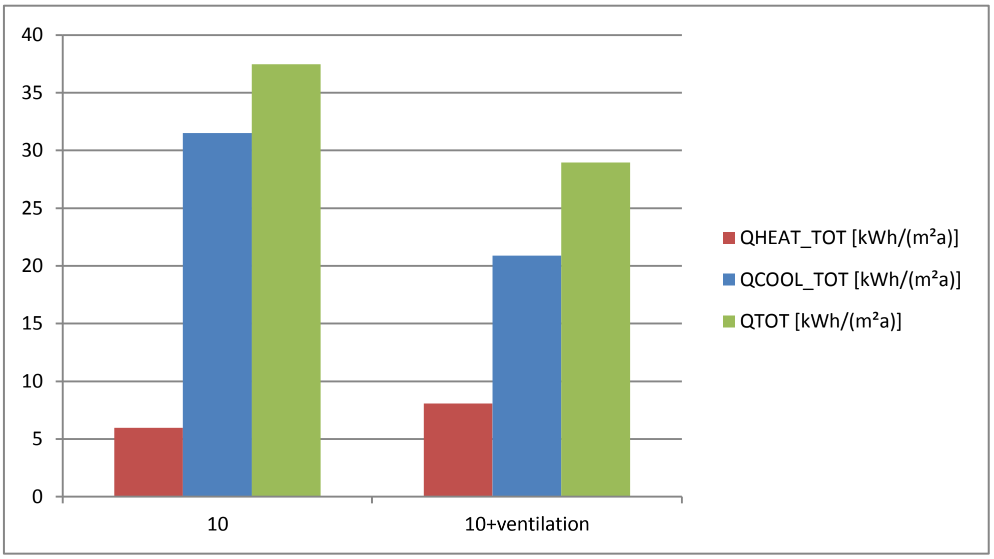
The results per air change rate show a general trend. Adding ventilation makes the heating demand increase and the cooling demand decrease. The cooling decreases because when the ventilation is working, the cooling shuts down. This means that when the criteria are fulfilled, the rooms are ventilated with fresh cooler air from outside. This is good to have clean air in the room and to cool the building. For buildings with a big thermal capacity, this modification will have the biggest influence.

The heating demand increases because the temperature can be low in the morning (in summer) and the heating has to work. This is a factor that is difficult to take into account. Somethimes the building can heat up quicker in the morning or slower, depending on the weather outside (clouded or sunny). If we introduce a minimum temperature in the secretariat to control the ventilation, this will heat up the builing much faster. This will make the cooling demand bigger again.

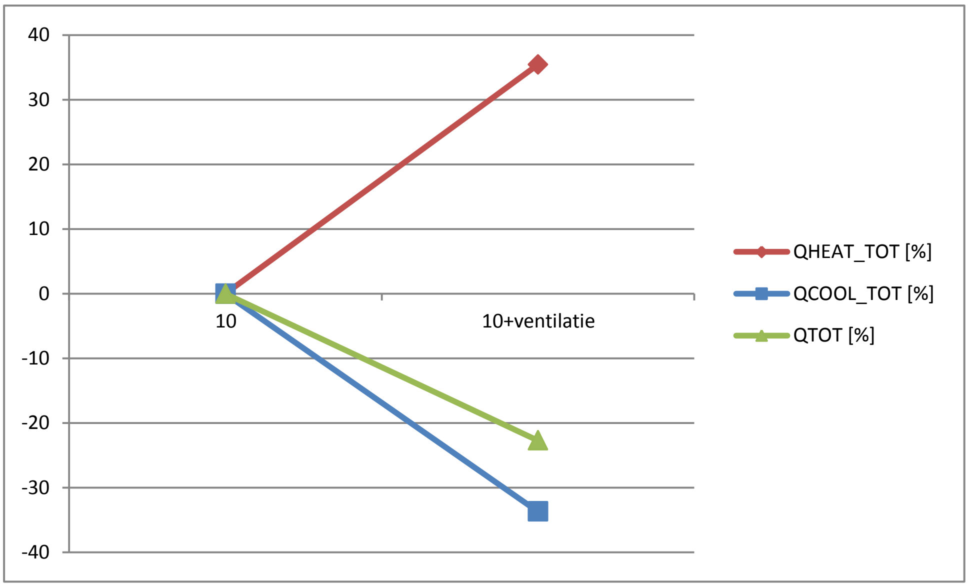
a) 10 air changes h-1

	QHEAT_TOT [kWh/(m²a)]	QCOOL_TOT [kWh/(m²a)]	QTOT [kWh/(m²a)]
10	5,956	31,505	37,461
10+ventilation	8,065	20,894	28,959

TABLE 27 - ENERGY DEMANDS WITH AIR CHANGE RATE 10 + VENTILATION



GRAPH 63 - ENERGY DEMANDS WITH AIR CHANGE RATE 10 + VENTILATION

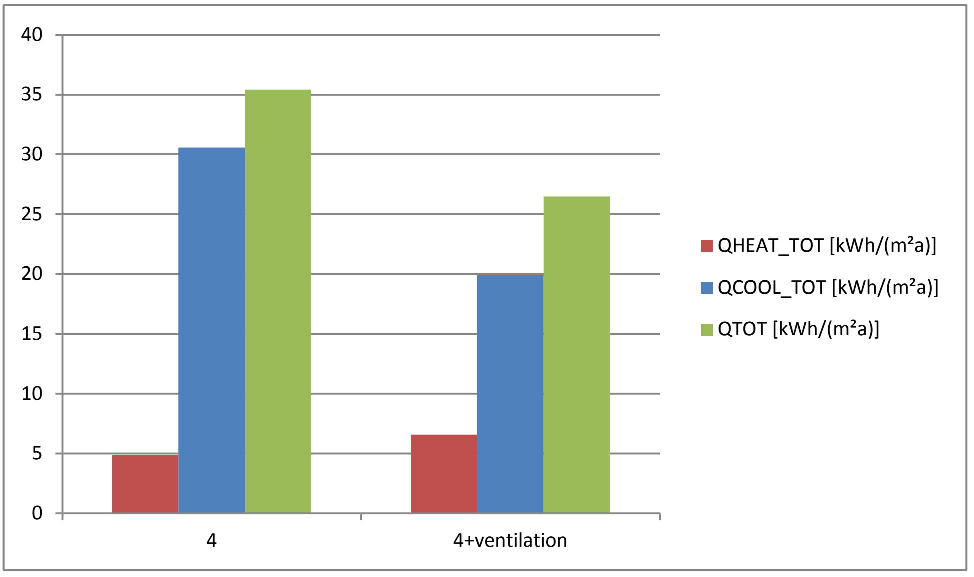


GRAPH 64 – VARIATION OF ENERGY DEMANDS WITH AIR CHANGE RATE 10 + VENTILATION

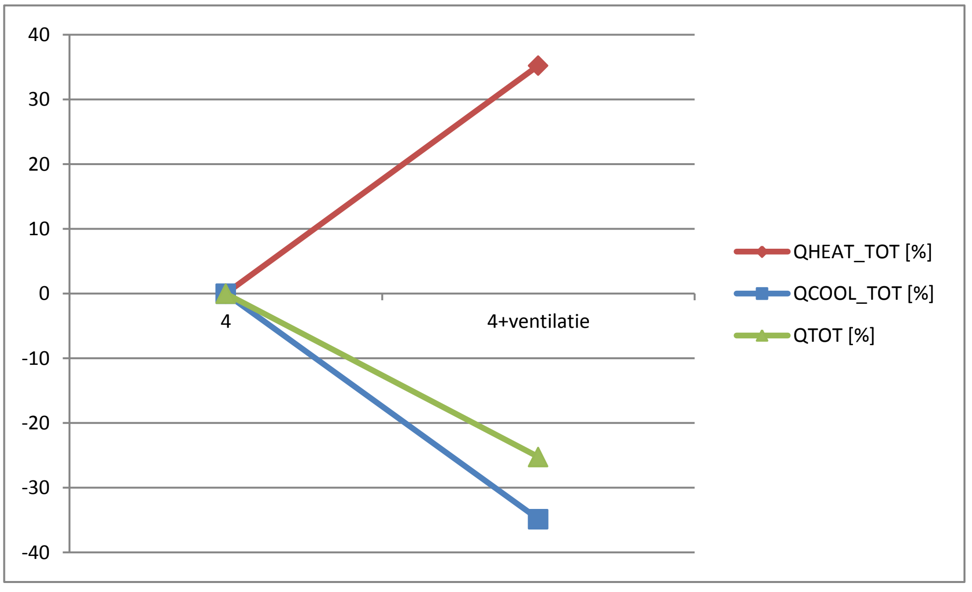
b) 4 air changes h^{-1}

	QHEAT_TOT [kWh/(m²a)]	QCOOL_TOT [kWh/(m²a)]	QTOT [kWh/(m²a)]
4	4,856	30,560	35,416
4+ventilation	6,566	19,910	26,477

TABLE 28 - ENERGY DEMANDS WITH AIR CHANGE RATE 4 + VENTILATION



GRAPH 65 - ENERGY DEMANDS WITH AIR CHANGE RATE 4 + VENTILATION

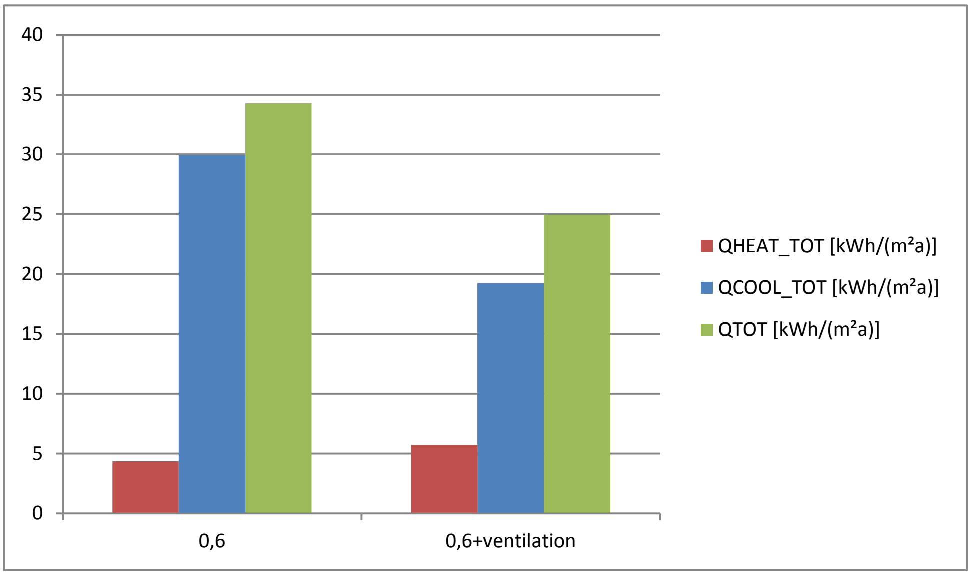


GRAPH 66 – VARIATION OF ENERGY DEMANDS WITH AIR CHANGE RATE 4 + VENTILATION

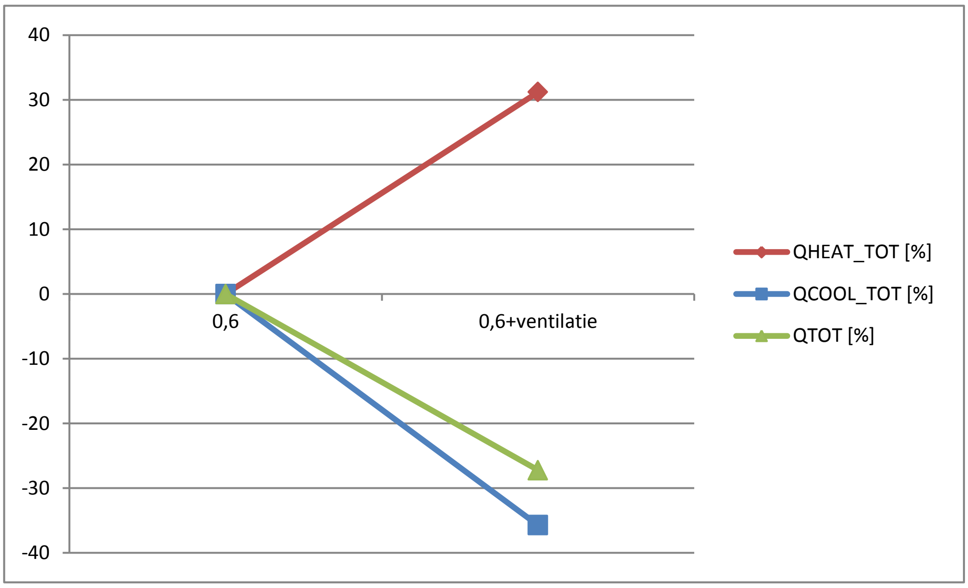
c) 0.6 air changes h^{-1}

	QHEAT_TOT [kWh/(m²a)]	QCOOL_TOT [kWh/(m²a)]	QTOT [kWh/(m²a)]
0,6	4,353	29,947	34,300
0,6+ventilation	5,711	19,252	24,963

TABLE 29 - ENERGY DEMANDS WITH AIR CHANGE RATE 0.6 + VENTILATION



GRAPH 67 - ENERGY DEMANDS WITH AIR CHANGE RATE 0.6 + VENTILATION

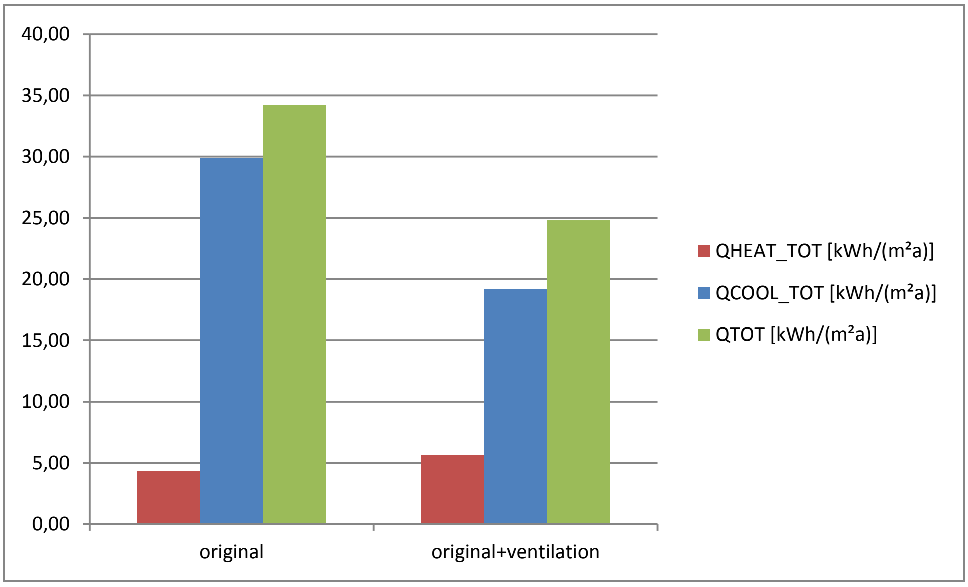


GRAPH 68 – VARIATION OF ENERGY DEMANDS WITH AIR CHANGE RATE 0.6 + VENTILATION

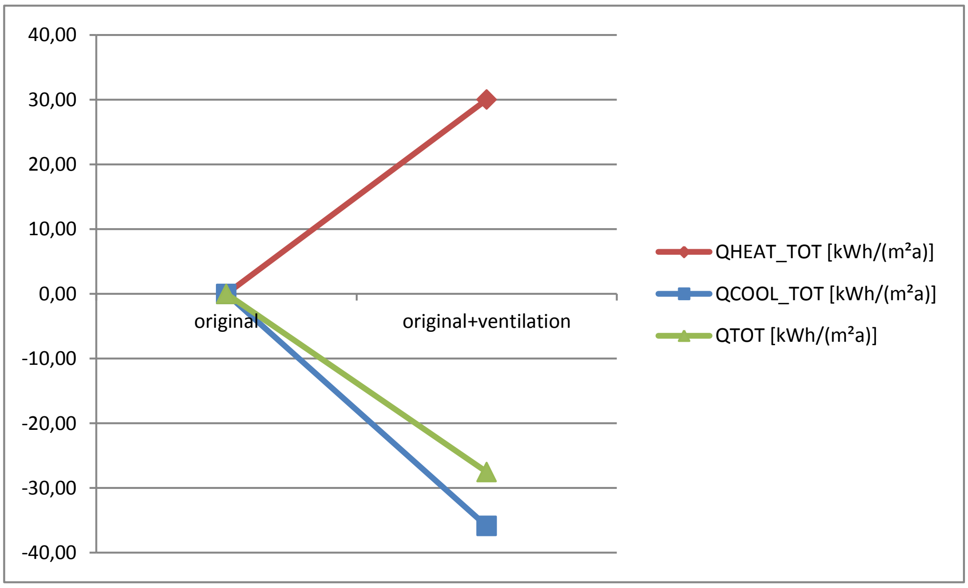
d) Initial model

	QHEAT_TOT [kWh/(m²a)]	QCOOL_TOT [kWh/(m²a)]	QTOT [kWh/(m²a)]
Initial	4,33	29,90	34,22
Initial+ventilation	5,623	19,178	24,801

TABLE 30 - ENERGY DEMANDS IN INTITIAL MODEL + VENTILATION



GRAPH 69 - ENERGY DEMANDS IN INITIAL MODEL + VENTILATION



GRAPH 70 – VARIATION OF ENERGY DEMANDS IN INITIAL MODEL + VENTILATION

5.4. COMBINING THE MODIFICATIONS

In this last paragraph the various modifications to the initial model are combined to a ultimate model that meets the criteria of the passive house standard. The combinations were made based on the conclusions of the separate modifications to the initial model.

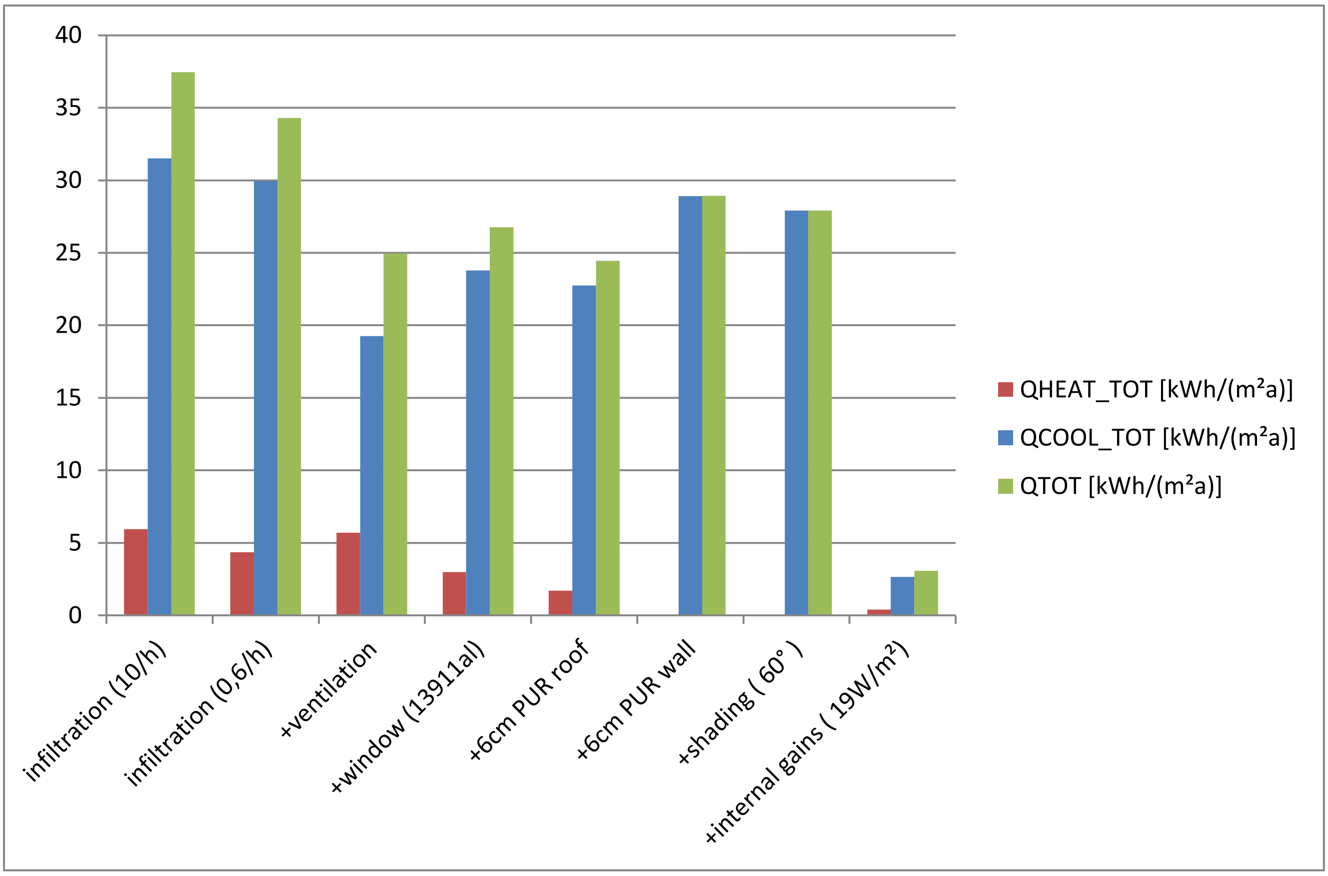
The choice was made to take the model with the air change rate of 10 volumes per hour as the initial model to apply the modifications on. The actual value for the infiltration into the building is unknown and it's much more probable that the air change rate of the building is somewhere around 10 h^{-1}. The air change rate of less than 0.6 h^{-1}, as we had to conclude with the actual model, is not representative.

The combination of improvements to the building model with the related energy demands are represented in Table 31 and Graph 71. The first improvement that was applied was decreasing the airtightness of the model to the required 0.6 h^{-1} for the passive house standard. Then the ventilation is introduced in the model to reduce the cooling demand. In the initial model the heating demand is already under the limit of 15 kWh/(m^2a) so no specific improvements are needed. But there is nothing implemented by TRNSYS to reach any level of airtightness in practice. TRNSYS just assumes that, next to the infiltration openings, the connections are perfect, without any airflow between both sides of the thermal envelope. To take into account this issue a different type of window and framework together with thermal insulation in the roof and the outer wall was inserted. These are components that are known for their insulating and airtightening properties assuming that they are installed in the right way. This is by making good connections between the framework of the windows and the thermal insulation, as well as the breaks between the insulating plates. These modifications are just a few that are necessary to obtain an airtight building in reallity. By inserting these modifications into the model the heating demand decreased and an increase of the cooling demand can be determined. This could be expected considering the previous analysis. The thermal insulation in the floor was not added because of the cooling effect that can occur with the ground. The cooling demand is still above 15 kWh/(m^2a), so the angle of the shading devices are increased to 60°. This ensures a more shade on the windows, so less heat enters by direct or indirect irradiation. In this way, less cooling demand is needed. When the internal heat gains of the lights are reduced to 19 W/m^2 a big drop of more than 25 kWh/(m^2a) occurs. Constraining the internal heat gains leads to an immense decrease of the cooling demand. By applying this improvement the cooling demand drops a lot below the annual cooling demand goal of 15 kWh/m^2. The result of this combination is a building model with a very low cooling, heating and total annual energy demand.

Besides having a building that is highly energy efficient, the Passive House standard also gives a guideline for involving the optimum standard of thermal comfort. The overheating frequency has to be smaller than 10% of the hours over 25°C during one year. In the final model 9.58% of the hours are above 25°C annually. So good thermal comfort inside the building model is garanteed.

	QHEAT_TOT [kWh/(m²a)]	QCOOL_TOT [kWh/(m²a)]	QTOT [kWh/(m²a)]
infiltration (10/h)	5,956	31,505	37,461
infiltration (0,6/h)	4,353	29,947	34,300
+ventilation	5,711	19,252	24,963
+window (13911al)	2,998	23,778	26,776
+6cm PUR roof	1,707	22,742	24,449
+6cm PUR wall	0,013	28,905	28,919
+shading (60°)	0,013	27,911	27,925
+internal gains (19W/m²)	0,410	2,662	3,072

TABLE 31 – ENERGY DEMANDS OF MODIFICATION COMBINATIONS



GRAPH 71 - ENERGY DEMANDS OF THE MODIFICATION COMBINATIONS

6. Conclusion

The importance of a passive house is reaching a high level of comfort inside together with very low energy consumption. The climate has a big influence when designing a passive house. Here in Valencia the heating demand is low due to mild winters and the cooling demand has a bigger importance because of the hot summers. Active cooling and heating should be low and passive heating and cooling techniques should be used as much as possible.

The goal was modifying a school building that fulfils the conditions of the Passive House standard. This was developed in three steps: obtaining measurements of the temperature inside and outside, making a model of the building in TRNSYS and make adjustments to have a passive house.

The initial model of the secretariat had a low energy demand. This was an unexpected result knowing the age and the construction method of the building. Making wrong assumptions probably caused this. The ceiling for example was modelled without implementation of the skylights. It was difficult to modify it more because of the limited knowledge of TRNSYS, the lack of detailed information about the building and the installations.

Keeping in mind the incorrect model, five improvements to the model were evaluated to see their impact on the energy demand:

The thermal insulation - The influence of thermal insulation was evaluated in the wall, the roof and the floor. Both the wall and the floor insulation result in a higher cooling demand and a lower heating demand. Increasing the thickness of the roof insulation lowers the heating as well as the cooling demand. The profitability of a few centimetres is high but this effect decreases as the thickness of the insulation increases. At a certain point this effect stabilizes as can be determined from Graph 50 and Graph 52 . Insulation in the floor is not recommended because the soil has passive cooling capacities in summer, which is important in designing passive houses.

The ventilation - The improvement of the ventilation has a big influence on the cooling demand as can be seen on Graphs 64, 66, 68 and 70 . When the ventilation is activated, the building is cooled with colder air from outside which makes this a passive cooling strategy. This is an important strategy against overheating and to provide the building with fresh air.

The internal heat gains - The electric devices, the lights and the people produce a big amount of heat. Especially in offices these heat production can be quite high. Changing the type of lights decreased the internal heat gains in the secretariat. Changing only the type of lights to low heat-emitting lights, the cooling demand decreases a lot. This effect is illustrated in Graph 60.

The Windows and the outer blinds - When the windows are changed from single glass to double glass, the heating demand will decrease due to the insulating property of double glazed windows. This has a reverse influence on the cooling demand. The shading devices have a big impact on the cooling demand. This depends on the angle of the blades. In this model they were fixed blinds and had the biggest demand for 0° and the lowest for 60°. This can be seen on Graph 56 and 58. A better improvement that we didn't use in our model was a shading device that can change the angle of the blades. This way it can obtain the natural heat in summer and avoid it during the summer.

This model is based on assumptions and is not always modelled like it is built in reality but the improvements give an idea of the effect that they have on the cooling and heating demands. This is of great importance to model a passive house, especially in times where environmental awareness is increasing.

BIBLIOGRAFIE

[1] *Boletin Oficial del Estado*. (n.d.). Retrieved March 2014, from Boletin Oficial del Estado: http://www.boe.es/boe/dias/2013/09/12/pdfs/BOE-A-2013-9511.pdf

[2] Cp GENERATOR. (n.d.). Retrieved April 2014, from TNO Webapplications: http://www.cpgen.bouw.tno.nl

[3] HEIJMANS N., W. P. (n.d.). Impact of uncertainties on wind pressures on the prediction of thermal comfort performances. Brussels: BBRI.

[4] HUIZENGA C. et al. (1999). *Teaching students about two-dimensional heat transfer effects in building components, equipment and appliances using THERM 2.0.* ASHRAE.

[5] Instruction Manual Comfort Sorftware x35 Professional. (n.d.). Retrieved March 2014, from TESTO: http://www.testo-international.com/

[6] KLEIN S.A. et al. (2012). TRNSYS 17 Add-Ons A1. TRNFLOW. In *TRNSYS 17 Documentation* (p. 58). Wisconsin: University of Wisconsin-Madison.

[7] KLEIN S.A. et al. (2012). Volume 1: Getting Started. In *TRNSYS 17 Documentation* (p. 80). Wisconsin: University of Wisconsin-Madison.

[8] KLEIN S.A. et al. (2012). Volume 2: Using The Simulation Studio. In *TRNSYS 17 Documentation* (p. 129). Wisconsin: University of Wisconsin-Madison.

[9] KLEIN S.A. et al. (2012). Volume 3: Standard Component Library Overview. In *TRNSYS 17 Documentation* (p. 101). Wisconsin: University of Wisconsin-Madison.

[10] KLEIN S.A. et al. (2012). Volume 5: Multizone Building (type56-TRNBuild). In *TRNSYS 17 Documentation* (p. 230). Wisconsin: University of Wisconsin-Madison.

[11] KNOLL B., P. J. (n.d.). *Pressure coefficient simulation program.* Delft: DNO.

[12] MITCHELL R. et al. (2013). *THERM 6.3/WINDOW 6.3 NFR Simulation Manual.* Berkeley: LBNL.

[13] Passive house certification criteria. (n.d.). Retrieved March 2014, from Passive House International: http://www.passivehouse-international.org

[14] RECTICEL EUROWALL. (n.d.). Retrieved May 2014, from Recticel: http://www.recticelinsulation.be/product/eurowall/technische-fiche

[15] RETROTEC 2200 Calibrated Fans. (n.d.). Retrieved May 2014, from Retrotec: http://www.retrotec.com

[16] SKYLIGHT. (sd). Opgeroepen op April 2014, van Walbers: http://www.walbers.be

[17] TESTO 435-2. (n.d.). Retrieved March 2014, from Testo Instuments: http://www.testo-international.com/

[18] Watchdog 200 series Weather Station. (n.d.). Retrieved March 2014, from Spectrum Technologies: www.spectmeters.com

[19] Werkgroep PaThB2010. (2009). *Toelichtingsdocument volgens "Ontwerp tot wijziging van BIJLAGE IV/V van het EPB-Besluit".* Brussels: Werkgroep PaThB2010.

APPENDIX A: INPUT AND RESULTS OF THE C_P GENERATOR

The input for the C_p Generator is simple. On the website you find a '.txt'-file as an example and they recommend you to work in (a copy of) this file by adjusting the file to your own specific situation.

The different inputs are:

- Title

General data of the project. The program doesn't need this to work.

- Wind.Zo

In this section we define the terrain roughness for different flow directions of the wind. For all four wind directions (N, E, S, W) we chose *Zo = 3,0 m* which means a terrain roughness of "a *normal suburb, industrial estate or village"*.

- North arrow

This is the direction in degrees to which the north arrow points in our plan with reference to the chosen coordinate system.

- Obstacles

Here we define the different objects of the problem. In the text block 'Name: building' we fill in the data of the object of which we want to have the C_p -values calculated. We specify coordinates X and Y for a base point of the building in the ground plan. Also we specify the azimuth in degrees for the first facade anti-clockwise from this base point (Figure 64). The Length (L), Width (W) and Height (H) of the building may be followed by a key (=1) for a pitched roof, the roof angle in degrees and the size of the roof basis. We specify the same variables for the obstacles which are the objects surrounding the calculated one. In the text block 'Name: meteo' we fill in the coordinates of our weather station.

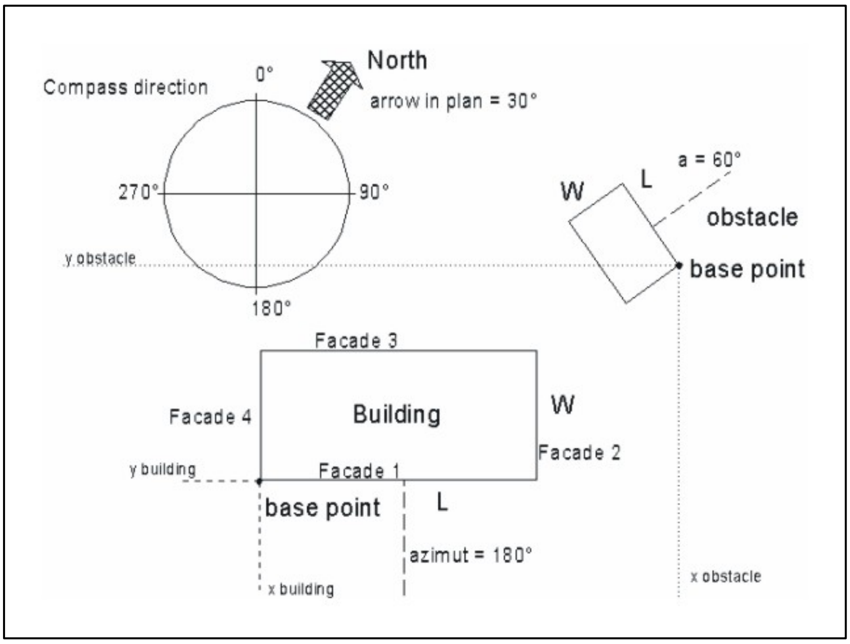


FIGURE 64 - GROUND PLAN WITH DEFINITIONS

- C_p positions

In this part we specify the coordinates of the C_p points at each façade looking towards it with X, Z = 0, 0 down left, and the roof looking from above with the base point situated down left is X, Y = 0, 0 (Figure 65). The facades are numbered anti-clockwise from 0 to 4.

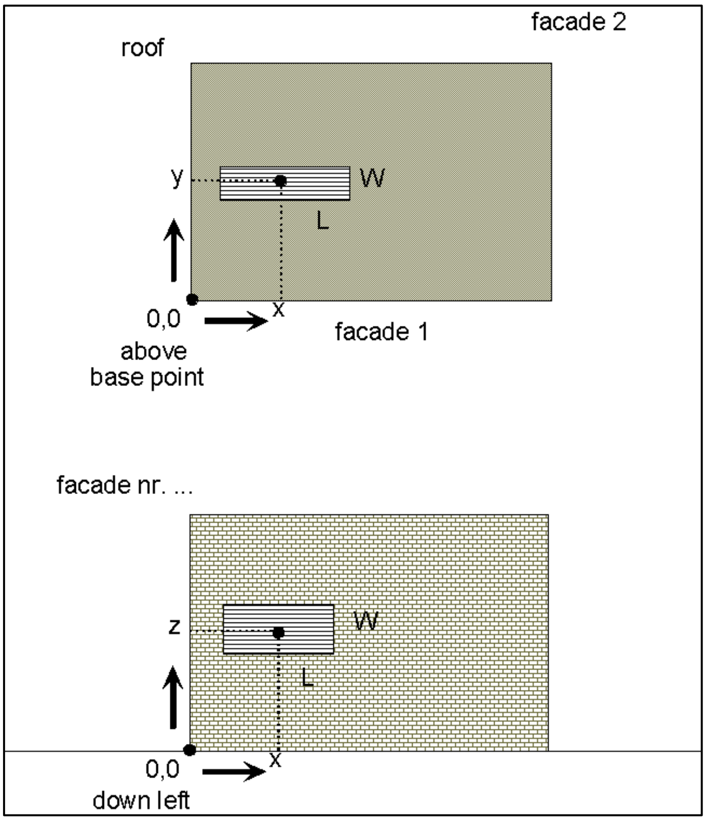
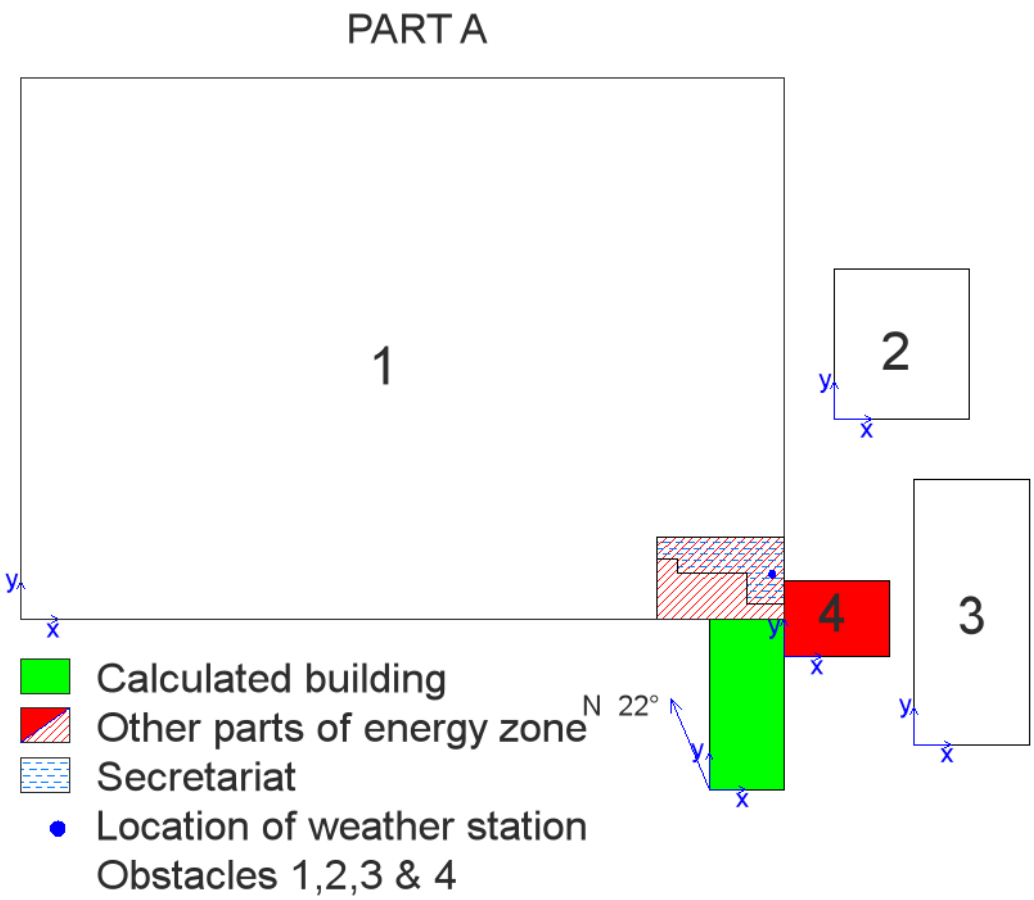


FIGURE 65 - DEFINITION OF CP POSITIONS

Calculating the C_p-values

The ground plan of the department of the school of building management has a difficult shape to define the obstacles therefore we simplified the project. When there are to many separate obstacles close to each other, the result of the C_p prediction only is reduced. The energy zone of which the secretariat is part of was divided into three blocks. For each block there had to be made a separate C_p-value calculation.



Inputfile

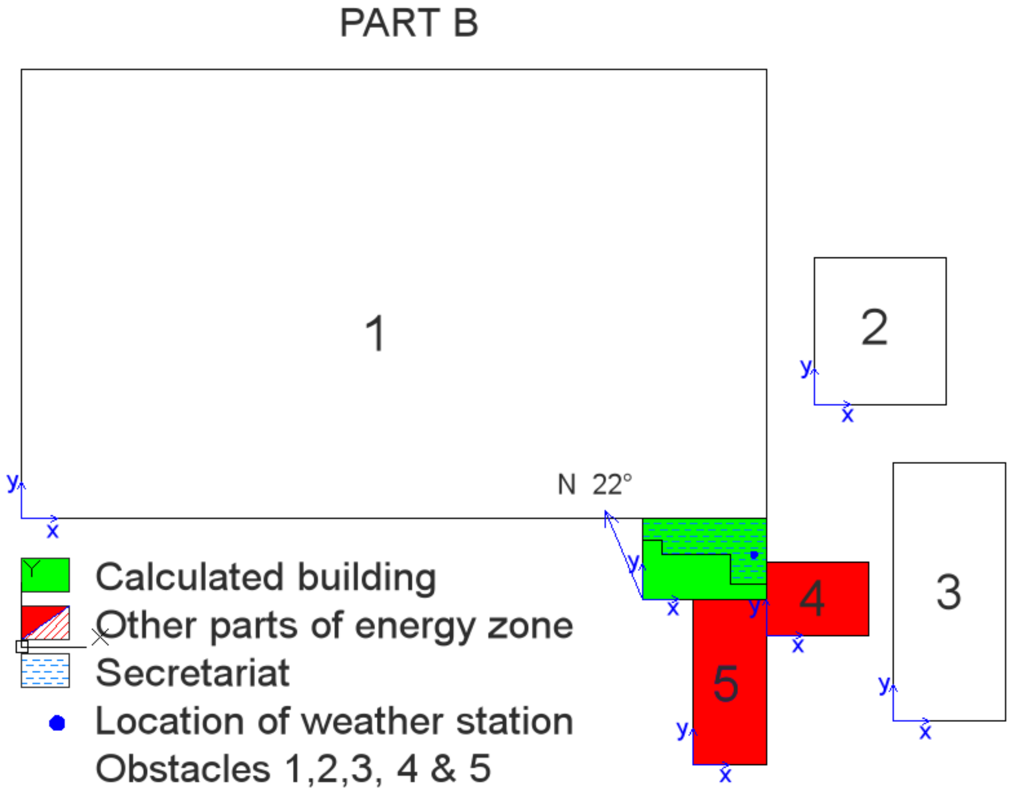
```
{file=input}
+------------------------+
| title                  |
+------------------------+
   title: Secretaria - UPV E.T.S. DE INGENIERÍA DE EDIFICACIÓN
   version: 1.0
   made by: Olivier & Edouard
   comment: none
+---------------------------+
| wind.Zo                   |
+---------------------------+
  Direction:  0      90      180      270
       Zo:  3        3       3        3
+-------------------------------------------------+
| north arrow compass direction in plan |
+-------------------------------------------------+
  Direction:  22
```

```
+------------------------------------------+
| obstacles (position in m(=meter))|
+------------------------------------------+
 Ground level:  0.
 Roof height :  5.0
       Name : building
        x,y : 0.      0.
     Azimut : 180.
  L,W,H,#,‡,w: 15.30  34.60   5.0

        Name: meteo
         x,y: 12.79    43.79
      Azimut: 180.
       L,W,H: 0.5      0.5      5.5

        Name: obstacle  1
         x,y: -139.71      34.60
      Azimut: 180.0000
       L,W,H: 155.  93.5   5.0

        Name: obstacle  2
         x,y: 25.40  75.21
      Azimut: 180.000
       L,W,H: 27.41   30.5   5.0

        Name: obstacle  3
         x,y: 41.67  9.14
      Azimut: 180.000
       L,W,H: 23.42   53.76   20

        Name: obstacle  4
         x,y: 15.3  27.1
      Azimut: 180.000
       L,W,H: 21.21   15.30   5.0
+----------------------------+
| cp-positions               |
+----------------------------+
       unit: m
Building side: facade 2
   Pos.  x,y : 0.50    2.50
Building side: facade 2
   Pos.  x,y : 8.00    2.50
Building side: facade 2
   Pos.  x,y : 15.50    2.50
Building side: facade 2
   Pos.  x,y : 20.35    3.50
Building side: facade 2
   Pos.  x,y : 24.85    2.50
Building side: facade 4
   Pos.  x,y : 6.00    2.50
Building side: facade 4
   Pos.  x,y : 20.00    2.50
Building side: facade 4
 Pos.  x,y : 34.10    2.50
```

Output

Degrees (°)	Façade 2					Façade 4		
	C_p 1	C_p 2	C_p 3	C_p 4	C_p 5	C_p 1	C_p 2	C_p 3
0	-0,252	-0,293	-0,359	-0,438	-0,647	0,063	-0,056	-0,039
5	-0,255	-0,298	-0,371	-0,471	-0,653	-0,052	-0,129	-0,088
10	-0,253	-0,297	-0,376	-0,471	-0,619	-0,164	-0,198	-0,135
15	-0,262	-0,316	-0,402	-0,493	-0,612	-0,284	-0,271	-0,186
20	-0,279	-0,346	-0,442	-0,527	-0,624	-0,404	-0,344	-0,237
25	-0,264	-0,333	-0,43	-0,517	-0,632	-0,449	-0,371	-0,258
30	-0,222	-0,282	-0,373	-0,469	-0,635	-0,43	-0,36	-0,255
35	-0,163	-0,21	-0,289	-0,398	-0,605	-0,409	-0,356	-0,255
40	-0,091	-0,12	-0,182	-0,306	-0,548	-0,382	-0,353	-0,258
45	-0,052	-0,056	-0,092	-0,221	-0,486	-0,358	-0,343	-0,252
50	-0,042	-0,016	-0,017	-0,141	-0,416	-0,335	-0,327	-0,24
55	-0,056	-0,022	0,005	-0,082	-0,338	-0,311	-0,308	-0,227
60	-0,092	-0,066	-0,018	-0,042	-0,254	-0,288	-0,285	-0,212
65	-0,108	-0,093	-0,041	-0,028	-0,198	-0,277	-0,264	-0,2
70	-0,107	-0,107	-0,068	-0,037	-0,163	-0,275	-0,243	-0,191
75	-0,085	-0,102	-0,079	-0,043	-0,141	-0,286	-0,229	-0,188
80	-0,041	-0,077	-0,076	-0,047	-0,13	-0,308	-0,221	-0,188
85	0,024	-0,031	-0,054	-0,04	-0,109	-0,314	-0,218	-0,193
90	0,108	0,036	-0,014	-0,022	-0,079	-0,308	-0,222	-0,203
95	0,206	0,121	0,046	0,013	-0,038	-0,302	-0,229	-0,215
100	0,317	0,225	0,125	0,066	0,015	-0,295	-0,24	-0,228
105	0,422	0,339	0,219	0,143	0,078	-0,293	-0,252	-0,24
110	0,522	0,463	0,327	0,242	0,157	-0,295	-0,263	-0,25
115	0,591	0,585	0,443	0,354	0,329	-0,294	-0,271	-0,256
120	0,63	0,701	0,565	0,477	0,569	-0,291	-0,275	-0,26
125	0,625	0,754	0,669	0,569	0,669	-0,281	-0,275	-0,262
130	0,582	0,75	0,753	0,632	0,655	-0,266	-0,271	-0,263
135	0,55	0,693	0,768	0,663	0,63	-0,252	-0,267	-0,266
140	0,526	0,592	0,721	0,658	0,586	-0,239	-0,262	-0,272
145	0,501	0,523	0,623	0,596	0,527	-0,228	-0,262	-0,283
150	0,474	0,478	0,48	0,483	0,453	-0,221	-0,269	-0,299
155	0,434	0,43	0,369	0,369	0,357	-0,222	-0,281	-0,324
160	0,379	0,378	0,283	0,251	0,245	-0,229	-0,298	-0,357
165	0,286	0,286	0,197	0,161	0,155	-0,24	-0,319	-0,4
170	0,16	0,16	0,113	0,093	0,084	-0,254	-0,343	-0,45
175	0,035	0,035	0,025	0,02	0,016	-0,268	-0,366	-0,497
180	-0,092	-0,09	-0,065	-0,055	-0,049	-0,281	-0,388	-0,54
185	-0,211	-0,21	-0,15	-0,127	-0,111	-0,286	-0,404	-0,565
190	-0,325	-0,325	-0,232	-0,195	-0,17	-0,286	-0,415	-0,575
195	-0,444	-0,439	-0,316	-0,268	-0,234	-0,289	-0,43	-0,591
200	-0,563	-0,546	-0,4	-0,34	-0,297	-0,292	-0,442	-0,604

205	-0,605	-0,575	-0,429	-0,367	-0,322	-0,26	-0,399	-0,543
210	-0,586	-0,54	-0,413	-0,357	-0,314	-0,199	-0,308	-0,419
215	-0,573	-0,511	-0,402	-0,351	-0,31	-0,143	-0,223	-0,302
220	-0,562	-0,484	-0,392	-0,346	-0,306	-0,089	-0,138	-0,188
225	-0,532	-0,454	-0,375	-0,334	-0,296	-0,032	-0,049	-0,067
230	-0,488	-0,421	-0,354	-0,317	-0,28	0,028	0,044	0,06
235	-0,44	-0,388	-0,332	-0,299	-0,265	0,088	0,136	0,186
240	-0,39	-0,355	-0,309	-0,28	-0,249	0,147	0,225	0,308
245	-0,35	-0,326	-0,29	-0,265	-0,236	0,206	0,305	0,392
250	-0,318	-0,303	-0,274	-0,253	-0,227	0,263	0,376	0,442
255	-0,295	-0,286	-0,264	-0,247	-0,228	0,316	0,433	0,481
260	-0,28	-0,276	-0,259	-0,248	-0,238	0,365	0,478	0,507
265	-0,27	-0,27	-0,258	-0,254	-0,248	0,407	0,511	0,527
270	-0,266	-0,269	-0,261	-0,263	-0,261	0,443	0,533	0,54
275	-0,262	-0,269	-0,265	-0,271	-0,271	0,473	0,545	0,531
280	-0,261	-0,27	-0,27	-0,279	-0,279	0,495	0,547	0,504
285	-0,258	-0,269	-0,273	-0,283	-0,282	0,512	0,548	0,479
290	-0,253	-0,268	-0,275	-0,283	-0,281	0,524	0,547	0,454
295	-0,247	-0,263	-0,273	-0,278	-0,274	0,534	0,54	0,429
300	-0,238	-0,256	-0,269	-0,269	-0,26	0,542	0,529	0,405
305	-0,228	-0,248	-0,264	-0,257	-0,243	0,554	0,514	0,38
310	-0,218	-0,239	-0,259	-0,241	-0,223	0,569	0,494	0,355
315	-0,209	-0,231	-0,254	-0,228	-0,206	0,579	0,469	0,329
320	-0,201	-0,225	-0,251	-0,217	-0,192	0,585	0,437	0,3
325	-0,197	-0,222	-0,252	-0,212	-0,185	0,581	0,398	0,268
330	-0,197	-0,223	-0,257	-0,213	-0,184	0,568	0,351	0,234
335	-0,2	-0,228	-0,266	-0,221	-0,204	0,541	0,297	0,196
340	-0,207	-0,238	-0,28	-0,235	-0,247	0,499	0,235	0,155
345	-0,216	-0,25	-0,296	-0,263	-0,35	0,417	0,168	0,111
350	-0,229	-0,265	-0,316	-0,303	-0,5	0,301	0,095	0,064
355	-0,241	-0,279	-0,337	-0,364	-0,596	0,184	0,02	0,014



Inputfile

```
{file=input}

+----------------------+
| title                |
+----------------------+
   title: Secretaria - UPV E.T.S. DE INGENIERÍA DE EDIFICACIÓN
   version: 1.0
   made by: Olivier & Edouard
   comment: none
+-------------------------+
| wind.Zo                 |
+-------------------------+
  Direction:   0        90           180          270
      Zo:   3           3            3            3
+----------------------------------------------+
| north arrow compass direction in plan  |
+----------------------------------------------+
  Direction:  22
+----------------------------------------+
| obstacles (position in m(=meter))|
+----------------------------------------+
 Ground level:  0.
 Roof height :  5.0
```

Name : building
x,y : 0.   0.
Azimut : 180.
L,W,H,#,‡,w: 25.8 16.75   5.0

Name: meteo
x,y: 23.3   9.2
Azimut: 180.
L,W,H: 0.5   0.5   5.5

Name: obstacle 1
x,y: -129.2   16.75
Azimut: 180.0000
L,W,H: 155. 93.5   5.0

Name: obstacle 2
x,y: 35.9 40.61
Azimut: 180.000
L,W,H: 27.41   30.5   5.0

Name: obstacle 3
x,y: 58.0 -25.46
Azimut: 180.000
L,W,H: 23.42   53.76   20

Name: obstacle 4
x,y: 25.8 -7.5
Azimut: 180.000
L,W,H: 21.21   15.3   5.0

Name: obstacle 5
x,y: 10.5 -34.6
Azimut: 180.000
L,W,H: 15.3   34.6   5.0

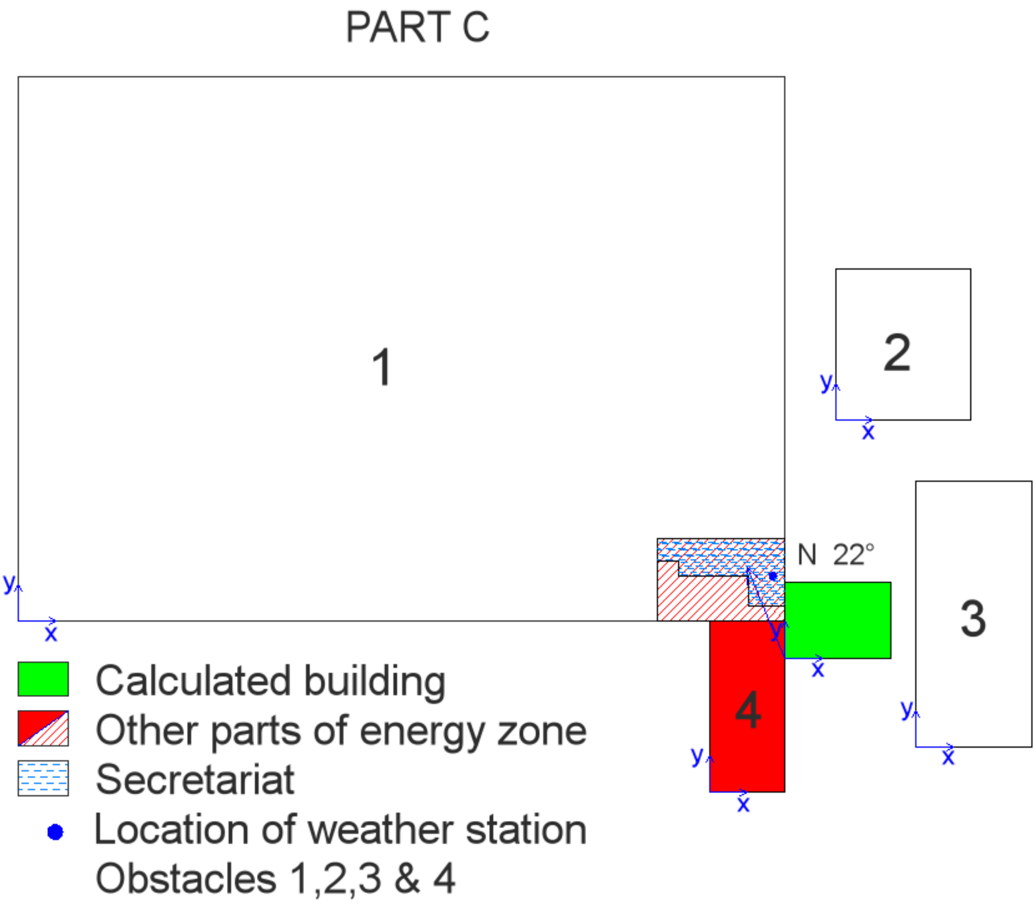
```
+----------------------------+
| cp-positions               |
+----------------------------+
       unit: m
```

Building side: facade 1
  Pos. x,y : 0.500   2.5
Building side: facade 1
  Pos. x,y : 4.50   2.5
Building side: facade 1
  Pos. x,y : 8.50   2.5
Building side: facade 2
  Pos. x,y : 10.30   2.5
Building side: facade 2
  Pos. x,y : 14.25   2.5

Output

Degrees (°)	Façade 1			Façade 2	
	C_p 1	C_p 2	C_p 3	C_p 1	C_p 2
0	-0,293	-0,295	-0,291	-0,427	-0,48
5	-0,291	-0,294	-0,293	-0,48	-0,542
10	-0,29	-0,295	-0,295	-0,527	-0,599
15	-0,287	-0,294	-0,296	-0,575	-0,656
20	-0,283	-0,291	-0,294	-0,617	-0,708
25	-0,276	-0,285	-0,29	-0,597	-0,691
30	-0,267	-0,276	-0,282	-0,525	-0,613
35	-0,257	-0,266	-0,273	-0,442	-0,521
40	-0,245	-0,255	-0,263	-0,344	-0,41
45	-0,235	-0,246	-0,253	-0,228	-0,275
50	-0,227	-0,238	-0,245	-0,097	-0,117
55	-0,223	-0,235	-0,253	0,028	0,034
60	-0,224	-0,238	-0,276	0,149	0,181
65	-0,233	-0,256	-0,315	0,284	0,335
70	-0,251	-0,286	-0,369	0,426	0,491
75	-0,273	-0,32	-0,416	0,545	0,629
80	-0,297	-0,356	-0,458	0,642	0,745
85	-0,308	-0,374	-0,474	0,703	0,779
90	-0,306	-0,375	-0,465	0,728	0,74
95	-0,294	-0,349	-0,415	0,72	0,669
100	-0,274	-0,302	-0,334	0,673	0,566
105	-0,269	-0,298	-0,356	0,534	0,443
110	-0,275	-0,329	-0,456	0,323	0,304
115	-0,269	-0,344	-0,503	0,191	0,195
120	-0,252	-0,346	-0,51	0,122	0,114
125	-0,223	-0,328	-0,501	0,069	0,059
130	-0,181	-0,291	-0,477	0,034	0,03
135	-0,132	-0,245	-0,438	0,008	0,019
140	-0,076	-0,19	-0,386	-0,01	0,024
145	-0,019	-0,131	-0,325	-0,032	0,031
150	0,039	-0,067	-0,254	-0,06	0,038
155	0,094	-0,003	-0,178	-0,107	0,03
160	0,146	0,062	-0,098	-0,17	0,006
165	0,195	0,126	-0,015	-0,243	-0,047
170	0,241	0,19	0,071	-0,324	-0,125
175	0,284	0,253	0,159	-0,4	-0,208
180	0,325	0,316	0,248	-0,472	-0,294
185	0,363	0,378	0,338	-0,525	-0,364
190	0,398	0,438	0,428	-0,561	-0,42
195	0,431	0,495	0,518	-0,59	-0,475
200	0,463	0,55	0,606	-0,611	-0,525

205	0,492	0,597	0,68	-0,631	-0,547
210	0,517	0,634	0,737	-0,648	-0,541
215	0,536	0,641	0,763	-0,655	-0,505
220	0,548	0,62	0,76	-0,649	-0,44
225	0,549	0,59	0,724	-0,567	-0,38
230	0,539	0,551	0,658	-0,423	-0,322
235	0,521	0,52	0,571	-0,312	-0,28
240	0,493	0,493	0,465	-0,227	-0,251
245	0,436	0,435	0,372	-0,181	-0,237
250	0,353	0,35	0,289	-0,171	-0,237
255	0,242	0,24	0,192	-0,179	-0,247
260	0,106	0,105	0,084	-0,205	-0,267
265	-0,032	-0,033	-0,027	-0,238	-0,278
270	-0,174	-0,174	-0,142	-0,278	-0,283
275	-0,307	-0,308	-0,25	-0,3	-0,285
280	-0,433	-0,435	-0,352	-0,308	-0,284
285	-0,56	-0,554	-0,452	-0,31	-0,28
290	-0,682	-0,658	-0,545	-0,304	-0,274
295	-0,723	-0,68	-0,569	-0,284	-0,261
300	-0,696	-0,632	-0,537	-0,253	-0,24
305	-0,665	-0,594	-0,51	-0,224	-0,219
310	-0,625	-0,558	-0,484	-0,198	-0,196
315	-0,574	-0,518	-0,456	-0,177	-0,179
320	-0,515	-0,474	-0,426	-0,162	-0,167
325	-0,462	-0,433	-0,396	-0,158	-0,167
330	-0,416	-0,394	-0,366	-0,165	-0,177
335	-0,377	-0,362	-0,34	-0,184	-0,201
340	-0,345	-0,335	-0,319	-0,216	-0,239
345	-0,321	-0,316	-0,304	-0,259	-0,288
350	-0,306	-0,303	-0,295	-0,312	-0,348
355	-0,297	-0,296	-0,291	-0,368	-0,412



Inputfile

{file=input}
+-----------------------+
| title |
+-----------------------+
title: Secretaria - UPV E.T.S. DE INGENIERÍA DE EDIFICACIÓN
version: 1.0
made by: Olivier & Edouard
comment: none
+-------------------------+
| wind.Zo |
+-------------------------+
Direction: 0 90 180 270
Zo: 3 3 3 3
+--+
| north arrow compass direction in plan |
+--+
Direction: 22
+--+
| obstacles (position in m(=meter))|
+--+
Ground level: 0.
Roof height : 5.0

Name : building
x,y : 0. 0.
Azimut : 180.
L,W,H,#,‡,w: 21.21 15.3 5.0

Name: meteo
x,y: -2.51 16.69
Azimut: 180.
L,W,H: 0.5 0.5 5.5

Name: obstacle 1
x,y: -155.0 7.35
Azimut: 180.0000
L,W,H: 155. 93.5 5.0

Name: obstacle 2
x,y: 10.10 48.110
Azimut: 180.000
L,W,H: 27.41 30.5 5.0

Name: obstacle 3
x,y: 31.91 -17.96
Azimut: 180.000
L,W,H: 23.42 53.76 20

Name: obstacle 4
x,y: -15.3 -27.10
Azimut: 180.000
L,W,H: 15.3 34.6 5.0

```
+----------------------------+
| cp-positions               |
+----------------------------+
```

unit: m
Building side: facade 1
Pos. x,y : 1.00 2.50
Building side: facade 1
Pos. x,y : 6.85 2.50
Building side: facade 1
Pos. x,y : 12.70 2.50
Building side: facade 2
Pos. x,y : 0.500 2.50
Building side: facade 2
Pos. x,y : 3.50 2.50
Building side: facade 2
Pos. x,y : 11.8 2.50
Building side: facade 2
Pos. x,y : 14.8 2.50
Building side: facade 3
Pos. x,y : 8.45 2.50
Building side: facade 3
Pos. x,y : 13.70 3.25
Building side: facade 3
Pos. x,y : 17.70 2.50

Building side: facade 3
Pos. x,y : 20.21 2.50

Output

Degrees (°)	Façade 1			Façade 2				Façade 3			
	C_p 1	C_p 2	C_p 3	C_p 1	C_p 2	C_p 3	C_p 4	C_p 1	C_p 2	C_p 3	C_p 4
0	-0,143	-0,194	-0,208	-0,683	-0,736	-0,797	-0,764	0,458	0,559	0,616	0,661
5	-0,171	-0,209	-0,221	-0,793	-0,867	-0,988	-0,961	0,482	0,56	0,589	0,609
10	-0,2	-0,229	-0,237	-0,875	-0,973	-1	-1	0,502	0,554	0,561	0,548
15	-0,247	-0,249	-0,256	-0,917	-1	-1	-1	0,52	0,553	0,547	0,52
20	-0,307	-0,268	-0,276	-0,914	-1	-1	-2	0,534	0,555	0,544	0,52
25	-0,337	-0,279	-0,288	-0,813	-0,945	-1	-1	0,547	0,549	0,539	0,52
30	-0,341	-0,281	-0,292	-0,63	-0,745	-1	-1	0,558	0,536	0,532	0,521
35	-0,341	-0,281	-0,292	-0,456	-0,549	-0,879	-1	0,571	0,517	0,518	0,515
40	-0,336	-0,277	-0,288	-0,291	-0,355	-0,612	-0,748	0,583	0,494	0,498	0,502
45	-0,33	-0,272	-0,283	-0,202	-0,227	-0,372	-0,462	0,575	0,465	0,468	0,479
50	-0,323	-0,267	-0,279	-0,179	-0,159	-0,159	-0,184	0,549	0,431	0,43	0,445
55	-0,318	-0,259	-0,276	-0,192	-0,151	-0,045	-0,016	0,501	0,388	0,382	0,399
60	-0,316	-0,25	-0,277	-0,237	-0,199	-0,019	0,057	0,432	0,336	0,323	0,342
65	-0,313	-0,25	-0,283	-0,276	-0,24	-0,012	0,098	0,349	0,273	0,258	0,274
70	-0,31	-0,259	-0,296	-0,314	-0,279	-0,029	0,103	0,251	0,2	0,186	0,198
75	-0,297	-0,275	-0,316	-0,352	-0,32	-0,055	0,089	0,159	0,123	0,111	0,118
80	-0,277	-0,298	-0,343	-0,391	-0,363	-0,092	0,053	0,07	0,042	0,033	0,036
85	-0,278	-0,321	-0,371	-0,427	-0,405	-0,138	-0,01	-0,021	-0,034	-0,041	-0,035
90	-0,295	-0,344	-0,401	-0,461	-0,444	-0,194	-0,097	-0,114	-0,104	-0,111	-0,098
95	-0,306	-0,362	-0,426	-0,481	-0,471	-0,258	-0,182	-0,202	-0,172	-0,172	-0,154
100	-0,314	-0,377	-0,446	-0,488	-0,485	-0,329	-0,266	-0,285	-0,237	-0,226	-0,205
105	-0,325	-0,394	-0,469	-0,474	-0,479	-0,389	-0,345	-0,37	-0,306	-0,282	-0,258
110	-0,334	-0,408	-0,489	-0,437	-0,453	-0,439	-0,419	-0,452	-0,374	-0,339	-0,31
115	-0,308	-0,379	-0,452	-0,373	-0,409	-0,47	-0,464	-0,476	-0,399	-0,357	-0,328
120	-0,253	-0,313	-0,366	-0,284	-0,346	-0,482	-0,483	-0,453	-0,386	-0,344	-0,317
125	-0,2	-0,25	-0,284	-0,192	-0,274	-0,475	-0,482	-0,434	-0,377	-0,334	-0,309
130	-0,146	-0,187	-0,2	-0,096	-0,194	-0,448	-0,46	-0,415	-0,367	-0,324	-0,302
135	-0,085	-0,113	-0,112	0	-0,124	-0,41	-0,426	-0,391	-0,353	-0,311	-0,294
140	-0,019	-0,029	-0,019	0,094	-0,062	-0,362	-0,381	-0,363	-0,335	-0,294	-0,286
145	0,056	0,054	0,077	0,16	-0,012	-0,314	-0,336	-0,336	-0,317	-0,277	-0,295
150	0,139	0,138	0,176	0,199	0,028	-0,265	-0,29	-0,313	-0,3	-0,261	-0,317
155	0,219	0,21	0,273	0,214	0,06	-0,219	-0,246	-0,296	-0,286	-0,249	-0,324
160	0,295	0,271	0,369	0,202	0,079	-0,175	-0,203	-0,286	-0,274	-0,242	-0,318
165	0,361	0,323	0,447	0,112	0,044	-0,131	-0,157	-0,279	-0,266	-0,242	-0,316
170	0,417	0,366	0,507	-0,049	-0,043	-0,095	-0,114	-0,277	-0,262	-0,248	-0,316
175	0,461	0,413	0,545	-0,293	-0,218	-0,144	-0,14	-0,279	-0,26	-0,26	-0,32
180	0,492	0,462	0,562	-0,608	-0,47	-0,267	-0,229	-0,283	-0,262	-0,277	-0,326
185	0,513	0,504	0,567	-0,895	-0,726	-0,432	-0,365	-0,287	-0,267	-0,295	-0,332
190	0,524	0,539	0,56	-1	-0,985	-0,633	-0,544	-0,291	-0,275	-0,313	-0,336

195	0,527	0,567	0,559	-1	-1	-0,826	-0,716	-0,291	-0,283	-0,326	-0,335
200	0,524	0,588	0,561	-1	-1	-1	-0,878	-0,289	-0,291	-0,333	-0,327
205	0,522	0,597	0,554	-1	-1	-1	-0,935	-0,285	-0,293	-0,335	-0,307
210	0,524	0,596	0,539	-1	-1	-1	-0,902	-0,278	-0,289	-0,33	-0,276
215	0,56	0,585	0,516	-0,97	-1	-0,928	-0,836	-0,267	-0,277	-0,303	-0,241
220	0,625	0,566	0,487	-0,765	-0,827	-0,805	-0,737	-0,253	-0,255	-0,256	-0,2
225	0,675	0,559	0,458	-0,634	-0,666	-0,665	-0,617	-0,238	-0,233	-0,221	-0,161
230	0,711	0,558	0,428	-0,564	-0,544	-0,512	-0,482	-0,222	-0,21	-0,196	-0,124
235	0,735	0,538	0,394	-0,495	-0,46	-0,411	-0,389	-0,215	-0,201	-0,186	-0,097
240	0,744	0,5	0,354	-0,432	-0,41	-0,353	-0,331	-0,215	-0,204	-0,191	-0,078
245	0,716	0,442	0,303	-0,375	-0,362	-0,309	-0,289	-0,226	-0,221	-0,203	-0,073
250	0,652	0,365	0,24	-0,325	-0,317	-0,28	-0,264	-0,248	-0,25	-0,222	-0,08
255	0,563	0,276	0,168	-0,286	-0,282	-0,256	-0,243	-0,277	-0,29	-0,249	-0,098
260	0,448	0,175	0,087	-0,256	-0,254	-0,237	-0,227	-0,315	-0,341	-0,284	-0,128
265	0,328	0,067	0,001	-0,234	-0,235	-0,224	-0,216	-0,354	-0,392	-0,32	-0,165
270	0,201	-0,047	-0,088	-0,221	-0,223	-0,216	-0,21	-0,395	-0,444	-0,358	-0,209
275	0,078	-0,156	-0,174	-0,214	-0,216	-0,211	-0,207	-0,429	-0,481	-0,39	-0,254
280	-0,042	-0,261	-0,259	-0,211	-0,213	-0,21	-0,206	-0,457	-0,506	-0,416	-0,297
285	-0,165	-0,364	-0,345	-0,21	-0,212	-0,21	-0,206	-0,483	-0,535	-0,449	-0,329
290	-0,286	-0,461	-0,428	-0,21	-0,213	-0,211	-0,208	-0,503	-0,56	-0,482	-0,345
295	-0,331	-0,495	-0,461	-0,211	-0,213	-0,213	-0,209	-0,461	-0,511	-0,434	-0,282
300	-0,31	-0,476	-0,452	-0,211	-0,213	-0,214	-0,211	-0,368	-0,402	-0,317	-0,151
305	-0,278	-0,458	-0,437	-0,212	-0,214	-0,217	-0,214	-0,281	-0,298	-0,198	-0,029
310	-0,233	-0,436	-0,413	-0,213	-0,217	-0,221	-0,219	-0,194	-0,193	-0,071	0,09
315	-0,189	-0,403	-0,382	-0,217	-0,222	-0,23	-0,229	-0,107	-0,083	0,061	0,213
320	-0,146	-0,36	-0,345	-0,223	-0,23	-0,243	-0,244	-0,02	0,029	0,197	0,339
325	-0,111	-0,315	-0,308	-0,233	-0,243	-0,263	-0,267	0,066	0,137	0,325	0,458
330	-0,083	-0,269	-0,271	-0,247	-0,261	-0,29	-0,297	0,149	0,241	0,444	0,57
335	-0,067	-0,231	-0,24	-0,266	-0,283	-0,325	-0,336	0,223	0,333	0,541	0,655
340	-0,063	-0,202	-0,216	-0,29	-0,311	-0,367	-0,384	0,289	0,414	0,616	0,714
345	-0,071	-0,184	-0,202	-0,346	-0,367	-0,415	-0,434	0,345	0,478	0,652	0,735
350	-0,089	-0,178	-0,196	-0,431	-0,451	-0,476	-0,492	0,391	0,524	0,652	0,722
355	-0,114	-0,182	-0,198	-0,545	-0,576	-0,607	-0,604	0,429	0,551	0,64	0,698

APPENDIX B: GROUND PLAN OF THE THERMAL ZONE