Assessment of energy savings related to sustainable solutions improving summer comfort

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Abstract

Today Energy efficiency policies are very oriented towards the reduction of energy consumption for heating purposes, even if the energy consumption for cooling is increasing very rapidly. In this context, KeepCool II aims to contribute to market transformation from “cooling” to “sustainable summer comfort. This work was inserted in the KeepCool II project and it main objective was to determine unitary savings and evaluation of summer Comfort after the application of an EEI action or a Package (several EEI actions) through simulations made in TRNSYS, in the tertiary sector.

To evaluate the energy savings after the introduction of an EEI action a methodology was created and a reference case was constructed in TRNSYS. These energy savings could come from a reduction of the consumption in AC systems or from the elimination of the AC system if the building is considered as comfortable. To define if a building is uncomfortable or not in free-running mode, the standard EN 15251 was used and an algorithm was created to simulate the opening of windows by occupants in the free-running buildings.

A sensitivity study was carried out to evaluate the impact of each passive solution in cooling demand and a calculation was made for some EEI actions to evaluate the Energy Savings.

A calculation was carried out in the reference case for some passive solutions and it was measured the impact in cooling needs. However the gains in cooling needs can come across heating needs losses. This study shown, that a comparison between heating and cooling needs has to be made when a passive solution is implemented.

At the end a chain of calculation was defined, based in the created methodology, in TRNSYS and EXCEL for future simulations.

Thanks

This work does not represent only the result of long hours of simulations and study, but a work that defined the direction of my Professional Plan. It must be said that, it would be almost impossible to finish this work without the help of several persons.

I am especially grateful to the Prof. Jérôme Adnot, who gave me the opportunity to elaborate this work and was always ready to help, no matter the subject.

To Laurent Grignon-Masse for all the advices, explications, cooperation and patience.

I'm also in doubt for all the other persons who helped me, gave support and shared their knowledge's. To them I dedicate this work.

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1. Introduction

Today the energy efficiency policy is very oriented towards the reduction of energy consumption for heating purposes, even if the energy consumption for cooling is increasing very rapidly (figure 1).

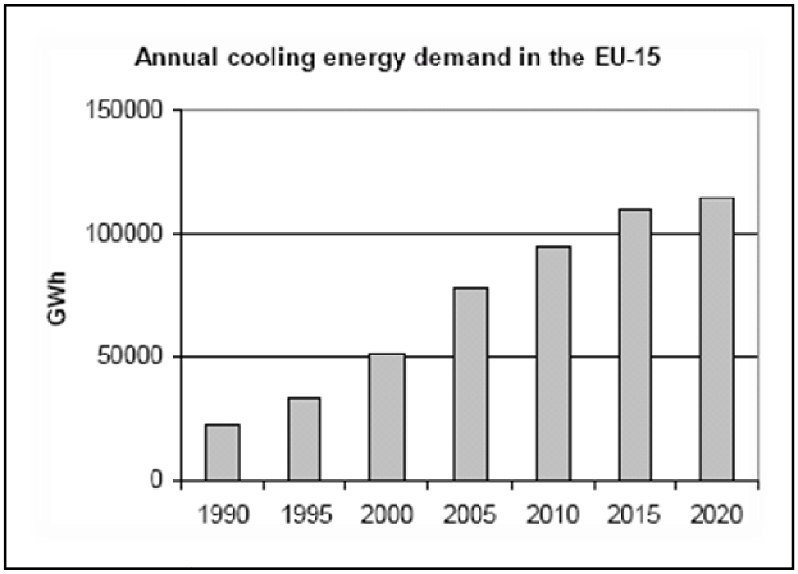

Figure 1- Annual cooling energy demand in the European Union, forecast by the project EECCAC (Adnot, 2003)

In the frame of the implementation of the Directive on Energy End-use Efficiency and Energy Services (EEE-ESD), each Member States needs to prepare Energy Efficiency Action Plans (EEAP) and this is a chance to introduce the cooling energy consumption issues into Energy Efficiency Policies. The EEAP includes an estimation of the Energy Savings related to the implementation of Energy Efficient Improvement Measures.

In the first EEAP each Member State has to describe how they will achieve their targets, and in a second plan they will have to report what has been achieved.

Despite the well-known passive solutions to achieve summer comfort, the application of mechanical air conditioning is still the safest way. There is a lack of knowledge in this area.

The work shown in this report tries to complete this lack of knowledge in this area, and determines the effect of passive solutions through simulations in typical buildings. This study is inserted in the Keep Cool II project.

In the Keep Cool II project two main goals are searched: dissemination of the knowledge about sustainable ways to cool buildings and give support to the national institutions preparing the EEAP under the Directive on Energy end use efficiency and energy services.

1.1 Presentation of the KeepCool Project

The KeepCool Project is co-financed by Energy Intelligent – Europe Programme of the European Commission and it aims to promote" sustainable cooling" in the service building sector.

The goal of the KeepCool II is to contribute to market transformation from "cooling" to "sustainable summer comfort" which can be defined as follows: achieving good summer comfort conditions with or limited use of the conventional energy and through the use of environmentally non-harmful materials. In particular, the project pursues the following objectives:

- Consolidating the market chain of sustainable summer comfort solutions;
- Creating incentives for designers and planners towards integrated planning;
- Introducing sustainable summer comfort into National Energy Efficiency Action Plans, guidelines for public procurement and national building regulation;
- Transporting the results directly into the relevant target group trough a wide range a dissemination activities on the national as well as on the European level.

The KeepCool II work is divided in to phases:

The first phase consists in three work packages that come up with analysis and technical input:

- Practical recommendations and supplementary material to overcome the most important market barriers – Work Package 2
- Procedures and tool to support the Member States in implementing their exemplary role – Work Package 3
- Assessment of energy savings related to sustainable summer comfort – Work Package 4

In a second phase the KeepCool Project contributes to market transformation through three dissemination campaigns addressing for different target groups:

- Entire market chain from the suppliers industry to the building owner – Work Package 5
- Input to the National policy making processes related to the EPBD (Directive on End-use Energy Performance of Buildings) and the EEE-ESD – Work Package 7
- Several dissemination activities towards key actors at the European level – Work Package 8

This study has been carried out in the frame of **Work Package 4 -** Assessment of energy savings related to sustainable summer comfort

1.2 Presentation of the Work Package 4

The Work Package 4 aims at developing an approach for a bottom-up assessment of the energy savings related to sustainable summer comfort solutions.

Bottom-up means a calculation method that starts with energy savings obtained through the implementation of a specific energy efficiency improvement measure, mechanism, program, or energy service (e.g. monitoring energy savings per participant and number of participants), and then aggregates results from all EEI measures reported by a Member State to assess its total energy savings in a specific field.

A distinction need to be made from Energy Efficient Improvement Measure and Energy Efficient Improvement Action.

- EEI Measure means: “all actions that normally lead to verifiable and measurable or estimable energy efficiency improvement” [ESD (Directive on Energy Services) article 3h]. Some examples of EEI measures are: EEI programmes, EEI policy instruments, energy services and other measures, e.g., incentive programmes, building codes…
- An EEI action is described as a technical, organizational, or behavioural action taken at an end-user’s site (or building, equipment…), but not necessarily by the end-user himself, that improves the energy efficiency of the energy end-using facilities or equipment, and thereby saves energy.

The objective of this Work Package is through simulations, in typical buildings, achieve unitary savings due the implementation of EEI actions that then can be usable by each MS EU Members.

This study was made in the ***heart of the Work Package 4 team*** **(ARMINES and the Politecnico di Milano)** and its goal was to ***determine unitary savings and evaluation of summer Comfort*** after the application of an EEI action or a Package (several EEI actions) through simulations made in **TRNSYS.**

The Work Package 4 consists in three tasks:

1.2.1 Determination of the reference base cases

The EEE-ESD (Directive on Energy End-use Efficient and Energy Services) specifies that “Energy savings shall be determined by measuring and/or estimating consumption, before and after the implementation of the measure […]. The determination of the base case is one of the major challenges for every energy savings calculation. This means that the Reference Case should be as possible representative of buildings in Europe.

The base case definition integrates market and/or stock values and probably introduces the main source of uncertainty in the calculation of the energy savings.

1.2.2 Selection of technical solutions suitable for a quantitative assessment

In a first part, all the technical measures analysed and disseminated under KeepCool I and II will be reviewed in order to select the solutions for which enough knowledge is available to assess the cooling load cut or cooling consumption reduction when applied in a particular building.

In a second step selected technical solutions for sustainable summer comfort will be grouped into typical packages, since very often these technical solutions are not used as stand-alone measures but in combination with other measures.

1.2.3 Evaluation of energy savings and normalisation for external parameters

This task converges the preparatory work in tasks 1 and 2 by evaluating the energy savings related to the implementation of a given (package) sustainable summer comfort solutions in the predefined base cases.

The unitary savings will be given in terms of energy need, energy use and primary energy savings.

1.3 Presentation of ARMINES

The work developed in this study was made in a company named ARMINES. This company is a contract research association that was created in 1967 by an initiative of the École des Mines de Paris, in partnership with other French schools.

Today Armines counts with 500 employees dispatched in 50 laboratories, with the participation of Schools' teacher-researchers and with a 37 Millions Euros annual sales figures. It can be said that ARMINES it is the first research organization working with school institutions. The research is industry-oriented and it is based on exchanges between researchers and industry. In contrast to pure or competitive research, it is built on a partnership that gives rise to a unique culture whereby the scientific approach must confront the realities of industry.

The work produced in ARMINES is oriented to industry research. These works includes many areas of engineering sciences, like:

- Material Sciences and Engineering
- Earth and Environmental Sciences
- Process Engineering, Thermal Energy and the Environment
- Information Technology, Automation, Applied Mathematics
- and others…

1.4 Organization of the report

The report is organized as follows:

I. Methodology for the Calculation of Energy Savings

At the beginning it will be made a presentation of the Program used to do the simulation. Next it will describe the methodology used to calculate the Energy Savings.
At the end an example of this methodology calculation will be made.

II. Simulation of the Reference Case

In this chapter it will be present the Reference Case and a study of the climatic zones for Europe made by the Work Package 4 team.
Next it will be described an algorithm made to take into account the opening of windows
Finally the results (cooling and heating needs and discomfort) for the reference case will be shown.

III. Sensitivity Study of the Reference Case

Next a description of the passive solutions will be made and after, a sensitivity study will be shown for the reference case.

IV. Energy Savings Calculation

During this chapter it will be shown an application of the studied passive solutions, into the simulation chain to derive energy savings.

V. Conclusions

Report conclusions, about the work developed in this study, will be shown and after, it will be presented some factors that were not included into the calculations, as like the met difficulties. To finalize, it will be given some words about the future work.

2. Methodology to the calculation of Energy Savings

The focus of this study was to simulate typical buildings (reference case) with or without EEI actions. Then the values were treated taking into account a methodology described in Part 2.2. From the final values given by this methodology, conclusions could be made regarding which passive solutions to be applied to the buildings. All these simulations were made resorting to TRNSYS. Next a short presentation of this program will be made and then the Methodology will be explained.

2.1 Presentation of the Software TRNSYS (Transient System Simulation)

The program used to do the simulations was TRNSYS version 16. This program is a complete and extensible simulation environment for the transient simulation of systems, including multi-zone buildings. It is used 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 behavior, alternative energy systems (wind, solar, photovoltaic, hydrogen systems), 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

TRNSYS has simple interface (Simulation Studio) were the items (machines, meteorological values for a climate…) can be added and then linked between them, like in figure 2.

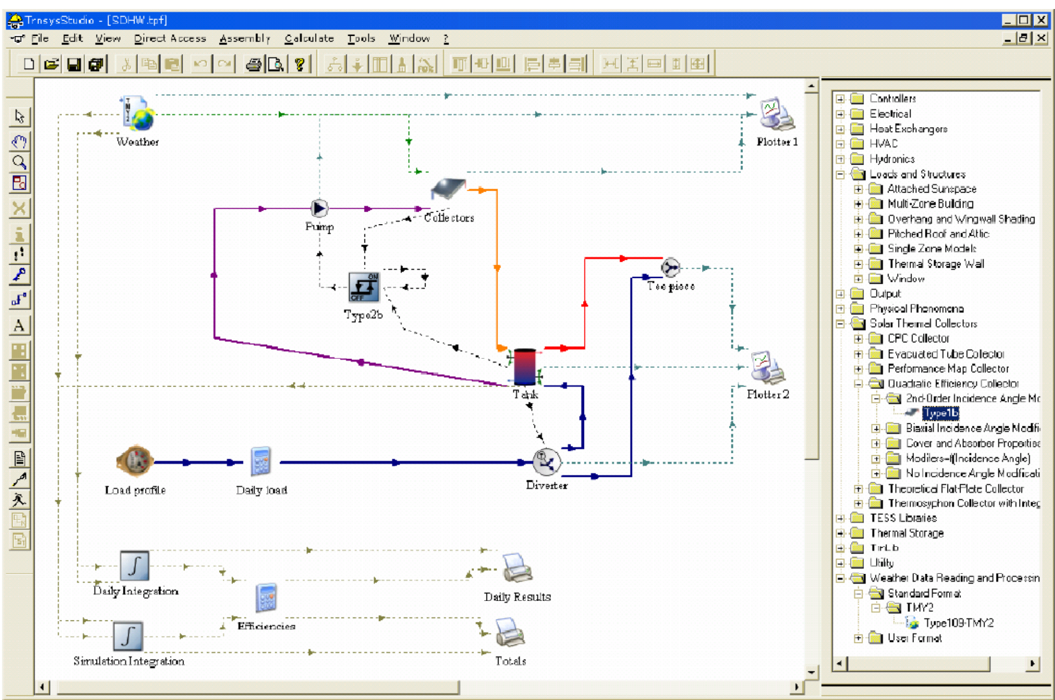

Figure 2 –Interface of the Simulation Studio

Within this program there are some "add-ons" that can be linked to TRNSYS to facilitate the construction of a project.

One of this "add-ons" is the TRNBUILD. This program was very useful in this project since it let us define almost everything in a building like:

- Walls
- Rooms and its surfaces
- Internal gains
- Windows
- Ventilation
- …

The interface of this "add-on" is shown in the figure 3.

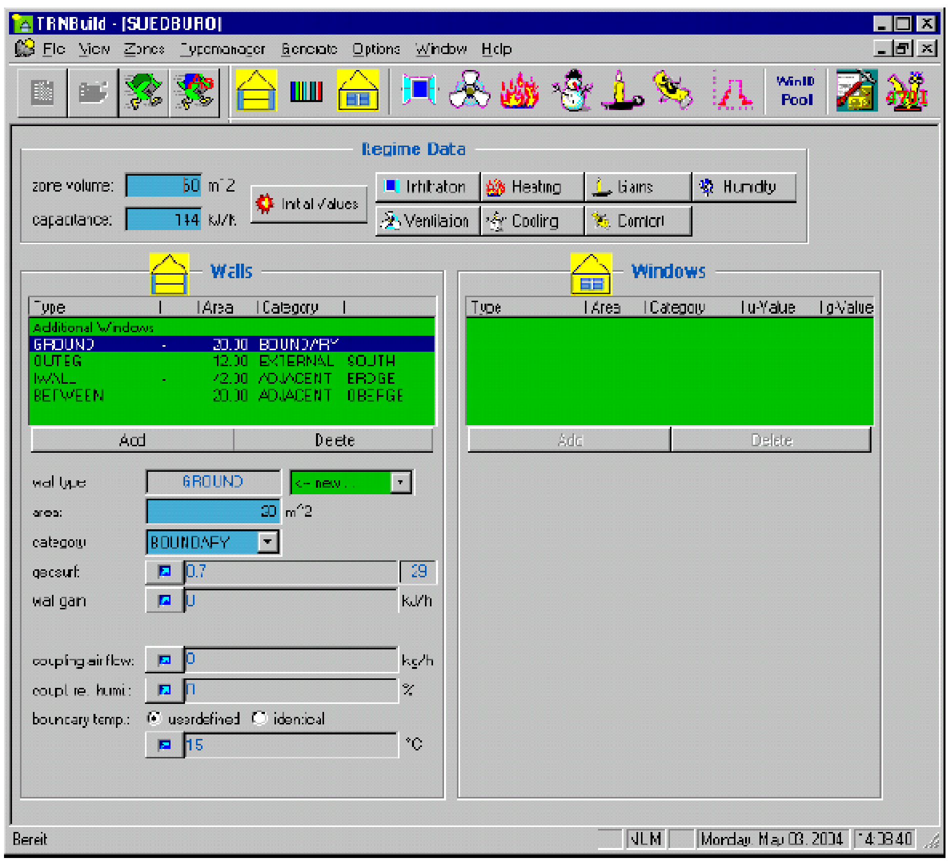

Figure 3 – TRNBUILD interface.

Its connection with TRNSYS Simulation Studio is made by items called Type 56.

Once all the variables of the project are defined the user only has to link the inputs and outputs to finish the project in the Simulation Studio.

There are some other “add-ons” but they were not used in the project because ARMINES did not have the license for them, like TRNFlow and SimCad.

2.2 Presentation of the Methodology

The focus of this study is to find Energy Savings when a passive solution (EEI) is applied to a building. To do this a Methodology was created by the Work Package 4 team in order to represent clearly the Energy Savings.

The proposed Methodology for calculations is represented in figure 4 and explained hereafter. This methodology looks at buildings (reference ones or improved ones) in two ways: AC and free ventilated ones (with possibility to open the windows).

After each simulation, the Software TRNSYS give the Heating and Cooling Needs of the reference case in which the EEI action has been applied.

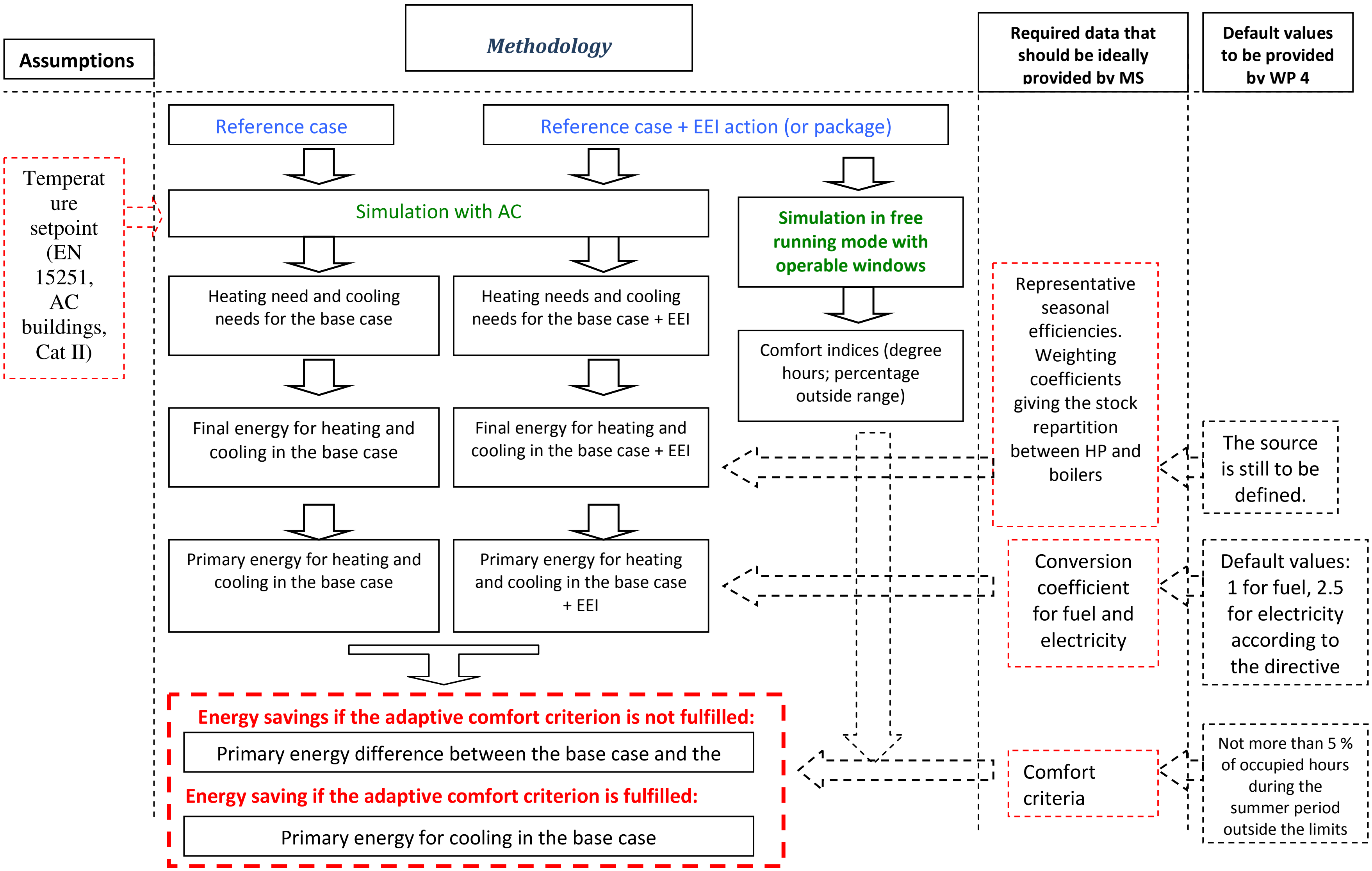

Figure 4- Scheme of the Methodology developed

Regarding AC buildings, some comfort conditions are defined to be reach (based on existing standards) in the base case (BC) and in the base case plus EEI (BC+EEI). Then, the "energy need" is calculated to reach this comfort, objective for the base case and for the case when a certain EEI action has been taken. From energy needs it becomes possible to calculate the final and primary energy consumptions for the base case and for the case when a certain EEI action has been taken (assuming default conversion coefficients).

Regarding free running buildings, the simulations enable to derive comfort indices. Then, it is up to MS to fix what they consider as comfortable in free running buildings and choose if the EEI action (or package) implies a reduction of the cooling load or enables to avoid the use of air conditioning.

2.2.1 Definition of the Comfort Criteria

This project deals with Energy savings related to EEI actions applied into buildings, with the objective to improve Summer Comfort. After the realization of the methodology of calculation of the Energy Savings two types of buildings were defined: buildings with AC systems and free running buildings.

Two different approaches of Comfort Criteria were chosen regarding these two types of buildings.

2.2.1.1 Summer comfort assessment in AC buildings

Four categories of buildings are defined in the standard EN 15251 (Table 1), according to the occupant's level of expectations and the comfort ranges depend on them. It was chosen to use the Category II.

Table 1 – Occupants level of expectations

Categories	Explanation
I	High level of expectation, recommended for spaces occupied by very sensitive and fragile persons with special requirements like handicapped, sick, very young children and elderly persons.
II	Normal level of expectation, should be used for new buildings and renovations
III	An acceptable, moderate level of expectation, may be used for existing buildings
IV	Values outside the criteria for the above categories. This category should only be accepted for a limited part of the year.

2.2.1.1.1 Comfort ranges based on the analytic approach

The comfort ranges are based on the use of PMV/PPD indices (Table 2)

Table 2 – PMV/PPD indices

Categories	Thermal state of the body as a whole	
	Predicted Percentage of Dissatisfied [%]	Predicted Mean Vote
I	< 6	-0.2<PMV<0.2
II	< 10	-0.5<PMV<0.5
III	< 15	-0.7<PMV<0.7
IV	>15	PMV<-0.7 or PMV>0.7

Given that the PMV/PPD indices are quite difficult to use because they require the knowledge of several parameters that are sometimes difficult to access, recommended indoor operative temperature ranges have also been determined assuming clothing, activity of the occupants, low airspeed and a humidity of 50 % (EN 15251). These ranges are given in the following table.

Table 3 – Ranges for the analytic approach

Building types	Categories	Operative temperature range in Winter (1 clo) [°C]	Operative temperature range in Summer (0.5 clo) [°C]
Residential (bedrooms, living rooms…) 1.2 met	I	21-25	23.5- 25.5
	II	20-25	23-26
	III	18-25	22-27
Residential, other rooms: kitchen… 1.5 met	I	18-25	
	II	16-25	
	III	14-25	
Offices: Single and landscaped office conference room, auditorium, classrooms. 1.2 met	I	21-23	23.5-25.5
	II	20-24	23-26
	III	19-25	22-27
Infant schools 1.4 met	I	19-21	22.5-24.5
	II	17.5-22.5	21.5-25.5
	III	16.5-23.5	21-26
Retails 1.6 met	I	17.5-20.5	22-24
	II	16-22	21-25
	III	15-23	20-26

2.2.1.1.2 Definition of the Set points

The energy consumption for cooling and heating purposes obviously depends on the chosen set point temperatures. Regarding the Category II of the Table 3 for the analytic ranges, it was determined the following set points:

- 20 °C in winter
- 26 °C in summer (upper limit of the comfort range according to the analytic approach)

2.2.1.2 Summer comfort assessment in free-running buildings

In order to conclude if an EEI action could enable to avoid the installation of classic air conditioning systems, an study about indoor climatic conditions must be done and provide comfort indices.

For free-running buildings it means that no air conditioners are used and that the occupants can open the windows when they feel uncomfortable.

The European standard (EN 15251) was used to define thermal comfort conditions.

2.2.1.2.1 Thermal comfort: index vs. criterion

It was used “index” for objective information and “criterion” as a factor that allows making a judgment. In this study, the number of hours outside a comfort range is an index; the fact to say that “when this index is higher than 5 % of the occupation time, the building is uncomfortable” is a criterion.

2.2.1.2.2 Comfort ranges based on the adaptive approach (EN 15251)

The acceptable indoor operative temperatures according to the adaptive approach are displayed in the following figure (for the three building categories). They depend on a running mean outdoor temperature defined by Equation 1. This is an exponentially weighted running mean of the daily mean external air temperature. It is also possible to use Equation 2 that is a simplification of Equation 1.

$$\Theta_{rm}=(1-\alpha).[\Theta_{ed-1}+\alpha.\Theta_{ed-2}+\alpha^2.\Theta_{ed-3}+...] \qquad (1)$$

$$\Theta_{rm}=(1-\alpha).\Theta_{ed-1}+\alpha.\Theta_{rm-1} \qquad (2)$$

Where Θ_{rm} is the running mean temperature for today, Θ_{rm-1} the running mean temperature for the previous day, Θ_{ed-1} the daily mean external temperature for the previous day, Θ_{ed-2} the daily mean external temperature for the day before and so on. α is a constant between 0 and 1and it is recommended to use 0.8

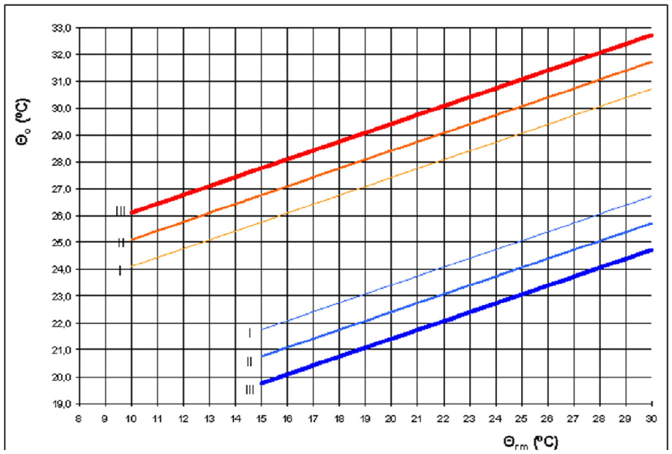

Figure 5 – Indoor operative temperature limits of EN 15251

2.2.1.2.3 Comfort zones kept

The defined limits for Comfort are shown in Table 4

Table 4 – Summer Comfort Limits

	Adaptive approach
Normal level of expectation (Residential, offices…)	Upper limit: $\Theta_{max}=0.33.\Theta_{rm}+21.8$ Lower limit: $\Theta_{max}=0.33.\Theta_{rm}+15.8$

2.2.1.2.4 Long term comfort indices

There are two main methods to assess thermal comfort over the year.

- **Percentage outside range**: the proportion of the occupied hours during which the temperature lies outside the acceptable zone
- **Degree hours criterion**: the time during which the actual operative temperature exceeds the specified range during occupied hours is weighted by the number of degrees by which the range has been exceeded

To achieve these two long term comfort indices a post treatment need to be made in EXCEL.

Then regarding that, if a building passes more than 5 % of its occupation time outside the Comfort ranges, the building is considered as uncomfortable.

In the following of the study, the time outside the comfort range is calculated for the worst thermal zone. The temperature that defines the comfort within a room is the operative temperature.

Operative Temperature = 0,5 x Temperature of air + 0,5 x Temperature of walls

Since the temperature of walls and air are an average of the room, the operative temperature will be an average temperature too.

Meaning that even when choosing the worst thermal zone the results in terms of time outside the comfort ranges, will be an average. So the particular discomfort within a room, like persons close to windows, is not taken into account.

2.3 Example of the process to determine the Energy Savings

As it was said before after each simulation, of the reference case plus the EEI action, TRNSYS gives the Cooling and Heating needs. Simulations are made for each Climatic zone and then the Table 5 is filled.

Table 5 - Cooling and heating needs (obtained from simulations)

Climatic zones	**Cooling needs [kWh/m²/y]**	**Heating needs [kWh/m²/y]**
Stockholm		
Brussels		
Milan		
Rome		
Palerme		

For the same EEI actions another cycle of simulations is made, in order to fill the table 6, but now in free-running mode. To allow the determination of comfort, a post treatment (in EXCEL) of the inside temperatures has to be made.

Table 6 - Comfort indices (obtained from simulations)

Climatic zones	Free running with operable windows	
	Percentage of time outside zone (adaptive)	**Degree hours outside zone (adaptive)**
Stockholm		
Brussels		
Milan		
Rome		
Palerme		

Then a calculation of the unitary gross annual savings in terms of Cooling and heating is made determined using the following equations:

Annual savings in terms of cooling needs are determined using the following equation:

If the comfort criterion is not fulfilled (more than 5% of the time outside Adaptive Zone):

Savings_CN=CN_{ref}-CN_{EEI}

If the comfort criterion is fulfilled:

Savings_CN=CN_{ref}

Where:

Savings_CN is the annual saving in terms of cooling needs [kWh/m²/y]

CN_{ref} is the annual cooling needs of the reference case obtained [kWh/m²/y]

CN_{EEI} is the annual cooling needs of the reference case in which the EEI action has been applied [kWh/m²/y]

Annual savings in terms of heating needs are determined using the following equation:

Savings_HN=HN_{ref} – HN_{EEI}

Where:

Savings_HN is the annual saving in terms of heating needs [kWh/m²/y]

HN_{ref} is the annual heating needs of the reference case obtained [kWh/m²/y]

HN_{EEI} is the annual heating needs of the reference case in which the EEI action has been applied [kWh/m²/y]

With these values the Table 7 is filled.

Table 7 - Savings in terms of Cooling and Heating Needs

Climatic zones	Savings in terms of Cooling needs [kWh/m²/y]	Savings in terms of Heating needs [kWh/m²/y]
Stockholm		
Brussels		
Milan		
Rome		
Palerme		

After the calculation of the savings in terms of needs, a calculation of the **unitary gross annual savings in terms of final energy compared to the reference case**, takes place.

For the time being no SEER (Seasonal Energy Efficiency Ratio) in cooling mode (representative of the AC existing stock) and no Seasonal efficiency in heating mode (representative of the boilers existing stock), have been delivered by any country in the project. An example of these values could be:

SEER=2

η=0.5

Calculation of unitary gross annual savings in terms of final energy:

A distinction should be made between electricity savings and fuel savings.

$$Savings\_E = \frac{Savings\_CN}{SEER}$$

$$Savings\_F = \frac{Savings\_HN}{\eta}$$

Where:

Savings_E is the annual savings in terms of electricity [kWh/m²/y]

SEERis the Seasonal Energy Efficiency Ratio in cooling mode representative of the AC existing stock

Savings_F is the annual savings in terms of fuel [kWh/m²/y]

η is the Seasonal efficiency in heating mode representative of the boilers existing stock

Once the calculations are done, the values are introduced in the Table 8.

Table 8 – Savings in Electricity and Fuel

Climatic zones	Savings in terms of electricity [kWh/m²/y]	Savings in terms of fuel [kWh/m²/y]
Stockholm		
Brussels		
Milan		
Rome		
Palerme		

Then and finally an estimation of the unitary gross annual savings unitary savings in terms of primary energy compared to the reference case is made:

For the values of the conversion factors for electricity and fuel, it was taken representative values:

Conversion factor for electricity - $CF_E = 2.5$

Conversion factor for fuel - $CF_F = 1$

The Calculation of unitary gross annual savings in terms of final energy is made regarding the following equation:

$$Savings\_P = Savings\_E * CF_E + Savings\_F * CF_F$$

Where:

$Savings\_P$ is the annual savings in terms of primary energy [kWh/m²/y]

$Savings\_E$ is the annual savings in terms of electricity [kWh/m²/y]

CF_E is the conversion factor for electricity

$Savings\_F$ is the annual savings in terms of fuel [kWh/m²/y]

CF_F is the conversion factor for fuel

With these values the table 9 is filled and then it can be seen if the real savings are positive or negative for each Climatic zone where the EEI actions was implemented.

Table 9 – Savings in terms of Primary Energy

Climatic zones	Savings in terms of Primary Energy [kWh/m²/y]
Stockholm	
Brussels	
Milan	
Rome	
Palerme	

3. Simulation of the Reference Case

To be able to realize the simulations in TRNSYS several parameters had to be defined:

- What are the Reference Case Characteristics?
- What are the climates (Cities) to be kept for the Simulations?
- How to simulate the opening of windows in free running buildings?

3.1 Reference Case

According to the EECCAC study, the most important air conditioning appliances in Europe are residential Room Air Conditioners and chillers (83 %). Another figure from this study gives the most important sectors for theses appliances (Figure 6):

- Offices/trade/houses/hotels&bars for RACs
- Offices/hotels&bars /hospitals /trade for chillers:

As a result, regarding their respective importance in terms of cooling surface, it appears that three sectors should be primarily focused on (office, trade, hotels) and two others can worth to be studied (houses and hospitals). The education sector is not a main concern in the case of this study, once that in the summer almost all schools are closed due to vacations. The hospitals were not included in this study because there are very specific needs (legislation, hygiene…)

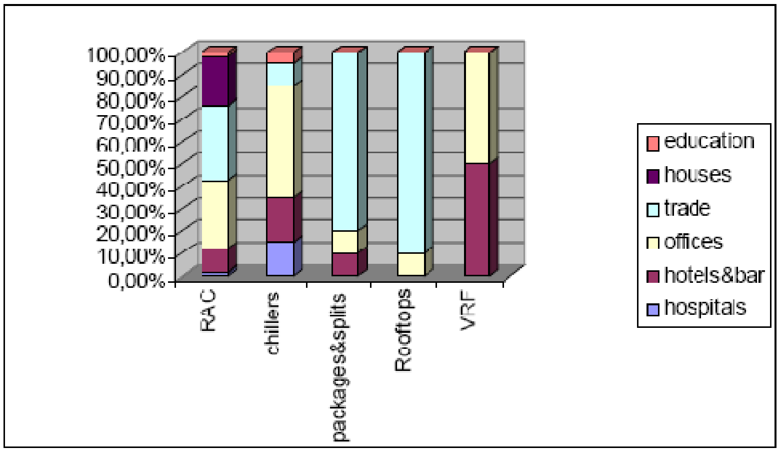

Figure 6 - Share of conditioned floor space by building type for each AC system type across the EU

In a first time, only one reference (Office Building) case was studied. In this study a simplification was carried, the building shell was kept the same for all the representative cities, since the values from the several countries in Europe are not known. Others will be studied later on to represent the European building stock more accurately.

The reference case most important characteristics are:

- High Internal gains
- Low inertia
- Set points : heating: 20 (ºC) / cooling: 26 (ºC)
- High glazed areas

The office building n°1 has 12 identical floors (Figure7) of 3 m height each.

The general dimensions of the building are given in tables 10 and 11.

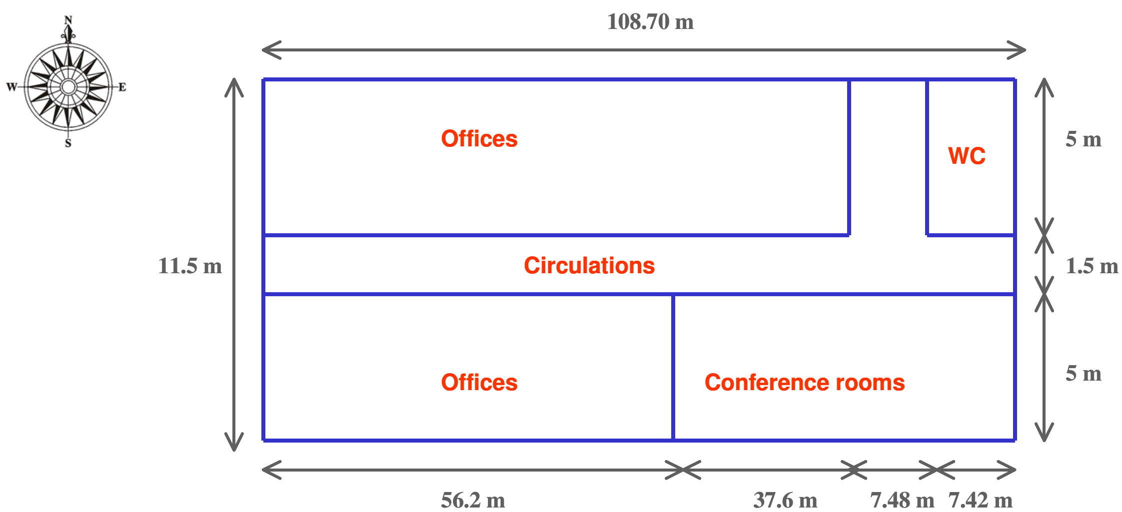

Figure 7 – Detailed description of rooms dimensions

Table 10 - Repartition of UTH by use

UTH	Usage	Surface area of one floor	Surface area of 12 floors	Percentage of total	Volume
1	WC	37.0	444.6	3	1333.8
2	offices	281	3372	60	10 116
3	offices	469	5628		16 884
4	meeting rooms	262.5	3150	21	9450
5	circulations	200.5	2405.4	16	7216.2
Total		1250	15 000	100	45 000

Table 11 - Outside surface area for one floor

Room height m	3	Outside surfaces for one floor								
Surface area m²	15000	Ceiling	Vertical (opaque and glazed)				Glazed surface			
Usage	UTH		N	S	E	W	N	S	E	W
WC	1	37.1	22.3	0	15	0	11.1	0	0	0
offices	2	281	0	168.6	0	15	0	84.3	0	0
offices	3	469	281.4	0	0	15	140.7	0	0	0
meeting rooms	4	262.5	0	157.5	15	0	0	78.8	0	0
circulations	5	200.5	22.4	0	4.5	4.5	11.2	0	0	0

A detailed description of the Reference Case is made in Annex A.

From Simulations values for the heating and cooling were calculated, as well for the discomfort in free-running mode (Table 12 and 13, and Figure 8)).

Table 12 – Heating and Cooling Needs for the Reference Case

Climatic zones	**Heating needs [kWh/m²/y]**	**Cooling needs [kWh/m²/y]**
Stockholm	123,6	6,2
Brussels	64,7	8,1
Milan	56,7	27,5
Rome	13	45,5
Palerme	1,6	63

Table 13– Discomfort for the reference case

Climatic zones	Percentage of time outside zone (adaptive)	Degree hours outside zone (adaptive)
Stockholm	5.45%	68.0
Bruxelles	14.04%	210.3
Milan	45.99%	1508.6
Rome	66.66%	2071.4
Palerme	87.38%	2959.3

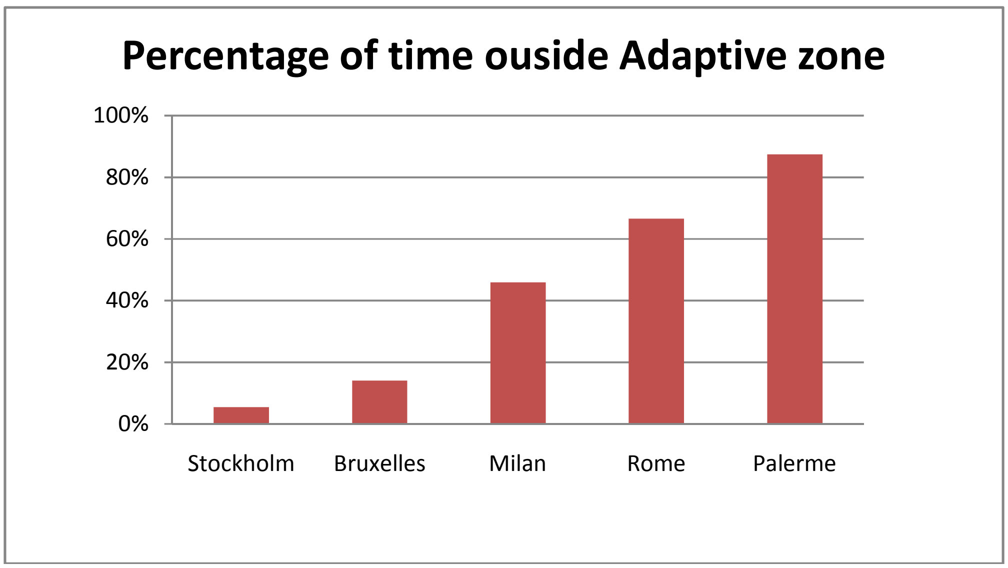

Figure 8 -Percentage of time outside range obtained when the reference case is free running mode

3.2 Climatic zones

Due to the lack of time it was impossible to afford to do too many simulations, so the whole Europe was reduce to 5 representative climates.
Ideally the energy saving values need to be as representative as possible for places in Europe. The participants countries in the project were chosen as possible in this climatic zones: this could be helpful when we have to deal with national dissemination that is likely to occur first in participant countries: Sweden, Austria, Portugal, Italy, UK, Belgium, Germany and Slovenia.

To choose the most representative cities a study was carried by the Work Package 4 Team, regarding to factors: Solar Radiation and Cooling Degree Days.

The global solar radiation has been summed and cooling degree days have been calculated (15 °C) over a year for 30 European cities: at least one city per EU 25 country (except Luxembourg for which Nancy has been kept and Gdansk for Lithuania) and several cities for France, Italy and Spain...

The results are given in the following figure. Based on this, four climatic areas have been defined and given in the following Table.

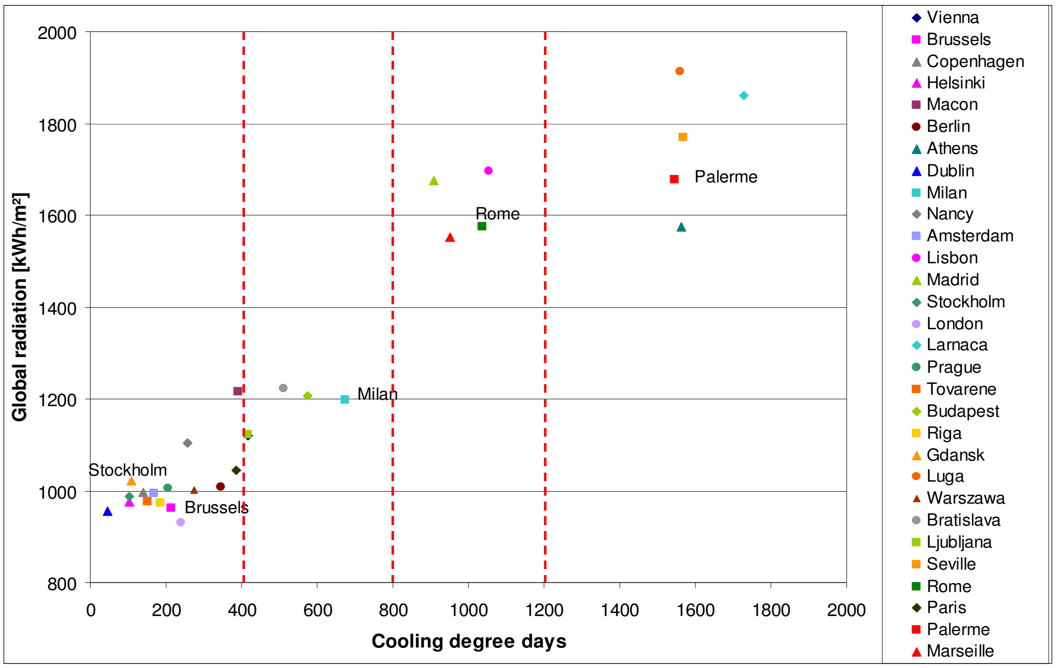

Figure 9 – Global radiation and Cooling degree days for several European Cities

The severity of winter is also an important parameter in the definition of the climatic zones. These characteristic modify for each zone the building shell and the Heating needs. As a result, a calcul was made in heating degree days (15 °C) for the same European cities (following figure). The Zone 4 could be separated into two areas. Climatic areas are given in the following table with possible representative cities.

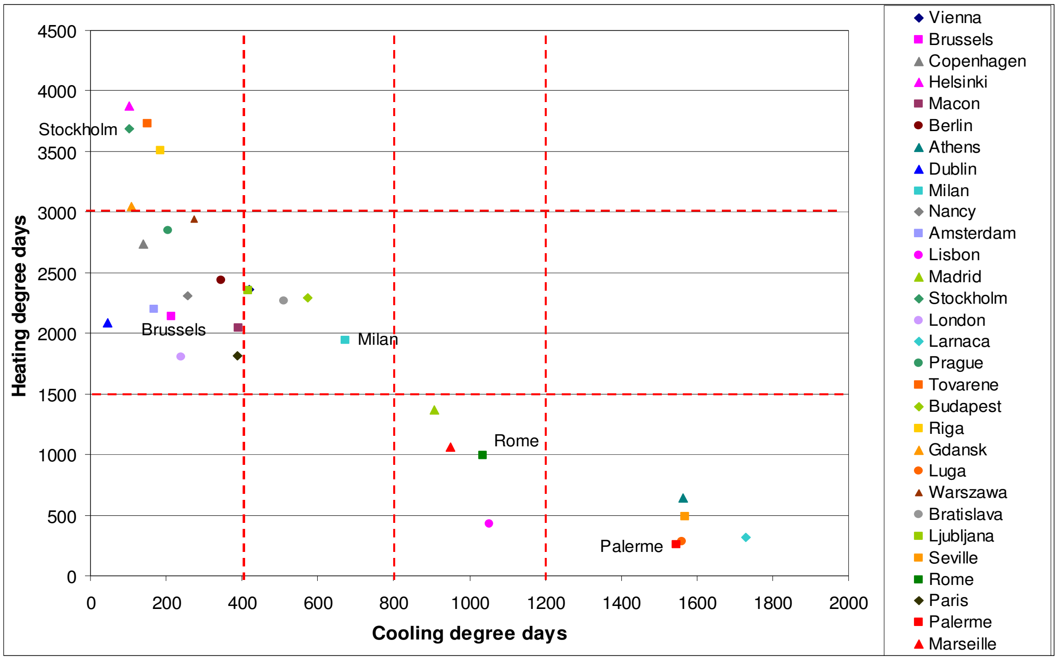

Figure 9 – Heating Degrees days for several European Cities

At the end, five climatic areas were kept:

Table 14 – Chosen Cities to represent the Climatic zones

Representative Cities
Stockholm
Bruxelles
Milan
Rome
Palerme

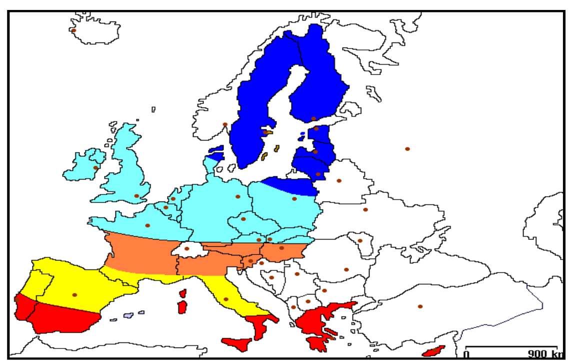

Figure 10 – Image showing the 5 Climatic Zones

3.3 Natural Ventilation in Free-Running Buildings

How to simulate the opening of windows in free running buildings?

This study does not only deal with air conditioned buildings but also with free ventilated ones. As a result, a correct simulation must be done to take into account the influence of window-opening.

There are in fact two problems. The first one is to simulate the air change rate induced by an opened window. The second one is to simulate the behaviour of occupants regarding operable windows.

The greater part of this study was oriented for the Simulations, so an algorithm was made in order to simulate the opening of windows. The following text is a short study of natural ventilation and description of the algorithm.

3.3.1 Study of Natural Ventilation

For each type of openings, the rate of natural ventilation depends on several parameters:

- Wind
- Indoor temperature
- Outdoor temperature
- The location of windows
- The ventilation technique (Cross flow, single-sided ventilation).

3.3.1.1 Ventilation mechanisms

Wind Pressure

When the wind strikes a rectangular shaped building, it induces a positive pressure on the windward face and a negative pressure on opposing faces and in the wake region of side faces. This difference of pressure causes the air to enter openings and pass through the building from the high pressure windward areas to the low pressure downwind areas.

Stack pressure

Stack effect is developed as a result of differences in air temperature, and hence air density, between inside and outside of the building. This produces an imbalance in the pressure gradients of internal and external air masses which results in a vertical pressure difference.

For example:

When the inside air temperature is higher than the exterior temperature, the air enters through openings in the low part of the building and escapes through openings at a higher level (Figure 11). The flow direction is reversed when the inside air temperature is lower than the outside air temperature.

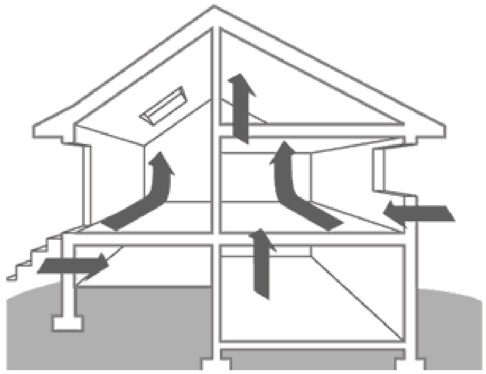

Figure11 – Stack pressure

3.3.1.2 Ventilation Techniques

Cross Flow techniques

Cross Flow Ventilation relies on establishing a clearly defined and unblocked air flow between the incoming and outgoing air steams, which pass through the occupancy zone. A scheme of this technique is shown in the following figure.

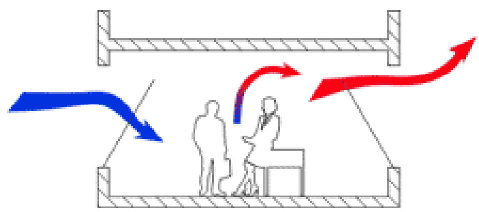

Figure 12 – Cross Flow Ventilation

Single-sided ventilation

This type of Ventilation design is defined when the openings are positioned along just one side of the room (Figure 13). Generally, more than one opening may be placed on the same wall or a single large opening, to provide an air flow trough it in both directions.

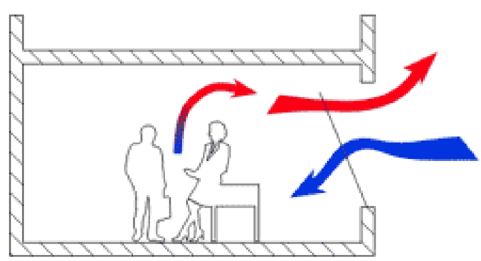

Figure 13 – Single sided Ventilation

There are other types of Ventilation techniques, like Passive stack pressure, Wind towers, or Atria ventilation, but their do not aim to our study of Natural Ventilation provoked by the opening of windows.

3.3.2 Development of the algorithm for the window opening

3.3.2.1 Aeraulic Software – ARMINES

In a first approach, and once the module Type 56 of TRNSYS is not able to calculate the aeraulic changes between the different zones of the building and their infiltrations, the Software COMIS was used but without great success.

The programme interface is not very friendly, without time, and because we only have the DEMO version, it was very difficult to achieve some results. There is an "add-on" of TRNSYS that can calculate easily these air flows, TRNFlow, but Armines did not have the license for this Program.

So a simulation of the air change due to window-opening in TRNSYS was done with some simplified equations.

3.3.2.2 Determination of simplified equations to take windows openings into account

In the simulations it is assumed that the natural ventilation is single-sided, and that it is driven by wind pressure and temperature difference. The literature on single-sided ventilation driven by both wind and thermal buoyancy is scarce, but De Gids and Phaff made some full-scale experiments in 1982 including both parameters [Vent, 1982]. The experiments in their work were carried in three different locations on building environment with surrounding buildings up to four floors high. The measurements were all made in the first floor of the building.

These measurements included Wind speeds, window and room air velocities, air-change rates and temperature, for a total of 33 cases.

From these experiments a simple equation system derived to determine the air flow rate:

$$Q_v = 0.5 \text{ x } A_{eff} \text{ x } V_m$$

Q_v is the volumetric air flow rate (m^3/s)

A_{eff} is the effective window opening (m^2)

V_m is the mean velocity in openings (m/s). It could be found by the following formula:

$$Vm = \sqrt{0.001 \text{ x Vwind} + 0.0035 \text{ x h x } |Ti - Te| + 0.01} \quad (3)$$

Vwind – meteorological wind speed (m/s)

Ti – Indoor temperature (ºC)

Te – outdoor temperature (ºC)

h – height of the opening (m)

Where:

0.001 is a correction factor to take into account wind pressure effect

0.0035 is a correction factor to take into account stack effect

0.01 is a correction factor to take into account the turbulence.

The 0.5 factor in the first equation comes from the fact that only half of the height of the opening is used in inlet. This happens because as shows the Figure 13 the fresh air enters through the bottom of the window, and the hot air escapes through the upper part of the window.

3.3.2.3 Simulation of the behavior of occupants

To simulate the behaviour of occupants, it was used a methodology presented in the article [Usin, 2007].

This methodology uses the adaptive comfort presented in the norm EN 15251 (August 2007), but the running mean outdoor temperature (T_{rm}) is difficult to calculate in TRNSYS, requiring a coupling with another programme like Matlab. This is the reason why we used a previous version of the norm EN15251 (May 2005) where the comfort temperature is a function of the mean monthly outdoor temperature which is directly given by the weather Type 15 in TRNSYS.

The implementation of this algorithm follows the next steps:

a) The first step is to define the comfort within a room. To do this, the norm EN15251 (May 2005) defines that the upper limit (hot – equation 4) and the lower limit (cold – equation 5), figure 14, are defined as:

T_{upper}= 17.8+3.5+0.31*T0 (4)

T_{lower}= 17.8-3.5+0.31*T0 (5)

Where,

To is the mean monthly outdoor temperature, ºC

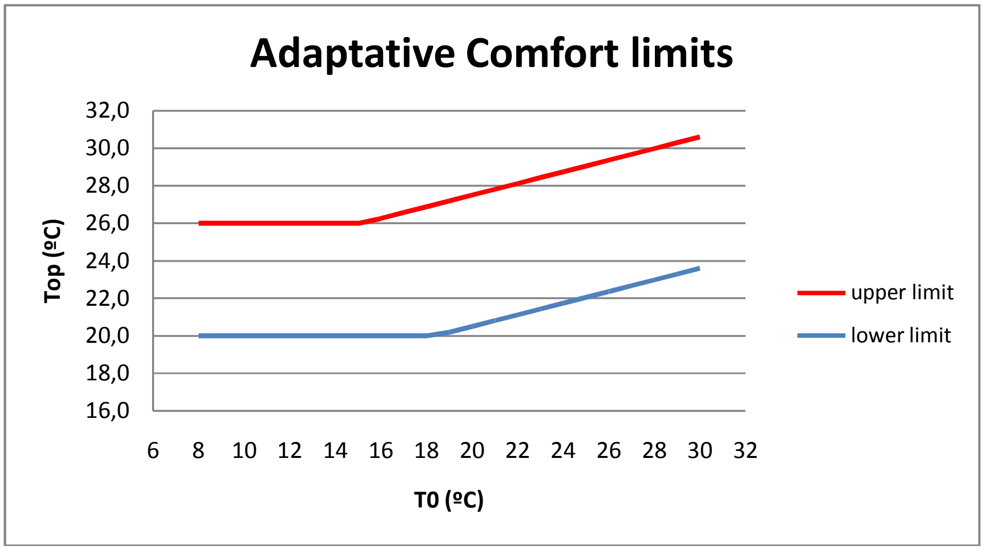

Figure 14 - Adaptive comfort range use in this study

If the Ti > T_{upper} than the state of the persons within the room is set to "hot"

If the Ti< T_{upper} than the state of the persons within the room is set to "cold"

If T_{lower} < Ti < T_{upper} no action is taken and the window remains as it was.

b) The second step consists in calculating the probability of the window being open or closed.

If the state is set "hot" and the window is closed, then there is a probability that it could be open. The opposite happens if the state is set "cold" and the window is open, so a probability exists for the window to be closed.

The probability for a window to be opened is given according to the outdoor temperature and the operative temperature by the following equation:

$$P = \frac{\exp\,(0.171\ x\ Top + 0.166\ x\ Te - 6.43)}{(1 + \exp\,(0.171\ x\ Top + 0.166\ x\ Te - 6.43)}\ (6)$$

From the study mentioned above, it was proved that the proportion of windows open increases with the increases in both the indoor and outdoor temperatures (Figure 15 and 16), but this increase is different between the temperatures.

It is assumed that exist several windows in each room, so it is just necessary to multiply the value of the function by the inlet area, giving this way the percentage of windows that will be open.

The step of the simulation was set to 30 min and only 1 oscillation (open or close the window) is allowed.

A schedule was made allowing the windows to be opened only when there is anyone in the room.

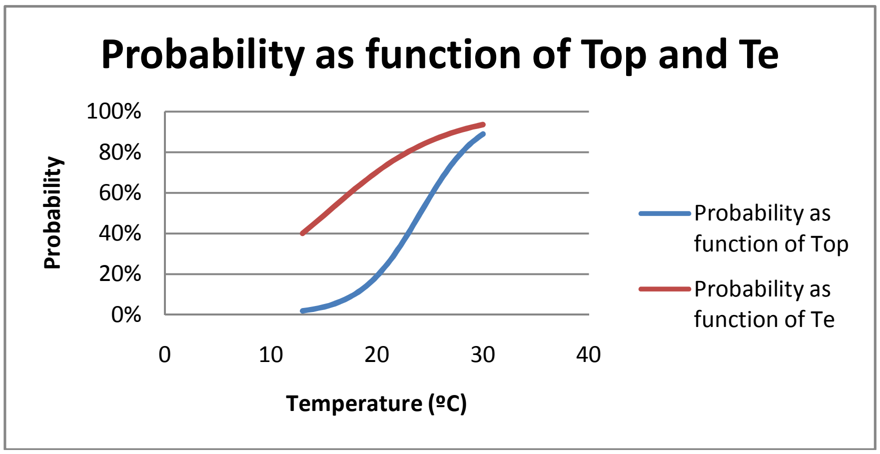

Fig.15 – Probability as function of operational temperature(Top) and Outdoor Temperature (Te).

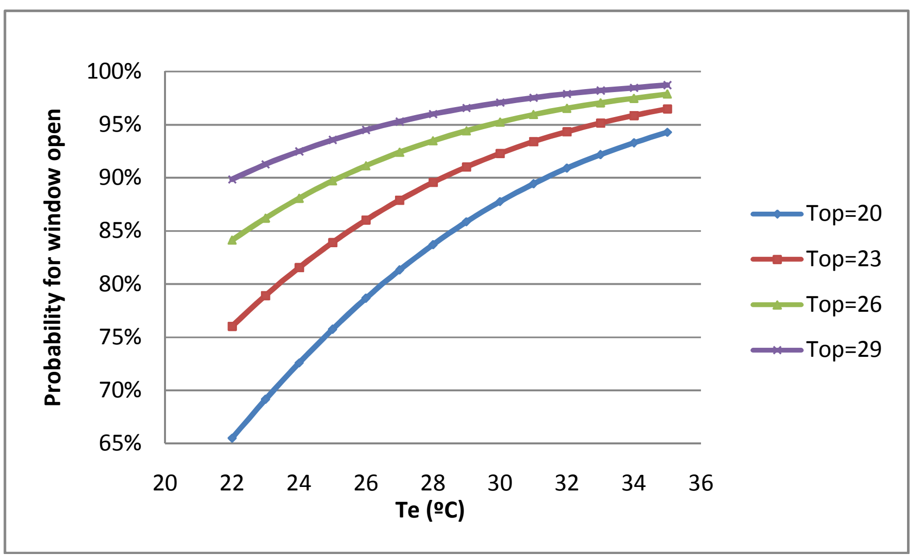

Fig.16 – Probability for a window to be opened for different Top and Te.

4. Sensitivity Study of the Reference Case

A sensitivity study was made to determine in which extent passive solutions could have a bigger influence in savings. The sensitivity study was made regarding simple variables in the reference case and choosing a low level and a high level comparing with the reference case.

4.1 Brief description of studied Passive Solutions

It exist a lack of information about individual Passive solutions regarding comfort level in the studied building, characteristics of air conditioners…

Some passive cooling technologies like evaporative, solar cooling, cooling towers, were not included in this study, because they represent a less important potential than other solutions since most of them are a non mature market, need very specific conditions (regarding climatic conditions or building location) and are heavy to install in existing buildings. To be able to do realistic simulations of these passive cooling technologies, different dimensions, machine properties have to be calculated for each country. At the end this would lead to a longer time of simulations too.

A bibliographical study was made, based in the KeepCool I information and other studies. The variables studied are shown in table 14

Table 14 - List of variables for the sensitivity study

Nº	Variable	Unit	Low level	Ref. Value	High level
1	**Wall Insulation**	(W/m^2.K)	0.15	0,8	1.45
2	**Ceiling Insulation**	(W/m^2.K)	0.15	0,4	1.3
3	**Internal gains**	(W/m^2)	6	15	24
4	**Light Power**	(W/m^2)	7	18	29
5	**Windows**	U – value (W/m^2.K)	5.74	2,95	1,43
		Solar Factor	0,87	0,777	0,597
		Solar Transmittion	0,901	0,817	0.769
6	**Solar Protection**	Solar Factor	0.15	0,20	1
7	**Inertia***	-	Light	Normal	Heavy
8	**Infiltration**	(1/h)	0.1	0,373	1
9	**Set Points**	(ºC)	H- 18 C- 27	H-20 C- 26	H-22 C- 23
10	**Ventilation rate**	(m^3/person/h)	15	25	35

11	**Window Wall Ratio (WWR)**	-	22%	45 %	65%

*-Furniture

4.1.1 Solar shading

Solar shading has a decisive role in energy for cooling. In some cases, like office buildings with fully-glazed façade, the solar radiation could be responsible for 70% of the peak cooling load.

An external shading system with a shading coefficient of 10-15 % may reduce this value drastically and at the same time allowing daylight to get into the building from diffused and redirected radiation.

The internal shading devices in thermal terms are not quite good because they do not block the entry of solar radiation. The adoption of this type of shading devices is normally used to prevent from glare effects, on desks and monitors, and also because external architectural design.

Normally shading effectiveness depends on:

- The positioning of shading device with respect to glazing and window components.
- Geometry of the device
- Incident angle of the radiation
- Control options
- Optical properties of the surfaces (diffuse and specular reflectance)

The effectiveness of the window/façade system, as for glazing systems, is expressed in terms of Solar Factor (**g-value**, also SHGF, Solar Heat Gain Factor and it is defined as the fraction of incident solar energy which is transmitted to the interior of the building) or in terms of Shading Coefficient, S.C.

There are several types of solar shadings devices like:

- Movable devices: Internal/External Blinds, Awnings
- Permanent devices : Overhangs, Vertical protections, Louvers

In the reference case the external shading device is already “efficient”, with a solar factor of 0,2. Even so, for this sensitivity study a low value of 1 (no shading device) and a value of 0,15 (even better solar protection) were chosen.

To simulate this variable, TRNSYS only needs the value of the Shading Factor (ratio of the non-transparent area of the shading device to the whole glazed area). To get the value of the Shading Factor***: 1= Solar.Factor+Shading.Factor***

So, just a simple calculation is needed to found the values. Then the values are introduced into the simulation together with the average usage of solar protection.

4.1.2 Insulation

The building envelope and construction can influence the cooling requirements as much as the internal loads or the climate.

The insulation reduces the heat transfer through roofs, walls, the floor and windows. In cold regions, the insulation reduces the heat demand, when the outside temperature is lower than the interior.

For regions where outside temperature is higher than the interior temperature, insulation reduce the cooling demand, if it is appropriate applied and combined with other measures.

A reduction between 20 and 40 % of cooling load can be achieved and better thermal comfort.

In the simulation, the level of the insulation of the wall or ceiling, was increased or decreased directly in TRNSYS to achieve the U-value desired.

4.1.3 Thermal mass

The thermal capacity of a building (Brick walls, masonry fireplaces…) store heat during the day and modulate the internal temperature swings. At night, the heat absorbed during the day is released and making it ready to absorbed heat again the next day.

The effect of this passive solution could be increased if the region of the building has a large diurnal temperature range (more or less 15ºK) and when it is combined with night cooling.

For the level of Thermal mass only the furniture was taken into account.

4.1.4 Reduction of internal heat loads

The normal internal gains in a building are the persons themselves, office equipment and lights. Office equipments release heat when they are in operation. The lights transform electric energy into light and heat (waste).

Energy efficient office equipments and light reduce not only the energy costs due to the electricity their consume but also the energy costs for air-conditioning. Some examples of energy efficient equipment and light:

- Use of fluorescence lights in offices. Minimum luminosity of 500 lux.
- Change the secretary computers by laptops.
- Change of laser printers by ink-jet printer.

The Internal loads are also directly introduced in TRNSYS, together with the user appliance load schedule.

4.2 Results of the Sensitivity Study

The influence of the variables in cooling and heating needs is listed is given in the Annexe B and plotted in figure following figures 17 and 18.

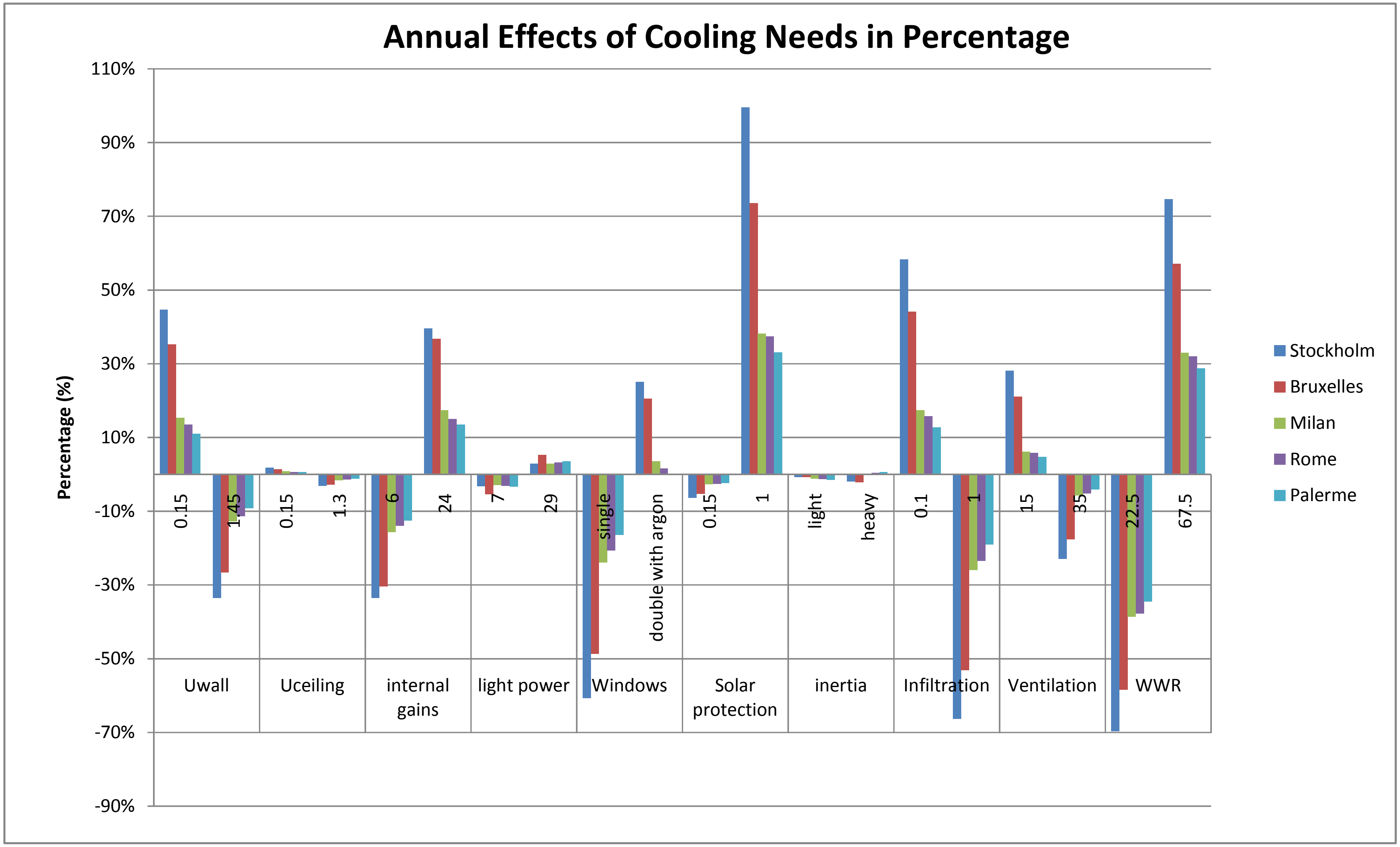

Figure 17 - Summary of the effect of each variable Cooling Need

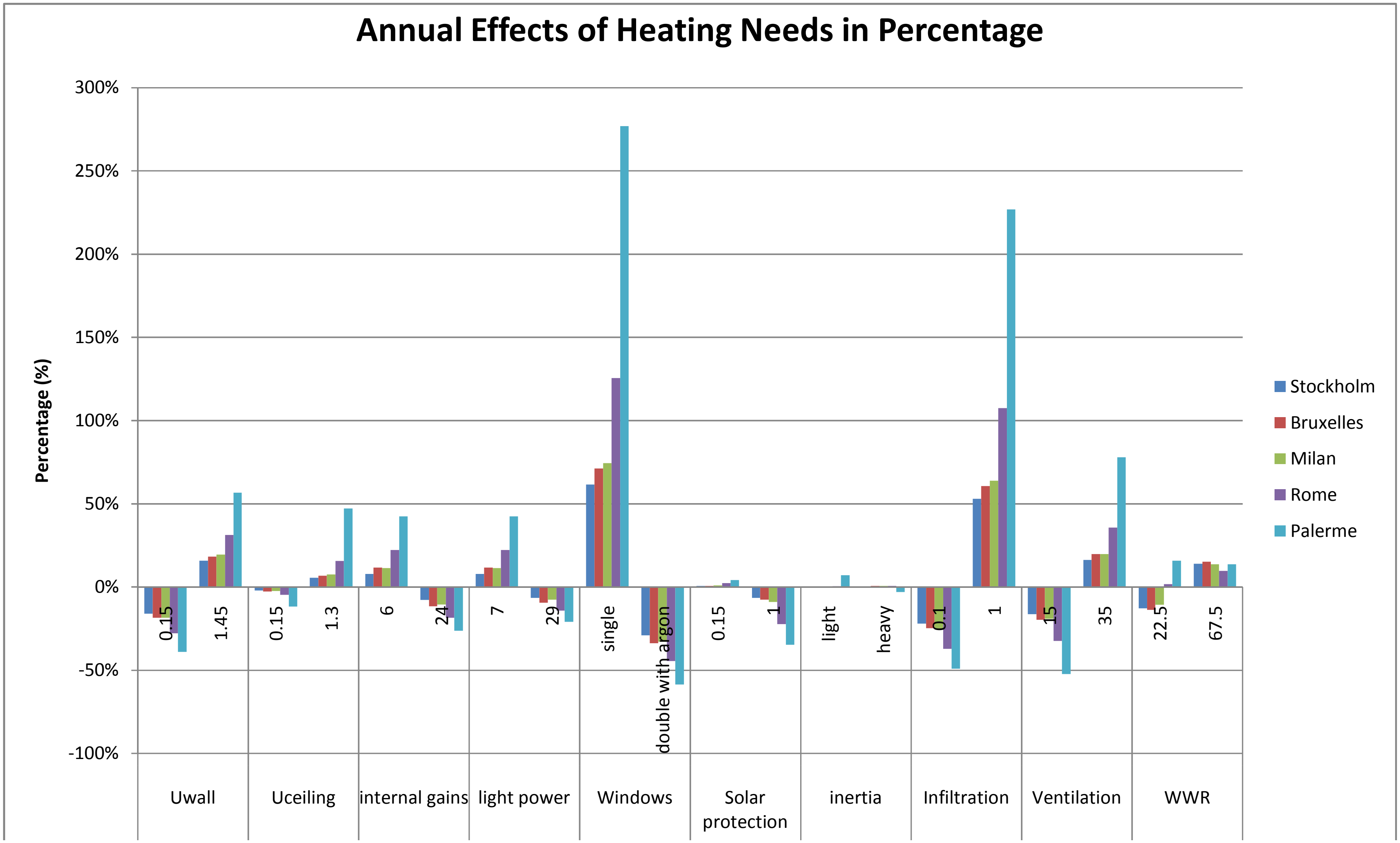

Figure 18- Summary of the effect of each variable on Heating Need

4.3 Conclusions of the Sensitivity Study

4.3.1 Insulation

In this sensitivity study, the values wall and roof insulation shows that the heating demand is always reduced and that the cooling demand is always increased, even for hot climates.

To prove that the results were good a study of external and internal temperatures of the walls and the roof was made in the hottest city was chosen (Palermo – Italy).

The study shown that, only 5% of the occupation time the external temperature of the wall, with south orientation, is higher than the internal wall temperature. For the roof this value was 20 %.

There are several reasons that explain these results, all depending on characteristics of the building:

- High reflection of walls
- High internal gains
- High Glazed area
- Low air circulation

At the end, these characteristics combined with wall insulation, trap the heat in the room, and increase the cooling demand. This project focuses in the summer season, so from the results in the sensitivity study this action was eliminated.

4.3.2 Internal gains

Making use of efficient office equipment it can be saved from 10 to 30% of the cooling needs, depending on the climate. However, heating needs increase with more efficient office equipment. So a well balance between cooling and heating needs to be done to achieve positive savings at the end.

4.3.3 Light Power

Efficient lights can save cooling needs (~5%), but the impact is not as good as the reduction of internal gains (office equipment).

4.3.4 Windows

It is shown that in most climates, the introduction of more Efficient Windows only decreases the heating and increases cooling. But considering this specific case, in the coldest climates (Stockholm), it can be used a more Efficient type of Window and despite of the cooling impact being almost zero, it can be achieved a less consumption in heating mode. As before this action is not the goal of the project so it was eliminated.

4.3.5 Solar Protection

The Solar Protection of the reference case is already efficient (SF=0.2), that's why the difference in cooling needs is low for a SF=0,15. The sensitivity study shown the solar protection has a great impact in cooling needs depending on the Solar Factor of the sun shading device.

4.3.6 Inertia

The Inertia demonstrates almost none impact in cooling needs. It must be said that only the inertia due to the furniture was changed. In order to have a greater impact the inertia of the walls or ceiling should be changed.

4.3.7 Infiltration

The Infiltrations appear as an important factor in this case. It is much easier to control this variable in new buildings once the leakages could be diminished. In the case of existing buildings it is a difficult task to eliminate the leakages.

4.3.8 Ventilation

The increasing of Ventilation leads to a decrease of 5 to 23 % in the cooling demand.

4.3.9 Window to Wall Ratio

The size of windows represents one of the best passive solutions studied in terms of Cooling and Heating Needs. The reduction of window area teases the reduction of the heat losses, but at the same time decreases the area for the entrance of solar radiation.

This solution is not very easy to apply to existing building but for new ones, a thermal study and a study of the luminosity should be made to achieve greater performance.

The results of the sensitivity study shown also that the building shell (Uwall, Uceiling and Windows) have a big influence in cooling and heat needs.

5 Energy Savings Calculation

The results presented hereafter <u>are not the definitive values</u>. For the time being, the partners of the project did not deliver yet the typical values of the building shell and seasonal efficiencies for cooling and heating for the cities in cause.

These results are an example of the application of the methodology.

The chosen Passive Solutions are shown in Table 15 and the Packages in Table 16.

Table 15 – Chosen EEI actions

	EEI actions	Target value
Sun shading devices		
1	Install a moveable external sun shading device controlled by occupants	SF=0.15
Lighting system		
2	Install energy efficient lightings and ballasts (electronic…) controlled by presence sensor and daylight linked controls	7 W/m²
Office equipment		
3	Use energy efficient office equipment	6 W/m²
Free cooling and ventilation		
4	Mechanical ventilation: automated (on outdoor temp) opening during the night (fixed dimensions) if the room temperature is higher than 22ºC + support fan	ACH: $6h^{-1}$

Table 16– Individual EEI actions for each Package

Packages	Individual EEI actions			
	1	2	3	4
A	X	X	X	
B	X	X	X	X

5.1 Energy savings assessment for the studied EEI actions and Packages

In this part it will be described from where come the Target values for the EEI actions and presented the results of heating and cooling needs for the reference case plus the EEI action.

5.1.1 Install a moveable external sun shading device controlled by occupants

The simulation of this passive solution was made changing only the Solar factor of the sun shading device. In the KeepCool I report it can be seen that the solar factor of the sun shading devices can vary from 0,5 to 0,1. So a value of 0,15 was chosen as passive solution. Although, the Solar factor of this dispositive in the reference case was already efficient 0,2. In reality this value is not so low, so in future simulations the reference case value will be changed.

The usage profile was equal to the reference case. As it is said in annex A, the usage of the sun shading devices is a function of the external luminosity. This way the occupant's behavior could be simulated.

The values for the Cooling and heating needs (obtained from simulations) for this EEI action are shown in the Table 17

Table 17- Cooling and heating needs of the reference case in which the EEI action has been applied

Climatic zones	Cooling needs [kWh/m²/y]	Heating needs [kWh/m²/y]
Stockholm	5,8	124,26
Brussels	7,67	65,13
Milan	26,76	57,28
Rome	44,4	13,26
Palerme	61,58	1,64

5.1.2 Install energy efficient lightings and ballasts controlled by occupants

The powers of the lights in office rooms and in the conference room are the same (18 W/m^2). After a research it was found that high efficient lights were already applied, into office buildings, with a power of $7W/m^2$. The lights in Circulations (12 W/m^2) were taken into account too. Its value was decreased to 5 W/m^2. This value was found in the [CLIM, 2007] that defines an efficient light system for circulation with 5 W/m^2, to achieve a minimum luminosity of 100 lux.

The value for WC's was let (6 W/m^2).

These values can be introduced directly in TRNSYS. Although, the simulation of the control by occupants, in offices and conference rooms, is a function of the interior luminosity, that could not be introduced directly.

To simulate this behavior an equation (7) was introduced in the Simulation Studio. The exterior lux is multiplied by the Window transmissibility and then by the fraction of the window that is directly exposed (Fraction not covered by the sun shading device), and finally devised by the surface of the room.

$Lux_{internal} = Lux_{ext} \times Window_{Trans} \times Window_{Fraction\_area} / Room_{area}$ (7)

Then an equation of usage was introduced as a function of this internal luminosity (see Annex A – Figure 26).

It must be said that due to the high glazed area, the lights during the day are almost always off.

The values for the Cooling and heating needs (obtained from simulations) for the application of energy efficient lights are shown in the Table 18.

Table 18 - Cooling and heating needs of the reference case in which the EEI action has been applied

Climatic zones	Cooling needs [kWh/m²/y]	Heating needs [kWh/m²/y]
Stockholm	6	131,22
Brussels	7,66	70,47
Milan	26,73	61,13
Rome	44,14	14,98
Palerme	60,95	2,07

5.1.3 Use of energy efficient office equipment

The simulation of this passive solution was made regarding only the maximum appliance load. A research was made and from the [CLIM, 2007], and the value for an efficient office equipment was calculated (6 W/m^2). This value was found considering more efficient computers and printers in offices.

The usage appliance of the office equipment defined in the Annex A was not changed.

The values for the Cooling and heating needs (obtained from simulations) for the use of energy efficient office equipment are shown in the Table 19.

Table 19 - Cooling and heating needs of the reference case in which the EEI action has been applied

Climatic zones	Cooling needs [kWh/m²/y]	Heating needs [kWh/m²/y]
Stockholm	4,12	133,16
Brussels	5,64	72,3
Milan	23,19	63,11
Rome	39,19	15,84
Palerme	55,11	2,24

5.1.4 Mechanical Ventilation: automated (on outdoor temp) opening during the night (fixed dimensions) + support fan

The Mechanical Ventilation was simulated with several specifications.

To simulate this EEI action a constant volume rate of 6 h^{-1} was found from [COOL, 2005]. The control of this ventilation was made regarding the following features:

- It can be turned on only at night.
- The system was turned on only if the room temperature was superior to 22ºC.
- If the exterior temperature was minus 2º C than the Interior temperature.

In order to do this, an equation was created in TRNSYS Simulation Studio, regarding these characteristics.

It must be said that no electric consumption of the fans was considered in simulations.

The Cooling and heating needs of the Reference Case plus this action are shown in table 19.

Table 19- Cooling and heating needs of the reference case in which the EEI action has been applied

Climatic zones	Cooling needs [kWh/m²/y]	Heating needs [kWh/m²/y]
Stockholm	2,44	124,14
Brussels	3,54	65,39
Milan	16,18	57,49
Rome	28,3	13,76
Palerme	43,22	2,06

5.1.5 Package A

The Cooling and heating needs of the Reference Case plus this action are shown in table 20.

Table 20 - Cooling and heating needs of the reference case in which the EEI action has been applied

Climatic zones	Cooling needs [kWh/m²/y]	Heating needs [kWh/m²/y]
Stockholm	3,71	142,10
Brussels	5,03	79,22
Milan	21,91	68,39
Rome	36,97	18,59
Palerme	52,08	3,10

5.1.6 Package B

The Cooling and heating needs of the Reference Case plus the Package B are shown in table 21.

Table 21 - Cooling and heating needs of the reference case in which the EEI action has been applied

Climatic zones	Cooling needs [kWh/m²/y]	Heating needs [kWh/m²/y]
Stockholm	1,35	142,4
Brussels	2,07	79,7
Milan	12,74	68,74
Rome	22,8	19,12
Palerme	36,06	3,54

5.2 Discussion of Results

Regarding the summer comfort in free-running buildings without AC, the application of the chosen solutions (Table 22), it is possible to achieve summer comfort in some regions (less than 5% of the time outside the adaptive zone). In the application of the Package B, the zone 5 and the zone 4 (the value outside the adaptive comfort zone is only 0.95% above), meaning that, AC systems could be avoided in these climatic zones.

Table 22 – Comfort values for the application of the several EEI actions

	Climatic zones	Stockholm	Brussels	Milan	Rome	Palerme
Sun shading device	Perc. Out. Adaptive zone	**4.99%**	13.16%	45.57%	65.13%	85.76%
	Degree hours out. Adaptive zone	62.6	191.6	1462.3	2007.4	2878
Eff. Lights	Perc. Out. Adaptive zone	**5.41%**	13.19%	45.26%	64.28%	85.00%
	Degree hours out. Adaptive zone	67.1	194.1	1470.8	2004.1	2857.4
Eff. Office Equip.	Perc. Out. Adaptive zone	**3.22%**	10.28%	42.04%	58.76%	78.86%
	Degree hours out. Adaptive zone	46.3	136.6	1229.8	1697.6	2482.4
Night Vent.	Perc. Out. Adaptive zone	**3,22 %**	9.63%	37.59%	50.90%	66.47%

	Degree hours out. Adaptive zone	39.05	119.20	973.84	1325.59	1989.50
Package A	Perc. Out. Adaptive zone	**2.88%**	9.36%	40.85%	55.50%	75.60%
	Degree hours out. Adaptive zone	41.7	122.1	1155.9	1586.5	2317.2
Package B	Perc. Out. Adaptive zone	**1.84%**	**5.95%**	31.95%	41.73%	57.65%
	Degree hours out. Adaptive zone	22.8	68.1	709.2	985	1542.1

The introduction of Efficient Lights has a low effect in the amelioration of summer comfort. The Efficient Office Equipment can arrive to a decrease of 10 % of the total time outside the adaptive zone for hot climates.

For a single EEI actions applied, the best results are provided by the Night Ventilation where the values of summer comfort are increased a lot. These values are more reinforced when a comparison towards the other EEI actions is made in terms of *degree hours outside Adaptive Zone.*

In the application of the Package A, there exists a substantial improvement. The amelioration of the summer comfort in the Package B is better because of the application of the night ventilation.

A resume of the values in terms of Cooling and Heating Needs are plotted in the following table 23.

Table 23 – Resume of the Cooling Savings

Cooling savings in [kWh/m²/Y]	**Package B**	**Package A**	**Night Ventilation**	**Eff. Office equip.**	**Eff. Lights**	**Sun Shade Device**
Stockholm	6.2	6.2	3.76	2.08	0.2	0.4
Brussels	6.03	3.07	4.56	2.46	0.44	0.43
Milan	14.77	5.6	11.32	4.31	0.77	0.74
Rome	22.74	8.57	17.2	6.31	1.36	1.1
Palerme	26.94	10.92	19.78	7.89	2.05	1.42

In figure 19 it can be seen the effects in cooling needs for each passive solution applied to the building.

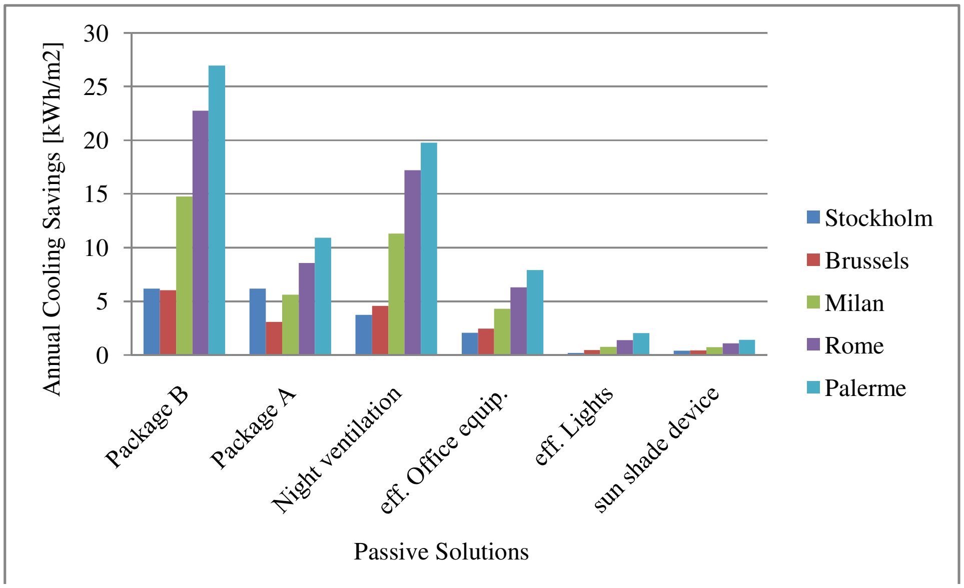

Figure 19 – Annual Cooling Savings for each Passive Solution

As in the summer comfort analysis, the single EEI action that has a bigger impact in cooling needs is the Night Ventilation.

If an analyze is made in terms of percentage is made (Figure 20), in the best practice (Package B) the cooling savings are comprehended between 43 % and 100 % depending on the climate area chosen.

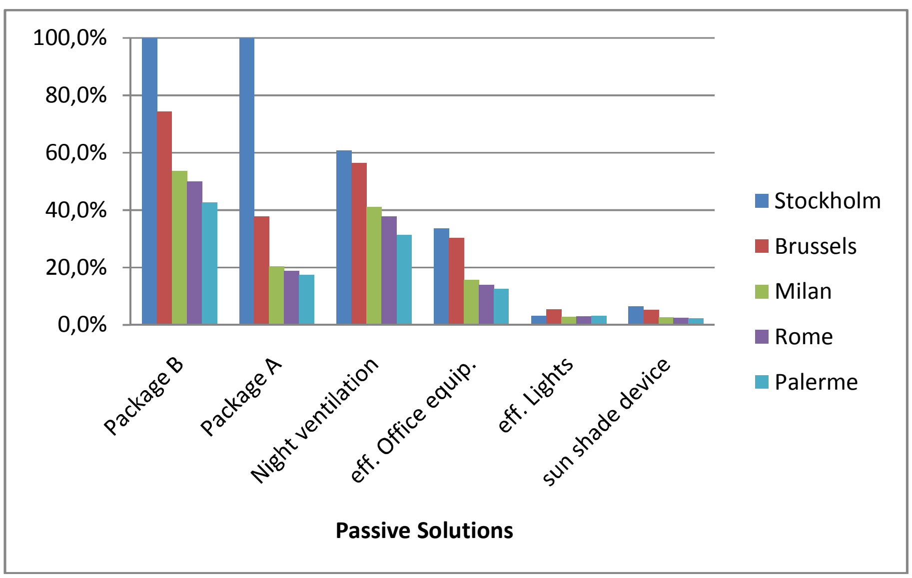

Figure 20 – Percentage of Savings in cooling needs

The results are all positive but a well balance between heating and cooling needs should be considered for each EEI action applied.

The results of Heating Savings are plotted in table 24, and it can be seen that the impact of all EEI actions is always negative.

Table 24 – Resume of the Heating Savings

Heating Savings in [kWh/m²/Y]	Package B	Package A	Night Ventilation	Eff. Office Equip.	Eff. Lights	Sun Shade Device
Stockholm	-18,77	-18,47	-0,54	-9,56	-7,62	-0,66
Brussels	-14,98	-14,50	-0,69	-7,6	-5,77	-0,43
Milan	-12,06	-11,71	-0,79	-6,41	-4,43	-0,58
Rome	-6,16	-5,63	-0,76	-2,84	-1,98	-0,26
Palerme	-1,97	-1,53	-0,46	-0,64	-0,47	-0,04

A way to finally compare the real Savings is to determine the Primary Energy, as it was explained in the Methodology (part 2.2).

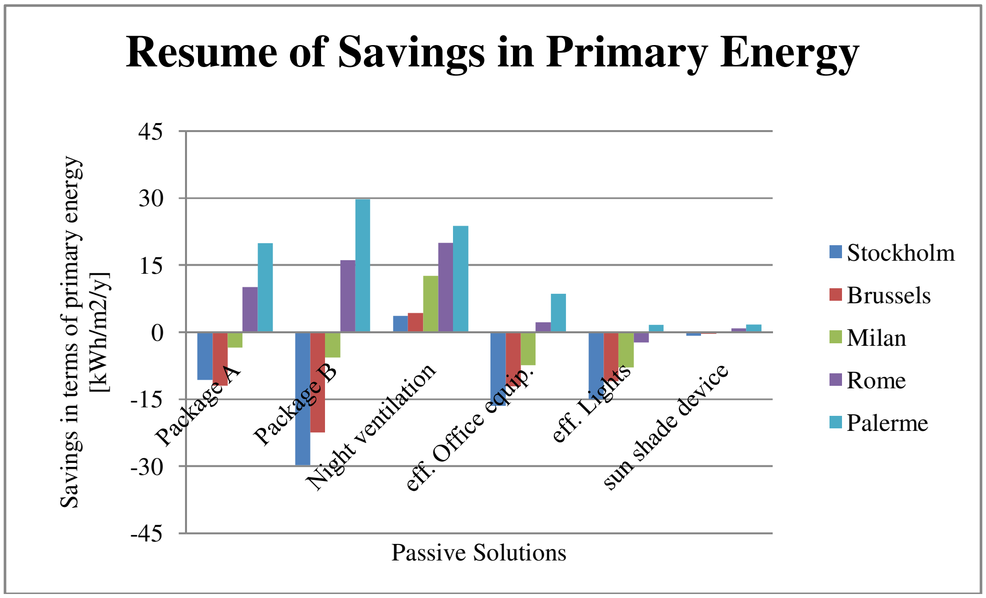

Figure 21 – Savings in terms of Primary energy

Regarding the primary energy savings (see Annex C for detailed results), only the night Ventilation has for all climatic zones positive values.

A good control of passive solutions should be revised in order to achieve positive values in primary energy. An example of this a good control of passive solutions could be the use of internal shading devices, instead of external shading devices, during the winter or other measure that let the solar radiation enter to the rooms but protects from glare.

Another factor for witch the primary energy savings are very sensible is the change of the SEER and η.

For example if a SEER=2 and a η=0.85 is chosen with the Package B:

Table 24 – Comparison of Savings in terms of primary energy for different η

	SEER=2 η=0.5	**SEER=2 η=0.85**
Climatic zones	**Savings in terms of primary energy [kWh/m²/y]**	
Stockholm	-29,79	-14,33
Brussels	-22,42	-10,09
Milan	-5,66	4,27
Rome	16,11	21,18
Palermo	29,74	31,36

As it can be seen in the Table 24 the values of savings for all cities increases. With a SEER=2 and a η=0.85, in Milan, savings in terms of primary energy are achieved with these new coefficients.

If the results of the example are chosen, only for Rome and Palermo (Hot Cities, zones 1 and 2) the final savings are positive values. In these two cases the savings in primary energy could arrive almost to 30 kWh/m^2/Year.

6 Conclusions

During this study a calculation chain was made for the application of the described Methodology (part 2.2). A reference case was constructed in TRNSYS and a post treatment in EXCEL was defined to assess thermal comfort. Even being these values not definitive a calculation chain is already made and ready to be used in future simulations.

In this report it was demonstrated that with simple passive solutions comfort conditions could be achieved for some countries. Although these comfort conditions were not studied in case of a heat wave. The results demonstrate that important cooling needs savings, values between 43 % and 100 %, are achieved with the application of the studied passive solutions.

Another finding that needs attention is a comparison between the cooling and heating effects must be made in order to really evaluate the savings.

This comparison is very sensible due to two major factors:

- The SEER and Seasonal energy efficiency in heating mode values used to do the study of primary energy.

- The defined reference building shell, as the sensitivity study shown.

In the results presented in part 5.1, there are few solutions that have a positive impact in the final energy to heat and cool the building.

One factor that was not taken into account in the simulations was the savings in electricity of using efficient office equipment and lights, and also the electricity dispended to operate the fans in the mechanical night ventilation. In this case however there exists always the possibility of using natural night ventilation, saving this way electricity. Either way, the goal of this study was to measure the impact of passive solutions in heating and cooling demand, and not to measure difference of the electric consumption when a passive solution is applied.

At the end it can be said that, it was demonstrated the passive solutions represent a decisive roll in the cooling needs of a building. To achieve real savings results in terms of primary energy of the whole building some points must be considered in more details:

- Good control (when it can be applied) of the passive solutions should be studied and then applied.
- A correct building shell of the reference case should be defined and a correct SEER and η should be used for each climatic zone.

6.1 Factors that were not included in the calculations

Besides the factor of the savings of electricity describe there are factors that were not included in the calculations.

The savings seen in this report refers only to sensible cooling and heating. No latent heat was considered in the calculations, and no set point in terms of humidification or dehumidification was made.

It was chosen not to considerate the latent heat because the influence of the humidity on the preferred ambient temperature is in the comfort range relatively small (EN ISO 7730). In EN ISO 7730 a humidity range of 30 to 70 % RH is recommended, but mainly for indoor air quality reasons.

For the free-running building, in order to access thermal comfort (EN 15251), it was only taken into account for comfort the operative temperature. The standard describes that humidification or dehumidification is used only in special cases like museums, hospitals…

Regarding the comfort conditions in free-running buildings, the opening of windows algorithm only take into account the operational temperature. Other variables that contribute to the opening of windows were not applied to this algorithm, like air draft, noise…

6.2 Met Difficulties

In the beginning some difficulties delayed the project. One of those difficulties was learning how to deal with the program once the manual, in some cases is not very clear.

The definition of base case was quite difficult because at the beginning there was not enough information about the building, leading to wrong results.

Some other difficulties appear like the simulation of the building in running mode, obliging the creation of an algorithm to calculate correctly the air flow.

All these difficulties were solved but with the cost of delaying the project.

6.3 Future work

During a meeting in Graz - Austria, some measures were deliberated.

Each Partner will send to ARMINES the average values of the newest regulation for new buildings. For existing buildings the values of the first thermal regulation will be sent.

Other typical characteristics will be sent too, like: Infiltrations, Ventilation and Set Points.

Once all values are received by ARMINES, a set of final simulations will be made and the final conclusions will be found.

It is expected that once the final simulations are made, the results could help the KeepCool Project in the dissemination of a correct usage of energy in Buildings.

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Annex A - Presentation of the reference case

1. Geometrical characteristics - Office building

The office building n°1 has 12 identical floors of 3 m height each.

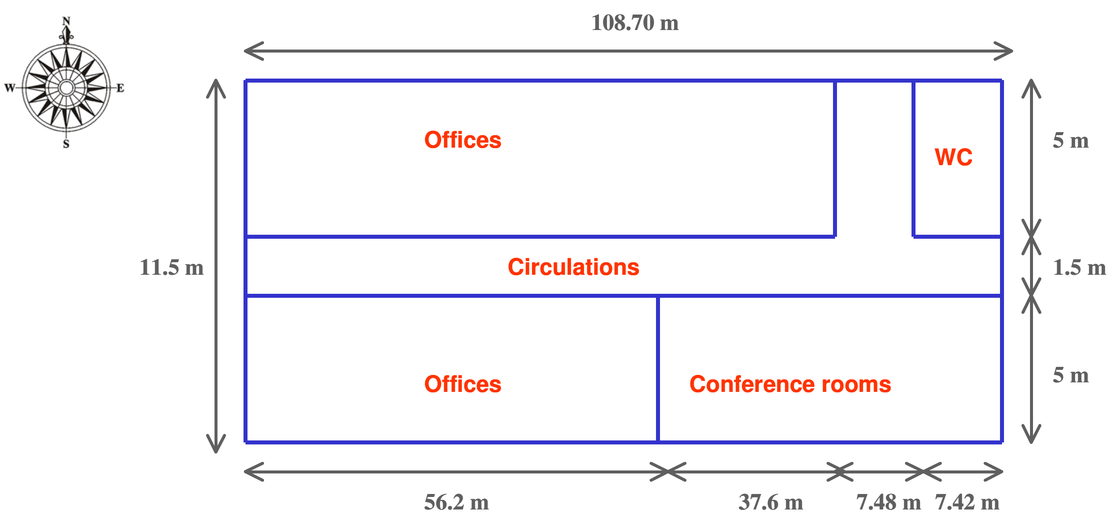

Figure 21 – detailed description of rooms dimensions

Table 25 - Repartition of UTH by use

UTH	Usage	Surface area of one floor	Surface area of 12 floors	Percentage of total	Volume
1	WC	37.0	444.6	3	1333.8
2	offices	281	3372	60	10 116
3	offices	469	5628		16 884
4	meeting rooms	262.5	3150	21	9450
5	circulations	200.5	2405.4	16	7216.2

Total	1250	15 000	100	45 000

Table 26 - Outside surface area for one floor

Room height m	3	Outside surfaces for one floor								
Surface area m²	15000	Ceiling	Vertical (opaque and glazed)				Glazed surface			
Usage	UTH		N	S	E	W	N	S	E	W
WC	1	37.1	22.3	0	15	0	11.1	0	0	0
offices	2	281	0	168.6	0	15	0	84.3	0	0
offices	3	469	281.4	0	0	15	140.7	0	0	0
meeting rooms	4	262.5	0	157.5	15	0	0	78.8	0	0
circulations	5	200.5	22.4	0	4.5	4.5	11.2	0	0	0

Table 27 - Total outside surface area

Room height m	3	Outside surfaces for the building							
Surface area m²	1500 0	roof	Vertical (opaque and glazed)				Total	Total	Total
Usage	UTH		N	S	E	W	Vertical		glazed
WC	1	37.1	267.1	0.0	180	0	447.1	484.2	133.6
offices	2	281	0.0	2023.2	0	180	2203.2	2484.2	1011.6
offices	3	469	3376.8	0.0	0	180	3556.8	4025.8	1688.4
meeting rooms	4	262.5	0.0	1890.0	180	0	2070.0	2332.5	945
circulations	5	200.5	269.3	0.0	54	54	377.3	577.7	134.6
total m²		1250					8654.4	9904.5	3913.2
Ratio (with respect to useful total surface area)							0.58	0.66	0.26

Surface Intermediate floors and ceiling (m^2)	28750
Inner walls (m^2)	12000

2. Thermal characteristics

- **Thermal insulation**

For the sake of simplicity, no thermal bridge is considered. These losses are balanced by the choice of a quite high U_{wall}. The heat losses by the ground are neglected.

Table 28 - Values of U in W/m²K

	U [W/m².K]	Description
Wall	**0.8**	Outside layer : Cement 0.13m (ρ=1900 kg/m^3 , λ=0.58 W/(m.K), c_p= 1000 J/(kg.K)) insulating material 0.024m (ρ=56 kg/m^3 , λ=0.029W/(m.K), c_p= 1220 J/(kg.K)) Inside layer: plaster 0.012m (ρ=1860 kg/m^3 , λ=0.72W/(m.K), c_p= 840 J/(kg.K))
Window	**3**	Double glazing of 4mm width for each glazing and 8mm air space.
Roof	**0.4**	Outside layer : Cement 0.13m (ρ=1900 kg/m^3 , λ=0.58 W/(m.K), c_p= 1000 J/(kg.K)) insulating material 0.06m (ρ=56 kg/m^3 , λ=0.029W/(m.K), c_p= 1220 J/(kg.K)) Inside layer: plaster 0.012m (ρ=1860 kg/m^3 , λ=0.72W/(m.K), c_p= 840 J/(kg.K))

- **Thermal Inertia**

The inertia of the wall is calculated by TRNSYS based on the characteristics given in the table below. The inertia of furniture was taken into account using a value of 24 kJ/m^2/K.

Table 29 - Wall description

Composition	
Outside Wall	Outside layer : Cement 0.13m (ρ=1900 kg/m^3 , λ=0.58 W/(m.K), c_p= 1000 J/(kg.K)) insulating material 0.024m (ρ=56 kg/m^3 , λ=0.029W/(m.K), c_p= 1220 J/(kg.K)) Inside layer: plaster 0.012m (ρ=1860 kg/m^3 , λ=0.72W/(m.K), c_p= 840 J/(kg.K)) Exteriour reflectance = 0.7
Windows	Double glazing of 4mm width for each glazing and 8mm air space.
Floor & ceiling	Cement 0.1m (ρ=1900 kg/m^3 , λ=0.58 W/(m.K), c_p= 1000 J/(kg.K))
Roof	Outside layer : Cement 0.13m (ρ=1900 kg/m3 , λ=0.58 W/(m.K), cp= 1000 J/(kg.K)) insulating material 0.06m (ρ=56 kg/m3 , λ=0.029W/(m.K), cp= 1220 J/(kg.K)) Inside layer: plaster 0.012m (ρ=1860 kg/m3 , λ=0.72W/(m.K), cp= 840 J/(kg.K)) Exteriour reflectance = 0.8
Inner walls	plaster 0.02m (ρ=1860 kg/m3 , λ=0.72W/(m.K), cp= 840 J/(kg.K))

The heat transfer, between floors, was neglected. It was considered that the temperature in the adjacent room was equal to the room in question.

3. Infiltrations

The air permeability of the building under 4 Pa is fixed to 1.7 × (heat loss surface: outside walls and roof) / (surface area)

Infiltration = **0.373 [ACH/h]**

4. Occupation schedules

4.1 Internal heat sources

People and electrical devices

The sizing of the offices is defined as one person per 12 m². The sensible heat released by each person is supposed to be 105W. The heat released by the appliances is sized to 15W/m². The appliances are essentially computer equipments. In the use of the building, one assumes that at maximum, the offices are occupied at 80% of the sizing values and the same for the appliance loads.

The occupancy profile is defined in Figure 22. Occupancy variations due to holidays are not taken into account.

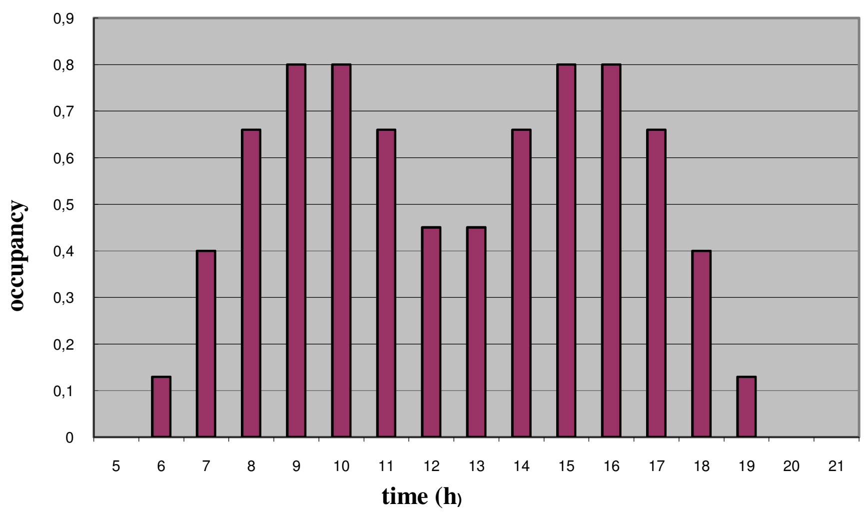

Figure 22 - Occupancy profile in the offices compared to the sizing value

The appliance load profile is defined in Figure 23.

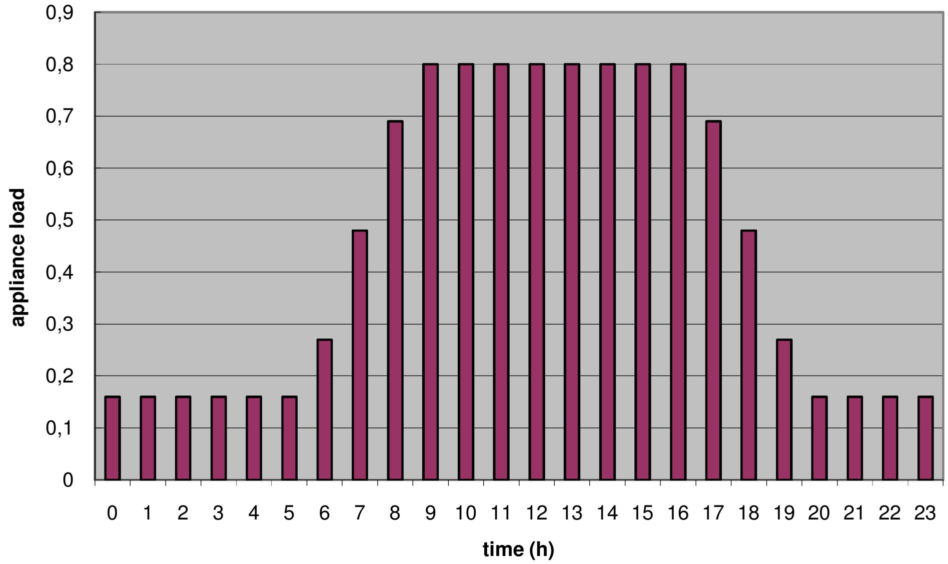

Figure 23 - Appliance profile in the offices compared to the sizing value

The conference rooms are sized for one person per 3.5m². One assumes there is no electrical device in the conference rooms at the exception of lighting. The occupancy profile of the conference room is given in Figure 24. No occupation is considered in toilets and circulations.

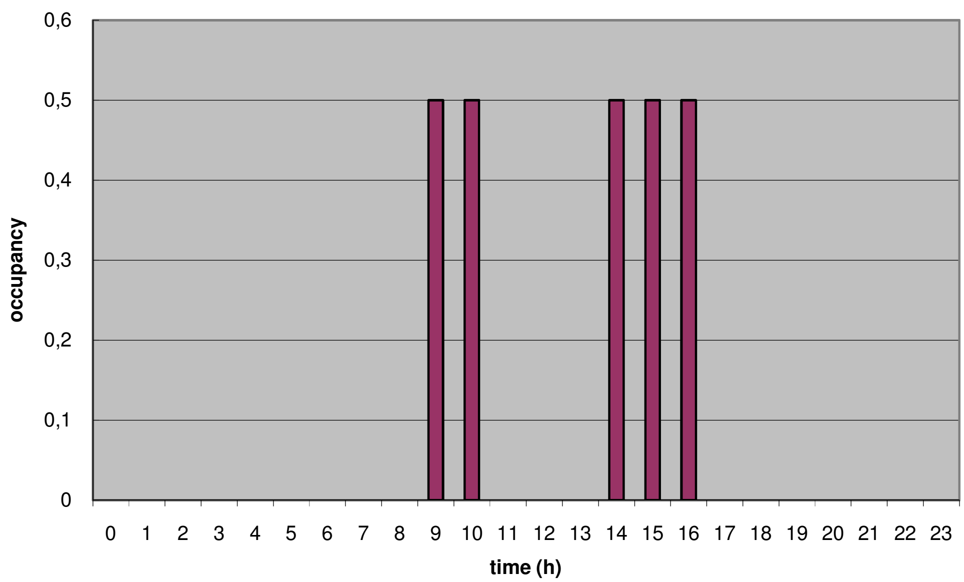

Figure 24 - Occupancy profile in the conference rooms compared to the sizing value

4.2 Solar protection and lighting

The lighting power is assessed to be 18W/m² in offices and conference rooms, 12W/m² in the circulations and 6W/m² in the toilets. The artificial lighting is dependent on the natural lighting and so on the solar protection use. The solar protection has a solar factor of 0.2. The use of solar protections by occupants is given according to the outside lighting in Figure 25. The position of solar protections during non occupancy is defined as equal to those in the last hour of occupancy.

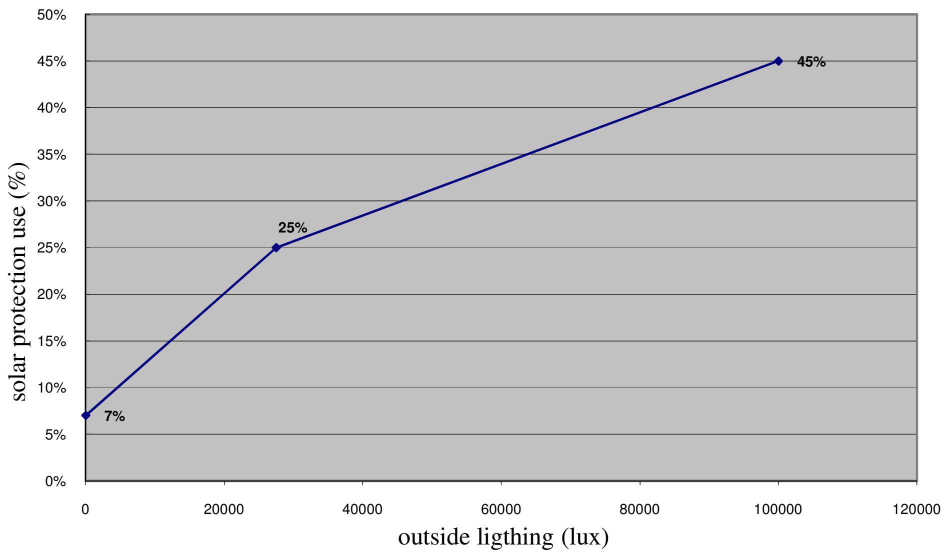

Figure 25 -Average use of solar protection

The artificial lighting is plotted according to the inside lighting in Figure 26. The artificial lighting is supposed switch off during non occupancy.

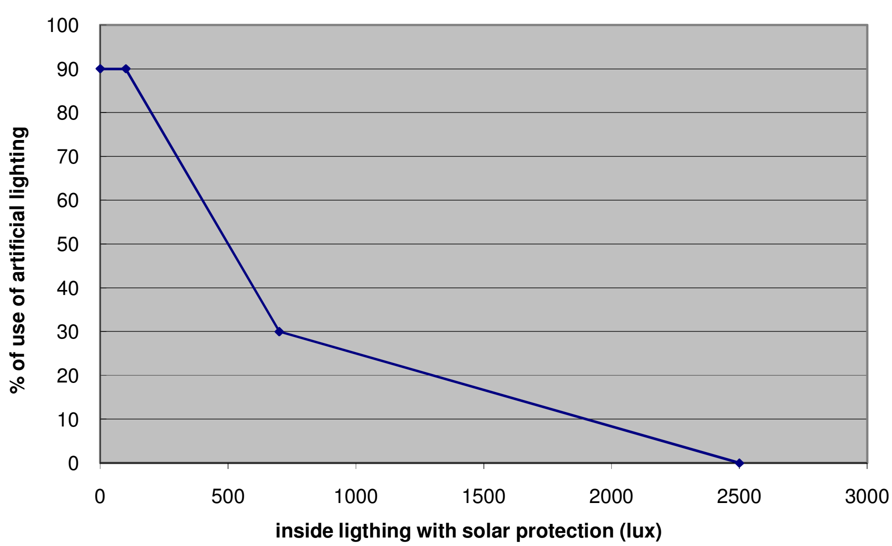

Figure 26 - Average use of artificial lighting

4.3 Ventilation and set point temperatures

Ventilation rate	25 m^3/h/person in offices 30 m^3/h/person in conference room 6h-20h during week – Stopped during weekend
Set point temperatures	20°C – 26°C inoccupation heating temperature : 15°C heating from 6h to 20h except Saturday and Sunday Air conditioning stopped during non occupation period

As no aeraulic software was available, there is not any air flow between floors. In each floor, it was assumed that the ventilation for the offices spread into the circulation zone and WC.

ANNEX B – Results in Heating and Cooling Needs for the Sensitivity Study

- **Wall insulation**

Table 30 – Values of the Wall insulation study

Uwall	*U=0.15 (W/m^2.K)*		*U=1.45 (W/m^2.K)*	
Climatic zones	Heating needs (kwh/m^2)	Cooling needs (kwh/m^2)	Heating needs (kwh/m^2)	Cooling needs (kwh/m^2)
Stockholm	103.97	8.97	143.20	4.12
Bruxelles	52.75	10.95	76.57	5.94
Milan	46.14	31.72	67.65	23.99
Rome	9.36	51.70	17.00	40.38
Palerme	0.96	69.97	2.46	57.20

Reference Uwall – 0.8 (W/m^2.K)

- **Ceiling Insulation**

Table 31 – Values of the Ceiling Insulation study

Uroof	*U=0.15 (W/m2.K)*		*U=1.3 (W/m2.K)*	
Climatic zones	Heating needs (kwh/m^2)	Cooling needs (kwh/m^2)	Heating needs (kwh/m^2)	Cooling needs (kwh/m^2)
Stockholm	120.91	6.31	130.63	6.01
Bruxelles	62.93	8.20	69.12	7.87
Milan	55.26	27.74	60.90	27.07
Rome	12.35	45.88	15.00	44.92
Palerme	1.39	63.39	2.32	62.28

Reference Uceiling – 0.4 (W/m^2.K)

- **Internal gains**

Table 32 – Values of the Internal gains study

Uwindow	*6 (W/m²)*		*24 (W/m²)*	
Climatic zones	Heating needs (kwh/m²)	Cooling needs (kwh/m²)	Heating needs (kwh/m²)	Cooling needs (kwh/m²)
Stockholm	133.16	4.12	113.96	8.66
Bruxelles	72.30	5.64	57.19	11.08
Milan	63.11	23.19	50.72	32.30
Rome	15.84	39.19	10.57	52.42
Palerme	2.24	55.11	1.16	71.53

Reference Internal gains – 18 (W/m^2)

- **Light Power**

Table 33 – Values of the Light Power study

Light Power	*7 (W/m²)*		*29 (W/m²)*	
Climatic zones	Heating needs (kwh/m²)	Cooling needs (kwh/m²)	Heating needs (kwh/m²)	Cooling needs (kwh/m²)
Stockholm	131.22	6.00	115.61	6.38
Bruxelles	70.47	7.66	58.61	8.52
Milan	61.13	26.73	52.34	28.33
Rome	14.98	44.14	11.13	47.02
Palerme	2.07	60.95	1.24	65.19

Reference Light Power – 18 (W/m^2)

- **Windows**

Table 34 – Values of the Windows study

		Simple		**Double (ref.case)**		**Double - low-e and Argon**	
Uwindow (W/m².K)		*5.74*		*2.95*		*1.43*	
Solar factor		*0.87*		*0.777*		*0.597*	
Solar Transmission		*0.901*		*0.817*		*0.769*	
	Climatic zones	Heating needs (kWh/m²)	Cooling needs (kWh/m²)	Heating needs (kWh/m²)	Cooling needs (kWh/m²)	Heating needs (kWh/m²)	Cooling needs (kWh/m²)
	Stockholm	199.74	2.44	123.63	6.20	87.66	7.76
	Bruxelles	110.79	4.15	64.72	8.10	42.83	9.76
	Milan	98.80	20.93	56.68	27.51	38.01	28.50
	Rome	29.25	36.18	12.96	45.54	7.21	46.27
	Palerme	5.93	52.67	1.57	63.00	0.65	62.98

- **Solar Protection**

Table 35 – Values of the Solar Protection study

Solar Protection	*SF = 1*		*SF = 0.15*	
Climatic zones	Heating needs (kWh/m²)	Cooling needs (kWh/m²)	Heating needs (kWh/m²)	Cooling needs (kWh/m²)
Stockholm	115.55	12.37	125.86	4.97
Bruxelles	59.80	14.06	65.94	6.99
Milan	51.56	38.00	58.35	25.26
Rome	10.08	62.62	14.02	41.56
Palerme	1.03	83.83	1.81	57.93

Reference Solar Factor for the Solar Protection – 0.2

- **Inertia**

Only the furniture inertia was changed in this sensitivity analysis. The walls inertia remained always as in reference case.

Light = Area x 12 (kJ/m^2/K)

Heavy = Area x 35 (kJ/m^2/K)

Reference inertia = Area x 24 (kJ/m^2/K)

Table 36 – Values of the Inertia study

Inertia	*light*		*heavy*	
Climatic zones	Heating needs (kWh/m^2)	Cooling needs (kWh/m^2)	Heating needs (kWh/m^2)	Cooling needs (kWh/m^2)
Stockholm	123.44	6.16	124.05	6.08
Bruxelles	64.56	8.04	65.10	7.93
Milan	56.74	27.17	57.11	27.53
Rome	13.02	44.97	13.06	45.75
Palerme	1.68	62.10	1.52	63.43

- **Infiltration**

Table 37– Values of the Infiltration study

Infiltration	*0.1 (m^3/h/m^2)*		*1 (m^3/h/m^2)*	
Climatic zones	Heating needs (kWh/m^2)	Cooling needs (kWh/m^2)	Heating needs (kWh/m^2)	Cooling needs (kWh/m^2)
Stockholm	96.48	9.82	189.05	2.09
Bruxelles	48.73	11.68	104.02	3.79
Milan	42.24	32.31	92.88	20.38
Rome	8.14	52.71	26.90	34.88
Palerme	0.80	71.03	5.14	51.02

Reference Infiltration – 0.373 (*(m^3/h/m^2)*

- **Set Points**

Table 38 – Values of the Set Points study

Set points	*19 (ºc)*	*27 (ºc)*	*22 (ºc)*	*23 (ºc)*
Climatic zones	Heat needs (kWh/m^2)	Cooling needs (kWh/m^2)	Heat needs (kWh/m^2)	Cooling needs (kWh/m^2)
Stockholm	116.47	4.11	150.33	15.94
Bruxelles	57.99	5.59	91.03	20.10
Milan	51.65	22.77	77.59	46.22
Rome	9.93	38.46	27.80	71.98
Palerme	0.86	54.21	8.79	94.62

Reference Set Points - Heating 20 ºC - Cooling 26ºC

- **Ventilation Rate**

Table 39 – Values of the Ventilation study

Ventilation Rate	*15 (m^3/p/h)*		*35 (m^3/p/h)*	
Climatic zones	Heating needs (kWh/m^2)	Cooling needs (kWh/m^2)	Heating needs (kWh/m^2)	Cooling needs (kWh/m^2)
Stockholm	103.42	7.94	143.65	4.78
Bruxelles	51.95	9.80	77.60	6.67
Milan	45.87	29.20	67.85	25.95
Rome	8.76	48.19	17.59	43.16
Palerme	0.75	65.98	2.80	60.40

Reference Ventilation – 25 *(m^3/p/h)*

- **Window Wall Ratio**

Table 40 – Values of the Window Wall Ratio study

Window Wall Ratio	*22.5%*		*67.5%*	
Climatic zones	Heating needs (kWh/m^2)	Cooling needs (kWh/m^2)	Heating needs (kWh/m^2)	Cooling needs (kWh/m^2)
Stockholm	107.84	1.88	140.92	10.83
Bruxelles	55.82	3.37	74.57	12.72
Milan	50.64	16.89	64.45	36.56
Rome	13.18	28.36	14.21	60.11
Palerme	1.82	41.27	1.79	81.09

Reference Window Wall Ratio - 45 %

ANNEX C – Energy Savings in terms of Primary Energy

Measure - Install a moveable external sun shading device controlled by occupants

Table 40 – Savings in terms of Primary energy

Climatic zones	Savings in terms of primary energy [kWh/m²/y]
Stockholm	-0,82
Brussels	-0,3225
Milan	-0,235
Rome	0,855
Palerme	1,695

Measure - Install energy efficient lightings and ballasts controlled by occupants

Table 41 - Savings in terms of Primary energy

Climatic zones	Savings in terms of primary energy [kWh/m²/y]
Stockholm	-14,99
Brussels	-10,99
Milan	-7,8975
Rome	-2,26
Palerme	1,6225

Measure - Use energy efficient office equipment

Table 42 - Savings in terms of Primary energy

Climatic zones	Savings in terms of primary energy [kWh/m²/y]
Stockholm	-16,52
Brussels	-12,125
Milan	-7,4325
Rome	2,2075
Palerme	8,5825

Measure - Mechanical ventilation: automated (on outdoor temp) opening during the night (fixed dimensions) + support fan

Table 43 – Savings in terms of Primary Energy

Climatic zones	Savings in terms of primary energy [kWh/m²/y]
Stockholm	3,62
Brussels	4,32
Milan	12,57
Rome	19,98

Palerme	23,81

Measure – Package A

Table 44 – Savings in terms of Primary Energy

Climatic zones	Savings in terms of primary energy [kWh/m²/y]
Stockholm	-29,19
Brussels	-25,16
Milan	-16,42
Rome	-0,55
Palerme	10,59

Measure – Package B

Table 45 – Savings in terms of Primary Energy

Climatic zones	Savings in terms of primary energy [kWh/m²/y]
Stockholm	-29,79
Brussels	-22,42
Milan	-5,66
Rome	16,11
Palerme	29,74