

# **Improving the passive building energy efficiency– Case study: Office building in Tetuan city in northern of Morocco**

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## **ABSTRACT**

Nowadays the construction in Morocco is poorly adapted to the climatic conditions of the country. This contributes to the increase of electricity demand by 7% annually. The Department of Energy is interested in introducing sustainable construction for large construction programs in Morocco. Especially as there is a large demand for new buildings and then the general goal is to build them energetically more efficient than in today's practice. To reach the said goal, energy demand of the building shall be minimized without trading off the environmental comfort for living. The dynamic building simulations are done to determine the thermal performance of the building by TRNSYS simulations in order to conduct analysis on the influence of building shell parameters to the heating and cooling demands, thus, the improvement of the passive building energy efficiency. A building thermal energy model is used for this purpose.

The study is carried out on a prototype of an office building in the city of Tetuan in northern of Morocco. This paper explains the procedure, simulations results in detail, discusses the major overall results and the effect of the building refurbishment steps in comparison with the Thermal Building Regulation in Morocco.

## **Keywords**

Dynamic building simulation, TRNSYS Software, Morocco Building Code Simulations

## **1. INTRODUCTION**

The building sector in Morocco is the largest consumer of energy with 25% from the total energy consumption of the country, including 18% dedicated to the residential and the rest for the tertiary sector [1]. This energy consumption is expected to increase rapidly in the coming years for two reasons: The significant developments in the buildings area because of major programs announced: Plan Azur Morocco 2020 [2], emergency program of national education, housing program of 150,000 per year, hospital rehabilitation program, etc. The significant increase in household equipment rate in HVAC equipment, lighting and hot water due to the improvement of living and the lower prices for such equipment (heating, cooling, water heating, refrigeration, etc. . .). However, Energy Efficiency and Renewable Energies are among the priorities axes to contribute to the reduction of the energy bill in Morocco. Energy demand of a building depends on so many factors, such as: temperature difference between outdoor and indoor, thermal conductivity of the building envelope, thermal mass of the building, internal and external convective heat transfer.

The background of the project is to provide effective solutions to improve the energy efficiency of the building and to carry out refurbishment combinations for an energy performance evaluation and thermal comfort of both summer and winter of the building. An interest is demonstrated in this study in a prototype already made in the climate zone Z2;

Tangier-Tetuan region in the northern of Morocco. This work is done using numerical simulation tools adapted with high performance as TRNSYS software [3].

## 2. METHODOLOGY

The improvement of the building energy efficiency is achieved by reducing the energy consumption and emissions. Since buildings' thermal behavior depends on different variables, which complicates the control of predicting energy consumption, the use of buildings' thermal simulation models which are based on the building energy balances for each zone, is what fits best. To establish the energy balance of a building, the system limits must be clearly defined. It is also necessary to define the initial and boundary conditions of the system, e.g., climatic environmental conditions or internal gains. The state variables, e.g., ventilation and surface temperatures and the energy requirement can be derived.

### 2.1 Building thermal energy model

The building energy balance for a zone is a non-geometrical balance model. Each zone corresponds to one air node and represents the thermal capacity of the zone air volume. In this balance model any air point in the zone has the same temperature, humidity and other properties. The TRNSYS output in the multi-zone building component "NTYPE 904" represents the energy balance for a zone using the Eq. (1):

$$\frac{DQ_{air}}{dt} = \dot{Q}_{heat} - \dot{Q}_{cool} + \dot{Q}_{vent} + \dot{Q}_{inf} + \dot{Q}_{trans} + \dot{Q}_{gain} + \dot{Q}_{sol} \quad [\text{kJ/hr}] \quad (1)$$

$\frac{DQ_{air}}{dt}$  : Is the change of internal energy calculated with capacitance of air in the zone

$\dot{Q}_{heat}$  : Heating demand (convective + radiative)

$\dot{Q}_{cool}$  : Cooling demand

$\dot{Q}_{vent}$  : Ventilation gains

$\dot{Q}_{inf}$  : Infiltration gains

$\dot{Q}_{trans}$  : Transmission gains into the wall from inner surface node and environment

$\dot{Q}_{gain}$  : Internal gains (convective and radiative)

$\dot{Q}_{sol}$  : Absorbed solar gains on all inside surfaces of zones, the absorbed solar gains of the inside surface of all windows are taken into account. These absorbed gains may go inside or outside.

The system boundary for this energy balance model includes the inside surface node of all surfaces of a zone. Due to this also all radiative heat fluxes appear in this balance. More details on the mathematical description of the building thermal energy model can be found in the TRNSYS user manual [4].

### 2.2 Building description

The building under investigation is located in the city of Tetuan, a city in the north of Morocco (N 35° 34' W 5° 22'). The building is used as an office and represents an entire area of 20m<sup>2</sup>.

This model is then considered as a reference office-building model and the results can be extrapolated for a large series of buildings.

All the geometry and characteristic sizes are summarized in the chart below:

Table 1. Geometry and wall data for the building in its actual state

Building Element	Orientation	U-value* [W/m <sup>2</sup> K]	Area [m <sup>2</sup> ]		Structure
			Zone 1 "South Room"	Zone 2 "North Room"	
Outside Wall	North	1.43	-	9.5	Cement+Brick+Air+Brick+Cement 2 cm + 4.5 cm + 13.5 cm + 4.5 cm+ 2 cm
	South	1.43	9.5	-	
	East	1.43	8.7	8.44	
	West	1.43	8.7	8.44	
	South	5.8	1.56	-	
	West	5.8	1.56	1.56	
Adjacent Wall	-	1.61	6.48	6.48	Cement + Brick + Cement
Roof	Horizontal	1.82	9.88	9.56	Cement+Hollow block+Concrete+Cement
Floor plate	-	0.81	9.88	9.56	Gravel + Concrete+Cork (4cm) + Screed + Tile
WWR (%)	North	-	-	-	Window-to-Wall Ratio
	South	-	16 %	-	
	East	-	-	-	
	West	-	18%	18%	

\* *U-value*: thermal transmittance of the building element (W/ m<sup>2</sup>K);



Figure 1. Office Building: real model, FS, UAE, Tetuan

### 3. CLIMATIC DATA

The climate data used in this study are the climate of the city of Tetuan. They were provided by a Weather Station based in the Energy Laboratory at the University located in Tetuan, Morocco.

To estimate the heating and cooling load and the annual energy consumption, the air temperature is needed.

In order to have an overview on the ambient temperature fluctuations, the two followings graphics represents respectively the days showing hourly values of the ambient temperature, the daily extreme and the daily mean values of the ambient temperatures.

The graphical representation (Figure 2) is called "carpet plot" and consists of 365 horizontal dots which are equivalent of the 365 days of the year. The vertical axe represent the 24 hours of the day.

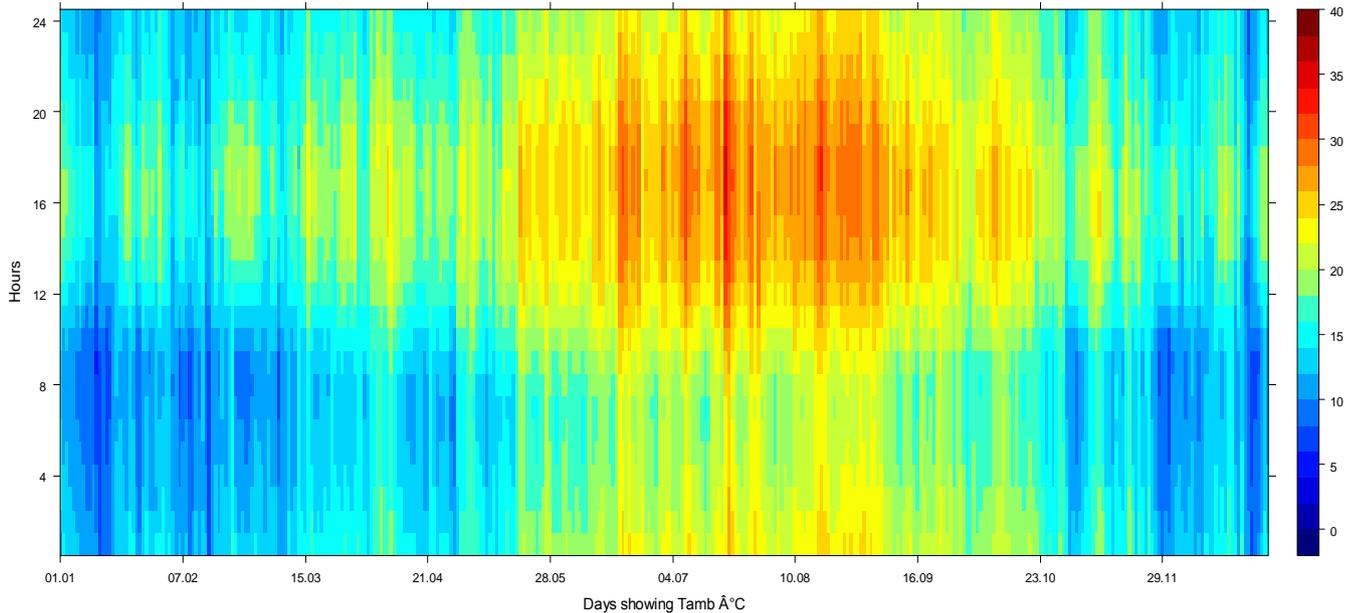


Figure 2. Days showing hourly values of the Ambient Temperature °C in Tetuan

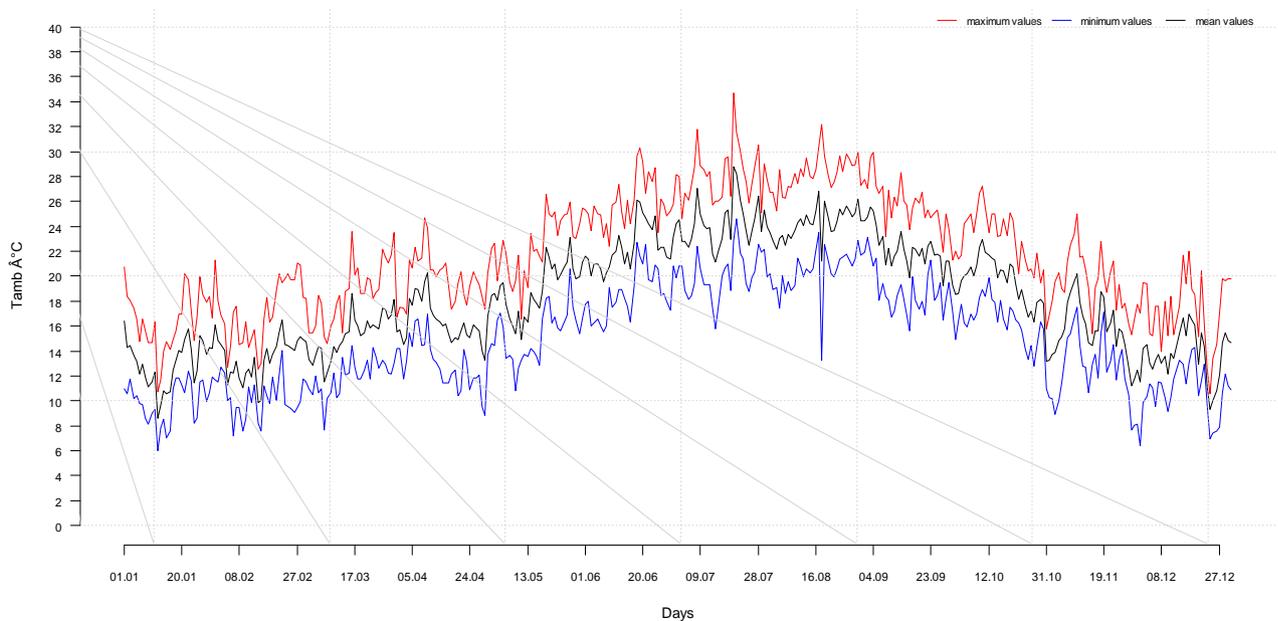


Figure 3. The daily means, minimums and maximums measured air temperature values

#### 4. MODELING AND DYNAMIC BUILDING SIMULATION

The building model is created employing TRNBuild, which is a TRNSys's interface creating and editing all of the non-geometrical information required by TRNSYS Building Model.

The office building is used by 4 persons from 9 am to 6 pm, two persons in each room. The building is simulated as two adjacent zones called « South Room » and « North Room ».

The simulation period is one year, from the 1st of January at midnight to the 31st of December at midnight.

Infiltration is fixed at 1 air change per hour during unoccupied and occupied times.

The heating turns on during occupied times when the zone temperatures fall below 20°C. As the office must not cool down during the night, we fixed the night setback temperature at 16°C. According to reality the simulation is being run without cooling but we determine a fictitious cooling energy requirement for a simulated cooling set point of 26 °C during summer.

The simulation results are given in one-hour steps.

To analyze the influence of individual measures and to compare the thermal behavior of the two areas within the building using different variants, a dynamic thermal simulation was applied using the simulation package TRNSYS16 [3].

**Reference Model**

This first simulation is considered as the reference state. It corresponds to the thermal simulation of the prototype without any insulation of the horizontal and vertical walls or refurbishment. The building has already a floor insulation of 4 cm Cork and an air layer of 13.5 cm in the walls.

Energy balances for both south and north rooms are to be set up in order to analyze the thermal behavior and to determine the energy requirements of the building.

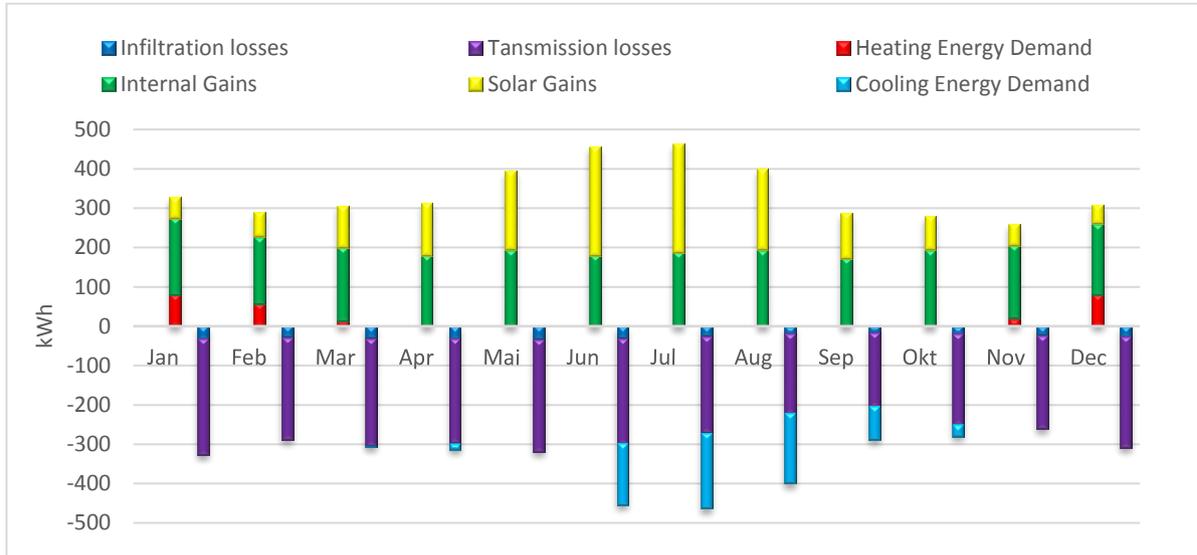


Figure 4. Monthly energy balance in the South Room of the building

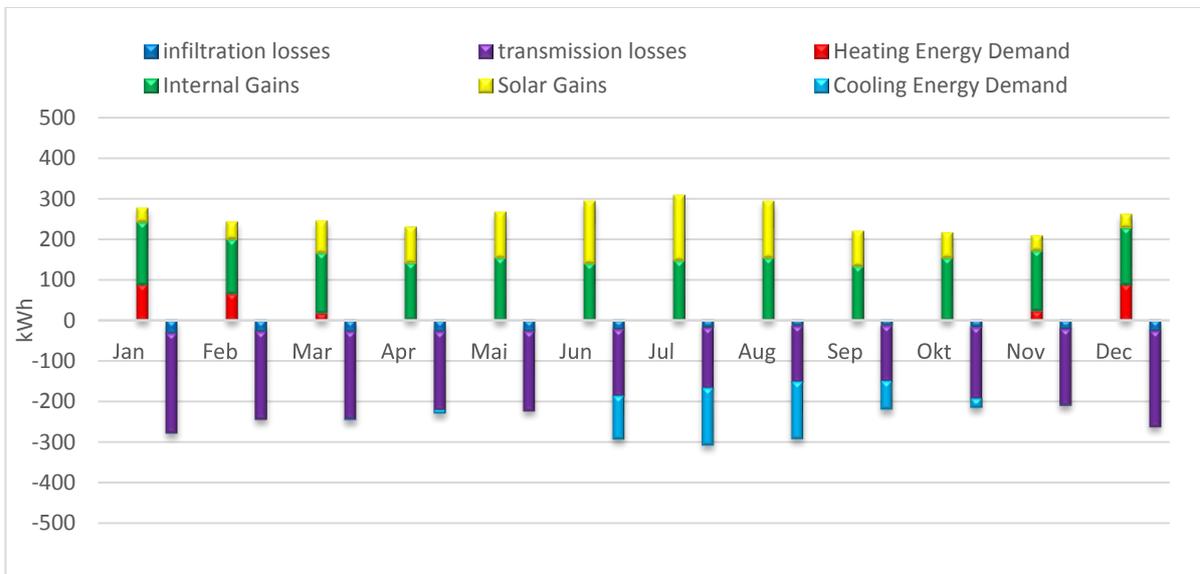


Figure 5. Monthly energy balances in the North Room of the building

- From the calculations of thermal building simulation results, a total annual heating demand of 532 kWh is observed. With a net floor area of 19.5 m<sup>2</sup>, the heating demand becomes specifically 28 kWh / (m<sup>2</sup> \* a). An insulated building envelope can reduce considerably the heat loss in winter.
- The total annual cooling energy demand of the building is 67 kWh / (m<sup>2</sup> \* a). This value is unacceptably high and makes it clear that measures must be taken for the reduction of the cooling energy demand.
- The yearly energy balances for the two rooms show that the energy for the three months of cooling is significantly higher than the total heating demand during a year.

Uncomfortable room conditions in summer are generally caused either by too large window areas without sun protection or interior shading devices, or by insufficient possibilities to ventilate the building, or a lack of storage mass as well as the internal heat gains obtained by equipment and occupants [5].

## 5. COMPARISON OF REFURBISHMENT VARIANTS

An energy efficiency refurbishment should improve the building energy efficiency in such a way that its heating and cooling depend on the climate conditions dominating on site. In addition to problems concerning the insulation, existing buildings often have problems with summer heat protection. They regularly overheat due to insufficient structural measures [5] and have to be cooled.

The simulations of variations contribute immensely towards finding the ideal solution to avoid overheating in summer and selecting the perfect plant technology to cater for the building's requirements.

### 5.1 Variant (a): External wall insulation

This simulation allows the comparison between the reference state and the impact of the use of an external insulation of walls. Then a second comparison was made between two different insulation material thicknesses and the energy demand.

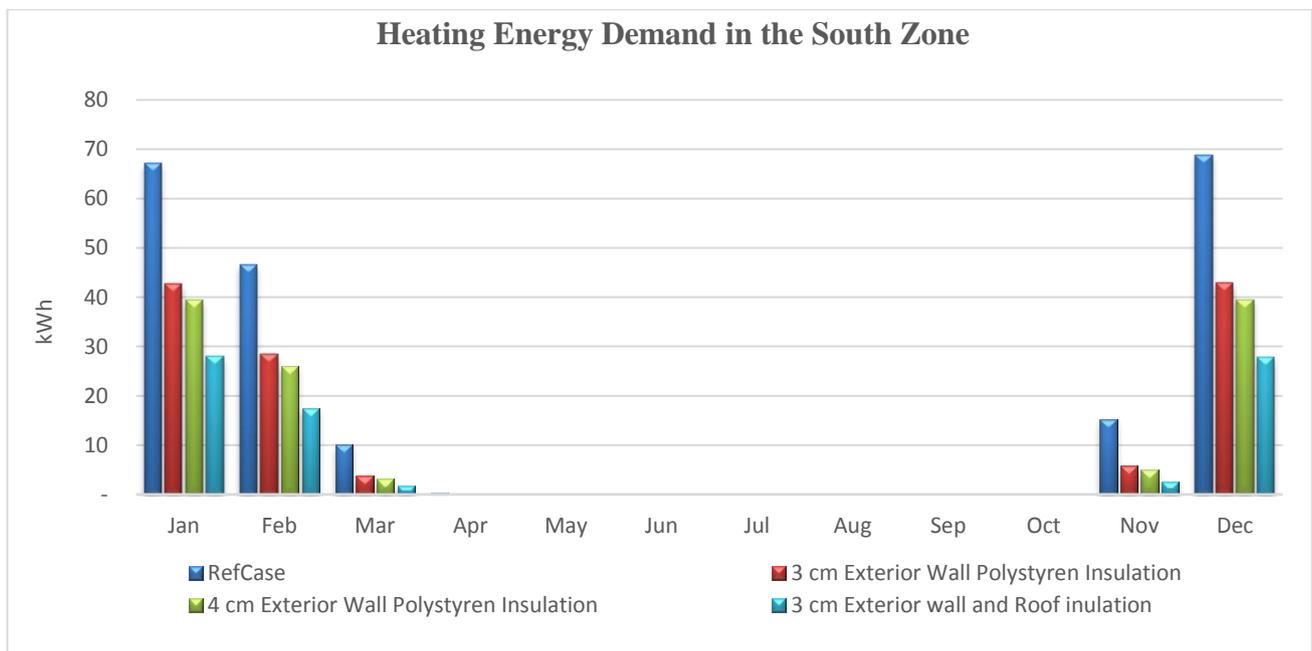


Figure 6. Heating energy demand in the south room

A large decrease in the heating energy demand is observed after the addition of 3cm of insulation material on the external vertical walls and on the roof. The use of a greater thickness also reduces the energy demand but remains not the optimal solution with regards to its impact in summer and also to the cost that increases in general with the thickness increase.

To measure the comfort during a year and particularly during the working hours' time, a number of uncomfortable working hours [6] within the two rooms is calculated. The heating and cooling are set to "OFF mode" during the simulation.

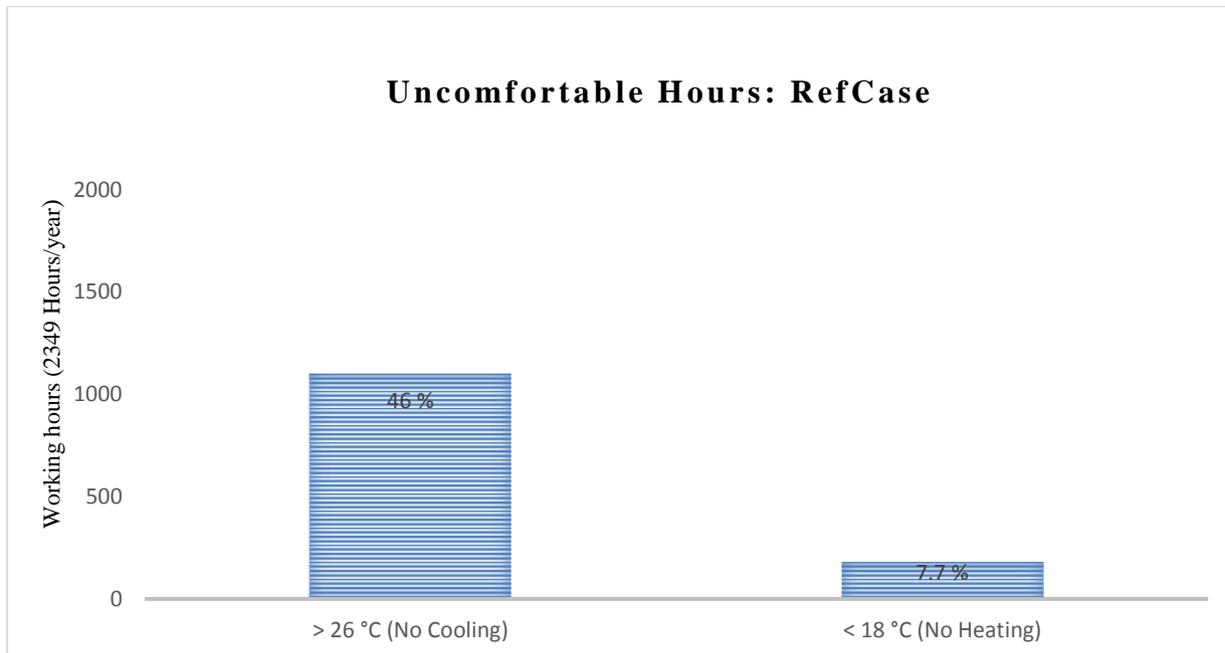


Figure 7. Annual number of uncomfortable working hours without heating and cooling

## 5.2 Variant (b): Night Ventilation

### Principle and model:

Night ventilation is a passive cooling technique consisting in ventilating the room or the building with an additional supply of outside air at night with or without mechanical assistance. That means during night-time ventilation the cold outdoor air is used as a heat sink to cool the building. Whenever, the outdoor air temperature is below building temperature, the building can be cooled by ventilation.

In this case study the natural night ventilation during summer is operated manually by opening the windows at night, depending on the temperature difference between the inside and outside and according to a time schedule. It can be also automatically operated using a central building management system.

### **Window opening**

- 45° opening angle
- 76 cm x 40 cm



Figure 8. Opening window in the Office Building: real model, FS, UAE, Tetuan

Table 2. Interiors conditions as simulated

Interior conditions	Monday-Friday	Monday-Friday	Weekend
	9h - 18h	18h - 9h	
Occupancy	4	0	0
Ventilation 1/h	3	3	3
Infiltration 1/h	1	1	1
Set point temperature Heating	20 °C	Night setback temperature at 16°C	Night setback temperature at 16°C
Set point temperature Cooling	26 °C	off	off
Devices	On	Off	Off

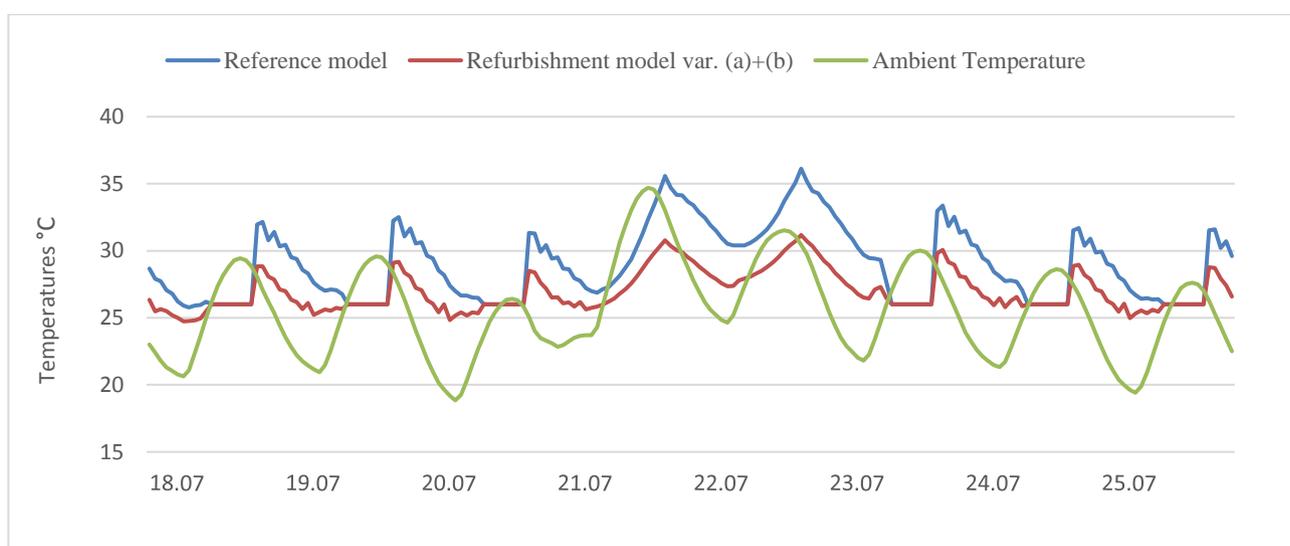


Figure 9. Dynamic temperature of the south room in summer and the outdoor temperature

The lower temperature of night can be exploited to retrofit the heat stored during the day. Therefore, night ventilation may be added to reduce the cooling energy demand and the number of uncomfortable working hours during summer.

Table 3. Energy demand in the comparison of the refurbishment variant (a) and (b)

	Reference model	External Wall + Roof insulation (3cm)	Night ventilation
<i>South Room</i>			
QHeat (kWh/m <sup>2</sup> .a)	26	6	7
QCool (kWh/m <sup>2</sup> .a)	74	80	70
<i>North Room</i>			
QHeat (kWh/m <sup>2</sup> .a)	30	9	10
QCool (kWh/m <sup>2</sup> .a)	56	57	50
<b>Total Energy Demand in the office building (kWh/m<sup>2</sup>.a)</b>	<b>93</b>	<b>76</b>	<b>68</b>

- The external wall and the roof insulation decreases the heating energy demand in winter but increases the cooling energy demand in summer. As a potential solution, using the night ventilation during summer can be

sometimes the optimal way to reduce the cooling energy but in this case of study, the results show that night ventilation is insufficient to cool the building passively during hot summer months. For this reason, further studies should be conducted to find optimal parameters.

- Also the electrical load or equipment increases significantly the internal gains and these have a significant impact on the cooling energy demand and therefore, each working group must understand that not only electrical energy can be saved, but that these measures have a direct impact on the cooling energy demand.
- The external or internal shading devices can be added to the windows. Hence, this measure offers the possibility to reduce the solar gain.

### 5.3 Variant (c) : Sun protection device using overhangs and wings

Retrofitting a sun protection device to the building is one of the most effective ways to shield windows from direct radiation and to reduce solar heat gains in summer months.

A study was done to determine the effect of external shading devices on building performance using TRNSYS simulation. The shading devices model adopted in this study were overhangs and side wings on the south and the west windows of the building. This model is carried out in TRNSYS through the component Type 34. The inputs of this component are dimensions of the windows, distance between overhangs and windows and between wings and windows, and radiation data on horizontal and windows surfaces. The radiation data is provided from the solar radiation processor component that interpolates radiation data, calculates several quantities related to the position of the sun, and estimates insolation on up to 8 surfaces of either fixed or variable orientation [4].

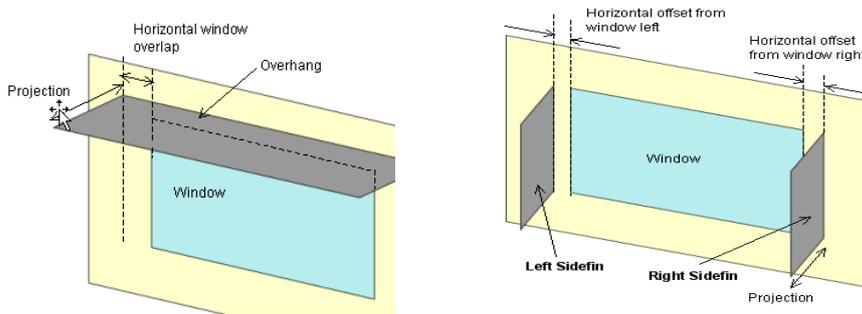


Figure 10. Schema Shading Geometry; windows with overhangs and side wings [7]

The following representation summarizes the combination investigated for this building in comparison with the refurbishment steps.

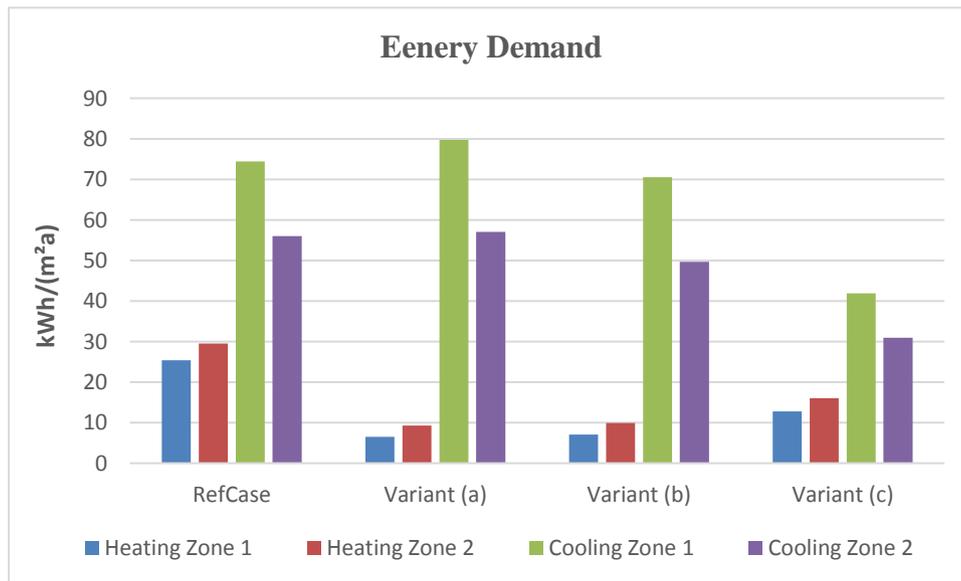


Figure 11. Energy demand in the comparison of the refurbishment variant (a), (b) and (c)

- The office building simulations results show overall relatively high-energy demands that are dominated by cooling energy needs. The reason for this behavior is the floor insulation that lowers the heating energy demand, but increases the cooling energy demand. During summer, overheat from the building may be transferred to the ground. Consequently the cooling load will be reduced as long as the base plate is not insulated, because insulation keeps the heat inside.
- The results also show that by combining several measures in Z2 climate conditions, the total energy demand is lowered by approximately 54% from the reference case. Otherwise, the impact of the thermal regulation on the reduction of the heating and cooling needs of administrative buildings in Morocco is around 52% of reduction.
- According to the thermal regulation, the annual maximum thermal requirements for heating and cooling in the administrative buildings in Morocco in Z2 is 49 kWh / m<sup>2</sup> / year.
- According to a study carried out in order to establish the Moroccan Building Energy Code [8], ceiling insulation is a low-cost measure that improves the energetic behavior regardless of climatic conditions or the type of building.

## 6 CONCLUSION

Dynamic thermal building simulation serves as an effective tool in order to carry out the thermal analysis of an existing building by improving the energetic behavior, thus performing a sustainable refurbishment.

The proposed study essentially rests on the following points, which constitutes the best refurbishment combinations investigated in the Climate Zone Z2 for an office building:

- In the Climate Zone Z2 the floor insulation is not recommended. Otherwise, an overheating summer will be held. A not insulated floor could reduce the cooling demand by absorbing the excess heat from the building during summer months.
- The different variants and measures aim to reduce primarily the cooling loads that depend on solar irradiance and internal gains.
- In order to reduce the transmission losses the thermal conductivity must be reduced as well by adding insulation on outside surfaces.
- To reduce the solar gains in summer it is recommended to use variable shading devices.

In summary, the use of simulation models shows promising features to be an efficient forecast tool for comparing cooling and heating demand considering the various interactions of individual measures. These measures are inherently included in the context of the mathematical model forming the simulation basis.

The thermal building regulations in Morocco could be improved and combined with a recent cost study considering current costs available in Morocco. Thus reducing the additional cost related to compliance with the Moroccan thermal building regulation [1]. Currently the additional cost associated with thermal regulation in administrative buildings is on average 83 DH\*/m<sup>2</sup>. And the additional cost associated with the thermal regulation in the residential sector implies an average additional investment cost of around 112 DH\*/m<sup>2</sup>.

\* Moroccan Dirham, MAD = 0,10 US-\$ (January 31, 2017)

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## **Biography**

**Prof. Dr. El Bouardi Abdelmajid** holds a postgraduate thesis in solar energy since 1983. Senior Researcher at the International Foundation for Science IFS in Rural Technology from 1988 to 1996. He was awarded a PhD degree in materials used in construction and insulation science in 1991. He is currently a Full Professor in the Faculty of Science, Abdelmalek Essaadi University, Tangier - Tetouan, Morocco. His research interest Physical and Chemical, Mechanical and Thermophysical of building materials. Additionally his research interest is moreover directed towards the field of the Heat transfer, Energy Efficiency in Building, Energetic studies, Technical and Economic studies of solar installations, solar Energy and Technical drying. He is author and co-author of shed more than 100 papers in thermal characterizations of materials used in construction and insulation and solar systems. In last December 2010, he was designed among a Group Member of the National Energetic Efficiency Code Establishment and Group Member of the New National Program of Social Building Sustainable Team and National Contact point Energy (Morocco) for European research program H2020.

**Prof. Dr.-Ing. Friedrich Sick** is Professor in the field of Renewable Energies at the HTW Berlin University of Applied Sciences in Berlin, Germany. He earned a PhD from the faculty of Architecture at the technical University in Karlsruhe, Germany, on investigations about the influence of elementary architectural measures on the indoor daylight quality. He holds a Master's degree of the University of Wisconsin, Madison, USA, on research about liquid desiccant cooling systems with solar thermal regeneration, and a Chemical Engineering Diploma of the University of Stuttgart, Germany. He has devoted himself to renewable energies. He dedicated eight years of research to this topic at the Fraunhofer Institute for Solar Energy Systems in Freiburg, and then worked as a product manager in industry and as a project manager in an engineering firm. Since his appointment as a professor at HTW Berlin in the year 2000, he has committed himself to teaching and research in the Renewable Energies degree program. His focus is almost exclusively on energy supply concepts for buildings, using dynamic building simulations as the major analysis tool.