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Use of Solene-microclimat to evaluate the impact of building materials selection on buildings' façade temperatures

Bisam Al-HAFIZ^{1,2,3}, Marjorie MUSY^{1,2}, Turki Hassan ALI³

¹Institute for research on urban sciences and techniques (IRSTV), Nantes, France, ²CRENAU laboratory, The national school of architecture in Nantes (ENSA Nantes), Nantes, France,

³Department of Architectural Engineering, Mosul University, Mosul, Iraq

bisam.al-hafiz@crenau.archi.fr, marjorie.musy@ec-nantes.fr, turk61ali@gmail.com

Abstract

In this century, the world is facing a rapid urban growth, most of them (about 4.9 billion) will live in urban areas. These changes increased the use of land and reduced the green areas. As a result, our cities will be warmer climates compared to their surroundings. One of the main reasons behind these changes is the changes in the construction materials, especially the high heat capacity of both building envelopes and urban areas. This study tries to find some suitable types of construction materials compatible with climate conditions in Iraq; to avoid the increase of buildings' facade temperature on a real case of the residential complex in Mosul city-Iraq. To conduct this assessment, Solene-microclimat simulation tool is used in: Identifying the effect of new construction materials on building's facade temperature, Carrying out sensitivity analysis over a period of time to determine types of materials Carry out a comparison over selected materials types with respect to their thermal performance. The results of this study proved that the main influence of thermal performance of any either exterior or interior building surface is the material type, which depends on its effusivity. Regarding Solene-microclimat, it has contributed significantly to the selection process.

Keywords: Construction materials; UHI; Solene-microclimat; surface temperatures, buildings' façade, Mosul.

1. Introduction

Globally, the world's population is expected to reach about 9.6 billion, with about 66 per cent living cities by 2050 [15], especially in developing countries (Africa, Asia and the Pacific, Latin America and the Caribbean [8]. Iraq as one of the continents of Asia is witnessing a significant increase in the population which is projected to trend about 71.3 million by 2050 [18].

Indeed, rapid urbanization and increase move from villages to towns led to an increased demand of basic facilities such as public transport services, water supply, hospitals, housing, and employment opportunities [19]. Accordingly, the urban areas have been expanded compared with rural areas, and many modifications have been happened on their surfaces, through replacing the green area with buildings, roads, and other infrastructure, especially when using low reflective materials [9]. As a result, many of the environmental problems occur is unavoidable at global and regional levels [17]. In this regard, the urban thermal environment stands as one of the main urban environmental issues, the cause of which must be identified its causes, and evaluated in a realistic and accurate manner, and finally optimal solutions must be found.

The construction materials in both buildings and urban spaces play a major role in affecting the urban temperatures by: their capacity to store heat. The near-surface air temperatures depend mainly on the behaviour of the surface with solar radiation and how the energy is reflected, emitted, and absorbed [7]. The radiative behaviour of a surface depends mainly on a set of self-properties of the material, such as physical thermal properties (thermal conductivity, specific heat capacity, and density), their radiative properties (albedo and emissivity) and the amount of solar radiation (direct and indirect) falling on it [14, 11].

Therefore, we can conclude that one of the main causes of environmental problems and increase air temperatures for a city is the construction materials. Hence, emerged the need to select the appropriate construction materials from a high range of materials proposed by construction market, in line with the changes in the Earth's environment. In addition there is a need to find some good ways and new methods in harmony with the development of the computer software, methods of simulation that create a virtual

environment for any realistic scenario to assess these substances. Indeed, in many cases the specifications of construction materials are not sufficient to give the final decision in selecting appropriate materials, but give a preliminary report on the thermal behaviour where there are many other factors affect the thermal behaviour of the materials e.g. the shape of the building, orientation, geographic region, etc.

From the foregoing, the aim of this study is to indicate the appropriate building materials that help to provide high level of indoor thermal comfort through storage the heat and prevent it to pass into the interior spaces, which can be used in the Middle East in general and in Iraq especially. The second aim is to give a full conception of what can the computer simulations method such as Solene-microclimat contribute to provide a clear and a precise perception of the thermal behaviour of building materials.

2. Main idea of the paper

This paper has two ideas to present: - Firstly, the use of Solene-microclimat as a tool that allows simulating the impact of alternative urban development across the area on indoor/outdoor thermal comfort and building energy issues. - Secondly, the study of the thermal behaviour of different types of materials that suitable to be used in Middle East generally and Iraq especially. The simulation carried out on an important residential complex in Mosul city –Iraq, with respect to climate conditions, geographical location, and a group of characteristics associated with that region (see figure 1).



Figure 1: Al Hadba Residential Complex, Mosul city, Iraq

Solene-microclimat provides a range of abilities in relation with geometries: it can create any geometry 'real' and not just the forms included in a grid, as well as the ability to change any parameters related with location, climatic conditions, wall and roof design (e.g. thickness, number of layers, finishing), construction materials of the urban area or natural surfaces (water or vegetation), (see Figure 2).

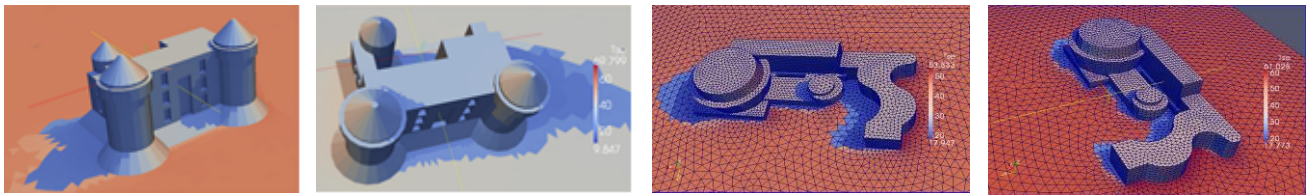


Figure 2: Geometry Samples - Solene-microclimat

Many researchers and construction materials companies are making great efforts to produce and to develop new types of building materials targeting to reduce their environmental effects, e.g. pumice block materials, concrete rubber aggregate, concrete/ mixed straw, act. (see figure 3).

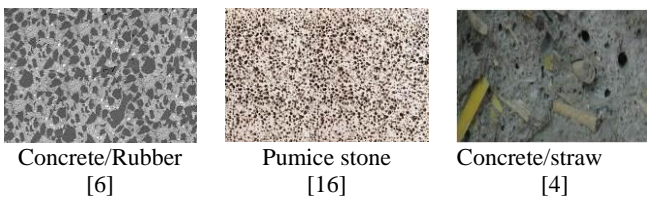


Figure 3: Types of new construction materials

3. Walls materials and configuration vs thermal performance

The building envelope materials types and its thermo-physical properties affect the nature of the climate surrounding the building. Therefore to achieve appropriate building envelope materials selection with aim to reduce the exterior/interior surface temperature and energy consumption, as well as improving thermal comfort, it is necessary to study the thermal performance of the building envelope. The thermo-physical properties, the thickness and type of construction material, (including insulation), their arrangement in layers in the wall, all these factors have an effect on the external and internal wall surface temperatures [3, 2, 12]. To characterize this effect the effusivity value is used. Thermal effusivity is the square root of the product of thermal conductivity (λ), density (ρ) and heat capacity (cp). i.e. $(\lambda \rho cp)^{1/2}$.

A material with high effusivity value quickly absorbs a large amount of energy without significantly warming (metal, stone, porcelain, etc.) while with a low effusivity value, it warms up in a short time and that mean it absorbs and stores the heat, therefore, reduce the heat pass into the interior space (insulation, wood, etc.), [1]. Therefore, it is an effect variable that could affect the process of materials selection from wide range of materials available in the construction market. For example (table 1), the effusivity of reinforcement concrete is $2197.7 \text{ J/m}^2\text{K}\cdot\text{s}^{0.5}$, while pumice block effusivity value is 312.5, this material having a high potential for insulation.

N.	Materials types	Thermal conductivity (W/(m.K))	Density Kg/m ³	Specific heat capacity J/(kg.k)	Effusivity J/m ² Ks ^{0.5}
1	Reinforcement concrete	2.3	2500	840	2197.726
2	Concrete/mixed with straw	1.32	1895	1560	1975.394
3	Ordinary concrete block	1.63	2300	1000	1936.234
4	Concrete rubber aggregates with radius 0	1.3	2150	970	1646.557
5	Concrete rubber aggregates with radius 30	0.76	1702	1380	1336.06
6	Light weight concrete block	0.56	1400	1000	885.438
7	Pumice block	0.15	650	1000	312.249

Table 1: Alternative building materials

4. The SOLENE-microclimat model

SOLENE-microclimat is the new version of solene software that includes new sub-models that provide it with many additional possibilities (see Figure 4).

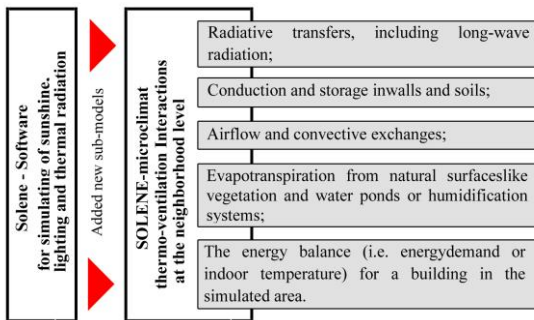
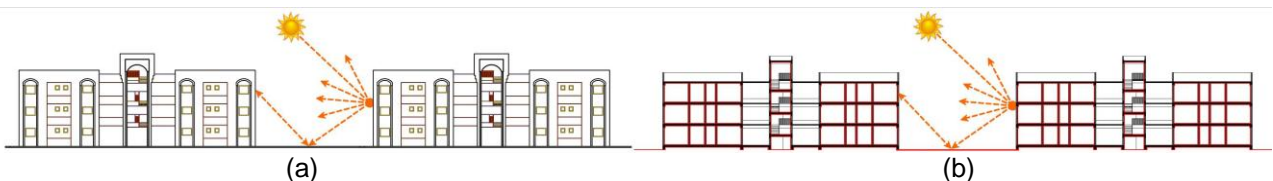


Figure 4: The new sub-models of Solene [13]

Generally, SOLENE-microclimat has three main models the thermo-radiative model, the thermo-radiative model of a building, and the thermo-radiative model coupling with other code e.g. Code_Saturne (CFD Simulation), (see Figure 5).



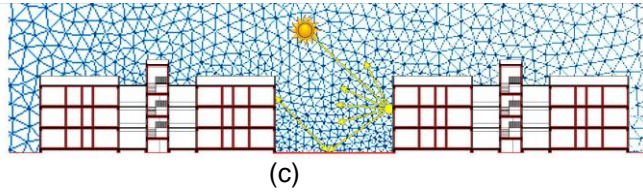


Figure 5: The SOLENE-microclimat model types (a-Radiative model, b-Thermal-radiative model of buildings, c-Thermal radiative model of building coupling with Code_Saturne

5. Building thermal model by using SOLENE

The thermal behaviour of the building related with energy consumption is represented in Solene by using a nodal thermal model. It has its own characteristics as following [12], (see Figure 6-e): 1. Multi-zone model with one zone for each floor. 2. One air node, one wall temperature node, and one internal glass node for each floor, 3. Non-homogeneous boundary conditions in the external surfaces, 4. Estimation of energy consumption for fixed set temperature or fixed indoor temperature e.g. 22 °C, this is done with the free running simulation condition. 5. Calculation of latent and sensitive loads, taking into account the internal gains and air change, 6. Not taking into account the direct thermal bridges.

6. Building thermal model by using SOLENE

The walls in relation to the outside (opaque or glazed) are represented by a nodal model with both strength and thermal capacity (R2C) calculated using assumptions similar to those of CoDyBa software [12]. These consist in assuming that the temperature profiles are linear in each of the layers of the wall, which is acceptable for the hourly time used. From this basic model, many variations are derived (see Figure 6-a, b, c, d).

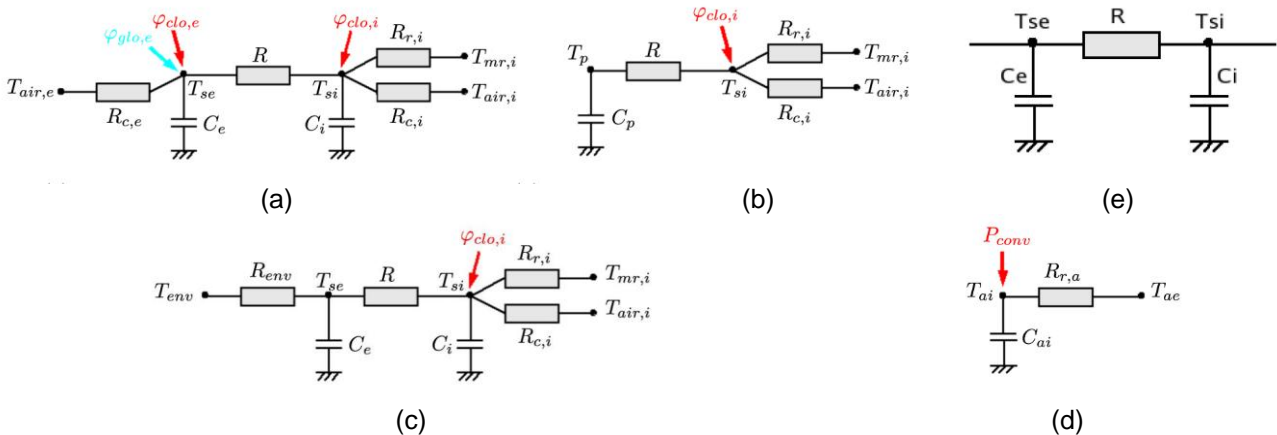


Figure 6: Details of the elemental components model of building model [12]

(a- Thermal model of external walls, b- Thermal model of interior walls, c- Thermal model of floors, d- Thermal model of indoor air, e- Elementary wall model of Solene [5]), ((R) Thermal resistance, (Ci) Thermal capacity of the indoor surface, (Ce) The heat capacity of the outdoor surface, (Rj) The thermal resistance of the layer)

7. Modeling of different building components by SOLENE-Microclimat

For any building, four types of wall are represented: exterior walls, glazing, interior walls, and floors or ceilings as figure 6. This figure explains four different scenario of thermal model of the building components. Figure 6-a represent thermal model of external walls, windows and roof. These components are located under the direct impact of air temperature and radiant temperature. Figure 7-b represent the thermal model of the internal walls, that affect the building thermal inertia, which is dependent on the absorptivity, specific heat, thermal conductivity, dimensions, and other factors of the wall. In the thermal system, it is in contact only with the indoor environment. Figure 7-c represent the thermal model of floor. It differs from the other components of building because it is located under the effect of the two separated thermal zones contrary to the ceiling and the ground floor [12].

8. Methodology: SOLENE-Microclimat simulation process

In order to achieve a simulation by solene-microclimat, some important data should provide: 1. An appropriate geometry (with extension .med), 2. Weather data (depending on the city and country), as well as taking in consideration the longitude and latitude 3. Types and properties of construction materials that are used, 4. The construction components design e.g. thickness of the walls, how many layers, and materials, and 5. The simulation period. Regarding the geometry, one should note that the geometry must be inside a virtual box representing the virtual wind tunnel. (see Figure 3).

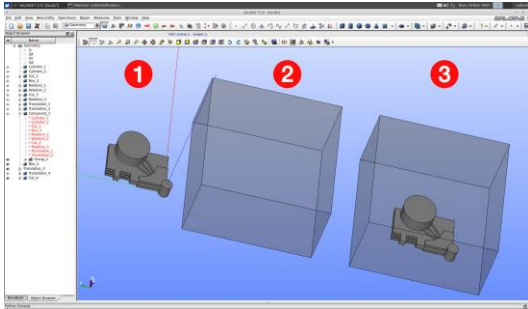


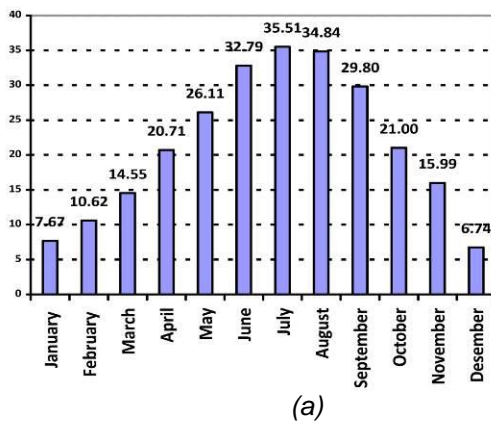
Figure 7: The steps to create the geometry

(1.the geometry, 2. The virtual wind tunnel, 3. The geometry inside the virtual wind tunnel)

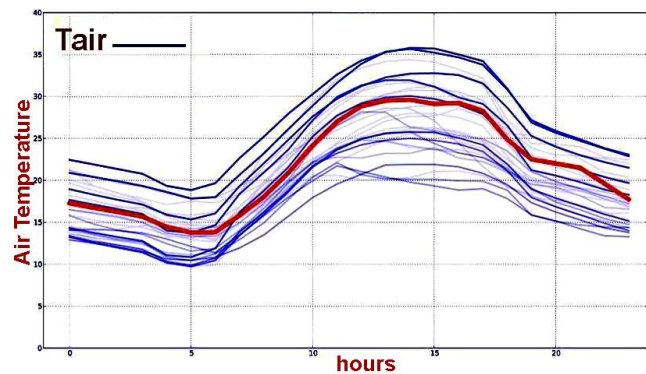
After completion of the necessary data, the process of simulation will start. The simulation of this study will consist of two phases: a preparatory steps for the simulations, and simulation steps

8.1 Step one: Selecting the day for simulation (preparatory step)

Regarding the period of simulation, in most cases, the result are collected in the last day of a period at least two weeks (to be sure that initial conditions are no more influential). Therefore, the period should be carefully selected. In this study (Al-Hadba Residential Complex), the simulation will be conducted in the hottest day that represents the most frequent days over the hottest months in the year. From figure (8), the hottest month in Mosul city is July where the temperature reached 35.5 C°, while the most frequent hottest day over July is 13th of July (see Figure 9 and 10)



(a)



(b)

Figure 8: Selecting the day of simulation

(a-The hottest month in the year, b- The most frequent days in July)

8.2 Step two: Selecting the construction materials (preparatory step)

In order to conduct the simulations, it is necessary to select building materials. This preliminary study identifies the alternative construction materials that are produced and manufactured in the world generally and in France especially, that can be used in Al Hadba Residential Complex in Mosul city. These materials are: R. Concrete, H. W. Concrete, L.W. Concrete, Concrete/Straw, Concrete/Rubber R0, Concrete/Rubber R30, and pumice block.

Initial thermal performance classification of the selected building material:

Solene-microclimat can help to give initial perception of the thermal behaviour of the material by achieving assessment simulations with respect to climate conditions and location. The results of these assessments are given as Figure (8)

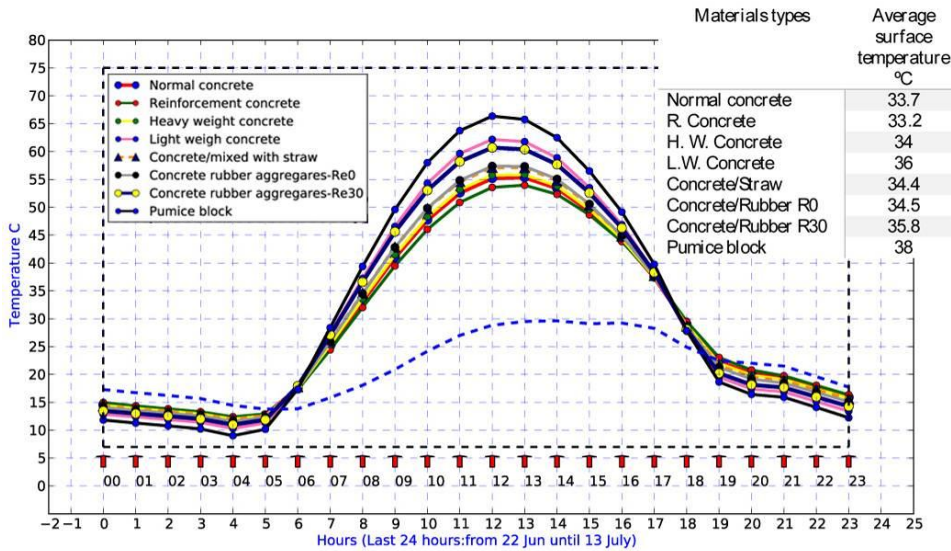


Figure 8: The Initial thermal performance assessment of difference type of materials

From these results, we can say that pumice block is a good insulation material, the surface temperature of which has reached high temperature compared with the rest materials. In another word, this material absorbed most of the solar radiation. On the contrary, the reinforcement concrete materials had low surface temperature compared with the rest. This material does not absorb the heat, which passes quickly into spaces. A result it affects the level of thermal comfort within the indoor space. These are preliminary estimations of surface temperatures. Now, what is the surface temperature ranges when we use these materials in the building? and how buildings will affect these ranges?

8.3 Step three: step of simulation (simulation step)

This represents the final step of simulation process, which will give us the final decision of materials type, with respect of climate condition and location (Iraq), geometry shape, special distribution of buildings. This simulation stage consists of 28 simulations, as given in diagram below, table 3.

Types of the wall	Simulation steps	Types of materials
Walls with thickness 12 cm	Simulation each types of the walls with all types of materials from 1-7	Reinforcement concrete
Walls with thickness 20 cm		Concrete/mixed with straw
		Ordinary concrete block
Cavity walls with air gap		Concrete rubber aggregates with radius 0
		Concrete rubber aggregates with radius 30
Cavity walls with rock-wall gap		Light weight concrete block
		Pumice block

Table 3: Types of walls and materials for simulation

9. Results and Analysis

The results showed that there is a clear difference between the external and internal surfaces temperature among each elevation (North, South, East, West elevation) which depends mainly on the amount of radiation falling on each elevation, which were North elevation=55 Watt/m², South elevation=390 Watt/m², East elevation=645 Watt/m², and West elevation 855 Watt/m². From that and as the result of the simulation the maximum surface temperature was in the western façade. Since there is some limitation related to number of

pages, this study only show the results related to the west elevation and for pumice block wall, and with thickness 20 cm, but it will be discussed all the findings related to other types of the wall and other materials, (Figures 10).

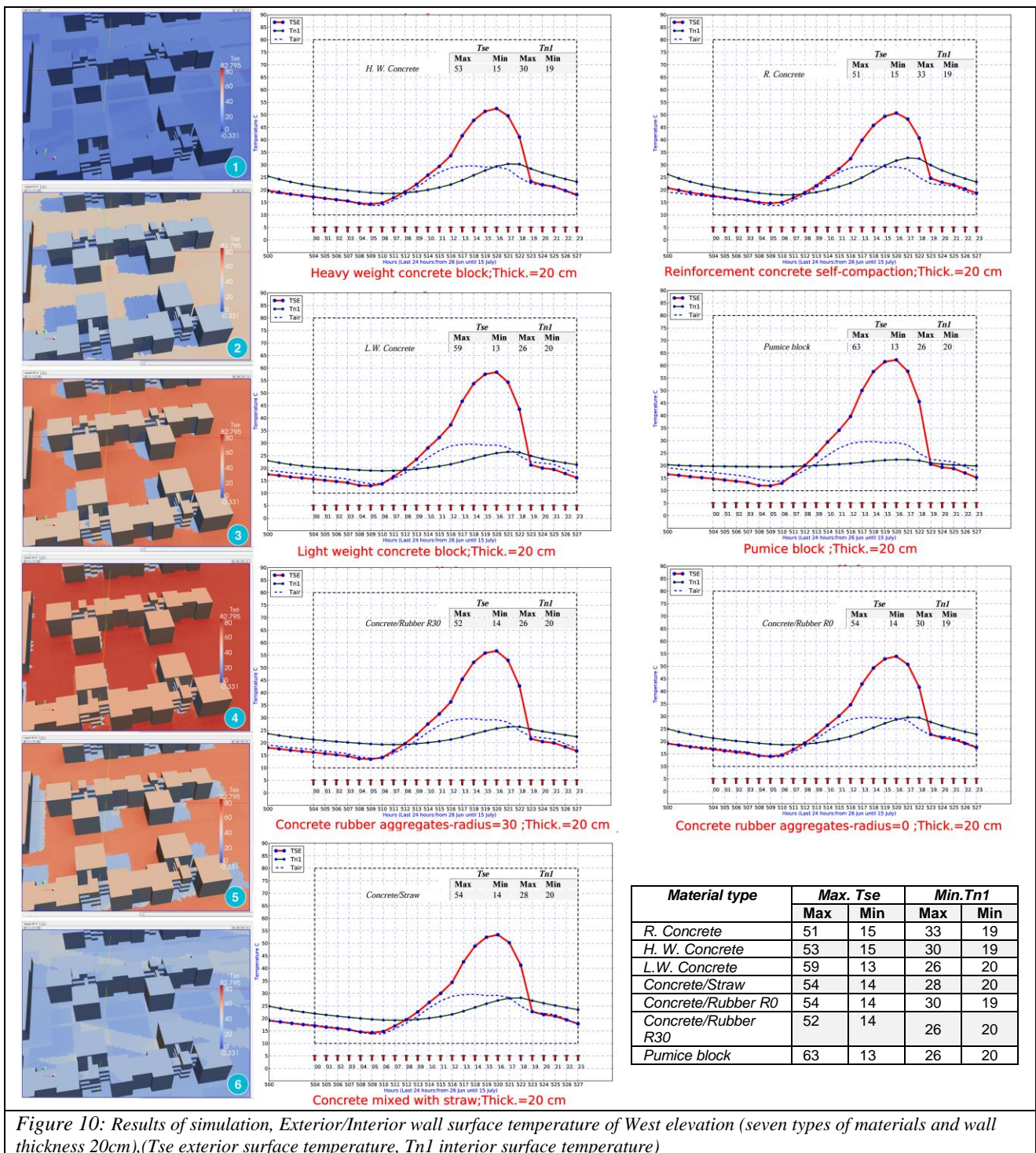


Figure 10: Results of simulation, Exterior/Interior wall surface temperature of West elevation (seven types of materials and wall thickness 20cm),(Tse exterior surface temperature, Tni interior surface temperature)

The final results of this simulation for all walls types and all materials types can be in two categories:
 -One, results that are related with the wall design.
 -Two, results that are related with the type of material.

The results have proved that the thickness of the wall not always affects the temperature of the external and internal surfaces. It depends on the type of wall materials and the components of the wall layers, for more clarification:

9.1 The effect of the wall thickness

When we use heavy weight concrete block material, we found that the thickness has a significant effect on the ability of the wall to conduct the heat from exterior surface to interior surface, thick walls reduce the ability of heat to pass through it or in other words, increase the lag time [10]. As a result, the interior surface temperature of thick wall (20cm) will be lower than the one of the walls with a lower thickness (12cm), where it reached, sequentially, 30°C, 36°C at 17h:00. On the contrary, the external surface temperature of thick wall will be higher than the one of walls of lower thickness, where it reached ,sequentially, 52°C,50°C at 16h00 (see figure 11).

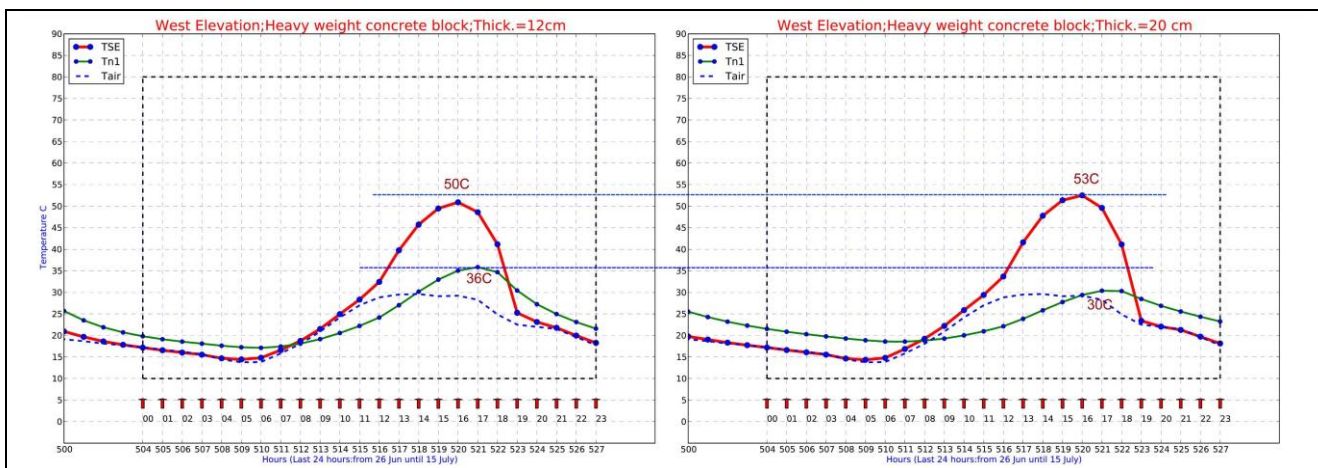


Figure 11. Comparative external and internal surface temperature of heavy weight concrete block wall with thickness 12cm and 20cm

But for pumice block the situation will be different, where the thickness of the wall has no significant effect on the external and internal temperature of the wall or in other words, the lag time is very tight, where the interior surface temperature at 16h:00 reached 22°C for wall 20cm, and 20°C for wall 12cm. While the exterior surface temperature at 16h:00 reached 62°C for wall 20cm and 60°C for wall 12cm (see Figure 12).

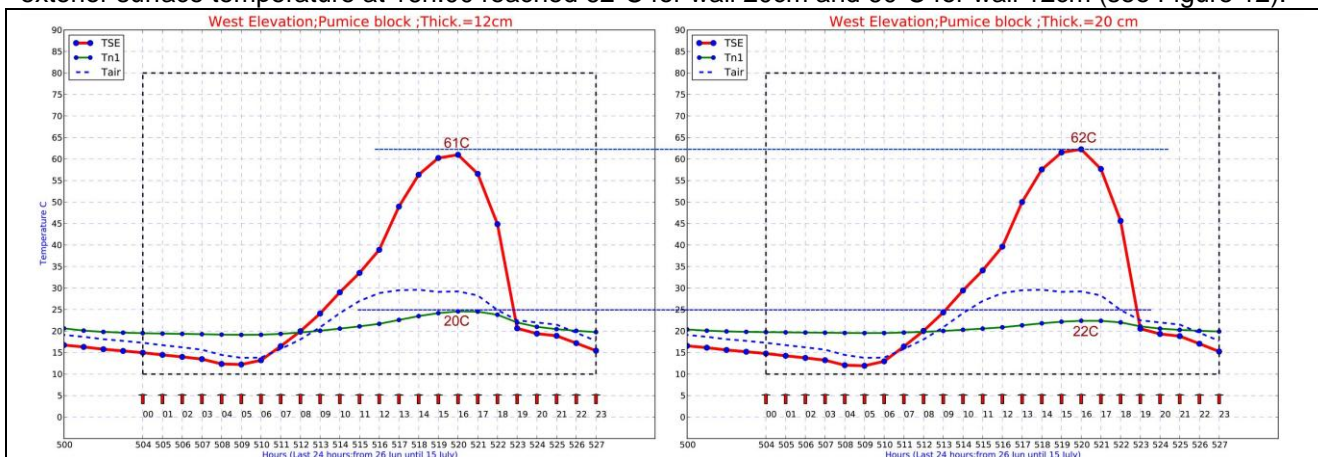


Figure 12. Comparative external and internal surface temperature of heavy weight concrete block wall with thickness 20cm and pumice block wall with thickness 12

9.2 The effect of the wall layers

In this case also we can say that in some cases there is no difference in thermal behaviour between the normal type of the wall and cavity wall, which it depends on the materials that will be used.

Now, when comparing the walls with one layer, and air/cavity wall (heavy weight concrete block materials – air - heavy weight concrete block materials), we found that there are ability to increase the thermal insulation

of the walls by using cavity wall, where the interior surface temperature reached 21°C at 17h:00 for cavity wall, and 36°C at 17h:00 for wall 12cm. While the exterior surface temperature reached 62°C at 16h:00 for cavity wall and 50°C at 17h:00 for wall 12cm (see Figure 13).

But when changing the wall materials from heavy weight concrete block materials to pumice block materials (pumice – air – pumice) the situation is different: we find that there is no effect due to the number of layers, (see Figure 14).

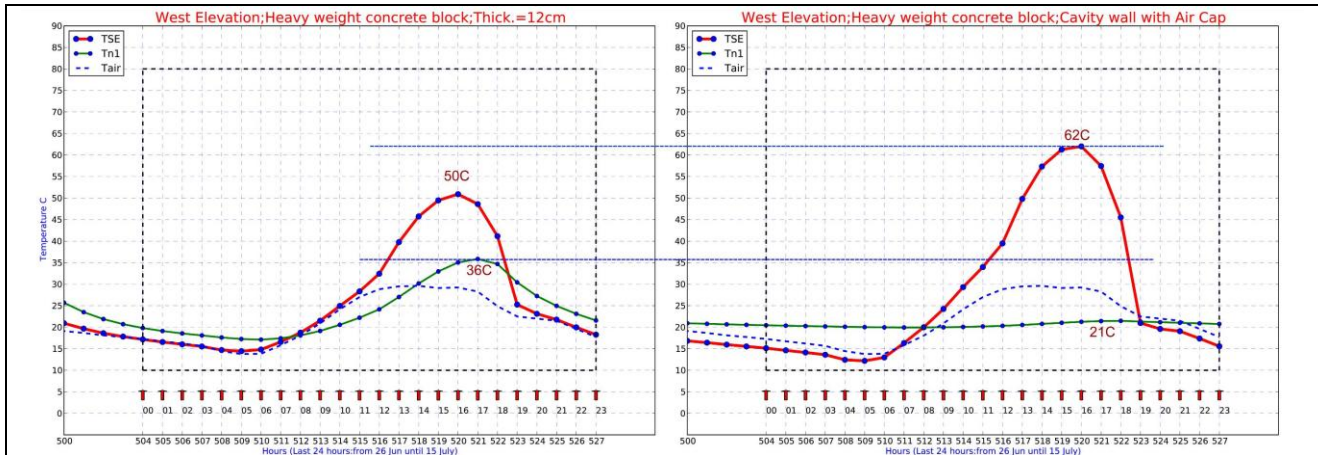


Figure 13. Comparative external and internal surface temperature of heavy weight concrete block wall with thickness 20 cm and heavy weight concrete block air/cavity wall.

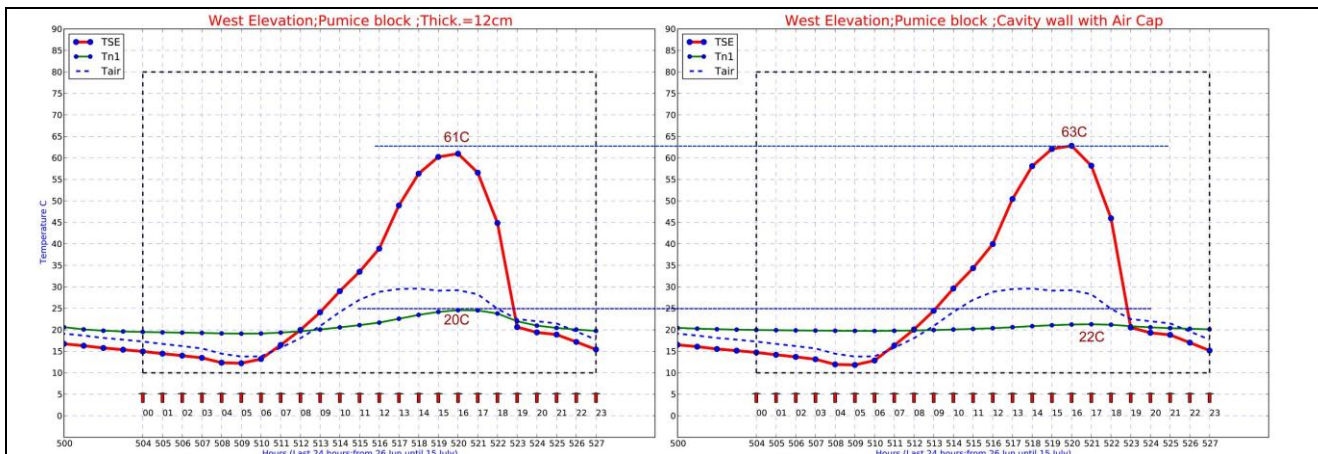


Figure 14. Comparative external and internal surface temperature of pumice block wall with thickness 12 cm and heavy weight concrete block air/cavity wall

10. The conclusion

The conclusion of this study consist of two parts:

Relating Solene-microclimat, it has proven its capabilities in achieving the goals of the study, which include calculation of surfaces walls exterior/internal temperature.

Relating building materials; I can say that the main effect on the wall thermal behavior is material selection, where it depends mainly on the thermal effusivity. Where thermal effusivity, is the capacity of a material to store heat and give it back later. It is the square root of the product of thermal conductivity, density and thermal capacity.

For any materials there are two possibilities: First possibility, materials lead to reduce the external surfaces' temperature but adversely affected the indoor surfaces' temperature and thermal comfort such as heavy weight concrete block materials. So we need to find some ways to maintain thermal comfort inside building spaces, e.g. air conditioning. Second possibility, materials lead to reduce the internal surfaces' temperature and finally maintain indoor thermal comfort such as a pumice block. So we need to find some methods to reduce the external surfaces' temperature such as using double wall, green wall and roof, shade and shadow and high value of albedo.

Finally and after having compared the results, this study will select pumice block materials, where this material has lower thermal effusivity, therefore, it helps me to make the surface temperature of the internal wall at a lower level, and finally leads to reduce the energy needed to maintain the air temperature inside the spaces at the comfort level.

For reduce the external surfaces temperature; as a mentioned above; there are many strategies can follow

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