Numerical Simulation of Underground Thermal Energy Storage Application in Universitary Buildings in Summer Conditions

Eusébio Z. E. Conceição and Hazim B. Awbi

Abstract—In this numerical simulation the Building Dynamic Software is used in an application of underground thermal energy storage in a university building with complex topology. The numerical simulation is made in summer conditions with mediterranean environment. In this numerical simulation, the passive and active solar strategies are considered. Building Dynamic Software calculates the air temperature of the spaces, the surface temperature of opaque bodies, transparent bodies and internal bodies, the mass of contaminants and water inside the spaces and in the surfaces, the thermal comfort and air quality and the energy transport and consumption. The university building is divided into 319 spaces, distributed by four floors, and is composed by 329 transparent surfaces (windows) and 3585 opaque surfaces (internal and external walls, doors, and others). Below the ground floor is considered, numerically, an underground floor, with the same area of the building and with a typical floor height, used to thermal energy storage. The building internal airflow, during the day, transport the airflow from the underground to uncomfortable spaces. In the morning, the airflow is transported to spaces turned to East and in the afternoon the airflow is transported to spaces turned to West. However, all day the airflow is transported to spaces turned south. A numerical simulation without and with underground thermal energy storage is made. In the numerical simulation the occupation and the internal ventilation are considered. In accordance with the obtained results the internal airflow rate used and the external air temperature during the day and the night, guarantee the underground thermal energy storage to cool the more uncomfortable spaces. The air quality is acceptable and the thermal comfort level, considering the adaptive concepts, guarantee levels near the suggested by the standards.

Keywords— Building Dymamic Software; Undeground Space; Thermal Energy Storage; Thermal Comfort, Indoor air quality.

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I. Introduction

Different techniques to cool or warm the building indoor space using application of renewable energy were developed in the last years by several authors. In the present work the application of renewable energy are used to cold the internal spaces using undergraduate thermal energy storage. This technique, using underground spaces, consider adapted ventilation in the night, using low external air temperature to cool the air in the underground spaces, and day, using low air temperature in the underground spaces to cool the air in the occupied spaces.

Some authors developed some studies using the cold thermal energy storage concept. The benefits and operating strategies of cold thermal energy storage technologies can be analysed in Kosi et al. [1] and the thermal energy storage of either heat and either cold to be used afterward can be analysed in Cabeza [2].

In this study the underground thermal energy storage is analysed numerically, using a Building Dynamic Software developed by the authors in the last decade. This software was applied mainly to develop more occupied spaces being more comfortable with more efficient consumption levels. In vehicles, as example, in Conceição et al. [3], or in buildings, as example, in Conceição *et al.* [4], Conceição and Lúcio [5], Conceição and Lúcio [6], Conceição *et al.* [7], Conceição *et al.* [8], are some examples of application of development of more comfortable occupied spaces. Conceição and Lúcio [5] and Conceição and Lúcio [6] analyzed the shading devices and the solar radiation. Conceição *et al.* [7], Conceição *et al.* [3], Conceição *et al.* [4] and Conceição *et al.* [8] analysed the thermal comfort and air quality in vehicles and buildings.

The thermal comfort level, developed by Fanger [9] and presented in ANSI/ASHRAE Standard 55 [10] and ISO 7730 [11], using PMV (Predicted Mean Vote) and the PPD (Predicted Percentage of Dissatisfied) indexes, consider the environmental variables (indoor air temperature, indoor air velocity, indoor air relative humidity and Mean Radiant Temperature) and personal parameters (clothing level and activity level). This philosophy was used by the Buildings Dynamics Software, in an integral philosophy, or used by the coupling of the Human thermal Response and Computational Fluids Dynamics, in a detailed evaluation.

In the first one, in an integral philosophy, Conceição *et al.* [4], Conceição and Lúcio [5] and Conceição and Lúcio [6]

applied the Building Dynamics Software which uses the integral PMV and the PPD indexes to evaluate the comfort level that all people are subjected.

In the second one, using the coupling philosophy, Conceição and Lúcio [12], Conceição e Lúcio [13], Conceição *et al.* [16] and Conceição *et al.* [15] use the same index to evaluate the thermal comfort level that each occupant is subjected. In Conceição and Lúcio [12], Conceição and Lúcio [13] and Conceição *et al.* [16], as example, the Human Thermal Response is used. Conceição *et al.* [14], as example, the coupling of two software, the Human Thermal Comfort and Computational Fluids Dynamics, are used. Finally, Conceição *et al.* [15], in a coupling of three software, the Human Thermal Comfort, Computational fluids Dynamics and Building Dynamic software are used.

The PMV and PPD indexes were developed to be used in spaces equipped with Heating, Ventilating and Air-Conditioning system (see Fanger [9]). The concept of adaptive thermal comfort level, developed for spaces not equipped with Heating, Ventilating and Air-Conditioning system, were presented, as example, by Yang *et al.* [16], Yao *et al.* [17] and Conceição *et al.* [18]. Fanger and Toftum [19], also for spaces not equipped with Heating, Ventilating and Air-Conditioning system, developed a extension of the PMV model to be used in warm climates. Other similar models and studies, developed to be used in spaces equipped with Heating, Ventilating and Air-Conditioning system, are presented in models as Conceição *et al.* [20], using a preferred air temperature, and Conceição *et al.* [21], using a control based in PMV index.

In order to evaluate the indoor air quality, that the occupants are subjected, the carbon dioxide concentration is used (see ASHRAE 65 [22] and D.L. [23]). However, the airflow rate, the age of the air or the air exchange rate, can be also used. Examples of these applications scan be seen in Conceição *et al.* [24] or in Conceição *et al.* [25].

In this numerical simulation the Building Dynamic Software is used in an application of underground thermal energy storage in a university building with complex topology. The numerical simulation is made in summer conditions with mediterranean environment. In this numerical simulation, using passive and active solar strategies, the underground thermal energy storage is considered.

II.   Numerical Model

The Building Dynamic Software, using data from Computational Aid Design, generate a system of energy and mass balance integral equations used to calculate not only the air temperature of the spaces, the surface temperature of opaque bodies, transparent bodies and internal bodies, but also the mass of contaminants and water inside the spaces and in the surfaces. The software also calculates the thermal comfort, the air quality and the energy transport and consumption.

More details about this Building Dynamics Software can be analysed in Conceição *et al.* [26]. Some applications can be seen in Conceição *et al.* [4], Conceição and Lúcio [5] and Conceição and Lúcio [6].

III.   Numerical Metodology

The numerical study was developed in a university building, mainly consisting of classrooms, laboratories, offices and other spaces. The building is divided into 319 spaces, distributed by four floors, and is composed by 329 transparent surfaces (windows) and 3585 opaque surfaces (internal and external walls, doors, and others).

The study is made in summer conditions and two cases are considered:

- Without underground thermal energy storage;

- With underground thermal energy storage;

Below the ground floor is numerically considered an underground floor, with the same area of the building and with a typical floor height, used to thermal energy storage. In internal building, during the day, airflow is transported from underground spaces to uncomfortable spaces. In the morning the airflow is transported to spaces turned to East and in the afternoon the airflow is transported to spaces turned to West. However, during all day the airflow is also transported to spaces turned south.

Perspective of the university building and internal structure of the university building considered in the study are presented in Figures 1 and 2, respectively. In Figure 1 the external details are presented, while in Figure 2 the external and internal details are presented.
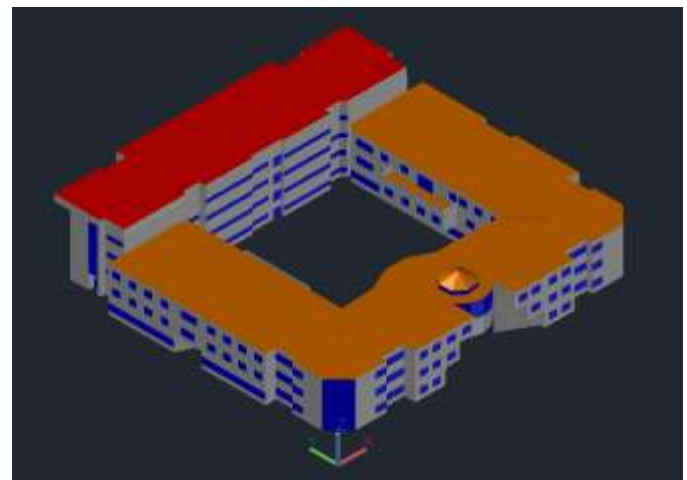

Figure 1.   Perspective of the university building considered in the study.

In these Figures the colours are associated to:

- in grey are represented the interior and exterior walls;

- in blue are represented the windows;

- in green are represented the doors;

- in orange are represented the plates;
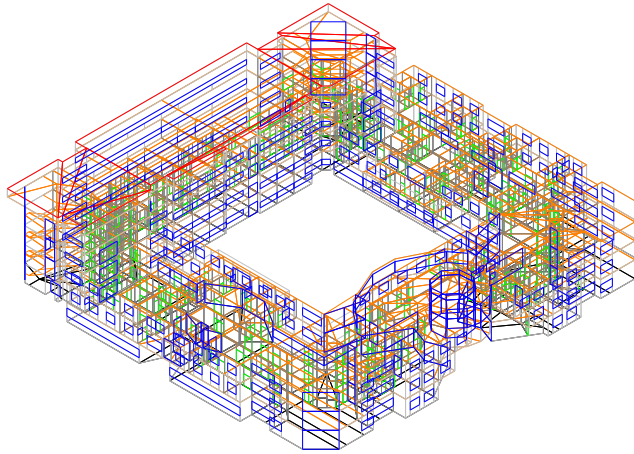
- in red are represented the roofs.

Figure 2.   Internal structure of the university building considered in the study.

IV.   Results and Discussion

A numerical simulation without and with underground thermal energy storage is made. In the numerical simulation the solar passive, using the underground thermal energy storage, and active, with internal ventilation, are considered.

In this numerical simulation, summer conditions are considered. In the simulations the evolution of internal air temperature (Tair), thermal comfort level (PMV), using the PMV index, and carbon dioxide concentration (CO_2), using carbon dioxide concentration, are presented.

In the following figures the W is associated to the situation without underground space, while the U is associated to situation with underground space.

In Figures 3 and 4 the evolution of air temperature in the first floor, in compartments with windows turned, respectively, to East and West, in summer conditions, when are used underground spaces, are presented.

The air from the cold underground (space number 1), located below the building ground floor level, is transferred, in each building floor level, to spaces with windows turned to East, West and South. In the present work, in the first floor, only are showed results for spaces with windows turned to East, as example:

- space 48 (office with window turn East);
- space 50 (office with window turn East);
- space 51 (laboratory with window turn East);
- space 52 (laboratory with window turn East)

And spaces with windows turned to East, as example:

- spaces 2 (office with window turned West);
- spaces 11 (classroom with window turned West);
- spaces 41 (office with window turned West).

In general, the underground space decreases around 3 ℃ the air temperature, during the day, while the occupied spaces decrease, in general, 1 to 2 ℃ the air temperature. It is possible to decrease more the air temperature in the occupied space, however, it is necessary to increase the airflow rate.
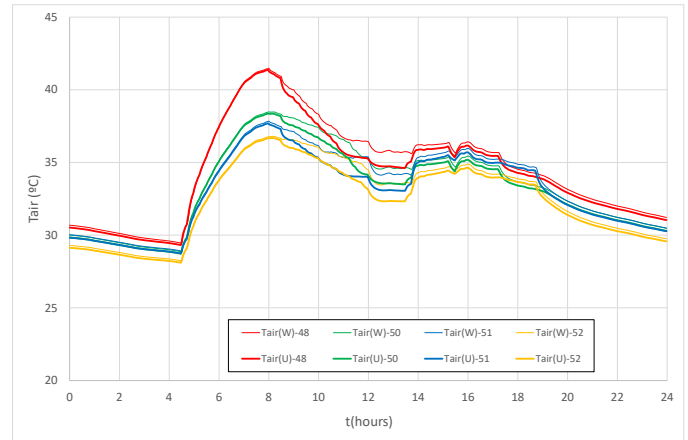

Figure 3.   Evolution of air temperature in the first floor, in compartments with windows turned East, in summer conditions, when are used underground spaces.
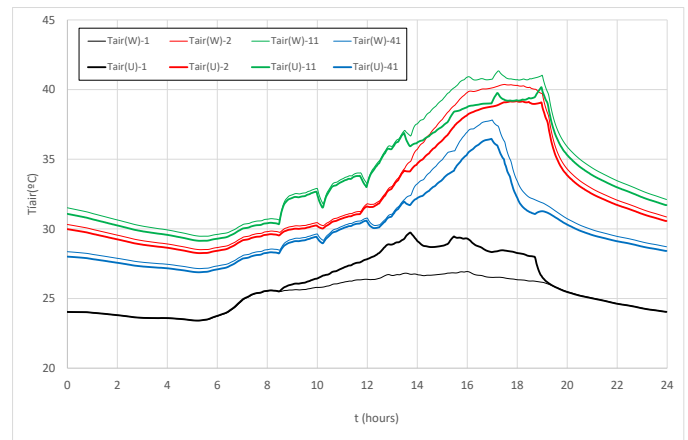

Figure 4.   Evolution of air temperature in the first floor, in compartments with windows turned West, in summer conditions, when are used underground spaces.

The evolution of PMV index, in the first floor level, in compartments with windows turned East and West, respectively, in summer conditions, when are used underground spaces, are present in figure 5 and 6.

In these figures the extension of the PMV model, developed in Fanger and Toftum [19], to spaces not equipped with Air Conditioning system, in warm climates, are considered.

In the present situation, the thermal comfort level that the occupants are subjected is not acceptable, in accordance with the category C of the ANSI/ASHRAE Standard 55 [10] and ISO 7730 [11]. However, the thermal comfort level are near

the standard recommendation. The air temperature level, that the underground space is subjected, although nor to be occupied, guarantee acceptable thermal comfort levels.
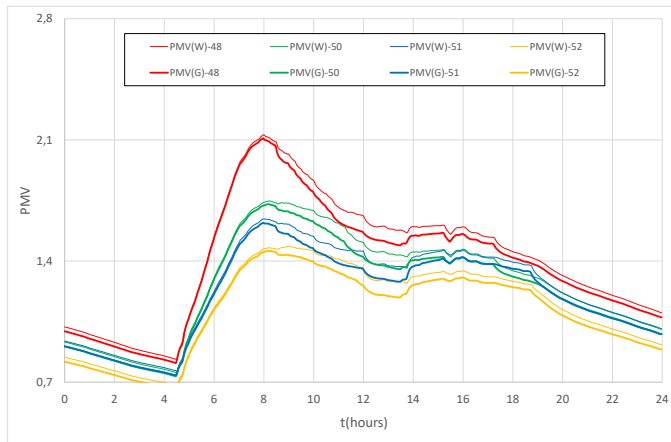

Figure 5.   Evolution of PMV index in the first floor, in compartments with windows turned East, in summer conditions, when are used underground spaces.
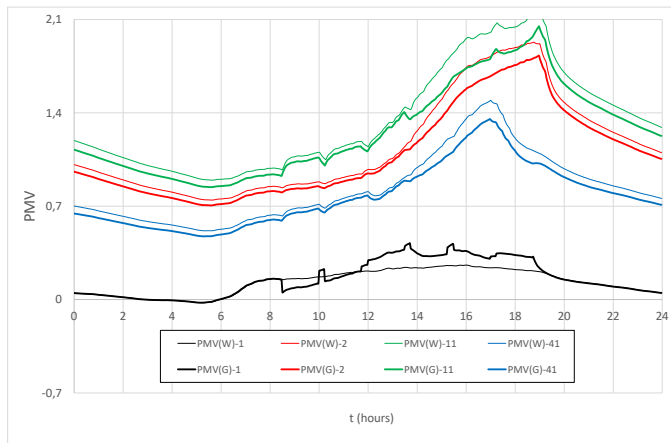

Figure 6.   Evolution of PMV index in the first floor, in compartments with windows turned West, in summer conditions, when are used underground spaces.
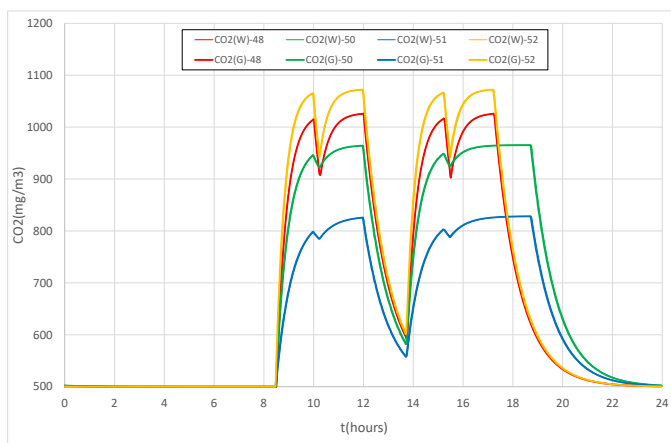

Figure 7.   Evolution of Carbon Dioxide concentration in the first floor, in compartments with windows turned East, in summer conditions, when are used underground spaces.
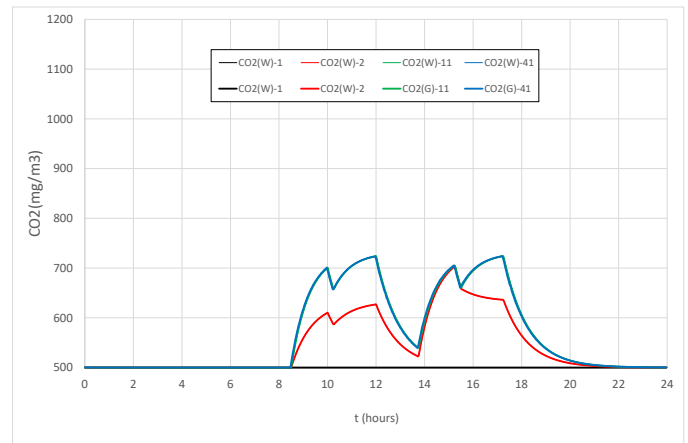

Figure 8.   Evolution of Carbon Dioxide concentration in the first floor, in compartments with windows turned West, in summer conditions, when are used underground spaces.

In Figures 7 and 8 the evolution of Carbon Dioxide concentration in the first floor, in compartments with windows turned East and West, respectively, in summer conditions, when are used underground spaces, is presented.

In accordance with the obtained results the indoor air quality are acceptable in accordance with the ASHRAE 65 [22] and D.L. [23] recommendations.

V.   Conclusions

In this study a numerical simulation of underground thermal energy storage application in universitary buildings in summer conditions is made. A simulation without and with underground thermal energy storage is made.

The underground space decreases, during the day, around 3 ºC the air temperature, while the occupied spaces decrease, in general, 1 to 2 ºC the air temperature.

The thermal comfort level, that the occupants are subjected, is not acceptable, however, the thermal comfort level are near the standard recommendation.

The indoor air quality are acceptable in accordance with the standard recommendations.

In future works is suggested to increase the airflow rate from the underground space to the occupied spaces, in order to transport more energy to cold the occupied spaces. However, is necessary to analyse if the underground space cooling, verified in the night, is sufficient to compensate the underground space warmed, verified during the day.

Acknowledgment

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