International Journal of Engineering and Technology, Vol. 15, No. 2, May 2023

Physical Modeling for Thermal Proposal Validation (TES) in Lima Offices with Air Conditioning

Washington Rojas Casaverde*, Angel De La Torre Galdo, Ada L. Arancibia Samaniego, and Rubén Esaú Mogrovejo Gutiérrez

***Abstract*—Climate change adaptation measures are demanding the use of technologies that promote energy saving. The search for thermal comfort has encouraged the use of technologies such as the TES tank (Tank Energy System). This article presents the validation of the results obtained in the CFD simulation of a TES tank, through an evaluation of the model at 1/25 scale, to corroborate the thermal resistance of the tank whit thermal conductivity of 1.63 W/m. °K and expanded polystyrene with thermal conductivity of 0.036 W/m°K for both the walls and the lid. The circular TES tank designed guarantees, in addition to adequate thermal resistance, impermeability and durability so that it can function correctly during temperature measurements. In the model, the thermal resistance of the tank was corroborated, by obtaining an increase in the temperature of the temperature of the water in 8 hours of 7 °C (12.6 °F). That is, from 5.9 °C (42.62 °F) to 12.9 °C (55.22 °F), which does not exceed 15 °C (59 °F), the recommended value for its viability.**

***Index Terms*—Energy, thermal, TES, construction, climate, LEED, climate adaptation**

I. INTRODUCTION

Thermal comfort in office buildings requires a high consumption of electrical energy, which impacts the generation of greenhouse gases. Office buildings. Thermal comfort in office buildings requires a high consumption of electrical energy, which impacts the generation of greenhouse gases. Office buildings have been estimated to account for about 18.9% of energy consumption and 19.6% of total greenhouse gas emissions in the United States [1, 2]. Effective solutions can make buildings welcoming to hot climates to curb rising Greenhouse Gas (GHG) emissions and make energy use more efficient. There is an energy saving potential of between 50 and 90% in new and existing buildings [3].

To reduce energy consumption in buildings and, consequently, reduce greenhouse gas emissions, the Tank System (TES) is proposed with measures in accordance with the Chiller cooling plant of the air conditioning system. Only a few research efforts have focused on quantifying potential energy savings from integrating occupant needs into building systems [4, 5].

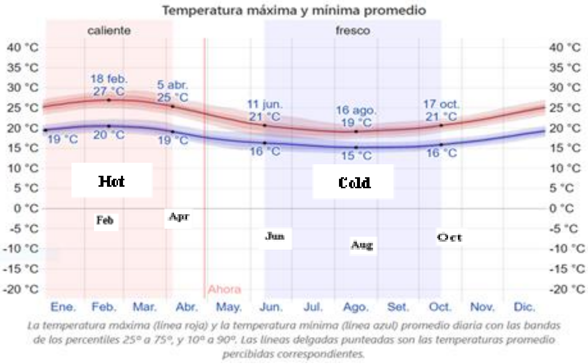
TES systems are energy storage tanks in the form of frozen water, which are widely used in the United States and Europe to store water in a period of 8 hours, obtaining at the end of the operation a term increase of just 7° C (12.6 °F).

The administration of office buildings generally allocates a monthly budget to be able to cover the electricity costs of the Air Conditioning systems in summer. To solve the problem of office buildings in Metropolitan Lima and to be able to carry out the investigation, the implementation study of a water energy storage tank (TES) with polystyrene insulation will be carried out.

The increase in temperatures is reflected in the radiation to which buildings are subjected during the period of highest temperature from January to March in Metropolitan Lima. These tend to increase the use of air conditioning systems. This situation occurs frequently in cities like Lima, since the average annual temperature rises to 27 °C (80.6 °F).

The temperature in Lima in the year 2021, in the hot season lasts for 3 months, from January 3 to April 5, with an average daily maximum temperature above 24 °C (75.2 °F). The hottest day of the year is February 18, with an average maximum temperature of 27 °C (80.6 °F) and an average minimum temperature of 20 °C (68 °F). The cool season lasts for 4.2 months, from June 11 to October 17, with an average daily high temperature below 21 °C (69.8 °F). The coldest day of the year is August 16, with an average minimum temperature of 15 °C (59 °F) and an average maximum of 19 °C (66.2 °F). As the following Fig. 1 shows.

Average Maximum and Minimum



La temperatura máxima (línea roja) y la temperatura mínima (línea azul) promedio diaria con las bandas de los percentiles 25º a 75º, y 10º a 90º. Las líneas delgadas punteadas son las temperaturas promedio percibidas correspondientes.

Fig. 1. Average maximum and minimum temperature.

District Cooling type cooling systems provide a centralized solution to provide thermal comfort to an entire district, these District Cooling are chilled water production plants that drive cold water to the premises through underground pipes. Although it is true that this solution provided citizens with significant savings in energy consumption, currently the work is focused not only on the generation of cold, but also on its management. One of the most outstanding solutions is the incorporation of energy storage systems (TES, from the English Thermal Energy Storage) for cold, so that they are used as reservoirs where you store excess cooling energy (volumes of water at low

---

Manuscript received December 15, 2022; revised January 29, 2023; accepted March 17, 2023.

The authors are with Universidad Peruana de Ciencias Aplicadas (UPC), Peru. E-mail: u201424276@upc.edu.pe (A.D.L.T.G.); pcciadar@upc.edu.pe (A.L.A.S.); pciprmog@upc.edu.pe (R.E.M.G.)

*Correspondence: u20141a549@upc.edu.pe (W.R.C.)

DOI: 10.7763/IJET.2023.V15.1223

temperature) and extract it when needed. Among the advantages offered by these storage systems, the opportunity to make operating conditions more flexible, the design of smaller equipment, a more efficient use of the same, as well as the reduction of energy consumption stand out. In fact, by having an auxiliary system capable of storing excess cold, the oversizing of equipment to cope with periods of high demand is avoided.

In García and Máster's [6] study on the implementation of thermal energy storage systems in the form of cold water and ice for urban cooling, concludes that the production of night cold to be stored will be less in volume of frozen water since there will be priority to the direct production demanded by the network, thus reducing the power available to load the sensitive storage system. Once the TES system was implemented, a saving of 37% was obtained on the total opex. The cost in Euros of each item of OPEX operating expenses is shown below (Table I).

TABLE I: ENERGY CONSUMPTION

OPEX	
Electricity consumption of the summer system	€ 75,599.13
System electrical consumption Spring/Autumn	€ 35,384.21
Winter system electrical consumption	€ 19,199.07
Term Power Cost	€ 68,289.91
Chiller Maintenance + Icebat	€ 4,000.00
Water consumption (534 m3)	€ 907.80
TOTAL, OPEX	€ 203,380.11
Total Annual Electric Savings	€ 76,577.80

Finally, the research mentions that it would be beneficial to build a tank with concrete to be able to store large amounts of cold water.

Iten and Liu *et al.* [7] faced with the problem of knowing that thermal energy storage (TES) technologies incorporating Phase Change Materials (PCM) are proving to be a viable option to achieve energy efficiency. economically in buildings. This article reviews the application of air-PCMTES studies and technologies for free cooling and heating of buildings. In this review, the TES system in general and the air-PCM-TES in particular were analyzed. They indicate that the authors carry out extensive research on air-PCM-TES systems through passive and active methods and the advantages and disadvantages of each are detailed. To solve the problem, they investigated the thermal performance of these systems through experimental and numerical approaches and list it in their paper. Obtained as a result by the passive method, for example, with the use of PCM in the building envelope, they present difficulties in exchanging a high rate of heat and are therefore not suitable for extreme climates. Therefore, active methods for extreme weather were adopted to meet the demand. In general, when applied correctly, air-PCM-TES systems have been shown to effectively provide free cooling and heating to buildings through auxiliary sources.

In Gongora's [8] research work studied the mechanical, thermal and acoustic properties of a lightened mortar with Expanded Polystyrene Particles (EPS). The results obtained were compressive strength values of 5 MPa to 13 MPa. Thermal insulation valuesimproved up to 40%, obtaining an average thermal conductivity coefficient of 0.42±0.05 W/Mk.

Christoph and Ingo *et al.* [9] faced with the problem of seeing the lack of information that can contrast the difference between temporary and stationary energy storage systems for renewable use, developed an article that offers reviews of renewable and sustainable energy. They collected information from 31 locations in Europe that had TES systems to give their readers a futuristic perspective on these types of systems. The schematic designs they used for the comparative analysis are shown below (Fig. 2).

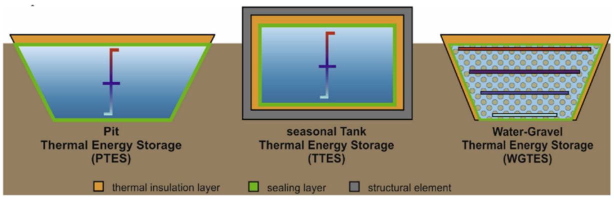


Fig. 1. Schematic designs they used for the comparative analysis.

This article concludes that the technology applied to seasonal TES systems has been advancing throughout this time, allowing each system to be adapted to the needs of each project. In addition, TES built on the ground is recommended, which require structural elements of steel-reinforced concrete to improve mechanical properties.

This article shows the physical modeling at scale for the thermal validation of the energy tank design proposal (TES) in air-conditioned office buildings. This generates a direct benefit for the end users of the offices by reducing electricity billing in summer.

With the use of the tank, there would be a potential saving of electrical energy in the air conditioning systems, since these systems represent the majority of energy use and greenhouse gas emissions (43% of the energy consumption of buildings). commercial). [1, 2], this being a measure of adaptation to climate change.

Finally, it has been possible to obtain an average heat transfer during the 8 hours of operation of 12.9 °C (55.22 °F), which complied with the permissible temperature variation (maximum temperature 15 °C (59 °F). It is recommended that the CFD model is parameterized to recreate temperature conditions variable environment, since only the highest critical temperature of 27 °C (80.6 °F) was considered.

II. MATERIALS AND METHODS

For this work, a physical model was developed to validate the mathematical model developed in CFD regarding the temperature increase in the design of the concrete and polystyrene TES tank. For this, the methodology was followed (Fig. 3):

It began with the determination of the optimal geometric scale. Given that very small models present difficulties in their manufacture and instrumentation, but large models are easier to build, they require equipment with greater capacity and demand more resources. The selected geometric scale is 1:25, since it has been considered what is established for modeling structures in plates [6]. Maintaining the thickness of the tank.

Fig. 2. Physical model flowchart.

Once the scale is determined, we proceed with the quantification of the construction materials, the construction of the model, installation in an open area (without roofs) with access for workability and measurements.

Once the construction process is finished, it proceeds with the filling with ice water and data recording of: internal temperature of the water, external temperature of the tank wall and ambient temperature. Data recording is considered on at least three occasions: immediately after filling with ice water, after four hours and after eight hours, as this is the maximum time that the water in a TES tank is stored.

Subsequently, the records will be compared with the results obtained from the CFD model of the TES tank. From the model it was obtained that the highest temperature recorded in the average heat transfer study during 8 hours of operation was 14.31 ºC (57.76 °F), a value that meets the permissible temperature variation to be efficient (maximum temperature 15 ºC (59 °F)).

The computational model was made up of a time-compromising thermal analysis.

Body heat transfer was used as the basis of the study. Convection and radiation heat transfer were considered. Each one listed for the characterization of the proposed materials.

For the discretization of the volumes of the 3D model, hexahedral elements were used, mostly, with an element size of 0.02m on average. A structured mesh was obtained for all the solids, in such a way that the number of nodes between the faces of the surfaces are approximately equal and are compatible with each other to calculate the information between volumes.

Finally, the iteration between the fluid and structure was considered to approximate the thermal calculation. Next, the results obtained by means of thermal and graphic images are attached (Fig. 4).

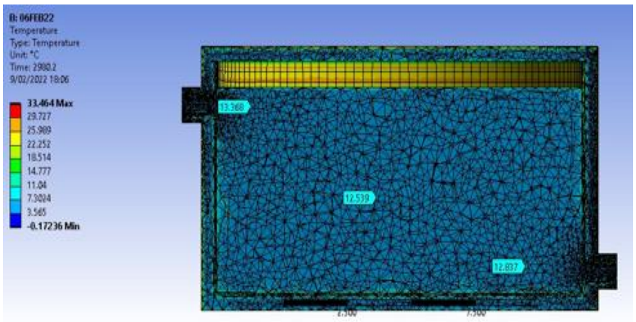


Fig. 3. CFD termal image on TES tank.

III. RESULTS

The tank has a water storage capacity of 0.024m3 (24 liters). The following temperature measurements were taken (Fig. 5):

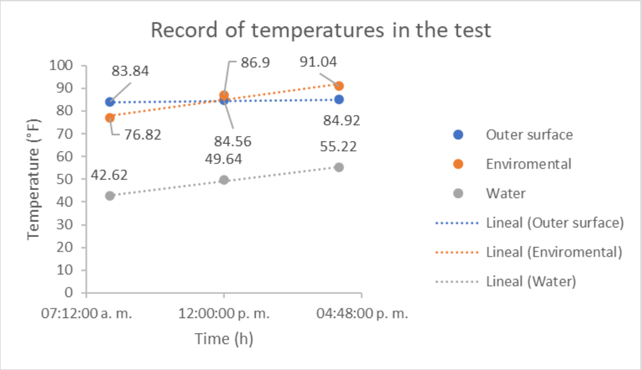


Fig. 4. Temperature in physical modeling.

It can be seen in the previous graph that the temperature of the external surface of the tank does not have much variation between 08:00 am and 4:00 pm, however the temperature of the environment does vary and even exceeds the temperature of the surface of the tank. 04:00 p.m (Table II).

TABLE II: TEMPERATURE IN MODELING

Hour/ Temp. °F	Environmental	Tank outer surface	Water
08:00 am	76.82	83.84	42.62
12:00 m	86.9	84.56	49.64
16:00 pm	91.04	84.92	55.22

IV. VALIDATION

The results of the physical model of the TES tank with water at a temperature of 5.9 °C (42.62 °F) at 08:00am being the outside ambient temperature 24.9 °C (76.82 °C) until reaching a maximum of 32.8 °C (91.04 °F) over the course of 8 hours. An increase in real temperature measured inside the water at 12.9 °C (55.22 °F) was observed (see Figs. 6–8).

Differences in results are due to differences in ambient temperature conditions as indicated in the Table III.

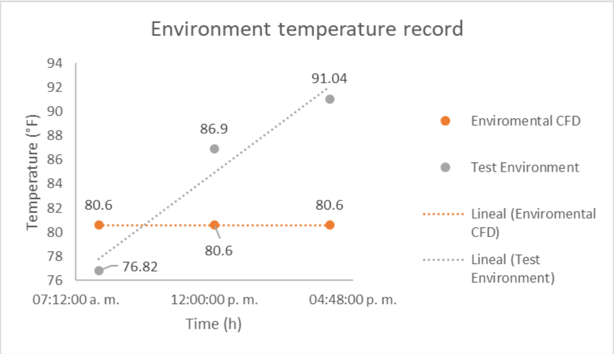


Fig. 5. Comparative ambient temperature in CFD.

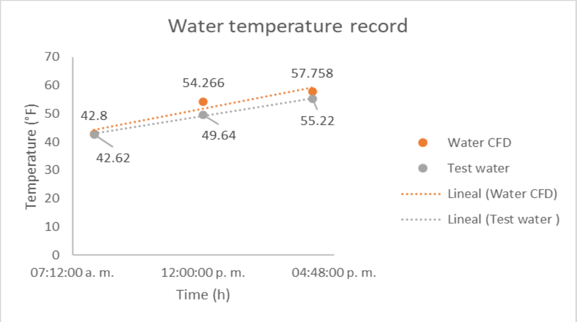


Fig. 6. Comparative water temperature in CFD and physical modeling.

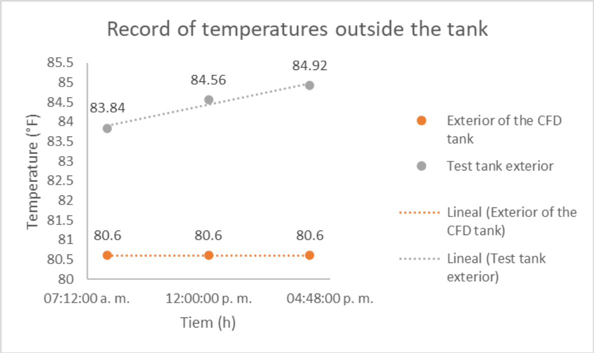


Fig. 7. Comparison of external wall temperature in CFD and physical modeling.

TABLE III: COMPARATIVE OF TEMPERATURE IN THE CFD AND PHYSICAL MODELING

Temperature (F°)	**Model CFD**	**Physical model**
Environment Home	80.60	76.82
Environment End	80.60	91.04
Water home	42.80	42.62
End water	57.76	55.22
Start external wall	80.60	83.84
External wall end	80.60	84.92

In addition to having considered the same wall thickness of the modeling. Despite the slight difference in the results, the functionality of the proposed design is validated since the condition of chilled water temperature loss in a period of 8 hours less than 15 °C (59° F) is met. In the graph of the water temperature record, a heat gain rate of 1.04 °C (1.87 °F) per hour in the CFD simulation and 0.875 °C (1.58 °F) per hour in the test is observed. The average ambient temperature of the test differs by +2.4°C (4.32 °F) from the CFD model. There is a relationship between the external temperature and the internal temperature variation thanks to the mechanical properties of the materials used to reduce the thermal transmission between the environment and the water.

V. CONCLUSIONS

The highest recorded water temperature in the average heat transfer test during the 8 hours of operation was 286.05 °K, which complies with the permissible temperature variation (maximum temperature 288.15 °K).

Easy to select materials for testing are commercial and construction.

The tests have been subjected to an external temperature greater than the CFD environmental conditions, despite this it has been possible to have an internal water temperature of less than 288.15 °K.

The total temperature increase of chilled water was 7° K and the rate of temperature increase of the water is 0.875 °K/hr.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

WR did the research, analyzed the data, wrote the article; ADT did the research, analyzed the data, wrote the article; RM reviewed the article; AA reviewed the article; all authors had approved the final version.

FUNDING

This work was supported in part by the professors of the Peruvian University of Applied Sciences (UPC) under the self-financing of the authors.

ACKNOWLEDGMENT

R. M. thanks for your unconditional support in revising the article; A. A. thank you for your unconditional support in revising the article.

REFERENCES

[1] Book BED, US Department of Energy, 2011.
[2] Emissions of Greenhouse Gases in the United States 2009, Distribution of total U.S. greenhouse gas emissions by end-use sector. (2011). U.S. Energy Information Administration. [Online]. Available: https://www.eia.gov/environment/emissions/ghg_report/pdf/0573%282009%29.pdf
[3] United States Business Council for Sustainable Development. (2014). Building for low-carbon future. [Online]. Available: https://www.usbcsd.org/news-articles/category/Energy+Efficiency
[4] X. Xu, P. J. Culligan, and J. E.Taylor, "Energy saving alignment strategy: achieving energy efficiency in urban buildings by matching occupant temperature preferences with a building's indoor thermal environment," *Appl Energy*, vol. 123, pp. 209–219, 2014.
[5] A. Ghahramani, F. Jazizadeh, and B. Becerik-Gerber "A knowledge-based approach for selecting energy-aware and comfort-driven HVAC temperature set points," *Energy Build*, vol. 85, pp. 536–548, 2014.
[6] J. A. W. Garcia and T. de F. de Máster, "Implementation study of thermal energy storage systems in the form of cold water and ice for district cooling," Polytechnic University of Madrid, 2019. (in Spanish)
[7] M. Iten, S. Liu, and A. Shukla, "A review on the air-PCM-TES application for free cooling and heating in the buildings," *ScienceDirect*, vol. 61, pp. 175–186, 2016, doi: https://doi.org/10.1016/j.rser.2016.03.007
[8] M. A. H. Góngora, "Mechanical, thermal and acoustic properties of a lightened mortar with recycled Expanded Polystyrene Particles (EPS) for wall and ceiling coverings," Yucatan Scientific Research Center, A.C. Postgraduate in Polymeric Materials, 2015. (in Spanish)
[9] B. Christoph, D. Ing, and B. Peter, "State-of-the-art review of closed seasonal thermal energy storage systems water based," *Elsevier*, vol. 113, 109241, 2019.
[10] A. E. R. Suesca, "Structural modeling for seismic loods," *Revista Facultad de Ingeniería*, UPTC, 2007.