UFSM

CIÊNCIA e NATURA

ISSN 2179-460X
OPEN ACCESS

Ci. e Nat., Santa Maria, v. 45, spe. n.3, e74572, p. 01-15, 2023 • https://doi.org/10.5902/2179460X74572
Submissão: 03/16/2023 • Aprovação: 04/10/2023 • Publicação: 12/01/2023

Special Edition

Numerical humidity assessment: analysis of the thermal performance of a residential building

Avaliação numérica da umidade: análise do desempenho térmico de uma edificação residencial

Michele Soares Netto[I], Ruth da Silva Brum[I], Cesar Antonio Oropesa Avellaneda[I], Joseane da Silva Porto[I], Taís Pereira da Silva[I]

[I] Universidade Federal de Pelotas, Pelotas, RS, Brazil

ABSTRACT

The earth-air heat exchanger (EAHE) is a device where the external ambient air is blown to use the ground as a heat source, through buried ducts with the aid of low power fans, thus powering the energy consumed in the building. The air at the outlet of the ducts is heated in winter and cooled in summer, providing thermal comfort conditions for indoor environments. The goal of the extensive search in recent decades has been to find solutions that can improve a building's thermal comfort in order to provide recommendations for the design of various devices utilized in the utilization of renewable energy sources. This work aims to evaluate the results found for humidity and air temperature in a building. The objective was to create a computational model that depicts practical operating circumstances for a building's ground-to-ground heat exchangers. These evaluations were carried out by numerical simulation with the EnergyPlus software, for which a meteorological file was created. To examine the building's behavior in various climates, the data are shown for two typical project days: one in the summer and one in the winter.

Keywords: Computer simulation; Thermal performance; Relative humidity; Earth-air heat exchanger (EAHE)

RESUMO

O trocador de calor terra-ar (TCSA) é um dispositivo onde o ar ambiente externo é soprado para usar o solo como fonte de calor, através de dutos enterrados com o auxílio de ventiladores de baixa potência, reduzindo assim a energia consumida na edificação. O ar na saída dos dutos é aquecido no inverno e resfriado no verão proporcionando condições de conforto térmico aos ambientes internos. Nas últimas décadas existe uma grande busca por tecnologias que possam auxiliar no conforto térmico das edificações com o objetivo de obter recomendações para o projeto de diferentes dispositivos empregados no aproveitamento de fontes de energia renováveis. Este trabalho tem como objetivo avaliar os resultados encontrados para a umidade e temperatura do ar de uma edificação. Buscou-se desenvolver um modelo computacional que represente condições realísticas de operação de trocadores de calor solo-ar em uma edificação. Essas avaliações foram realizadas por simulação numérica com o software EnergyPlus, para este foi criado um arquivo meteorológico. Os resultados são apresentados para dois dias típicos de projeto, um no verão e outro no inverno, a fim de comparar o comportamento da edificação em diferentes climas.

Palavras-chave: Simulação computacional; Desempenho térmico; Umidade relativa; Trocador de calor solo-ar (TCSA)

1 INTRODUCTION

In buildings, a comfortable temperature is desired on both hot and cold days. Thermal comfort is necessary for the person in the surroundings since it can interfere with certain activities, like working, studying, or relaxing. When an occupier experiences neither heat nor cold, thermal comfort has been reached. According to ASHRAE (2017), thermal comfort is the subjectively defined mental state that demonstrates contentment with the external thermal environment. Its standards are established by combining personal and internal environmental factors, guaranteeing comfortable conditions for the room's occupants, mostly local.

Cândido et al. (2010) suggest that utilizing natural ventilation in buildings can be a successful approach for achieving high levels of thermal comfort. Natural ventilation is the path taken by airflow inside environments as a result of the pressure difference that is created on certain surfaces.

The process of selecting building materials is crucial since the materials utilized in the building's construction also have a major impact on improving thermal comfort. The porosity of construction materials allows them to either emit or absorb water vapor into the atmosphere (Bénard et al., 2005). Ambient air temperature and relative humidity affect user comfort, air quality, heating performance and also the durability of the building material.

The building under study was built with existing materials in the region and reused materials, coming from demolitions of other works. Built for experimental studies, the building is located in the city of Viamão/RS, it is called the Ventura house described in the work of Vaz et al. (2011).

The development of air conditioning systems is concerned with improving the space required for installation and energy efficiency, aiming to reduce costs. A building becomes more energy efficient when it presents better or the same environmental conditions for its occupants, with lower energy consumption (Lamberts, Dutra, & Pereira, 2014).

To help with a better selection of building materials, thermal performance studies is crucial. So that, whatever the standard of the building, it can be built with the appropriate ambient temperature, regardless of external temperatures, managing to meet the needs of the client and the construction site.

The behavior of the building that is being designed can be predicted via computer simulation. Becoming a widely used alternative to evaluate the thermal performance of a building, aiming to improve it or increase its reliability. The EnergyPlus software is a world-renowned computational thermal simulator for buildings, it is normally applied to evaluate the thermal behavior of buildings. It estimates boundary conditions and is based on numerical methods seeking to provide approximate solutions for a real model (EnergyPlus, 2022). The basic EnergyPlus model calculates transient heat conduction through the layer of homogeneous material with surfaces of constant thermal properties, Goffart, Rabouille and Mendes (2017); Strand (1995).

Computer simulators can also be used to generate indoor climate data. A building simulation is developed to predict the climate inside the building for different climatic conditions, building characteristics and user behaviors, Crawley et al. (2001). These tools yield data that are relevant to a particular model in that area, but they can also be helpful for examining a building's overall performance by utilizing the city's climate record.

Air and soil temperatures follow periodic phase change patterns throughout the year, devices such as earth-air heat exchangers (EAHEs) take advantage of this phenomenon using buried ducts, where air is blown to use the soil as a heat source or sinkhole (Nóbrega et al., 2020). In this way, the air leaving the ducts is heated in winter and cooled in summer. Moreover, EAHE uses low power fans, which lowers the building's energy usage.

Studies developed in recent years have shown high thermal potential for EAHE installations (Vaz, 2011; Vaz et al. 2011, 2014), also estimated by models developed in Brum (2013); Brum et al. (2012, 2013). Aims of recent study have included analyzing its construction parameters (Brum et al., 2016); and improving its performance utilizing numerous pipes (Rodrigues et al., 2015; Brum, 2016; Brum et al., 2017, 2019b); Brum, Labat and Lorente (2019a). Work carried out by Estrada et al. (2018) presents the efficiency of EAHEs in several regions of Brazil, demonstrating that tropical climates are also a good option for installing EAHEs. In the work of Brum et al. (2016, 2019b) presented results from the use of multiple ducts. More recent research by Nóbrega et al. (2020) and Domingues et al. (2021) demonstrates analytical models for EAHE in Pelotas and Rio Grande, two cities in Rio Grande do Sul's southern region.

This study develops a realistic model of an earth-air heat exchanger coupled to a building. Seeking to evaluate the air temperature and humidity inside and outside this building. We aim to assess the findings for a building's humidity and air temperature through computer simulations with the EnergyPlus software, utilizing a meteorological file made specifically for this study.

2 PROBLEM DESCRIPTION

The simulation utilized a climate dataset from the city of Viamão, with latitude of-30.04° and longitude of -51.91°. The file covered a yearly period starting in 2007. For the purpose of this research, a yearly climate file was constructed in 2020 using reanalysis based on climate data obtained from ERA5 belonging to the European Center for Medium-Range Weather Forecasts. The input file used in EnergyPlus contains the following parameters: dry bulb temperature, precipitation, relative humidity, atmospheric pressure, dew point temperature, wind direction and wind speed.

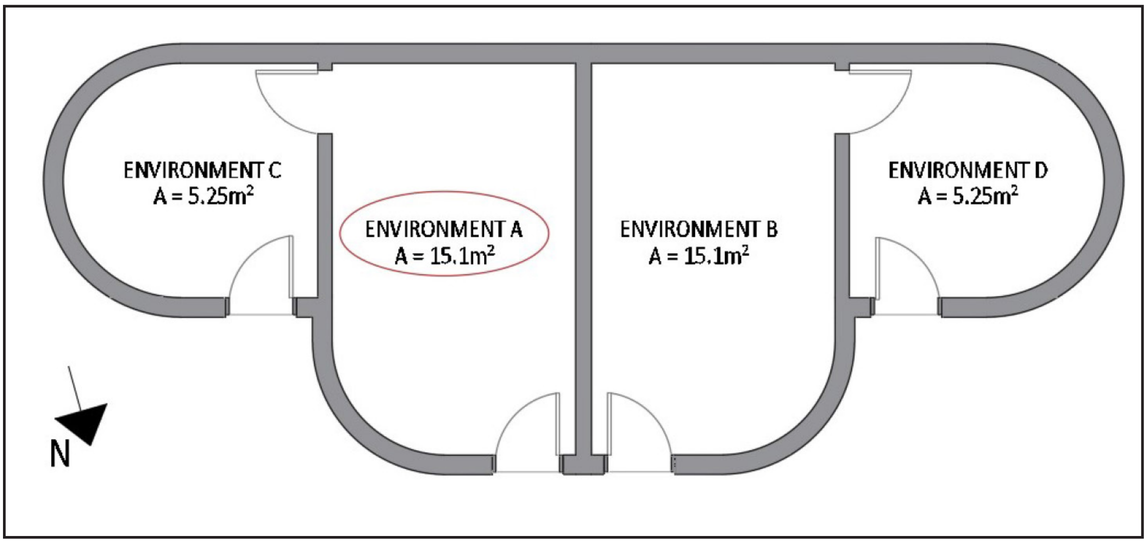
And the relative humidity was calculated using the air temperature and the dew point temperature, as ERA5 does not provide this parameter directly.

The study was carried out considering the climate of the city of Viamão/RS, where the computational domain model was developed with data from Casa Ventura, and for this analysis this building was defined as residential, with four rooms, with a built area of 40.70 m² and a ceiling height of 3.05 m. The construction systems, use and lighting were modeled in accordance with the Technical Quality Regulation for the Energy Efficiency Level of Residential Buildings (RTQ-R), which is the energy efficiency standard for residential buildings.

The external walls of the building are 0.2 m thick, built with sandstone, plastered with 0.03 m of mortar. While the internal walls are 0.1 m thick, built of perforated bricks, plastered on both sides with mortar, 0.03 m thick on each side. The doors are made of 0.04 m of plywood, the upper part of which is glazed with single glass; and fixed 0.005 m single-glazed windows. The roof is formed by 0.05 m of clayey soil, with wooden structures measuring 0.2 m in diameter. The subfloor is 0.05 m thick concrete.

The floor plan displaying the four environments, identified by the thermal zone software, is shown in Figure 1.

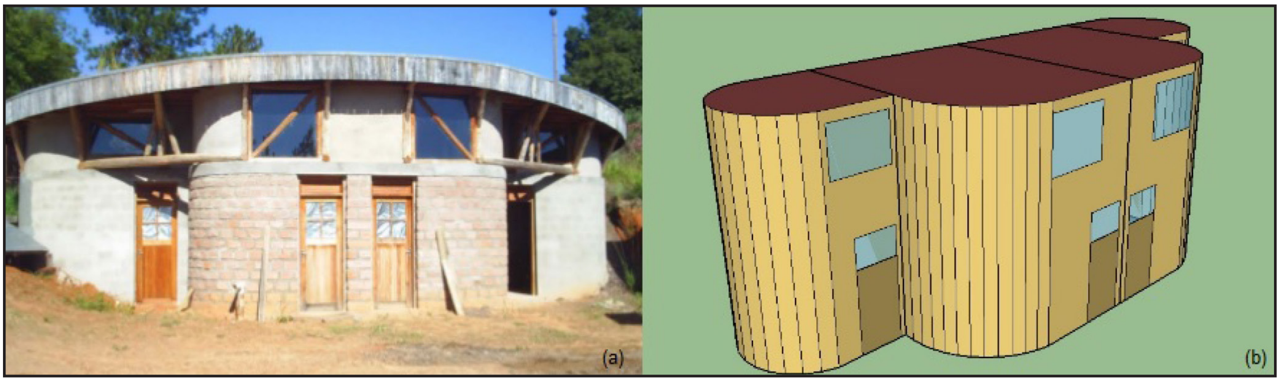
Figure 1 – Floor plan of Ventura house



Source: Authors

When implementing the computational domain, the true geometry in Figure 2(a) was simplified, with simple polygons used to represent the walls and roof. The computational domain is depicted in Figure 2(b) using SketchUp with the Euclid plugin enabled.

Figure 2 – Ventura house: (a) facade and (b) computational modeling



Source: Authors

Two simulations of the naturally ventilated building and employing EAHE were run for this study. The script for naturally ventilated buildings was used as a basis to configure the objects of the Airflow Network group of the EnergyPlus software. In the simulation of natural ventilation, air exchanges were taken into consideration 24 hours a day. EAHE was only utilized in the building's environment A in the EAHE simulation that was set up in the Zone Earth Tube object. In accordance with Vaz (2011), room A has an air renewal rate of 1.6 times the room volume per hour for the full year.

3 MATHEMATICAL AND COMPUTATIONAL MODELING

The Airflow Network object makes it possible to simulate multi-zone airflows driven by wind and also by a forced air ventilation system. Additionally, the model can simulate gains or losses in heat and humidity from the air distribution system itself, including ducting, for example.

The program determines the fundamental execution parameters for air flow calculation and then computes the wind pressure coefficients. Every window and door in a room that may be opened, both inside and outside, has a designated ventilation control.

3.1 Calculation of air humidity balance

The nodes that make up the EnergyPlus airflow network are connected by airflow components. It is a simplified airflow model compared to detailed models such as those used in Computational Fluid Dynamics (CFD) models.

The relative humidity of the air for each zone is represented by the relative humidity value in the data output. The calculation is dependent on the air temperature, air humidity rate, and pressure within the zone.

In accordance with the Engineering Reference Handbook (EnergyPlus, 2022), the zone's air humidity balance, or air mass balance equation, is:

$$\rho_{air} V_z C_W \frac{dW_z}{dt} = \sum_{i=1}^{N_{sl}} kg_{mass_{schedload}} + \sum_{i=1}^{N_{surfaces}} A_i h_{mi} \rho_{air_z} (W_{surfs_i} - W_z^t) + \\ + \sum_{i=1}^{N_{zones}} \dot{m}_i (W_{zi} - W_z^t) + \dot{m}_{inf} (W_\infty - W_z^t) + \dot{m}_{sys} (W_{sup} - W_z^t), \quad (1)$$

where CW is the moisture capacity multiplier, $\rho_{air} V_z C_W \frac{dW_z}{dt}$ is the change in the humidity rate of the zone, $\sum_{i=1}^{N_{sl}} kg_{mass_{schedload}}$ is the sum of the internal charges, $\sum_{i=1}^{N_{surfaces}} A_i h_{mi} \rho_{air_z} (W_{surfs_i} - W_z^t)$ is the air flow from the surfaces of the zone, $\sum_{i=1}^{N_{zones}} \dot{m}_i (W_{zi} - W_z^t)$ is the air flow due to air mixing between zones, $\dot{m}_{inf} (W_\infty - W_z^t)$ is the airflow due to infiltration, $\dot{m}_{sys} (W_{sup} - W_z^t)$ is the air flow in the HVAC system.

The approximation of the third order derivative is presented through the first order derivative of the Taylor series, used in calculating the air temperature of the zone, established by:

$$\left. \frac{dW_z}{dt} \right|_t \approx \frac{\left(\frac{11}{6} W_z^t - 3 W_z^{t-\delta t} + \frac{3}{2} W_z^{t-2\delta t} - \frac{1}{3} W_z^{t-3\delta t} \right)}{\delta_t} + O(\delta t^3). \quad (2)$$

Therefore, the derivative is substituted in the mass balance, and the terms with the humidity rate, demonstrated in Equation (1), are placed on the right side of the equation:

$$\frac{\rho_{air}V_zC_W}{\delta t}\left(\frac{11}{6}\right)W_z^t+\sum_{i=1}^{N_{surfaces}}A_ih_{mi}\rho_{air_z}W_z^t+\sum_{i=1}^{N_{zones}}\dot{m}_iW_z^t+\dot{m}_{inf}W_z^t+\dot{m}_{sys}W_z^t=$$
$$=\sum_{i=1}^{N_{sl}}kg_{mass_{schedload}}+\sum_{i=1}^{N_{surfaces}}A_ih_{mi}\rho_{air_z}W_{surfs_i}+\sum_{i=1}^{N_{zones}}\dot{m}_iW_{zi}+\dot{m}_{inf}W_\infty+$$
$$+\dot{m}_{sys}W_{sup}-\frac{\rho_{air}V_zC_W}{\delta t}\left(-3W_z^{t-\delta t}+\frac{3}{2}W_z^{t-2\delta t}-\frac{1}{2}W_z^{t-3\delta t}\right). \quad (3)$$

Equation (3) is is the basic air mass balance, which will be solved in two different ways by the software, to make calculationadjustments due to water vapor transfers between zones, using the forecast calculation method-correction.

With an analytical solution, we have the following for the humidity forecast scenario:

$$PredictedSystemLoad[kg_{water}/sec]=\left[\sum_{i=1}^{N_{surfaces}}A_ih_{mi}\rho_{air_z}+\sum_{i=1}^{N_{zones}}\dot{m}_iW_{zi}+\right.$$
$$\left.+\dot{m}_{inf}\right]\times\left[W_{SetPoint}^t-W_z^{t-\delta t}\times exp\left(-\frac{\sum_{i=1}^{N_{surfaces}}A_ih_{mi}\rho_{air_z}+\sum_{i=1}^{N_{zones}}\dot{m}_iW_{zi}}{\rho_{air}V_zC_W}\delta t+\right.\right.$$
$$\left.\left.+\frac{m_{inf}}{\rho_{air}V_zC_W}\delta t\right)\right]+\left[1-exp\left(-\frac{\sum_{i=1}^{N_{surfaces}}A_ih_{mi}\rho_{air_z}+\sum_{i=1}^{N_{zones}}\dot{m}_i+\dot{m}_{inf}}{\rho_{air}V_zC_W}\delta t\right)\right]^{-1}-$$
$$-\left(\sum_{i=1}^{N_{sl}}kg_{mass_{schedload}}+\sum_{i=1}^{N_{surfaces}}A_ih_{mi}\rho_{air_z}W_{surfs_i}+\sum_{i=1}^{N_{zones}}\dot{m}_iW_{zi}+\dot{m}_{inf}W_\infty\right).$$

The system reaction is approximative in the simulation prediction since the system's air mass fluxes are unknown. To get the best results possible, system modeling uses the air system's projected humidity load. Components of the system simulation with humidity control will try to match this anticipated humidity load.

An analytical solution to the adjusted humidity air mass balance equation yields:

$$W_z^t=\left[W_z^{t-\delta t}-\frac{\sum_{i=1}^{N_{sl}}kg_{mass_{schedload}}+\sum_{i=1}^{N_{surfaces}}A_ih_{mi}\rho_{air_z}W_{surfs_i}}{\sum_{i=1}^{N_{surfaces}}A_ih_{mi}\rho_{air_z}+\sum_{i=1}^{N_{zones}}\dot{m}_i\dot{m}_{inf}+\dot{m}_{sys}}+\right.$$
$$\left.+\frac{\sum_{i=1}^{N_{zones}}\dot{m}_iW_{zi}+\dot{m}_{inf}W_\infty+\dot{m}_{sys}W_{sup}}{\sum_{i=1}^{N_{surfaces}}A_ih_{mi}\rho_{air_z}+\sum_{i=1}^{N_{zones}}\dot{m}_i\dot{m}_{inf}+\dot{m}_{sys}}\right]\times$$
$$\times exp\left(-\frac{\sum_{i=1}^{N_{surfaces}}A_ih_{mi}\rho_{air_z}+\sum_{i=1}^{N_{zones}}\dot{m}_i+\dot{m}_{inf}+\dot{m}_{sys}}{\rho_{air}V_zC_W}\delta t\right)+$$
$$+\frac{\sum_{i=1}^{N_{sl}}kg_{mass_{schedload}}+\sum_{i=1}^{N_{surfaces}}A_ih_{mi}\rho_{air_z}W_{surfs_i}}{\sum_{i=1}^{N_{surfaces}}A_ih_{mi}\rho_{air_z}+\sum_{i=1}^{N_{zones}}\dot{m}_i+\dot{m}_{inf}\dot{m}_{sys}}+$$
$$+\frac{\sum_{i=1}^{N_{zones}}\dot{m}_iW_{zi}+\dot{m}_{inf}W_\infty+\dot{m}_{sys}W_{sup}}{\sum_{i=1}^{N_{surfaces}}A_ih_{mi}\rho_{air_z}+\sum_{i=1}^{N_{zones}}\dot{m}_i+\dot{m}_{inf}\dot{m}_{sys}}.$$

The following simulation results were achieved using the EnergyPlus software and the given equations.

4 RESULTS AND DISCUSSION

External heat is that which crosses to another environment in the form of sensible or latent heat, and can occur through external or internal surfaces, and the environment's renewal air. Heat storage in the building is when the peak gain does not coincide with the maximum thermal load nor with the maximum daily temperature in the thermal zone.

According to Ashrae (2017), the average air temperature is 24.5ºC, the operating temperature between 23.5°C and 27.5°C and the relative humidity between 65% and 35% in summer, while for winter, the average air temperature is possibly 22°C, the operating temperature between 20.5°C and 24.5°C and relative humidity between 60% and 30%.

The average air temperature in the thermal zone is equivalent to the internal temperature of the environment, seeking thermal comfort. The setpoint temperature, which is the temperature maintained over the duration of habitation of the thermal zone under investigation, was determined by configuring this parameter in the EnergyPlus software and setting it to 24°C.

The National Institute of Meteorology (INMET) states that the meteorological station in Porto Alegre/RS, which is 17 km from Viamão, was selected as a reference because it lacked data for the city of Viamão/RS for the year 2007. Table 1 displays the summertime temperatures and humidity of these cities, where as Table 2 displays the wintertime temperatures and humidity.

Table 1 – Average outdoor temperature and humidity on January 21 and July 21 (year: 2007)

	Temperature		**Humidity**	
	Porto Alegre/RS	**Viamão/RS**	**Porto Alegre/RS**	**Viamão/RS**
21/january	22,0°C	21,4ºC	67,0%	72,5%
21/july	14,0°C	12,3°C	77,0%	84,0%

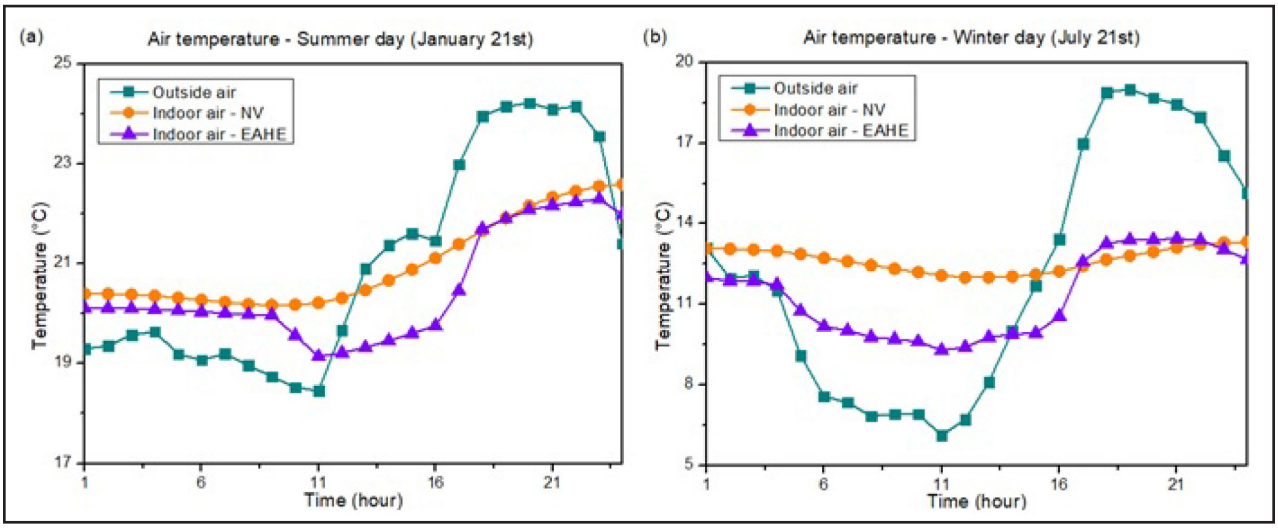
Source: Authors

As a result, the daily averages of these variables are comparable in the two cities.

Using the climatic archive of Viamão in 2007, the simulation results for this research will be presented on project days in the summer and winter. The daily temperatures of the building and the outside air on January 21st are displayed in Figure 3(a). Using EAHE, it was discovered that the indoor air temperature was reduced by 2.7%. The external temperature peaked at 24.2°C at 7 pm, and the internal environment of the building under natural ventilation (NV) reached a peak of 22.6°C at 11 pm.

In winter, on July 21st, in Figure 3(b) it can be seen that the internal temperature reaches the lowest temperature of 12.0°C at 11 am and in the outside air the temperature at that time was 6.7°C at 6 pm, using EAHE a reduction of 21.7% was found. As the adaptive comfort of these typical winter and summer days is analyzed, it is found that EAHE is not suitable for this region in the winter since it loses its advantage over NV as the temperature drops.

Figure 3 – Project day temperature graph in (a) summer and (b) winter



Source: Authors

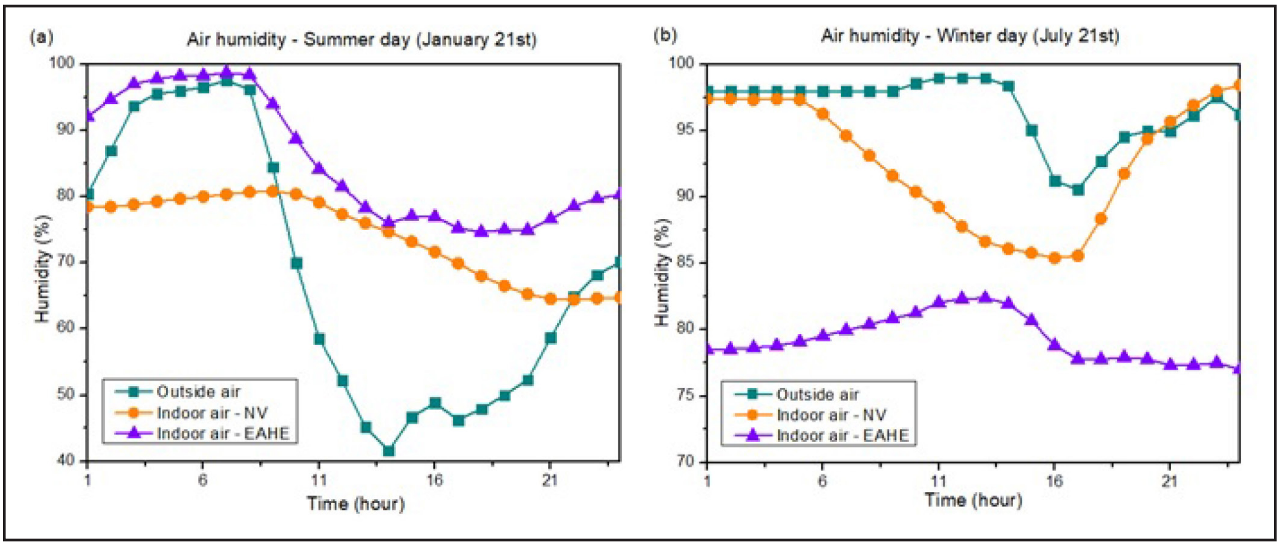
It has been noted that summertime is when the environment reaches the average air temperature needed for thermal comfort.

This graph shows that there is little difference in the room temperatures inside and outside. This is because heat cannot be removed from the environment by radiation exchange alone. This is because heat cannot be removed from the environment by radiation exchange alone. Owing to adaptive comfort, the building showed no comfort in any of the winter scenarios examined; nevertheless, in both summer simulations, a comfort level of 9.09% was obtained.

The relative humidity of the zone is an output variable represented by the calculations presented previously, it depends on the air temperature of the zone, the humidity rate of the air in the zone and the external barometric pressure.

Figure 4(a) shows that for the summer day in 2007, the daily air humidity in Viamão varies between 41.6 % and 97.6%, and in the internal environment of the building under NV conditions between 64.4% and 80.8%, in the simulation using the EAHE there was an increase of 14% in the building's humidity. In winter, Figure 4(b), we have the variation in external air humidity between 90.6% and 99.0% and in the internal environment of the NV building between 85.1% and 98.4%, using the EAHE maximum humidity decreases by 22.0%.

Figure 4 – Project day humidity graph in (a) summer and (b) winter



Source: Authors

Because the summertime average air temperature in the area is greater, less water vapor is present in the atmosphere. High percentage values, often near 100%, of the building's air humidity are noted in the winter.

An artificial air conditioning simulation of the building was run, and the energy consumption was 51.58 kWh. When compared to the EAHE usage, the summertime consumption increased by 28%, and the wintertime consumption by 42%.

5 CONCLUSIONS

In this study, the building's internal climate was modeled. There are many factors that affect internal air variables, mainly temperature and relative humidity.

The EnergyPlus software's simulation produced a number of internal climate data sets that were used to study the thermophysi- cal phenomena that were simulated. The results obtained, represented graphically, show that they are considered coherent when compared to works carried out using other computer simulation software, and tolerate being applied to all types of buildings, and can be of great use in estimating internal climatic conditions based on the external conditions of the location of the building.

Of the resources that can be used to improve the low humidity that causes discomfort, the authors suggest changes to the construction materials used in the house, such as changing the colors of the elements; and also in the geometry of the house, increasing the size of the windows for greater air flow in and out.

The building under study was built using materials that have good performance, generating good thermal comfort, as it does not cause a feeling of cold if the external temperature is very low. The temperature was reduced in summer using EAHE, and its use on this typical day is positive. The region where the building is located, southern Brazil, may have colder external conditions compared to other regions of the country, the ideal would be to carry out this comparison in other cities.

When it comes to humidity, it can occasionally approach 100%, particularly during the winter. This indicates that the air inside is saturated and extremely humid, with nearly all of the water vapor in the air. Another benefit of the building's natural ventilation is that the relative humidity of the air drops in the winter.

The study's positive findings thus demonstrate that this kind of simulation can be used as a resource for professionals and researchers who need climate data for their analysis of building performance. It can also be used as a tool to provide and show variables in building environments based on location and type of construction.

REFERENCES

Ashrae, (2017). Thermal environmental conditions for human occupancy. *American Society of Heating Refrigerating and Air Conditioning Engineers*, p. 549–561.

Bénard, J.; Eymard, R.; Nicolas, X.; Chavant, C., (2005). Boiling in porous media: Model and simulations. *Transport in Porous Media*, 60, 1–31.

Brum, R. S., (2013). Modelagem computacional de trocadores de calor solo-ar. *Dissertação* (Mestrado em Modelagem Computacional), Universidade Federal do Rio Grande, Rio Grande, Brazil.

Brum, R. S., (2016) Teoria construtal e desempenho termico de trocadores de calor solo-ar. *Tese* (Doutorado em Engenharia Mecânica), Universidade Federal do Rio Grande do Sul, Porto Alegre, Brazil.

Brum, R. S.; Rocha, L. A. O.; Vaz, J.; Dos Santos, E. D.; Isoldi, L. A., (2012). Development of simplified numerical model for evaluation of the influence of earth-air heat exchanger installation depth over its thermal potential. *International Journal of Advanced Renewable Energy Research*, 1, 505–514.

Brum, R. S.; Vaz, J.; Rocha, L. A. O.; Dos Santos, E. D.; Isoldi, L. A., (2013). A new computational modeling tob predict the behavior of earth-air heat exchangers. *Energy and Buildings*, 64, 395–402.

Brum, R. S.; Ramalho, J. V. A.; Rocha, L. A. O.; Isoldi, L. A.; Dos Santos, E. D., (2016). Transient models to analyze the influence of the air velocity and ducts diameter on the performance of earth-air heat exchangers. *Energy and Buildings*, 43, 503–520.

Brum, R. S.; Rodrigues, M. K.; Ramalho, J. V. A.; Rocha, L. A. O.; Isoldi, L. A.; Dos Santos, E. D., (2017). On the design of two eahe assemblies with four ducts. *Defect and Diffusion Forum*, 372, 31–39.

Brum, R. S.; Labat, M.; Lorente, S., (2019a). Improving the performances of earth-air heat exchangers through constructal design. *International Journal of Energy Research*, 43, 8822–8833.

Brum, R. S.; Ramalho, J. V. A.; Rodrigues, M. K.; Rocha, L. A. O.; Isoldi, L. A.; Dos Santos, E. D., (2019b). Design evaluation of earth-air heat exchangers with multiple ducts. *Renewable Energy*, 135, 1371–1385.

Candido, C.; Dear, R. J.; Lamberts, R.; Bittencourt, L., (2010). Air movement acceptability limits and. Energy and Buildings thermal comfort in Brazil's hot humid climate zone. *Building and Environment*, 45, 222–229.

Crawley, D. B.; Lawrie, L. K.; Winkelmann, F. C.; Pedersen, C. O., (2001). Energyplus: creating a new-generation building energy simulation program. *Energy and Buildings*, 33, 319–331.

Domingues, A. M. B.; Nóbrega, E. S. B.; Ramalho, J. V. A.; Brum, R. S.; Quadros, R. S., (2021). Parameter analysis of earth-air heat exchangers over multi-layered soils in south brazil. *Geothermics*, 93.

EnergyPlus (2022). EnergyPlus Engineering Reference, Version 22.2.0 Documentation. U. S. *Department of Energy*, United States.

Estrada, E.; Labat, M.; Lorente, S.; Rocha, L. A. O., (2018). The impact of latent heat exchanges on the design of earth air heat exchangers. *Applied Thermal Engineering*, 129, 306–317.

Goffart, J.; Rabouille, M.; Mendes, N. (2017). Uncertainty and sensitivity analysis applied to hygrothermal simulation of a brick building in a hot and humid climate. **J***ournal of Building Performance Simulation*, 10(1), 37–57.

Lamberts, R.; Dutra, L.; Pereira, F. O. R. (2014). Eficiência Energética na Arquitetura. *São Paulo*, São Paulo.

Nóbrega, E. S. B.; Brum, R. S.; Ramalho, J. V. A.; Quadros, R. S., (2020). A first study on earth-air heat exchanger in Pelotas. *Revista Mundi Engenharia, Tecnologia e Gestao*, 5, 1–15.

Rodrigues, M. K.; Brum, R. Da S.; ; Vaz, J.; Rocha, L.; Dos Santos, E. D.;, Isoldi, L. A., (2015). Numerical investigation about the imporvement of the thermal potential of an earth-air heat exchanger (EAHE) employng the Constructal Design method. *Renewable Energy*, 80, 538–551.

Strand, R. K. (1995). Heat source transfer functions and their application to low temperature radiant heating systems. *Tese* (Engenharia Mecânica), University of Illinois at Urbana-Champaign, Champaign, United States.

Vaz, J. (2011). Estudo experimental e numérico sobre o uso do solo como reservatório de energia para o aquecimento e resfriamento de ambientes edificados. *Tese* (Doutorado em Engenharia Civil), Universidade Federal do Rio Grande do Sul, Porto Alegre, Brazil.

Authorship contributions

1- Michele Soares Netto

PhD student in the postgraduate program in materials science and engineering at UFPel
https://orcid.org/0000-0001-5891-2078 • michelenetto@live.com
Contribution: Formal Analysis; Investigation; Methodology; Software; Supervision; Validation; Visualization; Writing – original draft; Writing – review & editing

2- Ruth da Silva Brum

Professor of the postgraduate program in mathematical modeling at UFPel
https://orcid.org/0000-0002-8527-8030 • cesaravellaneda@gmail.com
Contribution: Conceptualization; Funding acquisition; Project administration; Resources; Writing – original draft; Writing – review & editing

3- Cesar Antonio Oropesa Avellaneda

Professor of the postgraduate program in materials science and engineering at UFPel
https://orcid.org/0000-0003-4657-1354 • ruthdasilvabrum@gmail.com
Contribution: Conceptualization; Funding acquisition; Resources; Writing – review & editing

4- Joseane da Silva Porto

Professor at the physics and mathematics institute at UFPel
https://orcid.org/0000-0002-1717-8572 • joseaneclmd@gmail.com
Contribution: Conceptualization; Data curation; Funding acquisition; Project administration; Resources; Supervision; Validation; Writing – review & editing

5- Taís Pereira da Silva

Master's student in the postgraduate program in mathematical modeling at UFPel
https://orcid.org/0009-0009-4704-0134 • cagetawi@gmail.com
Contribution: Methodology; Visualization

How to quote this article

Netto, M. S., Brum, R. da S., Avellaneda, C. A. O., Porto, J. da S., & Silva, T. P. da (2023). Numerical humidity assessment: analysis of the thermal performance of a residential building. *Ciência e Natura, 45*(spe. 3), e740572. DOI: https://doi.org/10.5902/2179460X74572. Available from: https://periodicos.ufsm.br/cienciaenatura/article/view/74572. Accessed in: day month abbr. year.