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Walls composed of different materials: a brief review on thermal comfort

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ABSTRACT

The present work is dedicated to identifying the central researches related to the influence of the different materials that make up the walls in the performance of thermal comfort. At first, the keywords “Wall materials” and “Thermal comfort” were used in the search for scientific articles through a systematic review in the Scopus and Web of Science databases, restricted to the areas of Architecture and Urbanism, Social Sciences, Arts and Humanities. 85 scientific articles were identified, of which 44 were included in the research, the excluded did not have adherence, because they were out of the subject or in duplicate. In order to organize the data and discuss the subjects, four contexts were identified: building evaluation (39%), computer simulation (39%), prototype construction (15%) and laboratory experiment evaluation (7%). Among the materials, hemp and straw bales stood out by demonstrating the ability to cushion temperature variations in both winter and summer, and are therefore good thermal regulators. The melting temperature of the Phase-Change Material (PCM) of 25 ° C optimized the installation in all locations. The ceramic brick wall had a worse performance, from 1.25 to 1.45W / (m.K) in relation to the traditional mud walls at 1.1 to 1.2W / (m.K) and the earth block construction technique stabilized with cement at 1.05 to 1.25W / (m.K). The application of materials provided for wall construction is one of the best alternatives to achieve the condition of internal thermal comfort of buildings.

KEYWORDS: Wall materials. Thermal comfort. Energy efficiency.

1. INTRODUCTION

Considering that people spend about 80 to 90% of their time indoors (Jannat et al., 2020), it is necessary to be concerned with the quality of these environments to provide well-being conditions to occupants (HWANG et al., 2019).

According to Abdo et al. (2020) the negative environmental impacts of urbanization cause, in addition to physical discomfort and health problems, a greater demand for building cooling, leading to increased energy consumption. Li et al. (2018) mention that the walls and roof of the building, as a thermal mass, are able to adjust the air temperature by storing heat when the temperature is high and releasing heat when the temperature is low. Several variables, such as temperature, humidity, wind, precipitation, solar radiation and other characteristics of the climatic zone, as well as walls, roofs, windows and behavior of the occupants, influence the thermal comfort of a building (JANNAT et al., 2020); (AKSAMIJA; PETERS, 2017); (LEO SAMUEL et al., 2017).

Cold climatic regions require the collection of solar radiation, passive heating, since the buildings in this zone have heat loss in excess of the gain, with which improved insulation is needed to reduce the demands for artificial heating. In hot climates, however, protection from direct solar radiation becomes more important. In mixed climate regions, combined strategies that balance sun exposure must be implemented (AKSAMIJA; PETERS, 2017).

Low-inertia buildings tend to frequent fluctuations in internal temperature and are prone to overheating in the summer. These effects can be reduced by integrating the thermal mass in the building envelope. By improving thermal inertia, thermal delay is obtained, thus reducing the instantaneous cooling and heating loads in these buildings (BELMONTE et al., 2015) and (NGHANA; TARIKU, 2016).

According to Ibrahimet al. (2014), as the temperature of the outside air and solar radiation vary throughout the day, the temperature of the external surface of the walls is greatly affected, leading to fluctuations in the heat flow that passes through them. As a result, the internal environment can be changed. According to Unveret al., (2004) and Jannatet al., (2020) as walls and roof of the building, which separate the interior from the exterior, they play the most important role to materialize as necessary comfort conditions for users.

To obtain thermal comfort and reduce energy consumption in buildings, it is necessary to consider passive strategies, which include thermal insulation, natural ventilation, solar screens, cold ink, cold roofs, etc. (AMIRZADEH *et al.*, 2018). According to D'Agostinoet al., (2018) insulation as well as the ideal wall and roof thickness of the building can cause a reduction in energy demand of up to 40%.

Faced with this scenario, this article analyzes the literature review, characterizing studies published in journals on thermal comfort as a variable key in the quality of the internal environment, which is influenced by design techniques and by different types of materials that make up the construction of walls, used to minimize the external heat gain or the internal heat loss of buildings.

2. OBJECTIVE

To analyze the bibliographic production formed by research survey, restricted to the areas of Architecture and Urbanism, Social Sciences, Arts and Humanities, indexed in the Scopus and Web of Science databases, regarding the theme of the influence of the different types of materials that make up the performance of the thermal comfort of buildings.

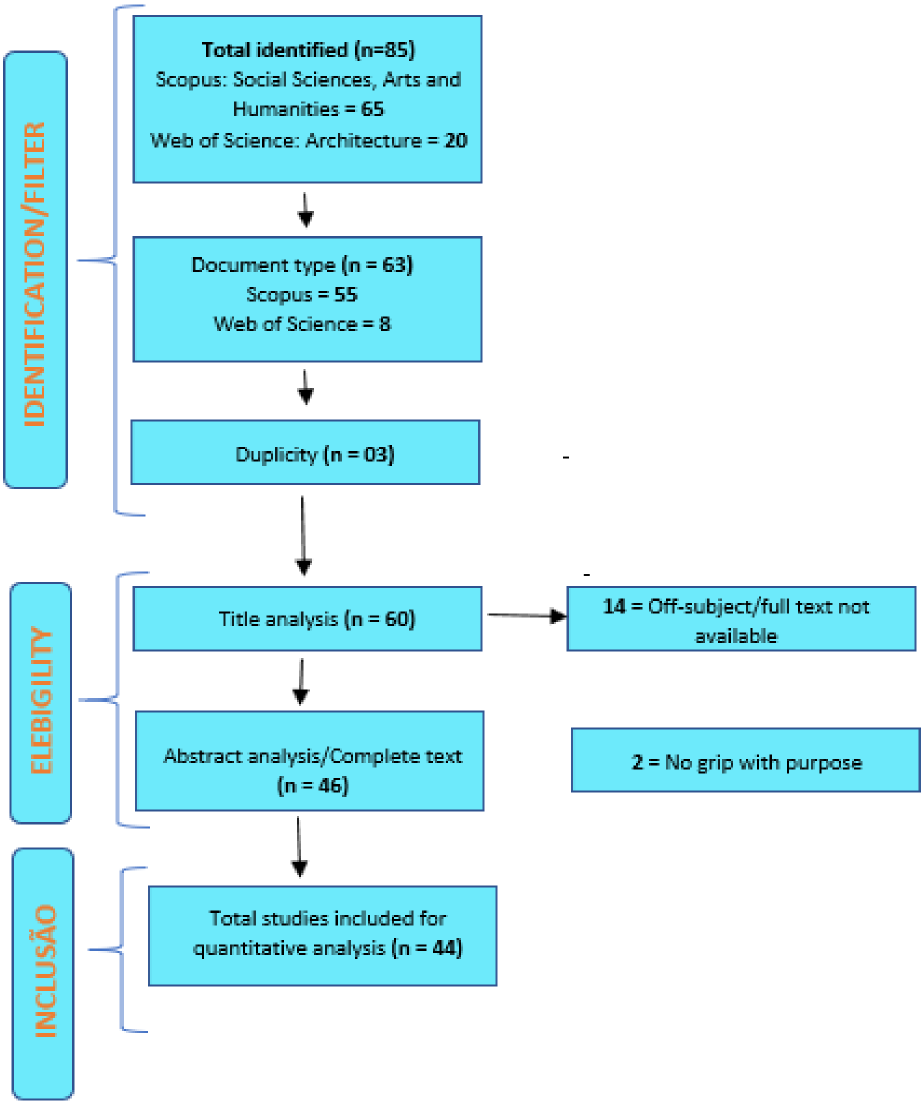
3. METHODOLOGY

In order to carry out the study, the keywords in English Wall materials and Thermal comfort were used in two electronic databases, Scopus and Web of Science, from 1981 to 2020, conditioned to the study areas in Architecture and urbanism, Sciences social, arts and humanities. The research works identified in the databases were imported into Endnote software, to remove duplicates.

For inclusion criteria: articles that evaluated the materials that make up the walls in the performance of the thermal comfort of buildings, through measurements in buildings, in prototypes, in the laboratory, or else in computer simulations.

For exclusion criteria: studies that did not evaluated the influence of wall materials on the thermal comfort of buildings, conference papers, full article not available, book chapter and systematic reviews. The steps followed to select the studies are illustrated in the flowchart (Figure 1) that is based on the PRISMA model (MOHER et al., 2009).

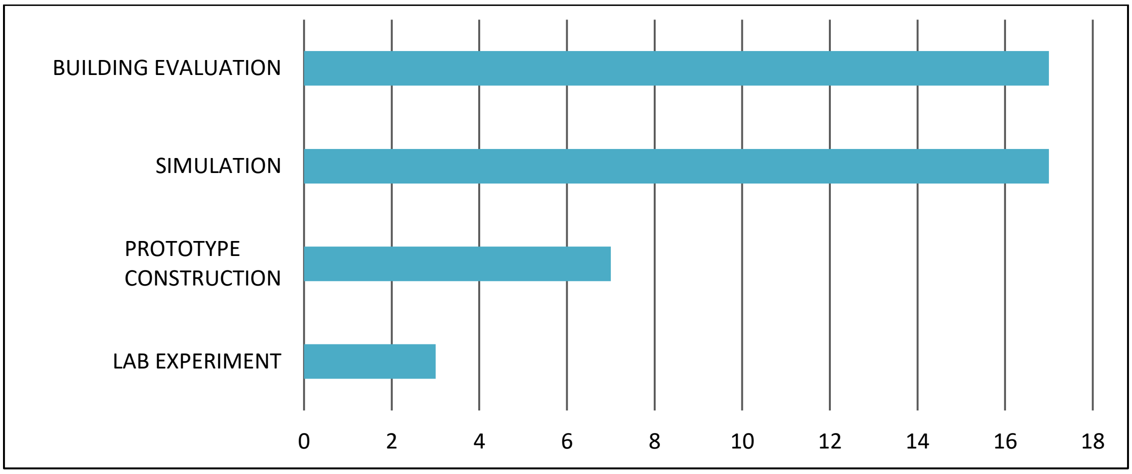
Figure 1: Flowchart



Source: THE AUTHORS, 2020. Based on the PRISMA model, Moher et al., 2009.

Overall, 39% of the studies evaluated thermal comfort in buildings through on-site measurements, 39% computer simulations, 15% prototype construction and 7% laboratory analysis (Figure 2).

Figure 2: Form of analysis



Source: THE AUTHORS, 2020.

The following data were collected in each article: authors, year of publication, geographic location, type of climate, objective, materials, methods and main results.

4. RESULTS AND DISCUSSIONS

4.1. Building evaluation

The monitoring activities aim, according to Moujalled et al., (2018) to evaluate the thermal performance in real climatic conditions, on the building scale. Table 1 presents the measuring instruments and their characteristics - for inclusion criteria: article that presented at least the accuracy of the device. In 50% of the works, measurements were made throughout the year - the four seasons, 22% were in summer and winter, 17% measured only in summer and 11% only in winter, and evaluated in the vast majority (88%) in Köppen class C climate, humid subtropical, oceanic and Mediterranean (Table 2).

Table 1: measuring instruments and their characteristics

Research study	Instrument model	Measured Parameters	Measuring range	Precision	Resolution
Aste, N. *et al.* (2019)	Episensor TES-11 / HTS-10: (wireless sensor)	T	−20 to +60 °C	± 0,2 °C	0,1 °C
		UR	11 to 89%	± 3%	0,10%
	HOBO UX100-011 (sensor with datalogger)	T	20 to +70 °C	± 0,21 °C (0… +50 °C)	0,024 °C (to 25 °C)
		UR	0 to 95%	± 2,5% (10… 90%)	0,05% (to 25 °C)
	HOBO U12-011 (sensor with dataloggerr)	T	−20 to +70 °C	± 0,35 °C (0… +50 °C)	0,03 °C (to +25 °C)
		UR	5 to 95%	± 2,5% (10… 90%)	0,03%
	HORIBA IT-545 NH / N / S (infrared thermometer)	T Superficial	−50 to +1000 °C	± 1,0 °C (0… +199,9 °C)	0,1 °C (0… +199,9 °C)
	Thermo-anemometer testo 405-V1	VV	0 to +10 m / s	± 0,1 m / s (0… +2 m / s)	0,01 m / s

		T	−20 to +50 °C	± 0,5 °C	0,1 °C
Costanzo, V.*et al* (2018)	Beeper-WSN	T	0–50 °C	± 0,5 °C	-
		UR	20-80%	± 3%	-
		CO$_2$	0–5000 ppm	± 50 ppm	-
Moujalled, B. *et al* (2018)	HOBO U12-002	T	-20 to 70 °C	± 0,35 °C	0,1 °C
		UR	5% -95%	<90%: ± 2,5%	<1%
	HOBO U12-006	T	-20 to 70 °C	± 0,35 ° C	<0,1 °C
	HOBO U14-002	T	−40 to 75 °C	± 0,21 ° C	<0,1 °C
		UR	0% –100%	<90%: ± 2,5% > 90%: ± 5%	<1%
	HOBO U30	T	−40 to 75 °C	± 0,21 °C	<0,1 °C
		UR	0% –100%	<90%: ± 2,5% > 90%: ± 5%	<1%
		RS	0-1280 W / m 2	± 10 W / m 2 ou ± 5%	<± 2%
		VA	0 to 45 m / s	± 1,1 m / s	-
		DV	0 to 355 °	± 5 °C	-
Hwang, T.I. et al (2019)	MSR 145 - Suíça	T	-20 to -65 °C	± 5 °C	-
		UR	0%- 100%	± 2%	-
Costantine, G. *et al* (2018)	Thermo hygrometer - TH BeanDevice	T	-	± 0,2 °C	-
		UR	-	± 1,8%	-
	Temperature sensor - T BeanDevice	T	-	± 0,1 °C	-
	Thermal flow meters	VT	-	± 5%	-
Gallegos-Ortega, R. *et al* (2017)	T-type thermocouple	T	-	± 0,1 °C	-
Nghana, B.; Tariku, F. (2016)	T-type thermocouple	T	-270 to 400 °C	± 1 °C	-
	L: 71 mm, D: 12 mm	T	-	± 0,6 °C	-
		UR	-	± 3%	-
Ibrahim, M. *et al* (2014)	K-type thermocouple	T	-	± 0,3 °C	-
	Pyranometers HUKSEFLUX	RS	0–2000 W/m ^{2}	± 10%	-
	HUMICAP HMP110	T	−40 ° C a +80 °C	± 0,2 °C	-
	Anemometer Pulsonic Aliza 147	VV	0–60 m / s	± 3%	-
		DV	0–360 °	± 5 °	-
Orosa, J.A.; Baaliña, A. (2009)	Innova 1221 with MM0034 temperature transducer MM0034	T	-	± 0,2°C	-
	Tinytag Plus 2 dual channel dataloggers with thermistor and capacitive sensors	T	-	± 0,2 °C	-
		UR	-	3% HR	-
Medjelekh, D. *et al* (2016)	Data loggers “LogTag”	T	25 °C	± 1 °C	-
		UR	20% –80%	± 3%	-
	Thermocouple EL-USB-TC-LCD and K-Type	T superfície	−200 to +1300 ° C	± 1 °C	0,5 °C
Abbreviations: T: Air temperature - UR: Relative air humidity - CO2: Carbon dioxide - VV: Wind speed - DV: Wind direction - RS: Solar radiation - VT: Thermal flow					

Source: THE AUTHORS, 2020.

Table 2: Studies on a real building

Author/ year	Evaluated Location	Climate Köppen	Period	Objective	Main results
Hwang, T.I. *et al* (2019)	Seoul, South Korea	Dwa	Winter	Condensation prevention, comparing to a study conducted in 2003.	Comparing the temperature and humidity results for 2003 and 2015, the average temperature values were not very different. However, the average relative humidity was 8.1% higher in 2015 than in 2003, this may be related to the Korean lifestyle change and the design criteria for using high performance materials, following the 2000 guidelines.
Aste, N. *et al* (2019)	Milan, Italy	Cfa	Four seasons	Characterize the hygrothermal behavior of the Milan Cathedral and assess the risks for the main materials that compose it.	The high thermal inertia of the Cathedral walls makes it possible to keep the temperature values almost constant during daily cycles (with variations below 2 ° C).
Costantine, G. *et al* (2018)	Fleury-La-Rivière, France	Cfb	Four seasons	Experimentally and numerically evaluate the thermal performance of the building with hemp lime insulation.	The results show a good agreement between the numerical values and the experimental measures and indicate an acceptable thermal comfort, with some high relative humidity being detected due to the behavior of the residents in relation to the apartment. The ability of hemp concrete to dampen external temperature variations is highlighted.
Costanzo, V. *et al* (2018)	Cesena, Italy	Cfa	Four seasons	Deepen the knowledge about the thermal and energy performance of a house certified as passive.	Registration of good thermal comfort in winter, but overheating in summer 50% of the time according to EN 15251.
Moujalled, B. *et al* (2018)	Périgueux, France	Cfb	Four seasons	Evaluate the hygrothermal performance of a lime and hemp concrete building.	Hemp concrete helps to maintain a good level of thermal comfort in winter and summer. Confirmed as a good thermal regulator.
Odgaard, T. *et al* (2018)	Copenhagen, Denmark	Cfb	Four seasons	Investigate hygrothermal conditions when applying the interior insulation of a solid brick surface.	The installation of insulation in solid masonry induced thermal changes: higher relative humidity distributed evenly and lower temperature throughout the masonry, compared to an uninsulated wall. The relative humidity of the non-insulated masonry wall was in the range of 50% inside to 60% outside, while the isolated wall showed values uniformly distributed around 80%.
Gallegos-Ortega, R. *et al* (2017)	Tecate, Mexico	Csa	Summer	Evaluate the thermal behavior of a house built with bales of wheat straw.	Use of the straw bale resulted in: 9-hour thermal delay, 93.6% temperature dampening and 25.6 ° C ± 0.5 ° C internal temperature.
Jentsch, M.F. *et al* (2017)	Timbu, Bhutan	Cwb	Four seasons	Evaluate the thermal performance of ten	In terms of thermal transmittance values, the type of ceramic brick wall

				buildings.	construction underperformed, 1.25 to 1.45W / (mK), compared to traditional mud walls, 1.1 to 1.2W / (mK) , and the construction technique of earth block stabilized with cement at 1.05 to 1.25W / (m.K).
Leo Samuel, D.G. *et al* (2017)	Hyderabad, India	Aw	Summer	Evaluate the thermal performance of eight buildings.	The increase in the thermal mass of the structure reduces temperature fluctuation and delays the time when temperature extremes are reached.
Nghana, B.; Tariku, F. (2016)	Burnaby, Canada	Cfb	Summer and winter	Investigate the effect of PCM on internal comfort and energy consumption.	57% of energy savings are achieved in the summer due to the PCM's ability to decrease the heat flow from the wall.
Hyde, R. *et al* (2016)	Mexico City	Cwb	Summer	Evaluate the Post-occupation called 'cycle closure' to understand the thermal behavior of the construction and the satisfaction of the building's occupants.	The internal temperature in the study areas of the house is within the comfort conditions for the summer (ie, temperature between 20 and 27 ° C). The humidity remained between 4–12 g / kg and the temperature below 25 ° C, which is within an acceptable range in relation to its thermal mass and shading.
Medjelekh, D. *et al* (2016)	Guelma, Algeria	Csa	Summer and winter	Field research of thermal inertia and its effects on the internal thermal comfort of a travertine stone wall.	The results of three years of monitoring in a travertine stone house showed the effect of thermal inertia in ensuring a strong attenuation of the thermal wave of 10.2 and 14.6 K in hot weather conditions.
Kabre, C. (2016)	Cyclades, Greece.	Cfa	Four seasons	Evaluate traditional Cycladic housing, Greece, in terms of their response to climate and thermal comfort.	During both seasons, the traditional solid stone walls show low temperature fluctuations, demonstrating that the wall is just as important as the roof in creating a stable environment in traditional Cycladic houses.
Ibrahim, M. *et al* (2014)	Nice, France	Csa	Winter	Evaluate the thermal performance of the exterior walls of insulating coating based on silica-aerogel.	During both seasons, the traditional solid stone walls show low temperature fluctuations, demonstrating that the wall is just as important as the roof in creating a stable environment in traditional Cycladic houses.
Varas-Muriel, M.J. et al (2014)	Talamanca de Jarama, Spain	Csa	Four seasons	Analyze rural churches by monitoring hygrothermal conditions and CO2 levels, and their effects on heritage conservation.	The internal levels of CO2 are due to human metabolism, not the heating system. The highest levels (> 1000 ppm) are recorded in the summer, when the church has a larger congregation, but these concentrations do not pose a risk to human health or internal property.
Elias-Ozkan, S.T., Summers, F. (2013)	Kerkenes, Turkey	Csa	Summer and winter	Thermal performance of three straw bales buildings.	Construction with straw bales is advantageous with regard to thermal insulation properties, in addition to the energy incorporated and savings compared to conventional materials.
Orosa, J.A.; Baaliña, A. (2009)	La Coruña, Spain	Cfb	Summer and winter	Assess the effect of the lining of the inner wall on comfort conditions.	The internal coatings have an influence on the internal environment and the transfer of moisture between the indoor

					air and the hygroscopic structures has the potential to moderate variations in the relative humidity of the indoor air and thus improve comfort.
Aw: Tropical de savanna / Cfa: subtropical humid / Cfb: temperate oceanic / Csa: hot summer Mediterranean / Dwa: humid continental / Cwb: Oceanic subtropical altitude					

Source: THE AUTHORS, 2020.

Costantine et al (2018) and Hwang et al (2019) claimed that the increase in relative humidity is related to the lifestyle of residents and the design criteria with the use of high-performance materials, for example, in the study by Odgaard et al (2018) the investigation showed that the installation of insulation in a solid masonry induced thermal changes, such as: higher relative humidity distributed and lower temperature throughout the masonry, compared to an uninsulated wall. Hyde et al (2016) and Leo Samuel et al (2017) reported that the humidity remained within an acceptable range in relation to its thermal mass and shading. Ibrahimet al (2014) mention that in addition to the thermal mass, the low conductivity has excellent thermal performance, and Varas-Muriel et al (2014) warn that for the heating of the environment in winter, the low humidity can cause minor health problems for some people and deterioration of materials.

Aste et al (2019); Jentsch et al (2017); Leo Samuel et al (2017); Hyde et al (2016) and Kabre (2016) evaluated that the high inertia of the walls allows to maintain the internal temperature values almost constant during the daily cycles, which causes gradual changes in relation to the external conditions. The authors also mentioned that the walls are just as important as the roof in creating a stable environment in buildings.

4. 2 Simulation

The software with the highest number of uses in the sample (Table 3) is EnergyPlus, used to perform thermal equilibrium load calculations, materials with variable thermal conductivities and thermal comfort for occupants. Studies using the simulation method can guide designers to preliminarily analyze the different wall materials in the building, under different climatic conditions (JANNAT et al., 2020; AMIRZADEH, A. et al., 2018).

Table 3: Main building simulation software

Software	Estudo
Energy Plus	Park, J. *et al* (2019); Costanzo, V. *et al* (2018); Amirzadeh, A. *et al* (2018); Aksamija, A. *et al* (2017); Ascione, F. *et al* (2015); Evola, G. *et al* (2013); Asadi, E. *et al* (2012)
COMSOL multiphysics	Alioua, T. *et al* (2020)
Matlab	Moujalled, B. *et al* (2018); Ascione, F. *et al* (2015)
Termus - Acca Software	Agliata, R. *et al* (2020)
Design Builder	Breçani, R.; Dervishi, S. (2019); Rosso, F. *et al* (2017)
IES-VE	Jannat, N. *et al* (2020).
Spark	Costantine, G. *et al* (2018)
JACK	Hasan, MI *et al* (2018)

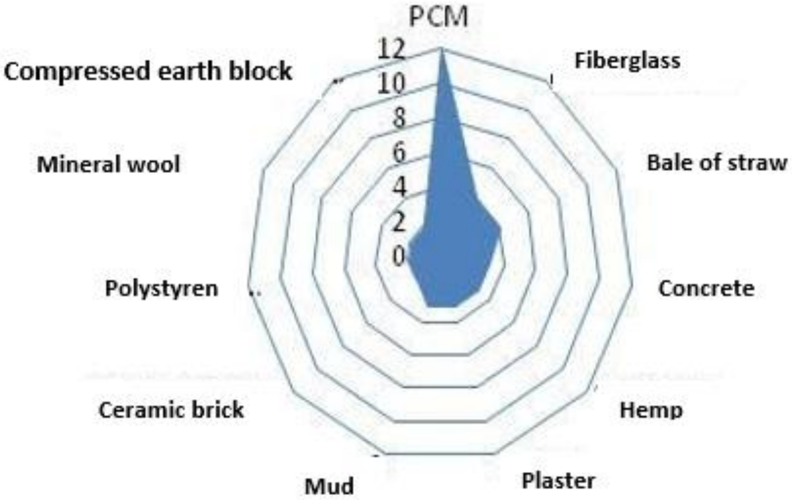
Esp-r	Lee, J.; Park, J. (2018); Van Hoof, J. *et al* (2008)
Software WUFI Pro	Moujalled, B. Lee, J. *et al* (2018)
TRNSYS	Belmonte, JF. *et al* (2015); Asadi, E. *et al* (2012)
Open Studio	Amirzadeh, A. (2018);
THERM 6.3	Aksamija, A. (2017)
GenOpt	Belmonte, JF. *et al* (2015); Asadi, E. *et al* (2012)
ANSYS	Moustafa, M.A. *et al* (2015)

Source: THE AUTHORS, 2020.

4.3. Prototype construction and laboratory evaluation.

The works of the prototype and laboratory construction sample (Table 4) generally seek to develop and evaluate low energy wall materials incorporated in production and high thermal performance. Phase change materials (PCMs) were evaluated in 24% of the studies, the PCM is of great interest to researchers, due to its efficiency in the thermal regulation of environments, as it changes from solid to liquid phase, by absorbing thermal energy during the day, which decreases the increase in ambient temperature. With climate change, due to pollutant gas emissions, and high energy consumption in production processes, the use of by-products to replace traditional materials is highly desirable, in this sample the straw bale was the material of 9% of the studies and the 7% hemp (Figure 3).

Figure 3: Wall building materials



Source: THE AUTHORS, 2020.

Table 04: Works on prototype analysis and laboratory evaluation

Author/Year	Rated Location	Building type	Climate Köppen	Period	Objective	Main results
Iwaro, J.; Mwasha, A. (2019)	Saint Augustine, Trinidad and Tobago	Prototype	Am	Summer	Evaluate coconut fiber as a thermal insulator to obtain energy efficiency and thermal comfort.	Coconut fiber has the necessary attributes to maintain thermal comfort and improve the energy efficiency of homes. Coconut fiber was able to improve the energy efficiency of buildings.
Hasan, M.I. *et al* (2018)	Al Kut, Iraq	Prototype	BWh	Summer	Experimentally investigate PCMs for thermal insulation of residential buildings.	The reduction in internal temperature using PCM was 2.18 ° C. Maximum electricity cost savings ($ 1.35 / day m3) when using 1 cm PCM thickness for all walls.
Li, Y. *et al* (2018)	Chengdu, China	Prototype	Cwa	Winter	Evaluate the thermal performance of walled buildings with PCM in a room with intermittent heating.	The heat release process from the PCM layer lasted 6-7 h after the heating was stopped. The heat flow from the internal surface of the PCM wall was 18.48% less than that of the reference wall in the heating process at all times
Rosso, F. *et al* (2017)	Perugia, Italy	Prototype	Cfa	Summer and winter	Develop innovative, cold-colored, cement-based materials to improve thermal performance.	Cold-colored materials can maintain lower surface temperatures (-8 ° C), while reducing energy demands for cooling (3%).
Kumar, A.; Suman, B.M. (2013)	Roorkee, India	Prototype	Cfa	Summer and winter	Experimentally evaluate Elastospray - insulating - for walls and roofs and its impact on internal thermal comfort.	The 50 mm thick Elastospray with conventional roof and wall satisfies local regulatory requirements, while other insulation materials require a higher thickness to meet the recommended values.
Garas, G., Allam, M. (2011)	Cairo, Egito	Prototype	BWh	Summer	Evaluate the thermal performance of straw bales walls.	Straw bale walls showed high temperature variation in the outer wall sensor, while in the inner wall sensor the temperature fluctuation was kept to a minimum.
De Grassi, M. (2006)	Ancona, Italy	Prototype	Cfa	Summer	Evaluate the thermal behavior of walls containing dry mounted PCM.	The solar radiation and the floor of the prototype are the two most statistically significant exogenous variables, with respect to the course of the temperature of the walls.

Author/Year	Rated Location	Building type	Objective	Main results
Abdo, P. *et al* (2020)	Laboratory	acrylic chamber	Investigate the PCM discharge process and variations in temperature and humidity inside a chamber equipped with a windcatcher.	The model with the PCM located on the floor, ceiling and walls, as well as in the entry channel of the windcatcher showed the best performance, with a minimum reduction in the average temperature in the chamber of about 2.75 ° C (approximately 9.33%) compared to the model without

				PCM.
Alioua, T. *et al* (2020)	Laboratory	Prism	Investigate the thermal performance of a bio-based concrete wall. Validate the numerical approach by comparison with experimental data.	The results showed that the new bio-based wall is very promising and can contribute to mitigate the variation in temperature and ensure thermal comfort in buildings.
Richardson, A. et al (2017)	Laboratory	Prism	Produce mortar incorporated with PCM to help regulate the internal temperature of buildings.	Mortar with PCM helps to regulate the temperature inside buildings, contributing to thermal comfort and reducing the amount of heating and cooling energy.
Am: tropical monsoon climate / Aw: Tropical Savannah / Cfa: humid subtropical / Cfb: temperate oceanic / BWh: Hot desert / Cwa: wet subtropical / ET: Tundra / Csa: Hot summer Mediterranean / Dwa: wet summer continental / Dfb: Cool summer wet continental / Dfa: Hot summer wet continental / Cwb: High altitude subtropical oceanic				

Source: THE AUTHORS, 2020.

Costantine, G. et al (2018); Moujalled, B. et al (2018) and Agliata, R. et al (2020) highlight the hemp's ability to dampen temperature variations in both winter and summer and confirm the material as a good thermal regulator.

According to Garas and Allam (2011); Elias-Ozkan and Summers (2013); Gallegos-Ortega et al (2017) and Moujalled et al (2018), construction with straw bales is advantageous with regard to thermal insulation properties, in addition to the energy incorporated and savings compared to conventional materials.

According to Parket al (2019) the melting temperature of the PCM of 25 ° C optimized the installation in all locations. Kaushik et al (1981) found that a PCM wall, although less thick than the common masonry concrete wall, is more desirable to provide thermal energy storage. Nghana and Tariku (2016); De Grassi (2006); Richardson et al (2017) and Abdo et al (2020) evaluated that the PCM achieved energy savings and reduced temperatures, due to the ability to decrease the heat flow from the wall. Hasan et al (2018) achieved a 2.2 ° C reduction in internal temperature with the use of PCM. The maximum savings in electricity cost was $ 1.35 / day m3 when using 1 cm of PCM thickness for all walls. According to Li, Y. et al (2018) the process of releasing heat from the PCM layer lasts 6-7 hours after the heating is stopped. The heat flow from the internal surface of the PCM wall was 18.5% less than the reference wall in the heating process at all times.

According to Medjelekh et al (2016) the results of three years of monitoring in a travertine stone house showed the effect of thermal inertia in guaranteeing a strong attenuation of the 10.2 K and 14.6 K thermal wave in hot climatic condition.

Jentsch, et al (2017) when evaluating ceramic walls, mud and cement-stabilized earth block, concluded that in terms of thermal transmittance values, the type of ceramic brick wall construction performed worse at 1.25 to 1, 45W / (m.K) than traditional mud walls at 1.1 to 1.2W / (m.K) and the cement-stabilized earth block construction technique at 1.05 to 1.25W / (m.K).

4.4 Types of building analyzed

The type of building most evaluated in the sample was residential with 59%, followed by prototype construction 16%, historical 9%, commercial building and laboratory analysis, both 7%, and institutional 2% (Table 5).

Table 5: Types of building analyzed

Research Study	Building type
Breçani, R.; Dervishi, S. (2019); Jannat, N. *et al* (2020); Amirzadeh, A. *et al* (2018); Park, J. *et al* (2019); Lee, J.; J. Park (2018); Moustafa, M.A. *et al* (2015); Hall, M.R. et al (2013); Asadi, E. *et al* (2012); van Hoof, J.; van Dijken, F. (2008); Li, Y., Holmberg, S. (1994); Hwang, T.I. *et al* (2019); Costantine, G. *et al* (2018); Costanzo, V. *et al* (2018); Moujalled, B. *et al* (2018); Gallegos-Ortega, R. *et al* (2017); Kaushik, S.C. *et al* (1981); Jentsch, M.F. *et al* (2017); Leo Samuel, D.G. *et al* (2017); Nghana, B.; Tariku, F. (2016); Hyde, R. *et al* (2016); Medjelekh, D. *et al* (2016); Kabre, C. (2016); Ibrahim, M. *et al* (2014); Ascione, F. *et al* (2015); Elias-Ozkan, S.T., Summers, F. (2013)	Residential
Aksamija, A.; Peters, T. (2017); Evola, G. et al (2013); Orosa, J.A.; Baaliña, A. (2009)	Commercial
Agliata, R. *et al* (2020); Aste, N. *et al* (2019); Odgaard, T. *et al* (2018); Varas-Muriel, M.J. *et al* (2014)	Historic
D'Agostino, D. *et al* (2018)	Institutional
De Grassi, M. (2006); Kumar, A.; Suman, B.M. (2013); Garas, G., Allam, M. (2011); Rosso, F. *et al* (2017); Hasan, M.I. *et al* (2018); Li, Y. *et al* (2018); Iwaro, J.; Mwasha, A. (2019)	Prototype
Abdo, P. *et al* (2020); Alioua, T. *et al* (2020); Richardson, A. *et al* (2017)	Laboratory

Source: THE AUTHORS, 2020.

4.5 Main technical standards used in the studies

The technical standards most used by the sample researchers were: ASHRAE 55: 2004, which assesses the thermal environmental conditions for human occupation, represents 25% of the works; ASHRAE 90.1: 2013 that sets the energy standard for buildings, except low residential buildings, corresponds to 14% of studies; the European EN 15251: 2008 for internal environmental input parameters for the design and assessment of the energy performance of buildings that address indoor air quality, thermal environment, lighting and acoustics constitutes 11% of the sample and the international ISO 13788: 2012 for methods of calculating hygrothermal performance of components and building elements and internal surface temperature to avoid critical surface moisture and interstitial condensation in 9% of the articles (Table 6).

Table 6: Technical standards

Standard	Work (research)
ASHRAE 55: 2004	Lee, J.; Park, J.(2018); Belmonte, J.F. *et al* (2015); Ascione, F. *et al* (2015); Moustafa, M.A. *et al* (2015); Asadi, E. *et al* (2012); Hasan, M.I. *et al* (2018); D'Agostino, D. *et al*(2018); Medjelekh, D. *et al* (2016); Nghana, B. *et al* (2016); Ascione, F. et al (2015); Moustafa, M.A. *et al* (2015)
ASHRAE 90.1: 2013	Park, J. *et al* (2019); Amirzadeh, A. (2018); Lee, J. *et al* (2018); Jentsch, M.F. *et al* (2017); Aksamija, A. *et al* (2017); Elias-Ozkan, S.T. *et al* (2013),
EN 15251:2008	Leo Samuel, DG. *et al, (*2017); Evola, G. *et al*, (2013); Costanzo, V. (2018); Moujalled, B. *et al*, (2018); Medjelekh, D. *et al* (2016); Ascione, F. *et al*, (2015)
ISO 13788: 2012	Agliata, R. *et al* (2020); Hwang, T.I. *et al* (2019); Moujalled, B. (2018); Odgaard, T. *et al* (2018)

Source: THE AUTHORS, 2020.

5. CONCLUSION

The articles included in this review, restricted to the areas of Architecture and Urbanism, Social Sciences, Arts and Humanities, indexed in the Scopus and Web of Science databases, regarding the influence of different types of wall materials on the thermal comfort of buildings, presented information relevant on the subject. Through this study, it was possible to identify the main forms of analysis of thermal comfort in buildings. In general, 39% of the studies evaluated the thermal comfort of buildings through measurements in place, 39% by computer simulations, 15% in prototype construction and 7% in laboratory analysis, which were conducted according to technical standards, with emphasis on ASHRAE 55: 2004 which assesses the thermal environmental conditions for human occupation.

The assessments were developed mainly in residential buildings, however, only one survey was identified that evaluates institutional building (school). Knowing what types of buildings are evaluated allows you to find research gaps.

There is also a trend towards the use of computer simulation, which can be useful in helping to identify the most convenient materials. In the most embracing studies, this analysis was complemented with monitoring, thus covering the project periods before and after occupation.

In addition to the discomfort and energy deficiency itself, specific factors associated with thermal discomfort can have a negative impact on the quality of life of building occupants. But most of these problems can be avoided or minimized with the application of materials suitable for wall construction, which is one of the best alternatives to achieve the condition of internal thermal comfort of buildings. The choice of wall materials with low thermal conductivity, for example hemp, straw bales and heat-absorbing materials, is part of these alternatives.

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