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A Review Paper on Thermal Comfort and Ventilation Systems in Educational Buildings: Nano-Mechanical and Mathematical Aspects

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Thermal comfort has always been an essential factor that affects students' productivity and success. Students spend considerable time at their schools or universities more than any other building type except their homes. Thus, indicating the importance of providing thermal comfort in educational buildings. Many studies worldwide are conducted to assess and optimize thermal comfort inside classrooms. However, the results have not been accurate even for similar study conditions due to the differences in the studies' conditions. This paper focuses on thermal comfort studies in educational buildings (classrooms). The studies are divided into two sections, the first covering field studies methodologies, objective, and subjective questionnaires, and the second reviewing thermal comfort results based on the climatic zone, educational level, and analysis approach. It is recommended that thermal comfort studies be carried out using rational and adaptive models as they provide more accurate, reliable results. Also, it is found that thermal comfort standards are generally inadequate to assess thermal comfort in classrooms. Thus, other international standards should be created and considered for classroom assessment. Over the past few years, the combination between nanotechnology and architecture engineering has been widely used in several disciplines because of its crucial significance in finding new nanodevices to contribute in reducing of energy consumption, particularly on construction materials. Filling functionalized tools with nanoparticles plays a critical role in improving the thermal and optical properties, particularly with respect to nanofluids applications, i.e., buildings applications of thermal comfort. The experimental results of long-term studies show that the calculation values of optimization have a consistent agreement with the experimental transmission of nanofluids models.

KEYWORDS: Thermal Comfort, Ventilation System, Educational Systems, Diffusion Rate, Temperature, Energy Consumption.

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1. INTRODUCTION

Educational classrooms consume a large amount of energy usage.[1] A significant amount of this energy provides thermal comfort to occupants. Thermal comfort is an essential factor in the indoor environment, especially in educational buildings, as it affects occupants' performance and productivity in their everyday tasks for both instructors and students. Thus, research on thermal comfort in educational buildings has been considered essential worldwide.[2–4] Nanofluids techniques can be widely used in many applications to increase the efficiency of systems or processes

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by improving thermal and optical properties and heat transfer performance.[5–13] Long-term studies of nanofluids have intensively addressed several manufacturing methods, Performance of heat transfer, fundamental characteristics, the behavior of transportation, and the practical application of existing equipment to improve efficiency, i.e., diagnostic and disease therapy,[14,15] by using the carbon nanomaterials as catalysts because of their unique properties, such as ease of cellular uptake, high rotational and reflective symmetry.

Thermal comfort models are divided into two main categories, namely rational models and adaptive models. Rational models[16] were developed by Fanger (1970), using heat-balance equations and empirical methods of skin temperature to define comfort, known as the predictive mean vote equations (PMV), and predicted percentage of dissatisfied (PPD). Adaptive models[17] are based on the idea that the outdoor temperature affects the indoor temperature as people adapt to different temperatures at different times of the year. Thermal adaptation has been divided into three categories, namely, behavioral, physiological, and psychological. Fanger rational model is used to study the thermal comfort of college students under steady-state conditions. However, many studies have agreed that this model could not accurately assess thermal comfort in actual classroom conditions.[18,19] Later, the adaptive thermal comfort model was introduced, and many studies were conducted to improve the adaptive models by establishing quantitative indexes that enhance occupants' thermal comfort.[20] Several studies have assessed the thermal comfort model in classrooms and investigated students' adaptive behaviors. Based on field study, several comfort equations have been established, considering the indoor temperature and the monthly outdoor temperature.[21] Thermal environment requirements need specific thermal comfort studies due to the differences in the occupation periods, occupant's clothing and activity, temperature change, and the level of freedom for adaptive actions.[22]

Assessment of thermal comfort is based on comfort standards, namely, ISO 7730, EN 15251, ASHRAE 55, as they have provided values for operative temperatures and comfort equations based on rational and adaptive thermal

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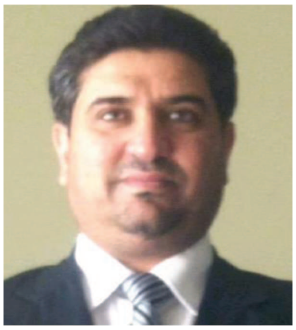

Hakim Al Garalleh was born on 31th of May 1980, had achieved the Bachelor degree in 2003. I then got job to work as a teacher in the Ministry of Education since 2003 till 2007. In 2007, I got an acceptance to do the Master degree in Applied Mathematics then it was done 2009. The step after, I started my Ph.D. which focuses on studying modelling in Nanobiotechnoloyg applications. Interestingly, we investigate the usefulness of carbon nanostructures for drug delivery and diseases. I have achieved 20 distinct publications in very high class journals and still working on new journal publications in the field of nanotechnology. I have been working as a lecturer and researcher since 2014 at the college of Engineering, University of Business and Technology, Saudi Arabia.

Table I. Thermal comfort standards in classrooms.

Standard	Thermal comfort approach	Operative Temperature °C Winter	Summer
ISO 7730 (2005)	Rational $-0.5 < PMV < 0.5$ PPD < 10	20–24	23–26
ASHARAE (2004)	Rational $-0.5 < \mathrm{PMV} < 0.5$ PPD < 10	20.5–25.5	24.5–28
EN-15251 (2007)	Adaptive	$T_n = 0.302\ \mathrm{TMRT} + 19.39$; TMRT > 10	$T_n = 22:88$; TMRT ≥ 10
ASHARAE (2010)	Adaptive	$T_n = T_0 + 17.8$	

Notes: TRMT: Running mean temperature T_0: Outdoor temperature T_n: Neutral temperature $T_n = 0.31T_0 + 17.8$ PMV: Predicted mean vote.

comfort models (Table I). Many thermal comfort studies of educational buildings have appeared in the literature, especially in Asian and European countries. These studies have been reviewed considering different thermal comfort issues. Thermal comfort studies on various buildings have been reviewed carefully over the last five decades. Van Hoof published a review article focusing on Fanger's theory.[22] Djongyang et al. and de Dear et al. wrote a general review paper discussing thermal comfort studies' development for the last 20 years.[23,24] Adaptive thermal comfort studies have been reviewed by Halawa and Van Hoof.[25] Mishra and Ramgopal published a review paper based on field surveys focusing on climatic zones.[21] Khodakarami and Nasrollahi discussed studies of thermal comfort in hospitals.[26]

Studying thermal comfort productively in classrooms utilizes the study method that compares previous studies. First, the studies are categorized and reviewed based on climate, educational level, and the thermal comfort approach. Second, the limitations of thermal comfort standards and approaches are discussed, and the effect of structural, constructional, and mechanical factors on thermal comfort are considered. Finally, recommendations are provided for future studies on thermal comfort in classrooms.

With respect to the nanotechnology applications, the usefulness of ideal glaze system plays a significant role in increasing the efficiency of energy consumption by manipulating in the optical thermal properties, especially in the classrooms and offices building[3,16,20] such the glass treated at the nanoscale sizes. A nanometer is a billionth of a meter, this means that it is very tiny as equal as the length of 10 hydrogen atoms or approximately 105 of the hair width. Functionalized nanomaterials used to improve the optical and thermal properties of treated glass by reducing the cost and consumption of energy.[25,27,28] The results obtained from the theoretical and experimental studies show that these nanomaterials have attained the prosperous target to replace the traditional techniques which formerly used to create an appropriate indoor environment.

In this paper, hundreds of papers on thermal comfort studies in educational buildings (classrooms), published from 2000 to 2020 in peer-review scientific journals, are reviewed. We also outline the long-term studies concerning the correct use of treated glass with nanotechnology techniques, i.e., glaze system. Each study is categorized based on the year of study, study country, climatic zone, ventilation type, thermal comfort model, number of subjects, and the study season.

2. LITERATURE REVIEW

In this study, the reviewed papers are limited to thermal comfort studies in classrooms, as shown in Table II. The studies have been categorized based on the climatic zone, educational level, analysis approach, year of study, country, continent, ventilation type, number of subjects, and the season of study, see Table II. The relationships based on the similarities, differences of the studies, and the parameters involved in Table II, have been statistically analyzed using graphs and percentages. However, due to the differences in the studies' parameters, there is no logical way to establish a general thermal comfort model; instead, a general conclusion is derived based on all these studies.

The reviewed papers have been carried out over the last two decades. Energy-efficiency issues in buildings have been considered increasingly in these studies. The studies were primarily carried out in Asia and Europe over differences in climate and cultures. The studies are reviewed in two sections; the first reviewing field studies methodologies, including subjective and objective surveys, the second reviewing the study's results based on the climatic zone, educational level, and analysis approach.

2.1. Field Study Methodologies

Field studies are one method to assess thermal comfort in buildings. Field studies depend on subjective and objective surveys that are done according to the regulations of ASHARE 55 and ISO 7730. The study duration may vary from one week to a whole-year study.[29–31] Linear regression is commonly used to analyze the interrelation between objective and subjective data.[17] There are many differences in the studied classrooms. The differences are classified as

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Table II. Summary of obtained results of reviewed studies.

Level of education											Comfort band				Method used	
P	H, S	U	Ref.	Year	Country	Continent	Climate	Ventilation strategy	Seasons	Size	L	Neutral	H	Thermal comfort models	Field M and surveys	Numerical and CFD
—	—	*	[46]	2011	Portugal	Europe	C	H.V.	—	25	—	—	—	Rational	F & S	N
*	*	—	[47]	2013	Italy	Europe	C	N.V.	S & W	4000	—	—	—	Rational	F & S	—
—	—	*	[80]	2018	Mexico	North America	A	A.C.	S	496	—	24.7	24.4	Adaptive	F & S	—
								N.V.			—	26.9	29.3			
—	—	*	[28]	2015	Egypt	Africa	B	N.V.	Sp	269	—	29.1	—	Rational	F & S	—
—	—	*	[103]	2017	Algeria	Africa	B	H.V.	S	—	—	—	—	—	F & S	—
—	—	*	[52]	2019	USA	America	C	HVAC	S	1336	22	23.5	24.5	Adaptive	F & S	—
—	—	*	[81]	2017	Malaysia	Asia	A	M.V.	S	1428	—	26.5	—	Both	F & S	—
					Japan	Asia	C	MV.		—	26.3	—				
*	*	—	[104]	2019	Jordan	Asia	B	H.V.	F	1836	24	—	27.5	Both	F	N
—	—	*	[29]	2017	France	Europe	C	H.B., N.V., HVAC	S.P., S, W	452	—	21.7	—	Rational	F & S	N
*	*	*	[42]	2016	Portugal	Europe	C	N.V, M.V.	Sp	487	—	—	—	Both	F & S	—
—	*	*	[105]	2017	Saudi	Asia	B	N.V	S, W	—	—	—	—	—	F	N
—	—	*	[82]	2015	Malaysia	Asia	A	A.C.	F, W	71	—	—	—	—	F & S	—
—	—	*	[56]	2019	Turkey	Europe	C	N.V.	W, Sp	600	—		—	Rational	—	N
—	—	*	[53]	2014	USA	America	C	HVAC	—	320	—	—	—	—	S	—
					Lebanon	Asia	C									
—	—	*	[83]	2013	Malaysia	Asia	A	HVAC	—	188	—	23.4	—	Rational	F & S	—
—	—	*	[1]	2013	The U.K.	Europe	C	N.V.	W	78	—	—	—	—	F	N
*	*	—	[24]	2020	Argentia	South America	C	N.V.	S, W	—	W: 20	—	25	—	F	N
											S: 25	—	29			
—	—	*	[87]	2018	Brazil	South America	A	H.V.	All	468	—	—	—	—	F	—
—	—	*	[88]	2019	Brazil	South America	A	H.V.	S	1590	—	24.8	—	—	F	—
—	—	*	[9]	2009	Italy	Europe	C	HVAC+N.V.	W, Sp, F	—	—	—	—	Both	F & S	—
—	—	*	[48]	2009	Italy	Europe	C	N.V., M.V.	Sp, F	160	—	—	—	Both	F & S	—
—	—	*	[89]	2019	Brazil	South America	A	H.V.	—	—	—	—	—	—	F & S	—
*	—	—	[49]	2017	Italy	Europe	C	H.V.	S, W	—	—	—	—	Adaptive	—	N
—	—	*	[17]	2013	Portugal	Europe	C	N.V.	Year	732	—	—	—	Both	F & S	—
*	—	—	[30]	2014	Italy	Europe	C	—	Sp, W	62	—	—	—	Rational	F & S	—
—	*	—	[31]	2014	Portugal	Europe	C	N.V., M.V.	Sp	—	—	—	—	Rational	F & S	—
—	*	—	[32]	2017	Portugal	Europe	C	N.V.	2- Years	—	—	—	—	—	F & S	—
—	—	*	[102]	2018	Egypt	Africa	B	H.V.	—	—	—	—	—	Rational	F & S	N
—	—	*	[19]	2018	China	Asia	C	N.V.	W, S	15	—	—	—	Adaptive	F & S	N
—	—	*	[60]	2018	China	Asia	C	A.C.	—	982	21.56	24	26.75	Rational	F & S	—
—	—	*	[61]	2015	China	Asia	C	H.V.	—	48	—	—	—	Rational	F & S	—
—	—	*	[62]	2016	China	Asia	C	A.C.	S	479	26.08	25.02	25.61	Adaptive	F & S	—
—	*	—	[65]	2018	Cyprus	Europe	C	N.V.	S	—	—	—	—	Adaptive	F & S	—
—	*	—	[33]	2019	Cyprus	Europe	C	N.V.	W	—	—	—	—	Adaptive	F	—
*	—	—	[67]	2015	Taiwan	Asia	C	N.V.	S	—	—	—	—	Adaptive	F & S	—
—	—	*	[84]	2013	Malaysia	Asia	A	A.C.	—	238	—	21.1, 25.2	—	Rational	F & S	—
*	—	—	[25]	2018	China	Asia	C	A.C., H.V.	W	12	—	15	—	Rational	F & S	N

Table II. Continued.

Level of education											Comfort band				Method used	
P	H, S	U	Ref.	Year	Country	Continent	Climate	Ventilation strategy	Seasons	Size	L	Neutral	H	Thermal comfort models	Field M and surveys	Numerical and CFD
—	—	*	[63]	2019	China	Asia	B	M.V.	W	40	—	19	—	Rational	F & S	—
—	*	—	[66]	2014	Cyprus	Europe	C	HVAC	Year	—	—	—	—	Rational	F & S	—
—	—	*	[69]	2010	Korea	Asia	C	M.V.	S, W	30	—	—	—	Rational	F	N
*	*	—	[20]	2018	Australia	Australia	C	N.V., H.V.	S	4866	—	24.4	—	Adaptive	F & S	—
*	*	—	[21]	2017	Denmark	Europe	C	M.V.	—	—	—	—	—	Rational	F	N
—	—	*	[106]	2018	India	Asia	B	N.V.	S	—	21.8	26.4	31.8	Adaptive	F & S	—
—	—	*	[90]	2018	Singapore	Asia	A	H.V., N.V, A.C.	2 Years	1043	—	29.5, 27.8, 26.7	—	Both	F & S	—
—	—	*	[57]	2016	The U.K.	Europe	C	N.V., HVAC	S	50	—	—	—	Rational	F & S	—
*	*	—	[68]	2012	Taiwan	Asia	C	N.V.	All	1614	—	26.9, 22.4	—	Adaptive	F & S	—
—	—	*	[34]	2019	China	Asia	C	N.V.	F	992	19.5	20.6	21.8	Rational	F & S	—
—	—	*	[64]	2016	China	Asia	C	N.V., HAVC	S, W	42	—	—	—	Adaptive	F & S	—
*	—	—	[73]	2017	Spain	Europe	C	HAVC	S.P., F, W	132	—	—	—	Rational	F & S	—
—	—	*	[35]	2018	France	Europe	C	HAVC	All	41	—	—	—	Rational	F & S	—
—	—	*	[92]	2014	India	Asia	A	N.V.	Sp	338	19.4	26.6	33.7	Adaptive	F & S	—
—	—	*	[93]	2014	India	Asia	A	N.V.	Sp	112	—	26.5	—	Adaptive	F & S	—
—	—	*	[18]	2015	India	Asia	A	N.V.	Sp, F	82	22.1	29	31.5	Adaptive	F & S	—
—	—	*	[36]	2017	Netherlands	Europe	C	HAVC	S	384	—	—	—	Adaptive	F & S	—
*	—	—	[58]	2016	The U.K.	Europe	C	N.V.	W	662	21	—	24	Adaptive	F & S	—
*	—	—	[7]	2011	Netherlands	Europe	C	A.C.	W, Sp, S	79	—	—	—	Adaptive	F & S	—
—	*	—	[37]	2009	The U.K.	Europe	C	H.V., MV, NV	W	—	—	—	—	Rational	F & S	—
—	—	*	[54]	2016	Japan	Asia	C	A.C.+M.V.	S	26	—	26.6	—	Adaptive	F & S	—
*	*	—	[96]	2017	Madagascar	Africa	A	N.V.	Sp, F	25	24.6	25.3	28.4	Adaptive	F & S	N
—	—	*	[50]	2015	Italy	Europe	C	HVAC	Sp	126	—	—	—	Both	F & S	—
—	—	*	[109]	2019	China	Asia	D	HVAC	F, Sp,W	30	20	21.5	24	Both	F & S	—
—	*	—	[22]	2016	Greece	Europe	C	N.V.	W	19	—	—	—	Rational	F & S	—
—	*	—	[51]	2015	Italy	Europe	C	N.V., HVAC	Sp, S,W	130	21.83	—	25.83	Both	F & S	N
—	—	*	[97]	2015	Thailand	Asia	A	A.C.	—	660	27.6	28.0	28.5	Rational	F & S	
—	*	—	[85]	2012	Malaysia	Asia	A	N.V.	—	60	—	—	—	—	S	—
—	*	—	[86]	2014	Malaysia	Asia	A	—	—	917	—	—	—	—	S	—
—	—	*	[98]	2017	Indonesia	Asia	A	—	—	55	—	—	—	—	F & S	—
—	—	*	[107]	2018	India	Asia	B	N.V.	S	900	21.8	26.5	32.1	Adaptive	F & S	—
—	*	—	[38]	2017	Italy	Europe	C	N.V.	W, Sp	—	—	—	—	Adaptive	F & S	—
—	—	*	[94]	2018	India	Asia	A	H.V.	S	180	—	28.6	—	—	F & S	—
*	—	—	[114]	2012	UK	Europe	D	N.V.	Sp, S	230	20	—	23	Both	F & S	—
*	—	—	[59]	2017	UK	Europe	C	N.V.	Sp, S	—	—	22.6	—	Adaptive	F & S	—
—	—	*	[95]	2016	India	Asia	A	N.V.	Year	356	—	—	—	Both	F & S	—
—	—	*	[75]	2019	India	Asia	C	N.V.	Year	436	—	—	—	—	F & S	—
*	—	—	[76]	2017	Chile	South America	C	N.V.	Sp, W	440	14.7	—	23.1	Adaptive	F & S	—
*	—	—	[39]	2017	Slovakia	Europe	D	HVAC	F	34	—	—	—	Rational	F & S	—
*	—	—	[40]	2013	Germany	Europe	C	N.V.	Sp, W	—	—	—	—	—	F & S	CFD

Table II. Continued.

Level of education											Comfort band				Method used	
P	H, S	U	Ref.	Year	Country	Continent	Climate	Ventilation strategy	Seasons	Size	L	Neutral	H	Thermal comfort models	Field M and surveys	Numerical and CFD
—	*	—	[78]	2015	Germany	Europe	C	HVAC	S, W	—	18	—	24	—	F & S	N
—	—	*	[110]	2016	China	Asia	D	N.V.	W	30	—	17.7, 19.3,19.4	—	Adaptive	F & S	—
											—	20.9, 21.8,21.2	—			
*	*	—	[113]	2017	China	Asia	D	HVAC	F, W	1126	—	14.2, 14.9	—	Both	F & S	—
											—	13.4, 14.4	—			
*	*	—	[111]	2018	China	Asia	D	HVAC	S	30	—	26.5	—	Rational	F & S	—
*	—	—	[41]	2018	Sweden	Europe	D	HVAC	Year	150	—	—	—	Rational	F & S	—
—	—	*	[116]	2010	China	Asia	C	N.V.	Year	3000	—	—	32.15	Adaptive	F & S	—
*	—	—	[70]	2014	Korea	Asia	C	N.V.	Sp, S	119	23	—	26	Rational	F & S	—
*	—	—	[74]	2009	Netherlands	Europe	C	H.V.	W	—	—	—	24	Rational	F & S	—
*	*	*	[71]	2015	Australia	Australia	C	HVAC	—	—	—	—	—	Rational	F & S	N
—	—	—	[26]	2017	China	Asia	D	HVAC	S	—	—	—	—	Adaptive	—	N
—	—	*	[27]	2018	Ireland	Europe	C	HVAC	Year	394	—	—	—	Rational	F & S	—
—	—	*	[115]	2019	Canada	North America	D	H.V.	F, Sp	—	—	—	—	Rational	F	CFD
*	*	—	[72]	2015	Australia	Australia	C	H.V.	S	2129	19.5	22.5	26.6	Both	F & S	—
*	—	—	[23]	2015	Greece	Europe	C	N.V.	Sp	193	—	23.5	—	Rational	F & S	—
—	—	*	[112]	2011	China	Asia	D	A.C.	W, S	205	24.1	—	29.7	Rational	F & S	—
—	—	—	[99]	2012	Ghana	Africa	A	N.V.	S	116	—	—	—	Adaptive	F & S	—
—	—	—	[108]	2009	Kuwait	Asia	B	A.C.	All	336	—	21.6	—	Both	F & S	—
—	—	*	[100]	2008	Nigeria	Africa	A	N.V.	S	200	24.88	26.27	27.66	Both	F & S	—
—	*	—	[91]	2003	Singapore	Asia	A	N.V.	S	493	—	26.1	—	Rational	F & S	—
—	*	—	[101]	2003	Japan	Asia	A	N.V., A.C.	S	74	—	—	—	Both	F & S	—
*	—	—	[77]	2014	Chile	America	C	N.V.	W, S	2100	16.7	—	21.1	Adaptive	F & S	—
—	*	—	[79]	2000	Brazil	America	C	N.V.	All	28	20.7	—	25.2	Rational	F & S	—
—	—	—	[55]	2002	Japan	Asia	C	A.C.	All	40	—	25.6	—	Rational	F & S	—

constructional, including thermal envelop properties, architecture such as dimensions of the room, windows, and mechanical, which deals with the type of ventilation system used.

2.1.1. Subjective Survey

Field studies are generally based on subjective surveys. Surveys that describe people's thermal experiences are collected from subjects to reach a general conclusion. Early surveys only considered questions on thermal sensation and subjects' preference; however, currently, questions about air velocity and dryness have been provided. Surveys tend to use descriptive scales such as the most common seven-point scale by ASHRAE, which is used to assess thermal sensation, and the three-point McIntyre scale, which is used for thermal preference and checklists, are used for subjects clothing and activity levels.[21] Different surveys are used with no specific rules regarding the number of respondents or the surveys' time duration.[21] The number of respondents in the reviewed papers differed from 15[32] to 4866.[33] The variables are assessed according to ASHRAE 55 and ISO 7730 standards.

2.1.2. Objective Survey

Objective surveys are used based on the study's purpose, and it is carried out by measuring the general thermal comfort parameters, including human parameters, i.e., the metabolic rate and activity level, and the environmental parameters, i.e., air temperature, air velocity, relative humidity, and the radiant temperature. These parameters are used to calculate thermal comfort indices such as the predicted mean vote (PMV), effective temperature (E.T.), and operative temperature (Top) at one point using the heights 0.1, 0.6, and 1.0 m, although some studies have used different heights such as 1.2, 1.3, 1.7, and 2.3 m.[34, 35] In addition to general comfort parameters, several studies, as shown in Table II, have also investigated illumination levels[1, 36–40] and CO_2 concentration.[36, 38, 40–54] Only one study has measured local discomfort parameters such as draft risk, floor temperature, and radiant asymmetry.[55]

2.2. Field Study Results

The reviewed papers' main findings are generally summarized and presented into the following subsections, climatic zone, educational level, and analysis approach.

2.2.1. Climatic Zone

This section focuses on the reviewed papers, see Table II, based on the studies' climatic zone. The Köppen–Geiger climate classification system has been used to sort the reviewed thermal comfort field studies. The Köppen– climate classification system,[56] published by Wladimir Köppen (1884), was used as a climate classification system. Later, Ruodolf Geiger changed the system; thus, it is now called The Köppen–Geiger climate classification system.[57] The Köppen–Geiger climate classification system divides climate into five main climate groups; then, each group is divided into temperature patterns and seasonal precipitation. The five main climate groups are A (tropical), a climate with an average temperature of 18 °C or higher every month of the year with significant precipitation. B (Dry), which is defined by little precipitation, C (temperate), which has the coldest month averaged between 0–18 °C and at least one month above 10 °C. D (continental), which has at least one month averaged above °C ten and at least one month averaging below 0 °C, and E (polar), which has every month of the year averaging below 10 °C. Figure 1 shows the illustration map of the Köppen–Geiger climate classification.[58]

From the collected data (see Table II), it is observed that most of the studies (58%) were conducted in group C, temperate/mesothermal climates; including Portugal,[30, 44, 45, 55, 59] Italy,[9, 30, 38, 60–64] USA,[65] USA and Lebanon,[66] Japan,[67, 68] France,[42, 48] Turkey,[69] UK,[1, 50, 70–72] Argentina,[37] China,[32, 38, 47, 73–77] Cyprus,[46, 78, 79] Taiwan,[80, 81] Korea,[82, 83] Australia,[33, 84, 85] Denmark,[34] Spain,[86] Netherlands,[18, 49, 87] Greece,[35, 36] India,[88] Chile,[89, 90] Germany,[53, 91] Irland,[40] and Brazil.[92] Studies in group A, tropical/mega-thermal climates are the second (23%), which were carried out in countries including Mexico,[93] Malaysia and Japan,[94] Malaysia,[95–99] Brazil,[100–102] Singapore,[103, 104] India,[31, 105–108] Madagascar,[109] Thailand,[110] Indonesia,[111] Ghana,[112] Nigeria,[113] and Japan.[114] The third (10%) are the studies conducted in group B, dry (semi-arid and arid) climate including Egypt,[54, 115] Algeria,[116] Jordan,[117] Saudi Arabia,[118] China,[76] India,[119, 120] and Kuwait.[121] Only nine studies were conducted in group D; the continental/microthermal climates, including China,[39, 122–126] UK,[127] Slovakia,[52] Sweden,[54] Canada.[128] No studies of thermal comfort in classrooms were found in group E, the polar and alpine climate. Table III provides the average lower, neutral, and higher comfort temperatures obtained for each climatic zone. Thermal comfort studies are carried out in both natural ventilation (N.V.) and air-conditioned (A.C.) classrooms during different seasons, although a few studies have been conducted throughout a whole year,[54, 79, 88, 108, 129] and one study lasted for two years.[103]

A considerable variation of neutral temperature is obtained in each climate since the studies were conducted in different seasons. The lowest neutral temperature has been reported in China and the highest found in tropical climates, Singapore, and Thailand. In group A, tral temperature is between 21.1–28.6 °C. The minimum was reported in the Winter in Malaysia and the maximum in India, 19–29.1 °C in group B in China and Egypt, 15–26.9 °C in group C in China and Taiwan, 13.4–26.5 °C in China. Studies noticed that the preferred temperature is not necessarily the neutral thermal sensation for most respondents. A significant variance has been found in neutral temperatures under the same climatic zone since the

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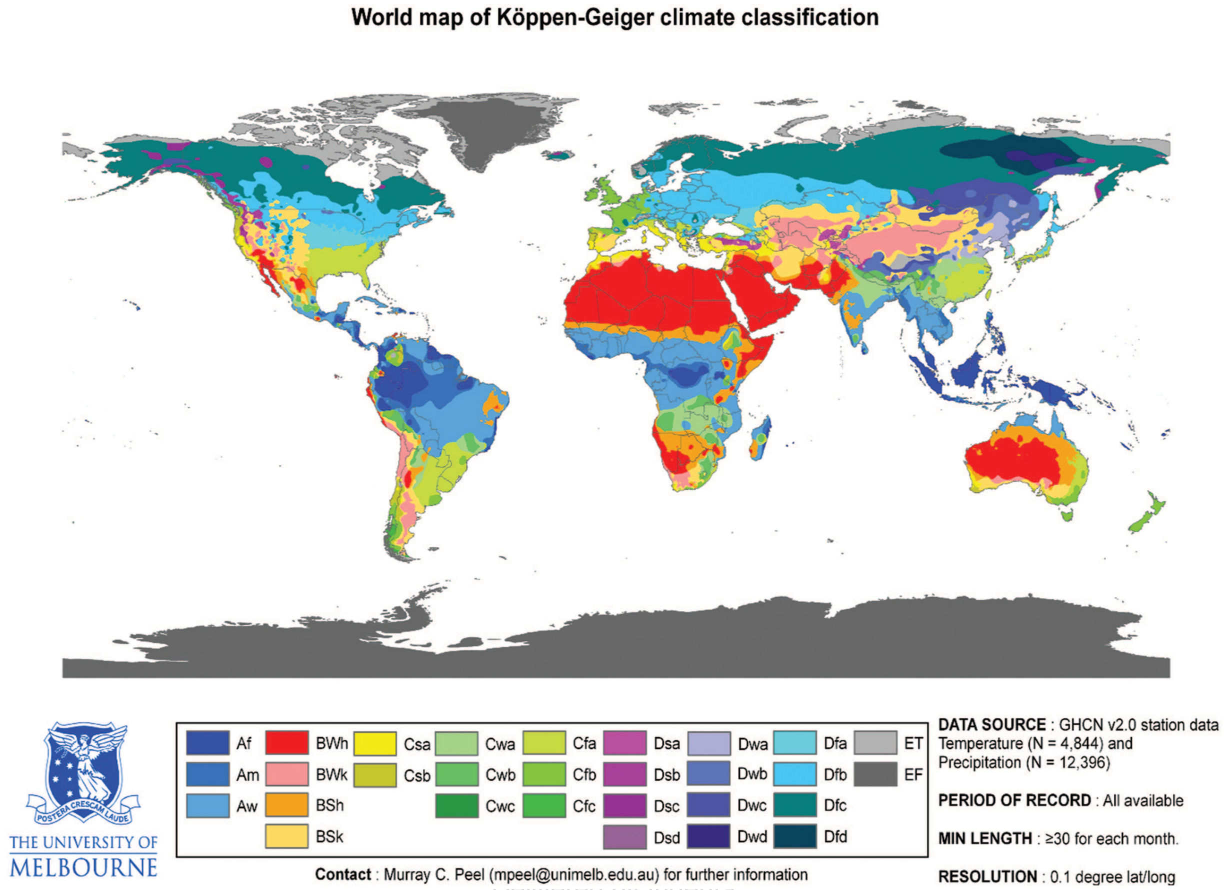

Fig. 1. The Köppen–Geiger climate classification.

studies were carried out in different seasons under different ventilation systems, thus comparing neutral temperature is not logical; however, it can be observed from the studies that neutral temperatures in Summer and Spring are higher than in Winter. In the studies conducted in group A, most of the studies were naturally ventilated through Summer. It is observed that students have adapted to higher temperatures, although the temperature has exceeded the comfort standards. Also, it is noticed that relative humidity has no significant effect on thermal comfort, although it is high in this group. This indicates the importance of considering passive cooling systems in this climate for energy saving. Studies carried out in group B are primarily conducted in air-conditioned and naturally ventilated classrooms during Summer and mid-seasons; only two studies were done during Winter.[76, 118] The neutral temperatures obtained from studies in group B are lower than in group A, and students have accepted higher thermal comfort levels in this climate. Studies in group C were mainly done in naturally ventilated classrooms during all seasons. Since various subtypes are included in group C, e.g., the humid subtropical subtype and Mediterranean subtype, a wide range of climates are available, granting a broad range of adaptability. Students from this climate are exposed to many weather variations showing higher thermal adaptability than those exposed to similar weathers. However, when the outdoor thermal conditions are higher than the average, such as in Taiwan[81] and Singapore,[103] students' thermal sensation is still neutral.

Table III. Neutral/comfort temperature for each climatic zone.

Climate versus Neutral/Comfort temperature			
Climate	Lower temperature (°C)	Neutral (°C)	Higher temperature (°C)
A	23.71	26.27	29.07
B	22.53	24.52	30.36
C	20.26	22.10	25.62
D	19.9	21.03	25.56

2.2.2. Educational Level

Since Fanger proposed his thermal comfort theory (1970), there has been a remarkable increase in thermal comfort studies in classrooms mainly through field studies. The two types of theories used in these studies are rational and adaptive. Thermal comfort results differ significantly in these studies due to the age difference, since different ages imply different metabolic rates and freedom levels, which significantly influence thermal comfort.

Hence, the reviewed studies are categorized into three groups of ages, primary level,[31–35] secondary and high school level,[23–26, 29, 30] and University level.[31–41] Among the studies, 56% have been conducted in universities, 44% carried out in primary, secondary, and high schools, or both, mainly in Asia and Europe. The average upper, lower limits, and neutral comfort temperatures obtained for each educational level shown in Table II are illustrated in Figure 2.

The first category studies thermal comfort in primary schools. Most studies were carried out in naturally ventilated classrooms with students aged 7–11 years old in climatic zone C; a few were done in the climatic zones D,[39, 52, 54, 126, 127, 130] and only one study was done in A,[109] during Winter and mid-seasons. The neutral temperature obtained across different climatic zones varies between 13.4–26.9 °C.

Three studies have been found in Italy; one supported Fanger's basic approach and proved its effectiveness in naturally ventilated buildings if the correct expectancy factor is available.[60] Enrico De Angelis proposed a simulation method based on a visual tool to support designers in assessing thermal comfort inside schools.[62] Valeria De Giuli performed a field study considering subjective thermal, air quality, and visual comfort responses. However, no exact correspondence has been found comparing students' sensations using this approach.[43] In China, Jing Jiang investigated the relationship between temperature and learning performance and found that setting PMV limits between −2 to −1 is preferable for optimal learning performance in a cold environment.[38] Dengjia Wang also studied the effect of temperature on learning performance in the Summer and suggested future work.[124] Dengjia Wang assessed thermal comfort in rural primary schools in Winter and provided recommendations for designing heating systems in rural schools in China.[126] Anxiao Zhang proposed an optimization method and found that the one-sided enclosed corridor type is the worst choice for saving energy and obtaining thermal comfort in cold climate.[34] In the U.K., Despoina Teli suggested children are sensitive to higher temperatures than adults when the temperature is 4 °C lower than the PMV.[127] He also highlighted the need to set higher school design standards based on children-based criteria.[72] Azadeh Montazami developed an

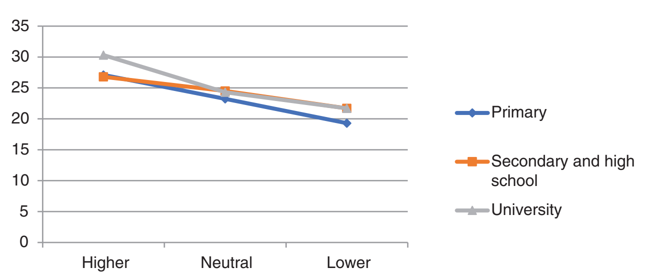

Fig. 2. Lower and upper comfort limits and the neutral comfort temperature in different educational levels.

algorithm that evaluates the dissatisfaction rates influenced by the indoor temperature as support for designers to control the classroom environment.[71] In Chile, Maureen Trebilcock found that thermal comfort temperature obtained from the field study was much lower than the one introduced by Humphreys formula, and the reason lies in the fuel poverty in children's homes, which motivates them to adapt to significantly low temperatures in Winter.[89, 90] Hikmat H. Ali compared the effect of envelopes of old and new schools in Jordan and found that both schools exceeded the comfort range level during peak hours.[117] In the Netherlands, Wim Zeiler investigated thermal comfort under thermo-active building systems and natural air supply and mechanical exhaust and found it could slightly improve thermal comfort in Winter.[87] Sander Ter Mors found that children prefer lower temperatures than the PMV model.[18] Modeste Kameni Nematchoua[109] found that the neutral temperature was 25.3 °C during rainy and dry seasons in the A climatic zone. In climatic zone D, Dengjia Wang[124] found the neutral temperature in the Summer 25.6 °C; in another study, he found the neutral temperature between13.4–14.9 °C in the Winter.[126] In the U.K., the neutral temperatures in the same climatic zone were between 20–23 °C.[127] It is noticed that most of the thermal comfort studies in primary schools are done in the climatic zone C. The lowest neutral temperature found was 15 °C reported in China,[38] and the highest was 26.9 °C reported in Taiwan.[81] Perhaps an appropriate explanation for lower temperatures found in the reviewed studies is the higher metabolic rates and the fact that children's schedules most likely include many outdoor activities.

The second category studies thermal comfort in secondary schools or high schools, targeting students the 12–18 years old. Most of the reviewed studies were conducted in countries inside the climatic zone C, including Italy, Argentina, Portugal, Cyprus, Australia, Denmark, Taiwan, U.K., Greece, Madagascar, Malaysia, Germany, China, Brazil, Ghana, Singapore, Japan, and Kuwait. Six studies were done in the climatic zone A, including Madagascar,[109] Malaysia,[98, 99] Ghana,[112] Singapore,[104] Japan.[114] Three studies were conducted in climatic zone B, including Jordan,[117] Saudi,[118] Kuwait,[121] and three studies as well were conducted in climatic zone D, all have been carried out in China.[39, 124, 126] Mainly, most of the studies were done during the Summer and Winter seasons, and although the ventilation type, climate, and season are like the first group in some cases, there are differences in the students' thermal sensation. The neutral temperatures in this group varied between 22.4–26.9 °C; only one study was done in the climatic zone D in China,[126] which was done for both primary and secondary schools that show lower neutral temperature, 13.4 °C.

The third group focuses on thermal comfort studies conducted in university classrooms. Fanger considered thermal comfort of Danish and American universities using climate chambers. There were differences in the predicted and the actual thermal sensation of the students, and it was observed that the neutral temperatures in classrooms were significantly higher in offices due to the differences in activities and clothes of students and officers.[22] Also, as this group studies university students' thermal comfort, other differences are noticed from the other studied groups as they spend less than 2–3 hours a day in classrooms. Hence, thermal perception is different. It is found from the reviewed states that the number of thermal comfort studies in university classrooms is higher than the other categories, and most of the studies are conducted in the climatic zones C, A, mainly in Asia. The neutral comfort temperature in these studies varied between 19 °C reported in China[76] to 29.5 °C reported in Singapore.[103]

2.2.3. Analysis Approach

The reviewed studies use both rational-RTC (37%) and adaptive-ATC (29%) models, and indeed as shown in Table II, there has been an increase in the use of the adaptive approach in recent years. Moreover, several studies (17%) use both methods to assess thermal comfort and compare them. Also, some studies (17%) considers comparisons of buildings, the impact of other comfort aspects, and other numerical methods involved with thermal comfort of educational buildings,[1, 37, 45, 53, 66, 88, 91, 95, 99, 100, 102, 107, 111, 116, 118, 131, 132] illustrated in Figure 3.

Rational thermal comfort models (RTC) uses Fanger's method, which provides very close results to the actual thermal, thermal votes in spaces that use heating, ventilation, and air-conditioning systems (HVAC), occupant's passive behavior, and fixed clothing,[63] however, adaptive models (ATC) only considers the outdoor temperature. Over the years, researchers have realized that some specifications should be added to the RTC model to keep it more accurate; thus, they considered the difference of expectation among people who are not used to occupying air-conditioned spaces, considering the behavioral, physiological, and psychological adaptations. As a result, they proposed the "ePMV," "aPMV," and "cPMV" indexes expand the use of the PMV model, even in non-airconditioned spaces using the expectancy factor and the adaptive coefficient.[29, 133, 134] A good agreement has been found from the reviewed studies in classrooms that have applied this improvement between the predicted and subjective results in Winter and Summer.[68] Among all the reviewed studies, the RTC method has been used in most universities, and most studies carried out in secondary and high schools used both RTC and ATC. It is observed that 37.9% of the studies carried out in primary schools have used the RTC model; the same percentage has been found using the adaptive model; only five studies have used both models. In secondary and high school studies, 34.6% used RTC, while 38.5% used the adaptive model, and five studies used both models. In universities, 36% used the rational model, 27.4% used the adaptive model, and 17.6% used both models.

The accuracy of the PMV model and the adaptive models has been criticized in several studies. These papers show a high level of disagreement between the PMV, adaptive model, and the students' actual thermal sensation, expressed as over-estimation and under-estimation, in all educational levels and climatic zones. Estimation details are illustrated in (Figs. 4 and 5). Results revealed a significant number of climatic zone C studies. The rational and adaptive models have underestimated the students' actual thermal sensation and an equal percentage of studies in all climatic zones, which shows that the models have overestimated the results. The overestimation of the models has been found more in primary and university studies, while underestimation is reported in most secondary and high school papers. Generally, incompatibility has been found vastly in temperate and tropical climates. However, the compatibility of the results with thermal sensation votes has been reported in many universities' thermal comfort studies.

Some results show that students adapt to the local climate and display adaptive behavior such as fans and window operations. However, the overall result concludes that human thermal sensation is dependent on both indoor and

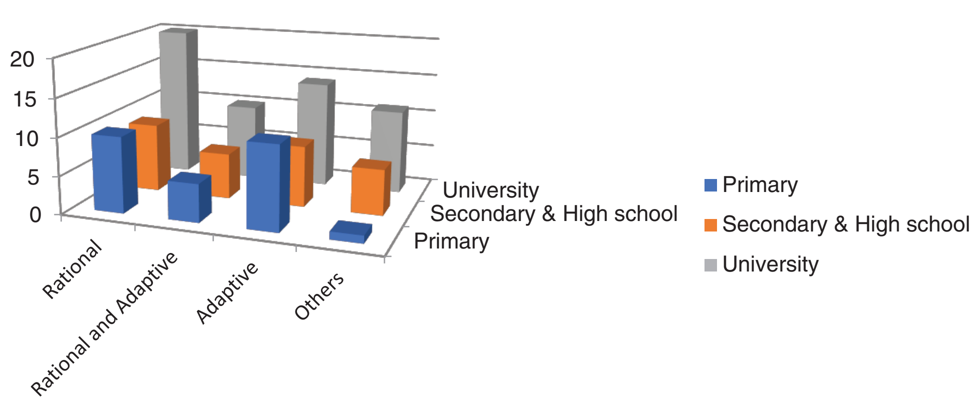

Fig. 3. The percentage of thermal comfort approaches in educational buildings.

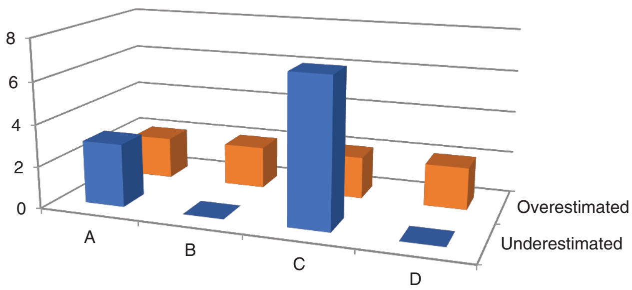

Fig. 4. Estimation of RTC & ATC in different climatic zones.

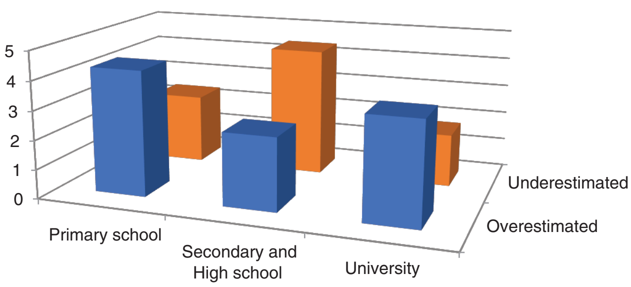

Fig. 5. Estimation of RTC & ATC in different educational buildings.

outdoor climates. Thus, the adaptive model may not accurately predict students' thermal sensation since their adaptive actions are limited.

3. DISCUSSION AND FUTURE RESEARCH

Long-term studies indicate that thermal comfort is an essential parameter for indoor environmental quality as it affects students' performance, as shown in Table II[87, 135] and university's energy consumption.[136] There has been rapid interest in low energy in educational buildings worldwide over the last five decades; however, thermal comfort studies in offices and residential buildings were way more. Also, doubts in comfort temperatures due to applying thermal comfort models and standards over different designs have resulted in unclear conclusions. This section presents discussions of the reviewed thermal comfort studies and future work recommendations in two main subsections; thermal comfort approaches and standards and confounding parameters involved with thermal comfort field studies.

3.1. Thermal Comfort Approaches and Standards

The rational (RTC) and the adaptive (ATC) models have been used in the reviewed studies to assess thermal comfort in educational buildings. Despite the enormous number of studies on thermal comfort in the literature, the reviewed papers reveal that neither approach can accurately predict students' thermal comfort. Van Hoof suggested that to improve the efficiency of the RTC model in evaluating thermal comfort in naturally ventilated buildings, clothing and activity levels should be considered.[137] Especially for students, an adaptive mechanism significantly influences thermal comfort.

The adaptive thermal comfort model (ATC) has been developed to keep occupants thermally comfortable by changing their activities, clothing insulation, and actions such as adjusting the heating or cooling mechanical devices or opening and closing windows. This model's basic idea is the control of occupants, which is, in some cases, limited in schools. Some studies stated that thermal classroom conditions are mainly controlled only by instructors, especially in primary schools.[19] The adaptive model's purpose is to allow the individual to have control based on his personal preference. It has been shown in many studies that personal preferences rely strongly on the occupant's thermal background.[138]

Moreover, recent studies report that nowadays, living standards with technology development have also raised students' expectations in schools. It is shown in the reviewed papers that people's neutral comfort temperatures have increased, and this is resulted by the heavy use of heating systems at homes; also, it is observed that comfort temperatures have decreased in hot seasons, which is a result of the increased use of air-conditioning.[138] Brager and de Dear encourage using both RTC and ATC models as complementary.[139] The reviewed studies have evaluated thermal comfort in classrooms according to thermal comfort standards, as shown in Table I, and indicated that these standards could not be used to assess thermal comfort in different climates. It is required to find common consent from all countries to make the ordinary faithful and international[140] so that thermal comfort is assessed using new databases. The adaptive model standards have benefited energy consumption; however, they are based on many boundaries.[141]

As shown in Table II, most of the reviewed papers have used thermal comfort indices, such as the PMV and Top and equivalent temperatures, to evaluate students' responses. In addition, long-time indices have been used in building in constant time and space.[142] Future work on thermal comfort in schools could consider using spatial limitations over students' occupation time as students sit in a specific position in their classrooms.

3.2. Confounding Parameters in Thermal Comfort Studies

Thermal comfort reviewed classroom studies differed in architectural, constructional, and mechanical characteristics. These are further discussed in the following subsections.

3.2.1. Architectural and Constructional Characteristics

The indoor thermal environment of a building is significantly affected by the buildings architectural. Moreover, constructional characteristics such as window wall ratios, layout, dimensions, building's thermal envelop properties,

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and external shading; thus, thermal comfort should be assessed, including these parameters. In the reviewed studies, it is observed that few surveys had been used to assess those parameters; however, many researchers considered them in evaluating thermal comfort studies of educational buildings, through numerical simulation and experimental studies, without considering students' actual thermal votes.

It is observed from the reviewed studies, as shown in Table II, that architectural and constructional characteristics have almost not been considered in most thermal comfort field studies, except for a few studies. Possibly, the reason behind this is that different architectural and constructional characteristics of buildings make the comparison of thermal comfort studies almost impossible. It is shown that most of the studies use uniform thermal zones by considering one point in the center of the room in evaluating thermal comfort; however, non-uniform zones could be resulted due to solar, radiant systems. Thus, it is vital to consider evaluating local thermal discomfort related to students' classroom positions.

Among the reviewed studies, as shown in Table II, Hikmat H. Ali focuses on envelopes' effect on two governmental school buildings' thermal comfort in Jordan.[117] M. Alwetaishi performed a numerical study of micro-climatically responsive educational school building designs.[118] In Turkey, Touraj Ashrafian investigated the impact of glazing ratio and window configurations on students' thermal comfort.[69] M.L. Boutet proposed a procedural contribution to the outdoor and indoor parameters that affect thermal comfort.[37] Enrico De Angelis proposed comparing bioclimatic design strategies based on assessing the thermal comfort of a school building.[62]

3.2.2. Mechanical Parameters (Ventilation Systems, Cooling, Heating)

The relationship between thermal comfort and heating/cooling and ventilation systems has been a critical concern to researchers for decades, and it has defined an essential issue of the thermal environment for years. All the reviewed studies indicate that researchers have been trying to achieve thermal comfort using different systems over different climates, as shown in Table II. It has been found in the literature that most of the studies consider naturally ventilated buildings as their case studies. This could be related to researchers' interest in reducing energy consumption and thermal comfort.

Among the reviewed studies, as shown in Table II, researchers not only considered assessing thermal comfort through field studies and subjective surveys; however, they also have used numerical simulations in optimizing thermal comfort and air quality and energy issues. Eusébio Z. E. Conceição numerically evaluated thermal comfort inside a classroom equipped with radiant cooling systems.[59] Y. Allab M developed a protocol that optimizes thermal comfort and energy consumption in educational buildings.[42] Also, Saadia Barbhuiya investigated how ventilation strategy affects energy consumption.[1] Ingy I. El-Darwish used three post-occupancy evaluation techniques to assess thermal comfort in higher educational buildings.[115] Martin Heine Kristensen performed a field study of thermal comfort of diffuse ceiling ventilation in a classroom.[34] Myo Sun Kim improved the central heating system in a university building through numerical simulation and experiment.[82] Yang Wang investigated the energy efficiency of natural displacement ventilation in public schools,[53] also he optimized HVAC control systems for thermal comfort and energy performance.[91] CharalamposVallianos investigated a school building's hybrid ventilation through a numerical study of predictive control.[128] Modeste Kameni Nematchoua studies the correlation between a mathematical model and experimental data under natural ventilation.[109] Lorenza Pistore assessed the IEQ in two high schools through field study, subjective surveys, and numerical simulation.[64]

4. NANOTECHNOLOGY'S CONTRIBUTION IN THERMAL COMFORT

4.1. Glass Treated with Nanotechnology

The mechanism of thermal comfort used to enhance the indoor environment in classrooms and office buildings focusing on manipulating in the optical and thermal properties of treated glass as low-cost effective tools at the nanoscale in the range of 1–100 nm, especially in the dried and hot climates to reduce the consumption of energy by monitoring the heat and cold transfer.[4, 16, 20, 22, 23, 28, 144–150] Through investigation, the obtained results have risen from the study of glass treated with nanotechnology, they have shown that this enhanced nanoengineered glass is able to control absorbing light, and heat and cold transfer. Abdin's work et al.[28] indicate that treated nano-glass considered to be an optimum glass specification and the solar heat gain coefficient (SHGC) is roughly 23% compared to the other types of glass of about 62%. Due to the distinct properties of nanomaterials, i.e., high conductivity, maximum loading, and huge potential, this has led to applying the nanomaterials as catalysts to the building structural of elements to create a clean indoor environment by reducing the amount of pollutants and saving energy with low-cost effective tools.[143–146] Work of Mauro et al.[146] who indicate that the glass structure, phase-change material (PCM), crystallization and modification factors effectively contribute in developing the premium and advanced materials capable of enhancing the air quality and reducing the energy consumption as well as monitoring the indoor environment by keeping the heat and cold transfer quite stable.

4.2. Thermal Comfort with Respect to the Nanofluids Applications

With respect to the field of nanofluids optical and thermal properties, there is an interesting challenge in how the optical properties of nanofluids are affected by the

Table IV. Models investigated and their validations.

Model type	Methodology	Nanoscale (size)	Mathematical model	Validation
Rayleigh model[147, 148, 156]	Optical transfer of the PCM based nanofluids	10–40 nm	$K_e = \frac{4\pi k_f}{\lambda} + \frac{2 f_v Q_e \lambda}{3D}$ $Q_{s\lambda} = \frac{8}{3} x^4 \left\lvert \frac{(m^2-1)}{(m^2+2)} \right\rvert$ $Q_{a\lambda} = 4 x I_m \left\{ \frac{(m^2-1)}{(m^2+2)} \left[1 + \frac{x^2}{15} \left(\frac{m^2-1}{m^2+2} \right) * \frac{m^4+27m^2+38}{2m^2+3} \right] \right\}$ $I = \left(\frac{\lambda}{2\pi r} \right)^2 \frac{I_0 (i_1 + i_2)}{2}$	This model used to calculate the optical properties of nanoflids contained very small particle
Mie model[151]	Predict the optical properties of the PCM based nanofluids	20–1000 nm and may deal with larger	$Q_{ext} = \frac{2}{\alpha^2} \sum_{n=1}^{\infty} (2n+1) R_e \{a_n + b_n\}$ $Q_{sca} = \frac{2}{\alpha^2} \sum_{n=1}^{\infty} (2n+1) R_e \{\lvert a_n \rvert^2 + \lvert b_n \rvert^2\}$	This model is an appropriate for the wide range diameter
Mie optimization model[149, 150, 158]	Combination of the Rayleigh model amd Mie model obtaines as a Monte Carlo model	Up to 10 nm	$\frac{dI_\lambda(s)}{ds} = -Q_{ext} I_\lambda(s) + (Q_{ext} - Q_{sca}) I_{b\lambda}(s) + \frac{Q_{sca}}{4\pi} * \int_0^{4\pi} I_\lambda(s', \Omega') \phi\left(\vec{\Omega}', \vec{\Omega}\right) d\Omega'$ $Q_\lambda(\theta) = \frac{2}{Q_{s\lambda}} \left(\lvert S_1 \rvert^2 + \lvert S_2 \rvert^2 \right)$	This model used to measure transmitten spectrum of PCM samples containing nanoparticles with average diameter of nanoparticles 10 nm

based-fluid of the nanofluids itself, and how they could significantly affect the performance of the solar-energy conversion. The thermal comfort and energy system have recently generated a lot of researches which are significantly affected by the building's architectural to reduce heating energy and air-conditioning consumption.[151] The scientific researchers have motivated to enhance the conceptual of thermal comfort in the building system by manipulating in the optical properties of the crude materials by filling with nanoparticles with diameter from 10 to 20 nm (100 to 200 Andstrom), for example, Al_2O_3, ZnO and CuO particles,[152–155] see Table IV. Colangelo et al.[152] show that the combination of water or oil-based fluid and Cu, CuO, ZnO, Al_2O_3 nanoparticles that improve the optical properties of nanofluids by enhancing the light absorbing and the size of these nanoparticles plays a key role in determining the thermal conductivity of nanofluids. Youse fifi et al. and Han et al.[153, 154] who investigated the effects of carbon-black aqueous and Al_2O_3/water nanofluids on the Solar's collector's efficiency and found out that the addition of functionalized nanoparticles significantly enhanced the light absorption of solar collectors' performance. Long-term studies have discussed the conceptual of optical and thermal comfort properties to produce the PCM nanofluids (at the nanoscale sizes), see Table IV.[28, 143–154] Rayleigh model investigated the optical transfer of the PCM based nanofluids with nanoparticles in the range of 10–40 nm[156, 157] and their experimental result have shown that the extinction and scattering coefficients of a single nanoparticle are affected by the material and shape as well as the relationship between the gap between the nanoparticles (contained very small particles) and the performance of optical properties. In addition, the work of Colangelo et al.[152] who indicate that Mie model is an appropriate for the wide range diameter (20–1000 nm) to predict the optical properties of the PCM based nanofluids and their calculations shown that the volume concentration (f_v) of the nanparticle is less than 0.6%. Furthermore, Mie optimization model indicate that the experimental results carried out by a dual-beam UV in the range of 250–900 nm[148, 149, 158, 159] consistently agree well with the experimental data calculated transmittance of the model is 0.53–26%.[160]

5. CONCLUSION

The built environment has always had a massive impact on learning progress, which is primarily dependent on providing thermal comfort in classrooms. The importance of thermal comfort research lies in the relationship between occupants' satisfaction and energy savings. Students spend most of their daily hours in schools and universities; therefore, providing thermal comfort and acceptable indoor air quality in educational buildings is necessary to build a pleasant educational environment. On the other hand, thermal discomfort could cause severe problems in classrooms, not only for students but also for instructors. The significance of thermal comfort research in classrooms is to

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design thermally prepared school buildings to facilitate learning and prevent occupant discomfort with minimum energy consumption use. A hundred thermal comfort studies have been reviewed and investigated in this paper. It is observed that thermal comfort standards are generally inadequate for assessing thermal comfort in classrooms; other international standards should be created and considered for classroom assessment. Also, based on review papers, it is found that most thermal comfort surveys have been done on a different and limited number of respondents during specific seasons. It is more efficient that these studies be done for at least a year to include many students to get a more comprehensive comfort range. It is not noticed that many of the studies that have been done in naturally ventilated buildings could not achieve the needed thermal comfort and indoor air quality due to the low airspeed; moreover, higher temperature leads to the increase of carbon dioxide, which is probably the main reason of the improper use of energy in educational buildings. Based on the reviewed studies, it is essential to develop thermal comfort metrics that consider both space and time of student setting in specific classroom positions; this could help design and evaluate school buildings. Additional comfort neutral temperatures have been found among all studies in the same climatic zones, which express the importance of using micro-level thermal comfort in future work. It is recommended that thermal comfort studies be carried out using rational and adaptive models as they provide more accurate, reliable results. With respect to the nanofluids applications, the nanomaterials tools considered to be the premium and superior devices because of extraordinary properties such as their huge potential, low-cost effective and, similarly, the long-term studies focus on examining the efficiency of the glass treated with nanotechnology and other types of traditional glass which have been used to enhance the indoor environment by reducing the energy consumption and minimize the cost.[28, 144–147] The obtained results from work of Abdin's et al.[28] shown that the treated glass at the nanoscale sizes, in the range 1–100 nm, have indices of SHGC 0.23, light transmission (LT) 0.42 and Ultraviolet (UV) 1.55 in contrast with that of other types of traditional glass with less effectiveness. Through investigation, the Rayleigh and Mie scattering models have been adopted to enhance the efficiency of the optical of thermal properties of the PCM at the nanoscale sizes.[148–160] Their results have shown that the extinction and scattering coefficients of nanofluids having a critical role by increasing the volume concentration when they increase and decreases when decreasing.

NOMENCLATURE

AC Air conditioning
ATC Adaptive thermal comfort models
a_n and b_n Mie scattering coefficients
α The particle diameter
ASHRAE 55 Thermal environmental conditions for human occupancy
D Distance between nanoparticles
EN 15251 Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting, and acoustics.
f_v The volume concentration of the nanoparticle in the PCM based nanofluids
HB Hybrid ventilation
HVAC Heating, ventilation, and air-conditioning system
I The scattered light intensity
I_0 The light intensity
$I_{b\lambda}$ The light intensity in the opposite direction
I_p The spacing of the nanoparticle inside the PCM
I_λ The spectral radiation intensity in one direction
k_e The extinction coefficient of PCM
k_f The extinction coefficient of PCM including the nanoparticles
k_p The extinction coefficient of the nanoparticles
λ The wavelength
m Dependent constant controlled by dimensionless optical constants
MV Mechanical ventilation
NV Natural ventilation
PCM Phase-change material
PMV Predictive mean vote equations
PPD Predictive percentage of dissatisfied
$Q_{a\lambda}$ The absorption factor
$Q_{e\lambda}$ The extinction factor for a single particle
$Q_{s\lambda}$ The scattering factor
Q_{ext} The extinction coefficient
Q_{sca} The scattering coefficient
RTC Rational thermal comfort models
S The optical path length
T_0 Outdoor temperature
T_n Neutral temperature
θ The scattering angle
TRMT Running means temperature
x Physical number

Consent to Participate

Consent to participate.

Consent to Publish

Consent to publish.

Ethical Approval

This article does not contain any studies with animals performed by any of authors.

Conflict of Interest

Has no conflict of interest.

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