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# Thermal comfort in educational buildings: A review article

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ABSTRACT

In modern societies people spend over 90% of their time indoors. Students spending more time at school than any other building except at home highlights the importance of providing comfortable indoor thermal conditions in these buildings. Thermal comfort since has been related to productivity and well-being and energy conservation in schools, has gained importance in recent years. This paper presents an overview of thermal comfort field surveys in educational buildings over the last five decades. The studies are reviewed in two sections; the first covering the field study methodologies including the objective and subjective surveys, and the second reviewing study results based on the climate zone, educational stage, and the applied thermal comfort approach. Confounding parameters have been discussed to outline priorities for the future research agenda in this field. Reviewed studies have assessed the thermal environment in classrooms compared to common thermal comfort standards. Most of the studies concluded that students' thermal preferences were not in the comfort range provided in the standards. Ventilation as an essential determinant of indoor air quality and thermal comfort has been highlighted in most studies. The wide disparity in thermal neutralities underlines the need for micro-level thermal comfort studies.



**Contents**



## 1. Introduction

Educational buildings, accounting for a large portion of building stock, are responsible for high energy consumption within a country's non-industrial energy usage [1]. A considerable amount of this energy is used to provide thermal comfort. Furthermore,

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when attempting to determine an energy benchmark for educational buildings indoor environmental conditions should be considered [2]. Due to high occupant density in classrooms and also the negative influence that an unsatisfactory thermal environment may have on students' learning and performance, providing comfort conditions for educational buildings has always been critical [3–5]. There are two main categories of thermal comfort models – Rational (RTC;[6]) and Adaptive (ATC;[7]). Although, Fanger's RTC model was grounded on studies conducted on college students within climate-controlled contexts, various studies argue that it could not predict the thermal comfort levels in real classroom conditions accurately [8–10]. Since the introduction of the ATC, several studies have evolved to support adaptive models in thermal comfort assessments and to establish quantitative indexes to allow the subject to enhance his/her comfort conditions [11]. This model of thermal comfort has also been assessed in classrooms and students' adaptive behaviors have been investigated. Various comfort equations have been developed based on field studies, relating the indoor comfort temperature to the monthly mean outdoor temperature [12]. As studies are based on field surveys with limited occupancy number and differences in the climate and building characteristics, generalization of the results is not usually possible.

Different thermal environment requirements due to specific occupation periods through the day and the year, difference in occupants' activity and clothing and level of freedom for adaptive actions(i.e., changing positions, clothing, opening/closing windows and blinds) and changing temperature set points in classrooms, compared to offices and residential spaces, require specific thermal comfort studies to be carried out. Furthermore, acceptable indoor condition would not be achieved unless a holistic acceptance in air quality, thermal, acoustical, and visual comfort at the same time. And any changes in these measures leads to discomfort and productivity loss in classrooms.

Current comfort standards, such as ISO 7730 [13], EN 15251 [14], and ASHRAE Standard 55 [15] determine design values for operative temperatures and comfort equations based on the rational and adaptive thermal comfort models (Table 1).

These standards provide thermal comfort ranges for three categories of spaces which classrooms are considered in the second category with normal level of expectations. Currently no specific standard exists for various age-ranges. Furthermore, studies have criticized the applicability of the existing standards in classrooms.

A vast literature has appeared in recent years dealing with thermal comfort field surveys especially in European and Asian countries. In addition to field surveys few review articles have been published regarding different issues of thermal comfort (theoretical framework and field survey reviews). Van Hoof (2008) reviewed thermal comfort studies in the past 40 years with a focus on Fanger's theory [16]. Halawa and van Hoof (2012) reviewed the studies on adaptive thermal comfort and look critically at the foundation and underlying assumptions of the adaptive model approach and its findings [17]. Djongyang et al (2010) and de Dear et al (2013) also reviewed the progress of thermal comfort studies over the last twenty years [18,19]. Yang et al. (2014) reviewed a number of studies of thermal comfort in general and those pertinent to building energy efficiency in different parts of the world [20]. Mishra and Ramgopal (2013) reviewed field surveys in different building types and grouped them based on climate zones [12]. Rupp et al. (2015) reviewed papers published in the last 10 years that examine the various sub-areas of research related to human thermal comfort (e.i. standards; experiments in climate chamber and semi-controlled environments; field studies in educational, office, residential and other building types; productivity; human physiological models; outdoor and semi-outdoor field studies) [21] Khodakarami and Nasrollahi (2012) also reviewed the thermal comfort studies particularly in hospitals [22]. No research has reviewed thermal comfort studies in educational buildings specifically. Although educational building studies are not comparable to the studies conducted in offices and residential buildings in number, they have increased over recent years and vary mainly in the theoretical approach, climate zone, and educational level.

In this paper, forty eight articles on thermal comfort field studies in classrooms, published from 1969 to 2015 in peer-reviewed scientific journals such as *Building and Environment, Building and Energy, Applied Energy, ASHRAE Transactions, and Indoor Air* and also those published in international conference proceedings such as Passive and Low Energy Architecture *(PLEA)* are categorized based on different criteria such as year of study, country, climate, ventilation type, thermal comfort approach, number of respondents, and study season. It was not meaningful to list all conclusions from each and every study included. Instead, general conclusions are summarized and discussed in different sections.

To provide a better understanding of thermal comfort in classrooms and related issues, and to achieve a holistic view in this field, the key points have been extracted by comparing and contrasting the previous studies. First, studies are categorized and reviewed to provide a wide literature review (i.e., based on climate, educational stage, and the thermal comfort approach) to find the similarities and contrasts. Second, limitations of thermal comfort approaches and standards, and confounding parameters in thermal comfort studies (i.e., architectural, constructional, and mechanical) are discussed. Finally, recommendations for future studies on thermal comfort in classrooms are presented.

**Table 1**
Thermal comfort standards in classrooms.

| Standard | Thermal comfort approach | Operative temperature winter (°C) | Operative temperature summer (°C) |
|---|---|---|---|
| **ISO 7730 (2005)** | Rational<br>$-0.5 < PMV < +0.5$<br>$PPD < 10\%$ | 20–24 | 23–26 |
| **ASHRAE 55 (2004)** | Rational<br>$-0.5 < PMV < +0.5$<br>$PPD < 10\%$ | 20.5–25.5 | 24.5–28.0 |
| **EN- 15521 (2007)** | Adaptive | $Tn = 0.302TRMT + 19.39$; $TRMT > 10$<br>$Tn = 22{:}88$; $TRMT \leq 10$ | |
| **ASHRAE 55 (2010)** | Adaptive | $T_n = 0.31T_O + 17.8$ | |

*TRMT: Running Mean Temperature.*
*$T_O$: Outdoor Temperature.*
*$T_n$=Neutral Temperature.*
*PMV: Predicted Mean Vote.*

## 2. Literature review

In this paper, the reviewed studies are limited to those focusing on thermal comfort field surveys in typical classrooms. These studies have been classified based on three main parameters: climate zone, educational stage, and the thermal comfort approach, and also sub parameters including year of study, country, continent, ventilation type, number of respondents, and the season of study (Table 2). Similarities and contrasts among the studies, and the relationships between the above mentioned parameters have been extracted by statistical analysis, presented in percentage and graphs. However due to the limited number of studies and the variety of study conditions, building a precise meta-analysis model was not possible.

Thermal comfort field studies in classrooms were reported first in 1969, by Auliciem and vastly presented over the last decade. Indeed