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Original Paper

The influence of thermal discomfort on the attention index of teenagers: an experimental evaluation

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Abstract
In order to measure the effect on the attention of teenagers of thermal discomfort due to high temperature and humidity, two experiments were conducted in two different indoor conditions of temperature and humidity in non-air-conditioned classrooms. The participants were a heterogeneous group of 117 teenagers, aged 12 to 18 years, and the experiments reproduced the actual conditions of teaching in a classroom in the Mediterranean climate. In order to measure the attention index, a standard Toulouse-Pieron psychological test was performed on the 117 teenagers in these two conditions, and the Predicted Mean Vote (PMV), the physiologically Equivalent Temperature (PET), the Standard effective Temperature (SET*) and the Universal Thermal Climate Index (UTCI) indices were calculated to estimate the grade of discomfort using the RayMan Pro model. Conditions of greater discomfort decreased the attention index in the whole group, especially in those aged 12–14, among whom the attention index dropped by around 45 % when compared to comfortable conditions. However, teenage attention at ages 17 and 18 shows little variation in discomfort in respect to thermally comfortable conditions. In addition, the attention index for boys and girls shows the same variation in discomfort conditions. However, girls have a slightly higher attention index than boys in discomfort and thermal comfort experiments.
Keywords
Thermal discomfort Attention index Experimental evaluation Predicted mean vote Physiologically equivalent temperature Standard effective temperature Universal thermal climate index RayMan pro model

Introduction

Attention and concentration are the foundation of many human activities, both intellectual and manual, and a comfortable thermal condition has some influence on the efficiency of these activities.

Thermal comfort can be defined clearly through different approaches. A psychological perspective defines thermal comfort as a condition of mind that expresses satisfaction with the thermal environment (ASHRAE *1997*). According to a thermo-physiological perspective, Mayer (*1993*) defines thermal comfort as the minimum rate of nerve signals from skin receptors to the hypothalamus. In addition, based on the heat balance of the human body, Fanger (*1972*) proposed that thermal comfort is achieved if the heat flowing to and from the human body is balanced, and if the skin temperature and sweat rate are within a comfortable range. These flows depend on weather conditions (temperature, moisture, wind speed), indoor conditions (radiant temperature), and the physiology of the person (metabolism, physical activity) as well as the kind of clothes worn. However, the fluxes associated with weather conditions do not have the same effect on the indoor environment as they do outdoors (e.g., wind is lower, temperature and humidity could be higher or lower).

The thermal component is an important factor in human comfort and is described and quantified by many thermal indices that contain the meteorological parameters of air temperature, humidity and wind speed; some of them include short and long wave radiation (e.g., Thom *1959*; Steadman *1971*; ISO *1983*; Matzarakis and Mayer *1996*; VDI *1998*). However, these indices do not take into account physiological factors. Some other indices are based on a balance of human energy and take into account some relevant physiological factors. We have used the following indices in the present study.

The physiologically equivalent temperature (PET) is one of the most used indices and it contains all meteorological parameters that affect thermal comfort, as well as physical activity and the clothing an individual wears. PET is defined as the equivalent air temperature required for reproducing a standardized indoor setting and in order for a standard person (80 W of metabolic activity and 0.9 clo of heat resistance as a result of clothing) to maintain the core and skin temperatures that are observed under the conditions being assessed (Mayer and Höppe *1987*; Höppe *1999*, *2002*; Matzarakis et al. *1999*). This index is based on the Munich energy-balance model for individuals (MEMI), which models the human body's thermal conditions from a relevant physiological point of view.

The predicted mean vote (PMV, Fanger *1972*) and the standard effective temperature (SET*, Gagge et al. *1986*) are also usually used. PMV is derived from the physics of heat transfer combined with an empirical fit to sensation, and it establishes a thermal strain based on steady-state heat transfer between the body and the environment. PMV assigns a comfort vote to that amount of strain. The SET* index represents the thermal strain experienced by a cylinder relative to a "standard" person in a "standard" environment.

The International Society of Biometeorology proposed the Universal Thermal Climate Index (UTCI), based on the equivalence of the dynamic physiological response predicted by a thermoregulation human model, according to the concept of an equivalent temperature, with 50 % relative humidity and where radiant and air temperatures are equal. This UTCI equivalent temperature for a defined wind, radiation, humidity and air temperature is the same temperature of the reference environment in which the same strain index is produced (Jendritzky et al. *2012*). It requests measures of

the wind velocity at a height of 10 m. This is an important limitation to be used in indoor environments.
However, none of these indices are suitable for teenagers. Thus, as there is no specific index to be applied to teens, we considered, as a first approach, to simply determine the thermal comfort of teenagers. In addition, these indices are defined in outdoor environments, where the radiant temperature plays an important role.
Version 2.1 of the RayMan Pro model (Matzarakis et al. *2007*, *2009*) was used to calculate the indices PET, PMV, SET* and UTCI. This model is free software developed by the Meteorological Institute of the University of Freiburg (available at http://www.urbanclimate.net/rayman/) and it is suitable for calculating radiation fluxes and thermal indices. The RayMan model is able to estimate the influences of long and short radiation, as well as radiation fluxes from the clouds, walls, trees and many other obstacles that have an important effect on the thermal balance of a human body (Matzarakis et al. *2009*). The RayMan model has been designed for urban applications with complex structures and microclimates. Indoor applications of the model are limited to those cases in which the main radiant temperature is equal to the air temperature. This occurs in spaces with small windows that are not exposed directly to sunlight.

Attention measurement

Many psychology handbooks define attention as a psychological state of the mind that allows direct focus on a particular object or action during a cognitive activity practiced by a human being. Psychologists make a distinction between voluntary and involuntary attention. The first depends on the willingness of the individual; while the second, of which the individual is unaware, is caused by many factors outside the individual himself (noise, discomfort, an excess or lack of light, etc.).
Attention and concentration are not elements of intelligence. However, they are preconditions for it. These personality traits appear to be highly relevant both in the acquisition of experiences and in the recognition of new situations, as well as having a clear conception of the problems to solve.
The classic standard Toulouse-Pieron test (Toulouse and Pieron *1972*) has been used commonly over the past decades by psychologists to evaluate concentration range in order to detect some anomalies in attention and concentration capacities. Because of its nature, this test demands great concentration and resistance to monotony. The test consists of 1,600 small boxes distributed in columns and rows (40 × 40). Each small box has a mark at a different position (top, bottom, left, right, one corner, etc.). 25 % of the 1,600 boxes match a model which is provided at the top of the page, and the subject must locate and mark those 400 similar boxes as rapidly as possible within a period of 15 min. The result is expressed on a scale of 100 (maximum attention range). According psychologists this kind of test is the most appropriate for measuring attention, and it is recommended for use on subjects that are 10 years or older, as well as for any cultural level, because it is not a verbal test.
There are not many previous studies regarding the influence of indoor thermal comfort on the attention index. Jaakkola et al. (*1989*) determined that the room temperature is the most important indoor air parameter for determining symptoms of sick building syndrome (SBS) and the sensation of dryness, concluding that controlling room temperature will improve thermal comfort and decrease SBS symptoms in office workers. Bell (*1981*) found that high temperatures may either increase or decrease wakefulness, narrow attention, and cause discomfort.

However, thermal comfort probably plays an important role in attention level. In order to analyze this role, the aim of this paper was to analyze and quantify its relationship to attention during one of the most important periods in which attention and concentration are most needed: high school. Effectively, concentration and the attention of teenagers in school is an important factor for proper learning. There are many different factors that influence teenagers' rate of attention throughout the classroom learning process. In addition, Dunn (*2008*) refers to some variables in the learning style, such as environmental (including air temperature), sociological, emotional and physical. Some of these factors are specific to the student (cultural, social, psychological, and physiological). On the other hand, comfort conditions within the classroom affect all of the students equally , and probably have some influence on their concentration rate. To be precise, the goal of this work was to analyze and quantify the influence of thermal comfort conditions on the attention rate in teenagers (aged 12 to 18 years), focusing on the influence of high temperature and humidity in the classroom.

The structure of this paper is as follows. In the following section, we explain the Methodology used in our experimentation. We then present the main Results, followed by a Discussion.

Methodology

Two experiments were conducted using 117 teenage students in a high school located 10 km from Barcelona city center (8 m a.s.l.). The entire group had approximately the same number of boys and girls, divided as follows: 27 students aged from 12 to 13, 60 students aged from 14 to 16, and 30 students aged from 16 to 18 years old.

In order to analyze the role of thermal comfort in attention rate, a standard Toulouse Pieron questionnaire for measuring attention index was performed by these students in two different environmental conditions in a classroom of approximately 90 m^2 without air-conditioning. It was located on the first floor of a high school at about 18 m a.s.l. and 50 m from the coastline, with a east-northeast orientation. The northeast wall had three windows, with no direct exposure to sunlight. The questionnaire lasted 15 min.

The first experiment took place on 26 July 2009 (summer experiment), and the second a few months later, on 18 October 2009 (autumn experiment). By using two standard mercury thermometers (like those located inside weather stations), with a range from −30 °C to 50 °C and an accuracy of 0.2 °C, the dry and wet temperatures were recorded during both experiments and the relative humidity was calculated. In order to take the main temperature in the classroom, the thermometer was placed on a small platform at a 1.5-m height in the middle of the classroom about 30 min before the test. Wet and dry temperature data were recorded three times during the 15 min that the test lasted, i.e., every 5 min. No significant variation in temperature was noticed in both experiments. In the summer experiment, the temperature at the beginning was practically the same as at the end of the test. During the autumn experiment, the difference between the temperature in the beginning and the end of the test was 0.4 °C. The average temperature was considered in this case.

During the experiment, the windows were closed and there was no ventilation, reproducing the same conditions as during a normal class session (even in early summer, open windows are not good practice during the teaching sessions in those classrooms, which are located close to the main road and other large streets, because the outside noise disturbs the teaching session). However, a weak fabric air infiltration has been assumed. According to Höppe (1999, 2002), infiltration wind velocities in buildings of around 0.1 m s^{-1} are usual. This value for the wind velocity in the classroom has been considered. In addition, the wind velocity has also been considered to be 0.1 m s^{-1} at 10 m height, as is suggested when evaluating the UTCI. Air temperature, air humidity and wind speed are required for estimating the PET, PMC, SET* and UTCI indices. However, the most important required meteorological input is the radiant temperature for obtaining the human energy balance. In indoor areas without large windows exposed to the sun, such as the classroom in which the experiment was performed, it is suggested to simply assume that the radiant temperature is equal to the air temperature (VDI 1998).

As a requirement for the volunteers, teenagers wore the same kind of clothes during both experiments in order to homogenize the clothing resistance parameterized in the considered indices. In the summer experiment, short trousers and short t-shirts were worn. During the autumn experiment, long trousers and long, thin t-shirts were worn. Clothing reduces the body's heat loss. Therefore, clothing is classified according to its insulation value. The unit normally used for measuring the insulation of clothing is the clo unit (1 clo = 0.155 m^2 °C/W). In addition, metabolism also plays an important role in reaching thermal comfort. Metabolism is the body's motor, and the amount of energy released by the metabolism is dependent on the amount of muscular activity. Normally, all muscle activity in the body is converted to heat. Traditionally, metabolism is measured in Met (1 Met = 58.15 W /m^2 of body surface). Our metabolism is at its lowest while we sleep (0.8 Met) and at its highest during sports activities, where 10 Met is frequently reached. In a sedentary activity (office, dwelling, school, laboratory), a typical value is 1.2 Met (70 W).

Fanger (1972) and ISO 7730 (1995) describe the clo and Met scales. According to these authors' scales, the teenagers were wearing 0.18 clo during the summer experiment and 0.44 clo during the autumn experiment. In both experiments, the metabolic activity was assumed to be 70 W.

Table 1 shows the average values of temperature and relative humidity during the experiments, and the estimated parameterization of clothing resistance and physical activity.

Table 1
Thermophysiological parameters during the experiments

	T (°C)	**RH (%)**	**Wind (ms^{-1})**	**clo**	**Met (W)**
Summer	33.6	68	0.1	0.18	70
Autumn	20.3	74	0.1	0.44	70

Results

The RayMan Pro model (Matzarakis et al. *2007*, *2009*) was used to calculate the indices PET, PMV, SET* and UTCI in both experiments. This model is free software developed by the Meteorological Institute of the University of Freiburg (available at http://www.urbanclimate.net/rayman) and it is suitable for calculating the radiation fluxes and these thermal indices.

The average values of the indices PMV, PET, SET* and UTCI, obtained using the RayMan Pro model in the experiments, are shown in Table 2. The mass, height and sex of the teenagers are required for the PMV index. The average of these parameters for each age, differentiating between girls and boys, has been assumed. However, no significant differences in the values of these indices are observed. The thermal comfort values are approximately equal for teenagers of the same age.

Table 2

Values of PMV, PET, SET* and UTCI indices calculated by using RayMan Pro model for the two experiments realized

	PMV	PET (°C)	SET* (°C)	UTCI (°C)
Summer experiment	2.8	34.4	34.7	37.2
Autumn experiment	−0.6	20.6	19.2	21.5

According to Matzarakis et al. (*1999*), thermal comfort is considered satisfactory if PMV values are between −0.5 and 0.5, and PET values are from 18 °C to 23 °C. According to Gonzales et al. (*1974*) and Gagge et al. (*1986*), values from 22.2 °C to 25.6 °C are required for thermal comfort in SET*. Values from UTCI between 9 °C and 26 °C are considered as no thermal stress (Nastos and Matzarakis *2011*).

The values of PMV, PET and UTCI in the autumn experiment confirm the defined comfort conditions during the experiment. However, according to SET*, the value of 19.2 °C is defined as unacceptably cool in terms of both thermal sensation and a body cooling slowly as a physiological degree.

During the summer experiment, high thermal discomfort is estimated. According to the 2.8 value obtained for the PMV, thermal perception is classified as hot, and the grade of physiological stress is defined as strong heat stress, the same category for the PET and UTCI index. This is also very close to very strong heat stress for the UTCI index. According to the SET* grade, the thermal perception is defined as slightly and unacceptably warm, with a physiological grade defined as causing slight sweat and vasodilatation.

The attention index obtained from the Toulouse Pieron test for each individual in the studied range of ages in both experiments (summer and autumn) is shown in Fig. 1a–c. In order to evaluate the attention index under comfort conditions, the PET index was used. However, the other calculated thermal indices may be used in both comfort and discomfort conditions, using the corresponding values shown in Table 2. In the summer experiment, the PET value was 34.4 °C (heat stress) and in autumn PET was 20.6 °C (comfort). Figure 1a shows the attention index for teenagers aged 12 and 13. In the majority of cases, the attention index is higher in comfort conditions than in heat stress. A large difference in the attention index between the summer and autumn experiments is observed at this age range. In addition, high variability in the value of this index can be observed between classmates.

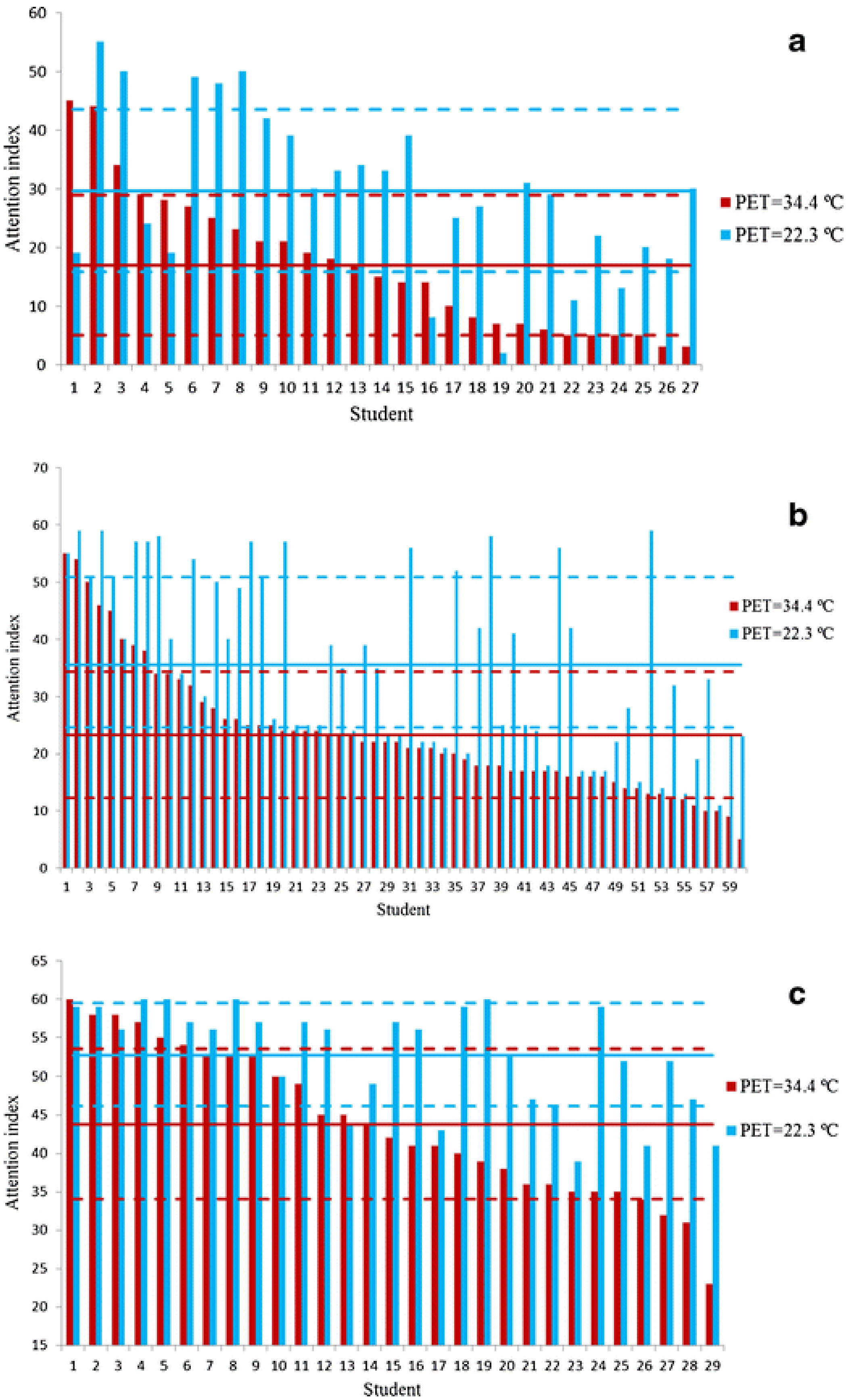

Fig. 1
Attention index for each questionnaire in the summer experiment (red bars) with high heat stress (PET = 34.4 °C), and in the autumn experiment (blue bars) with thermal

comfort (PET = 20.6 °C) for students aged a 12–14, b 14–16 and c 16–18 years. The red and blue continuous lines represent the average value of the attention index in both discomfort and comfort conditions. The dotted lines indicate the standard deviation with respect to the average value

Figure 1b shows the attention index for teenagers aged 14–16. In all cases, the value of the attention index is higher in comfort than in heat stress conditions. As in Fig. 1a, a large difference in the index is observed between the summer and autumn experiments. Also high variability between classmates is observed.

Figure 1c shows the attention index for teenagers aged 16–18, students in their two last years of high school. Two main differences are observed in respect to Fig. 1a and b. First, there is low variability in the attention index between classmates. It seems that the attention index is similar for the whole group aged 16–18. Second, a small difference in the value of the attention index between the summer and autumn experiments is also observed in this range of ages. This may be interpreted as: the attention of teenagers aged 16–18 is less sensitive to thermal discomfort conditions than is the attention of younger teenagers.

According to Fig. 1a–c, heat stress conditions affect the attention index of teenagers.

Figure 2 shows the distribution of teenagers according to the attention index obtained in both experiments. Every individual is represented by a symbol. The red line indicates the same values of the attention index in both experiments. For teenagers aged 12 to 14 (crosses), a large difference in the values of the attention index is observed. The main individuals are located to the right of the red line, which indicates that the attention index is higher in comfort conditions. However, five teenagers had high attention index values during the summer experiment.

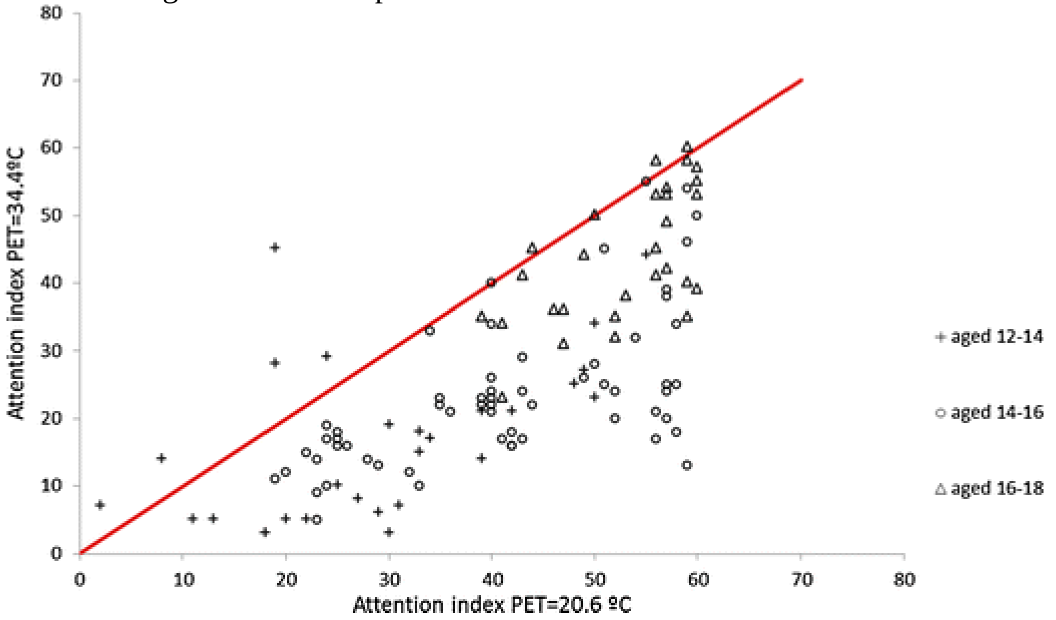

Fig. 2

Comparison between the attention index in no thermal comfort conditions (PET = 34.4 °C) and comfort conditions (PET = 20.6 °C) for students aged 12–14 (cross), 14–16 (circle) and 16–18 (triangles). Every point is the attention index for each student. The red line is the line in which the attention index has the same values in both experiments. The lineal correlation coefficients are 0.52, 0.61 and 0.62 for ages 12–14, 14–16 and 16–18, respectively

Teenagers aged 14–16 and 17–18 show a higher attention index during the autumn than during the summer experiment.

Figure 3 shows the average attention index linked to teenagers' age in both heat stress and thermal comfort experiments. Two different behaviors are observed. The attention index in teenager's aged 12 to 14 shows the minimum values of the whole group in both. In addition, large differences are observed between the attention index in the summer and autumn experiments: It is higher than 50 % in teenagers aged 13 and 14.

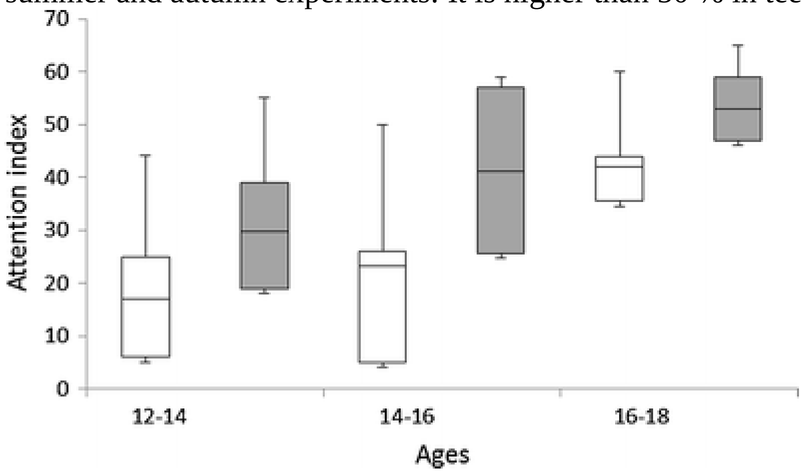

Fig. 3

Plot boxes for each age group in heat stress conditions (white boxes) and thermal comfort conditions (grey boxes), representing the smallest result, lower quartile (first quartile), median (second quartile), upper quartile (third quartile), and largest result Moreover, according to Fig. 3, teenagers aged 15–18 show similar attention index values during the autumn experiment (PET = 20.6 °C), and higher than those obtained by teenagers aged 12–14. However, only a small difference between the attention indices in both experiments is observed in teenagers aged 16–18 and, above all for those aged 18, there is practically no difference between the attention indices in the summer and autumn experiments. According to these results, it seems that heat stress affects the attention index more in teenagers aged 12–14 than in those aged 15–18. In addition, according to Fig. 3, there is a change in the tendency of the attention index for teenagers aged 14–15, especially in the autumn experiment.

The attention index values obtained are generally higher in comfort conditions versus discomfort conditions for all ages and sexes. However, an important difference in the attention index between comfort and discomfort conditions was detected in teenagers aged 12–16, as compared to the 16–18 group. In addition, for those teenagers aged 12–16, attention decreased by about 50 % in discomfort conditions with respect to the attention index obtained in the comfort conditions experiment. Table 3 summarizes the average attention index obtained for each group, and the variation in both experiments.

Table 3
Values obtained in the Tolouse-Pieron attention test in heat stress and comfort conditions, and the variation in each experiment for the three groups

Group	Heat stress	Comfort	Variation (%)
12–14 years old	16.9	30.5	44.5
14–16 years old	24.3	41.4	41.3
16–18 years old	43.8	52.8	17

In order to analyze whether the attention levels of boys or girls are more sensitive to heat stress, Fig. 4 shows the average attention index for boys and girls in the whole group. The attention index during heat stress (34.4 °C of PET) is slightly higher for girls (29.3 for girls and 26.2 for boys). In thermal comfort conditions (20.4 °C of PET) the attention index increases to 43.17 for girls and 40.0 for boys. Thus, the attention index is higher for girls in both heat stress and comfort conditions. However, boys and girls increase by the same percentage from heat stress to comfort conditions, around 14 points (boys 14.1 and girls 13.8).

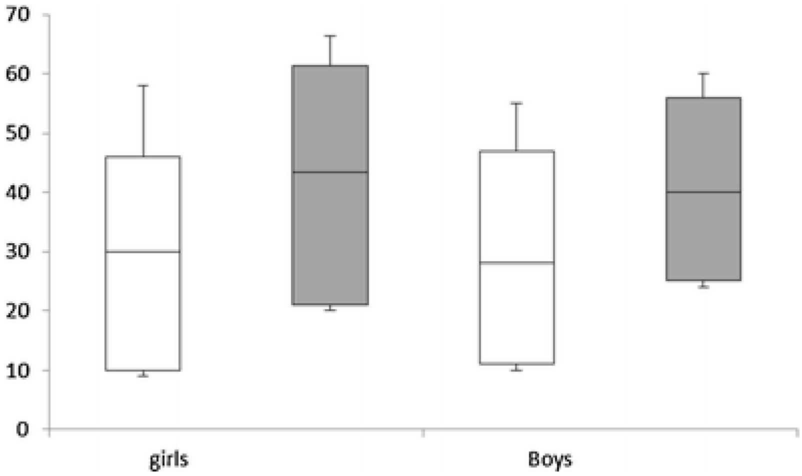

Fig. 4

Plot boxes for the girls and boys in heat stress conditions (white boxes) and thermal comfort conditions (grey boxes), in which are represented: the smallest result, lower quartile (first quartile), median (second quartile), upper quartile (third quartile), and largest result

Discussion

In order to analyze the role of thermal discomfort in the attention of teenagers in a classroom, two experiments were conducted. In the first experiment, realized in July 2009, the 117 volunteers performed a standard Toulouse-Pieron test to measure attention index in high thermal discomfort conditions—according to the PET, PMV, and UTCI indices (respectively 34.4 °C, 2.8 and 37.2 °C) and SET* (28.4 °C). In the second experiment, 3 months later, the Toulouse-Pieron test was conducted under thermally comfortable conditions—according to PET, PMV, and UTCI indices (respectively 20.4 °C, −0.6 and 21.5 °C), and slightly uncomfortable conditions according to SET* (19.2 °C).

Probably the main conclusions of this work is that the attention levels of teenagers aged 12–16 years is highly sensitive to discomfort conditions; this is particularly so for those aged 12–14, in which the attention index decrease around 50 % in discomfort conditions with respect to comfort conditions. However, teenagers aged 16–18 are less sensitive to discomfort, especially those aged 18. The attention index shows a small variation in both experiments for this age range.

In addition, the attention index for girls is slightly higher than boys in both thermal comfort and discomfort conditions. However, during the summer experiment the attention index decreased the same (by around 14 points) for girls and boys.

Teenager attention is significantly sensitive to discomfort conditions, especially in those aged 12–14. Proper thermal comfort could improve the attention index in the classroom and propel the learning process.

Moreover, according to projections from some regional models for moisture and temperature in the Mediterranean basin for future decades, global warming will probably increase both the sea surface temperature of the Mediterranean Sea and the air temperature (IPCC *2007*). This will in turn increase evaporation, which will greatly increase humidity and air temperature on the coastline. According to these models, an increase in temperature and moisture was observed in all scenarios defined by the IPCC, especially in the A2 scenario from mid-spring to mid-autumn. As an example, Table 4 summarizes the results for the control run (1960–1990) and the scenario A2 realized by the Danish Meteorological Institute from the regional model Hirham (25 km resolution) nested in the global model Arpege, within the ENSEMBLES project , focused over the Barcelona coastline.

Table 4

Relationship between the average temperature in June and September, and the average humidity from May to September in the Barcelona region according to the Hirham model (http://www.ensembles-eu.org)

Period	Average temperature in June / September (°C)	Average humidity from May to September (g/kg)
1960–90	21.1/22.5	7
2040–50	23.9/24.3	11

As a consequence, discomfort due to an increase in these atmospheric variables will also extend the summer period to the end of spring and the beginning of autumn (thus affecting the academic period). Will the attention of students be affected by the increase in discomfort conditions during the spring and autumn? Further research is needed to better analyze this issue.

Matzarakis (*2010*) predicted that thermal discomfort indices have increased in the west Mediterranean basin during late spring, summer and early autumn as a consequence of climate change. He also discussed the impact of this discomfort on tourism and proposed adaptations for reducing thermal discomfort, including measures for urban and regional planning as well as modifications of bioclimatic conditions (e.g., the role of urban trees).

It is important to note that the vast majority of public schools and high schools in Catalonia and Spain do not have air conditioning, because until now the period with thermal discomfort has been short, i.e., only a few weeks at the end of the academic course in June and July. Because of this fact, education policies should consider some actions that will guarantee thermal comfort conditions in public high school classrooms in these regions (e.g., investment in classroom air-conditioning systems, adaptation and modification of the academic calendar, etc.). Further analysis of the influence of climate change on comfort conditions is needed.

In addition, further research is also needed to expand our knowledge of how thermal conditions influence teen attention. The present study was limited to a small group of teenagers. Further experiments for many groups located in many other areas of the Mediterranean region are required in order to confirm the tendencies obtained by this preliminary research. Moreover, the comfort indices PMV, PET, SET* and UTCI are generally used for adults. As there is no specific index for teens, the values obtained by these indices are probably not precise enough for this group. A specific thermal index for teens is needed to improve both thermal analysis and index values.

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References

ASHRAE (1997) Handbook of fundamentals: physiology principles, comfort, health. American Society of Heating and Refrigerating Engineers, New York

Bell P (1981) Physiological, comfort, performance, and social effects of heat stress. J Soc Issues 37(1):71–94CrossRef

Dunn R (2008) The Dunn and Dunn learning style model and its theoretical cornerstone (2008). In: Dunn R, Griggs S (eds) Synthesis of the Dunn and Dunn learning styles model research: who, what, when, where and so what—the Dunn and Dunn learning styles model and its theoretical cornerstone. St John’s University, New York, pp 1–6

Fanger PO (1972) Thermal comfort. McGraw-Hill, New York

Gagge AP, Fobelets AP, Berglund LG (1986) A standard predictive index of human response to the thermal environment. ASHRAE Trans 92:709–731

Gonzales RR, Nishi Y, Gagge AP (1974) Experimental evaluation ofstandard effective temperature: a new biometeorological index of man’sthermal discomfort. Int J Biometeorol 18:1–15CrossRef

Höppe P (1999) The physiological equivalent temperature— a universal index for the biometeorological assessment of the thermal environment. Int J Biometeorol 43:71–75CrossRef

Höppe P (2002) Different aspects of assessing indoor and outdoor thermal comfort. Energy Build 34:661–665CrossRef

IPCC (2007) Fourth Assessment Report (IPCC AR4). Intergovernmental Panel on Climate Change, Geneva
ISO (1983) ISO 7730: Moderate thermal environments—Determination of the PMVand PPD indices and specification of the conditions of thermal comfort. International Organisation of Standardization, Geneva
ISO 7730 (1995) Moderate Thermal Environments—Determination of the PMV and PPD indices and specification of the conditions for thermal comfort. 1
Jaakkola JJK, Heinonen OP, Seppänen O (1989) Sick building syndrome, sensation of dryness and thermalcomfort in relation to room temperature in an office building: Need for individual control of temperature. Environ Int 15:163–168CrossRef
Jendritzky G, De Dear R, Havenith G (2012) UTCI-Why another thermal index? Int J Biometeorol 56(3):421–428CrossRef
Matzarakis A (2010) Climate change: Temporal and spatial dimension of adaptation possibilities at regional and local scale. In: Schott, C. (ed) Tourism and the implications of climate change: Issues and actions. Emerald Group Publishing. Bridging Tourism Theory and Practice vol 3, pp 237–259
Matzarakis A, Mayer H (1996) Another kind of environmental stress: thermal stress. NEWSLETTERS No. 18, 7–10. WHO Colloborating Centre for Air Quality Management and Air Pollution Control
Matzarakis A, Mayer H, Iziomon E (1999) Applications of a universal thermal index: physiological equivalent temperature. Int J Biometeorol 43:76–84CrossRef
Matzarakis A, Rutz F, Mayer H (2007) Modelling radiation fluxes in simple and complex environments—application of the RayMan model. Int J Biometeorol 51:323–334CrossRef
Matzarakis A, Rutz F, Mayer H (2009) Modelling Radiation fluxes in simple and complex environments—Basics of the RayMan model. Int J Biometeorol 54:131–139CrossRef
Mayer H (1993) Urban bioclimatology. Experientia 49:957–963CrossRef
Mayer H, Höppe PR (1987) Thermal comfort of man in different urban environments. Theor Appl Climatol 38:43–49CrossRef
Matzarakis A, Nastos P (2011) Analysis of tourism potential for Crete Island, Greece. Global NEST J 13:141–149
Steadman RG (1971) Indices of windchill of clothed persons. J Appl Meteorol 10:674–683CrossRef
Thom EC (1959) The discomfort index. Weatherwise 12:57–60CrossRef
Toulouse EY, Pieron H (1972) Toulouse-Pieron: prueba perceptiva y de atención manual. TEA, Madrid
VDI (1998) VDI 3787, Part I: Environmental meteorology, methods for the human biometeorological evaluation of climate and air quality for the urban and regional planning at regional level. Part I: Climate. Beuth, Berlin, p 29