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Design to Thrive

Evaluating Thermal Environment and Thermal Comfort in Schools Located in Kashan-Iran in Mid-Seasons

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Abstract: The study seeks the impact of design on thermal environment of a high school with courtyard design and of a primary school with compact design in mid-seasons in Kashan, hot and dry part of Iran, and studies students' Thermal Sensation Votes (TSV) and investigates their compatibility with Predicted Mean Vote (PMV) suggested by ASHRAE Standard 55. Indoor environmental parameters including air temperature, relative humidity, radiant temperature and air velocity were recorded under free running mode. Along with objective measurements, a total of 113 girl students aged 15-18 were surveyed three times in the high school, 59 students during April 2015 and 54 students during October 2015, collecting a total of 323 questionnaires. Moreover, 59 girl students aged 10-11 were surveyed in the primary school during May 2014, collecting a total of 172 questionnaires. Results show that T_{op} is closer to T_{out} in the high school with courtyard design than in the primary school with compact design, especially in north facing classrooms where the effect of solar radiation is less. Furthermore, results of this study show that PMV model overestimates high school students' thermal sensation while overestimates children's thermal sensation at higher temperatures and underestimates it at lower temperatures.

Keywords: Thermal comfort, High School, Primary School, Design, Courtyard

Introduction

Students have diverse activities during a day with limited adaptive actions in classrooms (Teli, Mark F Jentsch, et al. 2012) so their perception of thermal comfort may be totally different than that of occupants in an office. As a result, there is no guarantee that steady state heat-balanced model of thermal comfort obtained from experiments with adults (Fanger 1970) or adaptive model of thermal comfort developed from surveys in offices (Dear et al. 1998; Nicol & Humphreys 1973) can reliably represent student's perception of thermal comfort. Although several studies have considered thermal perception of children at schools (Humphreys 1977; Teli et al. 2014; Montazami et al. 2017; ter Mors et al. 2011; De Giuli et al. 2012), there are still fewer researches in hot-arid climates like Iran (Haddad et al. 2013; Haddad et al. 2016a; Zahiri et al. 2011), especially with regards to the effect of spatial configuration and design on thermal environment and thermal perception. In Iran, most school buildings have compact plans with poorly insulated envelopes and usually no external shadings while there are no regulations to control indoor temperature (Zomorodian & Nasrollahi n.d.). That results in overheated schools in summers and sometimes even in spring and fall. Therefore, the main objectives of the paper have been defined as follows:

- To study the impact of design on thermal environment in a school with courtyard design and in a school with compact plan design.
- To investigate the applicability of PMV model to predict primary school and high school students' thermal sensation votes.

Methodology

The methods applied in the paper include both measurement of environmental variables and questionnaire surveys. The study is conducted in mid seasons, fall and spring, to make sure that no heating system or cooling system is in use in the school. The average temperature of Kashan is 19.2^{o}C in April and 24.4^{o}C in May (Anon n.d.) but there is a large difference between day and night temperature.

Location, Building

Case study buildings are located in Kashan, Iran (33° 58' 59" N / 51° 25' 56" E) which is characterized with desert climate and clear-sky conditions, (Fig 1). The high school is chosen due to its design reminding Iranian traditional architecture with four south facing and four north facing classrooms surrounding a central courtyard, (Figs 1, 2 & 5). The studied primary school is located across the high school but with a typical compact design of schools in this region, (Figs 1 & 3). Schools have inclined 25 degree toward west and have North-West and South-East orientation, (Fig 1). As all the classrooms are the same in size and design, one south facing classroom and one north facing classroom have been selected in the middle of each school.

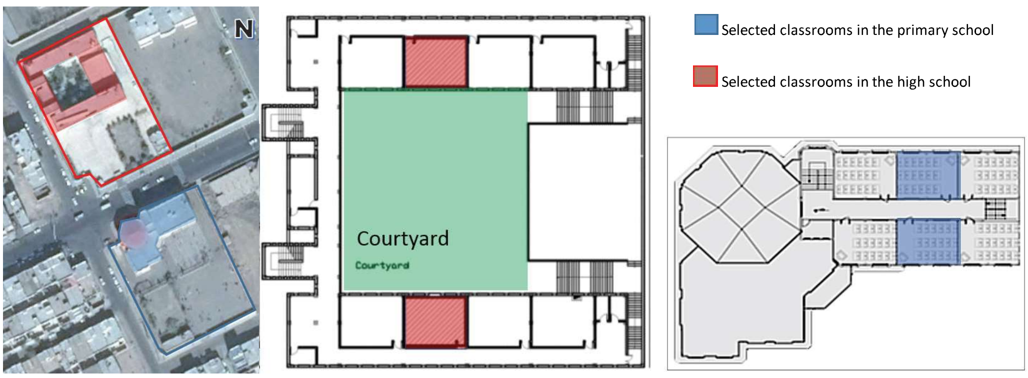


Fig 1. Left: location and orientation of the schools (Image from Google Earth). Fig 2. Middle: high school floor plan. Fig 3. Right: primary school floor plan

Both schools have medium thermal mass buildings with classrooms of approximately the same size, around 50 m^2. High school classrooms are day-lit through 4 double glazed windows with 2.3 m height and 0.5 m width, WWR=20%, (Fig 4), and primary school classrooms are day-lit with 2 double glazed windows which cover 21% of the wall, without external shadings, (Fig 6).

Fig 4. Left: high school. Fig 5. Middle: high school's Courtyard. Fig 6. Right: primary school

Subjective Measurements

A total of 113 girl students aged 15-18 were surveyed three times in the high school, 59 students from 20-22 April 2015 and 54 students from 19-21 October 2015, collecting a total of 323 questionnaires. 59 students aged 10-11 were surveyed in the primary school during 5-7 May 2014, collecting a total of 172 questionnaires. Table 1 provides detailed information of the number of subjects. The schools' academic year start around September 25 and ends around June 18 and classrooms are occupied from Saturday to Wednesday, 8:00 to 14:30.

Table 1. Provides detailed information of the number of subjects

School	Season	Classroom Orientation	Number of Votes/Number of Students			
			1st day	2nd day	3rd day	Total
High School	Spring	South	30/30	30/30	28/30	88/90
		North	28/29	27/29	29/29	84/87
	Fall	South	26/26	26/26	24/26	76/78
		North	28/28	23/28	24/28	75/84
Primary School	Spring	South	28/29	28/29	29/29	85/87
		North	29/30	30/30	28/30	87/90

Prior to doing the main study in the high school, a group of 10 students were selected from each classroom to fill out a 7-point scale questionnaire in two successive days in spring at three different times, 9, 11 a.m. and 12:30 p.m. Based on feedback received from students and teachers, the questionnaire was long and confusing so it changed to a five point scale questionnaire in its second edition, (+2) Hot, (+1) Warm, (0) Neutral, (-1) Cool and (-2) Cold. For devising the appropriate questionnaire for children in the primary school, authors took into account several studies (Fabbri 2015; Teli, Mark F. Jentsch, et al. 2012; Haddad et al. 2012), yet, teachers checked the questions and commented on changing the 7-point scale questionnaire to a 5-point scale questionnaire, (+2) Hot, (+1) Warm, (0) OK, (-1) Cool and (-2) Cold. The questionnaires were administered only once in each three days but at different hours as students found it tiring to fill out questionnaires three times a day. Although the study by (Goto et al. 2002) shows that 15 min of sedentary activity enables the body to reach a stable thermal state, the surveys were handed out after 30 minutes of the classroom activity to provide a safety margin (Montazami et al. 2017; Teli, Mark F. Jentsch, et al. 2012).

Metabolic rate was considered 1.2 met as students were engaged in sedentary activity after half an hour of the start of the class. The clothing values were found to be within a range of 0.7 to 0.8 Clo; the Clo value is relatively high for spring and fall in this region which is due to Islamic regulations and dress code. Moreover, as schools are segregated and students are exposed to same cultural background and outdoor temperature (Haddad et al. 2016a), clothing patterns are not very different.

Objective measurements

The environmental parameters were measured according to the standards of ISO 7726 (ISO 7726 2001) and simultaneous with physical measurements. Radiant temperature (globe thermometer with diameter=100mm), air temperature, relative humidity and air speed were measured by Testo data logger 175-H2, WBGT8778 and Testo flow meter at the height of 1.1 at the intervals of half an hour. To ensure acclimatisation to the classroom environment, instruments were set up an hour before experiment in the centre of the classrooms and away from sunlight patches. All measurements were done at sunny and clear days.

Results

Students' perception of the questionnaire

All replies were controlled in terms of inconsistency so that the cases with (TSV+TPV)<-3 or (TSV+TPV)>+3 are not reliable since a student feeling hot does not normally prefer a warmer environment (Teli, Mark F Jentsch, et al. 2012). The replies were all reliable, even in the primary school, which confirms students' good understanding of the questionnaires.

Students' thermal sensation and thermal preference vote

Fig 7 shows the distribution of TPV in relation to TSVs at each classroom, with mean operative temperature for each orientation. Students mostly find their environment 'warm' in south facing classrooms, 51% in high school and 59% in primary school. Students mostly feel 'neutral' in north/high school (54%) and have close warm (38%) and neutral sensations (31%) in north/primary school which is due to higher mean operative temperatures (29.3^{o}C), (Fig 7). TPVs are centred on cooler and colder with 83% in south/high school, 67% in north/high school, 87% in south/primary school and 95% in north/primary school. Students in both schools have a more neutral sensation towards north facing classrooms than south facing classrooms, especially in the high school where the difference between operative temperature in north and south facing classrooms is higher than in the primary school. This can be attributed to the special design of this school with the courtyard in centre.

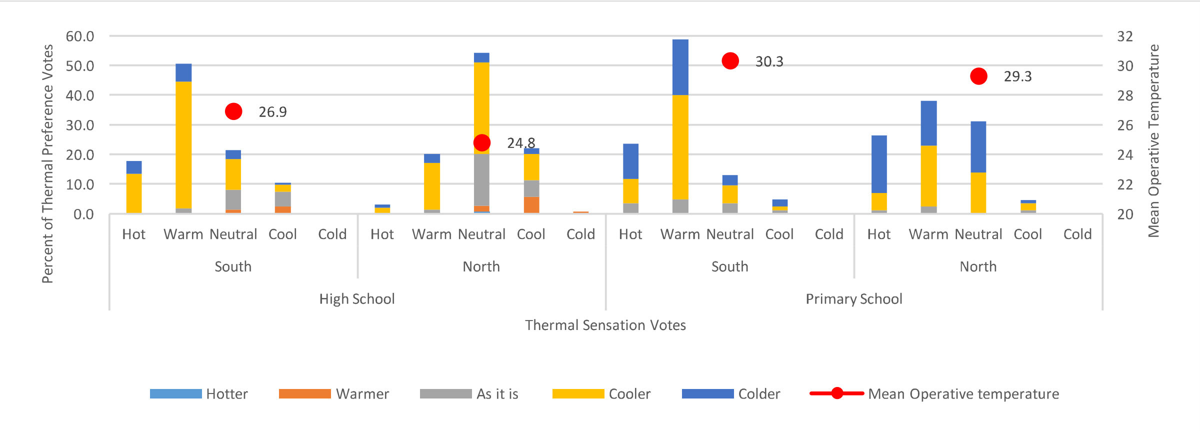


Fig 7. Relative Frequency of TSV against TPV and operative temperature

Effect of School Design on thermal Environment

As floor area, WWR, thermal mass and the number of students in each classroom are approximately the same, studying the effect of design on operative temperature and thermal environment is more controlled. By referring to Table 2, it can be seen that T_{op} is closer to T_{out}

in high school with the courtyard design than in primary school with compact design, especially in north facing classrooms where the effect of solar radiation is less. In the high school, T_{op} is averagely 11% higher than T_{out} in S/spring, 4% higher in N/spring, 9% higher in S/fall, 1% higher in N/fall. In the primary school, this difference is more significant, with T_{op} being 18% higher than T_{out} in S/spring and T_{op} being 16% higher than Tout in N/spring. The difference between T_{op} and T_{out} in the primary school is 1.6 times and 4 times higher than that in the high school in south and in north facing classroom, respectively. The courtyard design provides more shaded areas and wall surfaces with lower temperatures which can reduce indoor temperature. The effect of wall surfaces on indoor temperature has already been verified by (Rajapaksha et al. 2003) which also points to the importance of courtyards on optimizing natural ventilation to minimize indoor overheating. The study by (Taleghani et al. 2014) has also suggested that designing a courtyard in severest climate scenario, can provide an optimum balance between energy use and summer comfort (May to October). Another paper by (Taleghani et al. 2015) shows that the courtyard can provide the most comfortable microclimate in the Netherlands in June.

Comparison of PMV-TSV

To provide criteria for thermal comfort based on the PMV indices, environmental parameters including ambient air temperature, mean radiant temperature, air velocity and relative humidity were measured and clothing insulation and metabolic rate were also estimated while doing surveys (Fanger 1970). For PMV calculations, ASHRAE Standard 55 (Ansi/Ashrae 2013) equations were used. Table 2 shows the results from the field measurements (TSV, TPV and SD), PMV Predictions, T_{out} and calculated T_{op}, with highlighted rows for those that don't comply with ASHRAE 55 PMV method and estimate slightly warm or warm sensation.

There are not large variations within TSVs, with the standard deviation ranging from 0.52 to 0.89 in the high school and 0.66 to 1.18 in the primary school. S.D $_{mean}$ for the primary school is 0.8 which is smaller than the mean value of 1.07 based on studies done by (Humphreys et al. 2007). Although there is not high variation in TSVs but S.D. $_{mean}$ in the primary school, 0.8, is higher than that in the high school, 0.7, which can be attributed to children's higher metabolic rate and more diverse activities in the schedule. This finding has been confirmed by (Teli, Mark F Jentsch, et al. 2012).

Table 2. Presents Operative temperature, PMV, TSV and TPV of all surveys.

Stage	Orientation/Season	T_{out}	T_{op}	PMV	TSV	SD $_{TSV}$	TPV	SD $_{TPV}$	PMV	Sensation
High School	S/Spring	23.1	25.5	0.4	0.20	0.89	-0.83	0.53		Neutral
		23.8	26.9	0.74	0.67	0.61	-1.00	0.37	×	Slightly warm
		25.2	29.2	1.27	1.32	0.77	-1.35	0.49	×	Slightly warm
	N/Spring	23.1	24.7	0.22	-0.18	0.77	-1.00	0.72		Neutral
		23.8	25	0.27	0.11	0.80	-0.93	0.55		Neutral
		25.2	25.9	0.49	0.55	0.63	-1.00	0.50		Neutral
	S/Fall	22.1	25.4	0.44	0.00	0.69	-0.15	0.78		Neutral
		24.2	26.9	0.87	1.10	0.52	-1.10	0.39	×	Slightly warm
		26.8	27.6	1.06	1.33	0.64	-1.16	0.56	×	Slightly warm
	N/Fall	22.1	24	0.12	-0.21	0.69	-0.11	0.83		Neutral
		24.2	24.7	0.32	-0.17	0.58	-0.26	0.86		Neutral
		26.8	24.7	0.35	0.04	0.81	-0.58	0.72		Neutral
Primary School	S/Spring	24.7	30.5	1.89	0.93	0.81	-1.11	0.69	×	Warm
		25.3	31	2	1.18	0.77	-1.32	0.77	×	Warm
		27.3	29.5	1.63	0.93	0.65	-1.28	0.53	×	Warm
	N/Spring	23.7	29.5	1.63	0.66	0.94	-1.21	0.62	×	Warm
		24.3	30	1.76	1.07	0.91	-1.8	0.48	×	Warm
		26.3	28.5	1.38	0.86	0.71	-1.43	0.50	×	Slightly warm

Fig 9 shows the actual mean TSV against the calculated PMV. The correlation between TSV and PMV in the primary school (R^2=0.40) is not as strong as the correlation between TSV and PMV in the high school (R^2=0.92), meaning that thermal condition that is assessed by PMV Index is more reliable for high school students than for children in this study. The correlation between TSV and PMV in the primary school is very close to the correlation found in the study done by (Teli, Mark F Jentsch, et al. 2012).

Fig 10 shows the relationship between TSVs and PMVs plotted against T_{op} and linear regressions for both primary and high school which have the following equations, respectively:

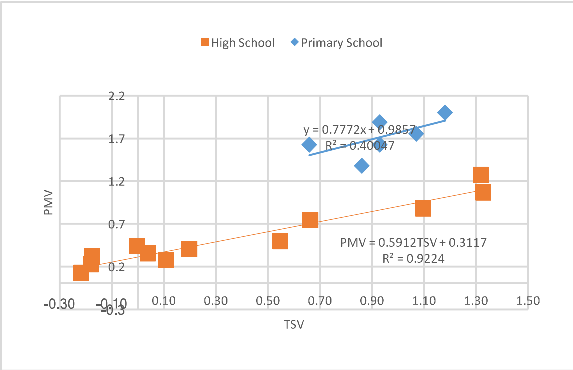
'Equation 1: $TSV_{(mean)} = 0.3652\, T_o - 9.0544,\ R^2 = 0.88$',

'Equation 2: $TSV_{(mean)} = 0.13 T_o - 2.94,\ R^2 = 0.40$'

According to equation 1, TSV in the high school remains close to neutral, between +0.5 and -0.5, when the operative temperature is between 23.7°C and 26.5°C and PMV is close to neutral when the operative temperature is between 21.4°C and 25.9°C. PMV slightly overestimates students' thermal sensation in the high school while they can tolerate higher temperatures. Most of PMV points fall a little above those of TSV in the high school or are very close to TSV points but TSV is slightly higher than PMV at higher temperatures, more than 27°C, which shows students sensitivity to higher temperatures.

According to equation 2, primary school students' TSV is close to neutral sensation, when the operative temperature is between 18.7°C and 26.4°C, and PMV is close to neutral when the operative temperature is between 20.9°C and 24.9°C, meaning that children accept a wider range of temperatures than what has been suggested by PMV model and feel less sensitive to temperature variations. Although all PMV points fall above those of TSV in the primary school, Fig 11, it cannot be concluded that PMV overestimates children's thermal perception as, first, graphs and equations show that at lower temperatures, PMV model would underestimate children's perception, second, the number of students are not large enough to draw any firm conclusion. According to the results derived from this study, it can be assumed that while PMV model underestimates children's thermal perception at low temperatures, it overestimates children's thermal sensation at high temperatures. Generally, the range proposed by PMV is much more limited that the range accepted by children in this study. While children tolerate lower temperatures than high school students, upper threshold of neutral temperature for them (26.4°C) is very close to that for adults (26.5°C) in this study and is higher than PMV predictions.

The correlation between TSV and T_{op} is quite satisfactory for the high school with r^2=0.88 showing that students' mean sensation of thermal conditions is greatly affected by operative temperature variations. The regression gradient of 0.36 derived from this study is very close to the mean value derived from the study by (Humphreys et al. 2007) for adult subjects which is 0.37 scale unit/°C. On the other hand, the correlation found between T_{op} and $TSV_{(mean)}$ in the primary school is less satisfactory (r^2=0.4). The low regression gradient of 0.13 shows that children are less sensitive to temperature changes which agrees with the studies done by (Teli, Mark F Jentsch, et al. 2012; Humphreys 1977). The derived value, 0.13, is lower than the value in the studies by (Teli, Mark F Jentsch, et al. 2012; Haddad et al. 2016b) which is 0.27.



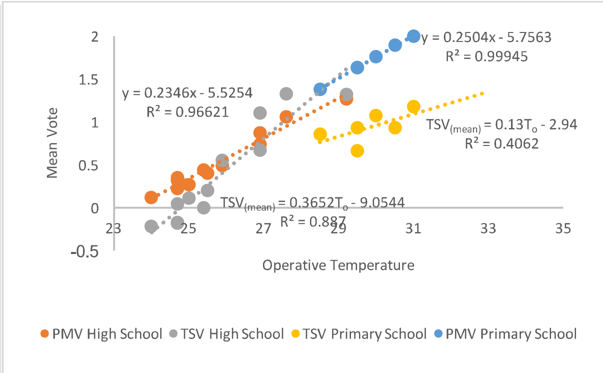


Fig 9. Left: TSVs by PMV. Fig 10. Right: TSV and PMV plotted against T_{op}

Conclusion

Results show that north facing classrooms provide lower temperatures and students' votes are more close to neutral in north facing classrooms. Moreover, T_{op} is closer to T_{out} in the high school with the courtyard design than in primary school with compact design, especially in north facing classrooms where the effect of solar radiation is less. Courtyard design can provide higher levels of natural ventilation and reduce overheating in this region.

Results show that PMV overestimates high school students' perception of comfort; TSV is lower than PMV in 8 out of 12 surveys and is higher than PMV only in high temperatures. According to the findings of this study and equation 2, PMV model also overestimates children's thermal sensation at high temperatures and underestimates it at low temperatures. A wider range of neutral temperatures are accepted by children (18.7°C =<Tn<=26.4°C) than that suggested by PMV (20.9°C =<Tn<=24.9°C) while many studies have confirmed that rational thermal comfort model underestimates children's thermal perception (Teli, Mark F Jentsch, et al. 2012; Montazami et al. 2017; ter Mors et al. 2011; Zeiler & Boxem 2009; Liang et al. 2012; Haddad et al. 2016b). The wider range of neutral temperature for primary school students than that by PMV model suggests that the physiology of children in this study can well adapt to wide outdoor temperature changes. Children' adaptability to lower temperatures can be justified by their higher metabolic rate and activity level as already confirmed by (Haddad et al. 2016b; Teli, Mark F Jentsch, et al. 2012; Montazami et al. 2017) and children' adaptability to higher temperatures can be justified by their expectations of the region. Moreover, higher PMV points than TSV points at high temperatures can also be attributed to the high mean value of Clo in this study (0.75) which results in high PMV values. As girl students have to follow dress codes and cannot take much adaptive behaviours towards clothing due to Islamic regulations, especially in mid-seasons, other behavioural and environmental behaviours should be provided and encouraged, especially for young children.

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