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Thermal comfort in primary schools: a field study in Chile

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Abstract
This paper presents the first results of a field study on thermal comfort in school buildings that is been carried out in Chile, with the aim of determining comfort temperature of students in state-owned primary schools. The paper presents the results of four schools located in Santiago, a city with low temperatures in winter and high temperatures in summer, which are typically free-running, as they have neither a heating nor a cooling system. The methodology included measurements of thermal parameters complemented with questionnaires based on the adaptive model and modified for the understanding of 9-10 years-old students. The field work was organized in two phases: winter (August) and summer (December), where in each phase the students responded the questionnaire up to three times per day in a period of three to four days. The results show that comfort temperature derived from the field work is significantly lower than comfort temperature calculated from Humphreys formula, while they also show that students form highly vulnerable schools voted lower comfort temperatures than those from less vulnerable realities.

Keywords: thermal sensation vote, primary school, children, comfort temperature

1 Introduction
The fact that thermal comfort in school classrooms has a significant impact on children's performance and health (Sensharma et al, 1998), while children spend more time in schools than in any other building except at home (Bluyssen, 2014) evidences the importance of achieving a comfortable thermal environment in school buildings.

There are very few studies on thermal comfort in schools (Mors et al 2011; Teli et al 2012, Montazami and Nicol, 2013; De Giuli et al 2014) and their results indicate that children have a different thermal perception compared with adults, suggesting that current comfort standards may not apply to school children, which emphasizes the need of more studies in this field.

In Chile, school buildings represent the most "passive" building typology, as the great majority of them has no heating or cooling system, even in climatic zones with relatively cold winters and hot summers. In addition, they usually have a poorly insulated envelope with single glazing and no solar protection, which results in important indoor temperature variations, both seasonally and daily. Currently, there are no regulations to control the quality of the thermal envelope and the only requirement for thermal comfort is an indoor temperature of 12°C, but only in the southern and colder climatic zones (south on latitude 36°) where a heating system is required. Post occupancy evaluations in school classrooms in the country (Armijo et al 2011, Trebilcock et al 2012) have found very low indoor temperatures in winter and high temperatures in summer, stressing the need for more studies in the field, with the aim of improving thermal comfort of school children.

Therefore, this work is based on a field study carried out in Santiago, Chile, which looks at thermal comfort in free running schools in both summer and winter conditions. The adaptive model has proven to be suitable for free running buildings (Nicol et al, 2013) as it suggests that there is a relation between preferred indoor comfort temperature and outdoor temperature.

2 Methodology

The paper presents part of the findings of a larger research project that covered a field study along three cities in Chile, showing only the case studies located in the capital city of Santiago, as they represent one of the most interesting results, due to the fact that the four cases are free-running schools, with different socio-economic backgrounds. In this climatic zone, school buildings are not legally required to have a heating or cooling system, and in general there are very limited regulations that apply to thermal environment. Consequently, students only manage their thermal comfort by regulating the number of articles of clothing they wear.

2.1 The context of Santiago

Santiago is the capital city of the country, with approximately 6 million inhabitants or 37% of the national population, and an extension of more than 600 km^2, located at latitude 33°26'South and longitude 70°32' West. It has a Mediterranean climate, with an extended dry season in summer, with average temperatures in January varying from 13°C to 29.5°C, and a maximum temperature of 34°C. In winter, average temperatures in July vary from 3.9° C to 14.9°C, with minimum temperatures that can go below 0°C, although on very few occasions. Precipitation is concentrated in winter, with an annual rate of 325mm, and low relative humidity with an average of 70%.

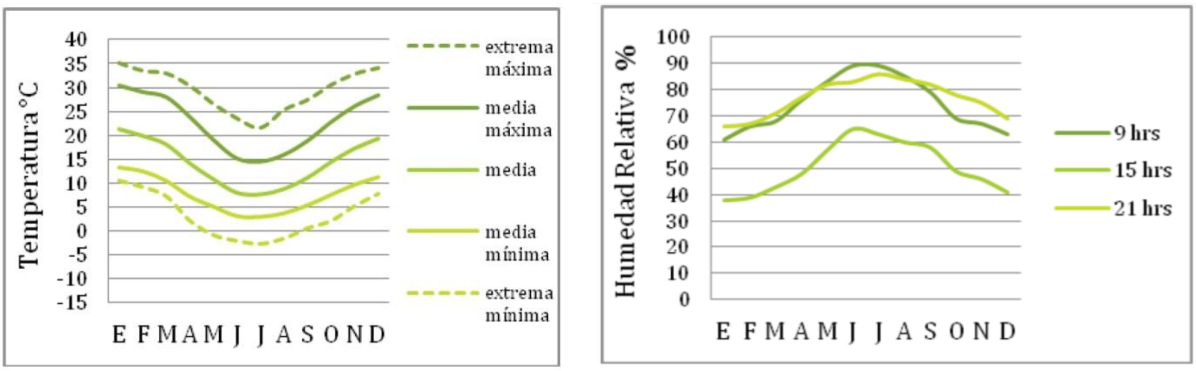
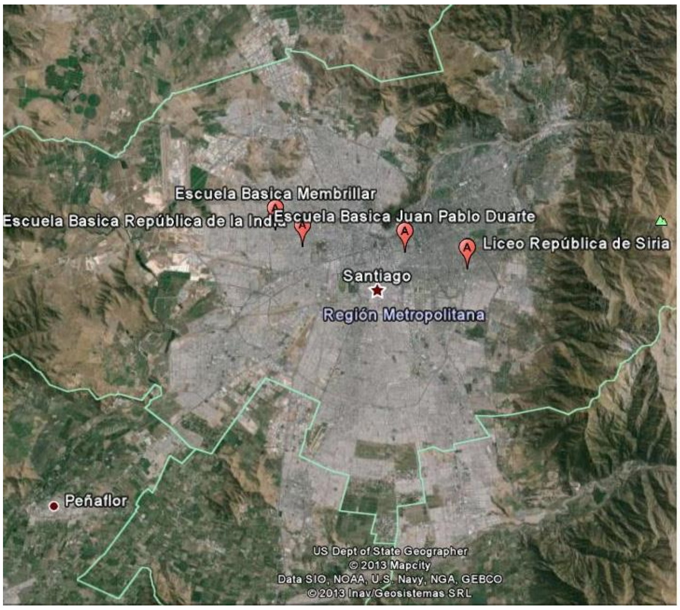


Figure 1. Climatic data of Santiago

2.2 Selection of cases

In the Santiago Metropolitan Area, there are a total of 3,817 educational establishments, which are categorized based on ownership and administration as public, subsidized, and private. The four case studies were selected from the universe of 501 state-owned schools within this group. The criteria for the selection of cases responded to the need of looking at schools from different socio-economic levels calculated by an index that represent the social vulnerability of the students (IVE SINAE index). This index reflects vulnerabilities associated to poverty, family composition, and all other factors that could lead to academic desertion. Figure 2 shows the location of the four cases in the urban area of Santiago, as well as their IVE index, where the higher value reflects higher vulnerability of the school´s students. According to this, Escuela Membrillar and Escuela República de India receive students from higher vulnerability levels than Liceo Juan Pablo Duarte and Liceo República de Siria. Photographs of each school are presented in Figure 3.



CASE STUDIES	IVE index
Escuela Membrillar	86.3%
Escuela Republica India	80%
Liceo Juan Pablo Duarte	43.3%
Liceo República Siria	37.6%

Figure 2. Location of case studies and their Index of Vulnerability

The unit of analysis for each school was one 4th year elementary class, with students varying in age from 9 to 10 years old, which was chosen for giving a good balance between a minimum age for properly understanding the questionnaire and a longer permanence in the classroom than older children. The number of students in each classroom varied from 35 to 40, but the number of responses was lower due to school attendance factors.

Membrillar School

República de India School

República de Siria School

Juan Pablo Duarte School

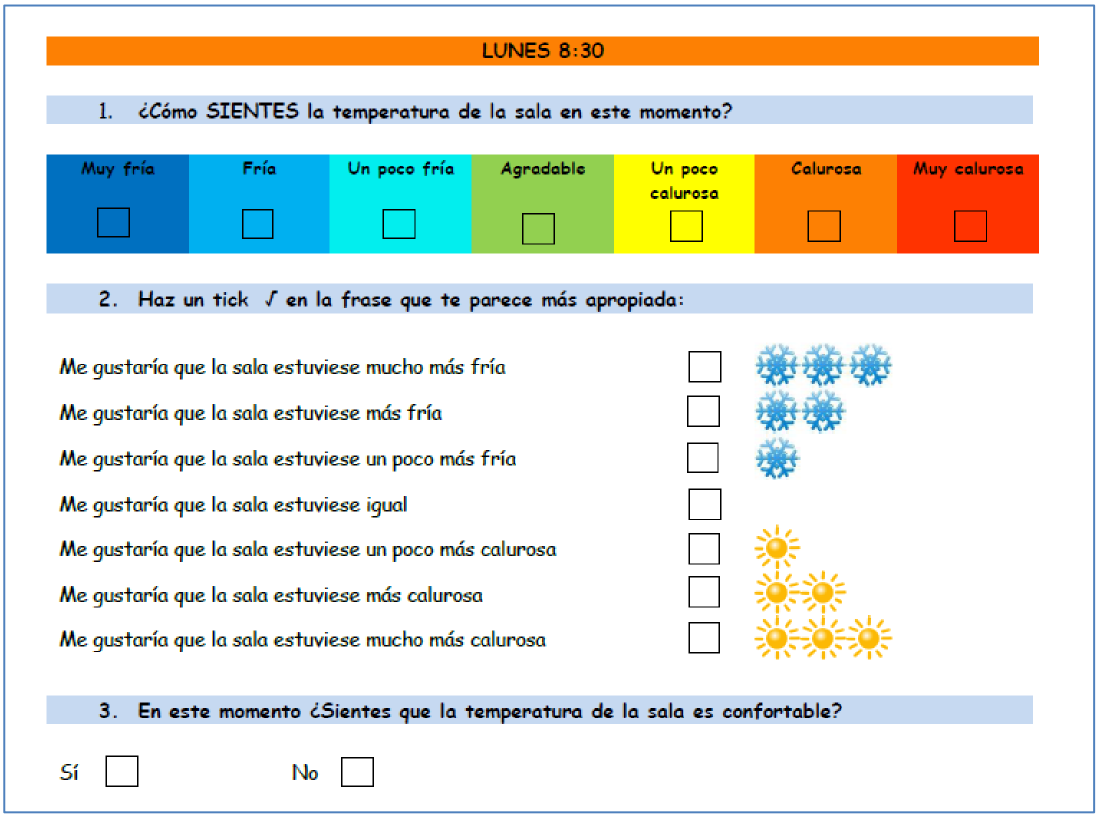
Figure 3: images of the four case studies

Figure 3 shows images of all four cases, where it is clear that the schools have different architectural characteristics. In terms of materiality, India, Siria and Juan Pablo Duarte schools have a heavyweight structure with high thermal mass, typically brick and concrete; while Membrillar has a lightweight structure of steel and timber. The thermal envelope is poor in all cases, with single glazing and no wall insulation. All four classrooms analysed have the main glazed façade facing eastwards, but JP Duarte school has an additional glazed area facing north, as it is located at the corner of the building. They are all accessed by an external corridor located at the west of each classroom.

2.3 Design of the questionnaire

The difficulties associated to the development of questionnaires for students have been discussed by some authors (Teli et al, 2012, Mors et al 2011). Therefore, the questionnaires for this project were developed according to Teli et al. (2012), using graphic information and colours that could be more easily understood by children. The questions included thermal sensation, thermal preference, thermal acceptability, clothing and activity. The clothing was simplified to include typical layers that students could wear over their uniform (usually a jumper and/or a parka), in the same way that the activity was simplified to include typical students' activities (sitting during the class, running during the break, etc).

The questions for thermal sensation vote and thermal preference vote did not include numbers in order to avoid confusing the children, but they did include colours and images accompanying the concepts, which ranged over the seven points scale; using terms in Spanish that are familiar to the children (Figure 4).



LUNES 8:30

1. ¿Cómo SIENTES la temperatura de la sala en este momento?

Muy fría	Fría	Un poco fría	Agradable	Un poco calurosa	Calurosa	Muy calurosa
☐	☐	☐	☐	☐	☐	☐

2. Haz un tick √ en la frase que te parece más apropiada:

Me gustaría que la sala estuviese mucho más fría ☐

Me gustaría que la sala estuviese más fría ☐

Me gustaría que la sala estuviese un poco más fría ☐

Me gustaría que la sala estuviese igual ☐

Me gustaría que la sala estuviese un poco más calurosa ☐

Me gustaría que la sala estuviese más calurosa ☐

Me gustaría que la sala estuviese mucho más calurosa ☐

3. En este momento ¿Sientes que la temperatura de la sala es confortable?

Sí ☐ No ☐

Figure 4: the first part of the questionnaire (own elaboration based on Teli et al, 2012)

Each questionnaire was designed to fit in a single colourful page, in order to be simple and attractive for the students, while all 12 questionnaires were put together in a booklet with a front page that registered personal data and the location of the student in the classroom. In this way, each student holds his/her own booklet of questionnaires that had to be responded up to three times per day (8:30 – 11:30 and 15:00hrs) during the period of study.

3 Field work

The field work was carried out in two phases: winter (August) and summer (December). In each phase, the students responded to the questionnaire up to 3 times per day during a period of 3 to 4 days, for a total of 146 answered questionnaires in winter and 127 in summer. The amount of responses was higher in winter than in summer, with a total of 1389 responses in winter and 774 responses in summer for all the cases, due to higher absenteeism during the summer period, as it was the week previous to summer holidays. The questionnaire was administered by the class teacher, who was trained by the researchers.

The measurements of thermal parameters covered a period of six days, as they started on the previous weekend. They included typical thermal data: dry bulb temperature (°C), globe temperature (°C), relative humidity (%) and air velocity (m/s). The instruments were located at the back/centre of the classroom, at 1.1m high, registering thermal data for one week in winter and one week in summer. It was not possible to locate the instrument at the centre of the classroom due to visibility and security problems, as they were fixed in that position for the whole measurement period. Figure 5 shows the location of the instrument in the classroom.

Figure 5. The instruments in two different case studies: Membrillar School (left) and Siria School (right)

The responses were firstly analysed in terms of their consistency, eliminating from the study all those responses that were inconsistent, such as giving a thermal sensation vote of -1 while stating that they prefer the classroom to be cooler.

4 Measurements

The measurements are presented in Figure 6 and Figure 7, which covers dry bulb temperature and external temperature for each case study during the winter period and during the summer period. External temperature was obtained from Quinta Normal meteorological station, located close to the city centre and near the schools.

Figure 6. Internal temperature in each classroom – winter period

The results show that in winter internal temperatures are generally low, varying between 13°C and 17°C during the occupancy period for India, JP Duarte and Siria School, while temperatures in Membrillar School were 2°C lower than the rest of the cases. These low values are the result of free running schools that lack of an appropriate thermal envelope, or other appropriate design strategy that could help to passively heat the building up in winter.

In addition, Membrillar shows the worst building quality, with a very poorly insulated and leaky envelope.

Figure 7. Internal temperature in each classroom – summer period

Similarly, indoor temperatures in summer are high, with maximum temperatures reaching 30°C during the occupancy period. Again, Membrillar School registered the poorest performance, due to its inadequate thermal envelope and lightweight structure that allows internal temperature to fluctuate according to the external temperature, while in the other three cases it is possible to observe the effect of thermal mass.

5 Thermal sensation vote

The results of the survey are presented in Figure 8, which shows the correlations between the thermal sensation vote and dry bulb temperature. The regression lines are shown in the graphs, giving the comfort temperature for each case for both winter and summer. The graphs are based on 201(w) and 214(s) votes for Membrillar; 388(w) and 290(s) votes for India; 402(w) and 162(s) votes for JP Duarte; and 398(w) and 109(s) votes for Siria.

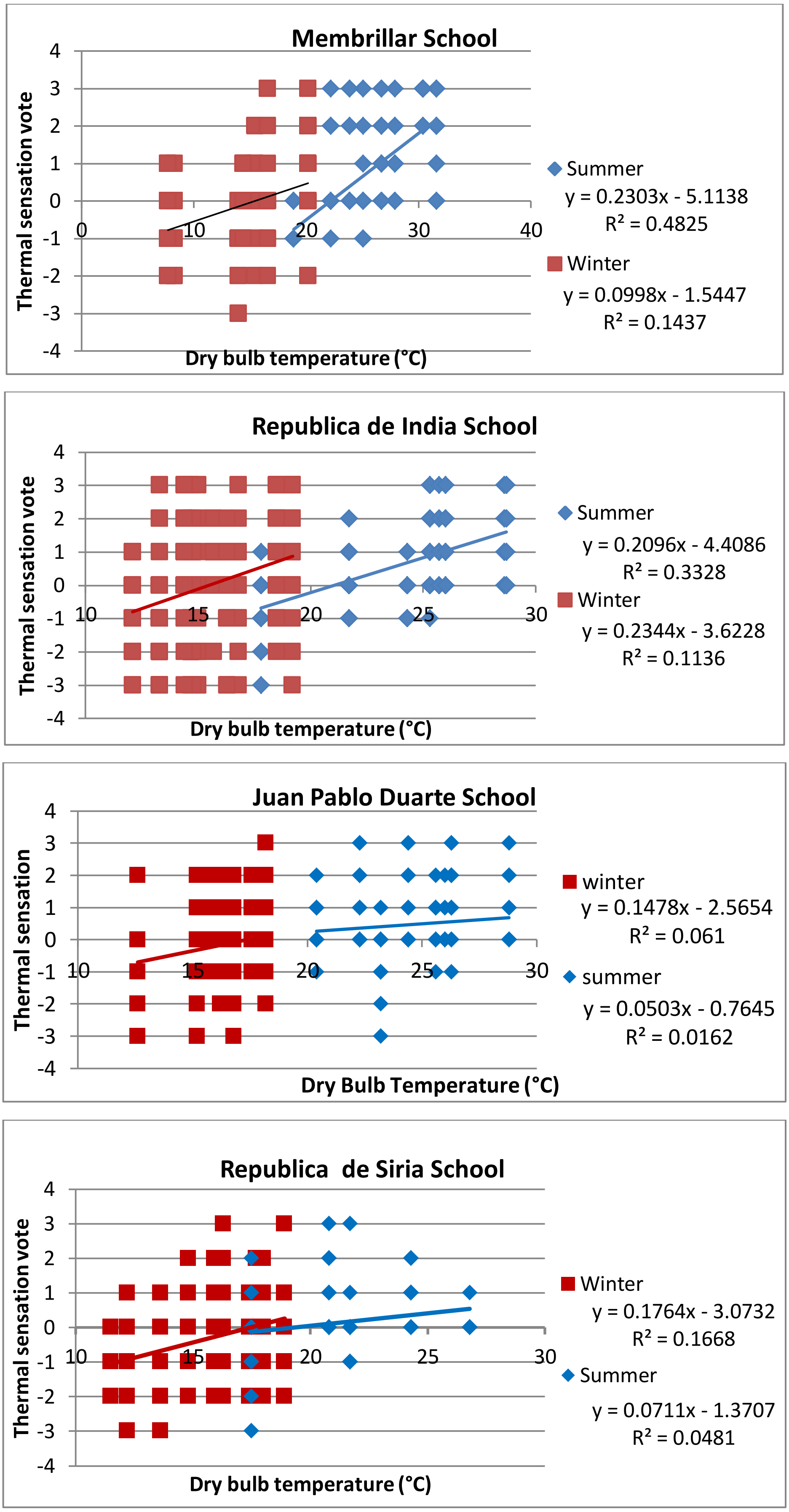


Figure 8: thermal sensation vote for each case study

Table 1: Neutral temperature from field study

	Neutral temperature winter (°C)	Neutral temperature summer (°C)
Membrillar School	15.5	22.2
Republica India School	15.5	21.0
JP Duarte School	17.4	-
Republica Siria School	17.4	-
All cases	**16.7**	**21.1**

Table 1 shows the neutral temperature for each case study, where it is possible to note that the two schools with highly vulnerable students (Membrillar and Republica de India) have significantly lower comfort temperature in winter than those with lower vulnerable students (Juan Pablo Duarte and Republica de Siria). In summer, the responses for Juan Pablo Duarte and Republica de Siria School presented a very low correlation, so only the comfort temperatures for the other two schools are presented in the table.

The results of the winter survey considering 1389 votes are shown in Figure 9, where the regression line gives a comfort temperature of 16.7°C; while the results of the summer survey considering 774 votes are shown in Figure 10, giving a comfort temperature of 21.1°C.

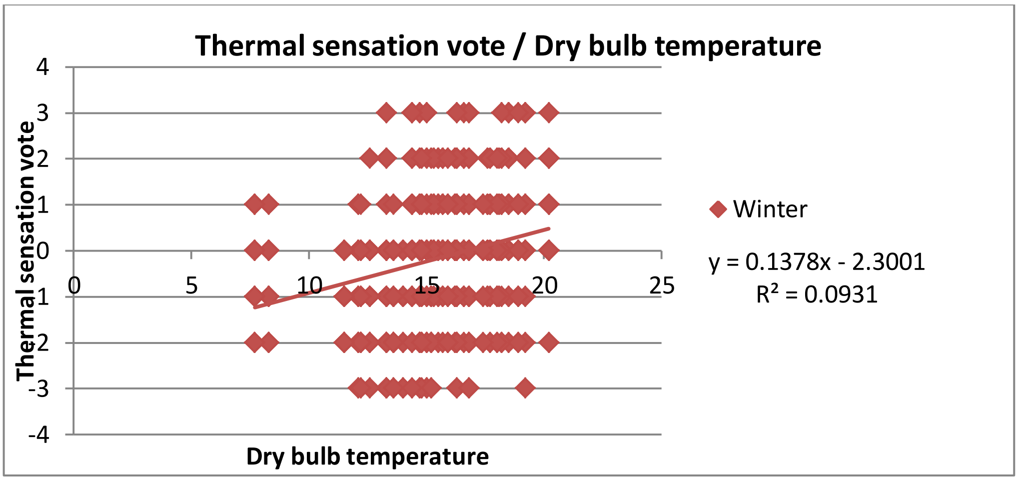


Figure 9: thermal sensation vote – winter period

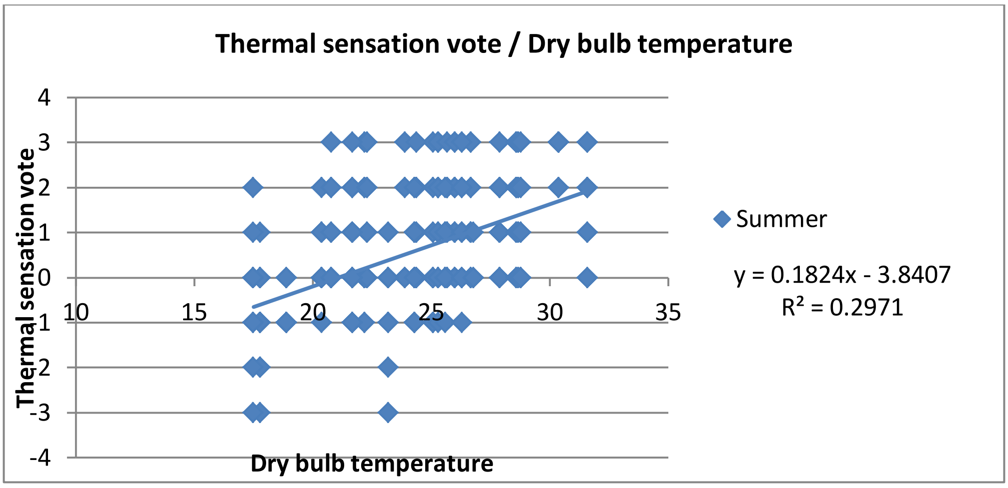


Figure 10: thermal sensation vote – summer period

Table 2 shows the results obtained from using the Humphreys formula (Humphreys et al, 2010) to calculate comfort temperature based on monthly mean outdoor temperature obtained from meteorological data, for the months when the survey took place. The results show that comfort temperature from the field work is considerably lower than the one calculated from Humphreys formula, for both winter and summer.

Table 2: Comfort temperature from Humphreys formula

	Comfort temperature from Humphreys formula (°C)
July	18.8
August	19.5
November	23.2
December	24.5

6 Conclusions

The conclusions of the first analysis of data obtained by this field study show that the comfort temperature derived from the thermal sensation vote of primary school students is significantly lower (3°C to 4°C) than those obtained from Humphreys adaptive comfort formula for free running buildings in Santiago. These results could be partly explained by the higher metabolic rate of children.

In addition, the results suggest that it might be a relation between the socio-economic vulnerability of the students in each school and comfort temperature in winter, as those students coming from highly vulnerable schools voted lower comfort temperatures than those coming from less vulnerable realities. These results might relate to the very low temperatures registered inside the classrooms, as well as fuel poverty at the children's homes, which motivate them to adapt to very low indoor temperatures in winter. Although these results are based on very few cases, they show a tendency that could be explored further with a larger sample.

7 Acknowledgements

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