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Thermal perception and satisfaction of Italian students in distance (home) learning vs face-to-face learning environments during the heating season

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Abstract. During the 2020-2021 COVID-19 pandemic situation, millions of high school students in Italy had to adapt a room in their home for partial distance learning. This paper investigates the thermal perception and satisfaction with the thermal conditions expressed by 45 teenage students alternating between Distance Learning (DL) and Face-to-face learning (FL) during that period. Students completed questionnaires about their perception and satisfaction with the thermal environment while air temperature and humidity were monitored for 14 weeks. The thermal conditions in the classrooms, where students attended classes every other day, were also monitored during this time. The results show that students at home experienced a high percentage of time with conditions outside recommended comfort limits. Nevertheless, most of the students expressed a TSV equal to 0. In addition, the proposed long-term thermal discomfort indicators, such as running mean of the indoor air temperature, correlated rather poorly with subjective votes. This may indicate that different indices should be considered when analyzing mid-term subjective thermal comfort evaluations.

1. Introduction

At the end of January 2020, the pandemic of COVID-19 spread worldwide becoming an international health concern and the World Health Organization (WHO) declared the need to introduce massive lockdowns for limiting the infection [1-2]. Before the health emergency, the time people used to spend indoor amounted to 60 % while throughout the duration of the pandemic, individuals were forced to stay at home for about 85 % of their time [3]. Among the restrictions to contain the infection, there was the introduction of Distance Learning (DL) in schools of all types and levels of education and Italy was one of the first countries to introduce the remote learning at the beginning of March 2020 until the end of the scholastic year and then alternating DL and face-to-face learning from September 2020 until June 2021. In this context, millions of students had to quickly convert a room in their home to a study room for remote learning. This exposure to a different learning environment and different Indoor Environmental Quality (IEQ) conditions during lectures had consequences on students' wellbeing [4] and their IAQ, thermal, acoustic, and visual comfort. Previous research has shown that students' mental effort and performance are arguably influenced by the quality of the environment where they carry out their activities [5], and this has been emphasized in recent studies on remote learning [11].

The aim of this study is to (i) inspect and compare the IEQ conditions during DL and FL and (ii) explore any correlation between subjective comfort and indoor conditions in DL environments.

2. Methodology

The dataset presented in this paper was collected during a field study that lasted 14 weeks, from February 22nd to May 28th 2021. During that period, students of a high school near Rome experienced different modalities of learning: in 10 out 14 weeks they alternated between Distance Learning (DL) at home and Face-to-Face learning (FL) at school every other day, while, during the 4 other weeks, they only had distance learning (Table 1). The study included (i) monitoring of physical parameters related to the thermal environment in students' homes and in classrooms and (ii) students' subjective evaluation of the home conditions, by means of a questionnaire about their perception and satisfaction with the indoor environment, filled at the end of each week of DL. For comparing the home indoor thermal conditions with the ones experienced at school monitored during the heating season, from February 22nd to 15th April, different long-term discomfort indexes, i.e., the percentage of time when temperature exceeds the comfort ranges (Discomfort Time) and the Degree-hours criterion (Weighted discomfort time) have been calculated according to the international standards [8-9] and adopted in [9-10]. Discomfort time according to ISO 7730 (i) and EN 16798 (i) required to calculate the percentage of the occupied time when the operative temperature exceeds the comfort ranges, i.e., To below 20 °C and greater than 24 °C [6] and To below 20 °C [7], respectively. The Degree-hours criterion (WDT) suggested by ISO 7730 (iii) and EN 16798 (iv), are calculated multiplying the time when the operative temperature exceeds the comfort range with a weighting factor, wf, based on the module of the difference between the actual operative temperature and the lower limit of 20 °C, in winter conditions. In this study indoor air temperature have been used as a proxy of operative temperature. Moreover, the indoor air temperature running mean (Θ_{rm}) and the mean indoor air temperature ($T_{a,mean}$) proposed by [9] as discomfort indicator, have been also calculated in order to compare the results with students' subjective responses.

2.1. IEQ monitoring during distance learning (DL) and face-to-face learning (FL)

During the campaign, 45 students were provided with temperature and humidity data loggers for monitoring the indoor air temperature and humidity in the room they occupied for distance learning. At the same time, the indoor conditions in the respective 5 classrooms occupied by these students during FL learning days were monitored during all 14 weeks.
Indoor air temperature (Ta) and relative humidity (RH) were monitored at 10-minutes intervals in both environments.
At school, Ta, RH and CO_2 concentration were recorded with a sensor located in each classroom, near the teacher's desk and away from heat sources or sun patches at a height of 1.1 m [8]. The details of the sensors are reported in Table 2.

Table 1. Occupancy schedule during the 14-weeks monitoring.

Week	Period	Type of learning
1-3	23/02/2021 – 11/03/2021	Face-to-Face learning (FL) + Distance Learning (DL)
4-6	15/03/2021 – 31/03/2021	Distance Learning (DL)
7-14	07/04/2021 – 28/05/2021	Face-to-Face learning (FL) + Distance Learning (DL)

Table 2. Characteristics of the loggers installed at home and school for the mid-term monitoring.

Environment	Logger	Parameters	Specification
Home	Brifit	Ambient Temperature (T) Relative Humidity (RH)	T: Range: -20°C to 65°C; Accuracy: ± 0.5°C RH: Range: 0% ÷ 100%; Accuracy: ±5%
School	HOBO® MX1102A	Ambient Temperature (T) Relative Humidity (RH) Carbon Dioxide (CO_2)	T: Range: 0°C ÷ +50°C; Accuracy: ± 0.2°C RH: Range: 1% ÷ 90%; Accuracy ±2% CO_2: Range: 0 ÷ 5000ppm; Accuracy ±50ppm;

2.2. *Mid-term subjective survey during DL*

During the campaign, students were asked to fill an online questionnaire at the end of each learning week in order to collect their perception of the indoor conditions experienced during DL. The questionnaire is divided into (i) general information about the DL room, (ii-v) IEQ perception related to thermal (Table 3), visual, acoustic and IAQ domains; (vi) global comfort and satisfaction. The questionnaire and the collection and management of sensitive data were approved by the University Ethics Committee of the Free University of Bolzano and Iuav University of Venice. The main questions and evaluation scales related the to the (ii-v) sections are summarized in Table 3. A quality check was carried out to remove possible inconsistent answers (i.e., responses given in delay), which were not included in this analysis. A total of 66 questionnaires were collected in the period 3rd March-4th April (i.e., weeks 3-6). In this work, the answers to the first question related to thermal environment (i.e., *How would you describe the DL room?)* were analyzed.

Table 3. Main thermal questions and evaluation scales of the mid-term questionnaire.

Question → Domain ↓	1. How would you describe the DL room?	2. How comfortable did you feel during DL learning this week?	3. Regarding this week, are you satisfied of the indoor conditions?
Thermal	from COLD (-3) to HOT (+3)	from COMFORT (0) to VERY UNCOMFORTABLE (3)	YES/NO

3. Results and discussion

3.1. *IEQ conditions in Distance Learning (DL) and Face-to-face Learning (FL) environment*

The indoor air temperature monitored during the heating season in 45 DL rooms and in the 5 corresponding classrooms occupied by the students during FL are reported as boxplots, in Figure 1 and 2, respectively. In many DL rooms the air temperature is outside the comfort range (20-24 °C suggested by EN ISO 7730 [6]); several rooms are below 20 °C degrees, while in some cases the temperature is higher than 24 °C, exceeding thus also the upper winter limit. Concerning the indoor air temperature in classrooms, it can be seen that the 25th and 75th percentiles are between the comfort conditions.

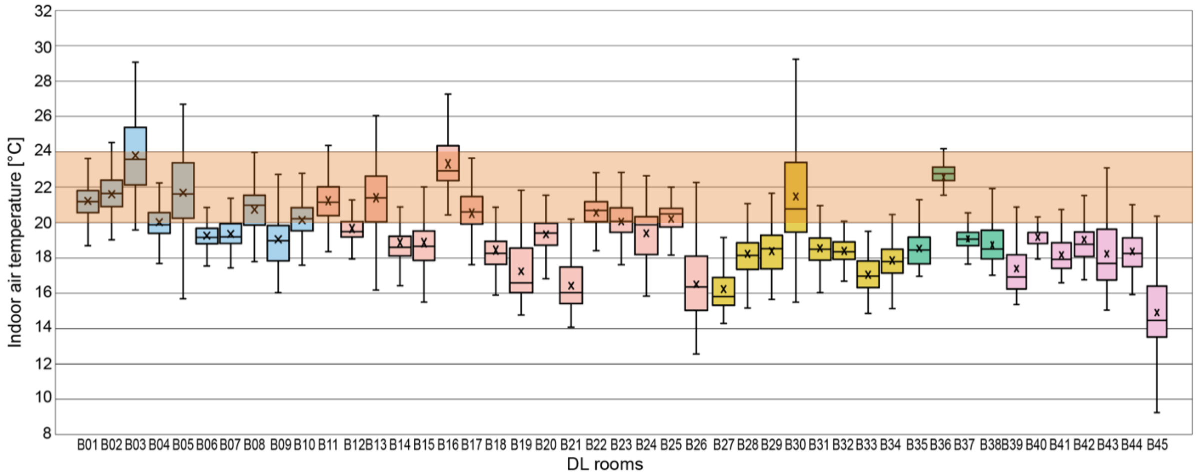


Figure 1. Boxplots of indoor air temperature distributions in students' rooms during DL. The cross indicates the mean conditions, the boxes indicate the conditions between the 25th and the 75th percentile, the horizontal line indicates the median, the extremes represent the maximum and the minimum condition. Colors distinguish students attending the same class in consistent colors as in Figure 2. Shaded red band highlight the thermal comfort range.

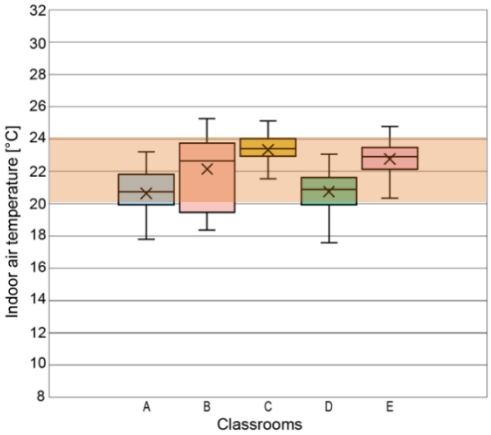


Figure 2. Boxplots of indoor air temperature distributions in students' classroom during FL. The cross indicates the mean conditions, the boxes indicate the conditions between the 25th and the 75th percentile, the horizontal line indicates the median, the extremes represent the maximum and the minimum condition. Shaded red band highlight the thermal comfort range.

3.2. Long-term indexes for thermal discomfort: homes versus classrooms

Table 4 summarizes the long-term discomfort indexes calculated from the indoor conditions in each of the 45 students' houses and in the 5 classrooms during winter. The first column on the left reports the number of the class, i.e., group of students which attended the FL learning in the same classroom. Discomfort indexes calculated for all students houses (B01-B45) are compared with the respective classrooms (A-E).

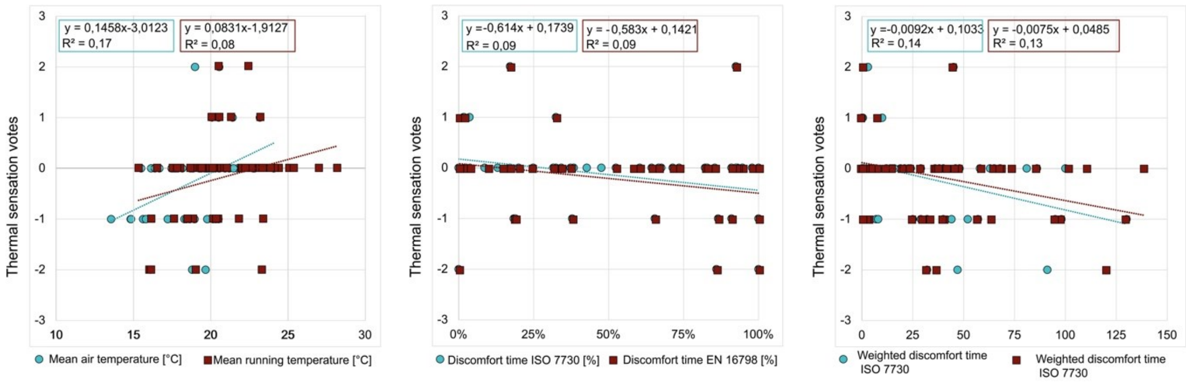
Table 4. Long-term discomfort indexes based on the indoor conditions in students' houses and in classrooms during the heating season.

Class	Room	DT ISO 7730	DT EN 16798	WDT ISO 7730	WDT EN 16798	Class	Room	DT ISO 7730	DT EN 16798	WDT ISO 7730	WDT EN 16798
1	Classroom A	28%	28%	24	17	2	B24	52%	52%	133	114
1	B01	7%	6%	13	8	2	B25	28%	28%	63	42
1	B02	9%	7%	16	12	2	B26	96%	96%	396	507
1	B03	44%	0%	1	0	3	Classroom C	39%	18%	18	12
1	B04	56%	56%	110	54	3	B27	98%	98%	379	469
1	B05	36%	23%	51	33	3	B28	79%	79%	202	170
1	B06	81%	81%	180	121	3	B29	64%	63%	162	137
1	B07	77%	77%	171	114	3	B30	50%	19%	41	27
1	B08	28%	27%	61	41	3	B31	69%	68%	154	106
1	B09	76%	76%	143	125	3	B32	80%	80%	172	108
1	B10	40%	40%	85	53	3	B33	97%	97%	243	259
2	Classroom B	45%	27%	22	13	3	B34	84%	84%	228	206
2	B11	15%	13%	27	15	4	Classroom D	38%	38%	36	23
2	B12	70%	70%	137	67	4	B35	91%	91%	249	227
2	B13	33%	24%	50	30	4	B36	8%	6%	14	9
2	B14	82%	82%	218	194	4	B37	93%	93%	211	147
2	B15	83%	82%	217	192	4	B38	86%	86%	227	200
2	B16	28%	0%	0	0	5	Classroom E	23%	18%	21	19
2	B17	24%	23%	55	42	5	B39	94%	94%	343	408
2	B18	89%	89%	229	217	5	B40	87%	87%	203	148
2	B19	95%	95%	339	397	5	B41	97%	97%	290	294
2	B20	74%	73%	117	81	5	B42	85%	85%	225	200
2	B21	99%	99%	403	513	5	B43	80%	80%	273	308
2	B22	21%	21%	44	26	5	B44	92%	92%	269	266
2	B23	46%	46%	92	48	5	B45	97%	95%	537	792

The color shades differentiate the results from the higher calculated percentage or value (full red) to the lower ones (white), meaning from higher to lower discomfort rates. In general, temperatures in classrooms were more favorable than those of most of the students' houses. In classrooms the discomfort time indexes is always below 50% in each classroom, while the ones calculated in some DL rooms reached 99%, highlighting significant thermal discomfort. Concerning the weighted discomfort time, the highest discomfort occurs in DL rooms with the worst conditions experienced by students belonging to Class 5.

3.3. *Indoor conditions versus Subjective responses*

Linear regression models were implemented (Figure 3) between thermal sensation votes and discomfort indexes, namely indoor temperature, mean running temperature (Fig. 3a), discomfort time (Fig. 3b) and weighted discomfort time (3c). Based on the collected data, the results show no evident correlation between TSV and any of these metrics. Figure 4 reports the comparison of the distribution of the indoor air temperature with the thermal sensation votes related to FL and DL experiences. It can be noticed that, even if the indoor conditions during DL are unfavorable for a high percentage of time (i.e., Ta,mean below to 20°C), while at school the indoor air temperature lies most of the time within recommended comfort limits, the percentage of students experiencing a neutral condition during DL is higher than at school. This might indicate the subjective votes are affected by some adaptation strategies which can be easily adopted in a domestic environment, rather than in a shared one, as classrooms are.



a) b) c)

Figure 3. Thermal sensation votes plotted against long-term indexes calculated based on air temperature monitored during the weeks of Distance Learning (weeks 3-6). The mean air temperature and the mean running temperature are represented in light blue circle and brown square, respectively.

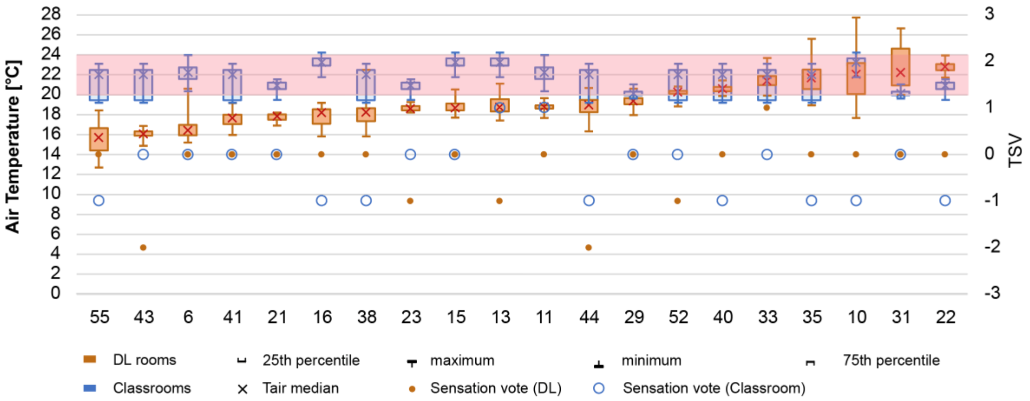


Figure 4. Distribution of indoor air temperature in classrooms (week 3) and students' DL rooms (week 4) and thermal sensation votes expressed by students. The results related to face-to-face learning and DL are shown in blue and orange, respectively. Red shades indicate comfort range.

4. Conclusion

At school, indoor temperatures were found to comply with the requisites of the technical standard EN 16798-1:2019 for a high percentage of time. Conditions outside the Standard limits can be attributed to the COVID-19 provisions issued by the Italian government, which suggested frequent and prolonged windows opening to ventilate the room and reducing the risk of disease transmission. Indoor temperature distribution in homes presented lower mean and median values with respect to the classrooms and a higher percentage of time with conditions outside the recommended limits. Some of the reasons could be due to the fact that students at home can easily adapt their clothing level to compensate for lower temperatures (instead of system-preset setpoints in schools). Moreover, there could be some energy poverty-related behavior such as switching off the heating system for reducing energy costs. Finally, it was observed that there is a poor correlation between students' votes and the calculated long-term indexes even though a coherent increasing trend of the thermal sensation vote with the median value of the air temperature can be seen. Different long-term indices will be tested in the future in order to inspect which ones predict the subjective responses better.

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