

THERMAL COMFORT AND AIR QUALITY IN A UNIVERSITY CLASSROOM

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ABSTRACT

The environmental conditions inside buildings can influence the productivity of the occupants. In the case of classrooms the environment can influence the students learning capacity. Evidence continues to mount demonstrating that Indoor Environmental Quality (IEQ) directly impacts student health, comfort and ability to perform. In a view of a more extensive project to correlate learning ability with thermal stresses and/or Indoor Air Quality, a monitoring campaign was performed in a typical class of the Engineering Faculty of the University of Rome Tor Vergata with the objective of investigating the air quality and thermo-hygro-metric conditions inside the class. The campaign was carried out during the cold season (November – December 2010). Three days were chosen for the campaign and for each day, the environmental conditions were monitored during a lecture performed in the morning and one given in the early afternoon to consider different periods of the day and different attendance of the class. The thermal comfort conditions were evaluated using objective, subjective (questionnaire) and adaptive approaches. The air quality inside the class was monitored through the CO₂ concentration measurements that were correlated with the students judgements about the air quality perceived through the PPD – CO₂ concentration correlation introduced by Fanger.

INTRODUCTION

Thermal comfort and air quality are key issues to guarantee a pleasant staying inside buildings. People spend most of their time inside buildings and for this reason it is of high importance to guarantee a safety and pleasant indoor environment. Great attention was paid in the research to the interaction between Indoor Environmental Quality (IEQ) and productivity of the occupants in offices [1], [2], [3], [4] [5], [6]. Fewer works were devoted to the study of the learning environment while more recently a higher sensitivity to the lower level education environment (schools) was demonstrated by the scientific community [7], [8], [9], [10], [11], [12], [13], [14], with particular focus on the CO₂ concentration as source of discomfort and decay of attention of the students and as a tracer for the ventilation rate evaluation. Also the environment devoted to higher level education like University classrooms deserves higher attention considering the impact of thermal stress and air quality on the students learning capacity. Quite recently some works appeared in the literature about field works conducted in Italy [15], [16] and abroad [17], [18] on the thermal comfort and air quality inside university classrooms evidencing the importance of combining experimental measurements (objective approach) with the use of questionnaires (subjective approach) to better understand the real environmental perception of the students in the classrooms. The same authors also introduced in their studies the concept of adaptation, recently taken in higher consideration by the scientific community.

In the view of a more extensive field activity with the objective of evaluating the comfort conditions in the University classrooms and of measuring the students grade of attention and learning ability, a preliminary experimental survey was conducted in a classroom of the Engineering Faculty of the University of Rome Tor Vergata where the

objective approach, the subjective approach and the De Dear and Brager adaptive approach [19] to the thermal comfort and air quality issues were applied.

EXPERIMENTAL

Site and Instrumentation

The experimental work was carried out in the period November – December 2010 in a classroom of the Engineering Faculty of the University of Rome Tor Vergata, named T7. An accurate survey of the class was conducted to characterize the site. Table 1 resumes the principal characteristics of the environment.

Table 1. T7 Classroom characteristics.

Classroom T7				
Volume [m ³]	785 m ³			
Surface [m ²]	227.6 m ²			
Capacity	240 people			
	N	S	W	E
Walls surface [m ²]	51.0	45.8	55.0	54.4
Glasses surface [m ²]	5.54	4.02	25.1	2.74
Doors	1	2	0	0
Windows	0	0	5	0
Radiators	2	2	5	2

The heating system consists of 11 radiators positioned on the perimeter walls, only half of which were active during the campaign.

No mechanical ventilation was available for the classroom and it was also noted that most of the windows could not be opened. Doors and windows were left closed during the test.

The instrumentation used for the survey consisted in a BABUC M data acquisition system with sensors to measure the microclimatic parameters and the CO₂ concentration.

Measurement survey

Measurement methodology for the thermo-hygrometric parameters was based on the indications of the UNI EN ISO 7730 [20] and UNI EN ISO 7726 [21]. A preliminary analysis was performed to check for the spatial uniformity of the microclimatic variables. Figure 1 shows a plan of the classroom with the indication of the points in which the measurements were made.

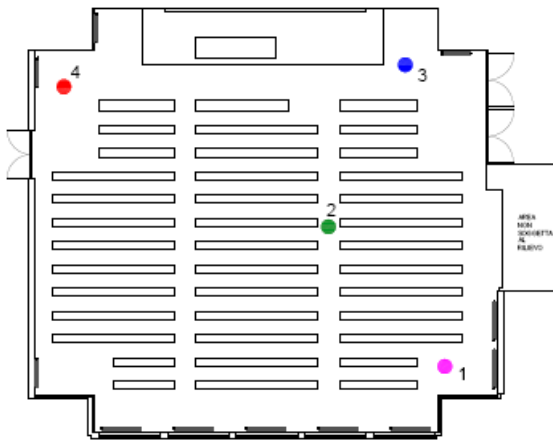


Figure 1. Plan of the classroom and measurement points.

The test was carried out during the lecture hours with the students in the class, locating the sensors at about 1.1 m height. For each position a ten minutes data acquisition was performed; in this period temperature and relative humidity were collected at a time rate of 40 s and air velocity at 8 s time rate. The positions were chosen to verify possible thermal loads induced by windows and doors and to verify the contribution of the students.

A general spatial uniformity was observed allowing to chose each of the point tested for the measurement survey. Point n. 2 was chosen because more representative of the effective conditions sensed by the students. The sensors were positioned at least at 1 m distance from the students to avoid direct interaction with the instrumentation.

The measurement campaign was carried out for three days (23rd and 30th of November and 14th of December 2010) registering the indoor microclimatic conditions and the CO₂ concentration (as indicator of air quality) during two different lectures, one given in the morning (11:30 – 13:00), named FTA, and one in the early afternoon (14:00 – 15:30), named SdC.

Table 2. Weather data for the days of test.

		WS [m/s]	T _{ext} [°C]	RH [%]
FTA	23-Nov	2.15	13.34	67.80
	30-Nov	2.67	12.42	90.24
	14-Dec	3.27	6.92	31.86
SdC	23-Nov	1.21	14.36	55.35
	30-Nov	0.38	11.06	95.84
	14-Dec	2.79	8.14	23.29

Climatic data for the site during the test period were obtained by the solar-weather station of the Environmental Applied Physics laboratories located in the nearby Departments building. Table 2 resumes the climatic data averaged over the lectures period, for the days of test.

Generally the outside temperature was higher during SdC, in the early afternoon than during FTA apart from the 30th of November where heavy rain occurred during SdC (confirmed by the 96% of relative humidity registered in the afternoon). The two days of November can be considered mild while the 14th of December a substantial lower temperature was measured with a very low relative humidity, indicating a cold clear and dry day. In Table 3 the indoor microclimatic parameters and the CO₂ concentration averaged for the FTA lecture and the SdC lecture are shown. Considering the prescription given by the EN 15251 [22] norm which states the CO₂ concentration limit for a class C environment to 1200 ppm, it can be observed how the scarce ventilation was responsible for the high average CO₂ concentrations especially during the SdC lecture which presented higher occupancy level for all the days tested.

Table 3. Synthesis of the measured data during the survey.

	Date	FTA		SdC	
n. stud.	23-Nov	53		144	
	30-Nov	35		120	
	14-Dec	27		106	
		Avg	St Dev	Avg	St Dev
v _a [m/s]	23-Nov	0.04	0.04	0.03	0.03
	30-Nov	0.03	0.03	0.02	0.03
	14-Dec	-	-	0.04	0.04
T _a [°C]	23-Nov	22.7	0.27	24.3	0.59
	30-Nov	21.4	0.19	23.1	0.27
	14-Dec	-	-	21.2	0.56
RH [%]	23-Nov	51.2	1.89	49.6	3.46
	30-Nov	51.2	1.89	60.5	2.01
	14-Dec	-	-	29.0	2.44
T _{mr} [°C]	23-Nov	22.0	0.28	23.6	0.69
	30-Nov	20.9	0.19	23.1	0.37
	14-Dec	-	-	20.3	0.63
CO ₂ [ppm]	23-Nov	1198	80	2237	543
	30-Nov	1006	77	2401	385
	14-Dec	-	-	1827	319

The 14th of December a fault in the acquisition system did not allowed to register the data for FTA. The relative humidity of the 30th of November for the same lecture was not registered so that the value measured on the 23rd was used considering a low variation of the parameter and its low influence on the comfort conditions. The high standard deviations calculated for the CO₂ concentration, especially during SdC are due to the high concentration gradients experienced during the lectures.

Questionnaire survey

Information about the subjective sensation of the occupants with respect to the thermal environment and to the air quality were gathered through the distribution of a questionnaire elaborated following the indications of the UNI EN ISO 10551 [23]. A copy of the questionnaire is shown in the Appendix.

The form was divided in three parts; each of them requested the following data:

- demographic information;
- questions about the thermo-hygrometric environment and on the air quality;
- information about the students clothing to calculate the clothing resistance for the PMV and PPD evaluation.

A total number of 485 questionnaires were distributed during the campaign. The distribution was made after 30 minutes from the beginning of the lecture.

RESULTS

Objective approach

The measured environmental parameters were used to calculate the PMV and PPD as prescribed by the UNI EN ISO 7730. The metabolic activity was fixed at 1.2 met and the clo values were determined averaging the information obtained by the questionnaires for each of the test conditions. Table 4 resumes the results obtained. It can be noted that the PMV for the FTA lecture is behind the ± 0.5 recommended range [20] and the PPD is lower than 10% indicating very good thermal comfort conditions. Also the SdC lecture shows good comfort conditions apart from the 23rd of November that exhibits a PMV value of 0.69, slightly higher than the values prescribed by the norm and a PPD of 14.8%. The 14th of December, owing to the above mentioned system fault, the PMV was not calculated for FTA.

Table 4. Results of the measurement campaign. A metabolic rate of 1.2 met was considered for the calculation.

		23 Nov	30 Nov	14 Dec
FTA	PMV	0.38	- 0.31	-
	PPD [%]	8	7.1	-
	I _{cl} [Clo]	1.1	0.8	-
SdC	PMV	0.69	0.25	- 0.3
	PPD [%]	14.8	6.5	7.1
	I _{cl} [Clo]	1.1	0.9	0.95

Subjective approach

The questionnaires distributed were analyzed focusing the attention on the Mean Vote (MV) considering the gender difference. Figure 2, as an example, shows the histograms of the normalized frequency of votes occurrence for FTA and SdC for the 23rd of November and the 14th of December, respectively. It has to be pointed out that the attendance of FTA was in general lower than SdC and for this reason the results showed can be considered more statistically representative for SdC than for FTA.

From the analysis of the collected data it is possible to draw the following conclusions:

- it is confirmed that females feel colder than males;
- in the 14th of December the students felt colder than the other days (MV= - 0.85 for FTA and MV= - 0.2 for SdC);
- the 23rd and 30th of November represent better comfort conditions for FTA and SdC, (MV = 0.075 and MV = 0.09, respectively).

The first assumption was proved dividing the sample only by gender and evaluating the most frequent vote expressed by males and females.

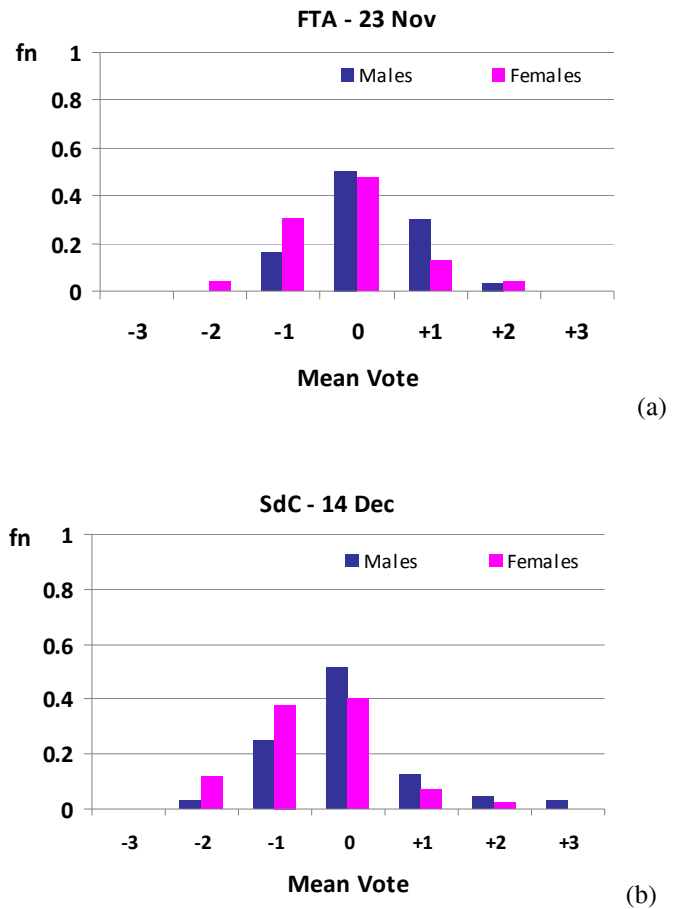


Figure 2. Histograms of the normalized occurrence of mean votes for FTA (a) and SdC (b).

It came out that the 46% of males expressed a vote for thermal neutrality and 24% for MV = +1 while females neutrality was voted by 38.5% of the sample and MV = -1 by the 38.5%. Moreover, the most desired thermal sensation for females was “feel warmer” with 58% of the sample while for males the 54% of the sample desired “no change” of the thermal environment.

A synthetic representation of the answers to the other questions is shown in figure 3 through a radar graph where for FTA (fig. 3a) and SdC (fig. 3b) the results obtained for the three days are showed. The desired thermal sensation (warmer), the thermal acceptability (positive) the MV (vote = 0), the satisfaction for the environment (positive), the judgement for the air quality (positive) and the judgement of the importance of the air quality for the students activity (positive) are listed on the radar graph as normalized frequencies.

In general the students appear less satisfied about the environment during the SdC lecture than during FTA especially for what concerns the air quality. This is essentially due to the higher class occupancy and the scarce ventilation for SdC also confirmed by the high CO₂ concentration levels. For SdC the 14th of December is characterized by a high request of warmer environment essentially due to the lower outside ambient temperature together with the lower attendance for that day with consequent lower thermal load induced by the occupancy with respect to the other days. Lower occupancy was also responsible for a better air quality.

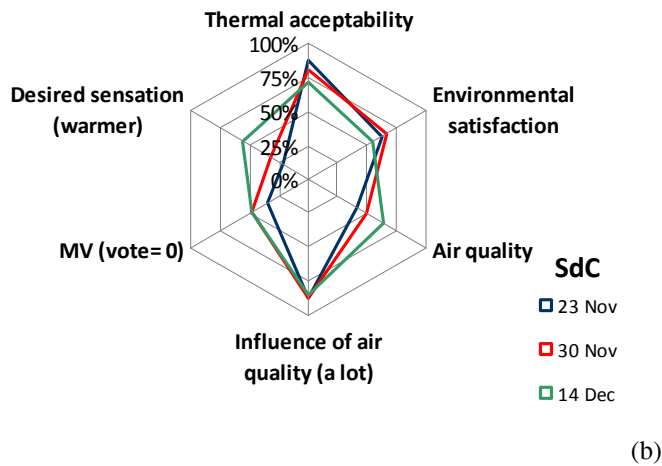
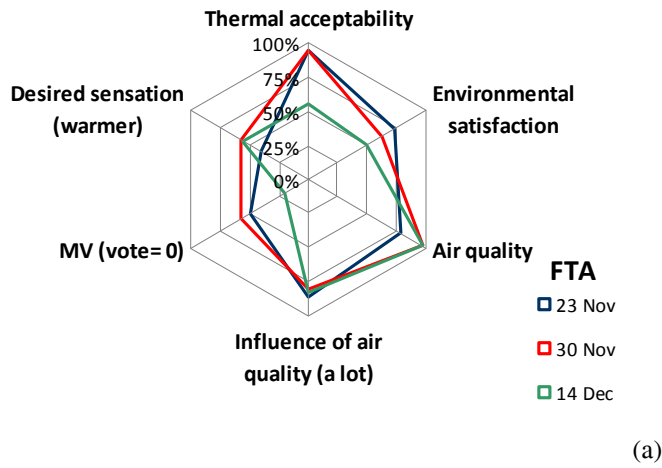


Figure 3. Synthetic representation of the questionnaires results: (a) FTA, (b) SdC.

It is also important to note that the majority of the sample considers the indoor environmental quality as a key issue for their academic performance.

Adaptive approach

Most recently the concept of adaptation has been introduced in the thermo-hygrometric comfort evaluation [20]. For this study the De Dear and Brager model [19] was used for the Percentage of Dissatisfied (PD) calculation with the objective to compare the results with the other approaches. The following empirical equation allows to calculate the operative comfort temperature as a function of the outdoor temperature:

$$T_{co} = 0.31 \cdot T_{ext} + 17.8 \quad (1)$$

If the difference between the calculated value and the experimental value is less than 2.5 °C the PD is considered lower than 10%. For all the cases tested the PD resulted lower than 10%.

Comparison between the different approaches

The results obtained for the various approaches were compared. In particular in figure 4 the correlation between PMV and MV is shown. From the graph in which also the bisector (PMV = MV) is traced, it can be concluded that the subjective judgement (MV) is slightly shifted towards the

“feel colder” sensation. However, more data should be collected to confirm this finding.

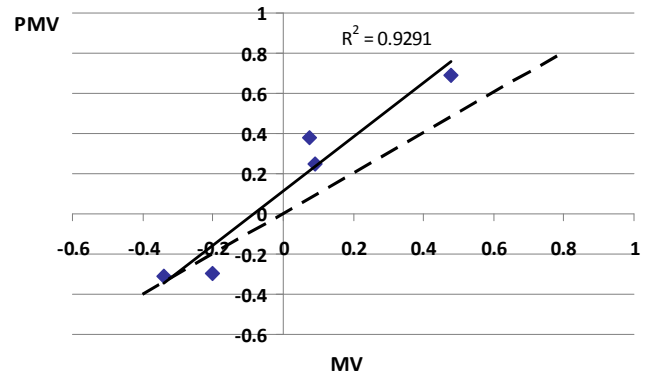


Figure 4. Correlation between PMV and MV.

In table 5 the PPD and PD values for objective, subjective and adaptive approach are listed. While the PPD prescribed by UNI EN ISO 7730 and the one obtained from the adaptive model fully fulfil the thermal comfort condition as prescribed by the norm, the subjective PD values, appear definitely higher than PPD. This result indicates that the subjective judgement on the thermal acceptance (PD) is influenced not only by the thermal environment but also by other factors. Poor air quality could be considered as such factor.

Table 5. Comparison of the grade of dissatisfaction evaluated with the three approaches.

		Objective	Subjective	Adaptive
		PPD [%]	PD [%]	PD [%]
FTA	23 Nov	8	25.75	< 10%
	30 Nov	7.1	37.85	< 10%
	14 Dec	-	50.9	-
SdC	23 Nov	14.8	37.9	< 10%
	30 Nov	6.5	33.5	< 10%
	14 Dec	7.1	46.3	< 10%

Discussion

Air quality was evaluated through the measured CO₂ concentration used as indicator for the global Indoor Air Quality. The PPD related to the air quality perception was calculated using the following equation [24]:

$$PD = 395 \cdot e^{(-15.15 \text{CO}_2^{-0.25})} \quad (2)$$

where the term CO₂ represents the gas concentration in ppm.

The results obtained were compared with the Percentage of Dissatisfied (PD) evaluated by the questionnaires considering the question about the air quality acceptability. Figure 5 shows the correlation between PPD and PD for thermal and air quality sensation, the dotted line represents the graph bisector. It can be noted the poor correlation for the thermal sensation with respect to the objective thermal PPD evaluation, while for the air quality a linear correlation can be recognized.

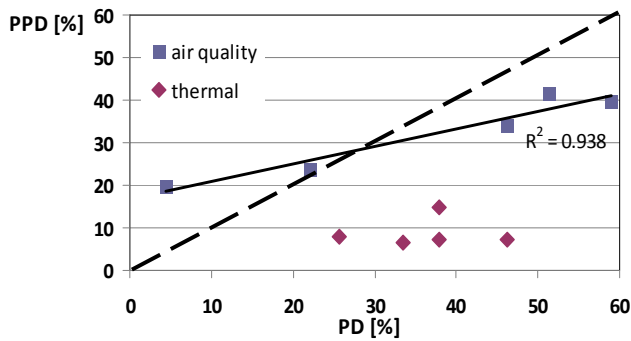


Figure 5. Correlation between PPD and PD for the air quality and thermal sensation.

However, this result indicates that the occupants can recognize the discomfort caused by poor air quality, while they seem to relate their thermal dissatisfaction to some other effect (most probably to poor air quality). The correlation showed in figure 6 between PD for air quality and PD for thermal environment, even if not strong, could in part confirm this assumption.

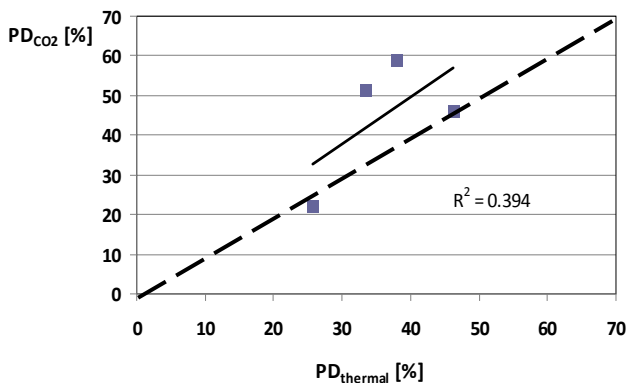


Figure 6. Correlation between PD for air quality and PD for thermal environment.

From the presented results it is possible to draw the following conclusions:

- There is a good correlation between the objective results and the subjective judgement of the thermal quality of the classroom;
- The sample found a certain difficulty to give a right judgement on thermal satisfaction because even if the MV is low the PD is very high;
- The sample is able to express a judgement on the air quality considering the correlation between PPD calculated with the CO₂ concentration and the subjective PD for air quality;
- It appears that the judgement on thermal environment is influenced by the indoor air quality.

CONCLUSIONS

A survey on the Indoor Environmental Quality was carried out in a classroom of the University of Rome Tor Vergata using different approaches. Objective measurements and subjective judgement of the occupants on the environment were correlated to verify congruity of the results. A substantial agreement between the Predicted Mean Vote evaluated using the ISO 7730 indications and the Mean Vote expressed by the occupants was found. The correlation shows

a slight shift toward colder vote given by the occupants. Comfort conditions were found in almost all cases studied. However thermal satisfaction was poor for most of the students interviewed. Air quality was evaluated through CO₂ concentration measurements and subjective judgement. Poor ventilation of the class and high occupancy is responsible for high values of CO₂ concentration during SdC lecture and a high grade of dissatisfaction was expressed by the occupants for all cases tested.

It is suggested that the high thermal discomfort could be related to the high dissatisfaction expressed for the air quality. This finding confirms the importance of considering the synergic effect of various external stimuli on the global comfort.

ACKNOWLEDGMENTS

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NOMENCLATURE

Symbol	Quantity	SI Unit
WS	Wind speed	m/s
T _{ext}	Outdoor air temperature	°C
RH	Relative humidity	%
v _a	Air velocity	m/s
T _a	Indoor ambient temperature	°C
T _{mr}	Mean radiant temperature	°C
CO ₂	CO ₂ concentration	ppm
T _{co}	Operative comfort temperature	°C

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APPENDIX

Questionnaire

LABORATORI DI FISICA TECNICA AMBIENTALE
UNIVERSITÀ DEGLI STUDI DI ROMA "TOR VERGATA"



QUESTIONNAIRE
THERMO-HYGROMETRIC COMFORT OF THE T7 CLASSROOM

DATE
TIME

Please indicate your gender
 M F

1) Age: years.

2) Are you an off-site student?
 Yes No

If your response is YES.....
 North Center of Italy South

3) How do you consider your thermal sensation now?
 +3 (very hot) 0 (neutral) -1 (slightly cool)
 +2 (warm) -2 (cool)
 +1 (slightly warm) -3 (very cold)

4) Do you consider acceptable your thermal sensation?
 Yes No


5) If you could choose one of the following thermal sensations, what would you prefer?
 Warmer
 Cooler
 Not change

6) From the thermal point of view do you consider the environment more than satisfactory at this time?
 Yes No

7) How do you consider the air quality now?
 Acceptable
 Non acceptable

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LABORATORI DI FISICA TECNICA AMBIENTALE
UNIVERSITÀ DEGLI STUDI DI ROMA "TOR VERGATA"



8) Do you think that the number of heaters is enough for the needs of the whole classroom?
 Yes No

9) Do you think that the quality of the environment (temperature, air quality, light, humidity ...) can influence the performance of your work?
 Very
 Little
 None

10) Mark with a cross the clothes you're wearing right now:

	Clo	
UNDERWEAR	briefs	0.03
	panties and bra	0.03
	camisole	0.04
	socks	0.02
	heavy ankle socks	0.05
	heavy long socks	0.10
	nylon stockings	0.03
SHIRTS AND SWEATERS	short Sleeve	0.15
	lightweight, long-sleeved	0.20
	normal, long-sleeved	0.25
	light sweater	0.20
	sweater	0.28
heavy sweater	0.35	
PANTS AND SKIRTS	light pants	0.20
	normal pants	0.25
	heavy skirt	0.25
	winter dress with long sleeves	0.40
	suit	0.55
OUTDOOR CLOTHING	jacket	0.35
	coat	0.60
	shoes (thin soles)	0.02
	shoes (thick soles)	0.04
	boots	0.10
	gloves	0.05
	hat	0.05
	scarf	0.05

Total Clo

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