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FULDSKALA DEMONSTRATION AF TERMOAKTIVE KONSTRUKTIONER

BILAGSRAPPORT

DTU Byg
Institut for Byggeri og Anlæg

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MIDDELFART SPAREKASSE

COWI

International Center for Indoor Environment and Energy

Technical University of Denmark

Yearly indoor comfort evaluation and energy consumption, and assessment of thermal activated building systems in Middelfart Sparekasse.

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Summary

1 Introduction

1.1 Objectives of the study

The work presented in this report shows the results of different analysis conducted in the Middelfart Sparekasse building during the first year of operation., from August 2010 to September 2011.

These analysis can be summarized in 3 different studies:

- Evaluation of the indoor climate in the building
- Evaluation of the energy consumptions.
- Evaluation of thermal activated building systems (TABS) in one specific room.

The evaluation of the indoor climate consists in the assessment of the thermal and air quality in the building. This analysis is mainly divided in two parts: long term evaluation during an entire year, and spot evaluation of the environment in particulars moments of the year (in this case in summer and in winter period). The scope of this work is to evaluate if the indoor environment condition respects the categories given by the comfort European standards 15251/2007 (Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics) and 7730/2005 (Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria).

The evaluation of the energy consumptions is an analysis of the energy demand for heat, cool, ventilate and light the building, and for the appliances and the driving force. This evaluation is divided in three main parts: it includes the total energy consumption required by the whole building, the detailed energy consumption of the different systems, and the focus on the energy required by a specific room.

The evaluation of thermal activated building systems (TABS) describes an experiment performed in the room 2.2.00, situated at the first floor, during the summer period. In this room the thermal quality in summer period is mainly controlled by a TABS system embedded on the floor. The scope of the analysis is to evaluate the performance of the system with different levels of internal gains, higher than usually. These gains were generated by heated dummies positioned homogeneously in the room, instead of the employees at their workstations or together with them.

1.2 Description of the building: architecture and systems

Middelfart Sparekasse is a 5380 m^2 building situated in the city of Middelfart, Denmark (Lat: 55.5°, Lon: 9.75°). The building shows a complex shape; from the architectural point of view the key elements is the roof shape: 83 prism-like skylights compose the spectacular roof surface defining the geometry of the building. A bookshop, a café, a real estate agent and the cash desk are placed at the ground floor level, around a central plaza. The working areas (basically open space offices) are mainly located on three open terraces, called “plateau”, internally connected by broad staircases. On each floor also single offices, meeting rooms and other rooms for dedicated services are placed. The building envelope is made mainly by structural glass, with transmittance U=1.1 [W/m^2K], and with the transmission coefficient (visible light/solar energy) equal to [0.64/0.35]. The offices are normally occupied during daily time from 8:00 to 18:00, from Monday to Friday.

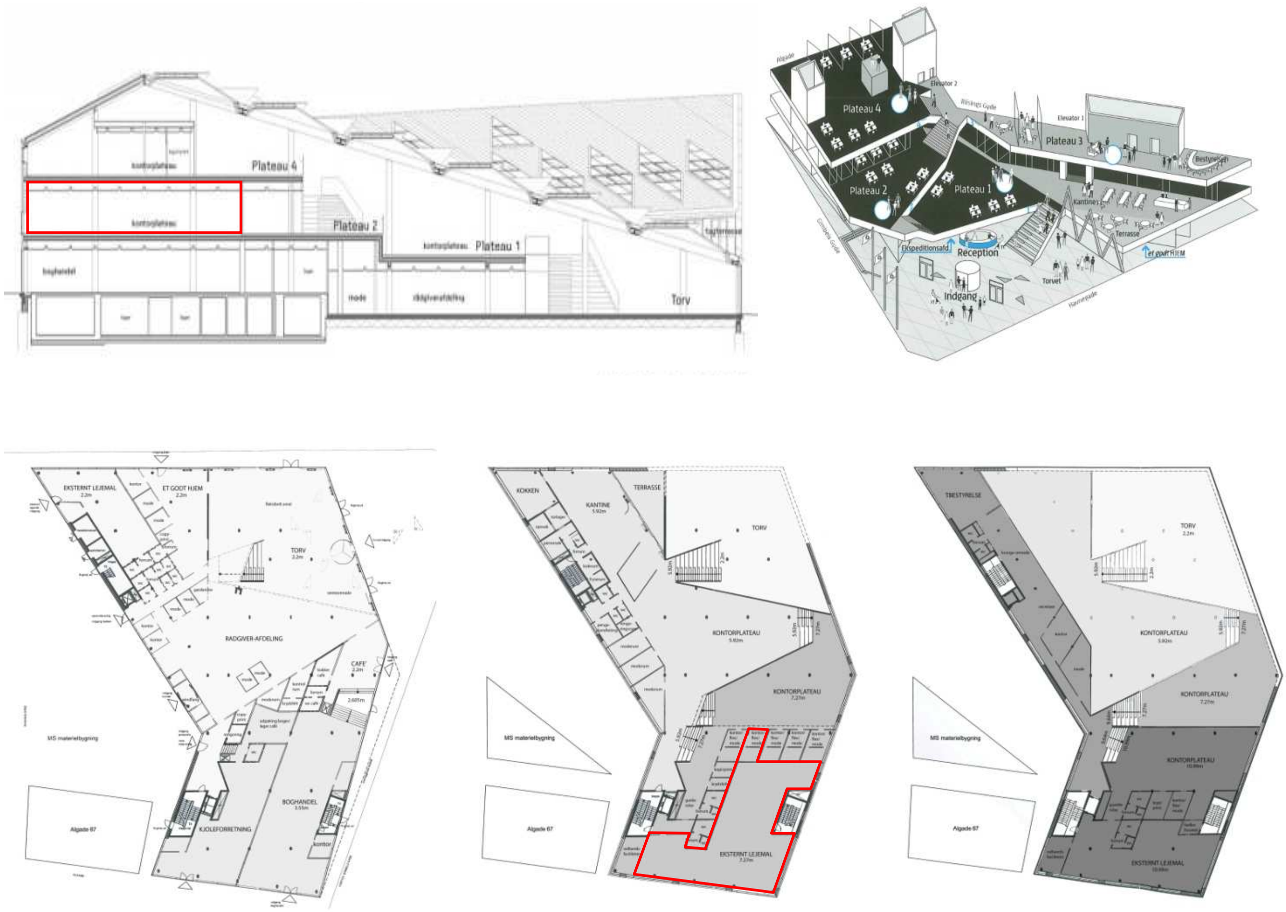


Figure 1. Middelfart Sparekasse building (vertical and horizontal sections, and axonometric projection of the building). Red lines highlight the position of room 2.2.00, on which part of the work focuses on.

Thermal environment and the air quality in the building are guaranteed by a different combination of systems. The heating load in winter is given in part by convectors, located on the floor along the perimeter of the building, and in part by an hydronic systems (floor heating). The cooling load in summer is given in part by an hydronic system (floor cooling) and in part by TABS (Thermo active building system). Also the ventilation systems, in addition to air quality control, contribute to add or remove loads respectively in winter and summer period, in some part of the building. The ventilation is in fact partially mechanical and partially natural. The mechanical ventilation is divided in five different systems. The natural ventilation is made by vents whose opening is controlled on the basis of indoor and outdoor temperature, indoor CO_2 concentration and outdoor wind velocity. The natural ventilation is also used in summer period for the night ventilation of the building.

More detailed information about the systems in all the single parts of the building will be explained in the paragraph referred to the energy consumptions. Here can be said that the indoor environmental control of the building is divided in two main strategies:

1- Embedded, water based radiant system (floor heating), and convectors for thermal control. Natural ventilation by controlled vents openings to provide acceptable indoor air quality. This kind of strategy is applied in all the large spaces, like in the offices situated on the terraces (plateaus), in the canteen and in the central plaza at the ground floor.
2- Convectors and balanced mechanical ventilation for heating and air quality control during the winter period, TABS and ventilation system for cooling and air quality control during summer. This kind of system is for example applied in the closed office and meeting rooms at the first floor and in the shops situated at the ground floor.

The systems' control is based on the single rooms air and thermal quality: air temperature and CO_2 sensors are installed in all the building in strategically positions and collected data every 10 minutes. Also a weather station collects data about temperature, relative humidity, air velocity, wind direction and velocity each 10 minutes. In the ventilation systems, supply and return air temperature in the duct is monitored, as the supply and return water temperature in the pipes of the hydronics systems.

Figure 2. Picture of the North and East façades of the building.

2 Evaluation of the indoor climate

The yearly evaluation of the indoor climate was performed thanks to the data of the physical parameters collected in the building from summer 2010. Sensors of air temperature and CO_2 concentration were positioned in all the rooms, at the aim to control the thermal and air quality of each single room. Since from August 2010, the air temperatures collected from these sensors were logged in 13 rooms and the CO_2 concentration in 12 rooms, each 10 minutes. From the same date also data deriving from the external weather station were logged: it means outdoor air temperature, relative humidity, wind direction and velocity. From December, 17, 10 sensors of operative temperature and relative humidity were installed in the building. Four of them were put in the room 2.2.00 at the first floor.

It should be explain that *Air Temperature* is the ambient temperature indicated by a thermometer exposed to the air but sheltered from direct solar radiation, while the *Operative Temperature* is defined as the uniform temperature of a imaginary black radiant enclosure, in which the occupants exchange the same amount of heat, by convection and radiation, as in an actual non-uniform environment. Mathematically, this corresponds to the average of the mean radiant and ambient air temperatures, weighted by their respective heat-transfer coefficients. In its calculation, three physical variables are considered: air temperature, mean radiant temperature, and air velocity. (ISO 7730/2005, ASHRAE 55/2004).

2.1 Long term evaluation

2.1.1 Outdoor climate conditions and systems operation during a whole year

The evaluation of the indoor environment cannot be done without considering, at the same time, also the outdoor weather conditions and the operation of the different systems. At this aim figure 3 shows the outdoor air temperature and relative humidity profiles during all the monitoring period. In dotted lines are highlighted the heating season (red) and the cooling season (blue) according with the systems operation periods (figures 4,5).

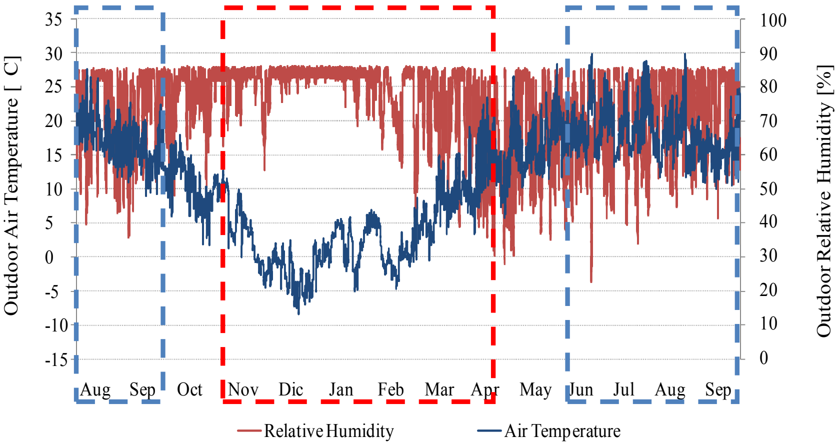


Figure 3. Outside air temperature and relative humidity from August 2010 to September 2011.

Figures 4 and 5 show the profiles of supply and return water temperature in the different systems. The dotted lines, as before, highlight the period in which the systems were working in a constant way. Figure 4(a-d) shows the water temperature profiles of the heating systems (supply in red and return in blue), while Figure 5(a-d) shows the water temperature profiles of the cooling systems (supply in blue and return in red).

Data about the tabs system were available from November 2010.

<u>Heating systems:</u>

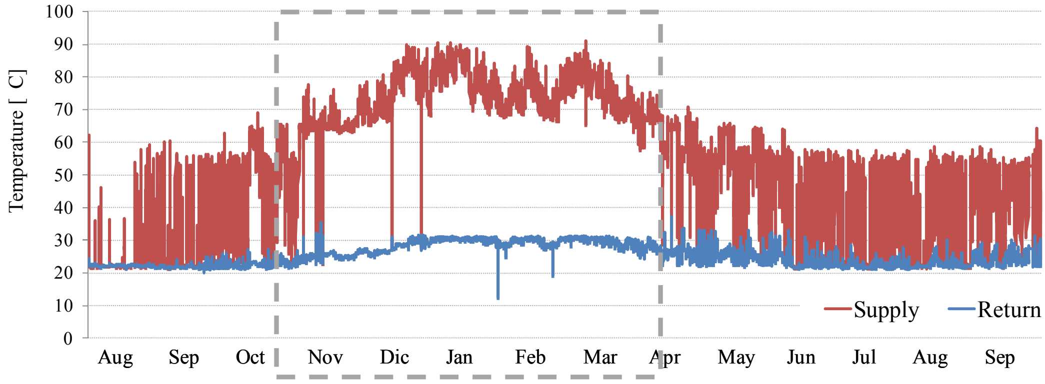


Figure 4a. Supply and return water temperature profiles: zone 1 - floor system.(*)

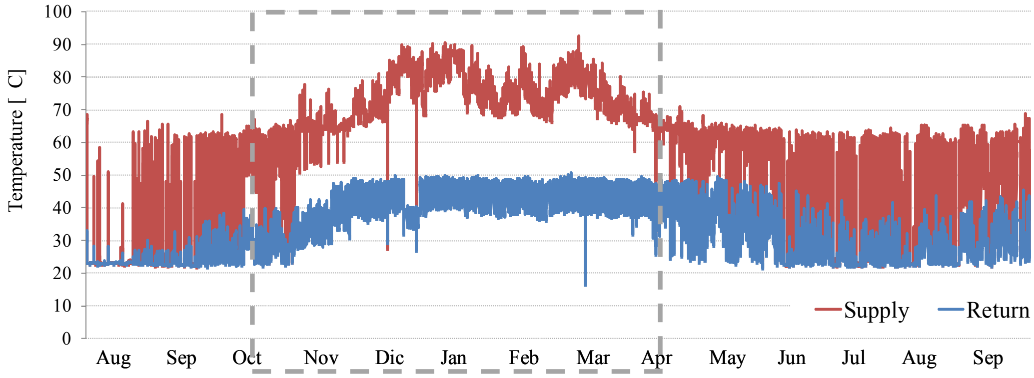


Figure 4b. Supply and return water temperature profiles: zone 2 - convectors.

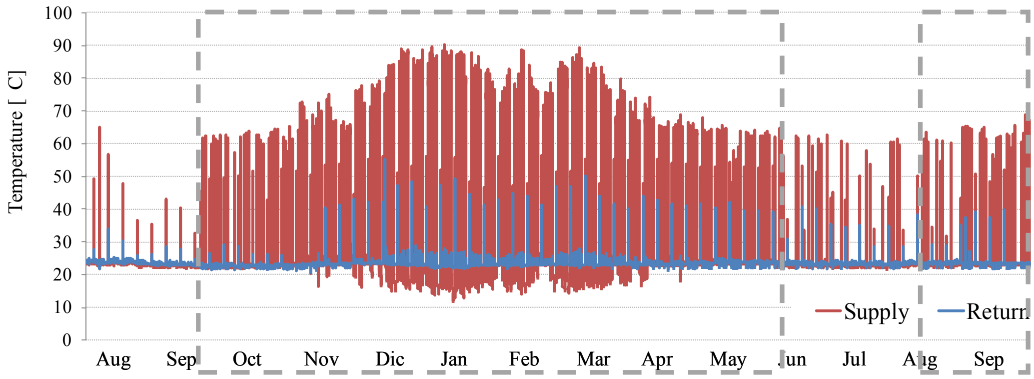


Figure 4c. Supply and return water temperature profiles: ventilation system 01 (office South).

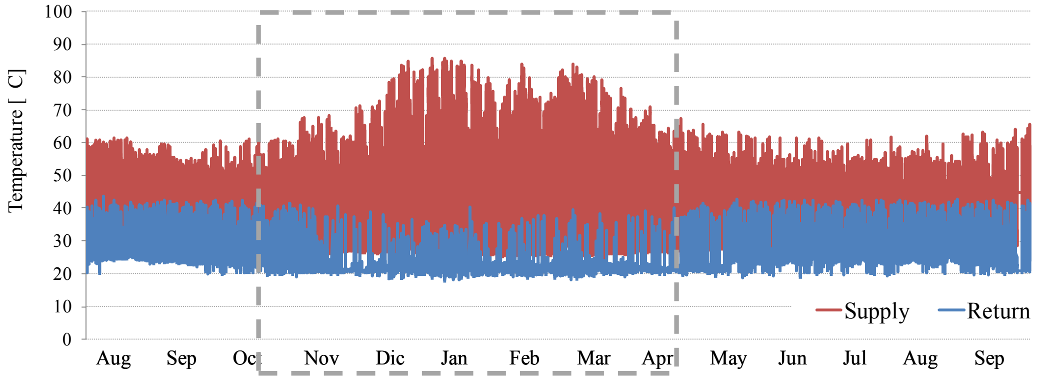


Figure 4d. Supply and return water temperature profiles: ventilation system 04 (canteen).

(*) Figure 4a shows high temperatures of the supply water. This temperatures have been monitored after the heat exchanger, in a point before than the mixing with cold water. Usually in a floorheating the supply water temperature in the pipes is about 35 °C. The graph is interesting because shows that from October to April the temperature was higher than in the rest of the year, and this means that the heating system was operating.

<u>Cooling systems:</u>

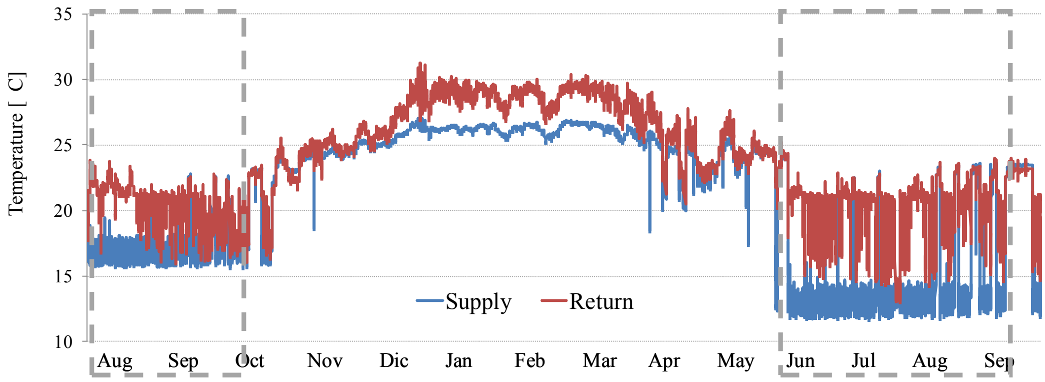


Figure 5a. Supply and return water temperature profiles: zone 1 - floor system.

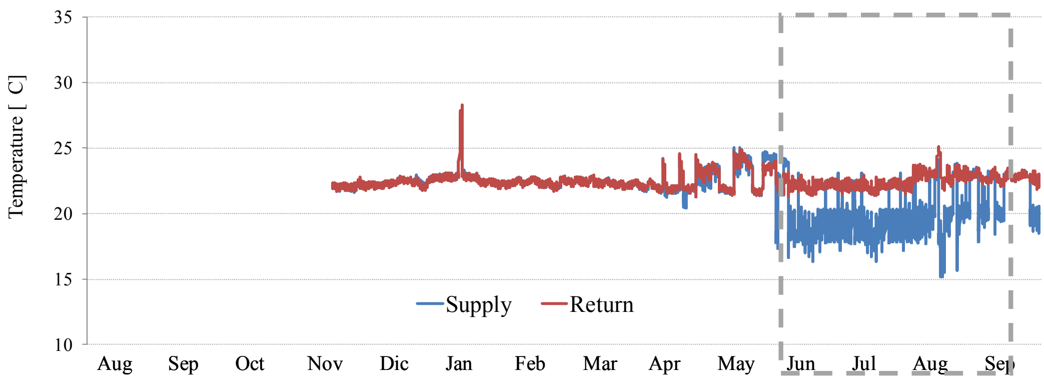


Figure 5a. Supply and return water temperature profiles: TABS.

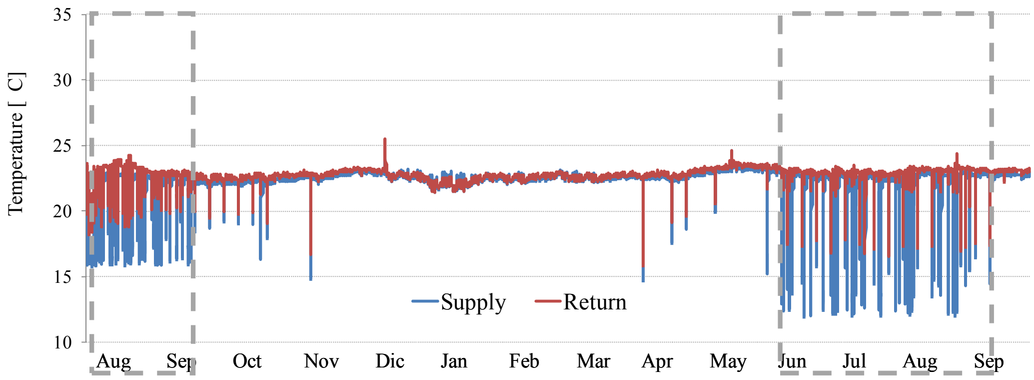


Figure 5c. Supply and return water temperature profiles: ventilation system 01 (office South).

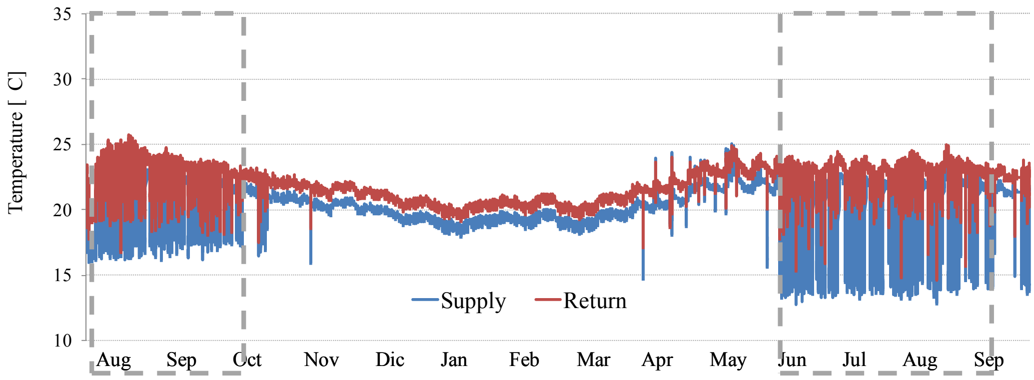


Figure 5d. Supply and return water temperature profiles: ventilation system 04 (canteen).

Looking at the graphs, except the ventilation ones, it possible to see that the heating season started in the mid-October and ended in mid-April, while the cooling season (2011) started in the beginning of June and ended in mid-September. Just 2 of the 5 ventilation systems are shown. The reason is that the profiles for ventilation 01, 02 and 03 were similar, and ventilation 05 was just heating of the basement. Ventilation 04 was rather different by the others: the supply temperature was over 50 °C for the whole year.

The natural ventilation, not showed in graphs, was not working in winter period. In March the vents on the last floor were opened just some days, during the working hours, in coincidence of high outside temperatures. The same happened in April. Moreover, in the end of April the natural ventilation was working, occasionally, also during the night. From the second week of May, until the end of September, the vents were opened all the nights, except on Friday and Saturday, from 10 pm to 6 am (with some interruptions). Also during the day the vents were opened, usually from 9 am to 18 pm. In September the percentage of opening of the vents was reduced of about the 50% respect to the other summer months.

2.1.2 Thermal and Air quality of the main offices during a whole year

The analysis of thermal environment and air quality was performed according to the comfort categories suggested by the standard EN 15251. These categories are expressed in Table 1.

Table 1. Categories of Operative temperature, ventilation (CO_2) Relative Humidity and PMV-PPD for offices buildings with sedentary activity.

Category	Operative Temperature range		Ventilation	Relative Humidity	Thermal Comfort requirements	
	Winter 1.0clo/1.2met	Summer 0.5clo/1.2 met	CO_2 Above outdoor		PMV	PPD
	[°C]	[°C]	[ppm]	[%]	[/]	[%]
I	21.0-23.0	23.5-25.5	350	30-50	-0.2< PMV<+0.2	< 6
II	20.0-24.0	23.0-26.0	500	25-60	-0.5< PMV<+0.5	< 10
III	19.0-25.0	22.0-27.0	800	20-70	-0.7<PMV<+0.7	< 15
IV	< 19.0-25.0<	<22.0-27.0<	800<	<20-70<	PMV $>\pm$0.7	> 15

Note: The building has being designed to be in category III.

Air and Operative temperature, and CO_2 profiles during the whole monitoring period are shown from Figure 6a to 6d. On the same graphs, comfort categories described in table 1 are indicated with red dot lines. The figures represent the main offices open space of the building: the one on the ground floor, the plateau 1, the plateau 4 and the room 2.2.00.

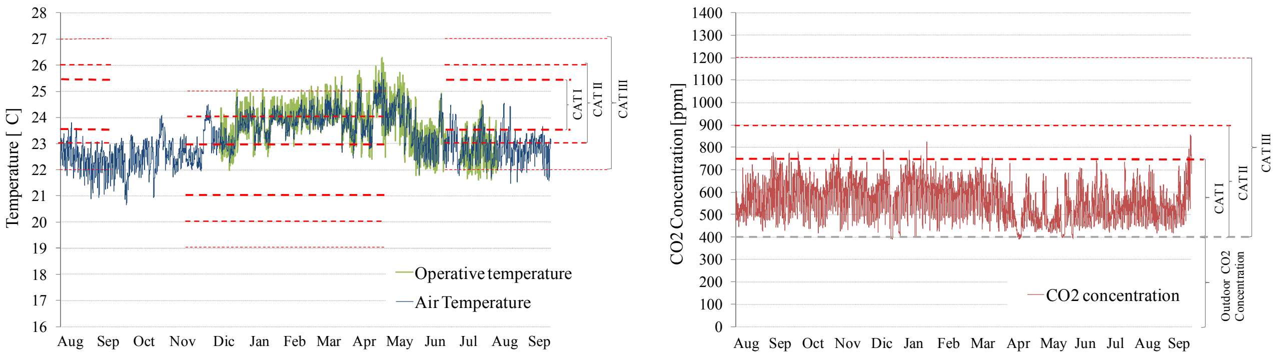


Figure 6a– Room 1.1.00, Ground Floor - Air and Operative temperature, and CO2 concentration profiles.

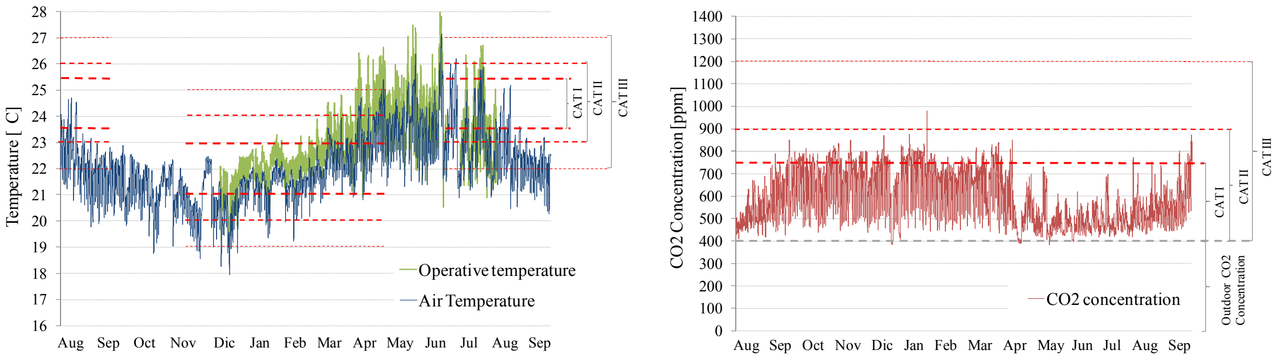


Figure 6b – Room 2.1.23, (Plateau1)First Floor - Air and Operative temperature, and CO2 concentration profiles.

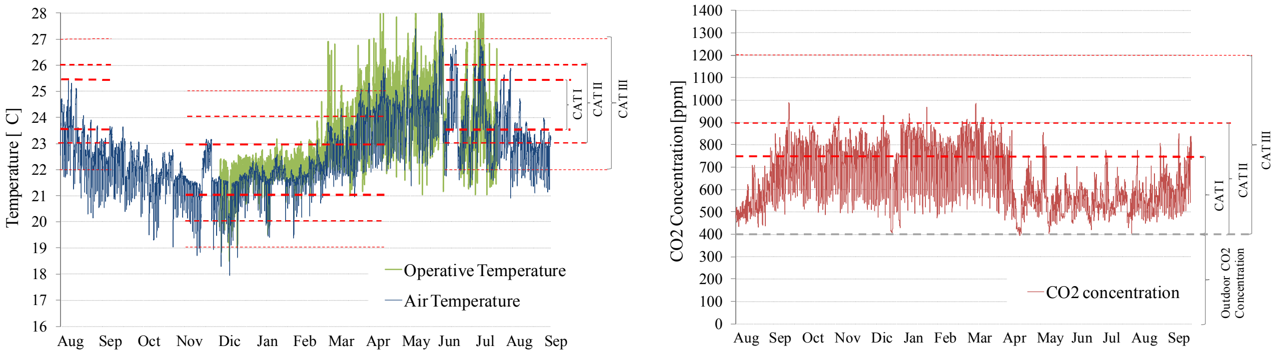


Figure 6c– Room 3.1.16, (Plateau4) Second Floor - Air and Operative temperature, and CO2 concentration profiles.

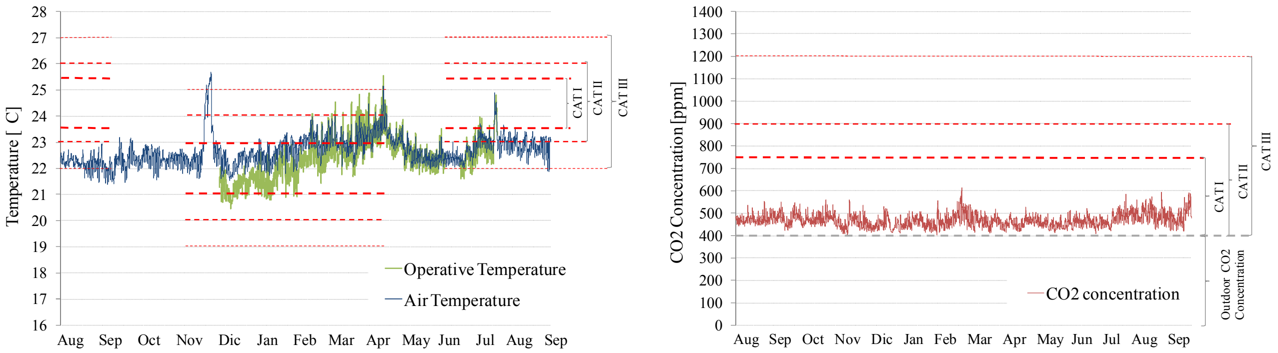


Figure 6d – Room 2.2.00, First Floor - Air and Operative temperature, and CO2 concentration profiles.

In the first three rooms, from figure 6a to 6c, the systems in the rooms are the ones described as strategy “1” in paragraph 1.2, while the systems strategy of room 2.2.00 is the one described as “2”. From the evaluation emerge the difference in the fluctuation of both, temperatures and CO_2 profiles between the two strategies: the standard deviation in room 2.2.00 was smaller than in the other cases. From the temperature profiles can be said that the temperatures in winter time were too high at the ground floor, while quite good or slightly high in the other rooms. Just in room 2.2.00 the operative temperature in winter period was lower of about 1°C respect to the air temperature. This probably depended by the lower mean radiant temperature in the room due by the big external surfaces. In the other cases the operative temperature was always a little higher than the air temperature. In summer time the temperatures were quite low in all the rooms, in particular in room 2.2.00. The air quality was quite good in all the building, in particular in the mechanically ventilated room 2.2.00. In the other rooms is visible that the CO_2 concentration was lower starting from April, since the natural ventilation started to work.

Note than in the room 2.2.00 there were no occupants, so no heat loads, until February.

2.1.3 Analysis of Temperature and Air quality of the whole building for Summer and Winter period.

According to the method “Percentage outside the range” suggested by the EN 15251 for the “long term evaluation of the thermal comfort conditions”, all the monitored rooms were analyzed. This method is based on the percentage of hours during which the building is occupied when the operative temperature is outside a specified range. The ranges are the same described in table 1. The standard proposes the same method also for the air quality evaluation, in terms of CO2 concentration.

Figure 7 and figure 8 show respectively the thermal and air quality evaluation for winter and summer periods. The winter period went from November 2010 to march 2011, while the summer period went from April to September 2011.

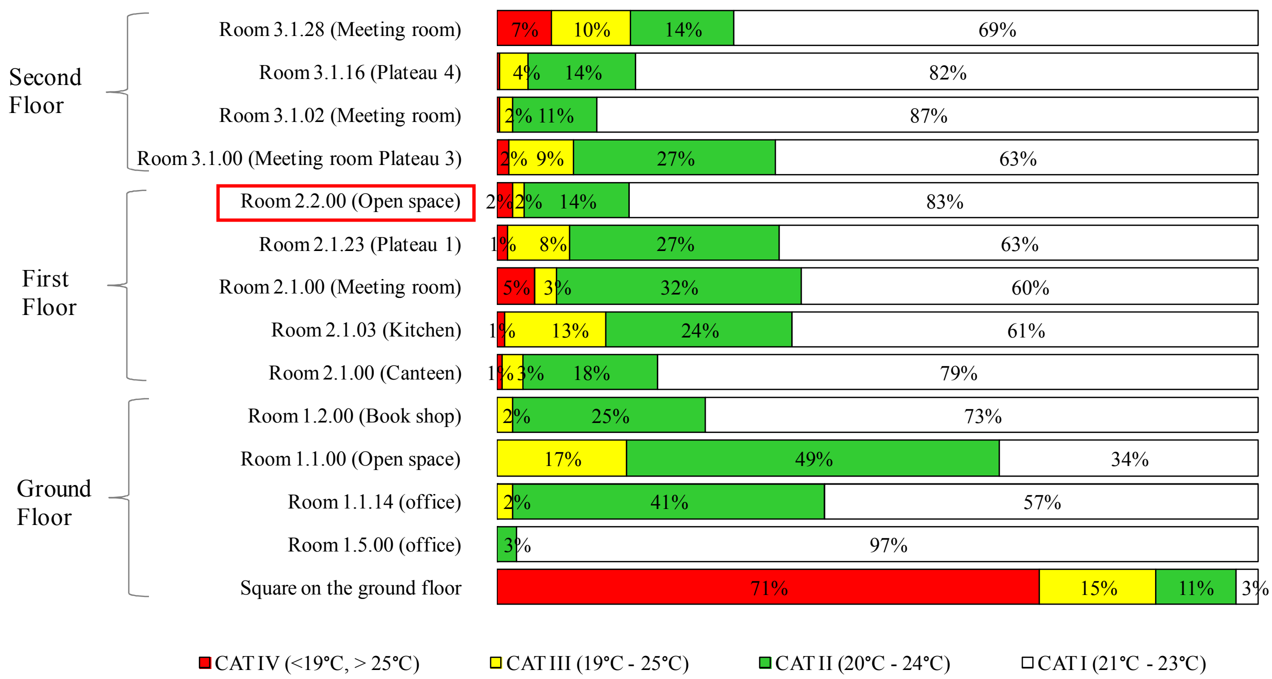


Figure 7a– Thermal quality evaluation of all the monitored rooms during the winter period.

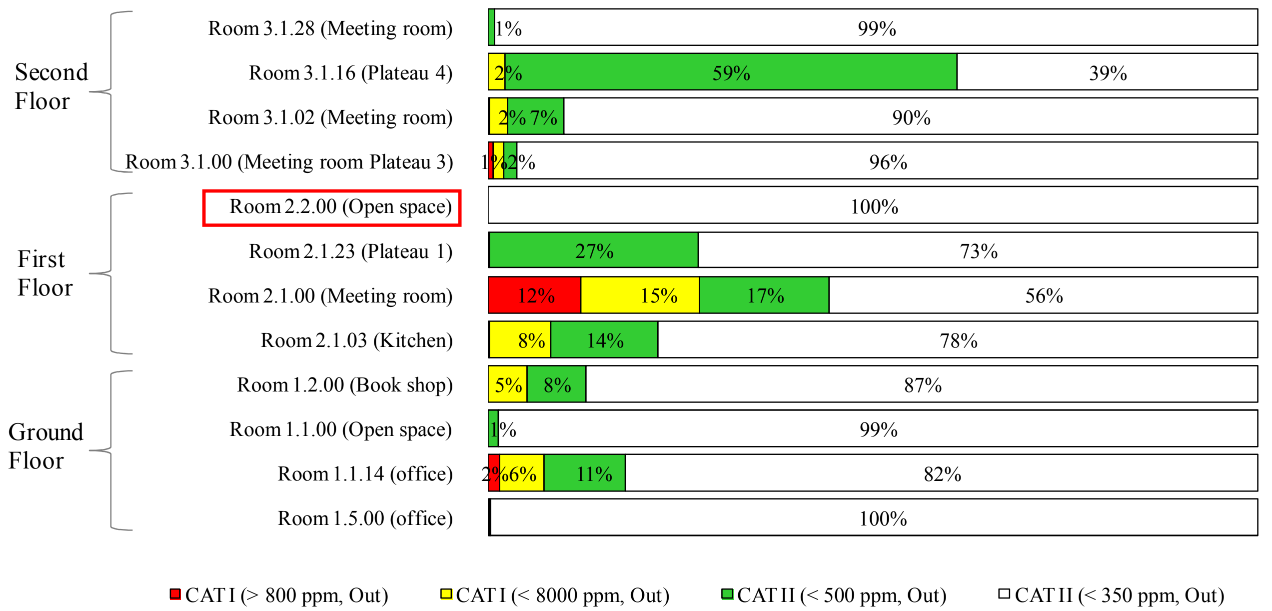


Figure 7b– Air quality evaluation of all the monitored rooms during the winter period.

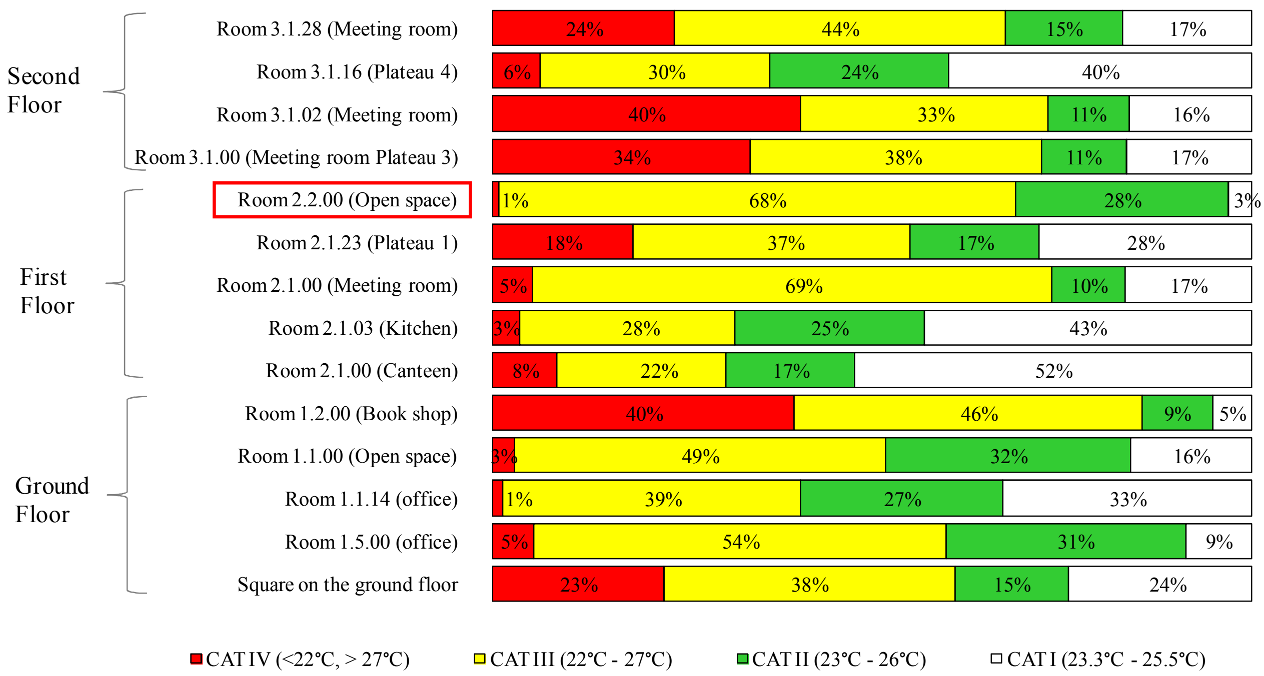


Figure 8a– Thermal quality evaluation of all the monitored rooms during the summer period.

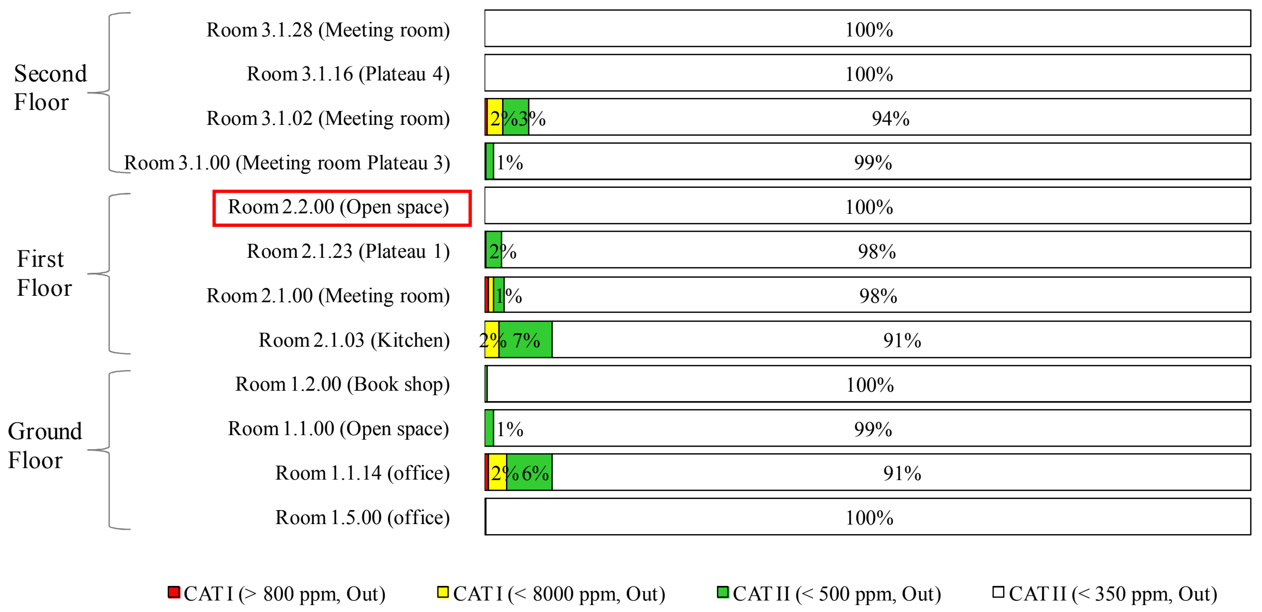


Figure 8b– Air quality evaluation of all the monitored rooms during the winter period.

The average temperature in the building was quite good in winter period. On average the temperatures fall in category I for at least the 60% of the time, and just for a little percentage of time the values fall in categories III and IV. Usually these values were higher than the range of category I. There is just an exception represented by the temperature in the central plaza at the ground floor: in this case for the 78% of the time the temperatures were in category IV: probably the sensor was close to a heat source and the data were not representative of the room. In summer period the temperatures were quite low in all the rooms. Figure 7a shows in fact that most of the time the temperatures fall in category III, and in all the rooms there was a percentage of time when the temperatures were in category IV. The worst results are in the meeting rooms, were usually there were not constant heating loads and so the temperatures were lower than in other cases. These meeting rooms, in particular the two analyzed at the second floor, were conditioned just by the mechanical ventilation system.

In general can be said that the air quality was quite good in all the building for both seasons, especially in summer period, when the vents of the natural ventilation were opened.

2.2 Short term evaluation

2.2.1 Summer and Winter period: physical measurements and subjective evaluation of the indoor climate

This paragraph shows the thermal comfort and air quality assessment conducted in the building, through spot measurements, in March and August 2011 (winter and summer period) in terms of both physical analysis and subjective answers of the occupant.

More detailed evaluation is developed in the annexes A and B.

The monitoring data elaborated and here presented derive from three different survey methods:

- Long term monitoring: The long term monitoring, as described in paragraph 2.2, is conducted in the building continuously during the whole year. Here, at the aim to better understand the results obtained during the spot measurements, data representing the three weeks before the spot evaluation are shown.
- Spot measurements: The spot measurement took place both in winter and in summer period. In particular in March, 22-23 and in August, 10-11, during the working hours. The monitored parameters were air temperature, operative temperature, air velocity, relative humidity and luminance. The luminance, were measured only with one sensor at the height of 0.6 m (work plane position), while all the other parameters were monitored at four different heights: 0.10 m (height of the ankles), 0.60 m (height of the body for a seated person), 1.10 m (height of the body of a stand person) and 1.70 (height of the head of a stand person).
- Subjective evaluation: During the spot measurements people were asked to fill subjective questionnaire about the comfort sensation, in terms of thermal quality, air quality, light, noise and about the symptoms perceived in the room. More detailed information is described in the following paragraphs.

In the next paragraphs winter and summer analysis are shown in parallel.

2.2.1.1 Physical measurements

Figure 9 and 10 show outside air temperature, relative humidity and solar radiation monitored by the weather station positioned outside the bank during the three weeks before the spot measurements. The 2 days in which the spot were performed are highlight from the red dot lines.

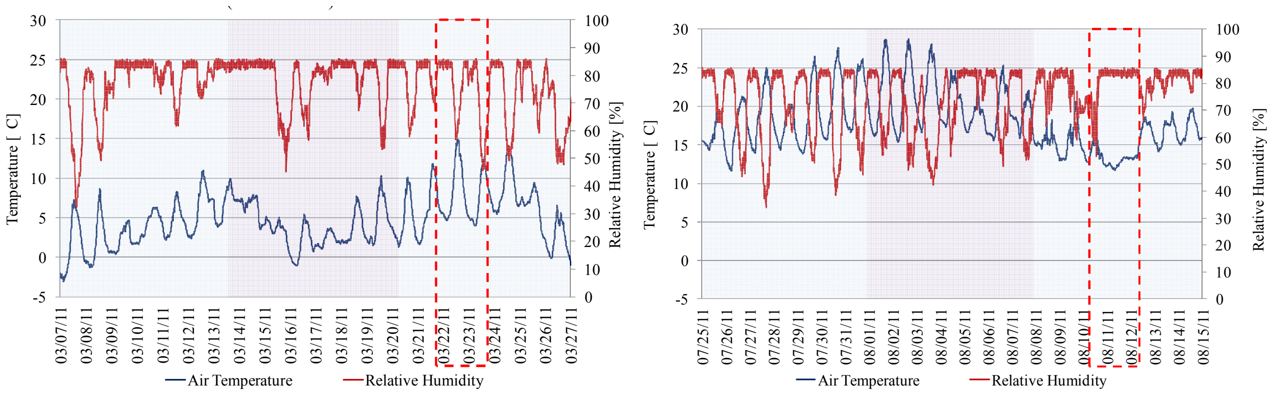


Figure 9 - Outside Air Temperature [°C] and Relative Humidity [%] monitored from Monday 07/25/2011 to Sunday 08/14/2011. Winter and Summer .

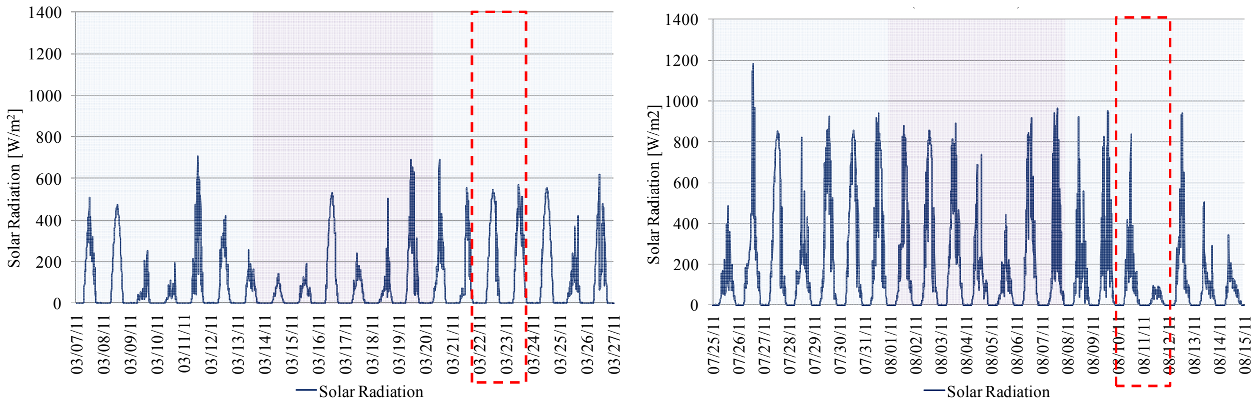


Figure 10 - Solar Radiation [W/m²] monitored from Monday 07/25/2011 to Sunday 08/14/2011. Winter and Summer

From figure 9 emerge that in both cases, winter and summer time, the outside air temperature during the spot monitoring was different respect to the profiles trend of the days before. The temperature during the spots was in fact high during the winter measurements and low during the summer measurements. Also from figure 10 can be done a similar consideration about the solar radiation: it was sunny in winter period and cloudy in summer.

Figures 11(a-c) show the temperatures and CO_2 profiles in three offices, (already analyzed in chapter 2). The air temperature shows that in winter the heating systems kept the temperature almost constant during the three weeks in all the rooms. In summer, a part on the ground floor, fluctuations of temperature inside the building were influenced by the outside temperature. This fact was probably due by the natural ventilation.

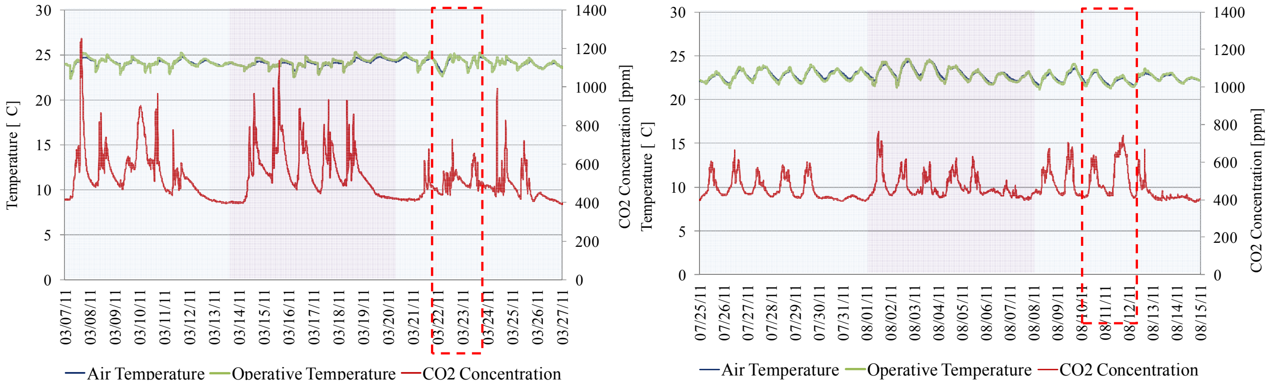


Figure 11a - Air Temperature [°C], Operative Temperature and CO_2 Concentration [ppm] monitored from Monday 07/25/2011 to Sunday 08/14/2011 on the Ground Floor (Open space, room 1.1.00). Winter and Summer.

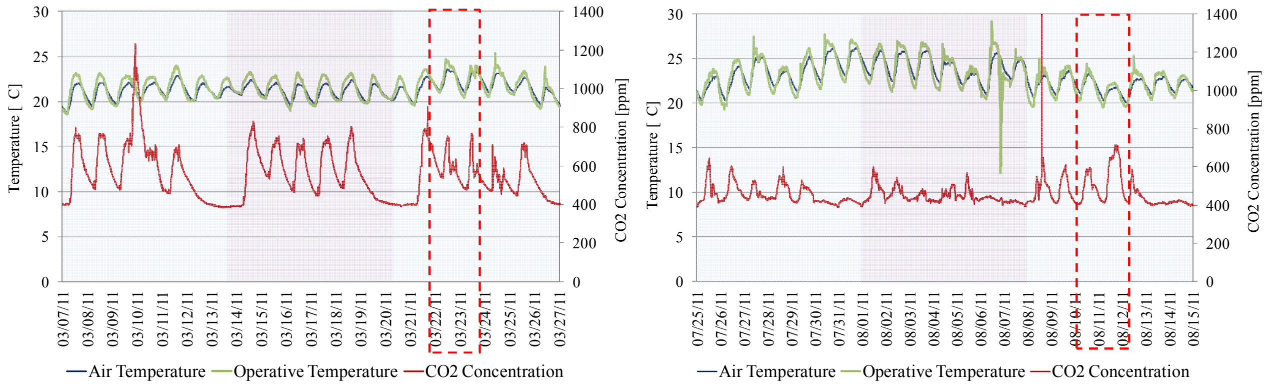


Figure 11b - Air Temperature [°C], Operative Temperature and CO_2 Concentration [ppm] monitored from Monday 073/25/2011 to Sunday 08/14/2011 on the First Floor (Plateau 1, room 2.1.23).Winter and Summer.

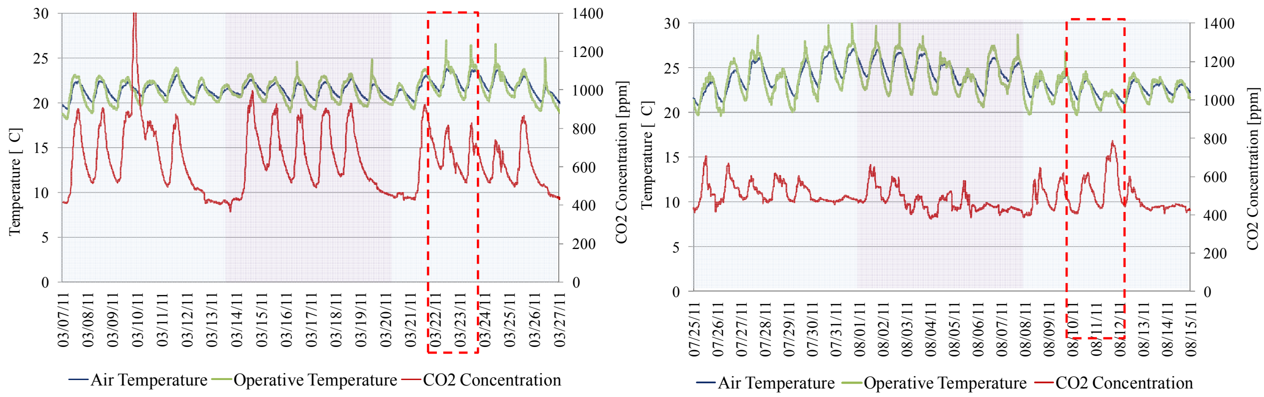


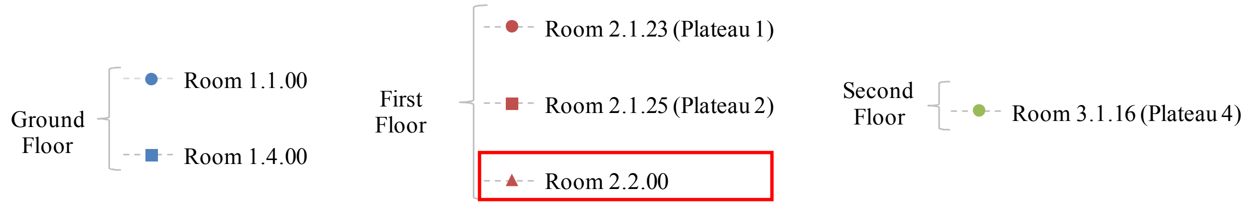
Figure 11c - Air Temperature [°C], Operative Temperature and CO_2 Concentration [ppm] monitored from Monday 07/25/2011 to Sunday 08/14/2011 on the Second Floor (Plateau 4, room 3.1.16).

The air quality, for both the three represented room, was guaranteed by natural ventilation in summer period, but there was not a system for the air quality control during winter. CO_2 profiles show in fact better values of concentration in summer than in winter period. However in both cases the air quality can be considered good. The outdoor concentration was not monitored. Variation of

CO_2 inside the building can also depend by the outside environment. In paragraph 2.1.2 the outside concentration was considered constant (400 ppm).

2.2.1.2 Spot measurements

The Spot measurements consist in the data collection of different parameters for a short period (about 15 minutes) in representative points of the analyzed rooms. These parameters, as already explained before, and then showed in figure 12 an 13, are: air temperature, operative temperature, air velocity, relative humidity and lighting. All these parameters, but lighting, were monitored at four different heights. The values represented in the figures are average values for each room. The monitored representative rooms are:



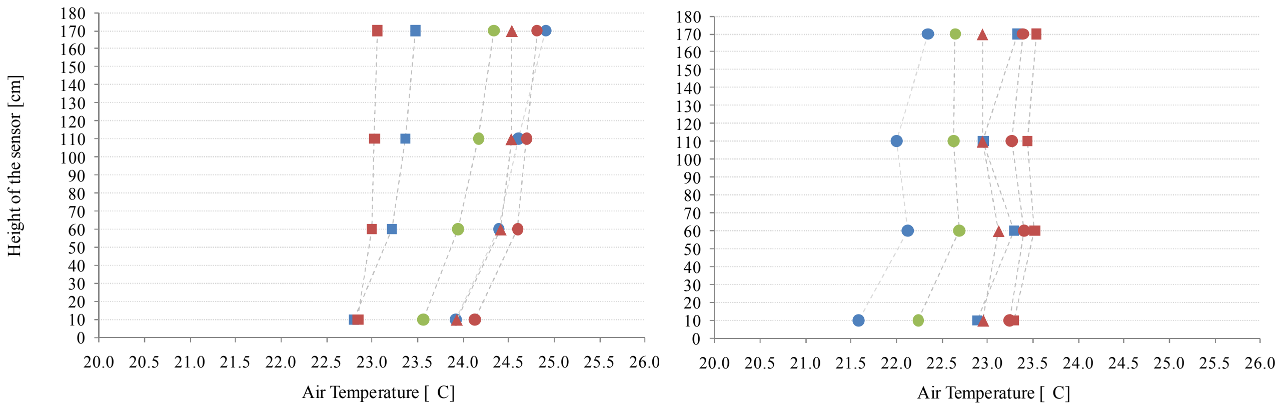


Figure 12a - Average value of Air Temperature [°C] at different heights in the analyzed rooms. Winter and Summer

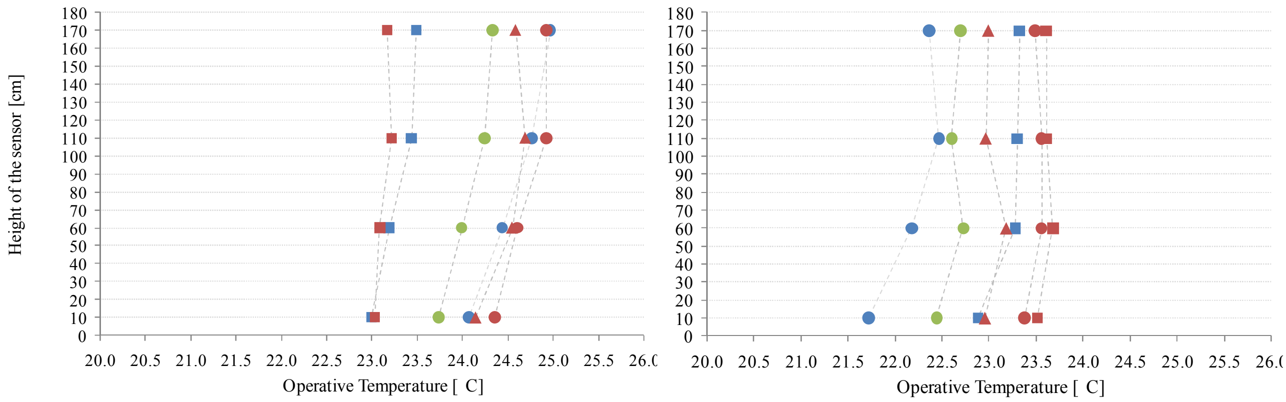


Figure 12b - Average value of Operative Temp.[°C] at different heights in the analyzed rooms. Winter and Summer

Figures 11a an 11b show average values of air and operative temperature in all the analyzed rooms. The measurements highlights that the difference of temperature between foot and head (0.1 m—1.7 m) was always lower than 1 °C. What is curios to notice, in particular from the operative temperature, is that the rooms with highest temperature in winter period had the lowest temperature in summer, and vice versa. Averagely the temperatures of the winter spots were higher than the summer spots. This was due by the abnormal trend of outdoors temperature during the days of spots respect to the seasonal averages.

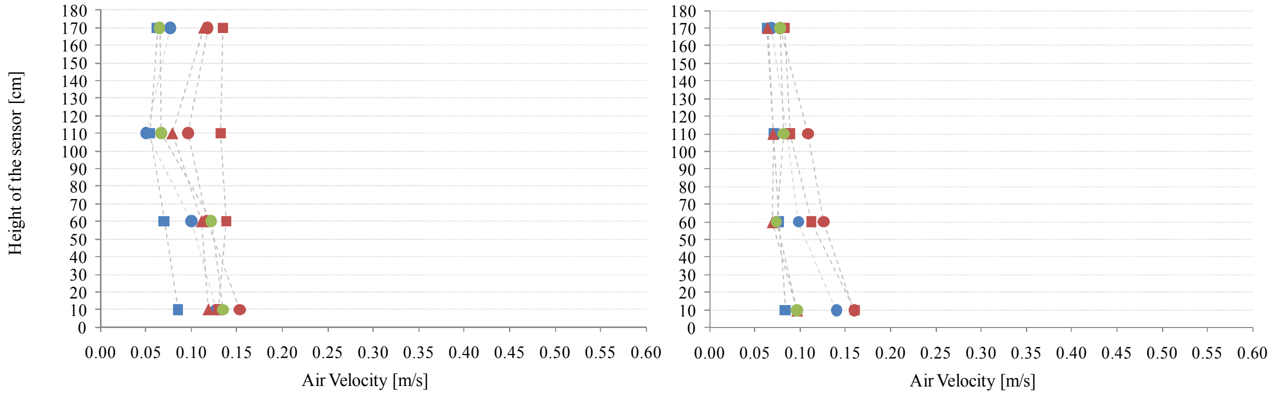


Figure 12c - Average value of Air Velocity [m/s] at different heights in the analyzed rooms. Winter and Summer

The air velocity was higher at the height of 0.1 m and 0.6 m, were usually the value exceeded 0.10 m/s, and decreased with increased height of the sensors. The average air velocity was lower in the smallest and closed offices (room 1.4.00 and 2.2.00) respect to the open spaces. On Plateau 1 and Plateau 2 the average air velocity was higher than in all the other cases, in both seasons. In these two rooms, as described in Annex A and B, areas with maximum percentage of dissatisfied for draught are signalized.

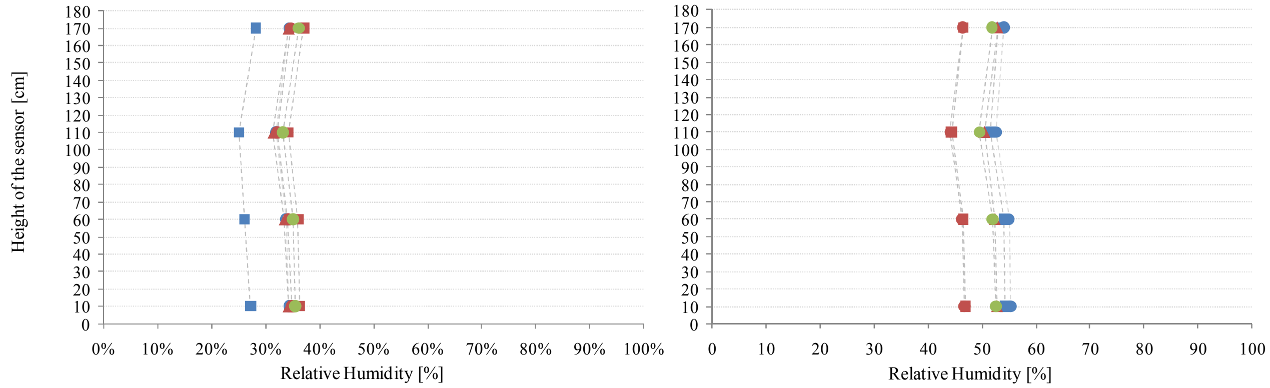


Figure 11d - Average value of Relative Humidity [%] at different heights in the analyzed rooms. Winter and Summer

The relative humidity (Figure 11d) presented almost the same values in all the rooms and at the different heights, but with different values between winter and summer. The values on Plateau 1 and Plateau 2 in summer, and room 1.4.00 in winter, were lower if compared with the other rooms. Considering the ranges of relative humidity described in table 1, the averagely monitored values fall in category I during the winter spots and in category II during the summer spots.

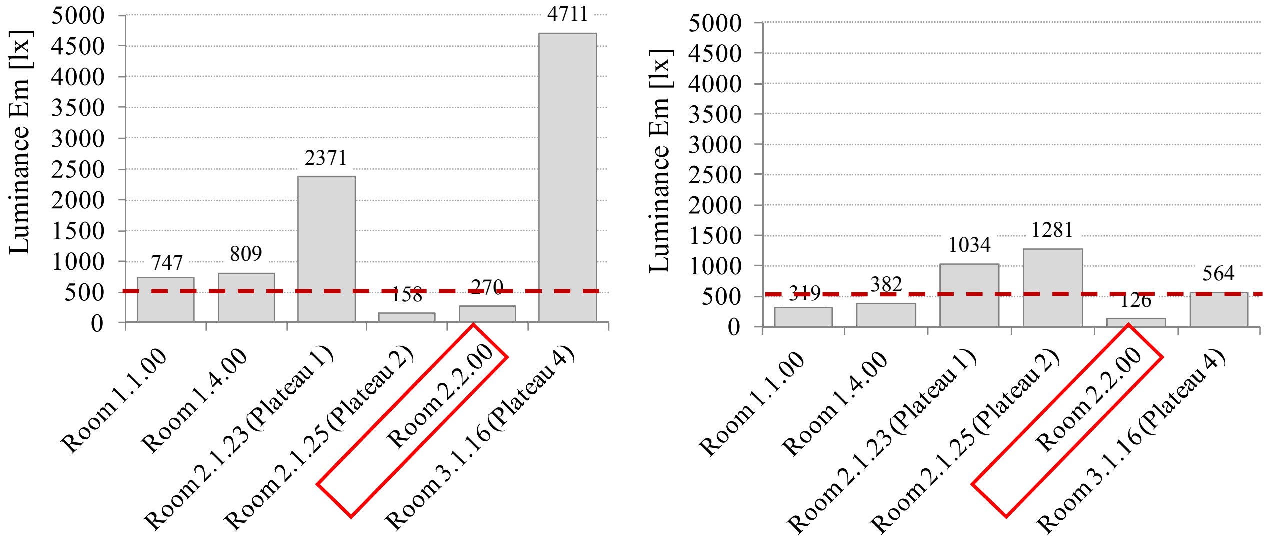


Figure 13- Average value of Luminance [lx] in the analyzed rooms. Winter and Summer

Figure 13 shows the different average levels of luminance in the rooms measured at the high of 0.6m. The minimum value of luminance required from standard EN15251, for office buildings, is 500 [lx]. Note that 200 [lx] are considered acceptable if the work plane desk is provided by a table lamp. The values of luminance between winter and summer spots were quite different. The minimum prescription of the standard was not always satisfied. For example, results of monitoring in room 2.2.00 highlight a really low average value of luminance in the room in both cases. At contrary, some other values, like Plateau 4 in winter, are really high. It is important to highlight that these values don't represent the average value during a day, but just during the monitoring time: probably the average for a day could be different.

Pictures of the analyzed rooms are shown from Figure 14a to 14f.

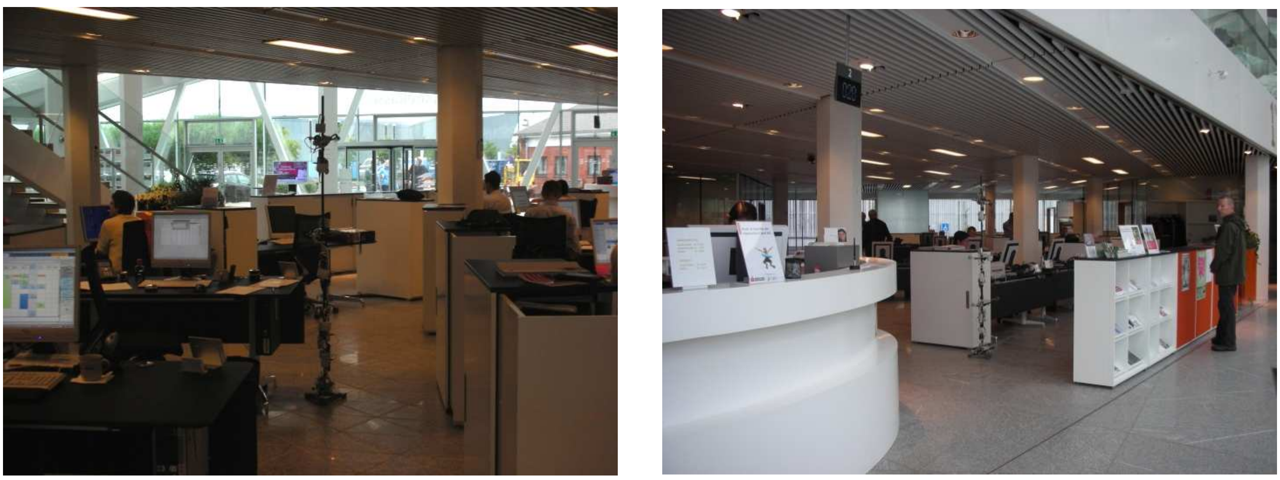


Figure 14a- Room 1.0.0 – Ground floor - during the measurements

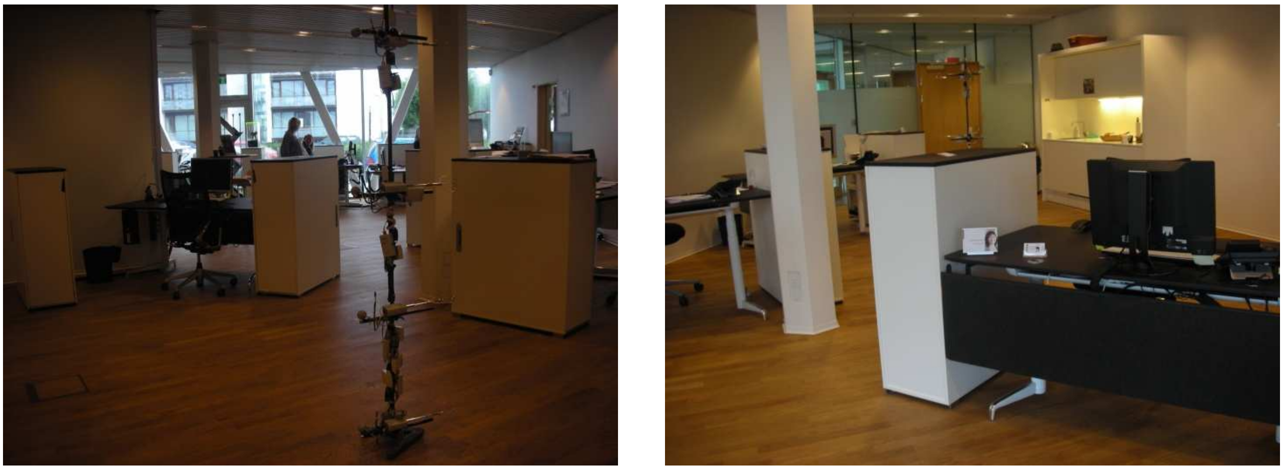


Figure 14b- Room 1.4.0 – Ground floor - during the measurements

Figure 14c- Room 2.1.23 – Plateau 1 – First floor - during the measurements

Figure 14d- Room 2.1.25 – Plateau 2 – First floor - during the measurements


Figure 14e - Room 2.2.00 - First floor - during the measurements


Figure 14f - Room 3.1.16 – Plateau 4 – Second floor - during the measurements

2.2.1.2 Subjective e valuation

Occupants in the rooms were asked to fill a questionnaire about the subjective evaluation of the environment at the same time when the spot measurements were performed. People were furthermore asked to give information about the clothes that they were wearing and about the position of their desk in the room. With the collected data and with the physical measurements, it has been possible to calculate the Predicted mean vote (PMV) and the Percentage of dissatisfied (PPD) in the rooms. The PMV index predicts the mean response of a large group of people according to ASHRAE thermal sensation scale, where:

- +3 hot
- +2 warm
- +1 slightly warm
- 0 neutral
- -1 slightly cool
- -2 cool
- -3 cold

PPD index, on the other hand, predicts the percentage of large group of people likely to feel “too warm” or “too cool”. Comfort categories ranges of PMV and PPD index are described in Table1.

From the questionnaires, then, subjective evaluation about the thermal comfort was performed. The comparison between result from questionnaires and from indexes calculation is shown in Table 2.

Table 2 - Subjective evaluation, Predicted Mean Vote and Predicted Percentage of Dissatisfied for the analyzed rooms.

Floor	Room	Season Winter/ Summer	Number of people that filled the questionnaire	Icl [clo]	Thermal Sensation Vote (TSV)	Calculated PMV (0.6 m)	Calculated PPD (0.6 m)
Ground Floor	1.1.00	W	18	0.73	1.15	-0.57	11.92
		S	17	0.7	-0.36	-0.19	5.96
	1.4.00	W	4	0.62	0.72	0.02	5.01
		S	6	0.68	-0.18	-0.6	15.25
First Floor	2.1.23 (Plateau 1)	W	9	0.83	0.26	0.18	5.65
		S	5	0.71	0.26	-0.26	7.06
	2.1.25 (Plateau 2)	W	9	0.84	0.26	-0.25	6.28
		S	8	0.66	-0.12	-0.32	9.13
	2.2.00	W	7	0.79	1.09	0.11	5.25
		S	3	0.77	-0.98	-0.16	9.15
Second Floor	3.1.16 (Plateau 4)	W	9	0.82	1.35	-0.1	5.2
		S	7	0.76	-1.11	-0.27	7.76

Table 2 shows that in all the rooms the average clothing value was between 0.62 and 0.84 [clo] during the winter spots and between 0.66 and 0.77 [clo] during the summer spots. Usually, in winter period, the value suggested by the standards is 1 [clo], while is 0.5 [clo] in summer. These values of Icl can be justified considering the low external temperature during the 2 days in summer and vice versa the high external temperature during the 2 days in winter.

The calculated average PMV value in all the rooms predicted a quite good thermal environment: between neutral and slightly cool in winter spots and between neutral and slightly cool in summer spots.

The average subjective response denoted that in general occupants felt the environment slightly warm or between slightly warm and warm. Also these results derive by the fact that during these days the outside temperature was hotter than in the previous weeks and people expected lower temperature inside the rooms. In summer the subjective response denote that the occupants felt the environment around neutral for the room 1.4.00, Plateau 1 and Plateau 2, slightly cool for Room 2.2.00 and Plateau 4 and between neutral and slightly cool in the office 1.1.00. Again these results depend by the cold outside temperature that made the people expected higher temperature inside the rooms. The subjective response with the relative standard deviation according to the thermal sensation scale, for both the spots, is shown in figure 15.

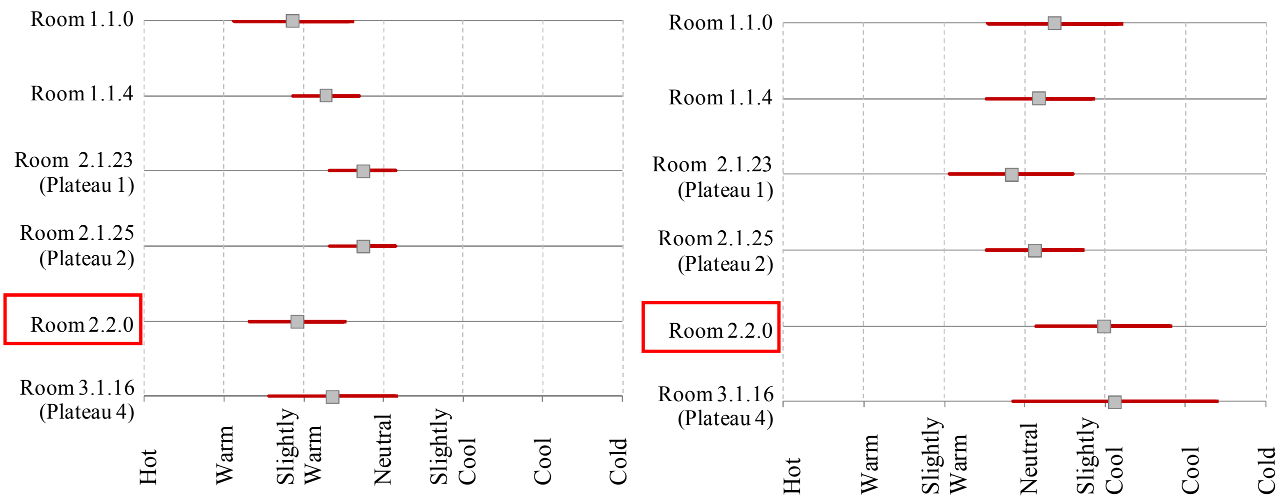


Figure 15- Thermal sensation in the different analyzed rooms. Winter and Summer.

People were then asked about the thermal indoor climate perceived from their workstation. The answers' range was from Clearly Comfortable to Clearly Uncomfortable. The occupants' average answer is shown in figure 16.

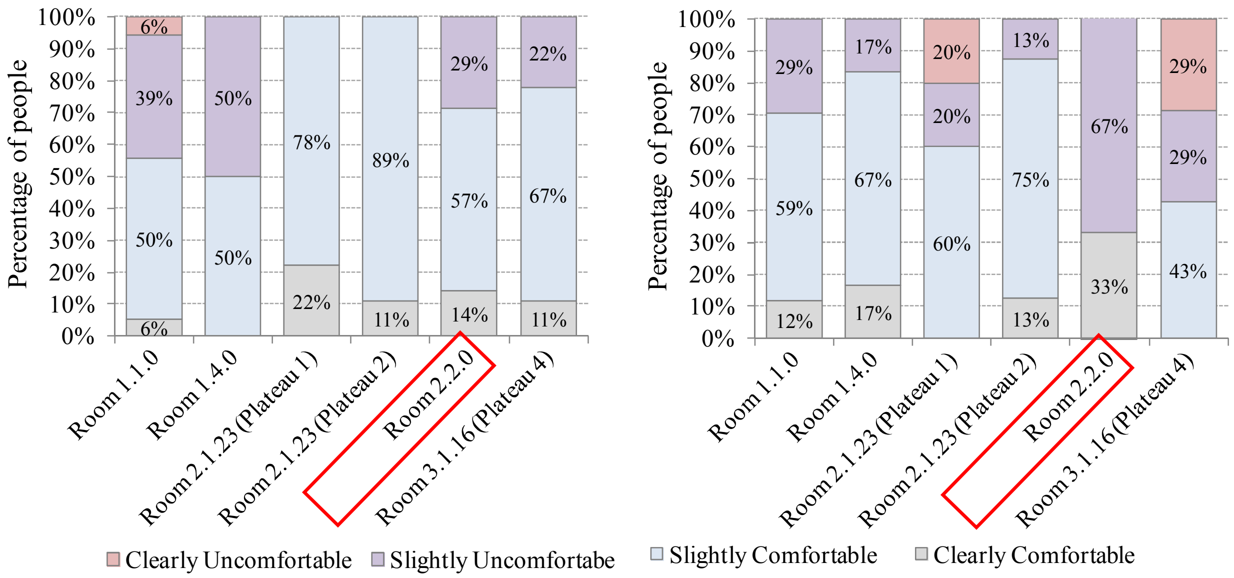


Figure 16 - Average thermal indoor climate in the rooms. Winter and Summer

In winter on Plateau1 and on Plateau2 the employees were apparently more satisfied than in the other rooms. Same result is evident in figure 15, where the thermal sensation of these two rooms was close to neutrality. Similar comparison can be done for the room 1.1.00 where the percentage of people dissatisfied in the room felt the environment too warm. In summer on the rooms at the ground floor, and on Plateau 1 and Plateau 2, at least the 60% of the employees were apparently satisfied, feeling the environment slightly comfortable or clearly comfortable. Similar result is also evident in figure 13, where the thermal sensation of these rooms was close to the neutrality. Similar comparison can be done for the room 2.2.00 and for Plateau 4, where the percentage of dissatisfied people in the room felt the environment slightly cool.

At the question "How would you prefer the temperature if you could choose?" (Figure 17), the answers highlighted that in winter less than half of the occupants would prefer a lower temperature, while more than half would not change anything. Opposite is in summer where a part a little percentage of people that would prefer a lower temperature, mainly the occupants would not change anything or would prefer an higher temperature. This happened in particular in the room 2.2.00 and on Plateau 4, where at the previous questions the cool environment was already denounced.

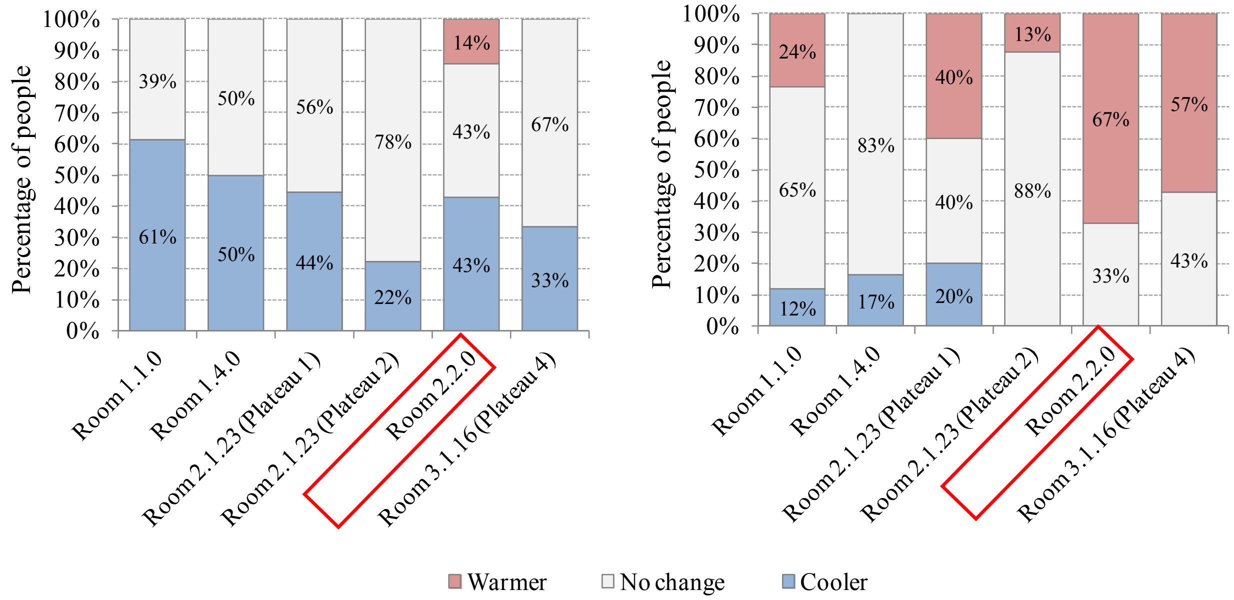


Figure 17- Preference of thermal indoor climate in the rooms. Winter and Summer

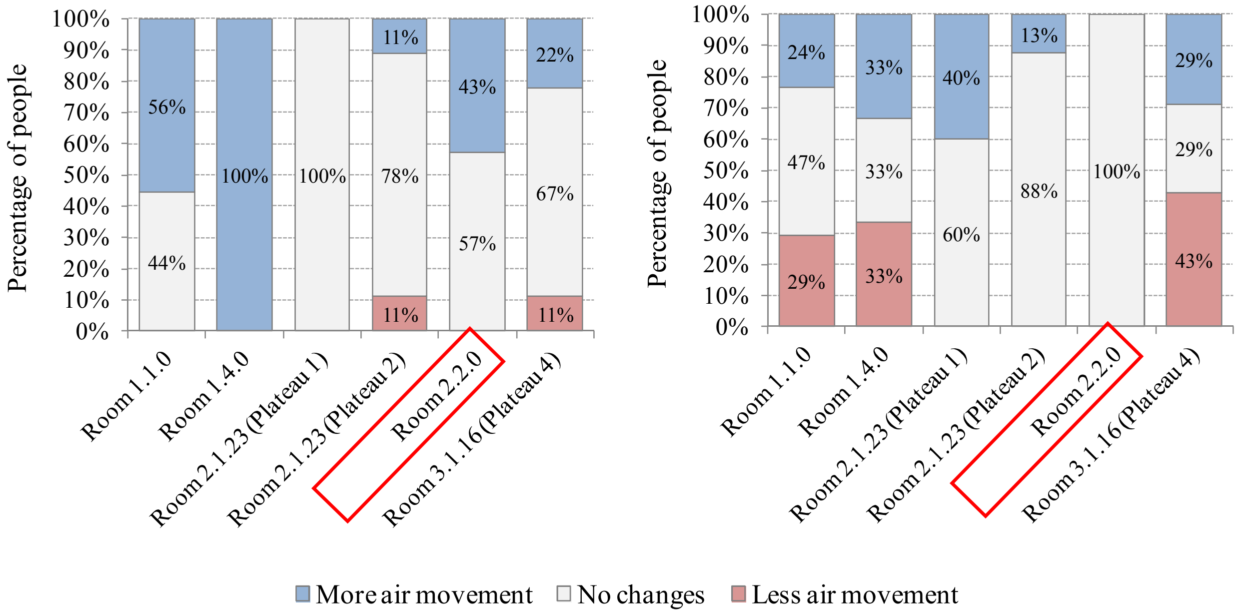


Figure 18 - Preference of air movement around the occupants in the different rooms. Winter and Summer

At the question about air movement assessment around the workplace (Figure 18), in winter most of the people answered that no changes were needed. A part Plateau 2 and Plateau 4, where in both cases one person would prefer less air movement, in general people was satisfied or would prefer to increase the air movements. This happened especially in Room 1.4.00. In summer the answers were different for each single room and sometimes opposite the expectations. In room 2.2.00, for example, where most of the occupants evaluated the thermal environment slightly cool, no changes in the air movements were required. On Plateau 1 and 2 a percentage of occupants, lower than the 60%, preferred to have more air movements, while in the rest of the building, averagely, a third of the people preferred more air movements, a third less air movements, and another third did not required changes. Focusing on room 1.1.00, people that would prefer less air movement were sit in the back of the room, while people that would prefer more air movements were sit on the right part of the room, behind the customers reception desk, and in room 1.4.00 people that denounced to prefer less air movement were sit close to the windows.

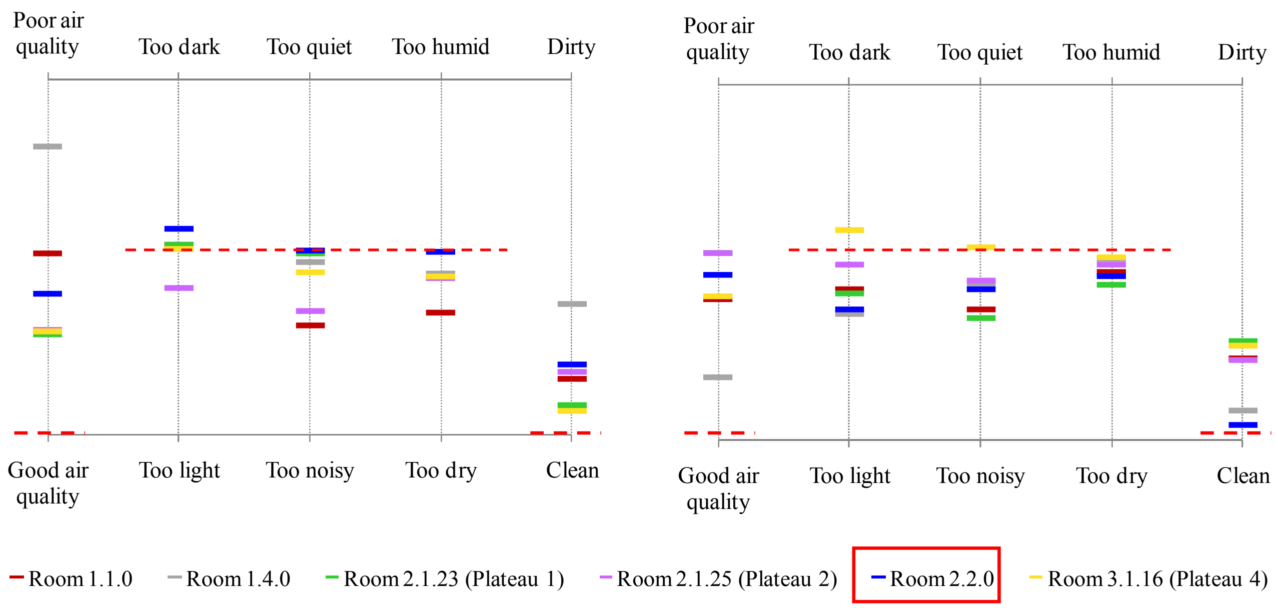


Figure 19 – Environmental factors perceived by the occupants in the rooms. Winter and Summer

Figure 19 shows the environmental factors perceived in the office by the occupants. The red dots lines indicate the optimal condition. The answers for both the spots were quite similar. In all the building the lighting level, the noise and the humidity were evaluated quite good. The average answers fall between the extreme situations (too light /too dark, too noisy/too quiet, too dry/too humid). The results also show that air in the rooms was perceived quite clean. Just room 1.4.00, in winter, presented some difference respect to the other rooms and to the summer evaluation: the air has been evaluated quite poor and a little dirty.

Symptoms perceived by occupants in the rooms are shown in figure 20. On the upper axis of the figure negative perceptions of the symptoms are shown, while positives are on the lower axis. In winter all the average values fall, for all the rooms, in the positive lower part of the graph. Lips and skin were perceived by the occupants as the driest part of the body. From this evaluation emerge that in general people didn't have concentration problems, were in a good spirit, were not tired, didn't have headache, eyes irritation or other symptoms that could contribute to damage or slow down their work. To confirm this fact, the answers given by the employees at the last question, about the difficulty working well, clearly demonstrate that people could work well. In summer the average values fall in the positive lower part of the graph, but not for all the rooms. In room 2.2.00 and Plateau 1, for example, the average answer at some symptoms fell in the negative upper part of the graph and, in general, these two rooms presented the most negative answers at most of the questions. However, also during the summer spots, in all the room people declared to be in good spirit, to work well, to don't have problem of concentration, to don't have headache and to feel the environment comfortable.

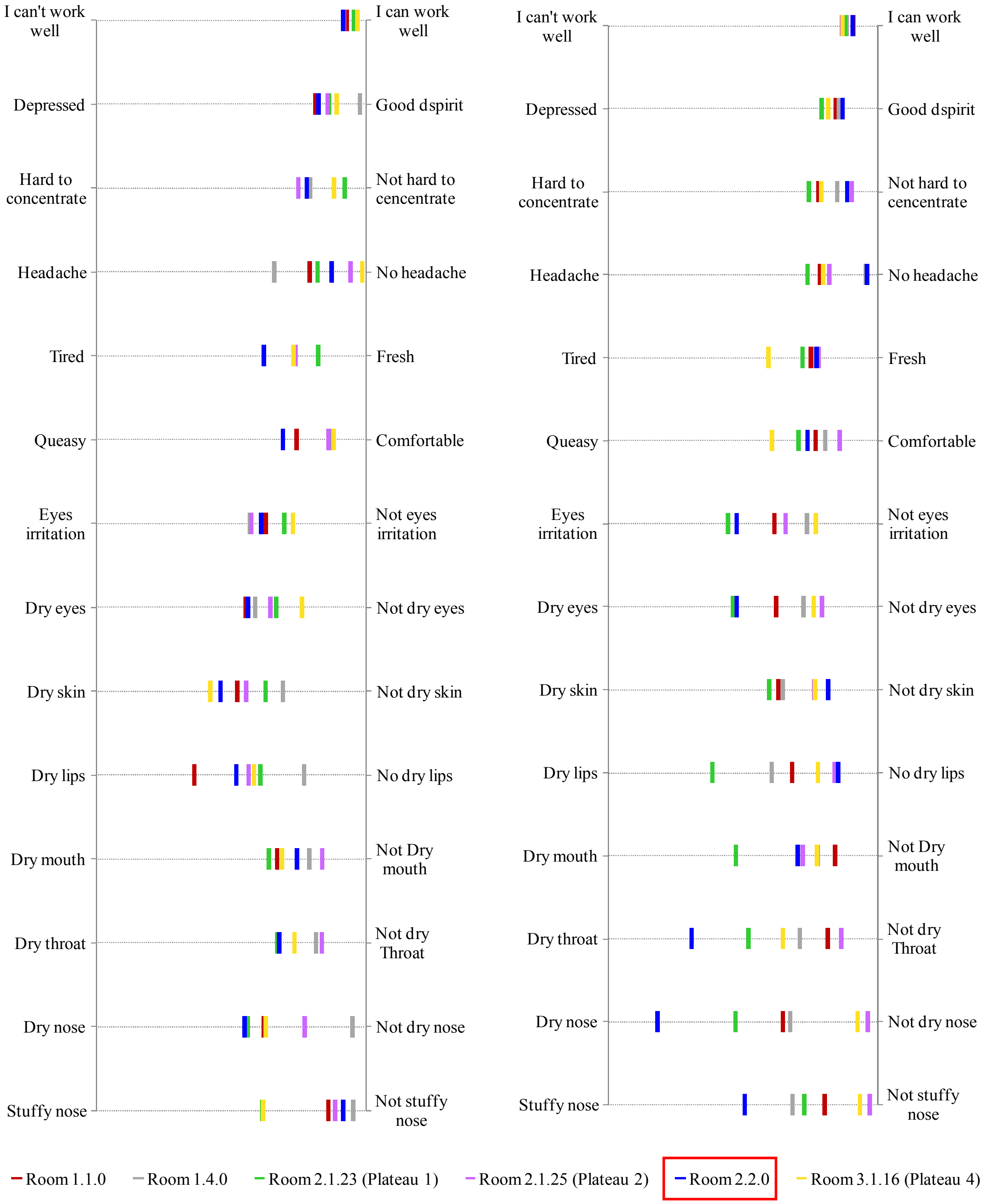


Figure 20 – Symptoms perceived by the occupants in the room. Winter and Summer.

2.2.2 Comparison with the results obtained in the old building in summer period.

Similar analysis like the one showed in the previous paragraph was conducted from 11 to 29 of June, 2007, just in summer period, in the old headquarters of Middelfart Savings Bank. In this paragraph a short comparison between the results obtained during the monitoring campaign in the old building and the results deriving from the analysis in the new offices is shown.

For more detailed information Annex C describes the summer spot measurements performed in the old building, while Annex A describes the spot summer measurements performed in August 2011 in the new building.

From the comparison of three weeks of monitoring between the two buildings emerge in particular that:

- The temperatures in the old building were generally good, but sometimes higher than the one prescribed by the standards, especially in the afternoon. In the new building the problem was the opposite: the temperatures were generally colder than the standard prescriptions. In both cases the average temperatures were in the range of Category II.
- The CO_2 concentration in the old building was quite good on the ground and on the first floor, but over the standards prescriptions on the second floor. In the new building the CO_2 concentration was really good in all the building. From the comparison can be said that air quality was better in the new building.
- The relative humidity was quite good in both the buildings. In the new building it was a little bit high respect to the limit of category I (EN 15251).

From the comparison of the spot measurements between the two buildings emerge in particular that:

- The temperatures during the spot monitoring in the old building were lower than the average seasonal temperatures in the building. At the contrary the temperatures during the spot monitoring in the new building were higher than the average seasonal temperatures.
- The calculated PMV value was closest to neutrality sensation in the old headquarter respect to the value calculated in the new building.
- The percentage of dissatisfied for draught was higher in the old building respect to the new.

From the comparison of the questionnaires between the two buildings emerge in particular that:

- People seemed more satisfied about the air quality in the new building respect than in the old.
- The perceived thermal sensation was better in the new building.
- The noise was more elevated in the old building respect than in the new.
- The evaluation of the perceived symptoms by the occupants in the rooms was better in the new building than in the old.

Comparisons of the calculated predicted mean vote and the perceived thermal sensation between the two buildings are shown in figures 21 and 22.

Note than the three rooms of the new building considered in this comparison are the three naturally ventilated open spaces already described before (room 1.1.00–GF, plateau 1–1F, plateau 4–2F).

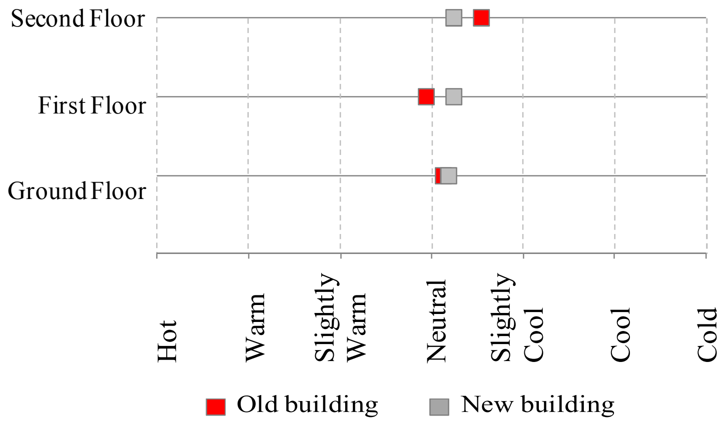


Figure 21 – Predicted mean vote (PMV) comparison between old and new building.

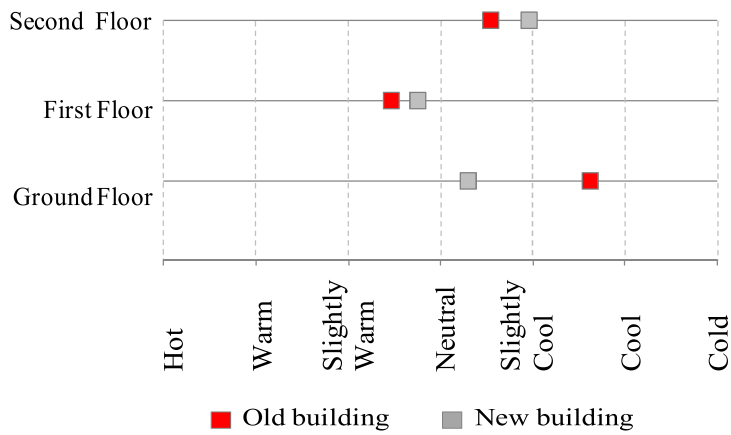


Figure 22– Perceived thermal sensation comparison between old and new building.

In both cases the calculated predicted mean vote was close to neutrality for all the floors, with tendency at the slightly cool evaluation. In the new building the value of the vote was almost the same for all the rooms: this highlights that the monitored parameters used for the PMV calculation (operative temperature, air velocity, relative humidity) were in general more homogeneous in the new building than in the old.

Different considerations emerge from the comparison of the perceived thermal sensation. The tendency of the answers follows the tendency of the PMV comparison, but here the evaluation were in both cases quite different between the three floors. Also in this case the values obtained in the new building were a bit more homogeneous than in the old one.

Figures 23 shows the perceptions of the environmental factors perceived in the building by the occupants.

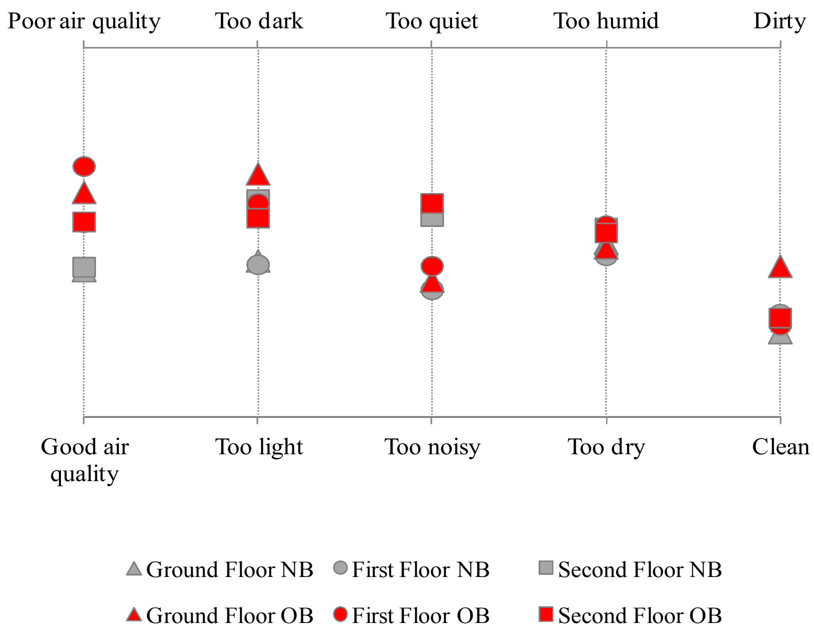


Figure 23– Comparison of environmental factors perceived by the occupants between old and new building.

The comparison does not highlight particular differences between the two buildings. As is possible to see in the graph the answers were really similar. In both cases the evaluation of the environment in terms of humidity, light and noise was quite good. Just the air quality was evaluated a little bit better in the new building than in the old one.

Comparison of the symptoms perceived in the building is shown in figure 24.

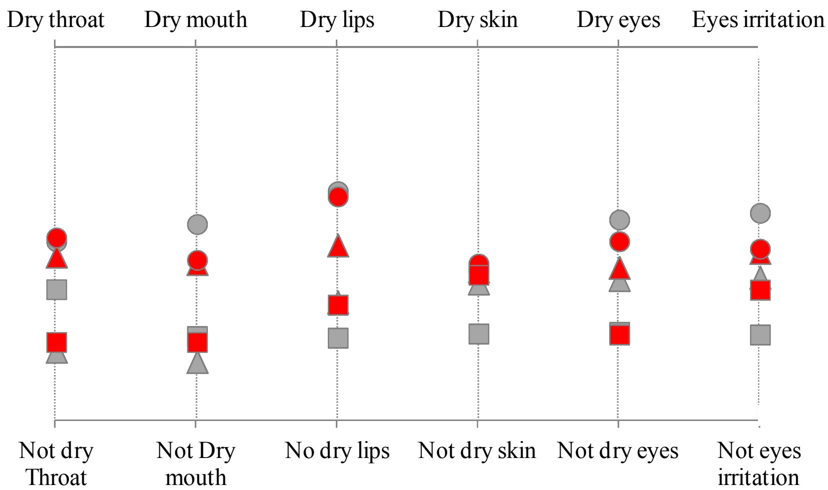


Figure 24a– Comparison of symptoms perceived by the occupants between old and new building.

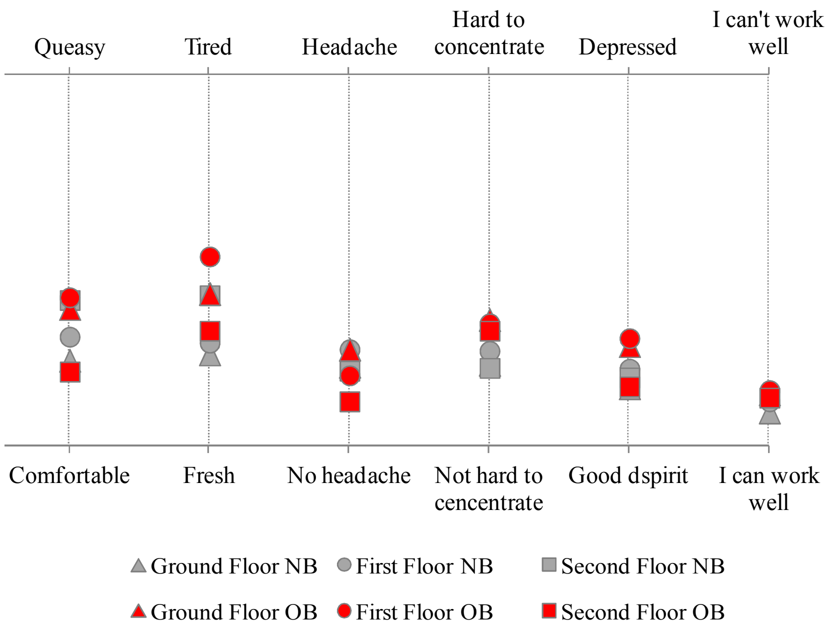


Figure 24b– Comparison of symptoms perceived by the occupants between old and new building.

Also in this case the differences between the buildings are very little. Is interesting to note than in general, for both cases, people gave a better evaluation of the symptoms on the ground floor respect to the first floor.

For both the buildings all the answers were in the lower part of the graph, people declared to be in a good spirit and to be able to work well.

The comparisons did not put in evidence a big difference between old and new building. Just in terms of air quality, from measurements and from subjective evaluation emerge an improvement in the new building respect to the old. Furthermore in the new building the environment in the different analyzed rooms was more homogeneous than in the old one.

3 Energy consumptions evaluation

The evaluation of building energy consumptions was performed through direct energy measurements in different parts of the systems from October 2010 to September 2011. Measurements about the whole year, and monthly data are shown in this chapter.

District Heating and Electricity are the public delivered energies.
The district heating:
- allow to heat the building, through floor heating pipe system and through convectors system
- is used to heat the supply air of the ventilation systems in winter
- provide the domestic hot water.

The electricity:
- powers the cooling system (chillers, dry coolers, pumps etc.), which cools the building through floor cooling and tabs pipe systems, and to cool the supply air of the ventilation in summer.
- it is used for lighting, other building installations, kitchen incl. cold store, computers and server room, and all kind of purposes/appliances in the building.

Figure 21 shows a scheme of the building systems. In red circles are indicated the points in which energy was monitored. Four different levels of detail in the energy evaluation were considered:
- Level 1: delivered energy
- Level 2: Building technical systems
- Level 3: Building technical systems – Detailed
- Level 4: Energy need - Room 2.2.00.

For better understand the graph is necessary to explain that:
- The electricity system was divided in 8 parts:
  1. General of the bank, including the power required from the system in all the building
  2. G 1.2, including the electricity consumptions of the tenancy room where bookstore and cafè were located (ground floor)
  3. G 1.3, electricity needs of dress shop (ground floor + deposit on the first floor)
  4. G 1.4, electricity required by tenancy room 1.4.00 (ground floor)
  5. G 1.5, electricity consumptions of tenancy room 1.5.00 (ground floor)
  6. G 2-2, electricity consumptions of tenancy room 2.2.00 (first floor)
  7. Sprinkler system
  8. Fire ventilation

  NB: Only the General meter (1) and consumptions in room 2.2.00 (6) were monitored constantly. Data about the other six meters have been manually collected, and just an yearly evaluation could be made.
- The ventilation system was divided in 5 parts:
  1. V01= Ventilation system in the offices South exposed (26 kW)
  2. V02= Ventilation system in the offices West exposed (22 kW)
  3. V03= Ventilation system in the canteen (11 kW)
  4. V04= Ventilation system in the bookshop and in the cafè (8 kW)
  5. V05= Ventilation system in the basement (5 kW)

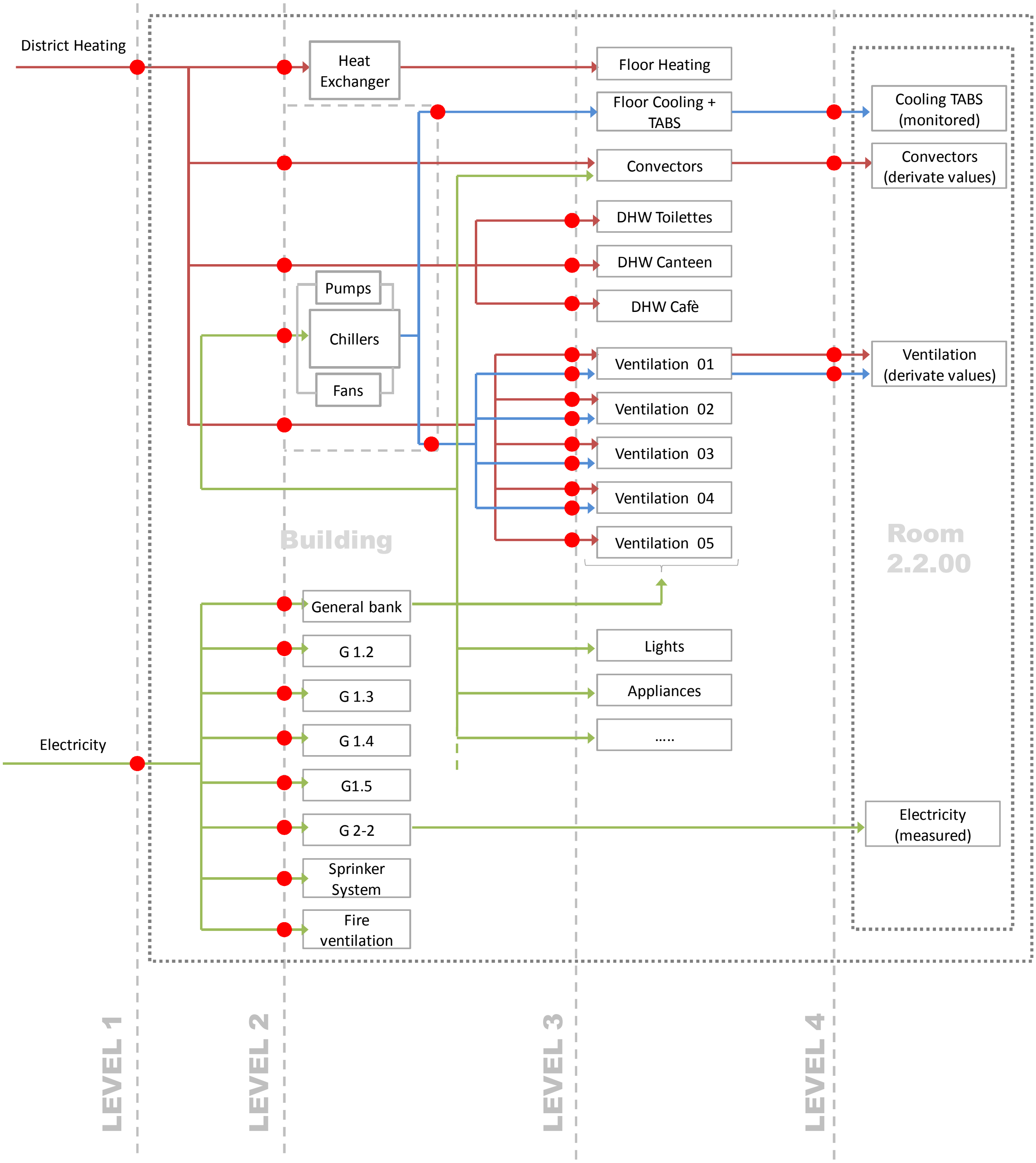


Figure 25 – Systems' scheme with indication of the monitoring point.

3.1 Yearly evaluation

Evaluation of the energy required by the building for one year is shown in figure 26. Where in figure 25 was indicated a monitoring point, here is indicated the energy registered in one year of monitoring in that specific points.

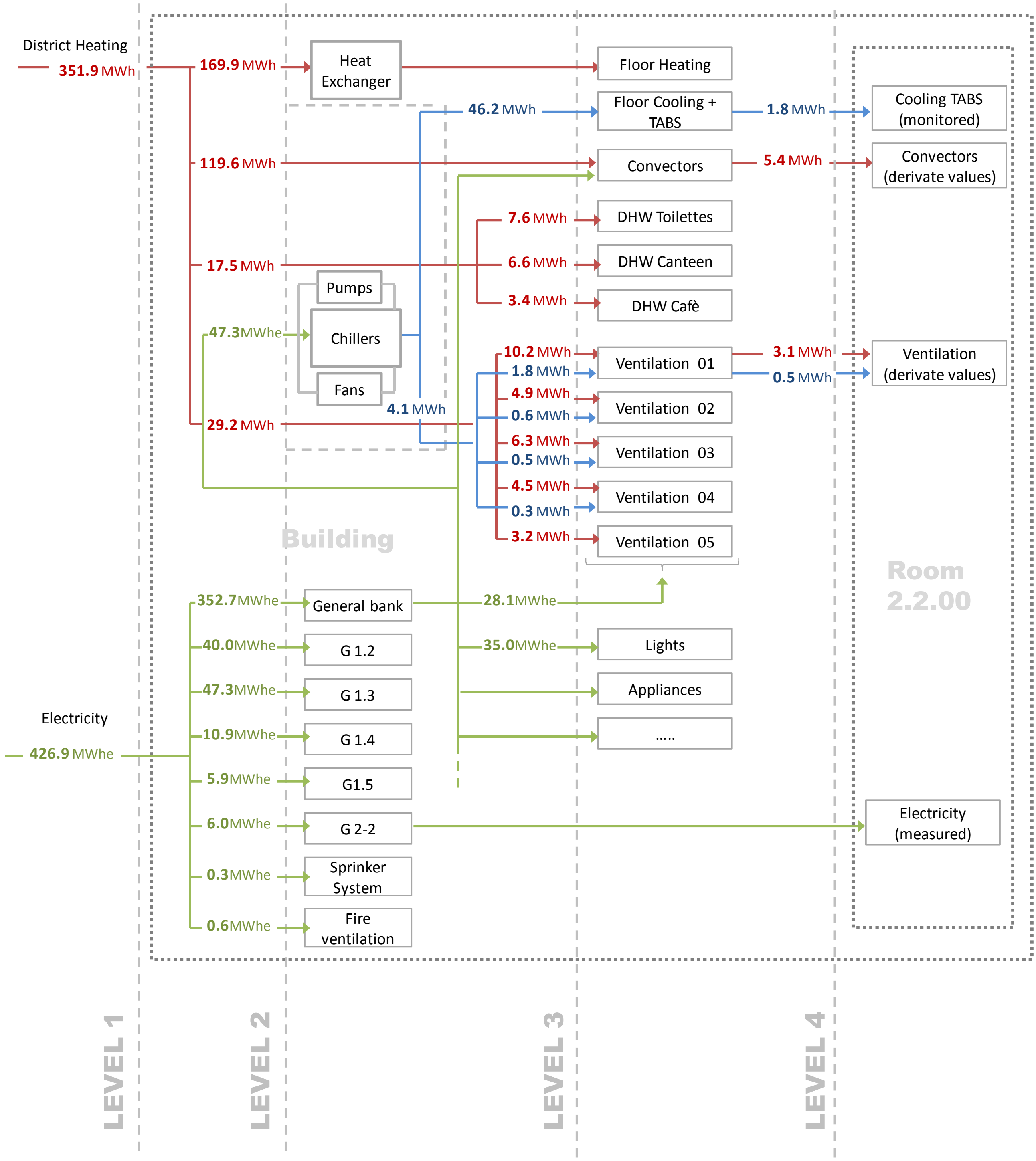


Figure 26 – Systems' scheme with indication of the energy consumptions.

Talking about thermal energy, from the values in figure 26, but especially from figure 27, emerge that the biggest amount of energy in the building was required for heating (76.5 kWh/m^{2}y). The cooling energy represented just the 13% (10.9 kWh/m^{2}y) of the total energy required for the building conditioning. The ventilation, during both heating and cooling season, influenced just in little percentage the total energy consumptions. This energy for ventilation do not include the electrical energy for fans, dampers and controls.

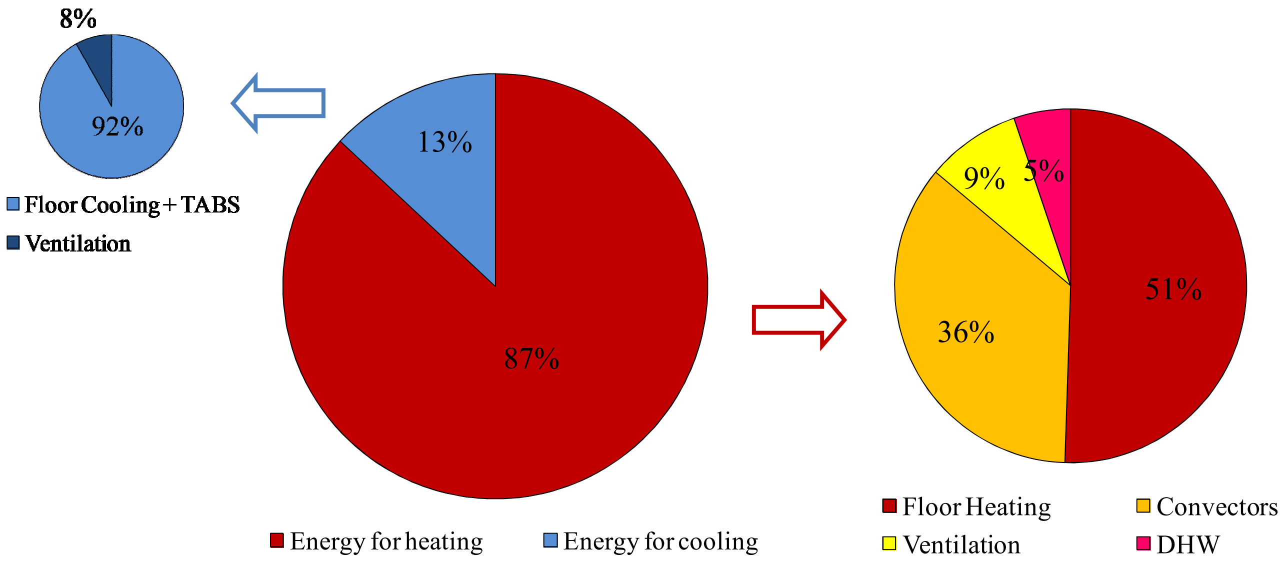


Figure 27 – Percentage of energy required for heating and cooling the building. (Level2).

About electricity consumptions, figure 28 shows that on the total demand (92.9 kWh/m^{2}y) the tenancy rooms, that represent 25% of the total floor surface, had a weight of 17%. The bookstore and the cafè required the biggest amount of energy of these rooms. The sprinkler system and the fire ventilation had a very little influence on the total energy consumptions, lower than the 0.2%. The biggest demand of electricity of the building , 83%, was registered by the general meter (bank spaces and systems). Another meter registered separately just the electricity adsorbed by the cooling system. As shown in the figure, on these 83% the percentage of energy required by the cooling system was the 13% , while the other 87% was used for lighting, appliances, driving force (etc.). From an estimation of the electrictricity consumptions (BE06), was possible to define that the energy consumptions of the ventilation system were the 8% of the total registered by the general meter (5.3 kWh/m^{2}y –> 28.1 MWh/y). Similar estimation was done for lighting consumptions: the electricity consumption has been estimated 35 MWh/y (6.6 kWh/m^{2}y).

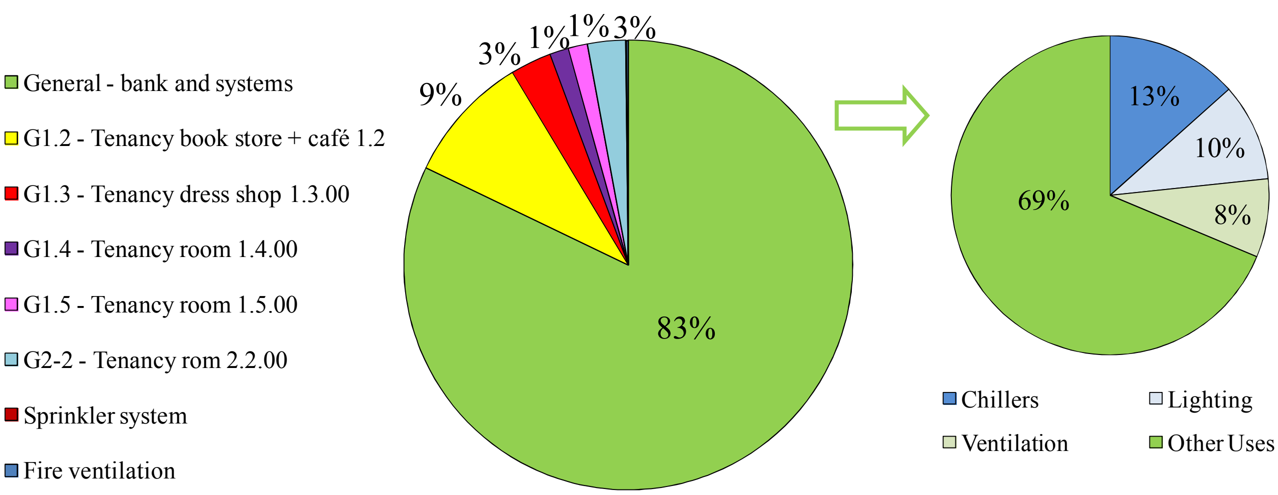


Figure 28 – Percentage of Electricity required by building and focus on the general meter(energy required from the cooling system)

3.2 Monthly evaluation

3.2.1 Level 1: Delivered energy

The first level of detail analyzes the district heating and electricity demand of the building. Figure 29 shows the energy demand distribution during all the months. On the left axis the energy is expressed in MWh, while on the right axis it is expressed in kWh/m^2. The building surface considered in the calculation (4594 m^2) does not take in account the basement (total 5381 m^2).

From the figure emerge that the maximum heating demand was in December, with 18 kWh/m^2. During all the heating season, from November to March, the value was not lower than 9 kWh/m^2. The electricity demand was almost constant around 8 kWh/m^2 for all the months. Note that as said before for six electricity meters didn't collect data in continuous. For these cases the monthly contribution has been calculated dividing the consumption for twelve months.

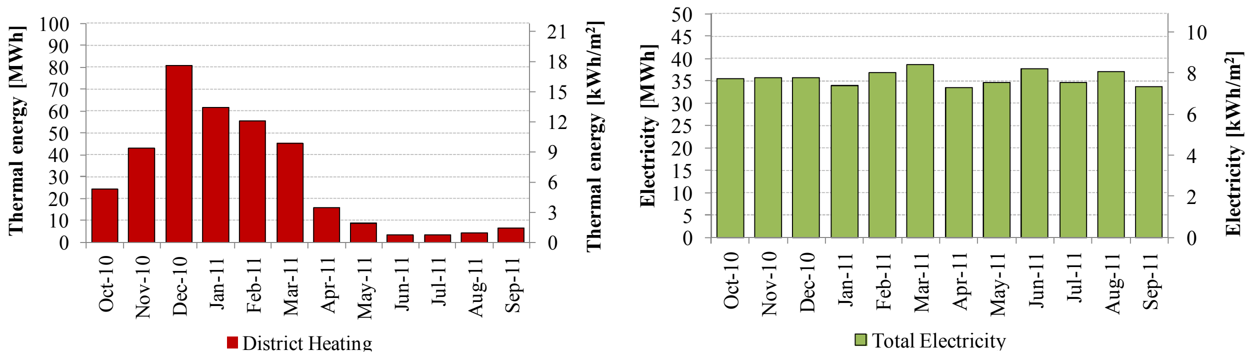


Figure 29 – Monthly energy consumption for delivered energy.

3.2.2 Level 2: Building technical systems

The second level analyses the energy demanded by the different systems. In winter energy demand form floor heating, convectors and ventilations respected the percentages indicated by figure 27. The same was for the energy demand in summer season. In the mid seasons convectors and cooling systems were sporadically worked together. The energy demand for domestic hot water was almost constant all the year. The electricity consumptions denote an increasing of energy demand from the chillers from April to September, with maximum in June.

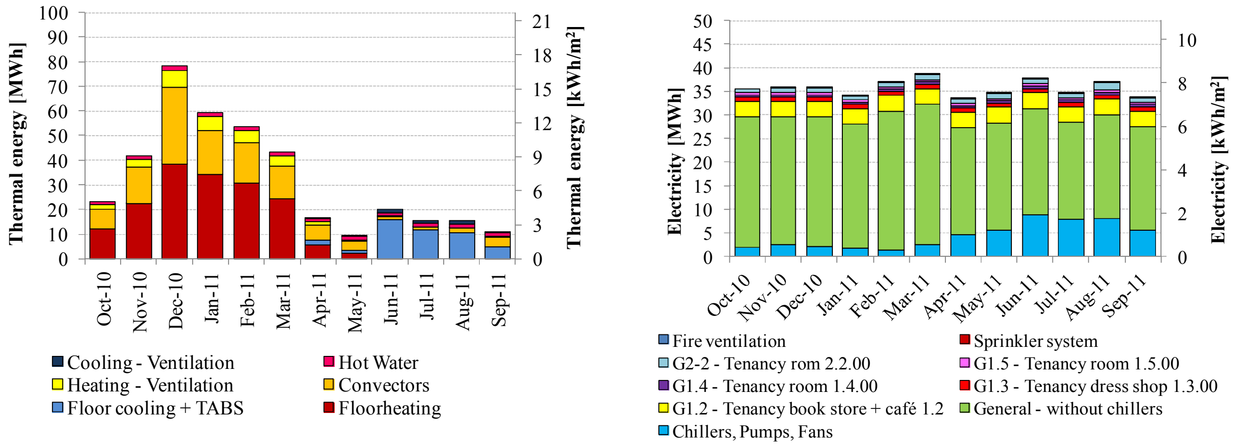


Figure 30 – Monthly energy consumption required by the different systems.

3.2.3 Level 3: Building technical system - Details

The third level investigates on the ventilation systems and the domestic hot water, highlighting the energy demand distribution of the systems during the different months.

V 01 is the ventilation system that required the biggest amount of energy, both in winter and in summer period. The canteen was at the second place in terms of energy demand in winter, but not in summer. In general the monthly profile of distribution is similar for all the systems.

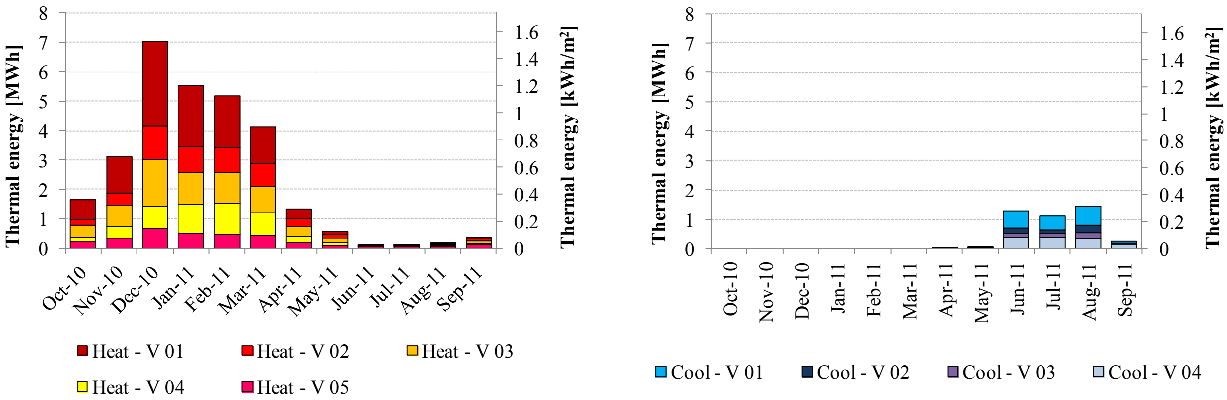


Figure 31 – Monthly energy consumption required by the different ventilation systems (heating and cooling).

The energy demand for domestic hot water was almost constant during the whole year: greater for the toilets and lower for the cafè.

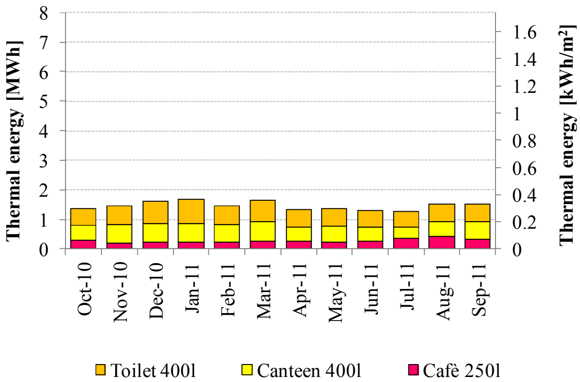


Figure 32 – Monthly energy consumption required for hot water production.

3.2.4 Level 4: Energy need – Room 2.2.00

Level 4 focuses on the energy demand required by the room 2.2.00, at the first floor. In this room, the heating in winter was given by convectors combined with the ventilation, while in summer the cooling was regulated through a TABS system embedded in the ceiling, and a ventilation system.

The yearly influence in energy consumptions of the room respect to the building, divided by different systems, is expressed in table 3. From the data emerge that the energy demand of the ventilation system is around 30% of the total energy demand of ventilation system 01. The heating required by the convectors represents 4.5% of all the energy demanded by the convectors, and the cooling energy of the tabs in the room represents 4% of the total energy of the cooling system.

Table 3 - Energy consumptions of the systems in room 2.2.00 in relation to the energy consumption of the same systems in all the building.

Total energy demand of the building [MWh]				
Heat - Convectors	Heat - Ventilation 01	Cool - Floor heating + TABS	Cool - Ventilation 01	Electricity
119.59	10.23	46.22	1.77	426.9

Detailed consumption in room 2.2.00 [MWh]				
Heat - Convectors	Heat - Ventilation	Cool - TABS	Cool - Ventilation	Electricity
5.37 (4.5%)	3.14 (30.7%)	1.83 (4.0%)	0.53 (29.8%)	10.8 (2.6%)

Analyzing the trend during the different months, as it is possible to see from figure 33, in winter the energy demanded by the ventilation system was just slightly smaller than the energy required from the convectors system. Convectors, with a small amount, continued to work also during the summer season. In September, contrarily to the rests of the building, the cooling system was also working with a small amount. In this room the energy demand from the TABS was negligible in September.

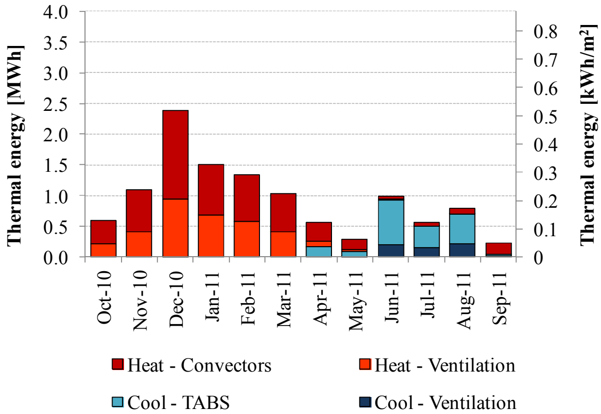


Figure 33 – Monthly energy consumption required for heating, cooling and ventilate the room 2.2.00.

4 Thermal activated building system performance in room 2.2.00

4.1 Description of the activity

At the aim to evaluate the performance of the cooling system (TABS), an experiment has been carried out in the room 2.2.00 from August 13 to August 16. This experiment consisted in the assessment of the system at the variation of the internal loads. Since the system was designed to cover 40 W/m^2 of heat loads, objective of the study was to evaluate how the system works when loads in the room are near to the design value.
The gains in the room were generated by heated dummies and heaters, positioned homogeneously in the room, instead of the employees at their workstations or together with them. Each dummy could produce 170-180 W, and represented a person plus a computer. 30 dummies were employed during the experiment. The heaters were 3, each one produced 1000W.

4.1.1 Characteristics of the room

The room was situated at the first floor. Characteristics of this room already explained in the paragraphs below are here summarized:

- Floor Surface: 268 m^2
- Expositions: East/South
- Heating/cooling systems: there is a mechanical ventilation system, there are convectors along the façade (for heating), and a TABS system on the ceiling (for cooling). On the floor is installed a raised floor with acoustic insulation and tabs below (for cooling the room below, at the ground floor). A floor heating/cooling is embedded in the slab of Plateau 4, that is situated on the second floor above room 2.2.00 (Figure 34).
- Lights: controlled by sensor of presence, and balanced with natural light.
- Curtains for the solar radiation control.
- Possibility of the employees to open/close the windows.

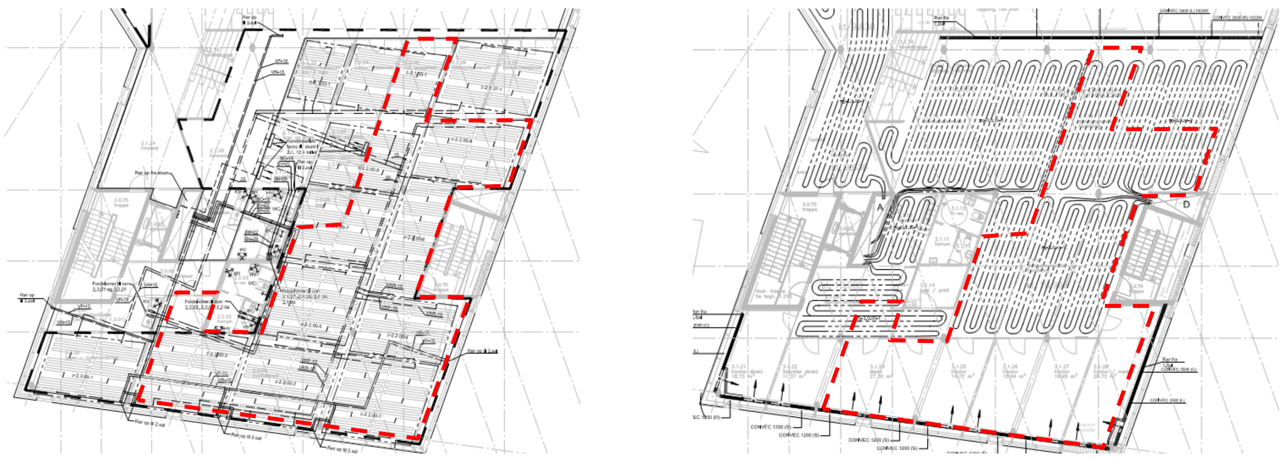


Figure 34 - Cooling systems with evidence of the room (red dotted line). First floor - tabs in the ceiling of the room, and Second Floor – floor cooling of Plateau 4.

4.1.2 Determination of the loads to insert in the room: dynamic simulations

At the aim to determine the level of internal loads to insert in the room, dynamics simulations were performed with the support of the energy simulation tool TRNSYS.

The simulations were performed considering:
- People + computer = 170 W/person (1 dummy)
- Artificial lights: regulated according with the solar radiation
- Ventilation system (total flow rate: 3.6 ach, estimated from design documentation, air supply temperature: 20 °C - average value estimated from the data collected in may)
- U value windows: 1.3 W/m^2
- U value walls: 0.2 W/m^2
- Trnsys weather file for the city of Copenhagen.

The simulation have been performed considering people in the room for 24 h a day and with the ventilation system always on.

Figure 35 shows the profiles of internal loads resulted by the simulations in a sunny day and in a cloudy day of August. From the results is possible to see that in a sunny day, with 30 dummies in the room, it was possible to reach 40 W/m^2 for about one hour. Wanting to analyze the systems for a longer time the increasing of loads was necessary. Increase the loads as if there were 20 more people meant insert also heaters in the room (with total power 3.4 kW). Totally different is the situation in case of cloudy/rainy day. For to reach 40 W/m^2, in that case, the loads need to be increased at least of 12 kW (like there were 70 more people).

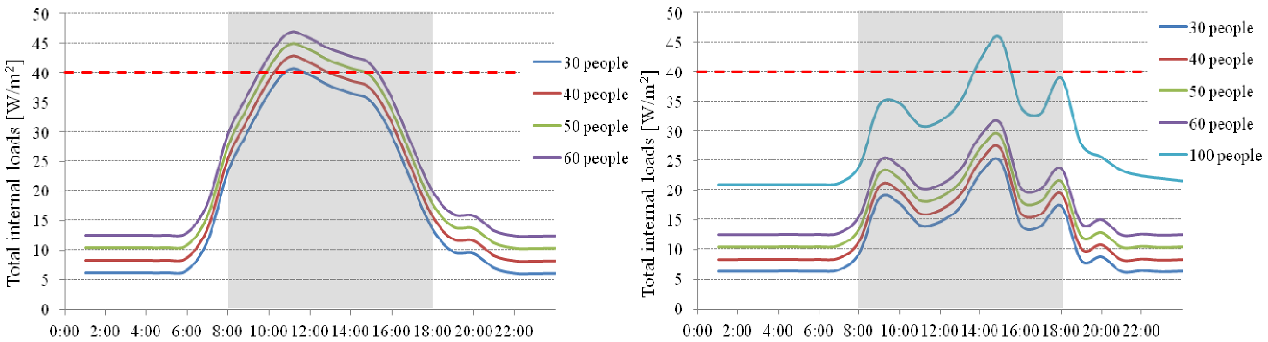


Figure 35- Results of the simulations: total internal loads evaluated in a sunny day and in a cloudy day.

4.1.3 Monitored parameters during the experiments

During the experiments the following parameters were monitored in the room:

- Operative temperature was measured in 4 different points of the room, at the high of 110 cm and with frequency 10 minutes.
- Air Temperature, Operative Temperature and Air Velocity were monitored by a stand positioned in the centre of the room, at different high:
    - Air Temperature: 10 cm, 60 cm, 110 cm, 170 cm and 250 cm. (1 min)
    - Operative Temperature: 10 cm, 60 cm, 110 cm and 170 cm. (1 min)

  - Air Velocity: 5 cm, 10 cm, 20 cm, 60 cm. (1 sec)
- Surface temperature was measured in different points of the room. Ceiling, floor, walls and windows. Measurement were performed manually with a thermocamera in different moment of the day.
- Air temperature and CO_2 were monitored each 10 min. by a sensor in the centre of the room.
- Temperature of supply and exhaust air of the ventilation system was measured in 4 points. Sensors were put in 1 diffuser and in 3 exhausts in different points of the room. The frequency of monitoring was 1 minute.
- Also the opening of the dumpers in the ventilation system was monitored, each 10 minutes, for determining the total flow rate.
- Temperature of the supply and return water in the pipes of the TABS system was measured each 10 minutes.
- Outside Temperature, Relative Humidity, Wind speed and direction and Solar radiation were monitored by a weather station each 10 minutes.

4.1.4 Different Scenarios of analysis

During the experiments different scenarios were performed. These scenarios were characterized by different levels of internal loads insert in the room, whose quantity has been determined through the dynamic simulations:

- First Scenario (S1) - 30 dummies and 3 heaters were positioned in the room
- Second Scenario (S2) - 30 dummies positioned in the room
- Third Scenario (S3) - in addition at the 30 dummies, in the room there were 11 people with 11 computers.

Distribution in the room of dummies, heaters and people in the three scenarios is shown in figure 36. In the same pictures also the position of the stand and the operative temperature sensors are shown. Note that S1 and S2 differs just by the presence of the heaters in the first case.

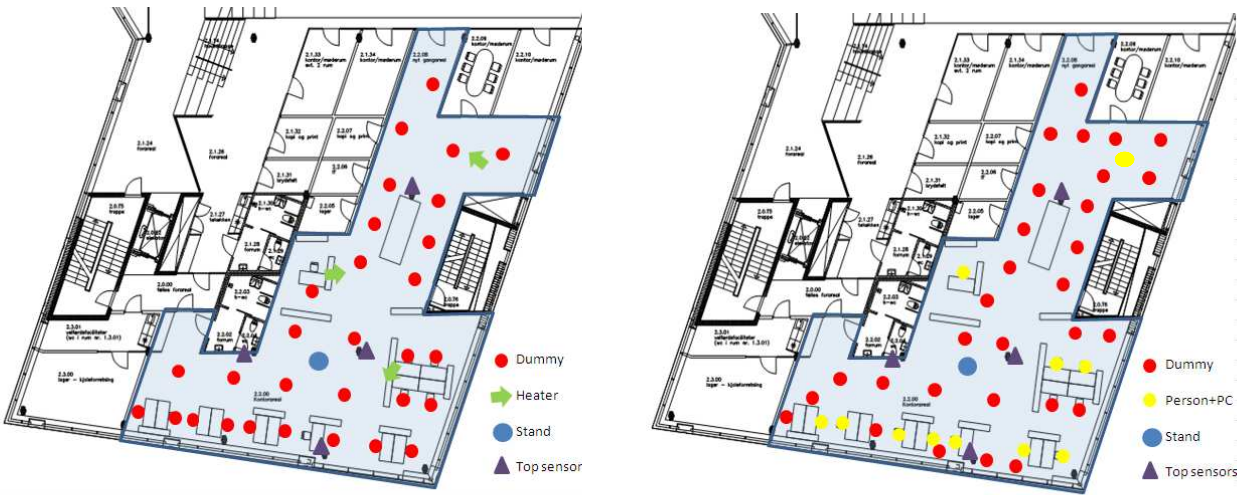


Figure 36 - Scenario 1-2 (without heaters) Scenario 3

The layout of the room during the experiments is illustrated by the pictures of figure 37.

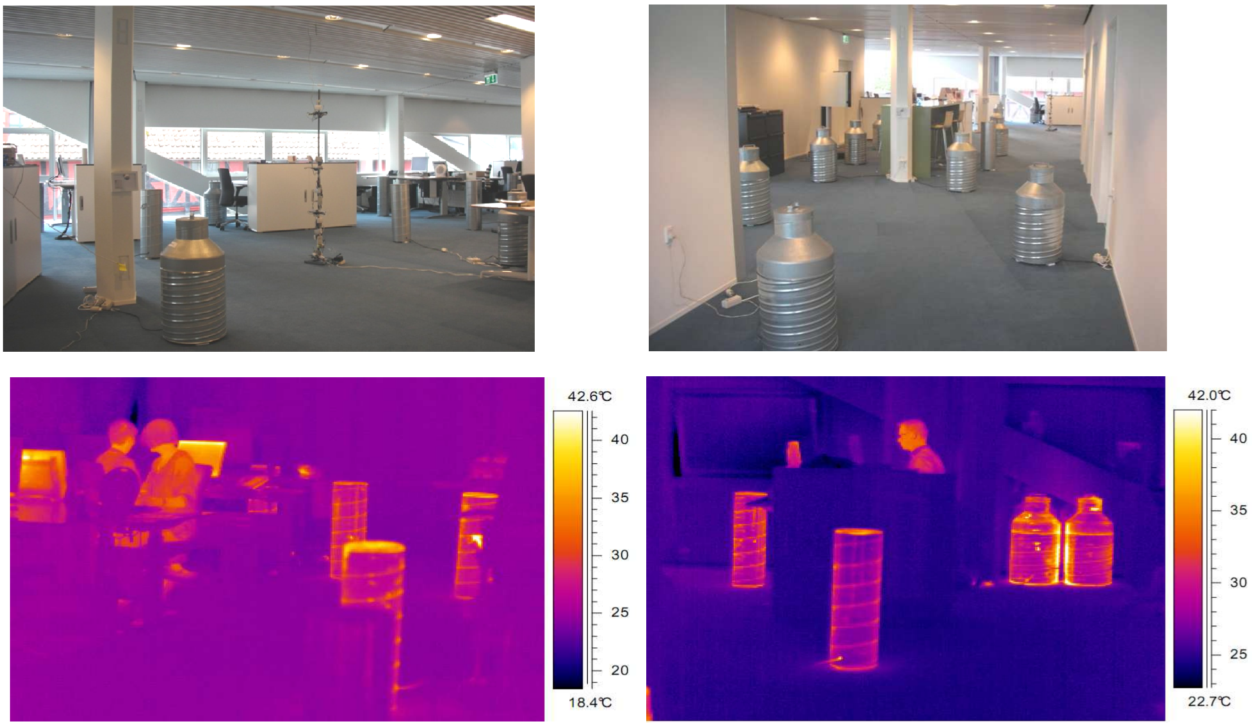


Figure 37 -Pictures and thermographies of the room during the experiments.

4.2 Results of the experiment

Outside weather conditions, inside temperature profiles and operating of the cooling and ventilation systems during the experiments are shown in this paragraph.

From the graph of figure 38 is visible that during the S1 and S2 the solar radiation was really low. In the third scenario the solar radiation was higher than the days before, but discontinuous. The average outside temperature during the day was increasing of about 2°C each day.

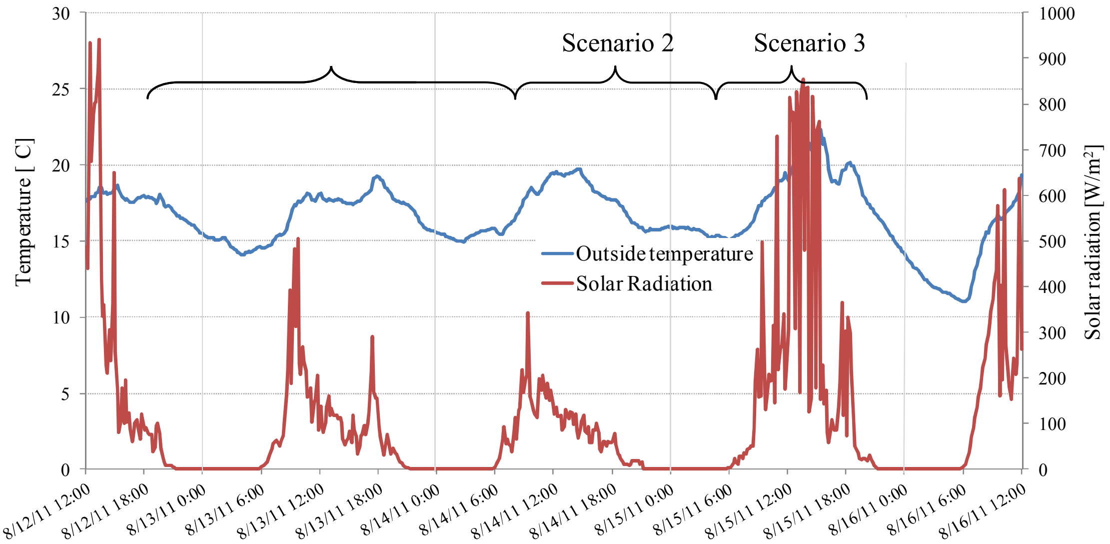


Figure 38 –Outside temperature and Solar radiation during the days of experiments.

Profiles of average operative temperature at 110 cm in the room, of supply and exhaust air temperature in the ventilation system and of supply and return water temperature in the pipes are shown in figure 39. In the graphs the three scenarios of loads are also represented. From the graph is possible to see that the tabs were not working until Saturday,13 at 18:00. Then the system started to work and the supply water temperature in the pipes fluctuated between 15 and 19 °C. The ventilation system was working on Saturday, 13 from 7:00 to 18:00, with little flow rate, and supply air temperature 23°C. It was switched off during Sunday, 14, and switched on again from 5:00 to 18:00 on Monday, 15. In the beginning of S1 both ventilation and tabs systems were not working. During the day just the ventilation system was cooling, and then in the night just the tabs system was operating. In S2 the cooling was guaranteed by tabs. In S3 both tabs and ventilation systems were working together.

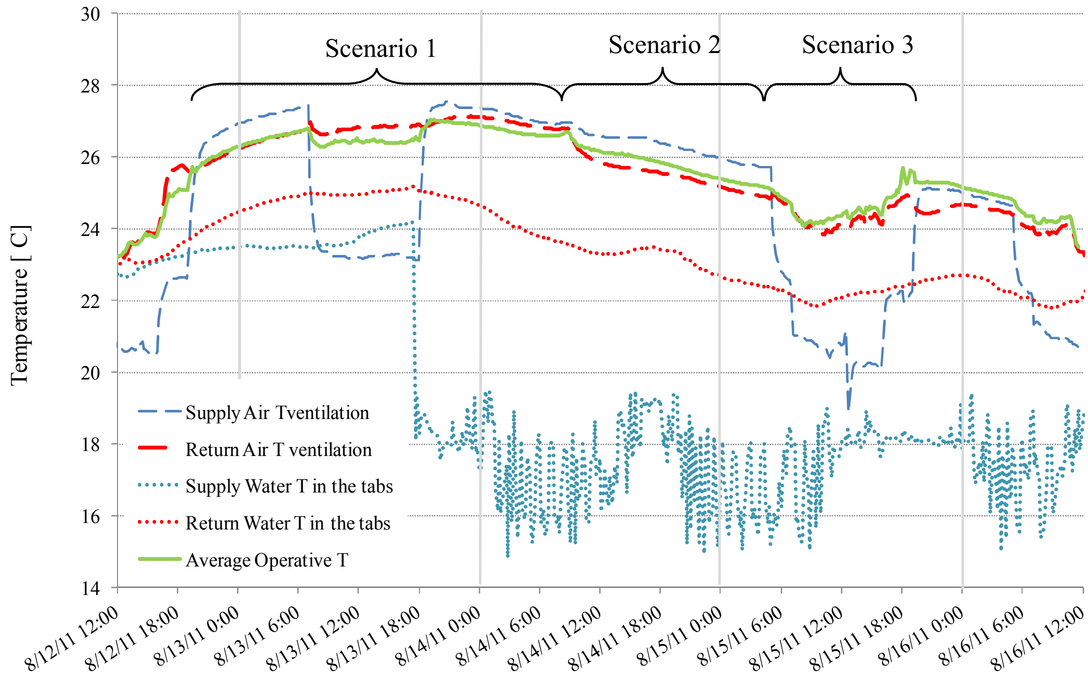


Figure 39- Temperature profiles of average operative temperature in the room, of supply and exhaust air temperature in the ventilation system and of supply and return water temperature in the pipes.

The air temperatures measured by the stand, whose profiles are shown in figure 39, changed their stratification in the last part of S1, when the tabs started operating. From that moment the sensor positioned at 270 cm, the one closest to the ceiling, measured temperatures lower than the ones measured by the sensor at 170 cm. In the beginning of S2 and in the end of S3 the temperatures at 250 cm were lower than all the other temperatures. ΔT between the five different heights, a part when systems were not working, was always lower than 1°C.

Figure 41 shows, in relation to the average air and operative temperature, the average surfaces temperature measured with the thermocamera. As is possible to see there are 3 surfaces: floor, ceiling at 270 cm and ceiling at 330 cm. There is in fact a false ceiling in steel bars 60 cm under the slab. In this false ceiling the lighting system is integrated, and in the empty space between this structure and the slab ducts of the ventilation system are located. Figure 41 shows that floor and false ceiling temperatures were in general really close to the air temperature in the room, while the ceiling temperature differed at least 2°C from the air temperature, when the tabs system was operating. The surface temperatures of the floor denote that the tabs integrated on the ceiling of the room below (ground floor) were not removing heat loads from room 2.2.00.

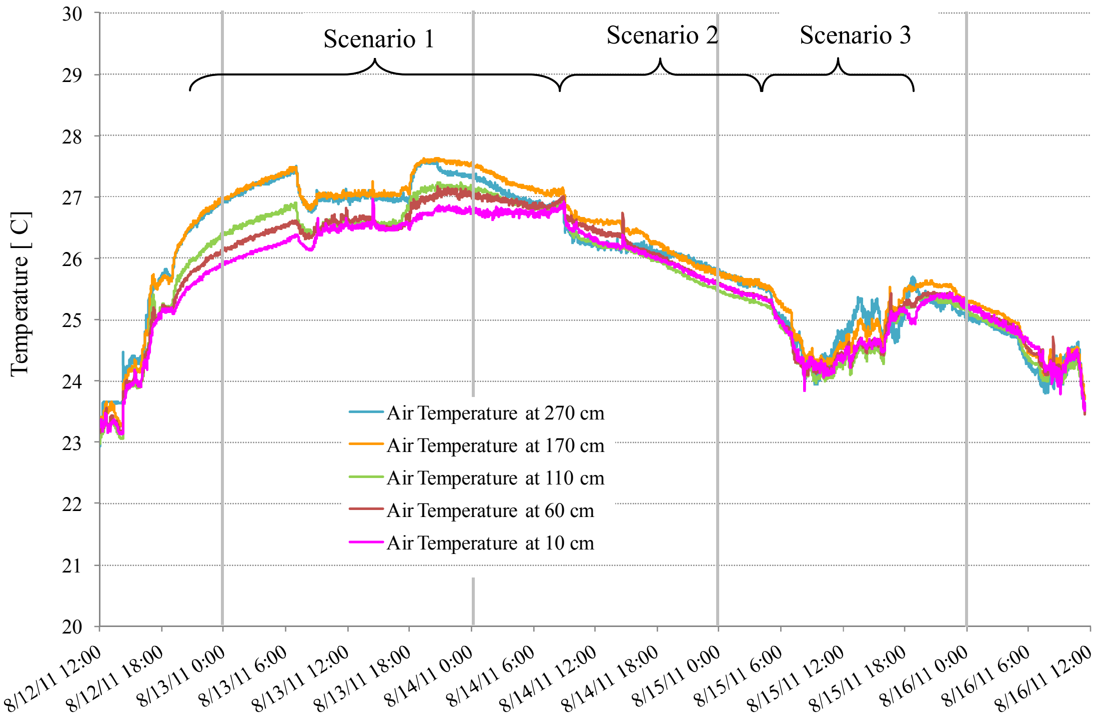


Figure 40 - Temperature profiles of air temperature in the room at different heights.

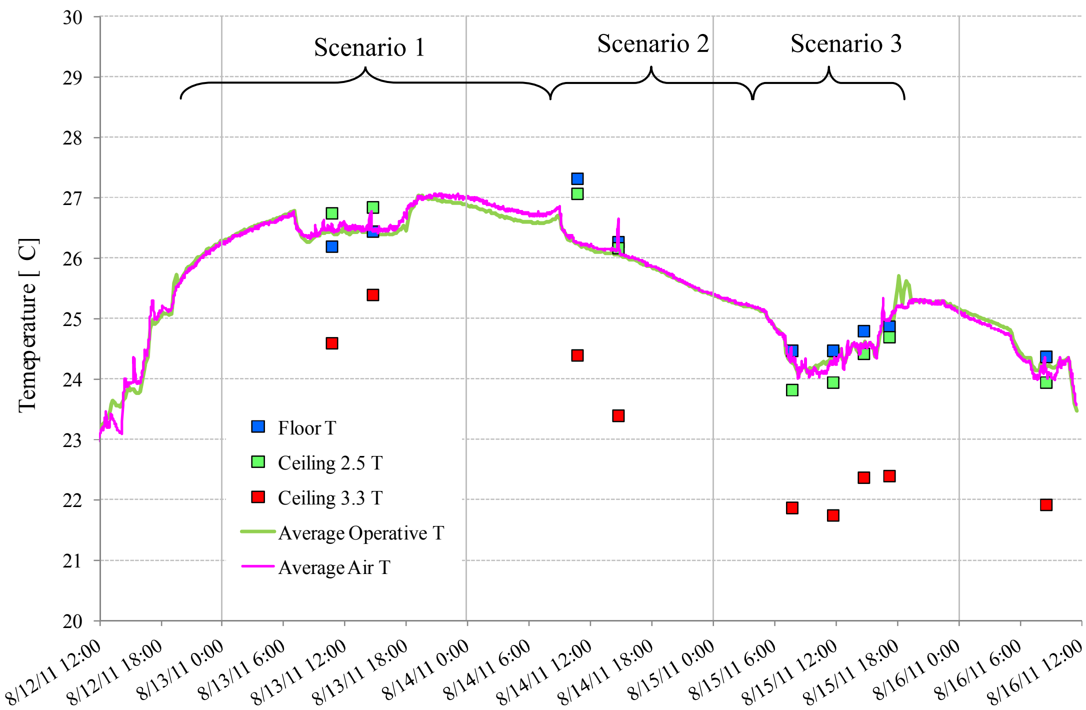


Figure 41- Average surfaces temperature in the room measured with the thermocamera.

Knowing supply and return water temperature in the tabs system, and flow rate in the pipes, loads removed by the tabs were calculate by using the following equation:

Q/A= m*cp*DT

Where:

m = flow rate in the pipes
Cp = specific heat of the water
DT = difference of temperature between supply and return temperature in the pipes

Note: the flow rate in the pipes used in the calculations was not measured. The value (0.42 l/s) is the design value of the circuit in that room.

Through dynamic simulations, performed this time with the support of Energy plus, also internal gains were calculated for the duration of all the experiment. In the simulations real monitored data where insert as input, like outside air temperature and relative humidity, and solar radiation. The model, simplified as shown in figure 42, has been useful in particular for the calculation of the internal gains. Since results of simulations, in terms of internal temperature, differed a little from the real monitored data, heat losses through envelope, infiltrations, and heat loads removed by the systems were calculated later using as reference the real temperatures.

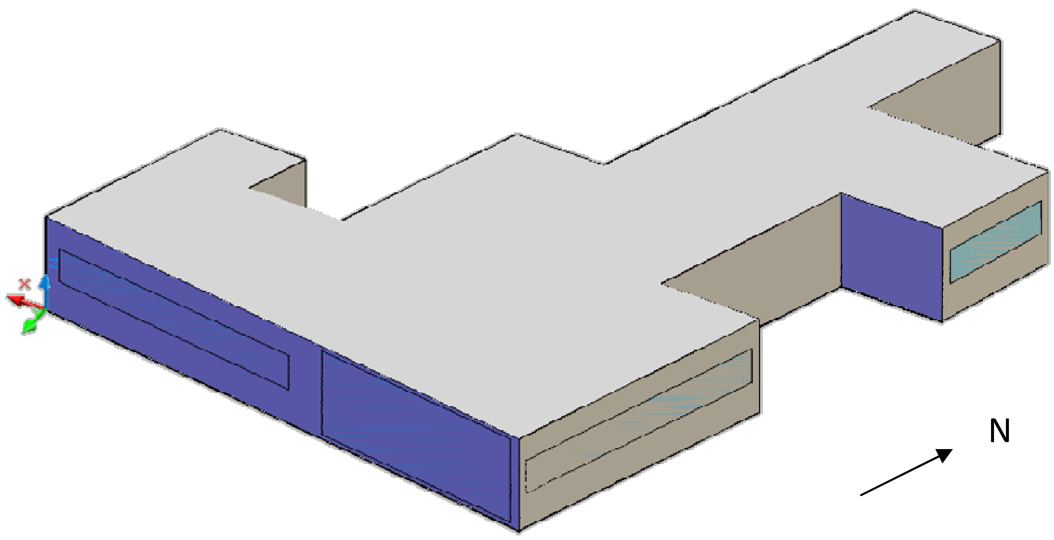


Figure 42- Model of the room simulated with Energy plus for the internal loads calculations.

Results of calculations are represented in figure 43.

During the first part of S1 the tabs were not working. The heat gains in the room exceeded 40 W/m^2 and the temperatures in the room increased (except when the ventilation system was operating). During this time the slab accumulated a lot of heat that began to be removed by the tabs when they started to work. The supply temperature in the tabs in the beginning was about 18°C, and then started to fluctuate between 16 and 18°C. As it is possible to see from figure 44, in the days next to experiments, usually the supply temperature in the tabs was around 20°C or fluctuated between 18 and 20°C. In the end of S1 the difference of water temperature between supply and return reached 8°C, and the loads removed by the system reached 60 W/m^2.

During S2 the heat loads in the room were reduced, and also the loads removed by tabs were reduced, in particular in the last part of the scenario. In that time the supply water temperature in the pipes was almost the same like in S1, but the return temperature was about 2°C lower. Figure 43 shows that in normal condition return water temperature was almost equal to operative temperature, while during the experiments the ΔT was about 2°C.

During S3 also people were in the room together with the dummies. Both tabs and ventilation system were working together: ventilation system contributed to remove heat gains from the room. The "loads in the room" represented in the graph are at the net of the loads removed by ventilation. The temperature in the room decreased at 24 °C and the supply water temperature in the pipes was almost constant around 18°C. Considering that the air temperature set point was 23°C, for to reach lower temperatures in the room, in case of high heat loads in the room, the supply water temperature in the tabs needs to be reduced.

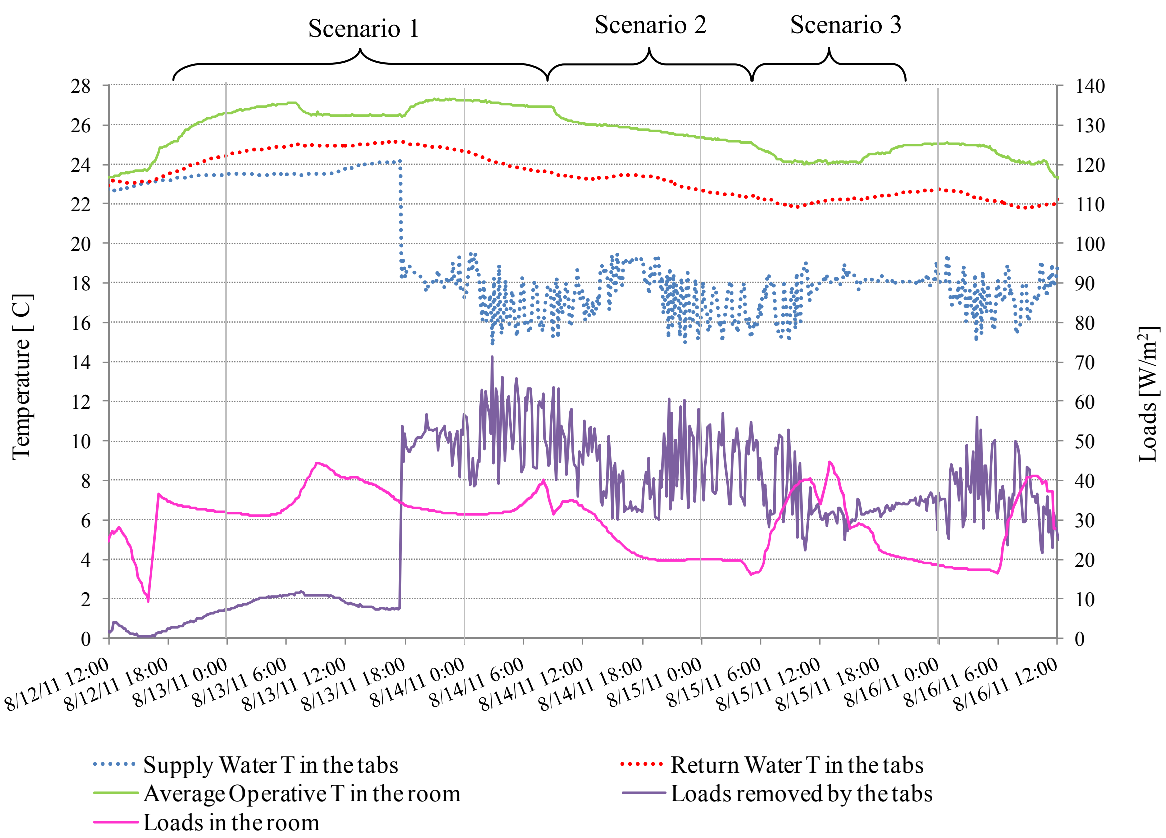


Figure 43- Profiles of Operative temperature, supply and return water temperature, loads removed by the tabs and loads in the room

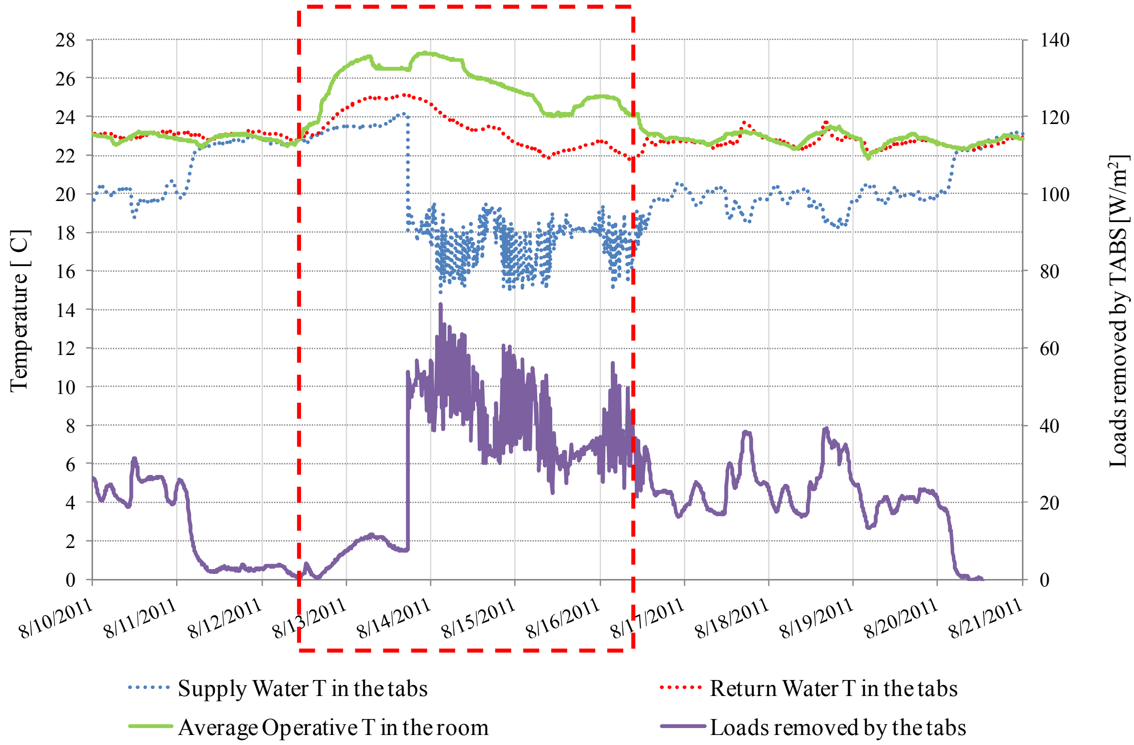


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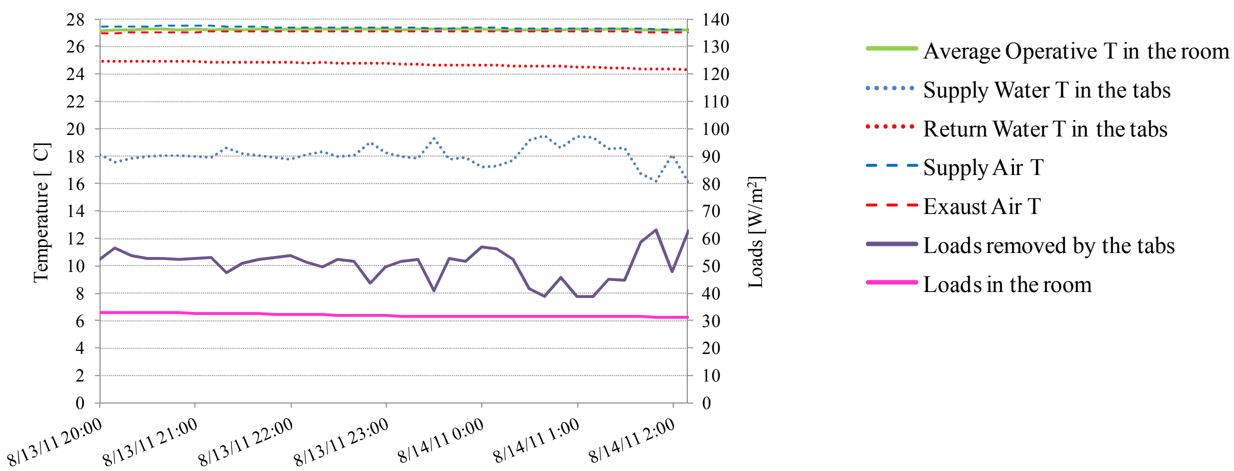
Figure 44- Profiles of Operative temperature, supply and return water temperature, loads removed by the tabs in the room in a longer period .

At the aim to evaluate the performance of the cooling system, three different intervals of time, one for each scenario, were analyzed during the system operating time:

Interval of Scenario 1:	From 13/08/2011, 20:00	to 14/08/2011, 2:00
Interval of Scenario 2:	From 14/08/2011, 12:00	to 14/08/2011, 18:00
Interval of Scenario 3:	From 15/08/2011, 9:00	to 15/08/2011, 15:00



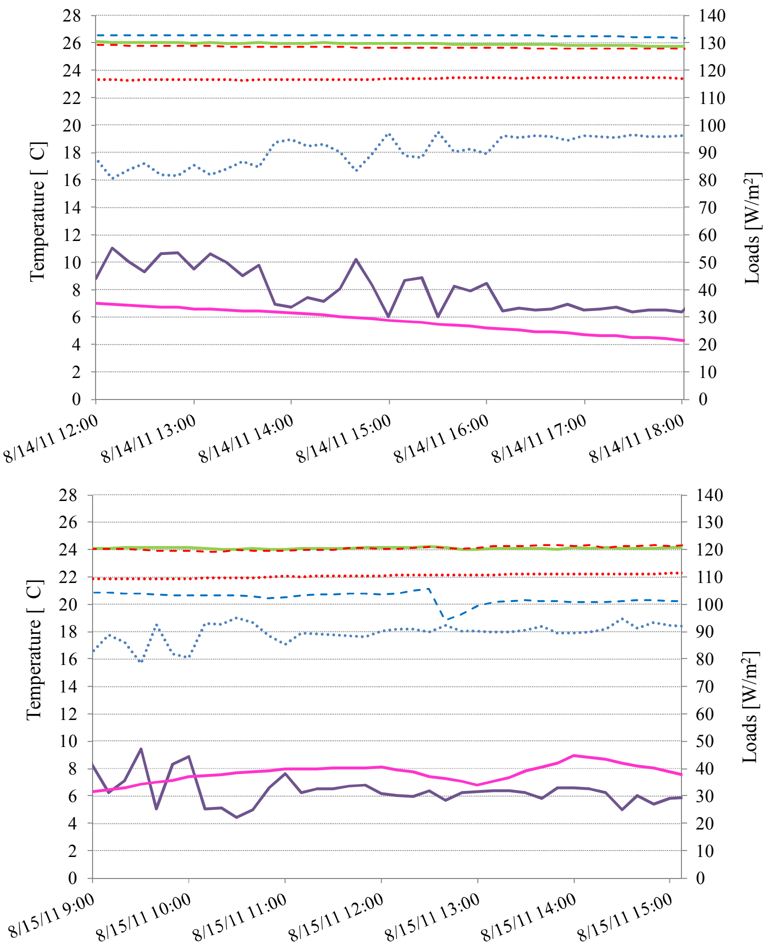


Figure 45- Temperatures and loads profiles in the different intervals scenarios.

During these intervals of time air temperature in the room and water temperature in the system were almost constant. For these intervals an heat balance, in stationary way, was made in the room and it is shown in table 5.

Table 5- Heat balance of the room in the different scenarios.

		Loads [W/m^2]		
		Int. Scenario 1	Int. Scenario 2	Int. Scenario 3
Heat gain	Dummies	22.2	22.2	22.2
	People	-	-	4.8
	Heaters	13.0	-	-
	Equipements	-	-	3.4
	Lights	3.9	3.9	3.9
	Solar gains	-	8.2	13.5
Heat loss	Infiltrations	-1.3	-0.8	-0.6
	Ventilation	-	-	-6.6
	Walls	-2.5	-1.6	-1.1
	Windows	-3.4	-2.2	-1.5
	Total	31.8	29.6	37.9

The maximum load was reached in the interval of scenario 3, when dummies and employees were present in the room and when the solar radiation contributed heating the environment. From figure 40 is possible to see that in some point loads were higher than 40 W/m^2.

As shown from figure 40 and from table 6, the outside temperature from scenario 1 to 3 increased, while the indoor air temperature decreased. This explain the higher losses for transmissions and infiltrations of table 5 in S1 than in S2 and S3.

Table 6- Measured temperature in the tabs system, in the ventilation system, in the room and outside.

scenario	TABS				Ventilation				Average temperatures		
	Supply [°C]	Return [°C]	DT	Flow rate (kg/s)	Supply [°C]	Return [°C]	DT	Flow rate (kg/s)	To [°C]	Ta [°C]	Tout [°C]
1	18.1	24.7	6.6	0.42	27.4	27.1	-0.3	no	27.0	27.1	16.1
2	18.1	23.4	5.3	0.42	26.5	25.7	-0.8	no	26.1	26.1	18.8
3	17.9	22.1	4.2	0.42	20.5	24.1	3.6	1.40	24.3	24.2	19.6

The loads removed from the room were calculated with the equation:

Q/A= (hc+hr)*DT

Where:

$(hc+hr)_{floor}$ = 6 W/m^2K
$(hc+hr)_{ceiling}$ = 11 W/m^2K
DT= difference of temperature between the average air temperature in the room and the surface temperature.

Table 7- Heat balance, Loads removed from the room and heat gains removed by the tabs for S1,S, S3.

Interval of Scenario	Internal gains from calculation W/m^2	Loads removed from the room W/m^2	Loads removed by TABS W/m^2
1	31.8	-	50.3
2	29.6	29.7	40.1
3	37.9	27.0	31.9

Total heat balance of the room for the three intervals of scenarios are graphically shown in figure 46.

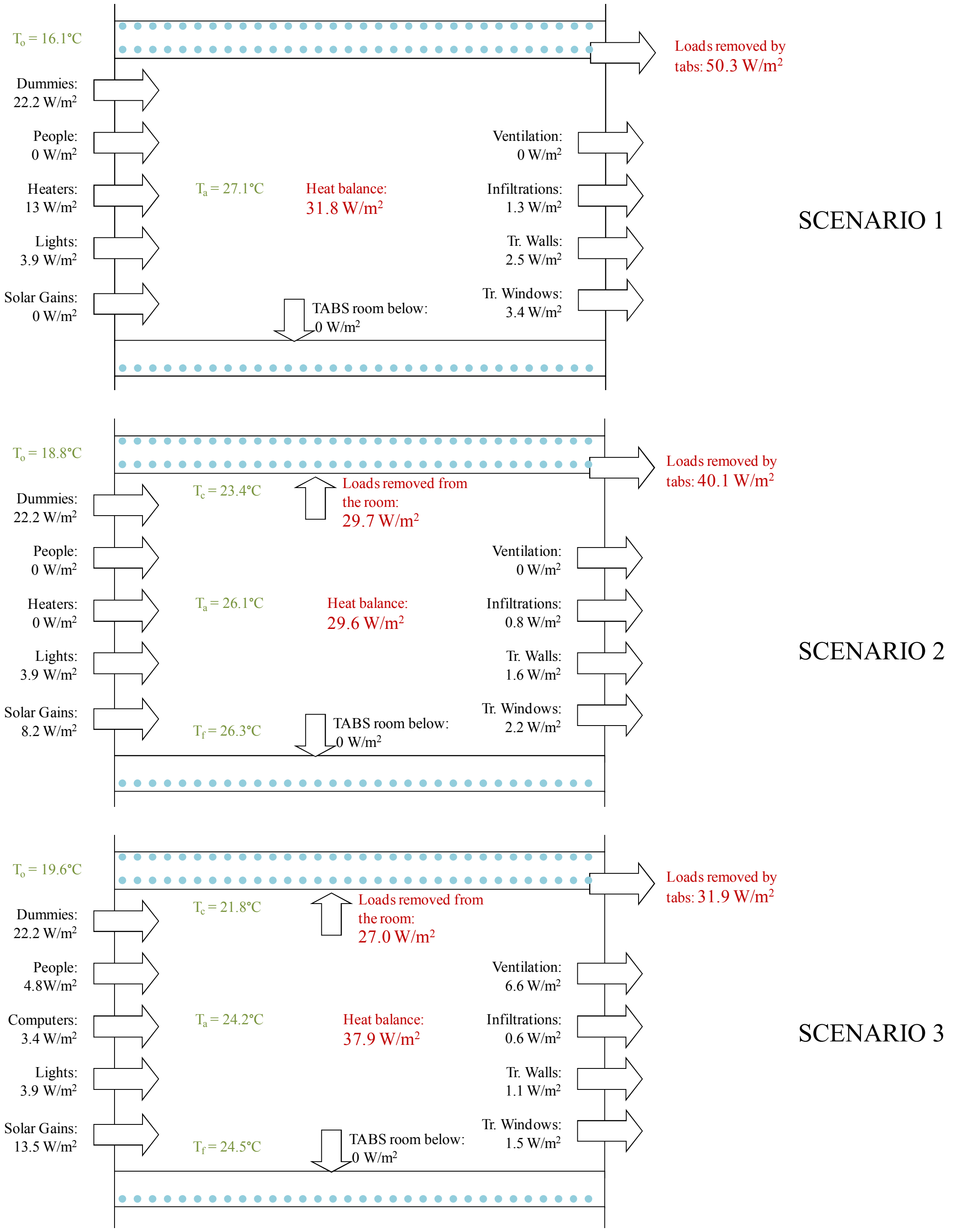


Figure 46 - Energy balance - intervals of scenario1, 2 and 3.

During the interval of S1 surfaces temperatures were not collected. In this case just an energy balance of the environment and the loads removed by the Tabs were calculated. As already said before, in the 2 days before the system was not running. The slab accumulated a lot of radiant heat that was removed in the following days. The temperature in the room was high, but this is explained by the fact that no system was working until some hours before. From this interval of time the temperature started to decrease.

During the interval of S2 the tabs continued to remove the loads accumulated in the previous day. Loads removed by the room are almost the same than the load calculated with the heat balance. This means that in that interval of time the tabs were balancing the cooling needs of the room.

During the interval of S3 the ventilation was contributing to remove loads from the room. The calculations denote that the system was not removing enough heat as required by the energy balance. However is important to specify that people in the office were moving and opening windows and doors. This means than the heat balance determined with dynamic simulations can be a little overestimate, or not be constant during all the 6 hours of analyzed interval.

From the experiments emerge that the system could remove from the room 30 W/m^2 using an average supply water temperature in the pipes of 18 °C. More loads could be removed with lower temperature. Figure 47 helps to explain this concept.

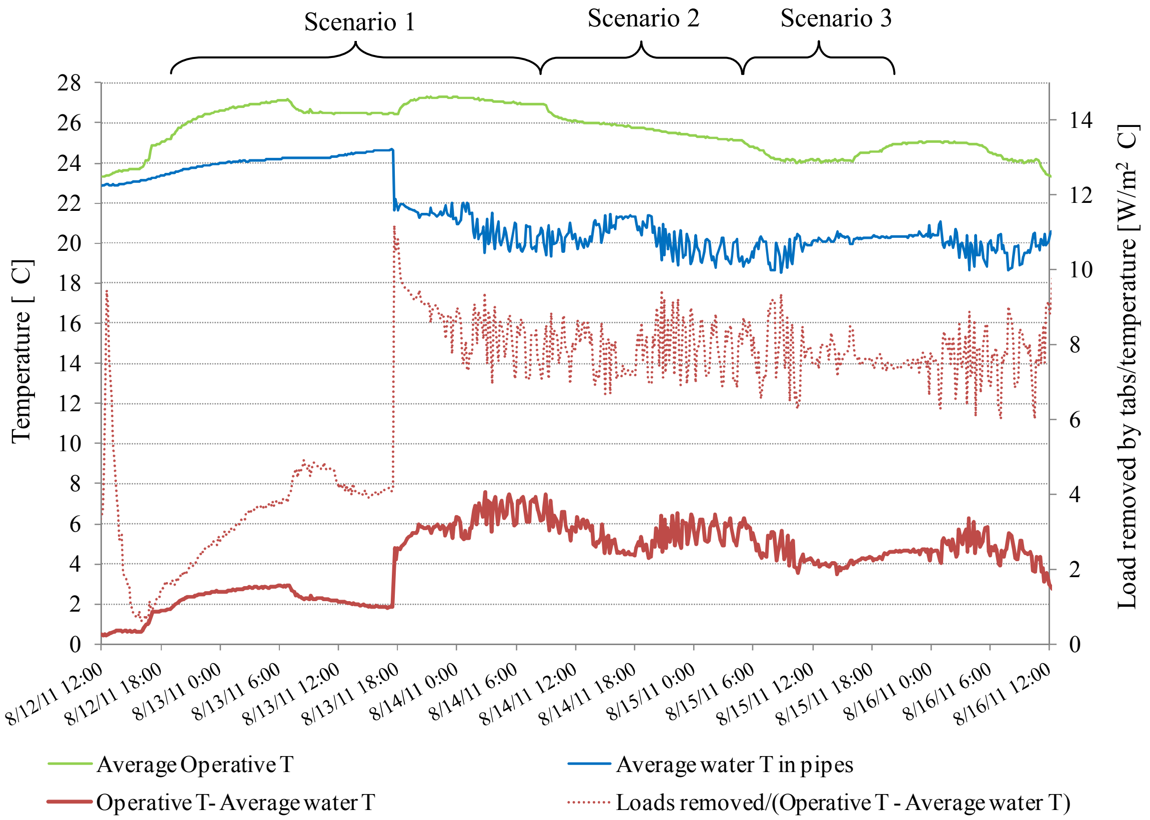


Figure 47 - Loads removed by the system per degree temperature difference between average water temperature in the pipes.

In the figure the heat removed by TABS divided by the difference between the average water temperature in the pipes (supply+return/2) and operative temperature in the room is shown by the red dotted line. From the calculations can be seen that averagely it was possible to remove about 8 W/m^2 per degree temperature difference between average water temperature. From the measurements the average water temperature in the pipes was around 20°C. If we consider to have an indoor operative temperature of 26°C, the system could remove 6*8 = 48 W/m^2. If the average water temperature in the pipes in that case was 22°C we could then remove 4*8 = 32 W/m^2.

This last analysis allowed to evaluate how much loads could be removed by the system at lower water temperature.

International Center for Indoor Environment and Energy

Technical University of Denmark

ANNEX A

Summer Thermal comfort assessment in Middelfart Sparekasse.

August 10-11, 2011

Physical measurements of the thermal environment and Subjective response of the occupants

DTU, 15/09/2011

Professor B.W. Olesen

PhD student D. Raimondo

Summary

1- INTRODUCTION

The work presented in this report shows the thermal comfort and air quality assessment conducted in August 2011 in terms of both physical analysis and subjective answers of the occupant in the Middelfart Sparekasse building.

Similar analysis were conducted in March 2011, for the environment evaluation in winter period, and in 2007 in the old headquarters of Middelfart Savings Bank. Future step of this work will be the comparison between the results obtained during the monitoring campaign in the old building and the results deriving from the analysis in the new offices.

The monitoring data elaborated and here presented come from three different survey methods:
- Long term monitoring
- Spot measurements
- Questionnaires

Long term monitoring
The Long term monitoring is conducted in the building continuously during the whole year. Air temperature and CO_2 sensors are installed in the building in strategically positions, and connected with an external weather station, they have an essential role in the thermal and air quality systems controls. Heating, cooling and ventilation systems are in fact controlled by the environmental parameters in the rooms and even on the basis of the weather conditions. Operative temperature sensors have been installed in the most representative rooms of the building from January, 2011. All the instruments collect data every 10 minutes.
In this study only data from July 25 to August 14 are shown.

Spot measurements
The short measurement took place August 2011, Wednesday 10 and Thursday 11, during the working hours. The monitored parameters are air temperature, operative temperature, air velocity, relative humidity and luminance. The luminance, were measured only with one sensor at the height of 0.6 m (work plane position), while all the other parameters were monitored at four different heights: 0.10 m (height of the ankles), 0.60 m (height of the body for a seated person), 1.10 m (height of the body of a stand person) and 1.70 (height of the head of a stand person).

Questionnaires
During the spot measurements people were asked to fill subjective questionnaire about the comfort sensation, in terms of thermal quality, air quality, light, noise and about the symptoms perceived in the room. More detailed information are described in the following paragraphs.

2- PHYSICAL MEASUREMENTS CONDUCTED FROM JULY 25 TO AUGUST 14, 2011.

As introduced in paragraph 1, long term monitoring are conducted continuously in most of the rooms of the building. This study shows just data collected from a short period. In particular, from figure 1 to 5, three weeks of monitoring are shown. In all the figures, the dashed square highlights the days when also the spot measurement took place.

Figure 1 and 2 show outside air temperature, relative humidity and solar radiation. A weather station positioned outside the bank monitors in continuous the weather parameters. The natural ventilation, heating and cooling systems control take into account the outside environment conditions. A vents system opens and closes comparing indoor and outdoor temperature and when CO_2 concentration inside the room exceeds a certain level.

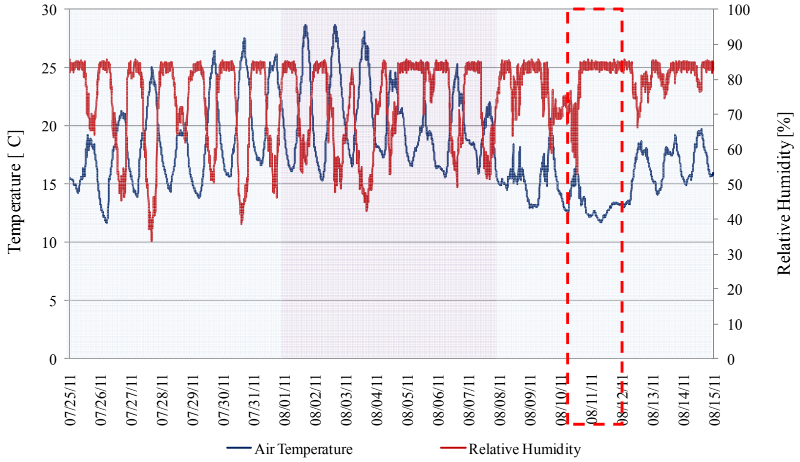


Figure 1 - Outside Air Temperature [°C] and Relative Humidity [%] monitored from Monday 07/25/2011 to Sunday 08/14/2011.

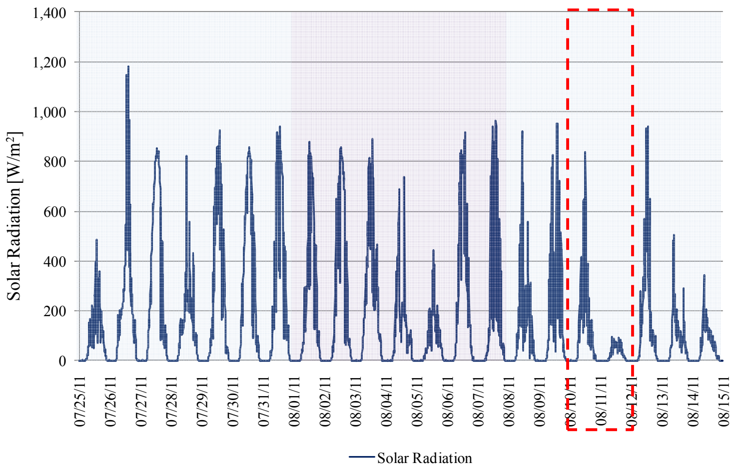


Figure 2 - Solar Radiation [W/m²] monitored from Monday 07/25/2011 to Sunday 08/14/2011.

From figure 1 it is possible to see that the outside air temperature during the last week was quite low comparing it with the weeks before. In particular, during the two days when also spot measurements were performed, Wednesday 10 and Thursday 11, the average temperature was lower than 15 °C, and so not considerable representative for the summer season. Looking at the week before, in fact, the outside air temperature usually reached 25°C during the working hours. Figure 2 shows that also the solar radiation, during the second day of monitoring, presented the lowest value of the analyzed period.

Inside the building the air temperature profiles highlight that cooling systems kept the temperature almost constant during the three weeks just on the ground floor. The analysis does not reveal the influence of outside temperature on the ground floor temperature (Fig. 3), while a difference in air and operative temperature is visible in the first and second floor (Fig. 4-5), where the daily peaks of temperature differ of about 3 °C between the second and the third analyzed week.

CO_2 concentration profiles show low values of concentration during all the three monitoring weeks. The values were slightly low during the first two weeks respect to the third, and this is probably due by the fact that many people was on holiday during the first period. The air quality, for both the three represented room, was guaranteed by natural ventilation, controlled by an automatic system of opening/closing of vents, situated along the external walls. The vents were usually open during the night, improving not just the air quality but also the air temperature in the offices through the night ventilation.

The average value of CO_2 during the working hours can be considered always acceptable because, a part some peaks, it was always lower than 700 ppm.

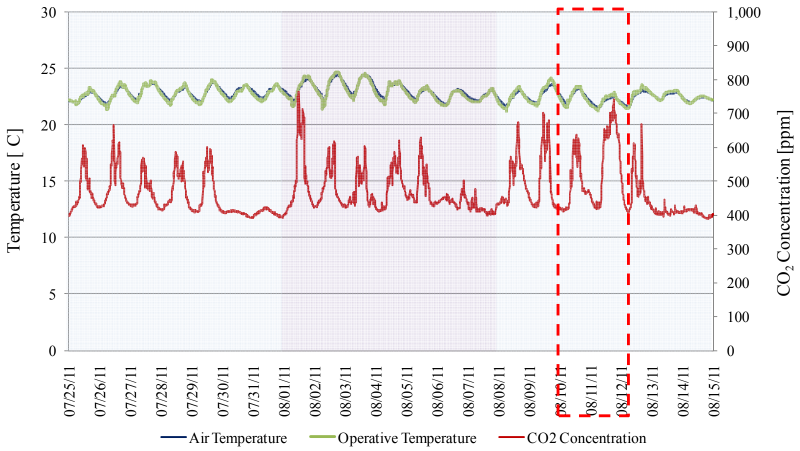


Figure 3 - Air Temperature [°C], Operative Temperature and CO_2 Concentration [ppm] monitored from Monday 07/25/2011 to Sunday 08/14/2011 on the Ground Floor (Open space, room 1.1.00).

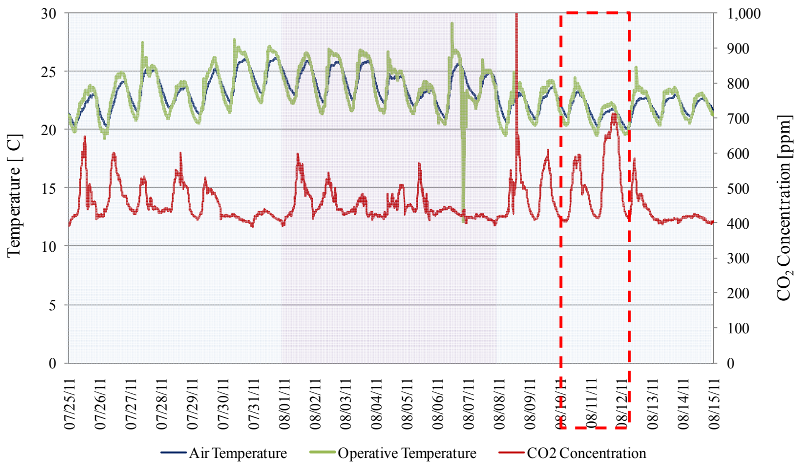


Figure 4 - Air Temperature [°C], Operative Temperature and CO_2 Concentration [ppm] monitored from Monday 073/25/2011 to Sunday 08/14/2011 on the First Floor (Plateau 1, room 2.1.23).

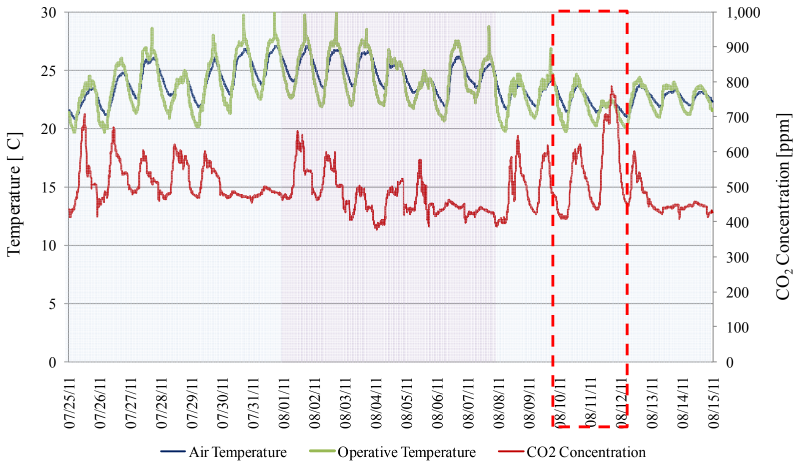


Figure 5 - Air Temperature [°C], Operative Temperature and CO_2 Concentration [ppm] monitored from Monday 07/25/2011 to Sunday 08/14/2011 on the Second Floor (Plateau 4, room 3.1.16).

3- Spot measurements. August 10-11, 2011

The Spot measurements consist in the data collection of different parameters for a short period (about 15 minutes) in representative points of the analyzed rooms. These parameters, as already explained in the first paragraph and then showed from figure 6 to 10, are: air temperature, operative temperature, air velocity, relative humidity and lighting. All these parameters, but lighting, were monitored at four different heights. The values represented in the figures are average values for each room. The monitored representative rooms are:

- Room 1.1.00 – Ground Floor
- Room 1.4.00 – Ground Floor
- Room 2.1.23 – First Floor, Plateau 1
- Room 2.1.25 – Firs Floor, Plateau 2
- Room 2.2.00 – Firs Floor
- Room 3.1.16 – Second Floor, Plateau 4

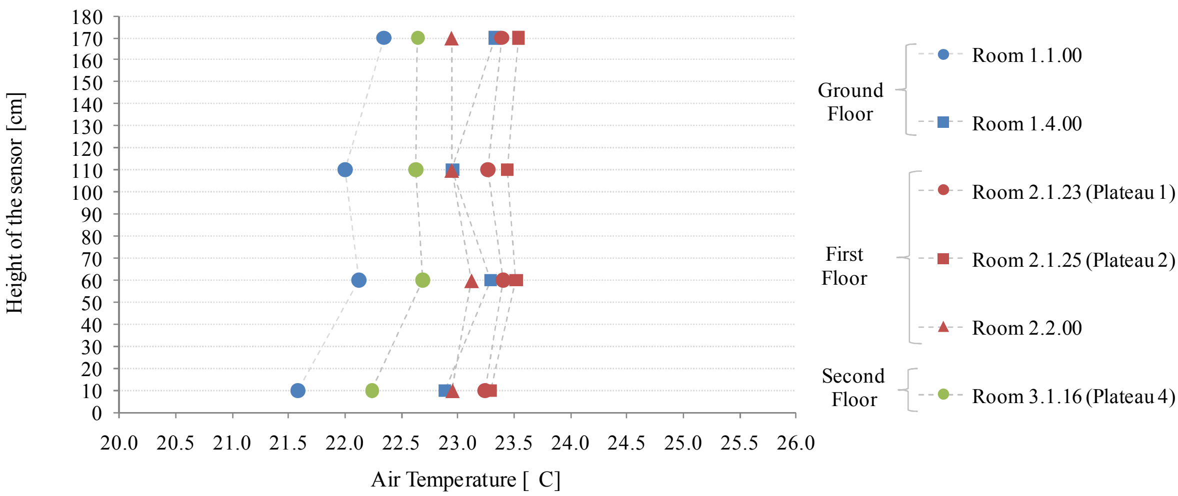


Figure 6 - Average value of Air Temperature [°C] at different heights in the analyzed rooms.

Figures 6 and 7 shows average values of, respectively, air and operative temperature. The results show that both, air and operative temperature, in all cases increased from 0.1 m to 0.6 m, while kept constant , or with very little difference (less than 0.15°C), from 0.6 m to 1.70 m. The Operative temperature profiles of Figure 7 show that in all the analyzed room the values are below 23.8 °C. Considering the limit for category I described by the standard EN 15251 (23.5°C < To<25.5°C), it is possible to denote that the average operative temperature in most of the rooms was lower than the one prescribed by the standard. In room 1.1.00 the value at 0.10 m was even lower than 22°C (limit described by the Standard for category IV).

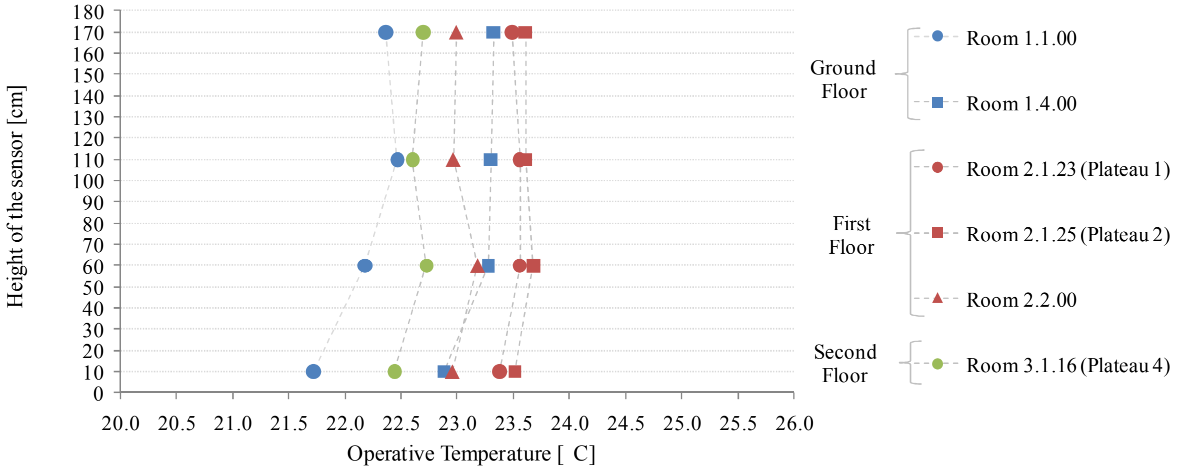


Figure 7 - Average value of Operative Temperature [°C] at different heights in the analyzed rooms.

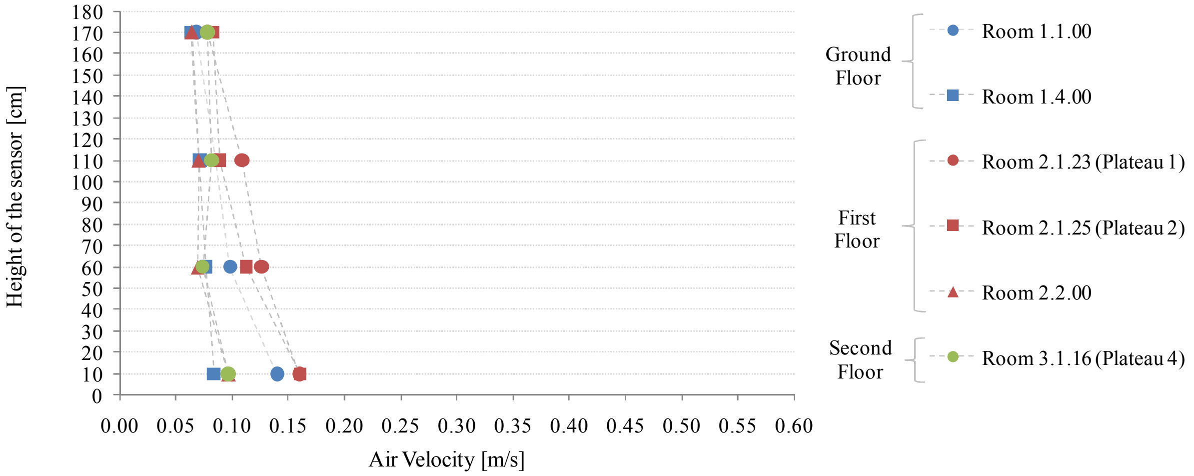


Figure 8 - Average value of Air Velocity [m/s] at different heights in the analyzed rooms.

The air velocity was higher at the height of 0.1 m and 0.6 m, were usually the value exceeded 0.10 m/s, and decreased with increased height of the sensors. With the exception of Plateau 4, the average air velocity was lower in the littlest offices respect to the open spaces. On Plateau 1 and Plateau 2 the average air velocity was higher than in all the other cases. In these two rooms, as described in chapter 5, are signalized the areas with maximum percentage of dissatisfied for draught.

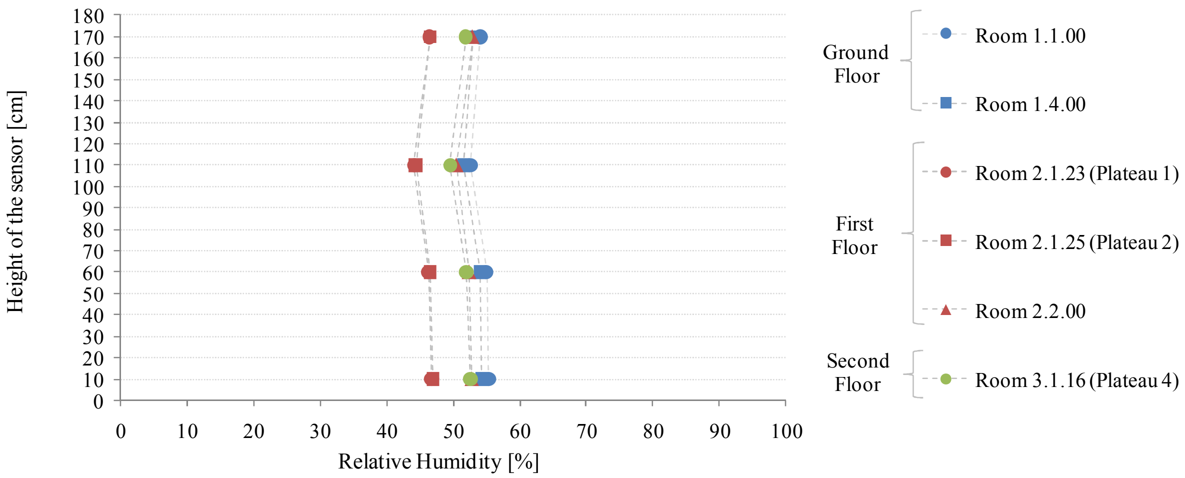


Figure 9 - Average value of Relative Humidity [%] at different heights in the analyzed rooms.

The relative humidity (Fig.9) presented almost the same values in all the rooms and at the different heights. The values on Plateau 1 and Plateau 2 were lower if compare with the other rooms. In general, the average values fall in a range between 45% and 55%.

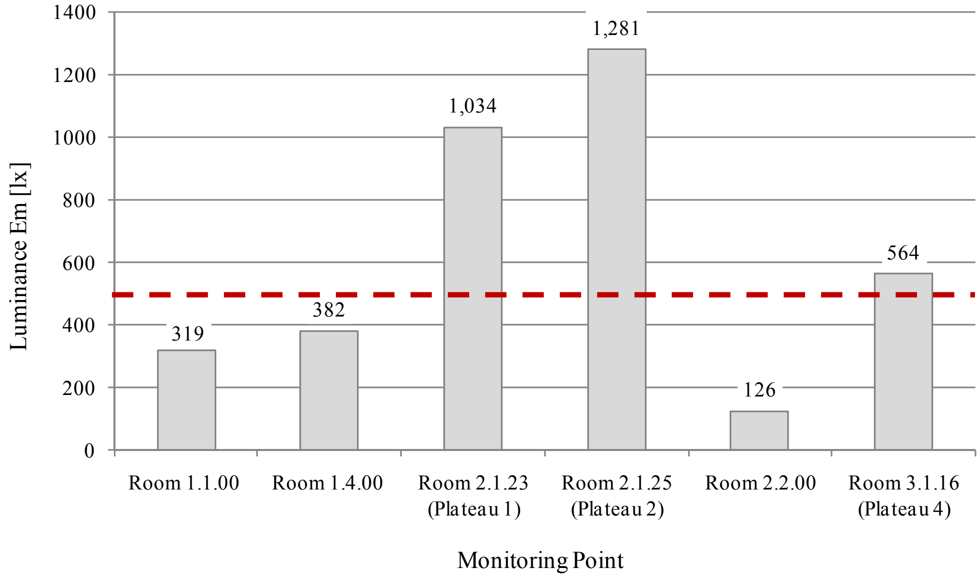


Figure 10 - Average value of Luminance [lx] in the analyzed rooms.

Figure 10 shows the different average levels of luminance in the rooms measured at the high of 0.6m. The minimum value of luminance required from standard EN15251, for office buildings, is 500 [lx]. For both the two analyzed room on the ground floor the value of luminance was lower respect to the standard prescriptions, while the two Plateaus at the first floor presented a good average level of luminance. Also on Plateau 4 the minimum required lighting level was satisfied. Results of monitoring in room 2.2.00 highlight a really low average value of luminance in the room.

4- SUBJECTIVE EVALUATION (QUESTIONNAIRES) AUGUST 10-11, 2011

Occupants in the rooms were asked to fill some questionnaire about the subjective evaluation of the environment at the same time when the spot measurements were performed. Results about this analysis are shown in this paragraph.

People were furthermore asked to give information about the clothes that they were wearing and about the position of their desk in the room. With the collected data and with the physical measurements, it has been possible to calculate the Predicted mean vote (PMV) and the Percentage of dissatisfied (PPD) in the rooms. The PMV index predicts the mean response of a large group of people according to ASHRAE thermal sensation scale, where:

- +3 hot
- +2 warm
- +1 slightly warm
- 0 neutral
- -1 slightly cool
- -2 cool
- -3 cold

The PPD index, on the other hand, predicts the percentage of large group of people likely to feel "too warm" or "too cool".

From the questionnaires, then, subjective evaluation about the thermal comfort was performed. The comparison between result from questionnaires and from indexes calculation is shown in Table 1.

Table 1 - Subjective evaluation, Predicted Mean Vote and Predicted Percentage of Dissatisfied for the analyzed rooms.

Floor	Room	Number of People	Icl [clo]	Average Subjective response	Calculated PMV (0.6 m)	Calculated PPD (0.6 m)
Ground Floor	1.1.00	17	0.70	- 0.36	-0.19	5.74
	1.4.00	6	0.68	- 0.18	-0.56	11.48
First Floor	2.1.23 Plateau 1	5	0.71	0.26	-0.24	6.22
	2.1.25 Plateau 2	8	0.66	- 0.12	-0.29	6.72
	2.2.00	3	0.77	- 0.98	-0.10	5.19
Second Floor	3.1.16 Plateau 4	7	0.76	- 1.11	-0.25	6.31

Table 1 shows that in all the rooms the average clothing value was between 0.66 and 0.77 [clo]. Usually, in summer period, the value suggested by the standards is 0.5 [clo], while is 1 [clo] in winter. Being still in summer period, the calculated values of Icl can be justified considering the low external temperature during these 2 days.

The calculated average PMV value predicts a good thermal environment: between neutral and slightly cool in all the rooms.

The average value deriving from the subjective response denote that the occupants felt the environment around neutral for the room 1.4.00, Plateau 1 and Plateau 2, slightly cool for Room 2.2.00 and Plateau 4 and between neutral and slightly cool in the office 1.1.00. Probably these results derive by the fact that during these days the outside temperature was colder than in the previous weeks and people expected higher temperature inside the rooms. Another cause of these thermal evaluation can be due by the operative temperature in the building: as describe in chapter 3, the average operative temperature in all the rooms was lower than the one indicated by the standard EN 15251 for category I.

The subjective response with the relative standard deviation according to the thermal sensation scale is shown in figure 11.

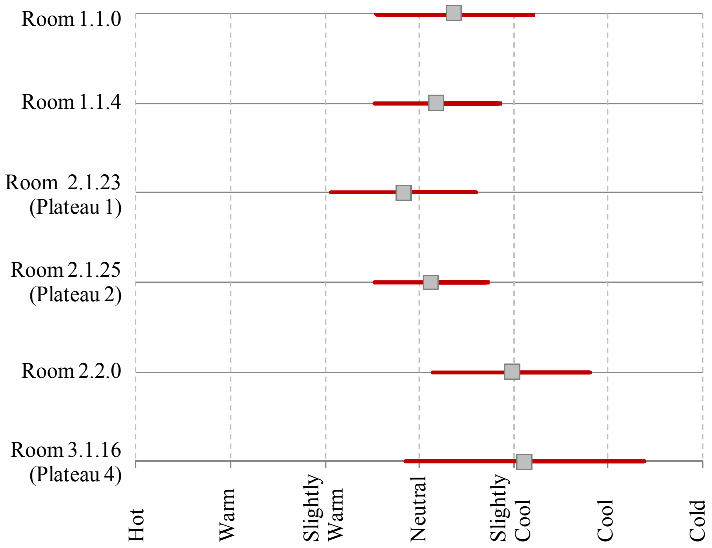


Figure 11 - Thermal sensation in the different analyzed rooms.

People were then asked about the thermal indoor climate perceived from their workstation. The answers range was from Clearly Comfortable to Clearly Uncomfortable. The occupants' average answer is shown in figure 12. On the rooms at the ground floor and on Plateau 1 and Plateau 2 at least the 60% of the employees were apparently satisfied, feeling the environment slightly comfortable or clearly comfortable. Similar result is also evident in figure 11, where the thermal sensation of these rooms was close to the neutrality. Similar comparison can be done for the room 2.2.00 and for Plateau 4, where the percentage of dissatisfied people in the room felt the environment slightly cool.

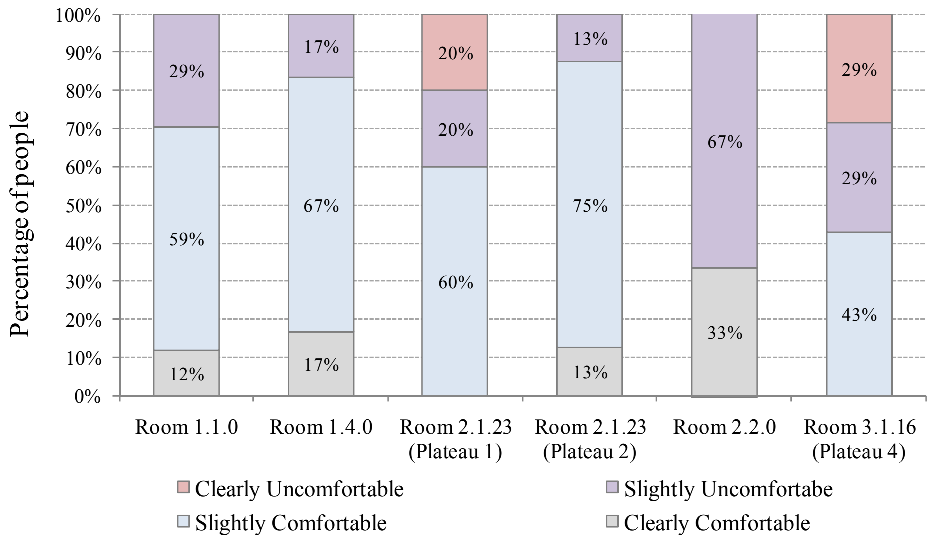


Figure 12 - Average thermal indoor climate in the rooms.

At the question "How would you prefer the temperature if you could choose?" (Fig.13), the answers highlight that a little percentage of people would prefer a lower temperature, while mainly the occupants would not change anything or would prefer an higher temperature. This happened in particular in the room 2.2.00 and on Plateau 4, where at the previous questions the cool environment was already denounced.

At the question about the assessment of thermal environment (Fig. 14), in the room 2.2.00 and in Plateau 4 a considerable percentage of occupants defined the thermal environment "Not acceptable", while in the rest of the building, in particular in room 1.4.00 and in Plateau 2, the environment was evaluated "Acceptable".

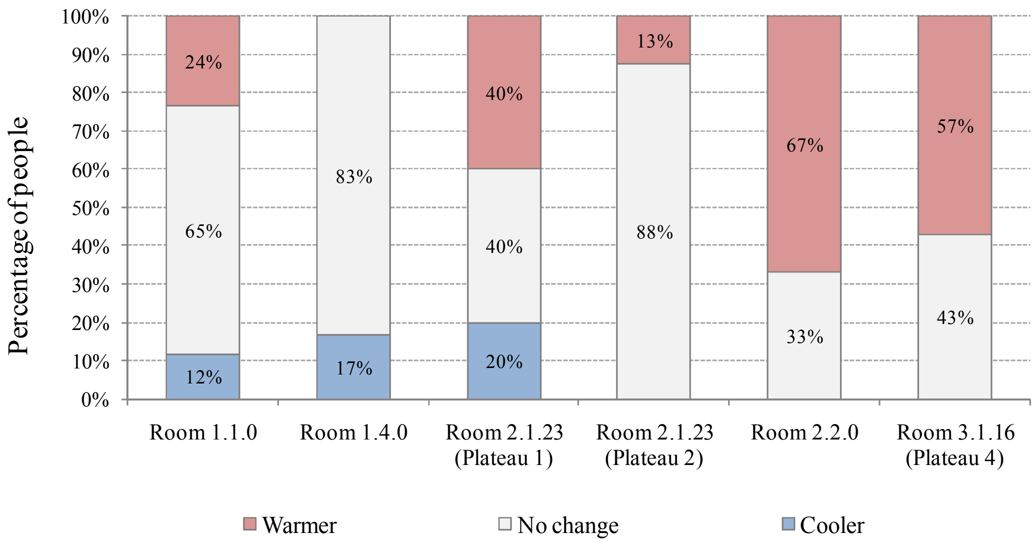


Figure 13- Preference of thermal indoor climate in the rooms.

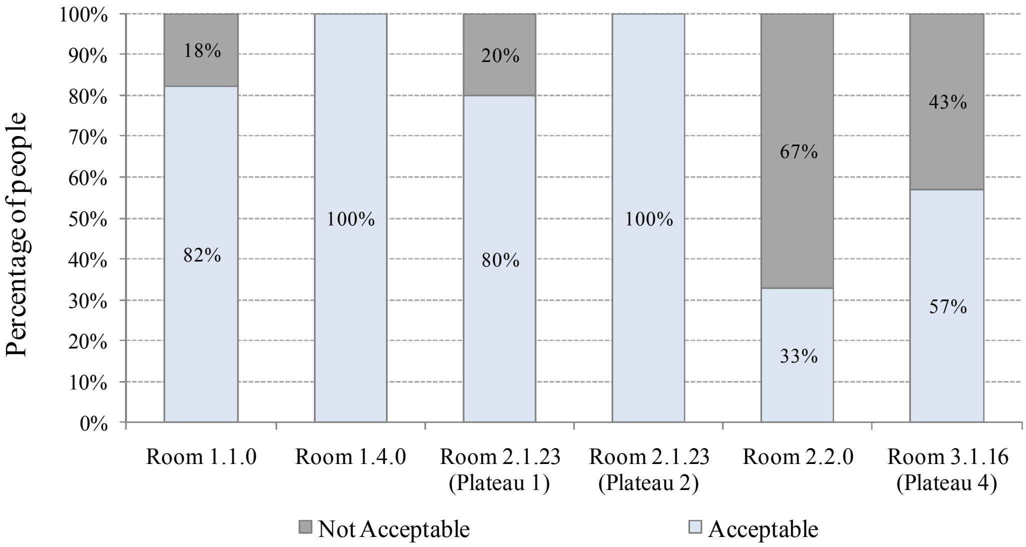


Figure 14 - Assessment of the thermal environment.

At the question about air movement assessment around the workplace (Fig.15) the answers were different for each single room and sometimes disaccording by the expectations. In room 2.2.00, for example, where most of the occupants considered the thermal environment not acceptable, because evaluated slightly cool, no changes in the air movements were required. On Plateau 1 and 2 a percentage of occupants, lower than the 60%, preferred to have more air movements, while in the rest of the building, averagely, a third of the people preferred more air movements, a third less air movements, and another third did not required changes.

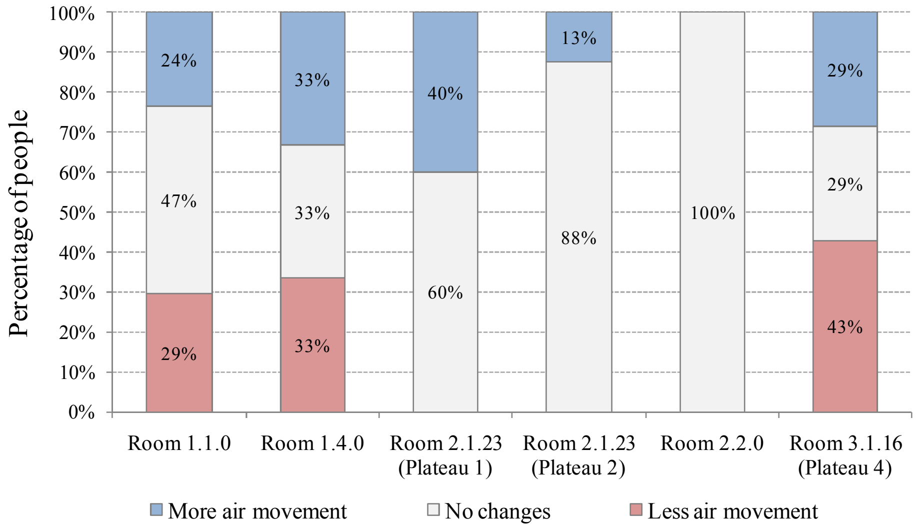


Figure 15 - Preference of air movement around the occupants in the different rooms.

Focusing on room 1.1.00, people that would prefer less air movement were sit in the back of the room, while people that would prefer more air movements were situated on the right part of the room, behind the customers reception desk. In room 1.4.00 people that denounced to prefer less air movement were sit close to the windows. In all the other rooms is not possible to make a similar consideration.

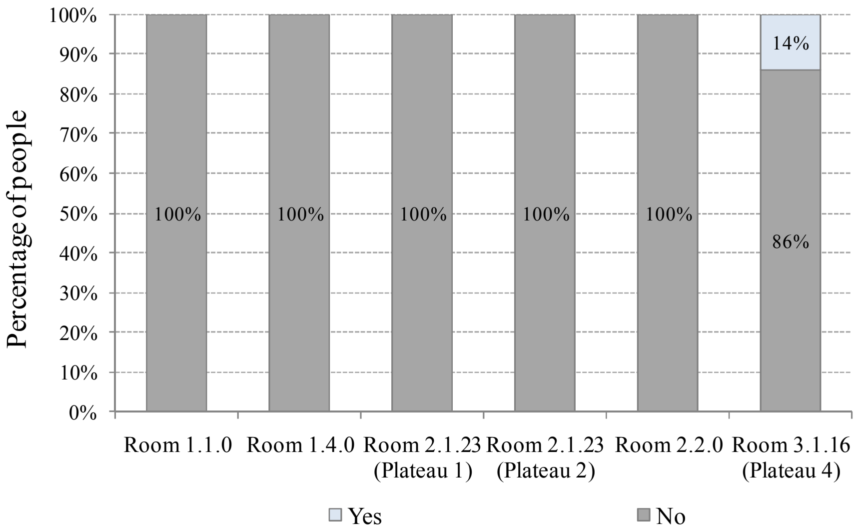


Figure 16 – Occupants affected by respiratory disorders in the different analyzed rooms.

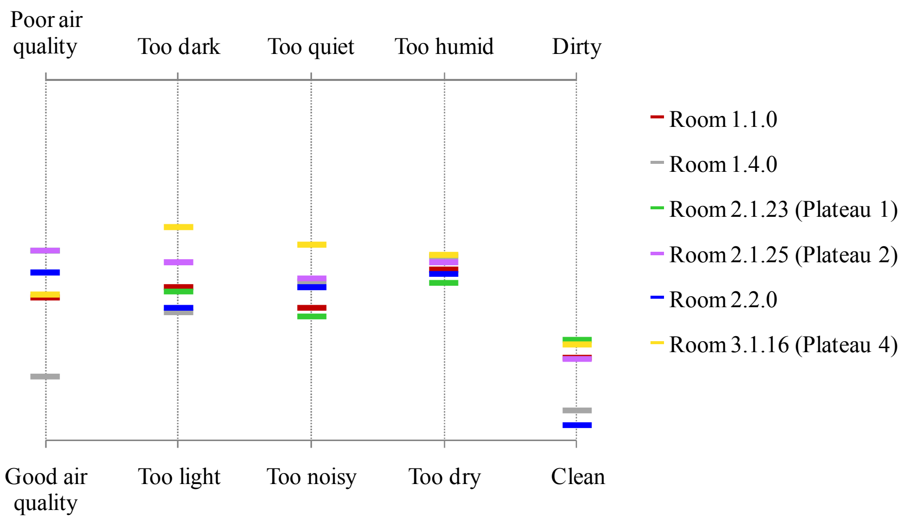


Figure 17 – Environment factors perceived by the occupants in the rooms.

Form figure 16 emerge that people in the building was not affected by respiratory disorders. Just in Plateau 4 a little percentage, that represents one person, declare to be affected by respiratory problems.

Figure 17 shows the environment factors perceived in the office by the occupants. In all the building the lighting level, the noise and the humidity were quite good. The average answers fall between the extreme situations (too light /too dark, too noisy/too quiet, too dry/too humid). The results also show that air in the rooms is perceived quite clean. In room 1.4.00, in particular, the air quality was evaluated better than in the other rooms.

Symptoms perceived by occupants in the rooms are shown in figure 18. On the upper axis of the figure negative perceptions of the symptoms are shown, while positives are on the lower axis. In general, all the average values fall in the positive lower part of the graph, but not for all the rooms. In room 2.2.00 and Plateau 1, for example, the average answer at some symptoms fell in the negative upper part of the graph and, in general, these two rooms present the most negative answers at most of the questions.

However, in all the room people declared to be in good spirit, to work well, to don't have problem of concentration, to don't have headache and to feel the environment comfortable.

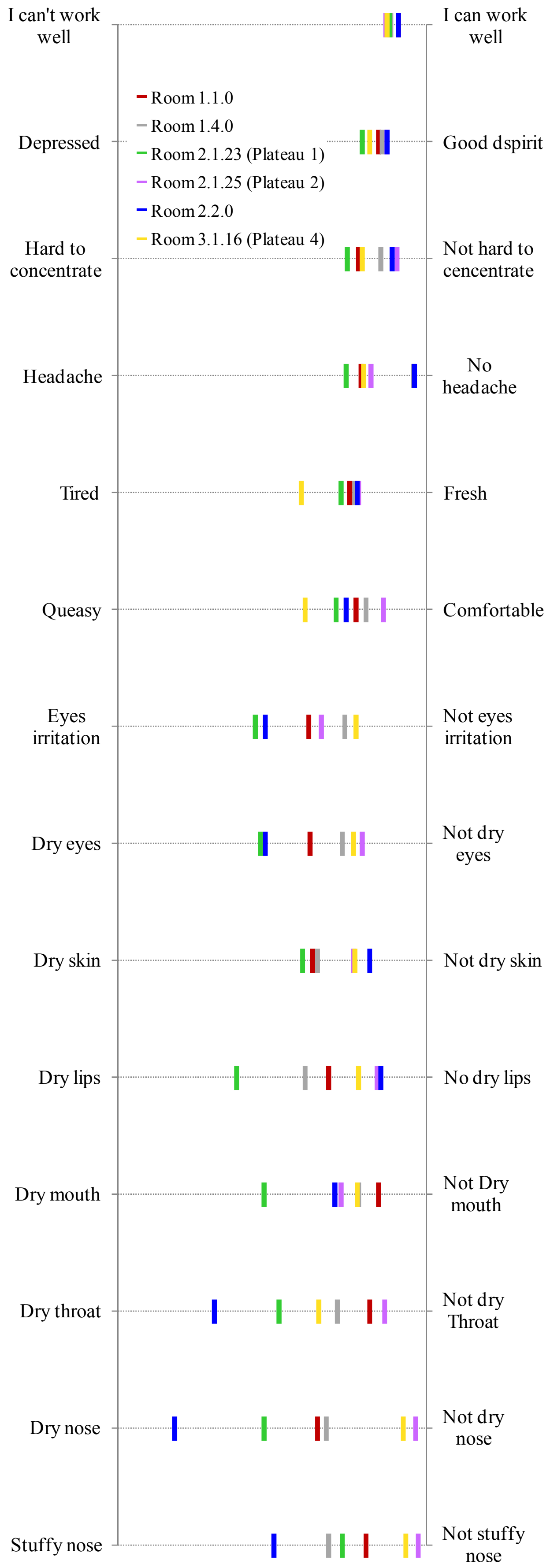


Figure 18 – Symptoms perceived by the occupants in the room.

5- ANALYSIS OF THE AREAS WHERE DRAUGHTS WERE SIGNALIZED

During the winter spot measurement some employees have complained that in some specified zone the perceived air movements were bigger than in other part of the building.

These areas, four in total, already analyzed in winter period, were monitored also in summer period, at the aim to verify if during the cooling season draught are present in the same areas too.

In all the cases these zone are in proximity of stairs, that connect the different floors, or area with a lot of people traffic.

The analysis focuses on the air velocity assessment and on the air and operative temperature difference evaluation at different heights.

For each zone the analysis show the position of the monitored points and the data elaboration about the physical parameters monitored in the rooms: air velocity, air and operative temperature. For each point is indicated the monitoring period. For each parameter the average value collected by the sensor during the monitoring time is shown in a summary graph. In case values of air velocity were too high, an additional graph shows the air velocity profile for these specific points (usually at the height of 0.1 and 0.6 m). Also discomfort due to draught risk, as described in Standard 7730:2005, is shown for every monitored point.

Zone 1 - Ground Floor

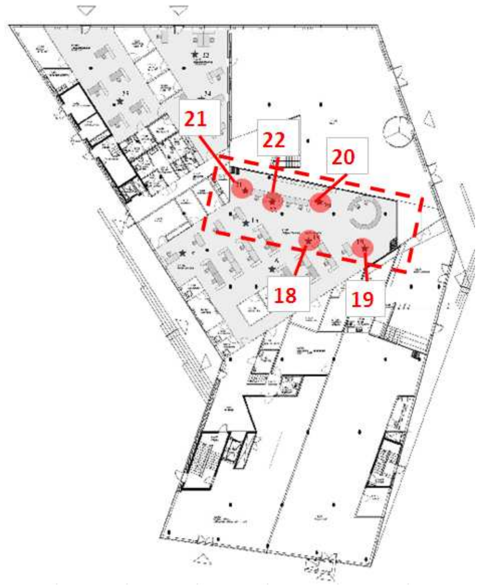


Figure 19/Table 2 – Ground Floor (Room 1.1.00). Area with draught risk , position of monitored points and information about the monitoring time.

	Time of monitoring		
Point	start	end	minutes
18	11/08/11 10:11:00 AM	11/08/11 10:25:00 AM	15
19	11/08/11 10:27:00 AM	11/08/11 10:41:00 AM	15
20	11/08/11 10:44:00 AM	11/08/11 10:58:00 AM	15
21	11/08/11 11:00:00 AM	11/08/11 11:14:00 AM	15
22	11/08/11 11:17:00 AM	11/08/11 11:30:00 AM	14

Table 3 –Average value of Air Temperature (Ta) [°C], Operative Temperature (To)[°C] and Air Velocity (Va[m/s]) at different heights for the five monitored points.

Height of the sensor	point 18			point 19			point 20			point 21			point 22		
	Ta [°C]	To [°C]	Va [m/s]	Ta [°C]	To [°C]	Va [m/s]	Ta [°C]	To [°C]	Va [m/s]	Ta [°C]	To [°C]	Va [m/s]	Ta [°C]	To [°C]	Va [m/s]
170 cm	22.4	22.4	0.08	22.4	22.4	0.05	22.2	22.2	0.10	22.4	22.5	0.07	22.4	22.5	0.07
110 cm	22.0	22.2	0.11	22.1	22.6	0.06	21.9	22.7	0.10	21.7	22.7	0.12	21.7	22.6	0.10
60 cm	22.0	22.0	0.12	21.9	22.0	0.08	21.7	21.7	0.12	22.1	22.3	0.14	22.1	22.2	0.06
10 cm	21.7	21.6	0.18	21.3	21.7	0.16	20.5	20.8	0.23	21.7	21.9	0.14	21.6	21.9	0.16

Table 4 – Predicted percentage of people bothered by draught, for different heights and for the five points.

Height of the sensor	Draught Risk (average values)				
	Percentage of Dissatisfied				
	point 18	point 19	point 20	point 21	point 22
170 cm	3	1	5	3	3
110 cm	5	2	5	6	6
60 cm	7	4	7	8	2
10 cm	10	10	14	8	10

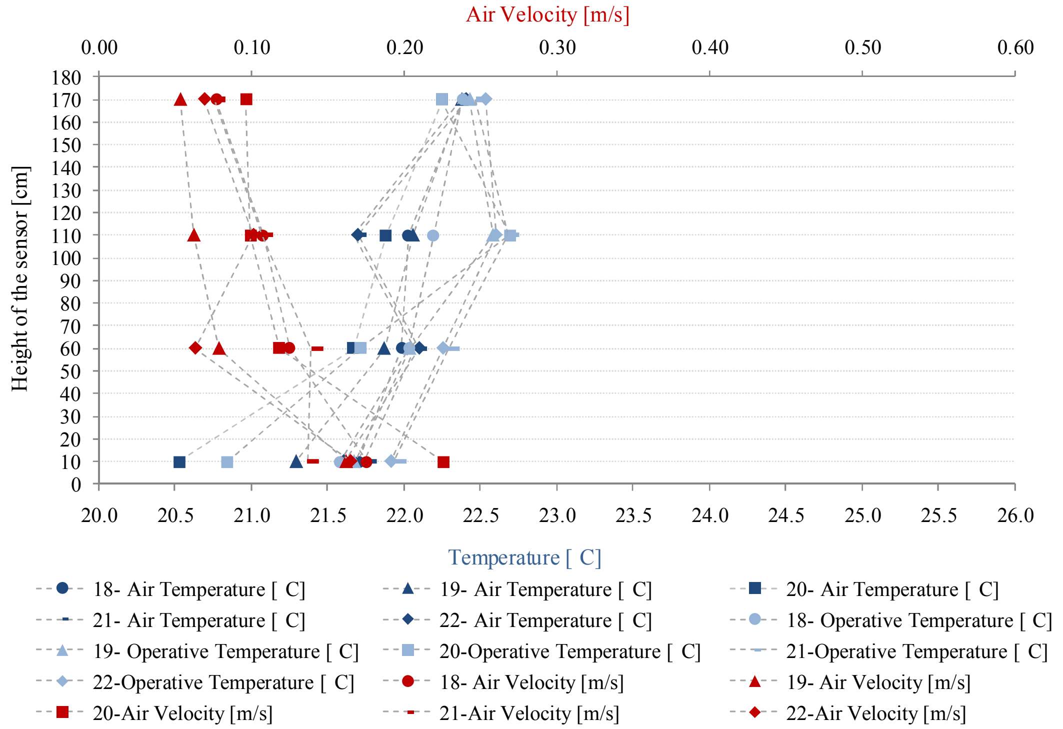


Figure 20 – Average value of Air Temperature [°C], Operative Temperature [°C] and Air Velocity [m/s] at different heights for the monitored points.

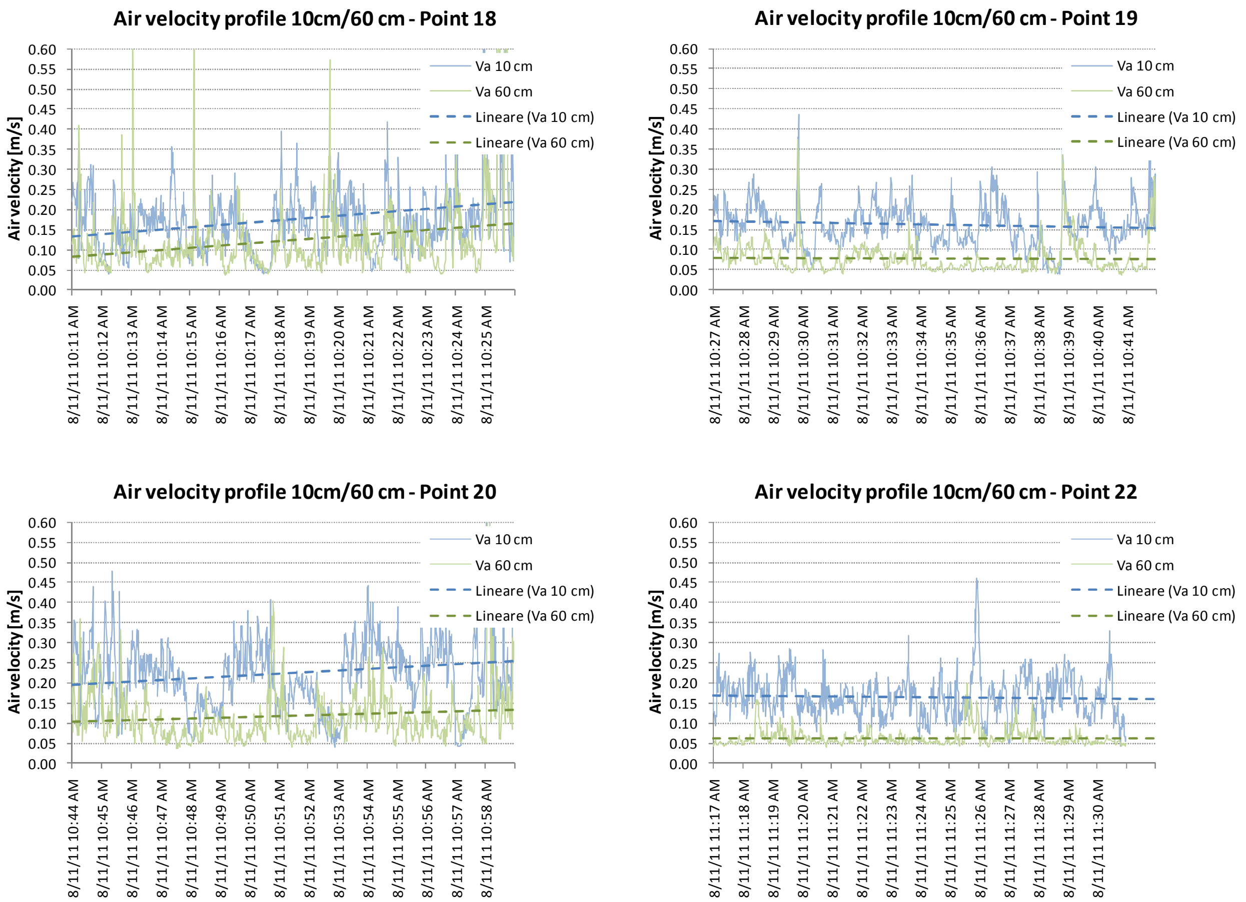
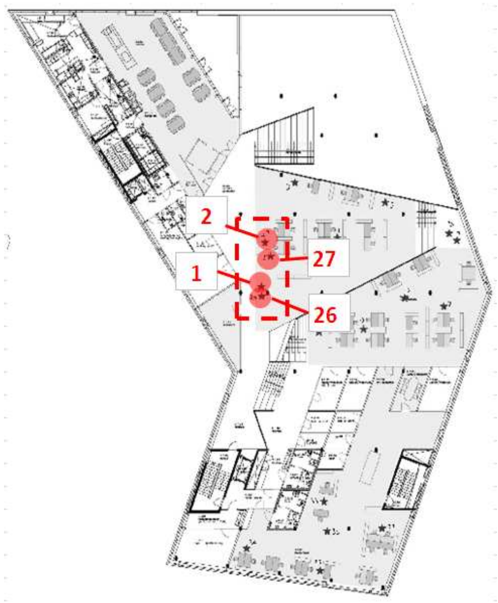


Figure 21 – Air Velocity profiles at 10 and 60 cm for three critical monitored points.

All the analyzed point, but 21, present draught at the height of 10 cm. The analysis were performed in the same area already analyzed during the winter season. In that occasion point 21 denounced the maximum drought, while this time the air velocity was lower than 0.15 m/s at 10 cm of height.

The point where maximum draughts have been found is the number 20. From figure 20 is possible to see that also the average values of operative temperature present, between 10 and 110 cm, the difference of almost 2 °C.

Plateau1



Point	Time of monitoring start	end	minutes
1	8/10/11 12:59 PM	8/10/11 1:17 PM	19
2	8/10/11 1:18 PM	8/10/11 1:36 PM	19
26	8/11/11 12:40 PM	8/11/11 12:58 PM	19
27	8/10/11 1:01 PM	8/10/11 1:19 PM	19

Figure 22/Table 5 – Plateau 1 (Room 2.1.23). Area with draught risk , position of monitored points and information about the monitoring time.

Table 6 –Average value of Air Temperature [°C], Operative Temperature [°C] and Air Velocity [m/s] at different heights for the four monitored points.

Height of the sensor	point 1			point 2			point 26			point 27		
	Ta [°C]	To [°C]	Va [m/s]	Ta [°C]	To [°C]	Va [m/s]	Ta [°C]	To [°C]	Va [m/s]	Ta [°C]	To [°C]	Va [m/s]
170 cm	23.3	23.5	0.15	23.6	23.8	0.10	22.1	22.0	0.06	22.1	22.1	0.02
110 cm	23.3	23.5	0.20	23.6	24.0	0.12	21.8	22.1	0.10	21.8	22.1	0.08
60 cm	23.3	23.5	0.25	23.5	23.7	0.12	22.2	22.3	0.14	22.3	22.3	0.11
10 cm	23.2	23.4	0.36	23.3	23.5	0.11	22.2	22.2	0.20	22.2	22.3	0.09

Table 7 – Predicted percentage of people bothered by draught, for different heights and for the four points.

Height of the sensor	Draught Risk (average values) Percentage of Dissatisfied point 1	point 2	point 26	point 27
170 cm	8	4	2	0
110 cm	11	6	6	4
60 cm	13	6	8	6
10 cm	17	6	12	5

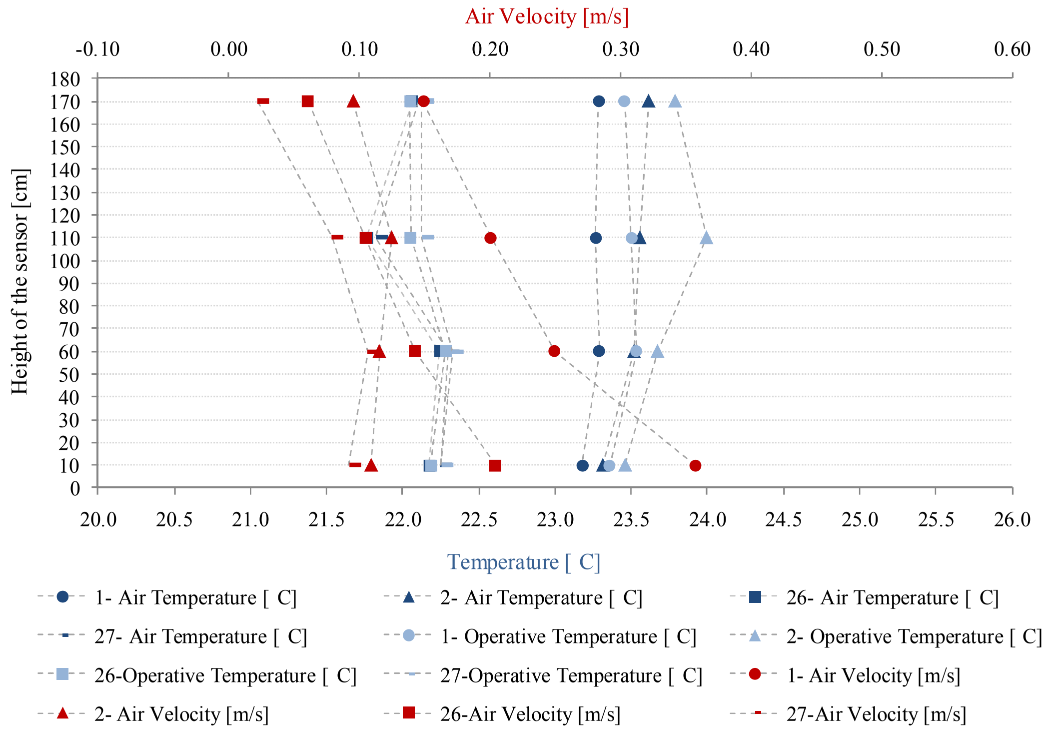


Figure 23 – Average value of Air Temperature [°C], Operative Temperature [°C] and Air Velocity [m/s] at different heights for the monitored points.

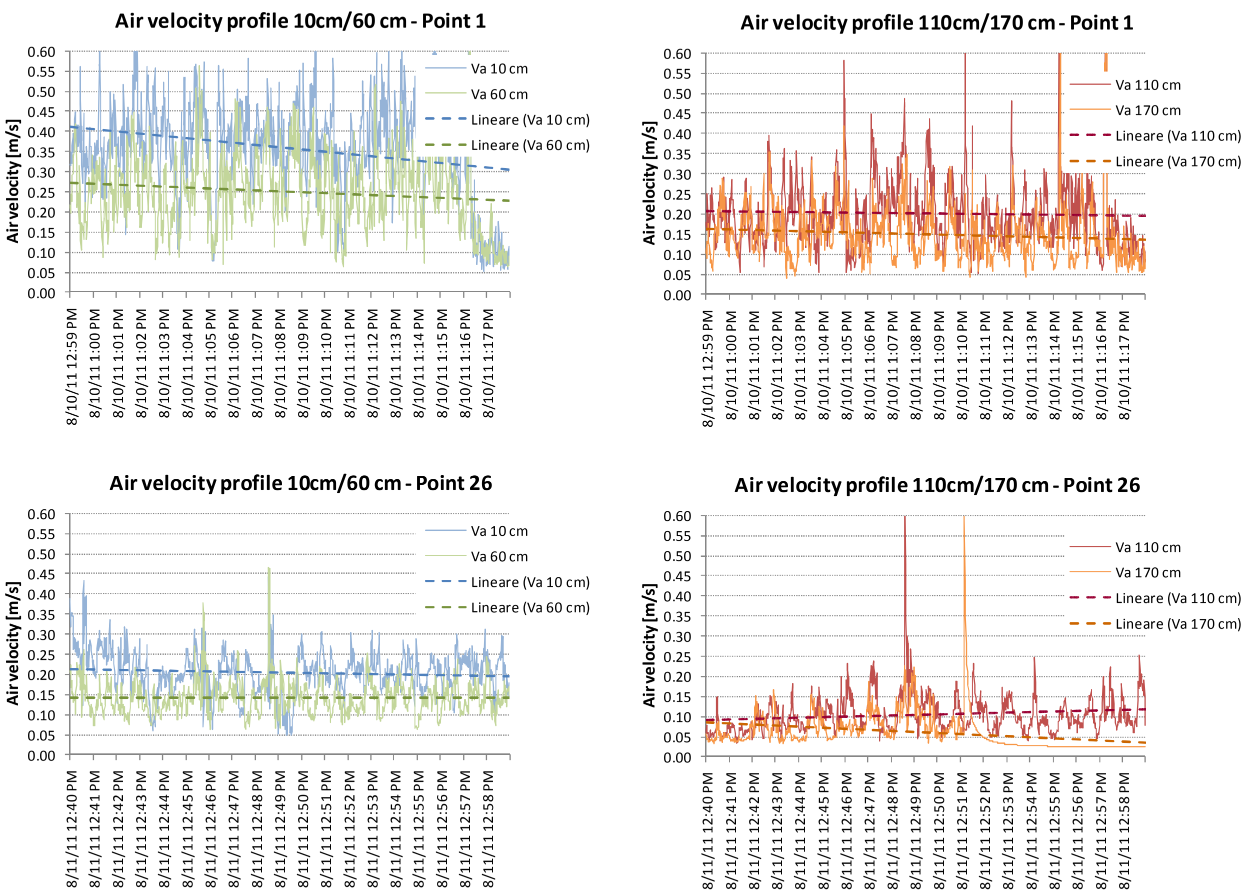
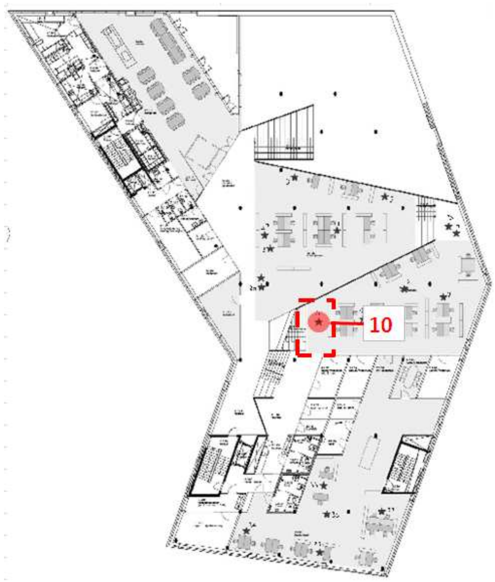


Figure 24 – Air Velocity profiles at 10 and 60 cm for two critical monitored points.

The measurement were performed in two days. In both the cases 2 point were analyzed: 1/26 and 2/27. Draught were put in evidence in correspondence of point 1/26 and in particular during the first day of monitoring. In that occasion, high values of velocity were also registered at the height of 110 and 170 cm. From table 7 is possible to read that, in that point, the percentage of dissatisfied for draught is greater than 10% at the height of 10, 60 and 110 cm. Figure 24 shows the air velocity profile of this critical point in both the performed measurements.

It is important to highlight that during the second day of monitoring the average temperature, for both the points, was lower respect to the first day from 1°C to 2°C.

Plateau 2



	Time of monitoring		
Point	start	end	minutes
12	10/08/11 03:39:00 PM	10/08/11 03:55:00 PM	17

Figure 25 / Table 8 – Plateau 2 (Room 2.1.25). Area with draught risk , position of monitored point and information about the monitoring time.

Table 9 –Average value of Air Temperature [°C], Operative Temperature [°C] and Air Velocity [m/s] at different heights for the three monitored points.

Height of the sensor	point 10		
	Ta [°C]	To [°C]	Va [m/s]
170 cm	23.3	23.3	0.14
110 cm	23.2	23.3	0.15
60 cm	23.1	23.3	0.22
10 cm	22.8	23.0	0.37

Table 10 – Predicted percentage of people bothered by draught, for different heights and for the monitored point.

Height of the sensor	Draught Risk (average values)
	Percentage of Dissatisfied
	point 10
170 cm	7.13
110 cm	8.00
60 cm	11.29
10 cm	17.22

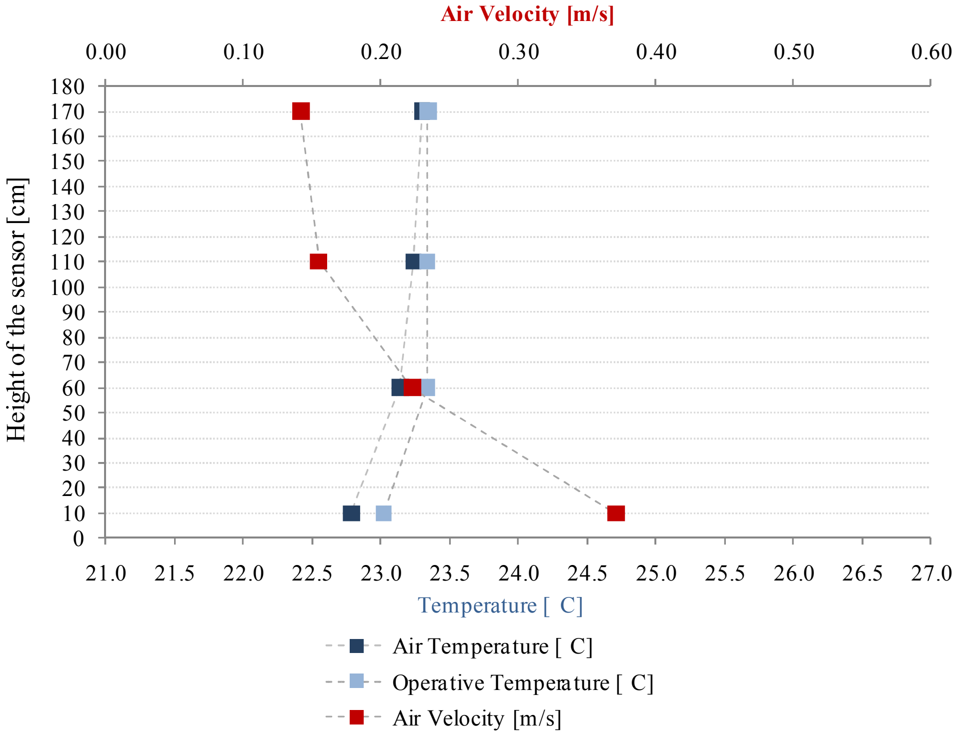


Figure 26 – Average value of Air Temperature [°C], Operative Temperature [°C] and Air Velocity [m/s] at different heights for the monitored point.

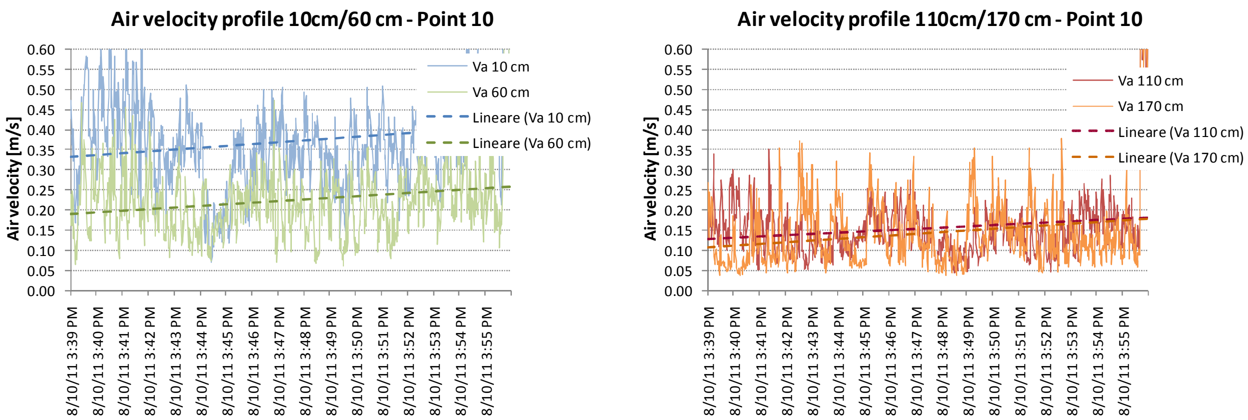


Figure 27 – Air Velocity profiles at 10 and 60 cm for the critical monitored point.

As in winter period, also in summer this area presents draught. At the height of 10 cm, in particular, the average air velocity is 0.37 m/s, with peaks of 0.60m/s, and with a percentage of dissatisfied for drought greater than 17%. Also at the other heights the air velocity presented high values, in particular at 60 cm. At 110 and 170 cm the percentage of dissatisfied is lower than 8%, but still high if compared at the other analyzed point in the room.

Plateau 4

	Time of monitoring		
Point	start	end	minutes
11	8/10/11 3:57 PM	8/10/11 4:11 PM	15
31	8/11/11 2:21 PM	8/11/11 2:39 PM	19

Figure 28 / Table 11 – Plateau 4 (Room 3.1.16). Area with draught risk, position of monitored point and information about the monitoring time.

Table 12 –Average value of Air Temperature [°C], Operative Temperature [°C] and Air Velocity [m/s] at different heights for the three monitored points.

Height of the sensor	point 11			point 31		
	Ta [°C]	To [°C]	Va [m/s]	Ta [°C]	To [°C]	Va [m/s]
170 cm	23.5	23.5	0.07	22.2	22.3	0.08
110 cm	23.3	23.3	0.07	22.1	22.1	0.07
60 cm	22.9	23.1	0.08	22.3	22.4	0.07
10 cm	22.2	22.6	0.10	22.1	22.3	0.20

Table 13 – Predicted percentage of people bothered by draught, for different heights and for the three points.

Height of the sensor	Draught Risk (average values)	
	Percentage of Dissatisfied	
	point 11	point 31
170 cm	3	4
110 cm	3	3
60 cm	4	3
10 cm	5	7

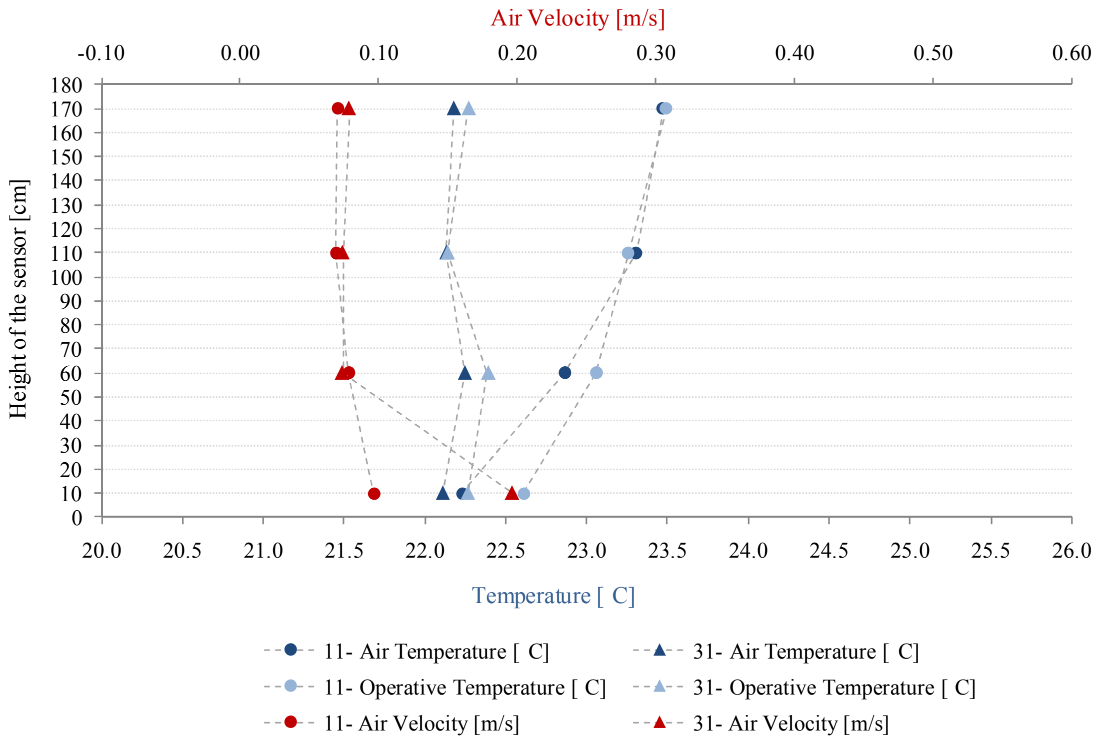


Figure 29 – Average value of Air Temperature [°C], Operative Temperature [°C] and Air Velocity [m/s] at different heights for the monitored point.

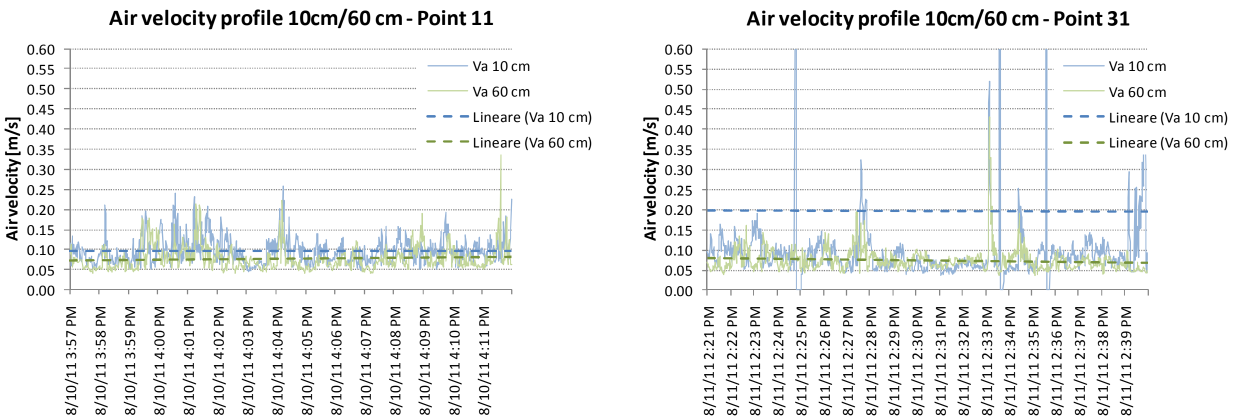


Figure 30 – Air Velocity profiles at 10 and 60 cm and at 110 and 170 cm for the critical monitored point.

Differently by the winter period, and contrarily by the occupants advise, draughts were not registered in this area. Measurement were carried out in two different days. In both cases the vent for the natural ventilation were opened.

6- ANNEXES

Annex a

Physical monitoring and subjective analysis for each single room

Ground Floor - Room 1.1.00

Figure 1.1.00.1/2 – Room 1.1.00 evidenced on the Ground floor (1) and position of the occupants that filled the questionnaires (2).

Figure 1.1.00.1/2 – Thermal sensation (1) and Average thermal indoor climate in the room (2).

Figure 1.1.00.3/4 – Preference of thermal indoor climate in the room (3) and assessment of the thermal environment (4).

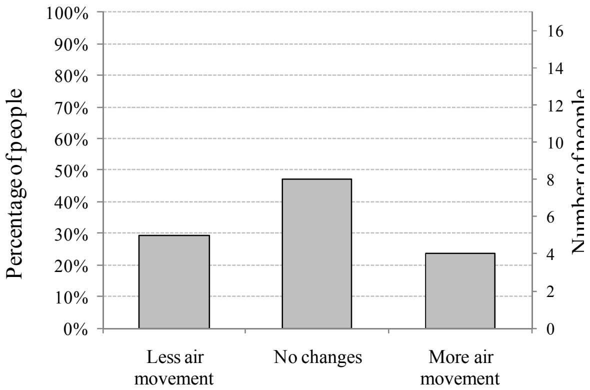


Figure 1.1.00.5 – Preference of air movement around the occupants.

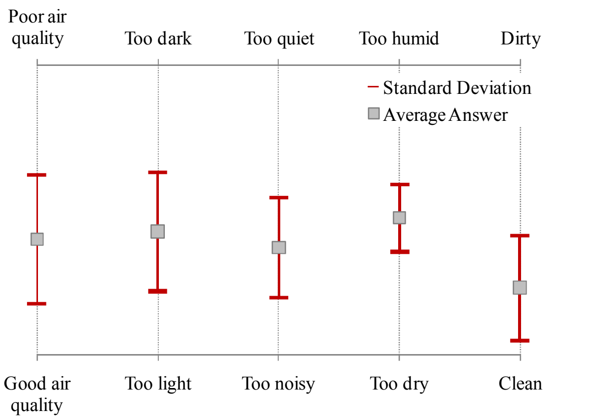


Figure 1.1.00.6 – Environment factors perceived by the occupants in the room.

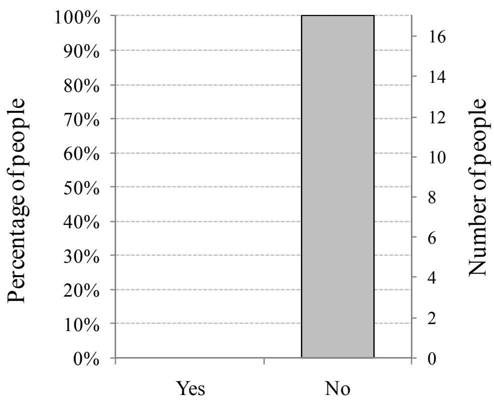


Figure 1.1.00.7 – Occupants affected by respiratory disorders.

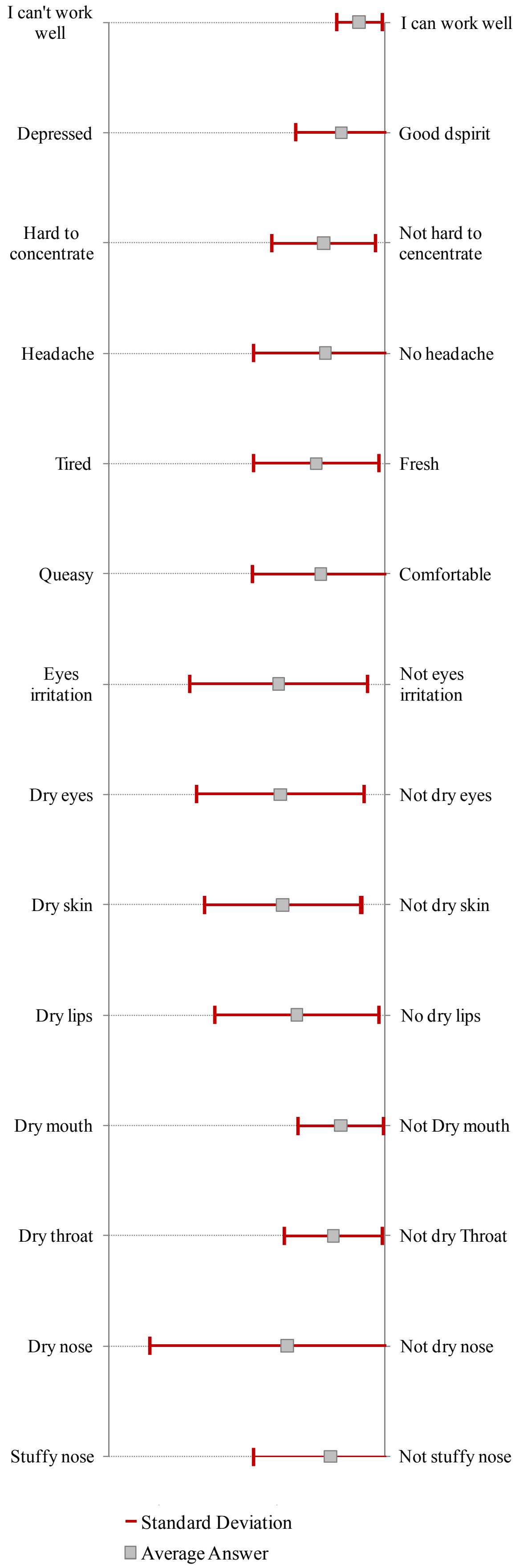


Figure 1.1.00.8 – Symptoms perceived by the occupants in the room.

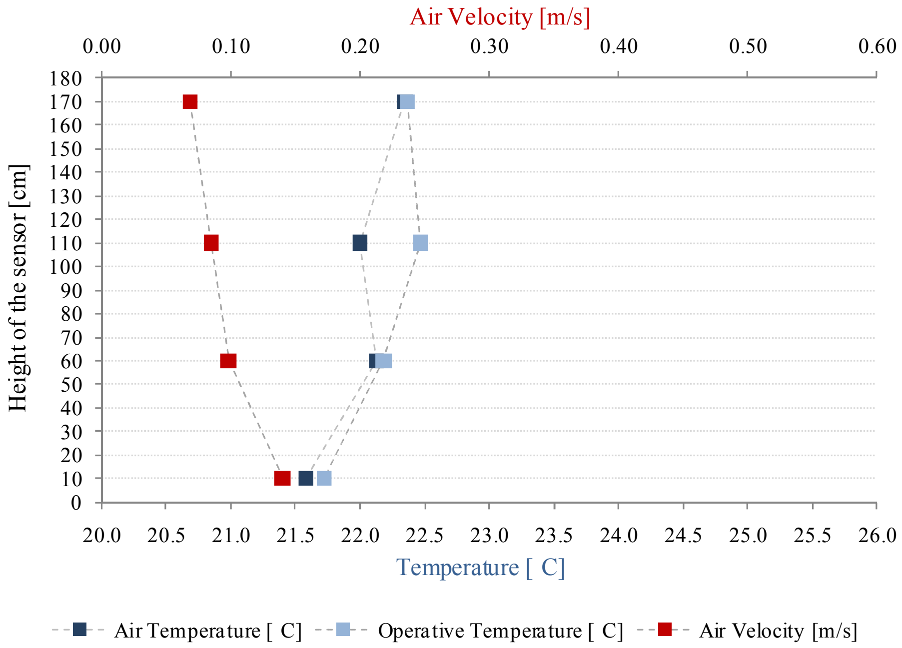


Figure 1.1.00.9 – Average value of Air Temperature, Operative Temperature and Air Velocity at different heights in the analyzed room.

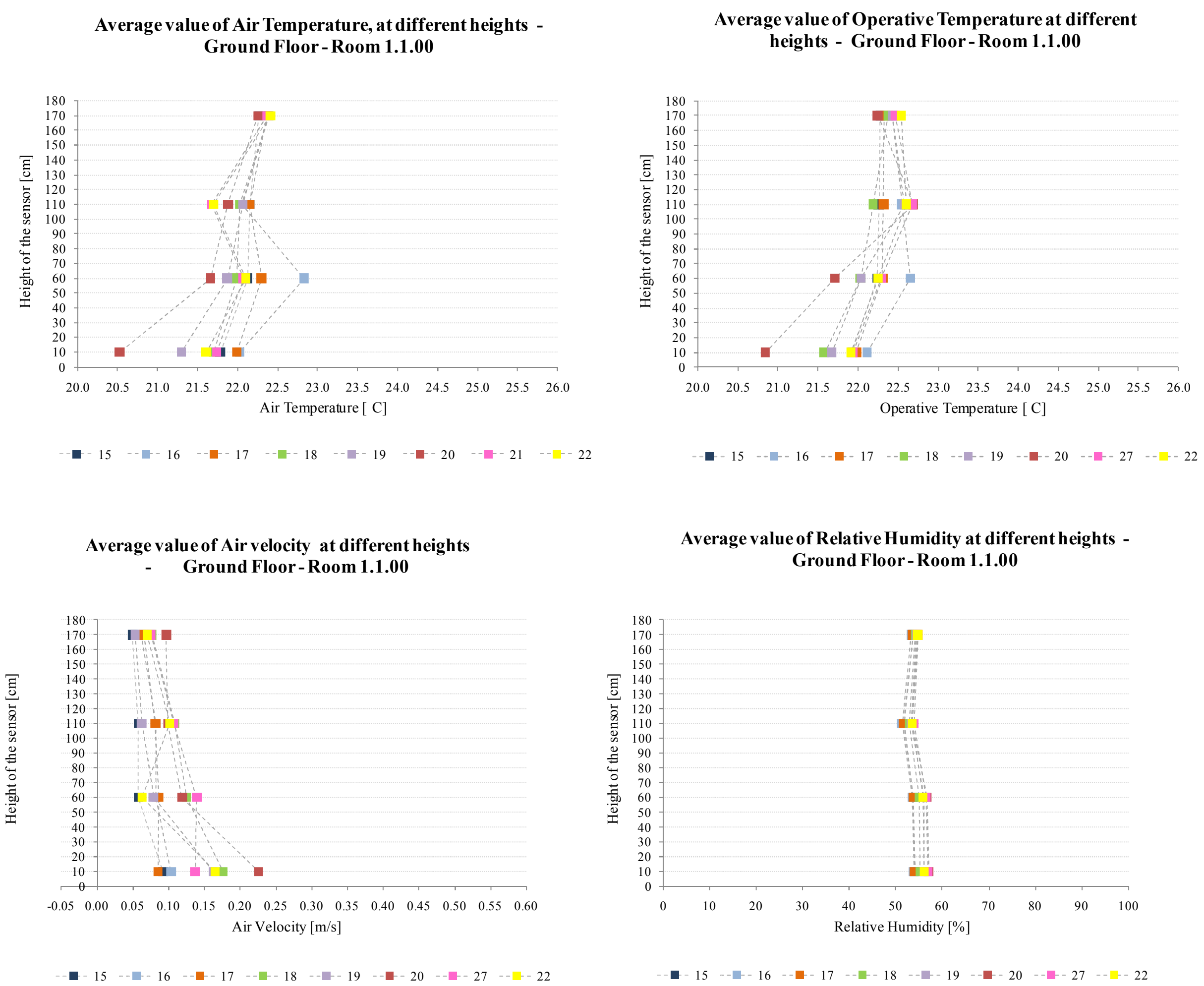


Figure 1.1.00.10 – Average value of Air Temperature, Operative Temperature, Air Velocity and Relative at different heights for the monitored points.

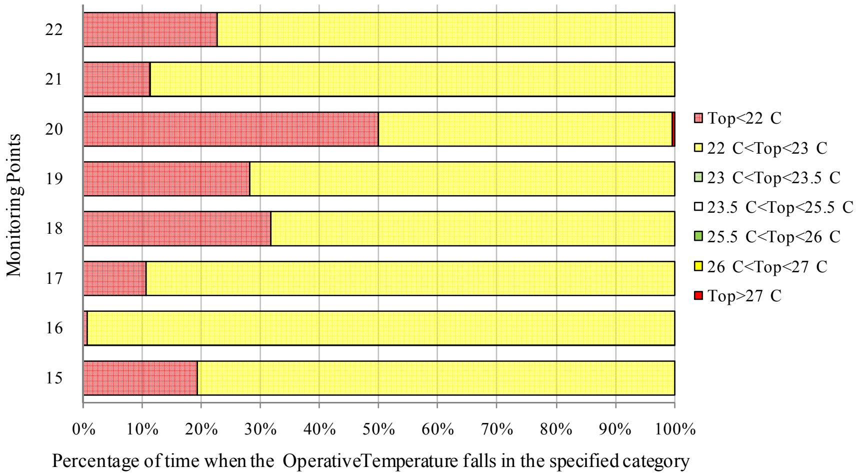


Figure 1.1.00.11 – Percentage of time when the Operative Temperature falls in the specified categories.

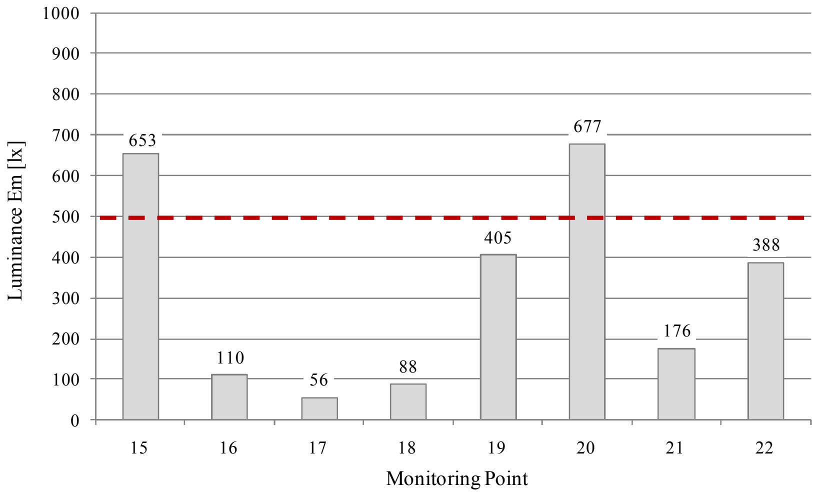


Figure 1.1.00.12 – Average value of Luminance monitored in the analyzed room.

Comments of the occupants

- There is much noise in the room. It is partially due by many people that talk loudly, and partially by the noise of the steps when people walk.
- Also if I felt hot during these last days, usually it is very cold in the department. I am often bothered by a row of windows facing the street.
- There is a big difference in the influence of light depending if the weather is cloudy or sunny.
- I have allergy at the eyes, and it is very troubled by an excessive backlight. Especially when there is sunshine, it creates glare in both the floors and cars park near the building or cars passing on the road. This works as a flash light.

Ground floor - Room 1.4.00

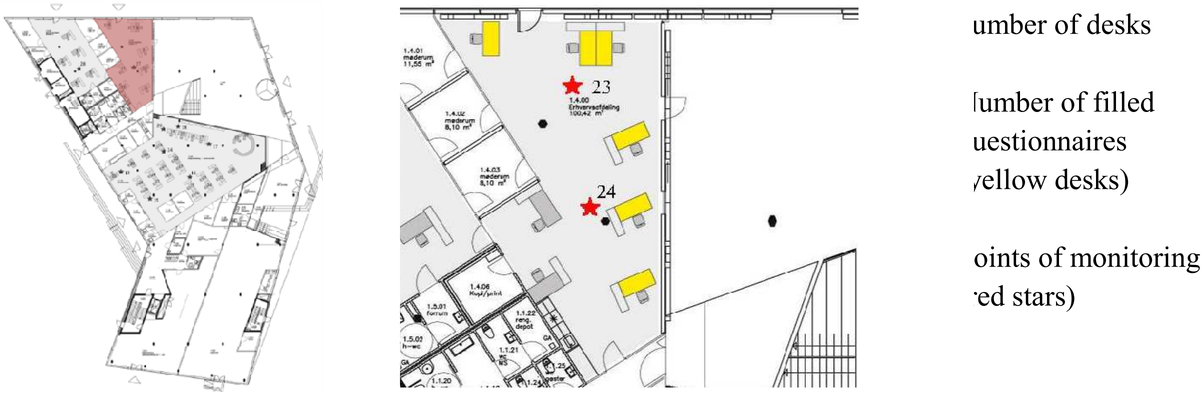


Figure 1.4.00.1/2 – Room 1.4.00 evidenced on the Ground floor (1) and position of the occupants that filled the questionnaires (2).

Figure 1.4.00.1/2 – Thermal sensation (1) and Average thermal indoor climate in the room (2).

Figure 1.4.00.3/4 – Preference of thermal indoor climate in the room (3) and assessment of the thermal environment (4).

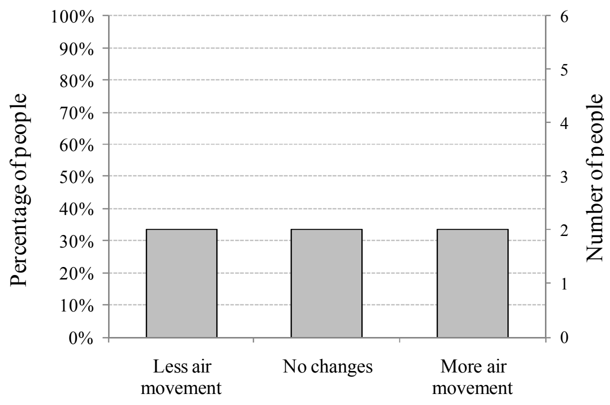


Figure 1.4.00.5 – Preference of air movement around the occupants.

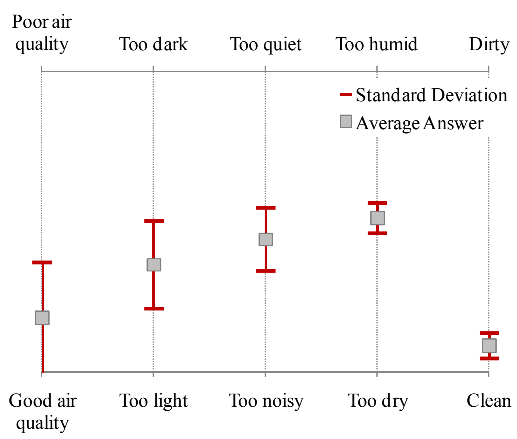


Figure 1.4.00.6 – Environment factors perceived by the occupants in the room.

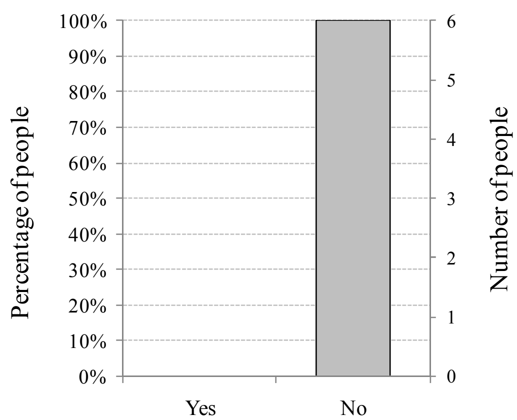


Figure 1.4.00.7 – Occupants affected by respiratory disorders.

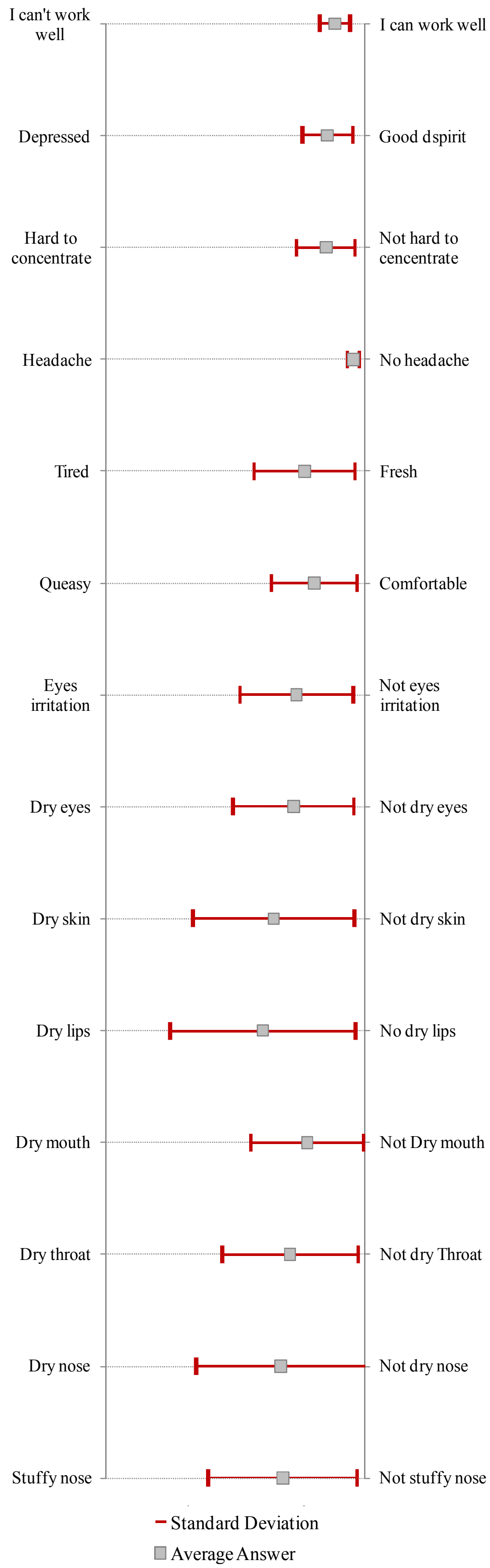


Figure 1.4.00.8 – Symptoms perceived by the occupants in the room.

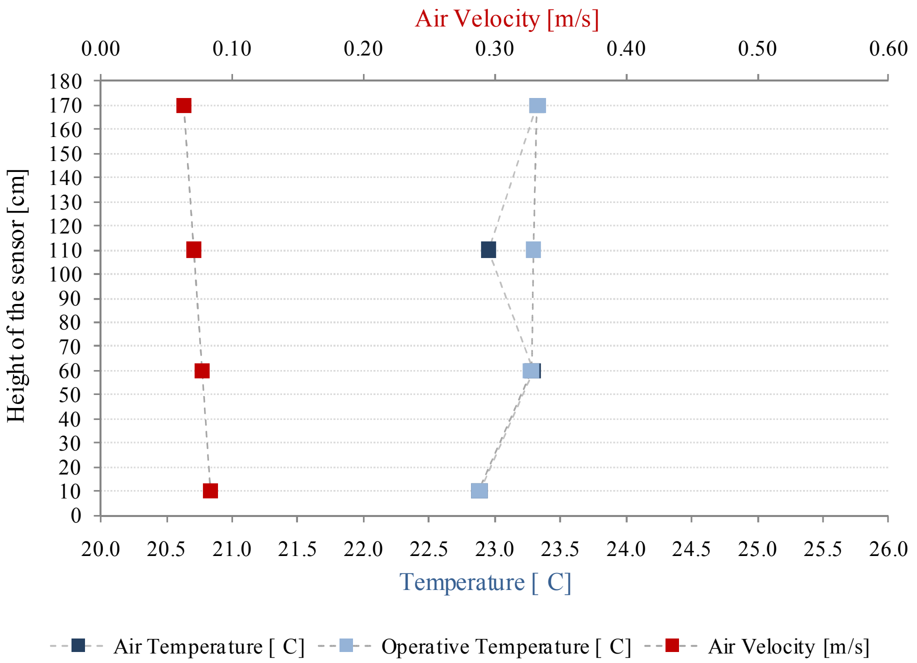


Figure 1.4.00.9 – Average value of Air Temperature, Operative Temperature and Air Velocity at different heights in the analyzed room.

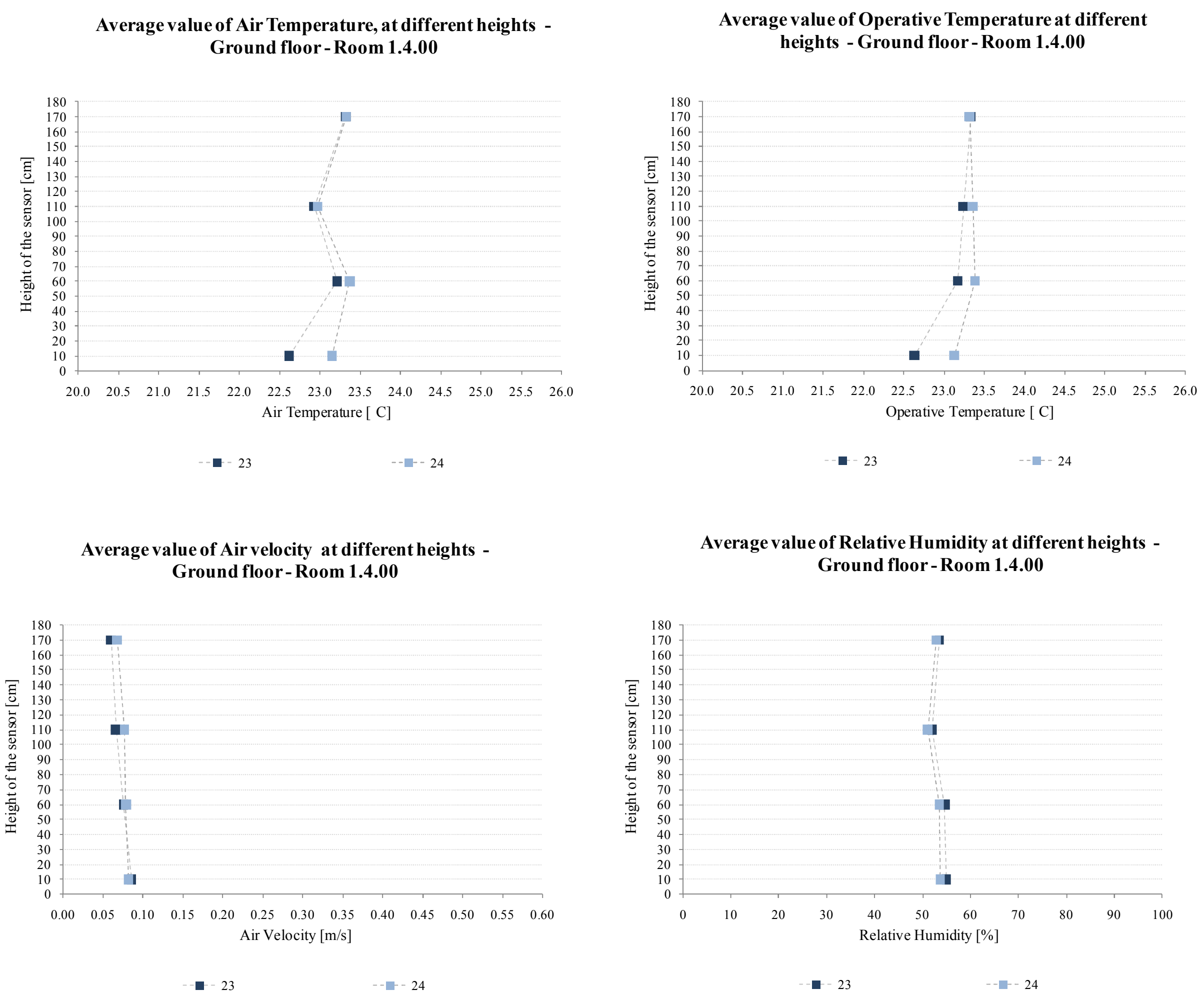


Figure 1.4.00.10 – Average value of Air Temperature, Operative Temperature, Air Velocity and Relative at different heights for the monitored points.

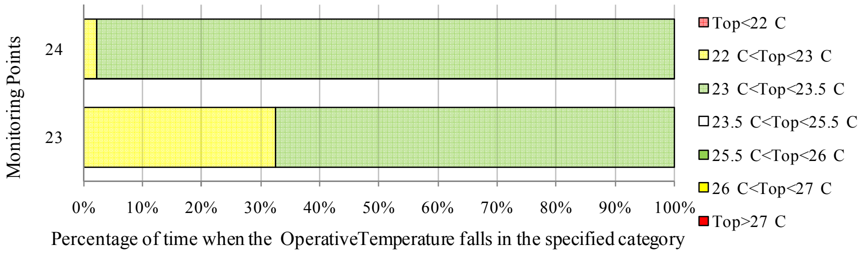


Figure 1.4.00.11 – Percentage of time when the Operative Temperature falls in the specified categories.

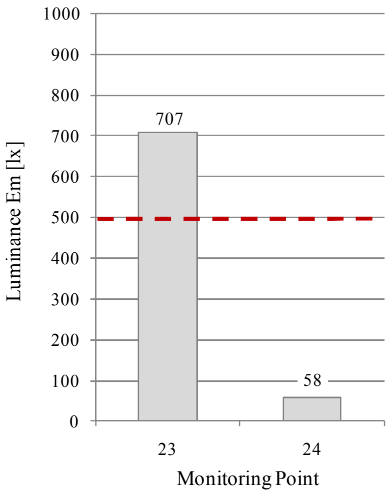


Figure 1.4.00.12 – Average value of Luminance monitored in the analyzed room.

Comments of the occupants

- The system supplied too cold air.
- There are draughts when the vents are open. More when it's windy outside.

First Floor - Room 2.1.23 (Plateau 1)

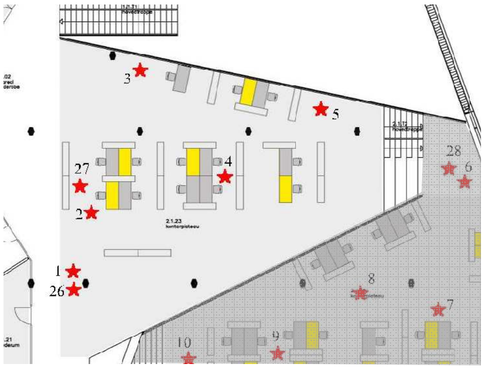


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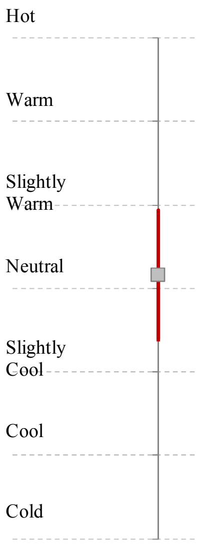
Figure 2.1.23.1/2 – Room 2.1.23 evidenced on the First floor (1) and position of the occupants that filled the questionnaires (2).



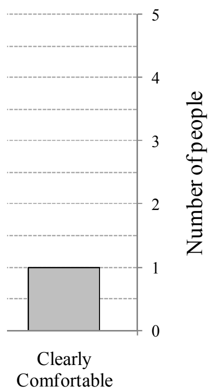
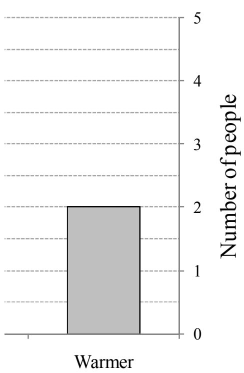


Figure 2.1.23.1/2 – Thermal sensation (1) and Average thermal indoor climate in the room (2).



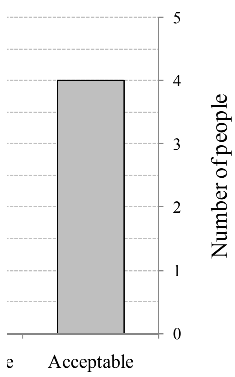


Figure 2.1.23.3/4 – Preference of thermal indoor climate in the room (3) and assessment of the thermal environment (4).

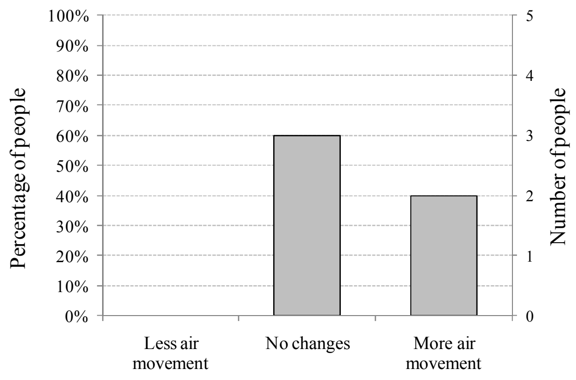


Figure 2.1.23.5 – Preference of air movement around the occupants.

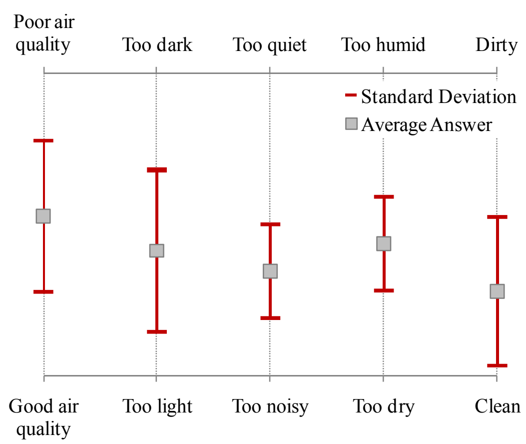


Figure 2.1.23.6 – Environment factors perceived by the occupants in the room.

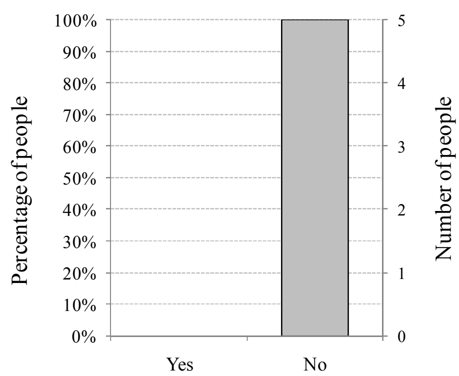


Figure 2.1.23.7 – Occupants affected by respiratory disorders.

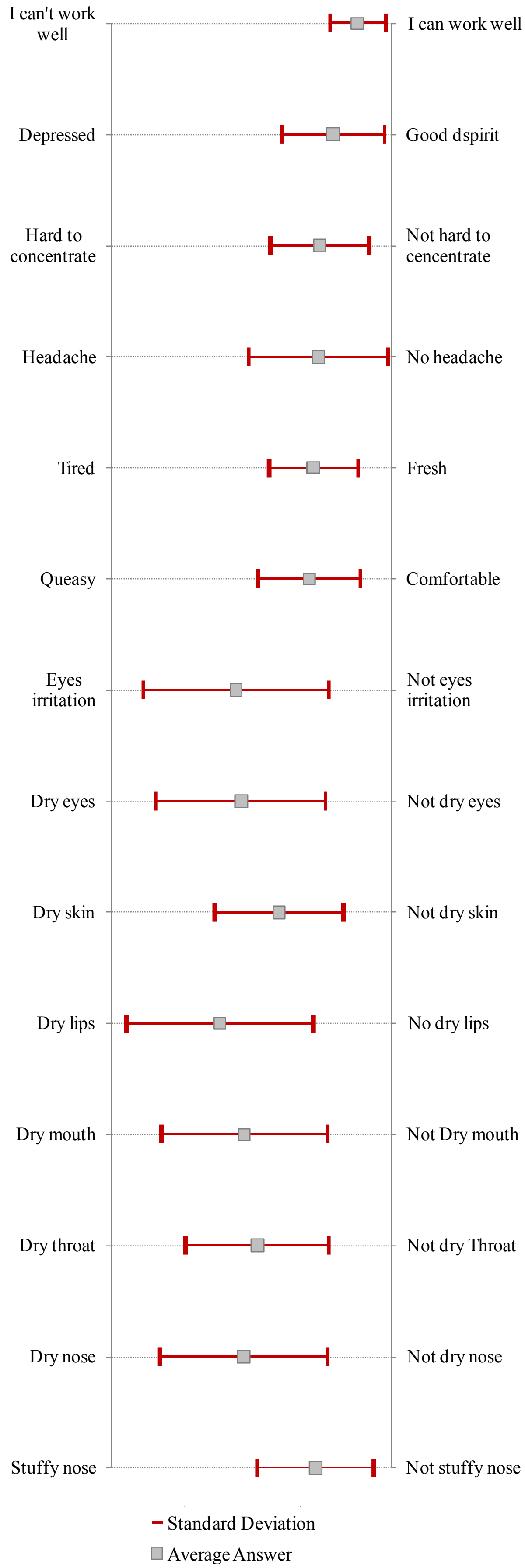


Figure 2.1.23.8 – Symptoms perceived by the occupants in the room.

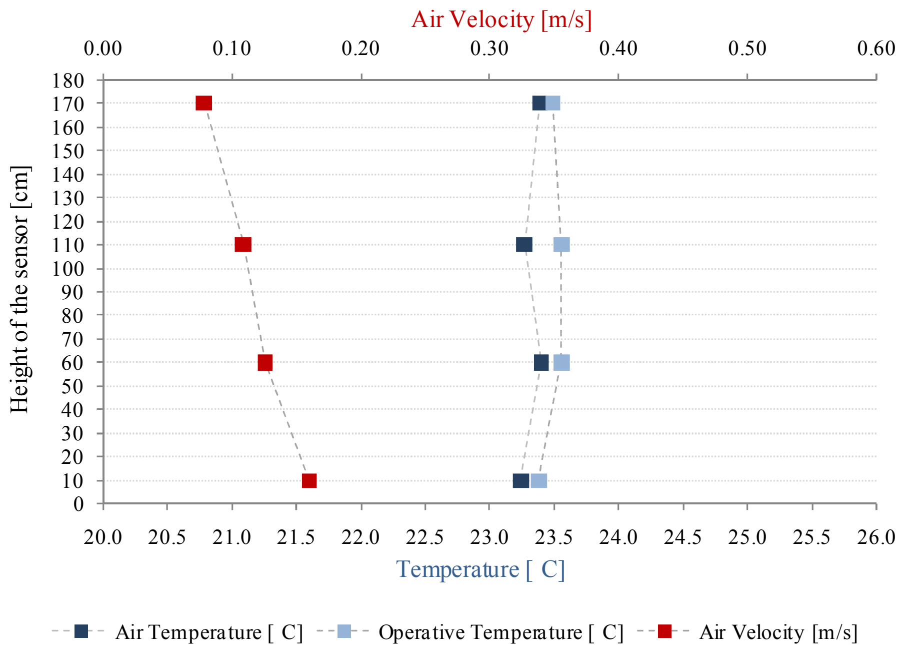


Figure 2.1.23.9 – Average value of Air Temperature, Operative Temperature and Air Velocity at different heights in the analyzed room.

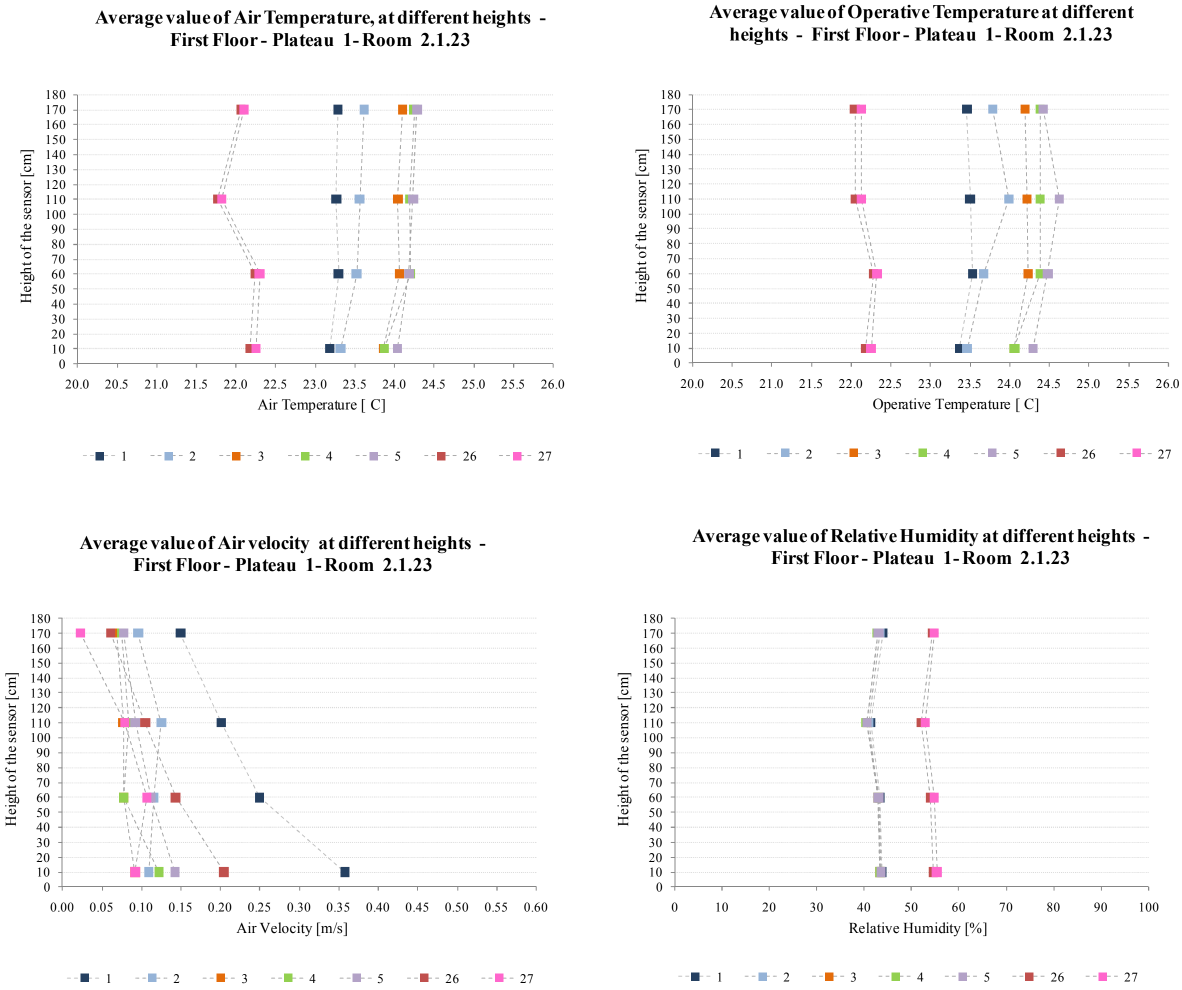


Figure 2.1.23.10 – Average value of Air Temperature, Operative Temperature, Air Velocity and Relative at different heights for the monitored points.

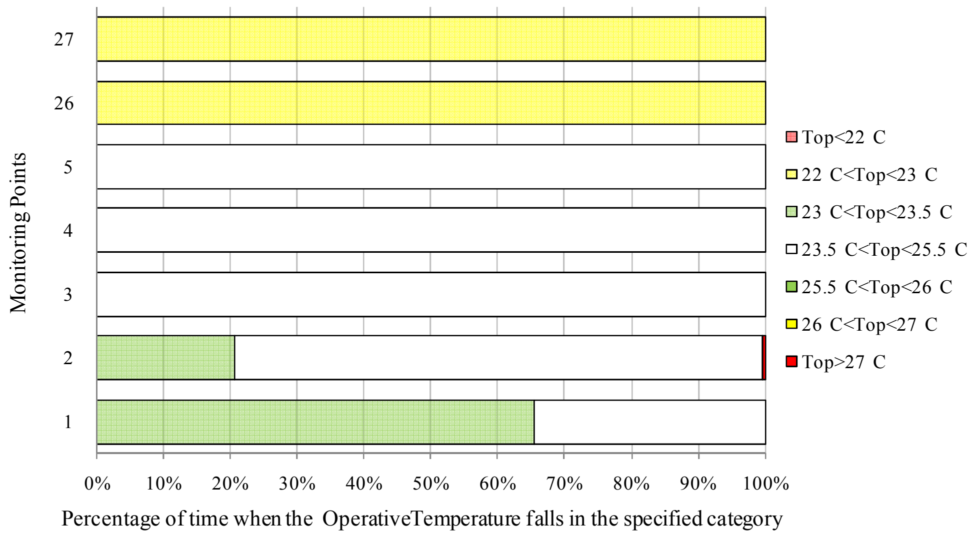


Figure 2.1.23.11 – Percentage of time when the Operative Temperature falls in the specified categories.

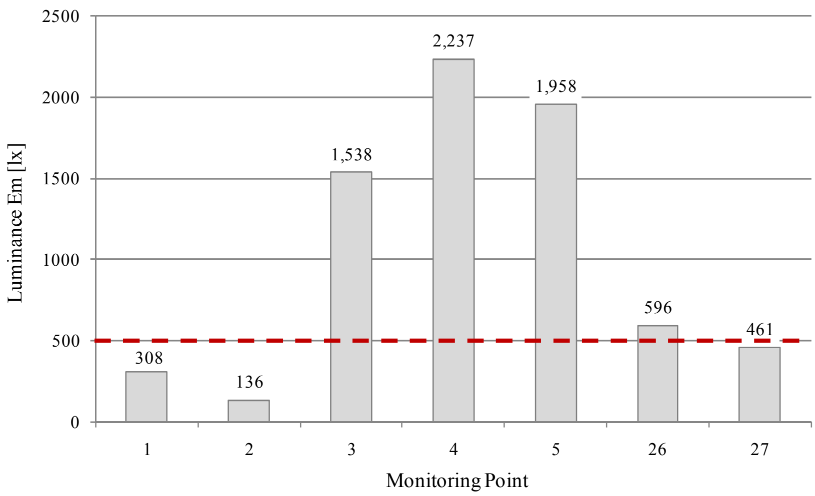


Figure 2.1.23.12 – Average value of Luminance monitored in the analyzed room.

Comments of the occupants

No comments

First Floor - Room 2.1.25 (Plateau 2)

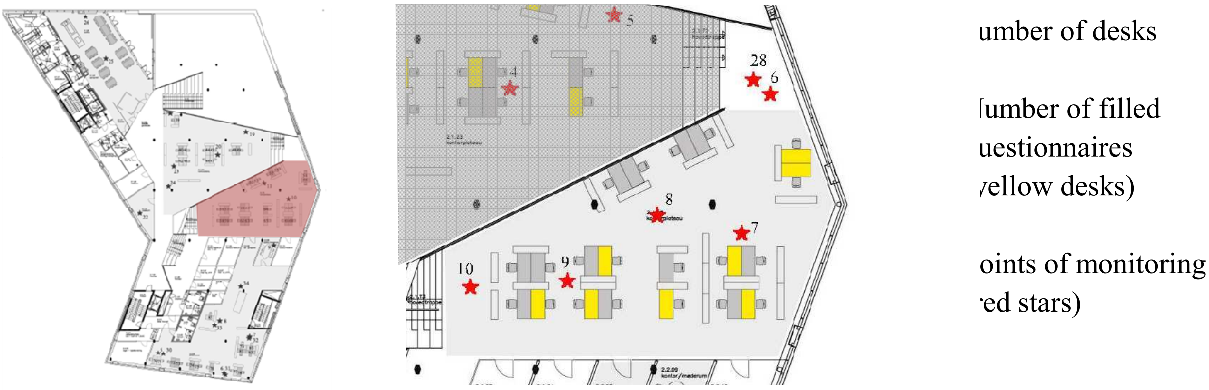


Figure 2.1.25.1/2 – Room 2.1.25 evidenced on the First floor (1) and position of the occupants that filled the questionnaires (2).

Figure 2.1.25.1/2 – Thermal sensation (1) and Average thermal indoor climate in the room (2).

Figure 2.1.25.3/4 – Preference of thermal indoor climate in the room (3) and assessment of the thermal environment (4).

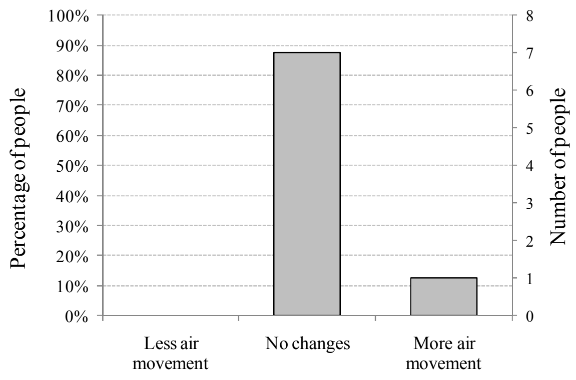


Figure 2.1.25.5 – Preference of air movement around the occupants.

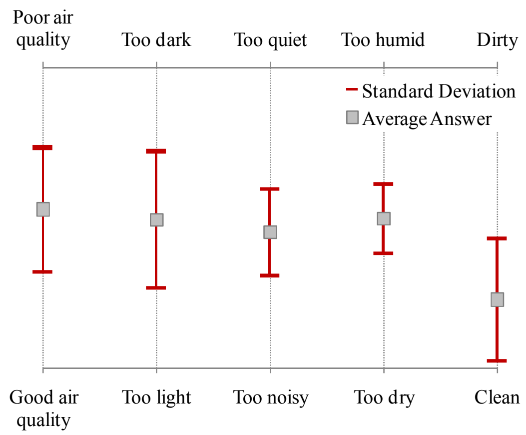


Figure 2.1.25.6 – Environment factors perceived by the occupants in the room.

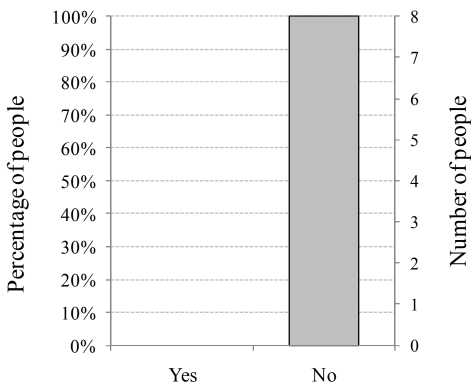


Figure 2.1.25.7 – Occupants affected by respiratory disorders.

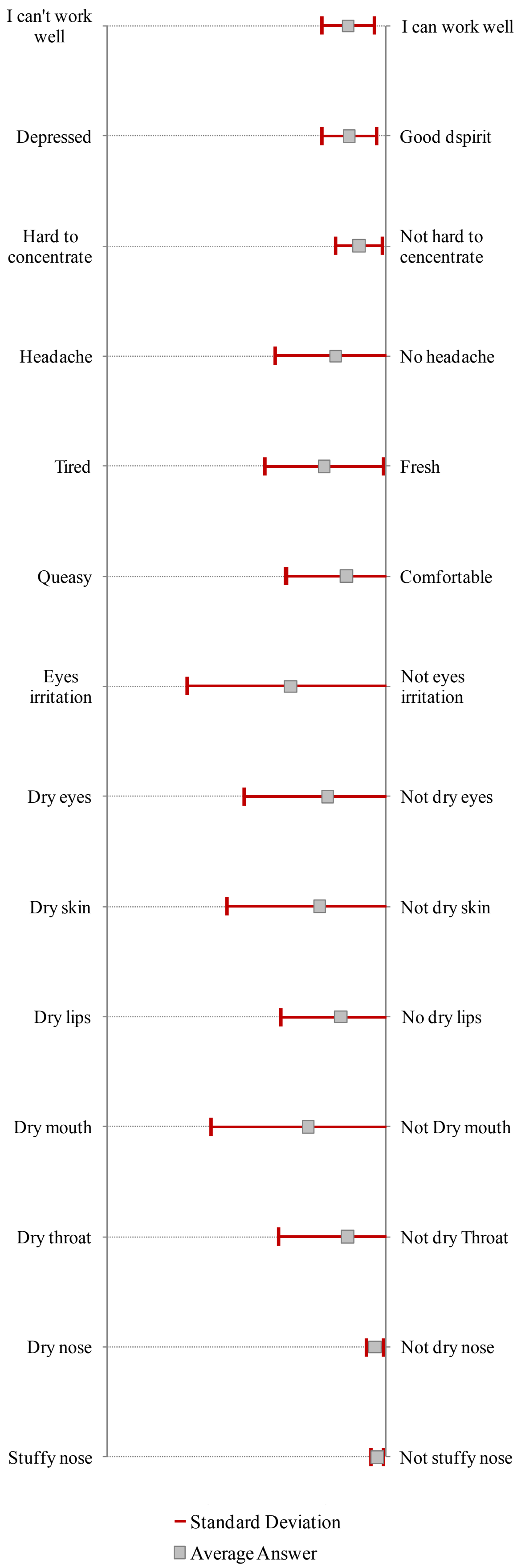


Figure 2.1.25.8 – Symptoms perceived by the occupants in the room.

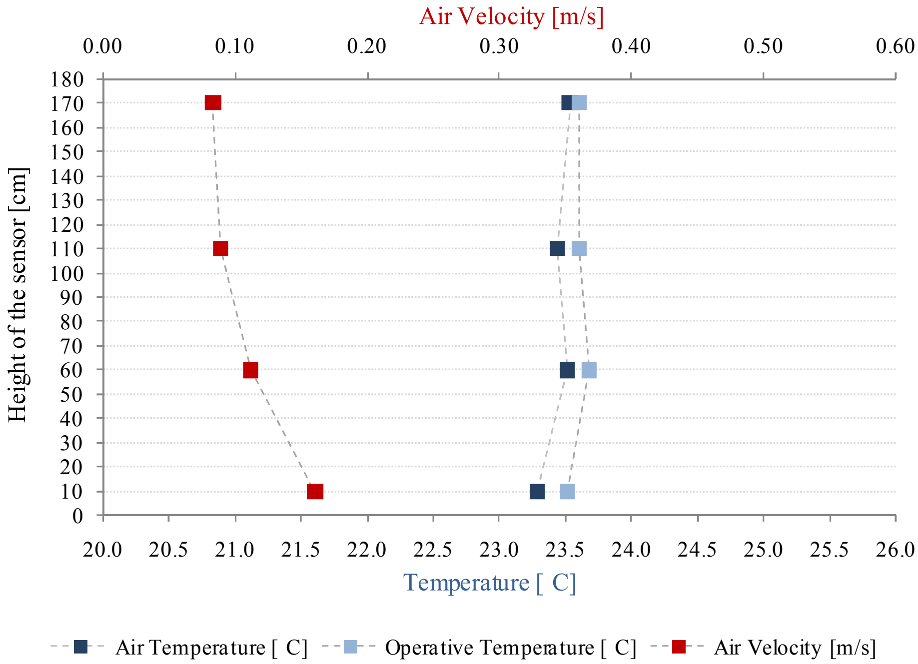


Figure 2.1.25.9 – Average value of Air Temperature, Operative Temperature and Air Velocity at different heights in the analyzed room.

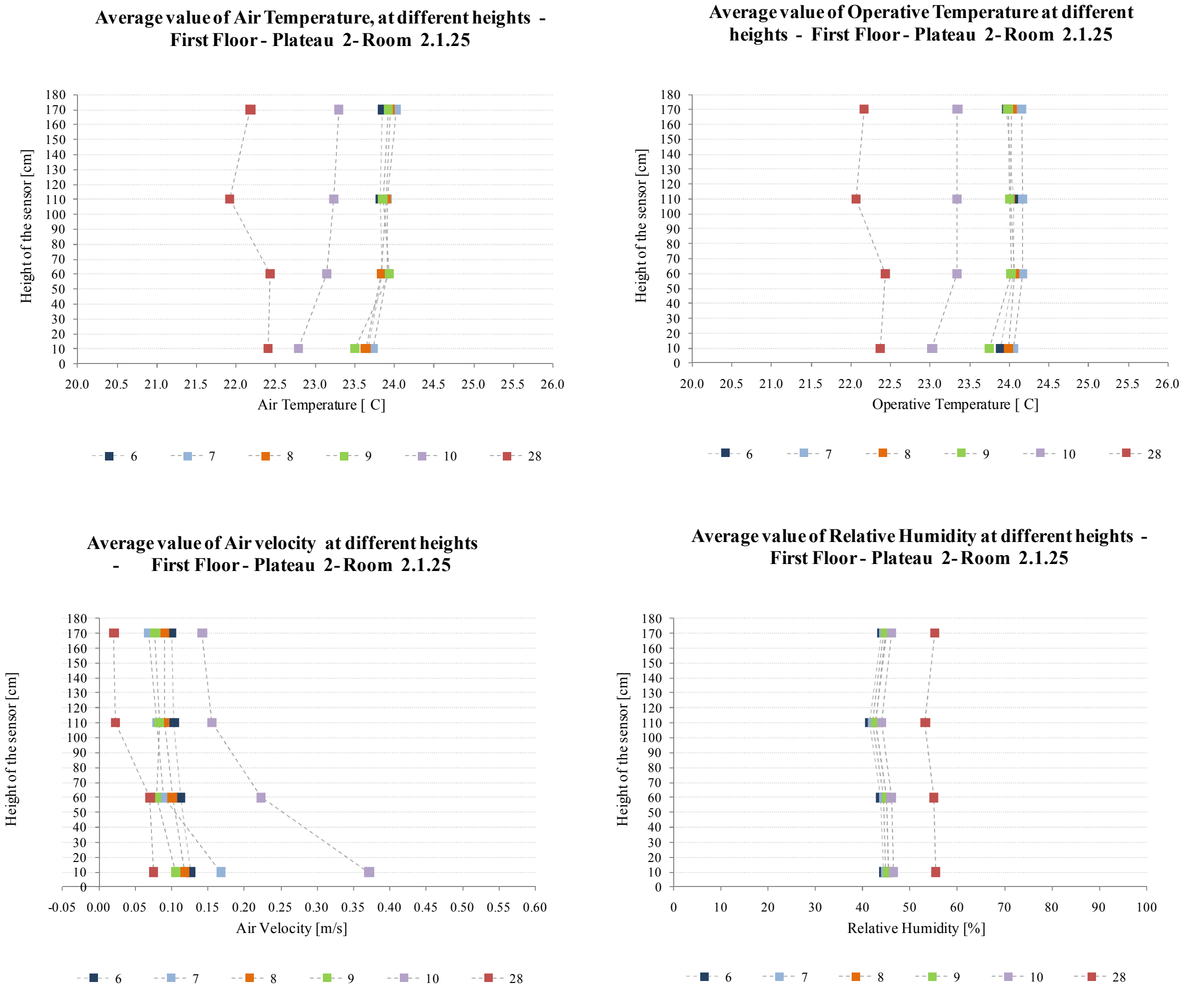


Figure 2.1.25.10 – Average value of Air Temperature, Operative Temperature, Air Velocity and Relative at different heights for the monitored points.

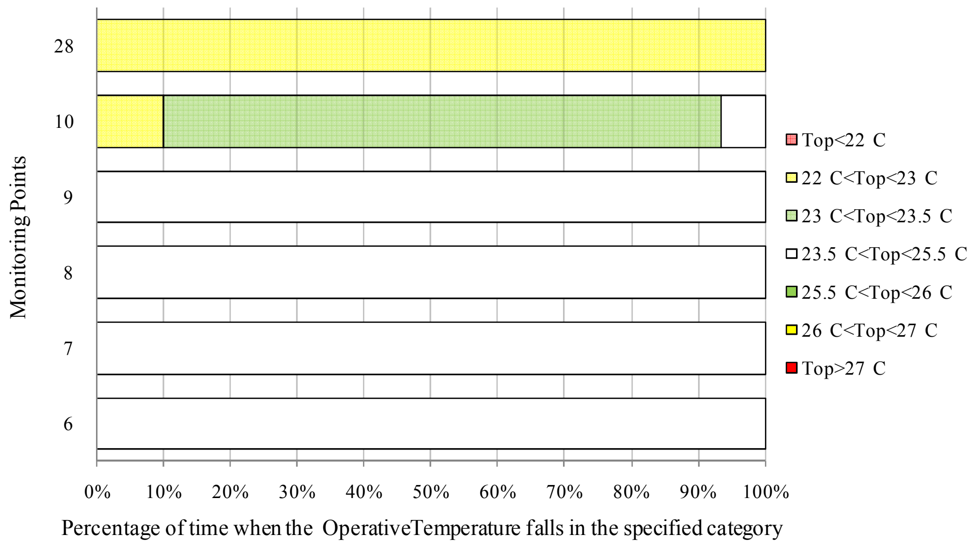


Figure 2.1.25.11 – Percentage of time when the Operative Temperature falls in the specified categories.

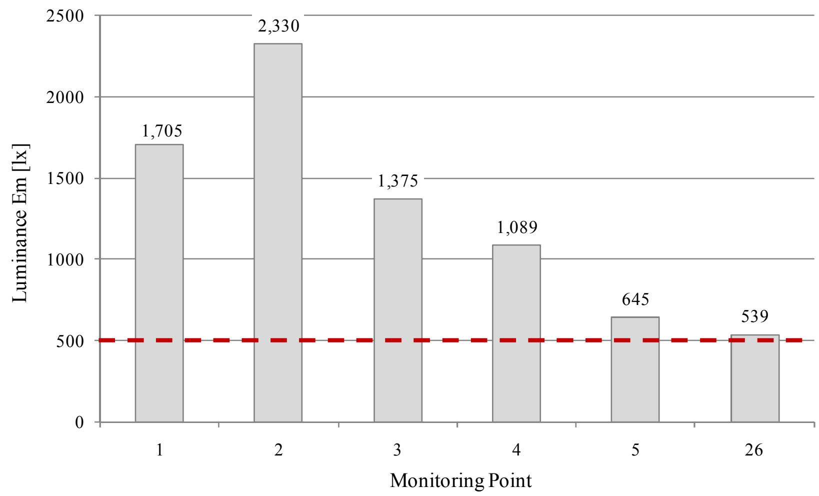


Figure 2.1.25.12 – Average value of Luminance monitored in the analyzed room.

Comments of the occupants

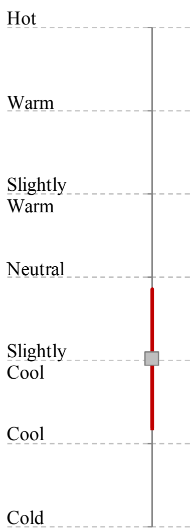
- Indoor climate is fine. Sometimes a little cold, but better that than too hot. The only annoyance is sometimes strong smell of food from the kitchen, but it should be resolved.

- Never mind if the climate it's cold or hot, we can never agree, but there are features certain locations in the building where the temperature is a problem and it is very annoying. It is better solve these problem before to become sick.

- It is generally very good.

First Floor - Room 2.2.00

Figure 2.2.00.1/2 – Room 2.2.00 evidenced on the First floor (1) and position of the occupants that filled the questionnaires (2).



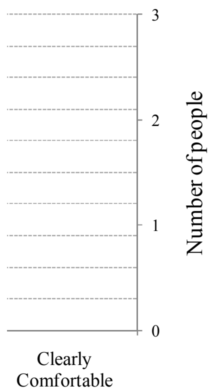
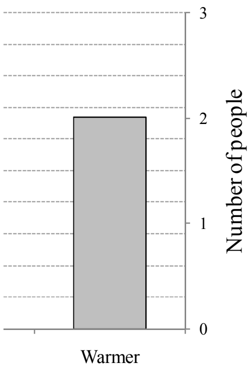


Figure 2.2.00.1/2 – Thermal sensation (1) and Average thermal indoor climate in the room (2).



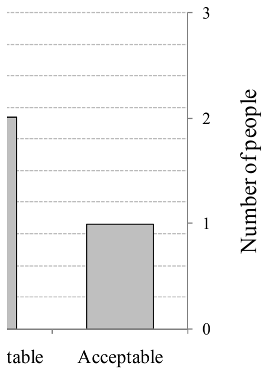


Figure 2.2.00.3/4 – Preference of thermal indoor climate in the room (3) and assessment of the thermal environment (4).

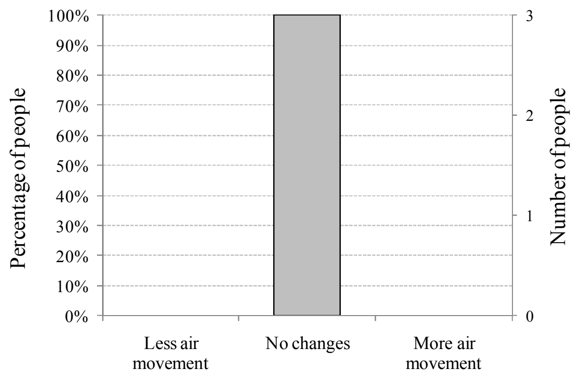


Figure 2.2.00.5 – Preference of air movement around the occupants.

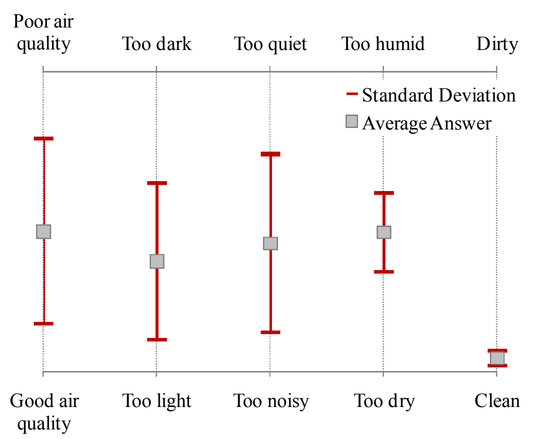


Figure 2.2.00.6 – Environment factors perceived by the occupants in the room.

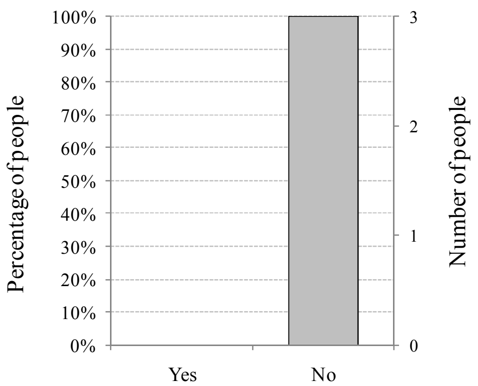


Figure 2.2.00.7 – Occupants affected by respiratory disorders.

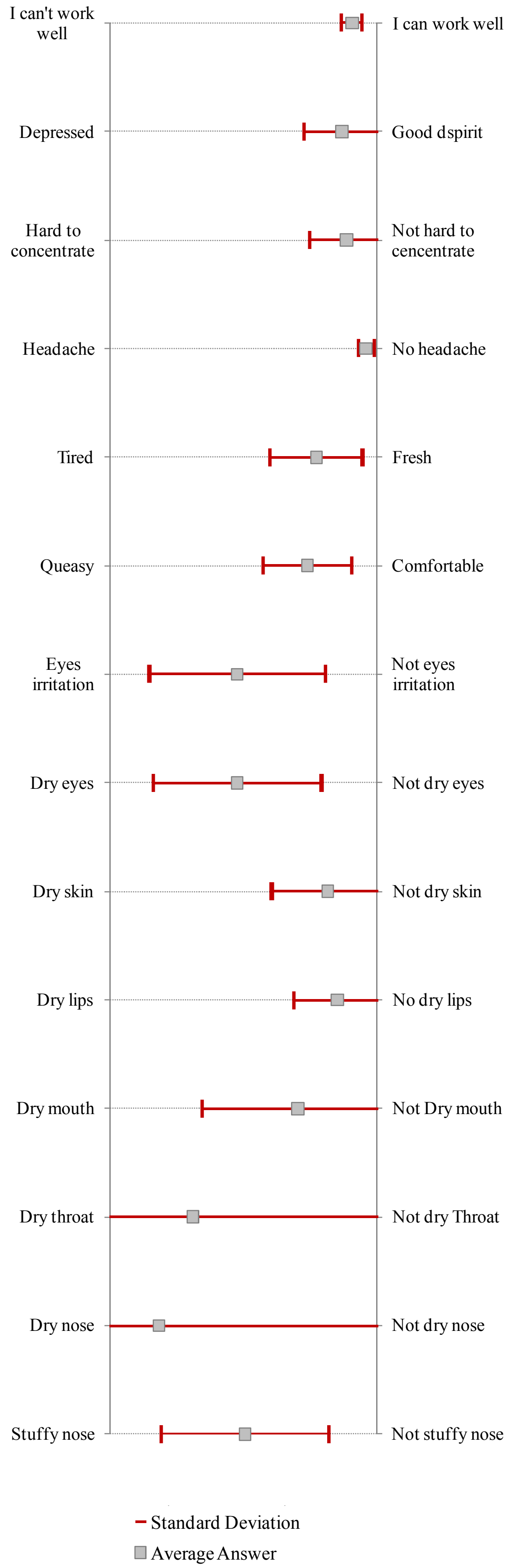


Figure 2.2.00.8 – Symptoms perceived by the occupants in the room.

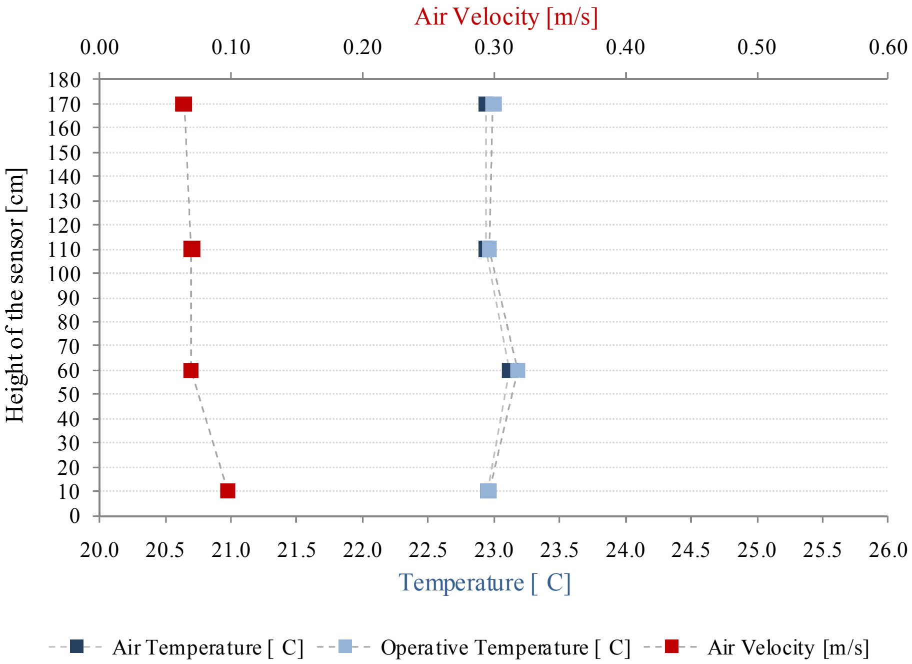


Figure 2.2.00.9 – Average value of Air Temperature, Operative Temperature and Air Velocity at different heights in the analyzed room.

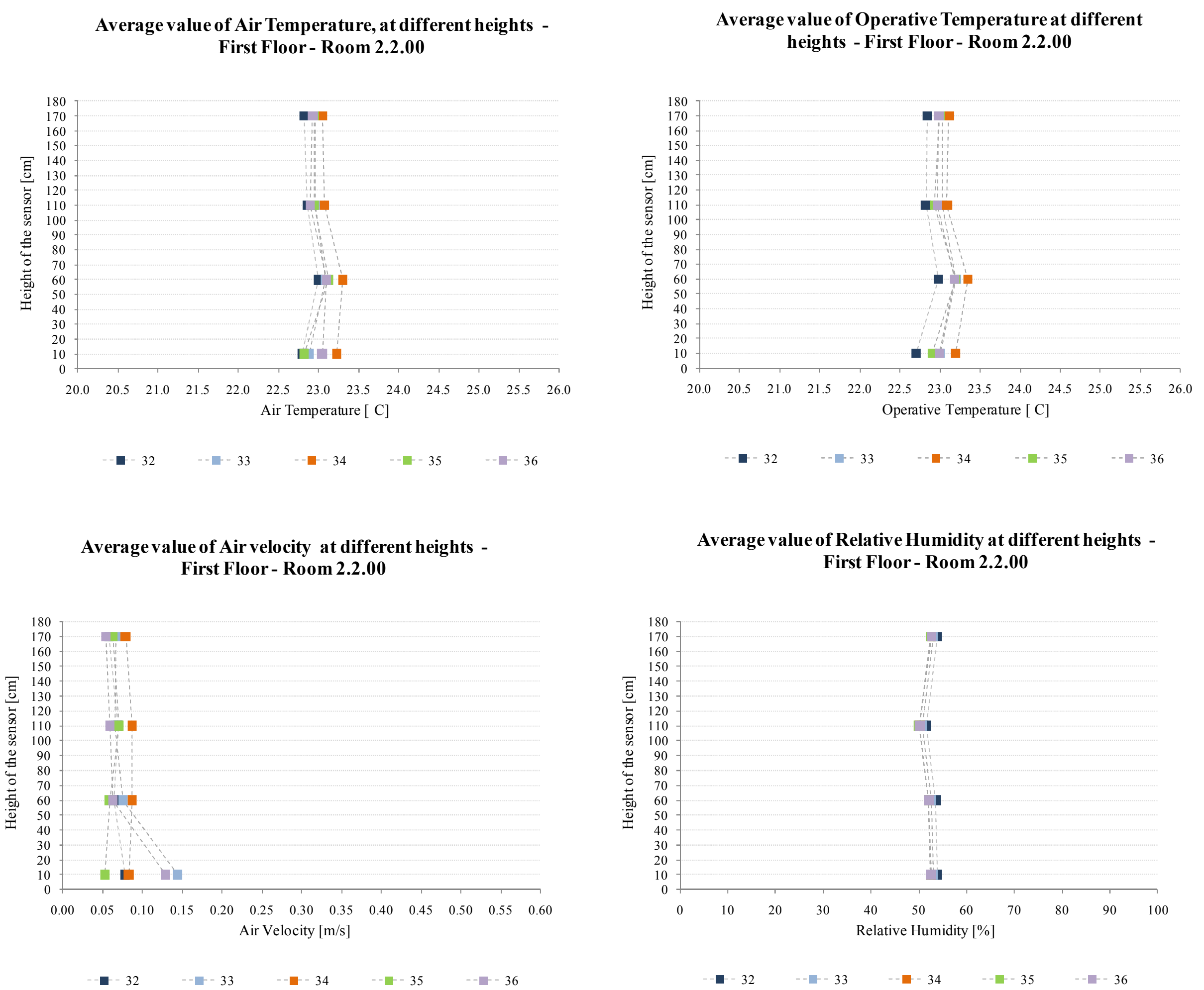


Figure 2.2.00.10 – Average value of Air Temperature, Operative Temperature, Air Velocity and Relative at different heights for the monitored points.

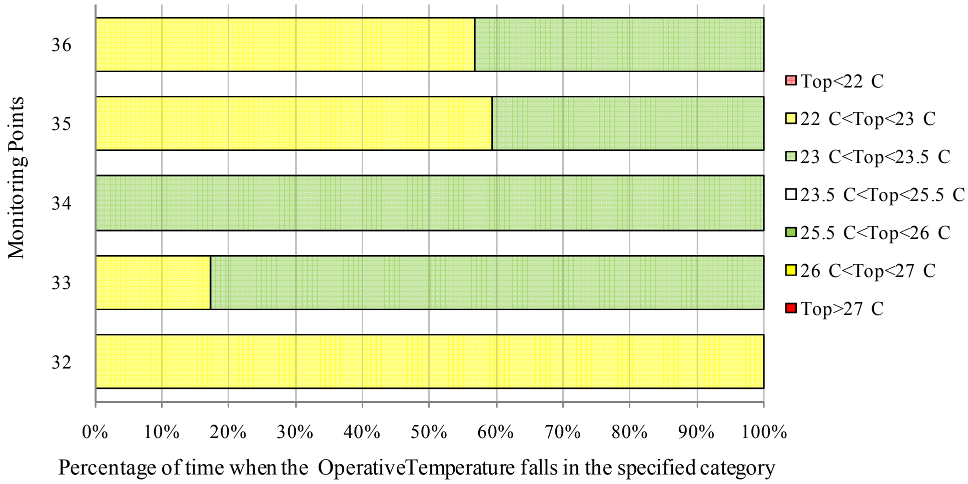


Figure 2.2.00.11 – Percentage of time when the Operative Temperature falls in the specified categories.

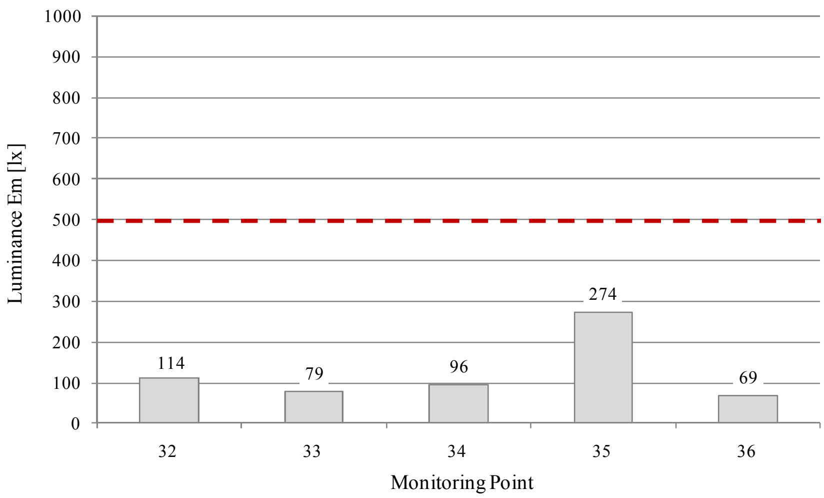


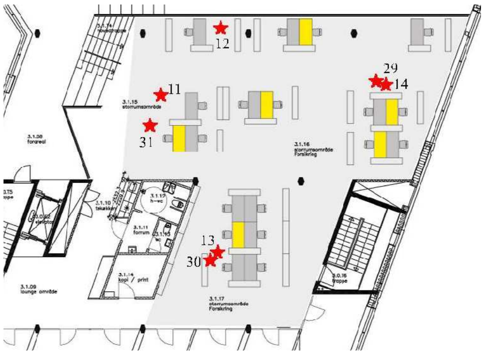
Figure 2.2.00.12 – Average value of Luminance monitored in the analyzed room.

Comments of the occupants

- The indoor climate in the meeting rooms are extremely poor. No ventilation, bad smell, too "stuffy / close", it rapidly becomes hot.

- Indoor environment is not only about the air: light - darkness, warmth and cold have a major influence, and sometimes they are very great inconvenience of the building.

Second Floor - Room 3.1.16 (Plateau 4)



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Points of monitoring
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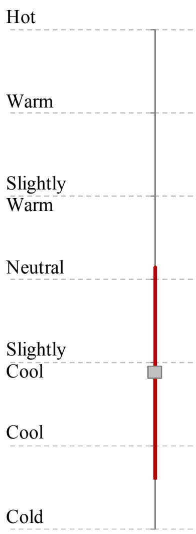
Figure 3.1.16.1/2 – Room 3.1.16 evidenced on the Second floor (1) and position of the occupants that filled the questionnaires (2).



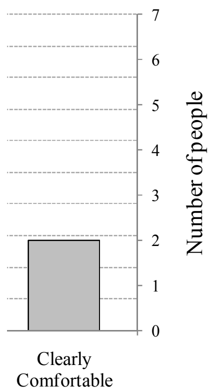
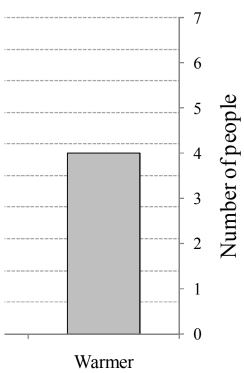


Figure 3.1.16.1/2 – Thermal sensation (1) and Average thermal indoor climate in the room (2).



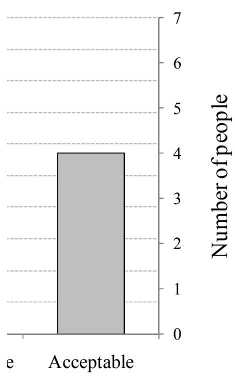


Figure 3.1.16.3/4 – Preference of thermal indoor climate in the room (3) and assessment of the thermal environment (4).

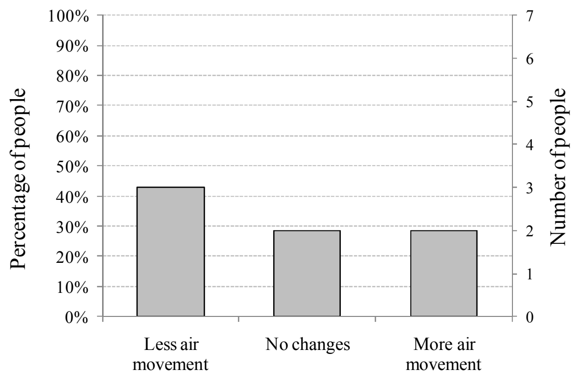


Figure 3.1.16.5 – Preference of air movement around the occupants.

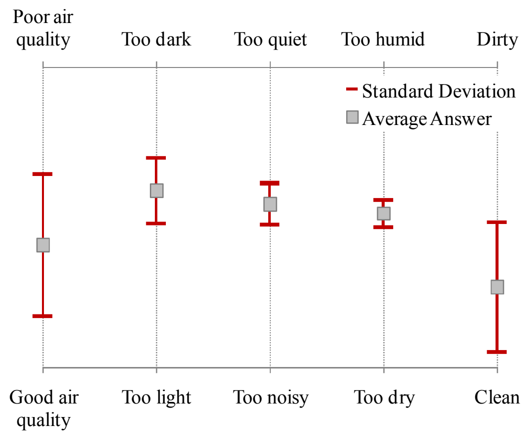


Figure 3.1.16.6 – Environment factors perceived by the occupants in the room.

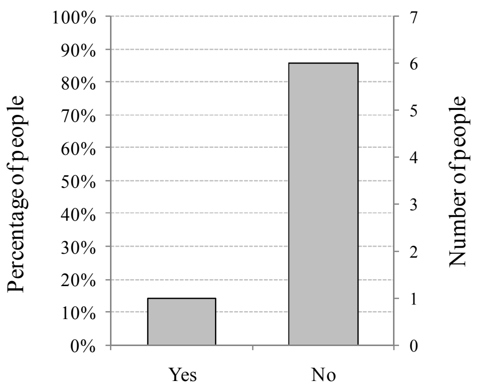


Figure 3.1.16.7 – Occupants affected by respiratory disorders.

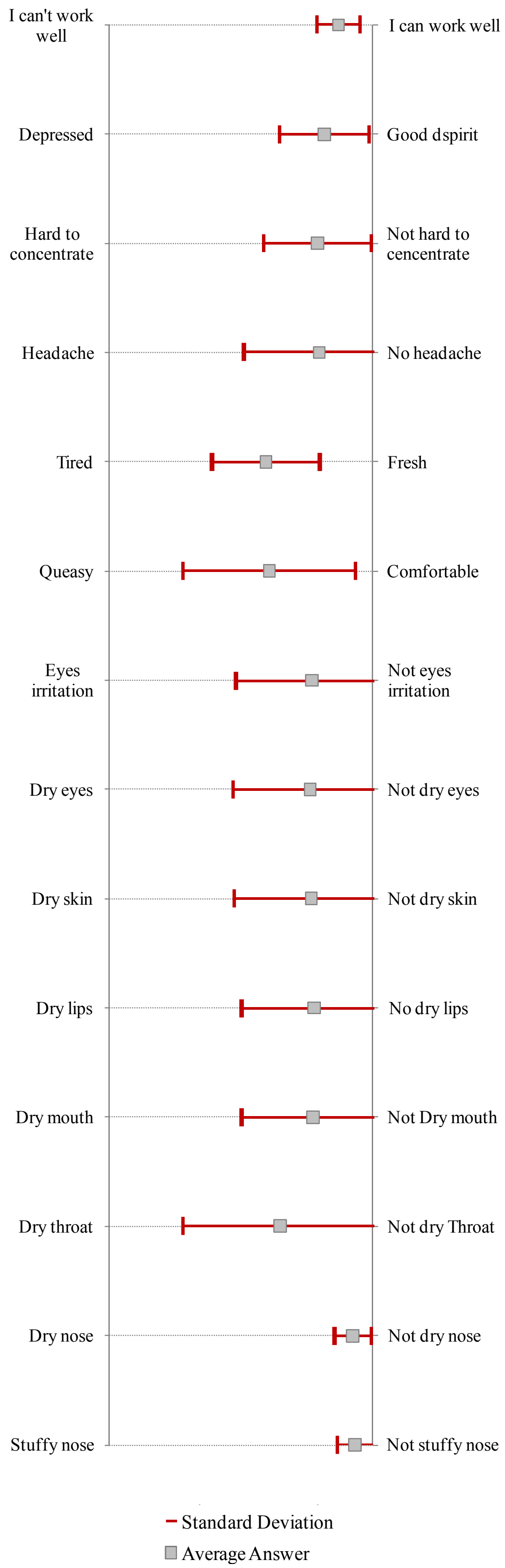


Figure 3.1.16.8 – Symptoms perceived by the occupants in the room.

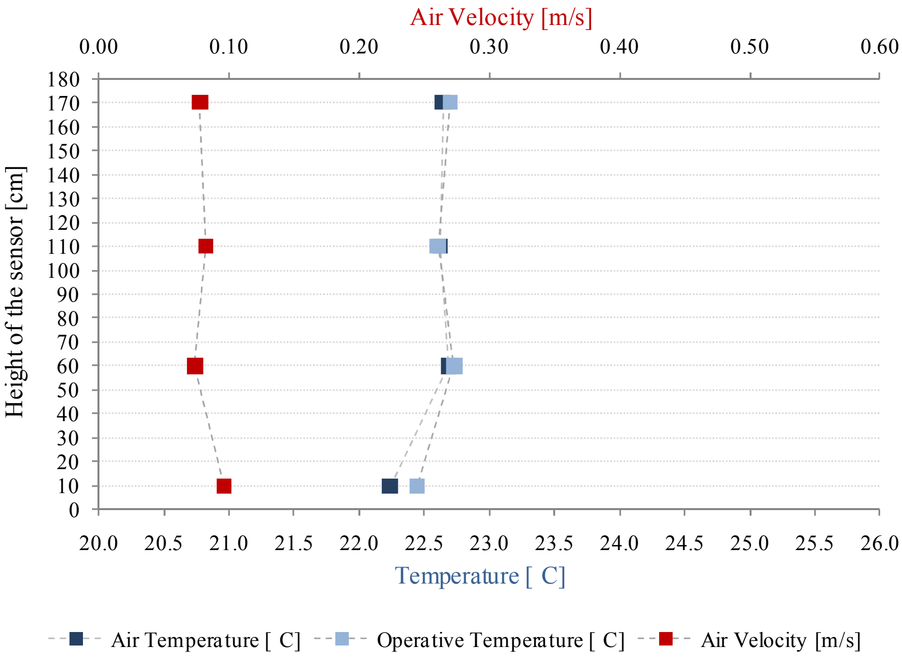


Figure 3.1.16.9 – Average value of Air Temperature, Operative Temperature and Air Velocity at different heights in the analyzed room.

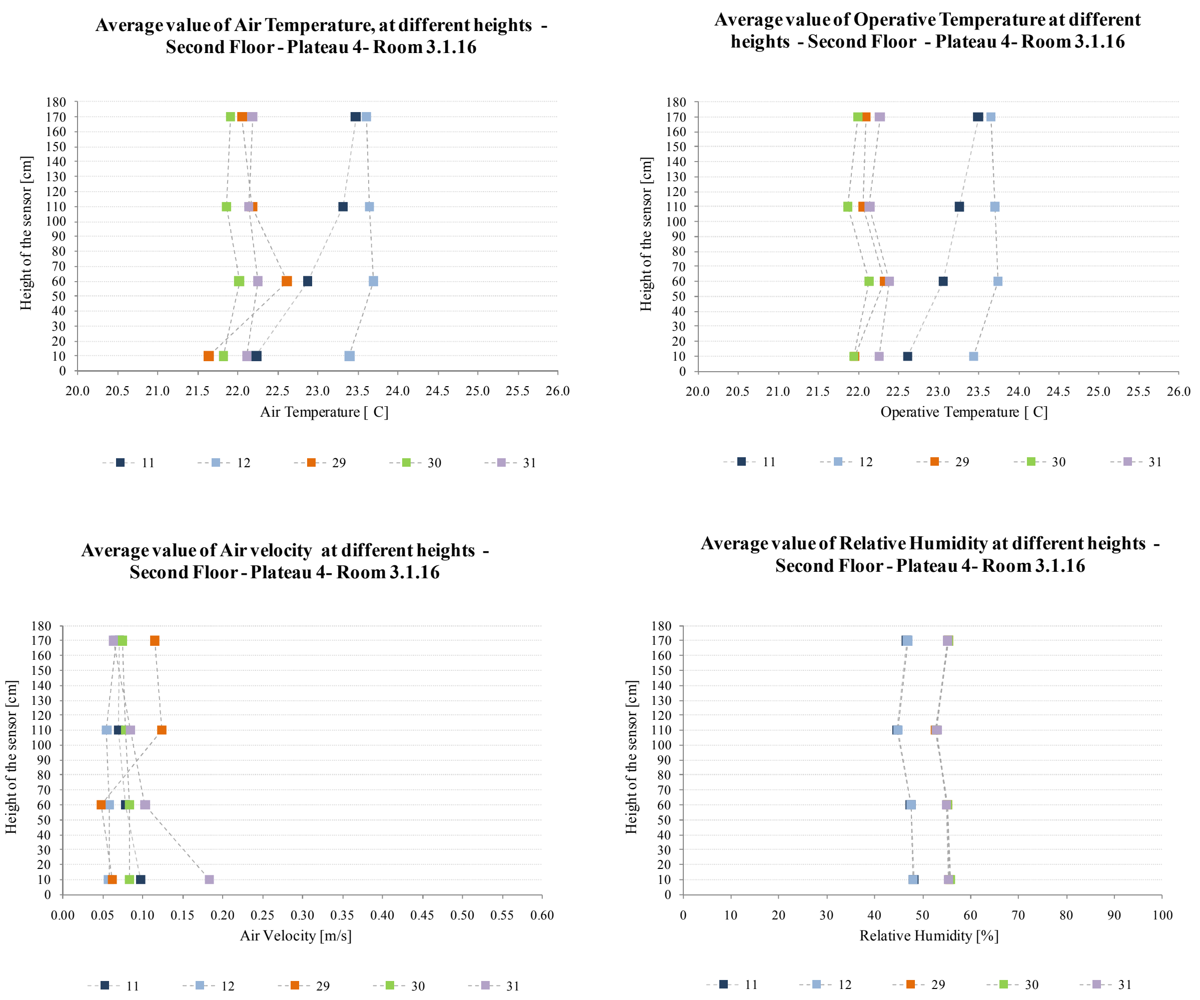


Figure 3.1.16.10 – Average value of Air Temperature, Operative Temperature, Air Velocity and Relative at different heights for the monitored points.

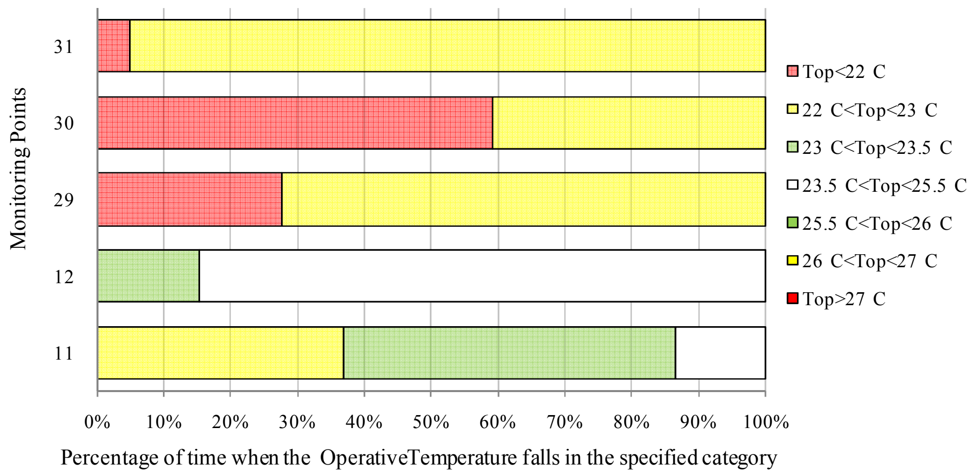


Figure 3.1.16.11 – Percentage of time when the Operative Temperature falls in the specified categories.

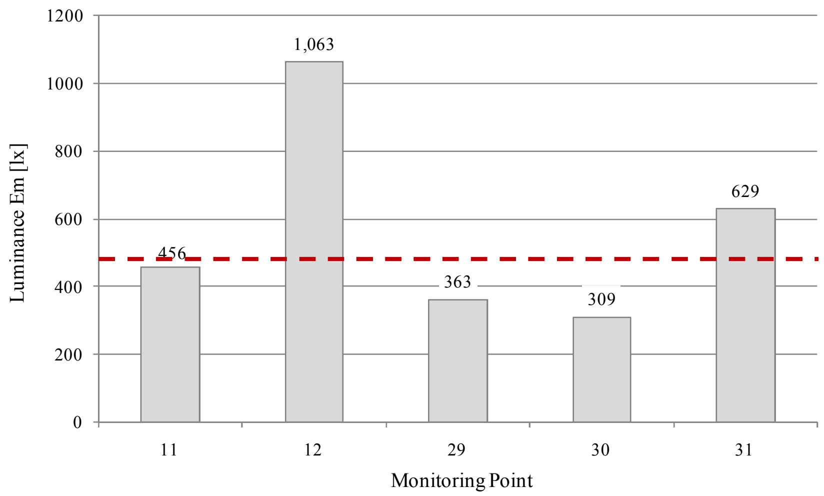


Figure 3.1.16.12 – Average value of Luminance monitored in the analyzed room.

Comments of the occupants

- In the recent days it was cold here. But It can also be very hot if it is sunny.
- Exactly today, the indoor temperature is very coo,l and there is a tendency to reduce it. For a long time we've had very hot and uncomfortable pressure, which has given me some headaches and simultaneously it has definitely reduced the pace of work.
- On sunny days, temperature is often too high, and stagnant air.
- This week, the climate has been a completely different than in recent months. In these days we freeze, and the system is still working. Two weeks ago, and most of the summer we have been in very hot, stagnant air.

International Center for Indoor Environment and Energy

Technical University of Denmark

Winter Thermal comfort assessment in Middelfart Sparekasse.

March 22-23, 2011

Physical measurements of the thermal environment and Subjective response of the occupants

DTU, 23/05/2011

Professor B.W. Olesen

PhD student D. Raimondo

Summary

1- INTRODUCTION

The work presented in this report shows the thermal comfort and air quality assessment conducted in March 2011 in terms of both physical analysis and subjective answers of the occupant in the Middelfart Sparekasse building.

A similar analysis was conducted in 2007 in the old headquarters of Middelfart Savings Bank, and the future step of this work will be the comparison between the results obtained during the monitoring campaign in the old building and the results deriving from the analysis in the new offices.

The monitoring data elaborated and here presented come from three different survey methods:

- Long term monitoring
- Spot measurements
- Questionnaires

Long term monitoring

The Long term monitoring is conducted in the building continuously during the whole year. Air temperature and CO_2 sensors are installed in the building in strategically positions, and connected with an external weather station, they have an essential role in the thermal and air quality systems controls. Heating, cooling and ventilation systems are in fact controlled by the environmental parameters in the rooms and even on the basis of the weather conditions. Operative temperature sensors have been installed in the most representative rooms of the building from January, 2011. All the instruments collect data every 10 minutes.
In this study only data from March 07 to March 26 are shown.

Spot measurements

The short measurement took place March 2011, Tuesday 22 and Wednesday 23, during the working hours. The monitored parameters are air temperature, operative temperature, air velocity, relative humidity and luminance. The luminance, were measured only with one sensor at the height of 0.6 m (work plane position), while all the other parameters were monitored at four different heights: 0.10 m (height of the ankles), 0.60 m (height of the body for a seated person), 1.10 m (height of the body of a stand person) and 1.70 (height of the head of a stand person).

Questionnaires

During the spot measurements people were asked to fill subjective questionnaire about the comfort sensation, in terms of thermal quality, air quality, light, noise and about the symptoms perceived in the room. More detailed information are described in the following paragraphs.

2- PHYSICAL MEASUREMENTS CONDUCTED FROM MARCH 7 TO MARCH 26, 2011

As introduced in paragraph 1, long term monitoring are conducted continuously in most of the rooms of the building. This study shows just data collected from a short period. In particular, from figure 1 to 5, three weeks of monitoring are shown. In all the figures, the dashed square highlights the days when also the spot measurement took place.

Figure 1 and 2 show outside air temperature, relative humidity and solar radiation. A weather station positioned outside the bank monitors in continuous the weather parameters. The natural ventilation, heating and cooling systems control take into account the outside environment conditions. A vents system opens and closes comparing indoor and outdoor temperature and when CO_2 concentration inside the room exceeds a certain level.

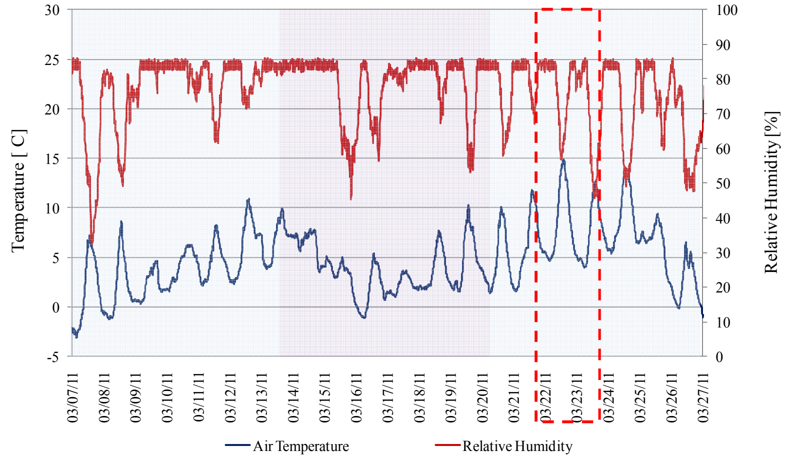


Figure 1 - Outside Air Temperature [°C] and Relative Humidity [%] monitored from Monday 03/07/2011 to Sunday 03/26/2011.

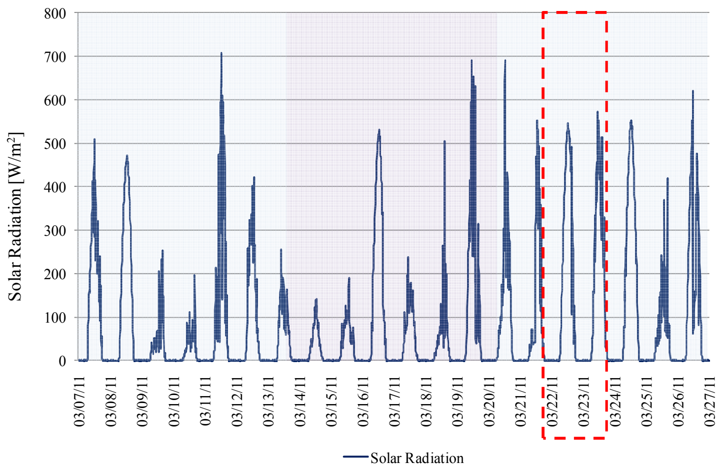


Figure 2 - Solar Radiation [W/m^2] monitored from Monday 03/07/2011 to Sunday 03/26/2011.

From figure 1 it is possible to see that the outside air temperature during the day was quite high for being winter period, because they refer about March days (end of winter). In particular, during the two days when also spot measurements were performed, the outside temperature reached the highest peak of the monitoring period. Figure 2 shows that also the solar radiation, during the last week of monitoring, presented high values (sunny days).

Inside the building the air temperature profiles highlight that heating and cooling systems kept the temperature almost constant during the three weeks. The analysis does not reveal the influence of outside temperature on the ground floor temperature (Fig. 3), while a minimum difference in air temperature is visible in the first and second floor (Fig. 4-5). Similar observation can be done looking at the operative temperature profiles, which have big fluctuations in particular on the second floor between day and night, and during the two days of spot monitoring.
The average ground floor air temperature was higher respect to the first and second floors average air temperature. This is probably due at the rooms' shape and volume: both the three rooms are office open space, but while for the two plateaus the ceiling is directly represented from the roof of the building, the ground floor ceiling is positioned at about 3 meters far from the floor.

The CO_2 concentration profiles show lower values during the two days of spot monitoring respect to the other days. This fact is probably due by the air vents that were opened in these particular days for cooling the air inside the building using the outside fresh air. The average value of CO_2 during the working hours can be considered always acceptable because, a part some peaks, it was always lower than 850 ppm.

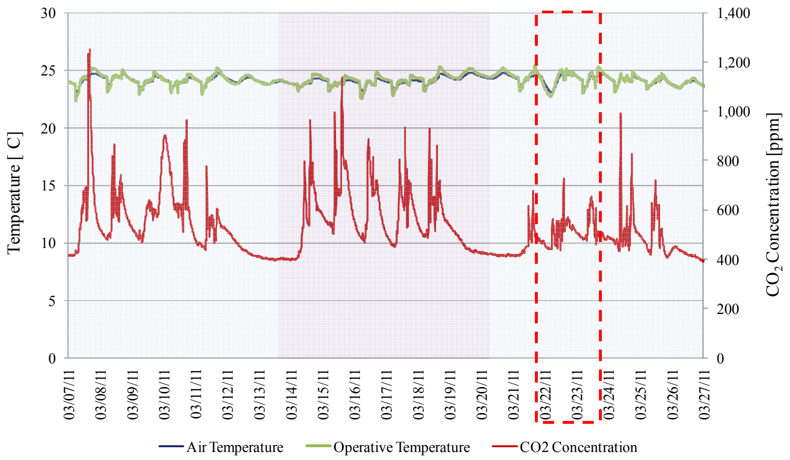


Figure 3 - Air Temperature [°C], Operative Temperature and CO_2 Concentration [ppm] monitored from Monday 03/07/2011 to Sunday 03/26/2011 on the Ground Floor (Open space, room 1.1.00).

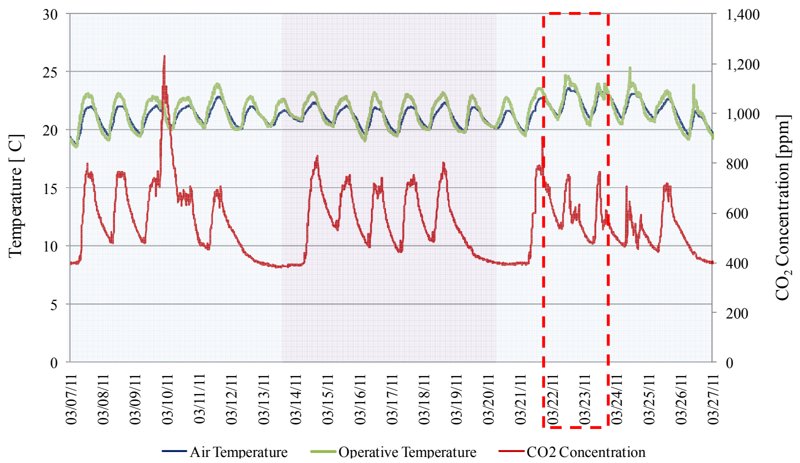


Figure 4 - Air Temperature [°C], Operative Temperature and CO_2 Concentration [ppm] monitored from Monday 03/07/2011 to Sunday 03/28/2011 on the First Floor (Plateau 1, room 2.1.23).

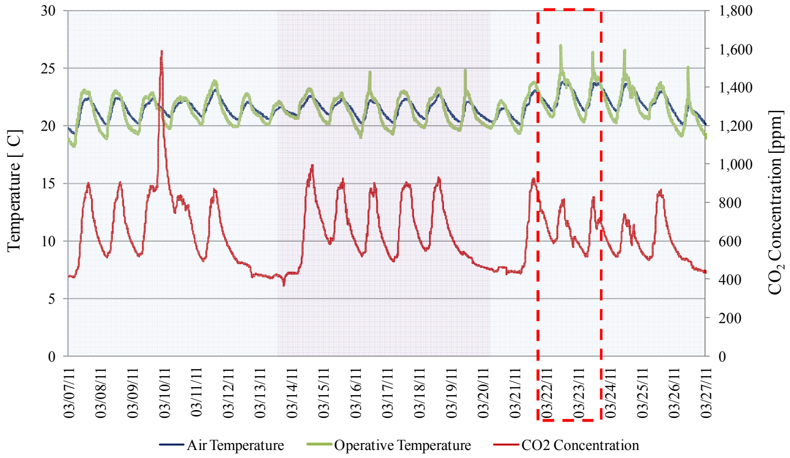


Figure 5 - Air Temperature [°C], Operative Temperature and CO_2 Concentration [ppm] monitored from Monday 03/07/2011 to Sunday 03/26/2011 on the Second Floor (Plateau 4, room 3.1.16).

3- Spot measurements. March 22-23, 2011

The Spot measurements consist in the data collection of different parameters for a short period (about 15 minutes) in representative points of the analyzed rooms. These parameters, as already explained in the first paragraph and then showed from figure 6 to 10, are: air temperature, operative temperature, air velocity, relative humidity and lighting. All these parameters, but lighting, were monitored at four different heights. The values represented in the figures are average values for each room. Just the main rooms of the building are showed in this paragraph while results of other analyzed rooms are illustrated in the Annexes. These main rooms are:

- Room 1.1.00 – Ground Floor
- Room 1.4.00 – Ground Floor
- Room 2.1.23 – First Floor, Plateau 1
- Room 2.1.25 – Firs Floor, Plateau 2
- Room 2.2.00 – Firs Floor
- Room 3.1.16 – Second Floor, Plateau 4

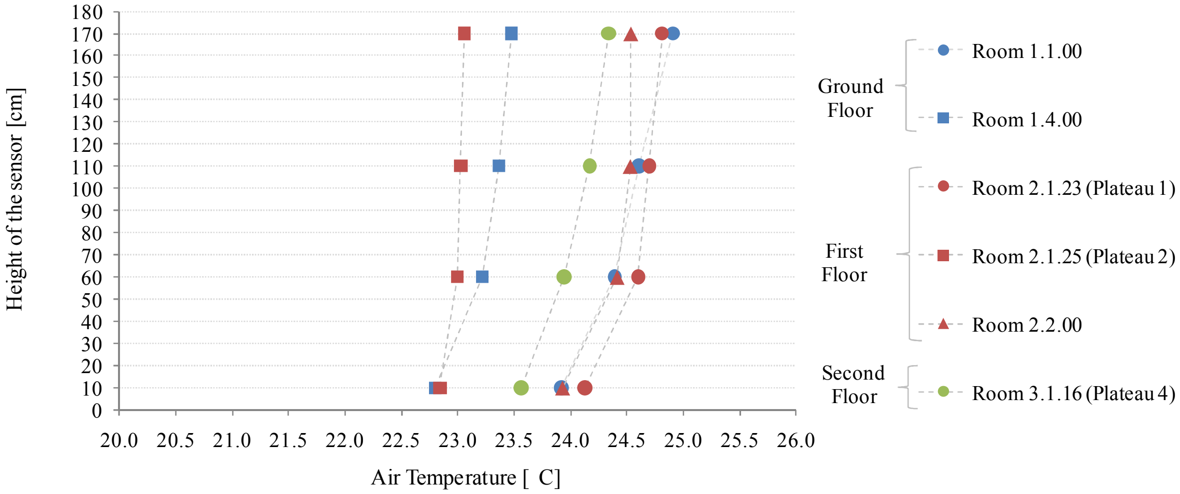


Figure 6 - Average value of Air Temperature [°C] at different heights in the analyzed rooms.

Figures 6 and 7 shows average values of, respectively, air and operative temperature. The results show that air temperature, in all cases, increased with height sensors. The operative temperature, instead, increased until 1.1 m, and then, but not in all cases, decreased a little. Contrarily at what was written in paragraph 2, where the air temperature was monitored with a single sensor positioned in the center of the rooms at 1.7m, from this more accurate data the same difference of temperature between the office Plateau 1 on the first floor and the office open space on the ground floor cannot be seen. This aspect can derive by the fact that the time of monitoring of these parameters was really short and took place in different hours of the day.

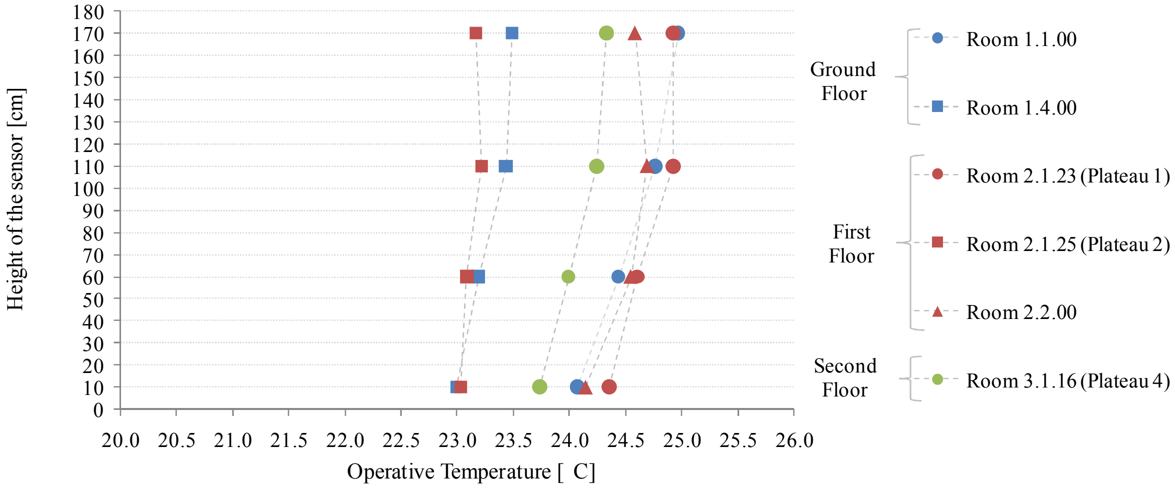


Figure 7 - Average value of Operative Temperature [°C] at different heights in the analyzed rooms.

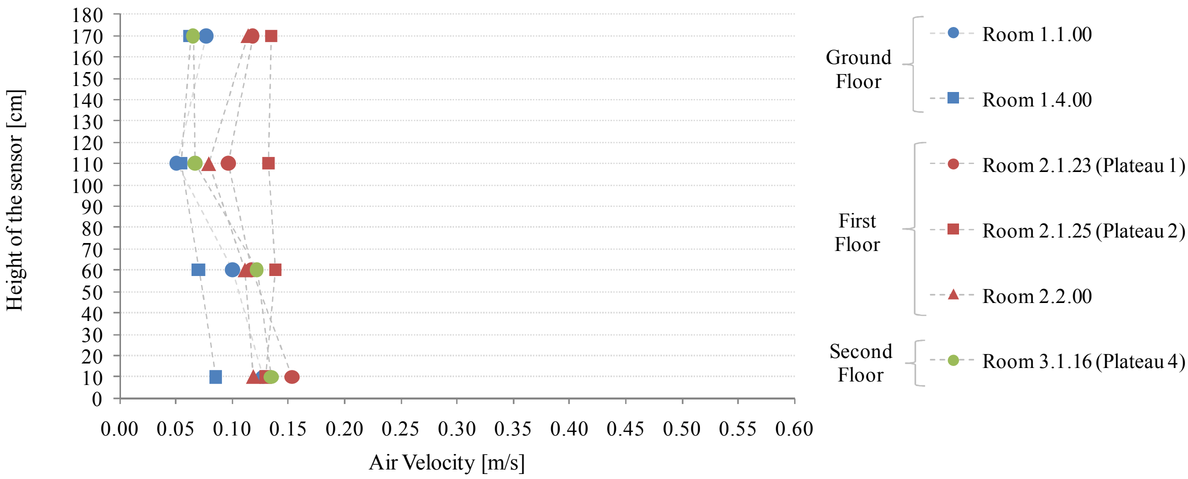


Figure 8 - Average value of Air Velocity [m/s] at different heights in the analyzed rooms.

The air velocity, in all the cases but Plateau 2, was higher at the height of 0.1m and 0.6m, were usually the value exceeded 0.10 m/s. From figure 8 is possible to highlight that in general the air velocity had higher values in the rooms at the first floor than in the rooms at the ground floor. In both cases the little offices presented lower values than the open spaces. On Plateau 2 the air velocity was higher than in all the other cases except at 0.1m. On the second floor there was the biggest difference of air velocity between the 4 monitored points: the air velocity decreased with the height sensors.

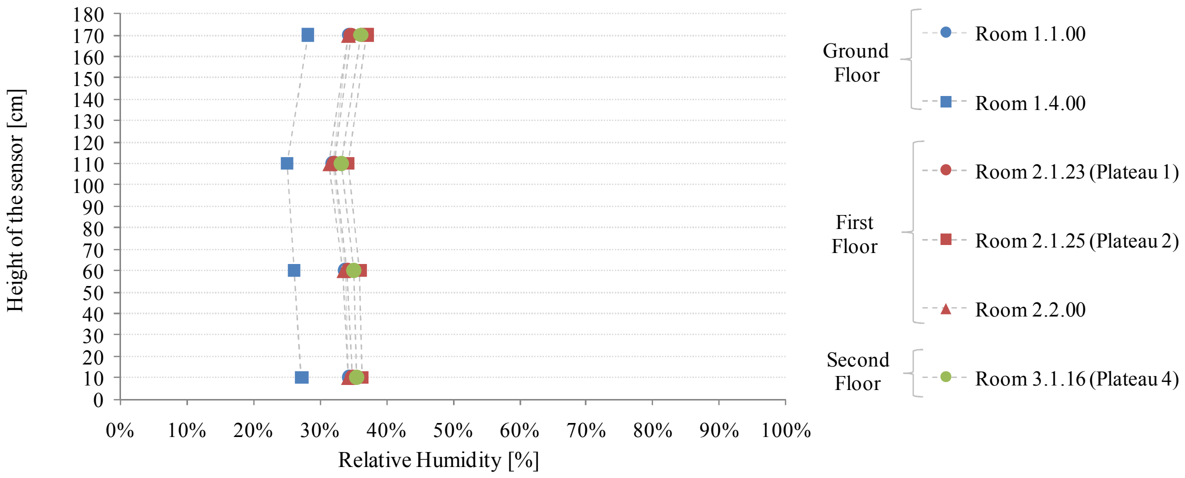


Figure 9 - Average value of Relative Humidity [%] at different heights in the analyzed rooms.

The relative humidity (Fig.9) present almost the same values in all the rooms and at the different heights. The average values fall in a range between 30% and 40%.

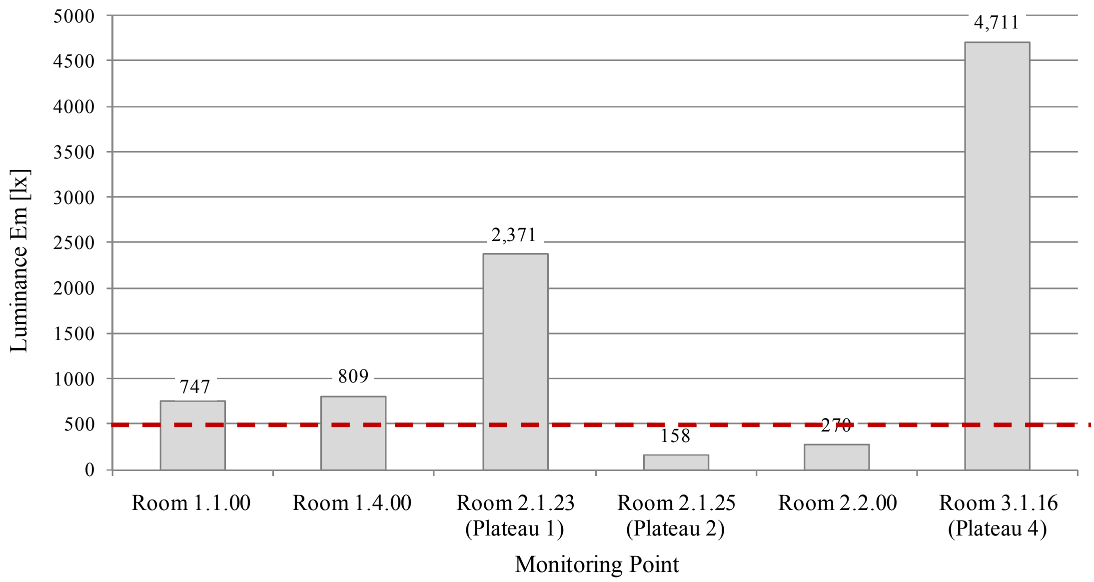


Figure 10 - Average value of Luminance [lx] in the analyzed rooms.

Figure 10 shows the different average levels of luminance in the rooms measured at the high of 0.6m. The minimum value required from standard EN15251, for office buildings, is 500 [lx]. The values of luminance on the ground floor were quite good, but it was not the same for Plateau 2 and for office 2.2.0, where the value were lower than 300 [lx]. On Plateau 1 and Plateau 4 high value of luminance were monitored. These value don’t represent the average value during a day, but just during the monitoring time: probably the average for a day could be different in both cases.

4- Subjective evaluation (questionnaires) March 22-23, 2011

Occupants in the rooms were asked to fill some questionnaire about the subjective evaluation of the environment at the same time when the spot measurements were performed. Results about this analysis are shown in this paragraph.

People were furthermore asked to give information about the clothes that they were wearing, age, sex, height, weight and position of their desk in the room. With some of these data and with the physical measurements, it has been possible to calculate the Predicted mean vote (PMV) and the Percentage of dissatisfied (PPD) in the rooms. The PMV index predicts the mean response of a large group of people according to ASHRAE thermal sensation scale, where:

- +3 hot
- +2 warm
- +1 slightly warm
- 0 neutral
- -1 slightly cool
- -2 cool
- -3 cold

The PPD index, on the other hand, predicts the percentage of large group of people likely to feel "too warm" or "too cool".

From the questionnaires, then, subjective evaluation about the thermal comfort was performed. The comparison between result from questionnaires and from indexes calculation is shown in Table 1.

Table 1 - Subjective evaluation, Predicted Mean Vote and Predicted Percentage of Dissatisfied for the analyzed rooms.

Floor	Room	Number of People	Icl [clo]	Average Subjective response	Calculated PMV (0.6 m)	Calculated PPD (0.6 m)
Ground Floor	1.1.00	18	0.73	1.15	-0.57	11.92
	1.4.00	4	0.62	0.72	0.02	5.01
First Floor	2.1.23 Plateau 1	9	0.83	0.26	0.18	5.65
	2.1.25 Plateau 2	9	0.84	0.26	-0.25	6.28
	2.2.00	7	0.79	1.09	0.11	5.25
Second Floor	3.1.16 Plateau 4	9	0.82	1.35	-0.10	5.20

Table 1 shows that in all the rooms the average clothing value was between 0.62 and 0.84 [clo]. Usually, in winter period, the value suggested by the standards is 1 [clo], while is 0.5 [clo] in summer. Being still in winter period, the calculated values of Icl can be justified considering the high external temperature during these 2 days.

The calculated average PMV value predicts a good thermal environment: between neutral and slightly cool in room 1.4.00 and Plateau 2, and almost around the neutral sensation for all the other rooms.

The average value deriving from the subjective response denote that in all rooms occupants felt the environment slightly warm or between slightly warm and warm. Probably these results derive by the fact that during these days the outside temperature was hotter than in the previous weeks and people expected lower temperature inside the rooms.

The subjective response with the relative standard deviation according to the thermal sensation scale is shown in figure 11.

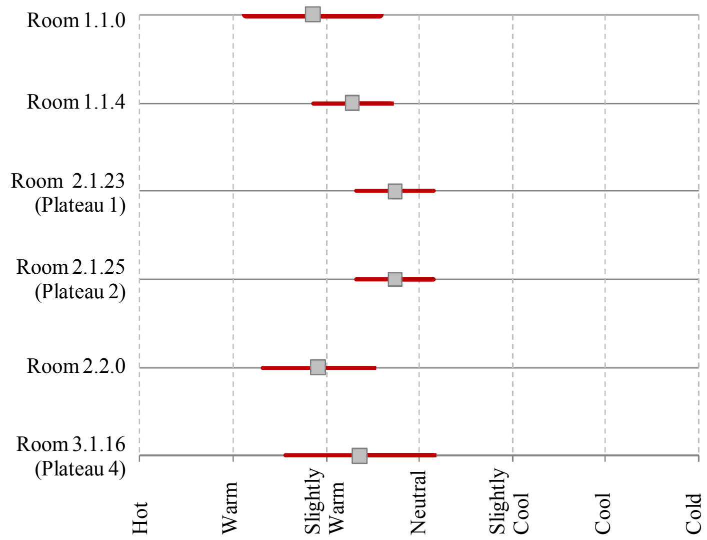


Figure 11 - Thermal sensation in the different analyzed rooms.

People were then asked about the thermal indoor climate perceived from their workstation. The answers range was from Clearly Comfortable to Clearly Uncomfortable. The occupants' average answer is shown in figure 12. On Plateau 1 and on Plateau 2 the employees were apparently more satisfied than in the other rooms. Same result is evident in figure 11, where the thermal sensation of these two rooms was close to neutrality. Similar comparison can be done for the room 1.1.00 where the percentage of people dissatisfied in the room felt the environment too warm.

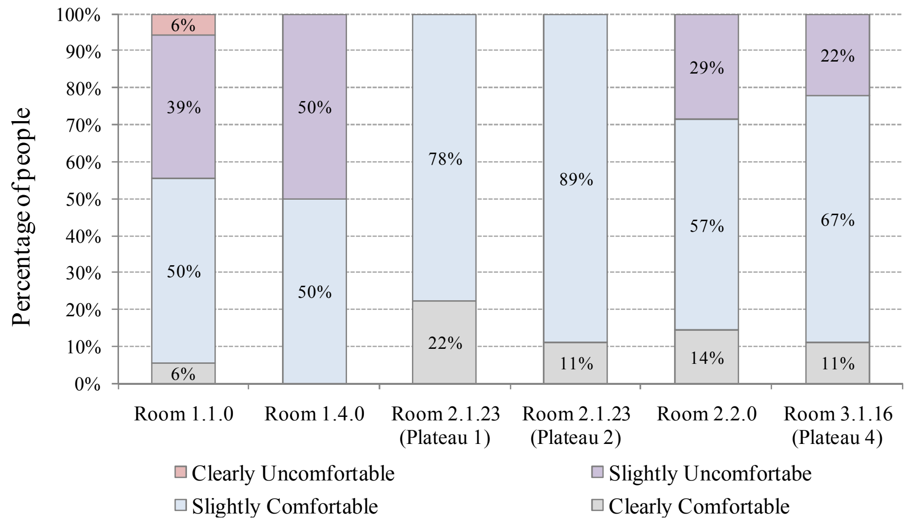


Figure 12 - Average thermal indoor climate in the rooms.

At the question “How would you prefer the temperature if you could choose?” (Fig.13), the answers highlight that less than half of the occupants would prefer a lower temperature, while more than half would not change anything. Just in room 2.2.00 there is a percentage of people that would prefer higher temperature, but looking at the specific schedule about that room in paragraph 6, Annex a.v, this percentage represent the evaluation of only one person. At the question about the assessment of thermal environment (Fig. 14), in room 2.2.00 the same person evaluated the thermal environment not acceptable, while all the other people evaluated it acceptable. Also in room 1.1.00 the 28% of the occupants evaluate the thermal environment not acceptable, and this confirms the same results showed in figure 12, where just in that specific room some people described the thermal environment Clearly Uncomfortable.

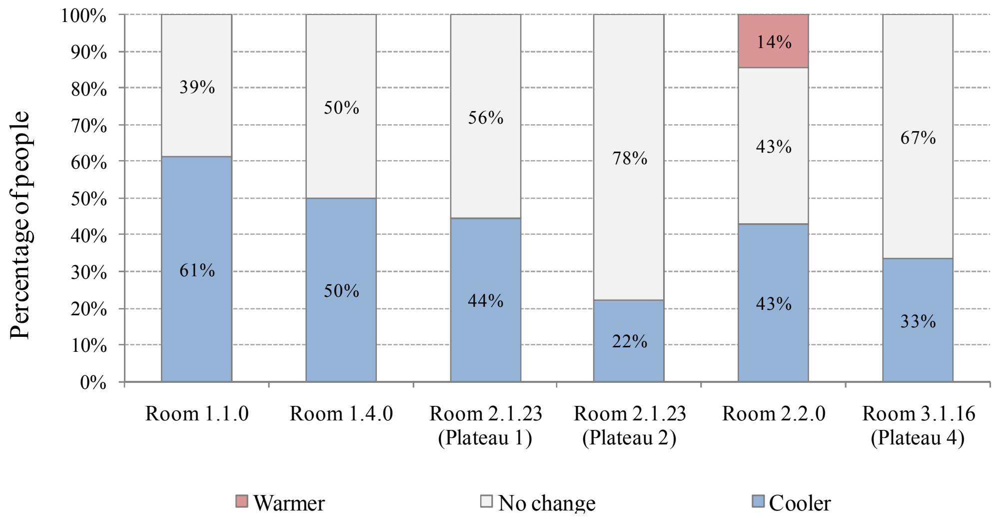


Figure 13- Preference of thermal indoor climate in the rooms.

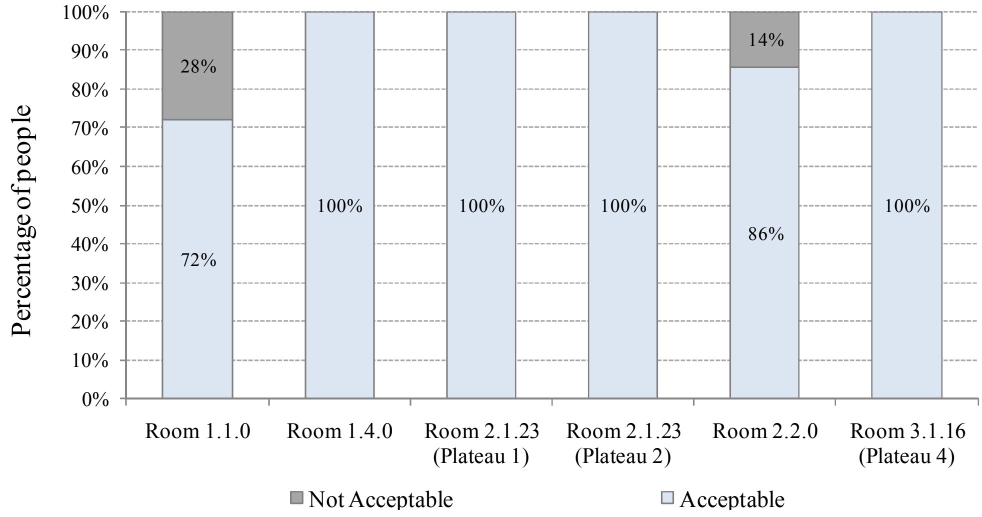


Figure 14 - Assessment of the thermal environment.

At the question about air movement assessment around the workplace (Fig.15) most of the people answered that no changes were needed. A parte Plateau 2 and Plateau 4, where in both cases one person would prefer less air movement, in general people is satisfied or would prefer to increase the air movements. Just in room 1.4.00 all occupants would like to have more air movement, while on Plateau 1 the air movement is considered acceptable by all the occupants.

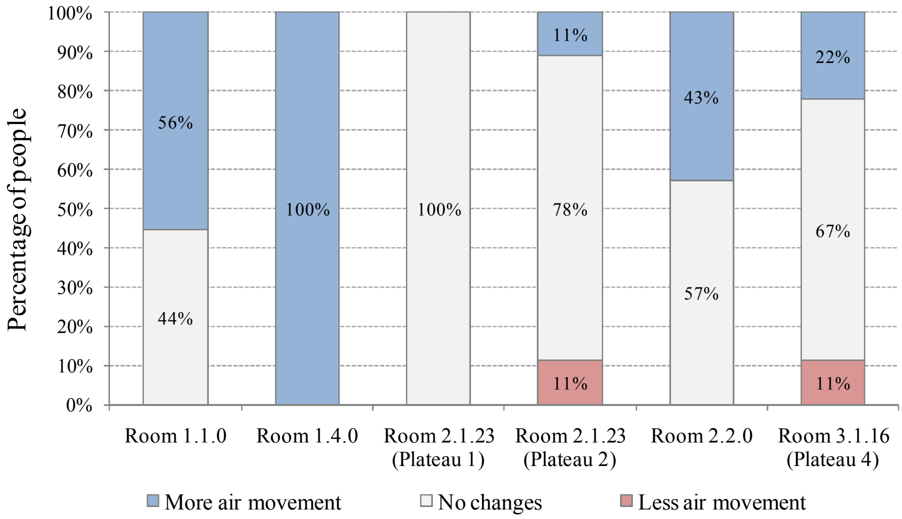


Figure 15 - Preference of air movement around the occupants in the different rooms.

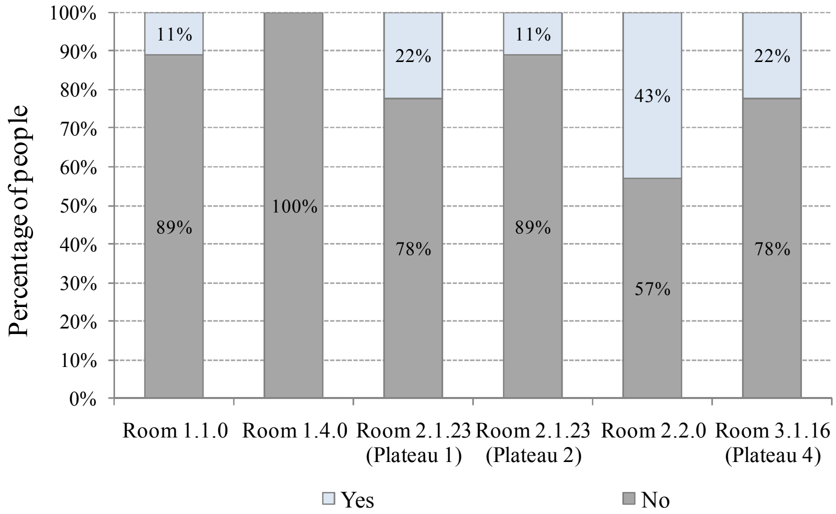


Figure 16 – Occupants affected by respiratory disorders in the different analyzed rooms.

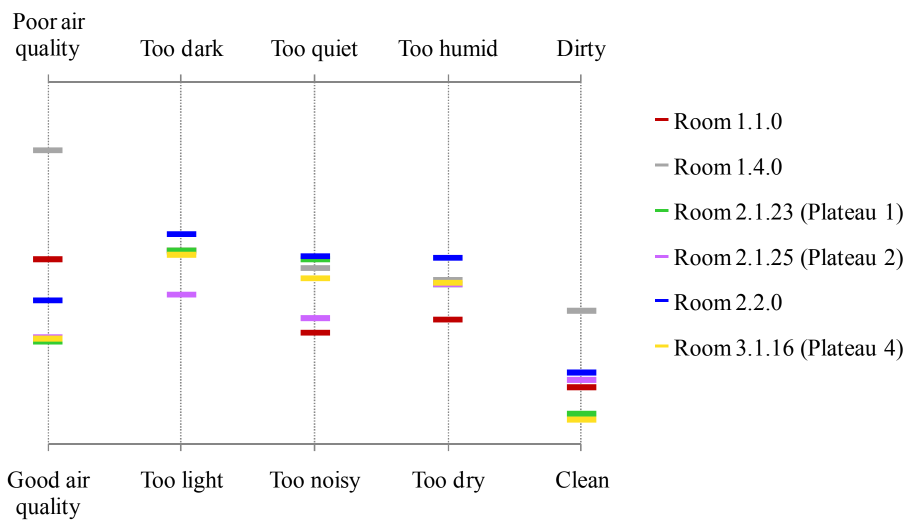


Figure 17 – Environment factors perceived by the occupants in the rooms.

In room 1.1.00 the all the satisfied people were sitting in the same area of the room, close to the main entrance of the building (big empty volume were reception desks were situated). Occupants that felt discomfort were situated in the back of the room (far from doors and from big empty spaces). The same consideration cannot be done for the room 2.2.00. In fact there, people that would prefer more air movements were sit in different part of the office.

Form figure 16 emerge that most of the people in the building was not affected by respiratory disorders. In all the room, but 1.4.00, a little percentage of people that felt disturbs is evidenced. Just in room 2.2.00 this percentage is greater than 40%.

Figure 17 shows the environment factors perceived in the office by the occupants. In all the building the lighting level, the noise and the humidity were quite good. The average answers fall between the extreme situations (too light /too dark, too noisy/too quiet, too dry/too humid). The results also show that air in the rooms is perceived quite clean. Just room 1.4.00 presents an average evaluation that differs a little from the other rooms' evaluation. Similar thing happens evaluating the air quality, where in the room 1.4.00 the air has been evaluated quite poor, while in all the other rooms it tend to be pretty good (but not good).

Symptoms perceived by occupants in the rooms are shown in figure 18. On the upper axis of the figure negative perceptions of the symptoms are shown, while positives are on the lower axis. All the average values fall, for all the rooms, in the positive lower part of the graph. Lips and skin were perceived by the occupants as the driest part of the body. From this evaluation emerge that in general people didn't have concentration problems, were in a good spirit, were not tired, didn't have headache, eyes irritation or other symptoms that could contribute to damage or slow down their work. To confirm this fact, the answers given by the employees at the last question, about the difficulty working well, clearly demonstrate that people could work well.

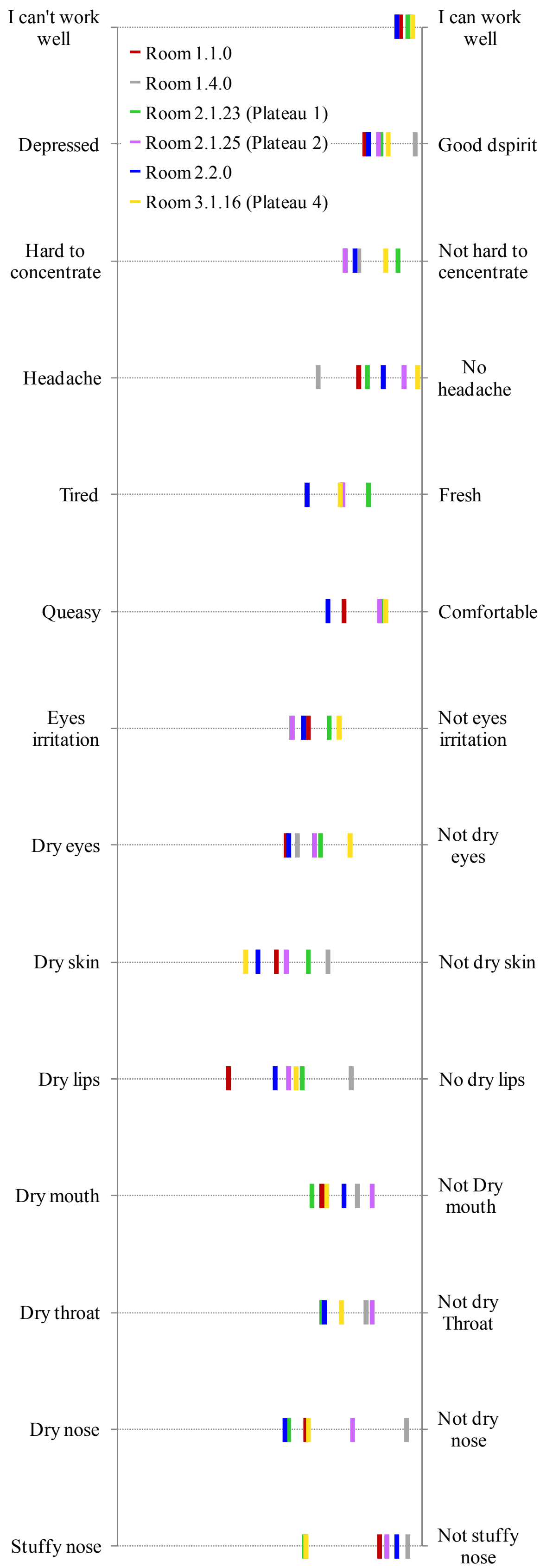


Figure 18 – Symptoms perceived by the occupants in the room.

5- ANALYSIS OF THE AREAS WHERE DRAUGHTS WERE SIGNALIZED

During the spot measurement some employees have complained that in some specified zone the perceived air movements were bigger than in other part of the building.

These areas are four in total and their analysis is shown below. In all the cases these zone are in proximity of stairs, that connect the different floors, or area with a lot of people traffic.

The analysis focuses on the air velocity assessment and on the air and operative temperature difference evaluation at different heights.

For each zone the analysis show the position of the monitored points and the data elaboration about the physical parameters monitored in the rooms: air velocity, air and operative temperature. For each point is indicated the monitoring period. For each parameter the average value collected by the sensor during the monitoring time is shown in a summary graph. In case values of air velocity were too high, an additional graph shows the air velocity profile for these specific points (usually at the height of 0.1 and 0.6 m). Also discomfort due to draught risk, as described in Standard 7730:2005, is shown for every monitored point.

Zone 1 - Ground Floor

Point	Time of monitoring start	end	minutes
17	23/03/11 10:16:00 AM	23/03/11 10:30:59 AM	15
18	23/03/11 10:37:00 AM	23/03/11 10:43:59 AM	7
29	23/03/11 02:20:00 PM	23/03/11 02:29:59 PM	10

Figure 19/Table 2 – Ground Floor (Room 1.1.00). Area with draught risk , position of monitored points and information about the monitoring time.

Table 3 –Average value of Air Temperature [°C], Operative Temperature [°C] and Air Velocity [m/s] at different heights for the three monitored points.

Height of the sensor	point 17			point 18			point 29		
	Air Temp. [°C]	Operative Temp. [°C]	Air Velocity [m/s]	Air Temp. [°C]	Operative Temp. [°C]	Air Velocity [m/s]	Air Temp. [°C]	Operative Temp. [°C]	Air Velocity [m/s]
170 cm	25.3	25.4	0.08	24.9	25.0	0.11	23.3	23.6	0.16
110 cm	25.0	25.2	0.05	24.6	24.6	0.08	22.5	23.0	0.08
60 cm	24.7	24.8	0.13	24.2	24.2	0.12	21.8	22.5	0.16
10 cm	24.2	24.5	0.16	23.9	23.9	0.13	21.3	21.9	0.25

Table 4 – Predicted percentage of people bothered by draught, for different heights and for the three points.

Height of the sensor	Draught Risk (average values) Percentage of Dissatisfied		
	point 17	point 18	point 29
170 cm	3	5	8
110 cm	2	3	4
60 cm	5	5	10
10 cm	7	6	14

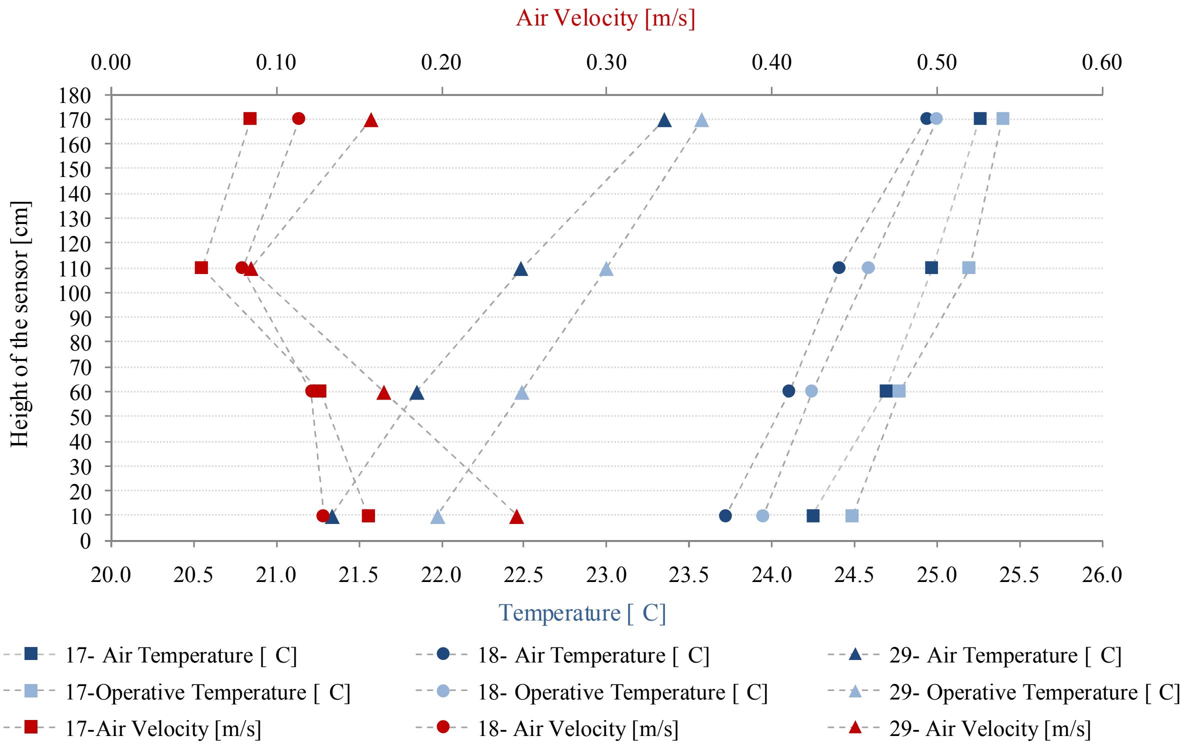


Figure 20 – Average value of Air Temperature [°C], Operative Temperature [°C] and Air Velocity [m/s] at different heights for the monitored points.

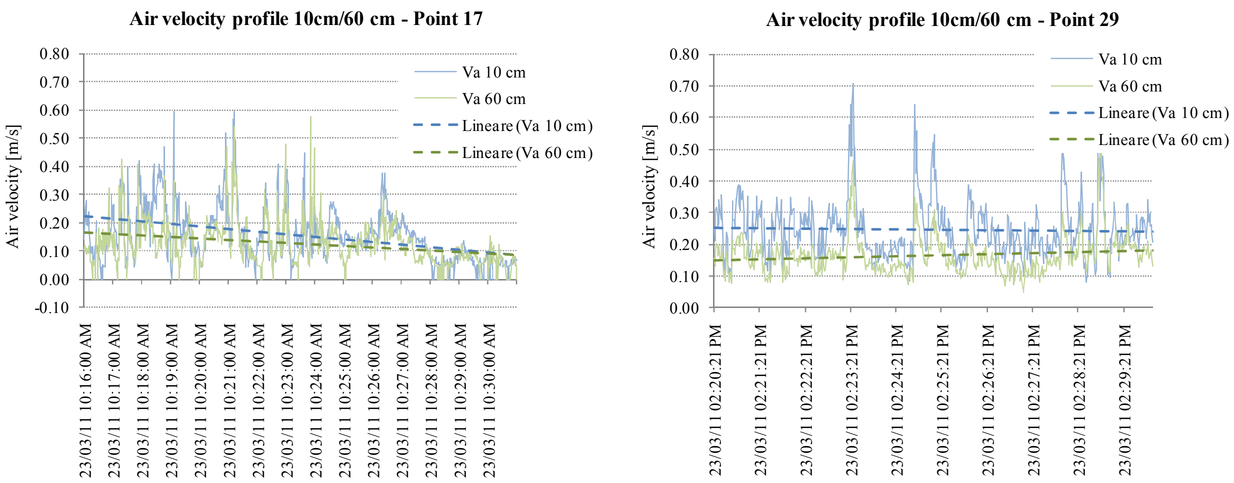


Figure 21 – Air Velocity profiles at 10 and 60 cm for two critical monitored points.

The position of the monitored point 29 was close to the door that connects the main office of the ground floor (room 1.1.00) to the bank back entrance corridor, while the position of point 27 was affected by the air movement due to the building main entrance revolving door opening. In both cases, the focus of figure 21 shows that air movements profiles are characterized by peaks depending in case of point 29 by the opening of the door, and in case of point 17 depending both by the opening of the door and by the movement of customers and employees. The occupant sitting at the desk close to the position 17 declared he felt draughts just when both the door were contemporarily open.

Plateau1

Point	Time of monitoring		
	start	end	minutes
21	23/03/11 11:19:00 AM	23/03/11 11:30:59 AM	12
23	23/03/11 11:51:00 AM	23/03/11 11:57:59 AM	7
24	23/03/11 11:59:00 AM	23/03/11 12:00:59 PM	2

Figure 22/Table 5 – Plateau 1 (Room 2.1.23). Area with draught risk , position of monitored points and information about the monitoring time.

Table 6 –Average value of Air Temperature [°C], Operative Temperature [°C] and Air Velocity [m/s] at different heights for the three monitored points.

Height of the sensor	point 21			point 23			point 24		
	Air Temp. [°C]	Operative Temp. [°C]	Air Velocity [m/s]	Air Temp. [°C]	Operative Temp. [°C]	Air Velocity [m/s]	Air Temp. [°C]	Operative Temp. [°C]	Air Velocity [m/s]
170 cm	25.1	25.1	0.12	24.6	24.7	0.15	24.6	24.7	0.13
110 cm	24.7	24.8	0.13	24.6	25.1	0.11	24.6	24.9	0.09
60 cm	24.7	24.6	0.09	24.5	24.5	0.18	24.3	24.5	0.18
10 cm	24.5	24.5	0.08	23.9	24.2	0.20	23.7	24.1	0.26

Table 7 – Predicted percentage of people bothered by draught, for different heights and for the three points.

Height of the sensor	Draught Risk (average values)		
	Percentage of Dissatisfied		
	point 21	point 23	point 24
170 cm	5	7	6
110 cm	6	5	4
60 cm	4	8	8
10 cm	3	9	12

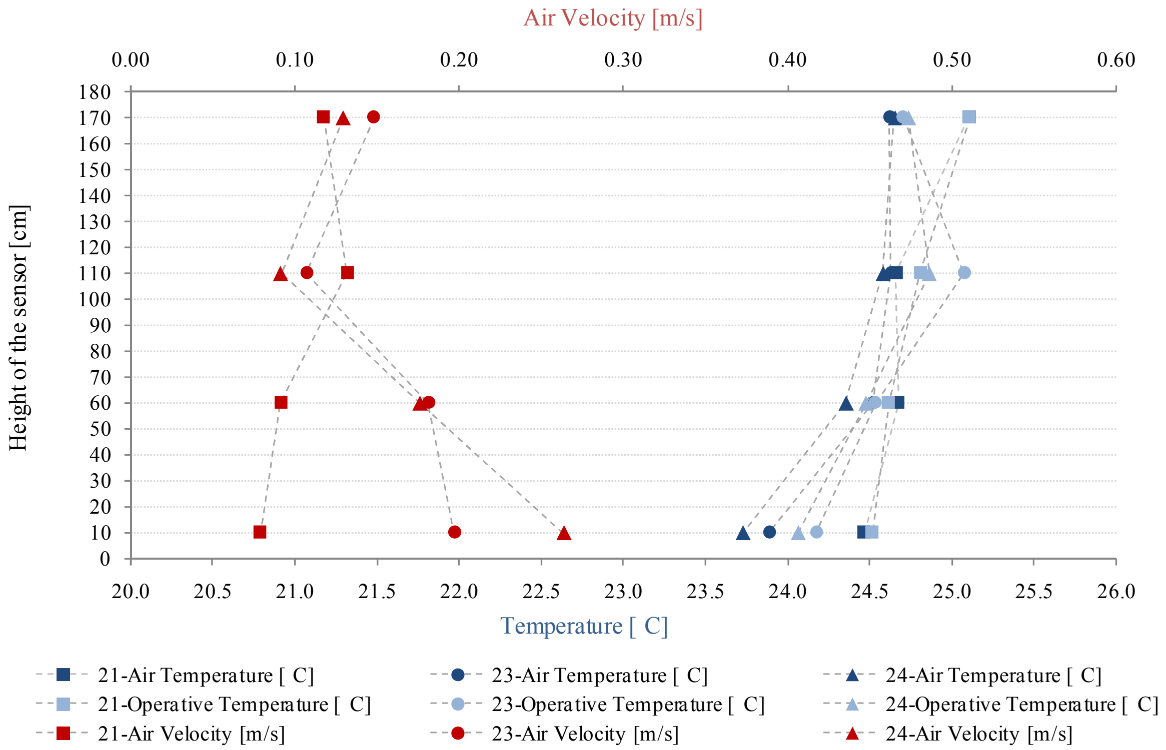


Figure 23 – Average value of Air Temperature [°C], Operative Temperature [°C] and Air Velocity [m/s] at different heights for the monitored points.

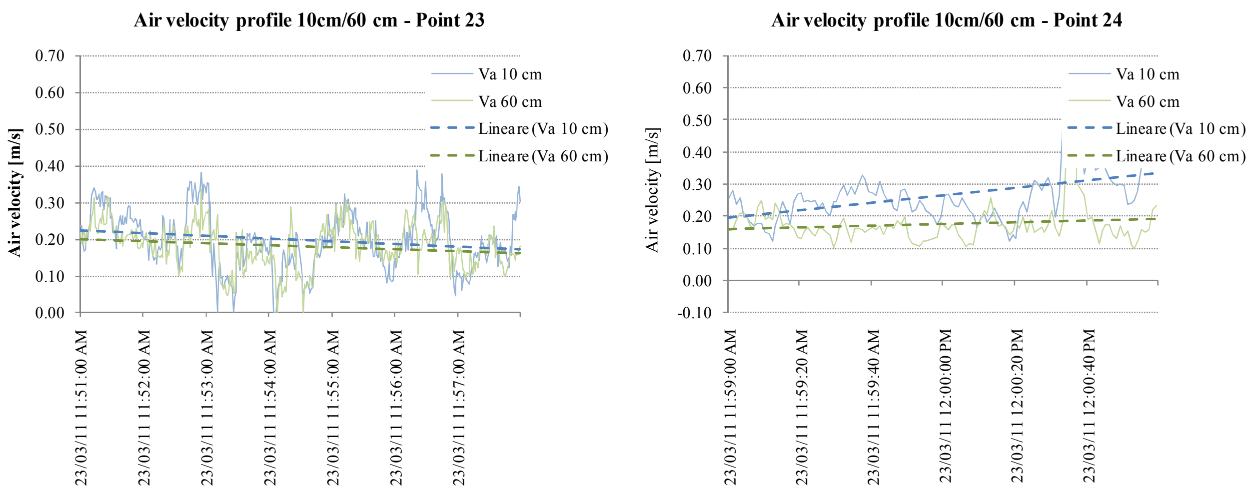


Figure 24 – Air Velocity profiles at 10 and 60 cm for two critical monitored points.

The analysis highlights presence of draught in this zone, for two monitored point in particular: 23 and 24. Employees sitting close to these positions reported to experience discomfort due to air movements. Air velocity profiles showed by figure 24 put in evidence presence of draughts, and it is important to emphasize that no people passed closed to the sensors during the monitoring time. In these two specific points the temperatures at the high of 0.1m were low if compared with the temperature of point 18 at the same high, where no draught were registered.

Plateau 2

	Time of monitoring		
Point	start	end	minutes
12	23/03/11 09:03:00 AM	23/03/11 09:13:59 AM	11

Figure 25 / Table 8 – Plateau 2 (Room 2.1.25). Area with draught risk , position of monitored point and information about the monitoring time.

Table 9 –Average value of Air Temperature [°C], Operative Temperature [°C] and Air Velocity [m/s] at different heights for the three monitored points.

Height of the sensor	point 12		
	Air Temp. [°C]	Operative Temp. [°C]	Air Velocity [m/s]
170 cm	23.0	23.0	0.14
110 cm	22.8	23.0	0.12
60 cm	22.7	22.8	0.19
10 cm	22.5	22.8	0.17

Table 10 – Predicted percentage of people bothered by draught, for different heights and for the monitored point.

Height of the sensor	Draught Risk (average values)
	Percentage of Dissatisfied
	point 12
170 cm	7
110 cm	6
60 cm	10
10 cm	9

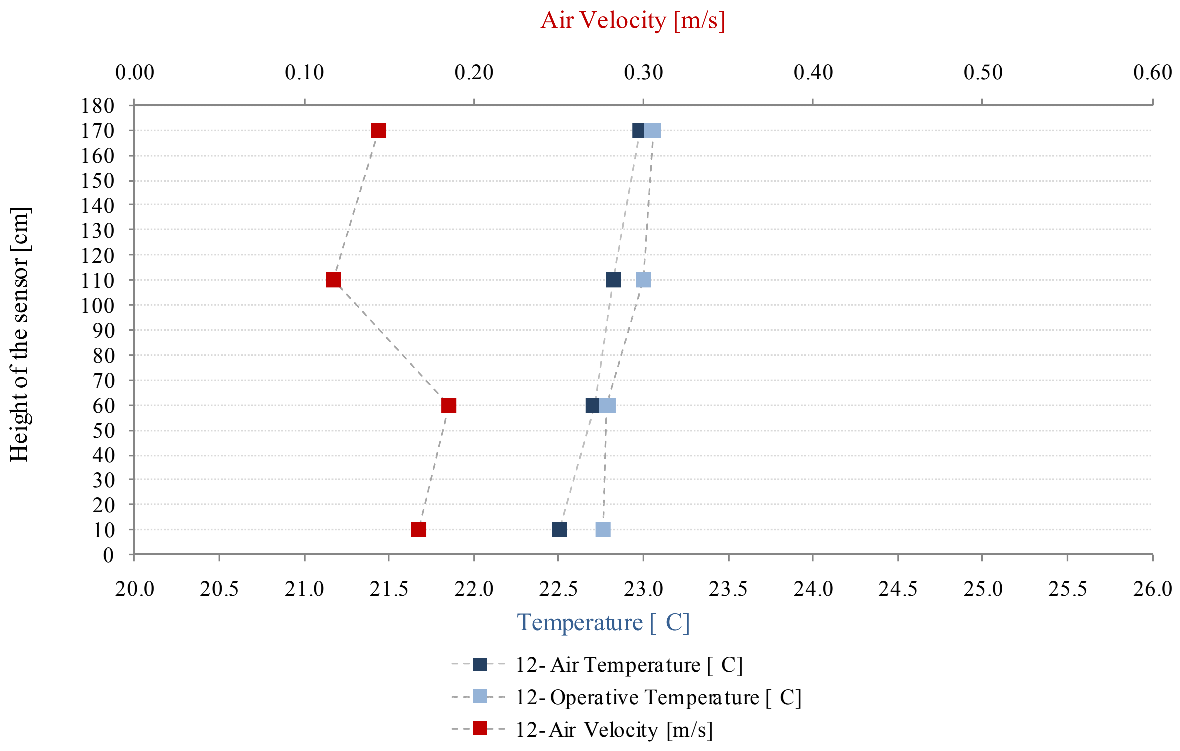


Figure 26 – Average value of Air Temperature [°C], Operative Temperature [°C] and Air Velocity [m/s] at different heights for the monitored point.

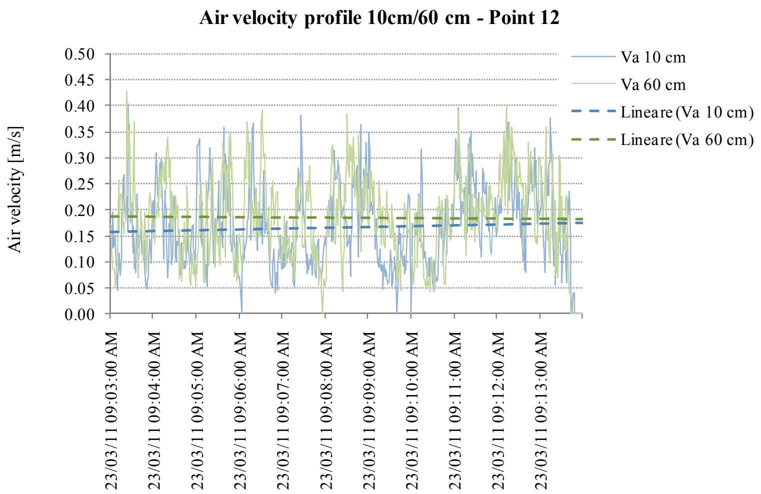
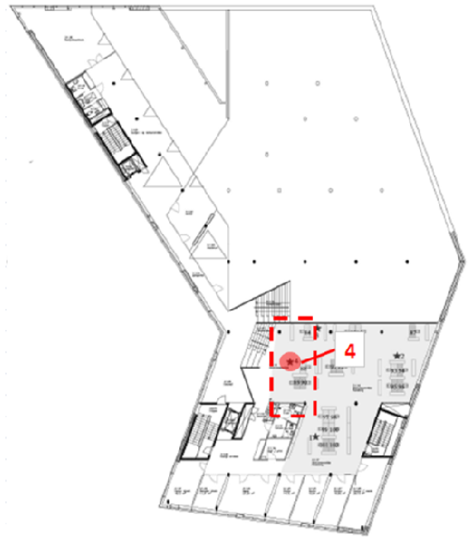


Figure 27 – Air Velocity profiles at 10 and 60 cm for the critical monitored point.

The monitored air velocity of point 12 on Plateau 2 highlights presence of draughts at both the heights of 0.1 and 0.6m. The air velocity profiles show that in less than one minute the air velocity could decrease and then increase again (more times) of about 0.3 m/s. Different by the other cases the maximum values of air velocity were registered at the height of 0.6m, and table 10 confirms that at that height there is the maximum discomfort due to draught.

Plateau 4



	Time of monitoring		
Point	start	end	minutes
4	22/03/11 02:15:00 PM	22/03/11 02:19:59 PM	5

Figure 28 / Table 11 – Plateau 4 (Room 3.1.16). Area with draught risk, position of monitored point and information about the monitoring time.

Table 12 –Average value of Air Temperature [°C], Operative Temperature [°C] and Air Velocity [m/s] at different heights for the three monitored points.

Height of the sensor	point 4		
	Air Temp. [°C]	Operative Temp. [°C]	Air Velocity [m/s]
170 cm	24.1	24.1	0.44
110 cm	23.9	24.0	0.41
60 cm	23.5	23.6	0.50
10 cm	23.0	23.4	0.51

Table 13 – Predicted percentage of people bothered by draught, for different heights and for the three points.

Height of the sensor	Draught Risk (average values)
	Percentage of Dissatisfied
	point 4
170 cm	17
110 cm	17
60 cm	20
10 cm	21

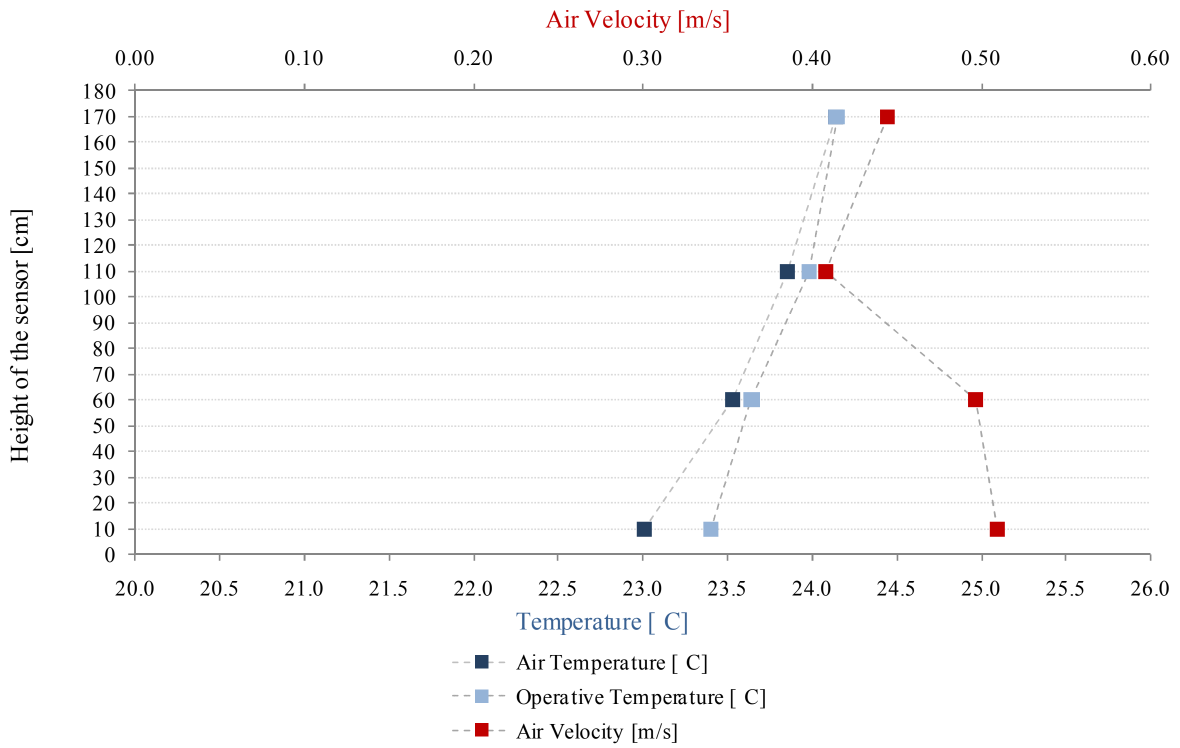


Figure 29 – Average value of Air Temperature [°C], Operative Temperature [°C] and Air Velocity [m/s] at different heights for the monitored point.

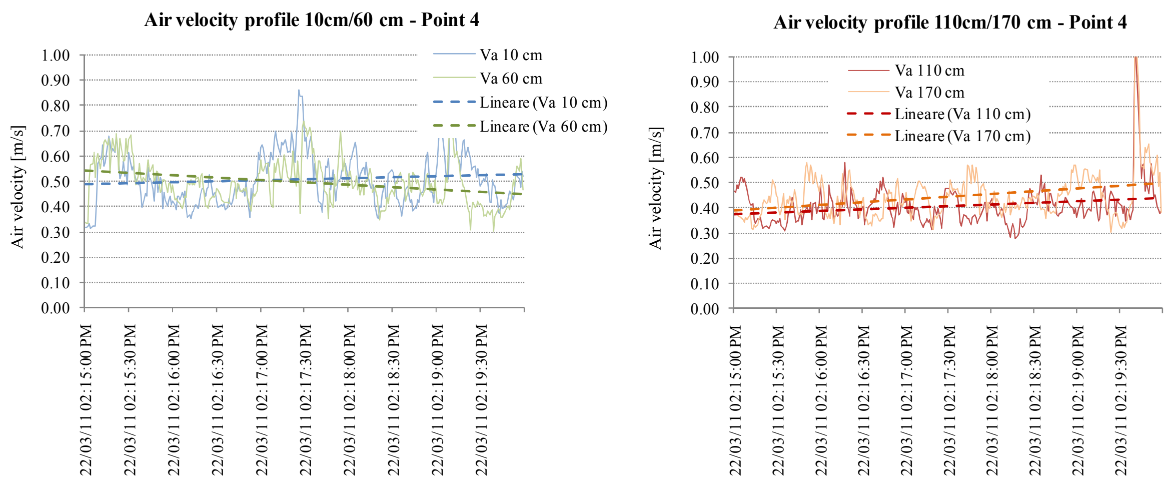


Figure 30 – Air Velocity profiles at 10 and 60 cm and at 110 and 170 cm for the critical monitored point.

Different by all the other zone, on the Fourth Plateau the presence of draught has been identified not just at the high of 0.1 and 0.6 m, but also at the other two highs, 1.1 and 1.7 m. From the profiles of figure 30, the values of air velocity were always above than 0.2 m/s. This fact can be due by the air vents, that were opened during the monitoring time. These vents are located on the wall West exposed.

6- ANNEXES

Annex a

Physical monitoring and subjective analysis for each single room

Ground Floor - Room 1.1.00

umber of desks

umber of filled
uestionnaires
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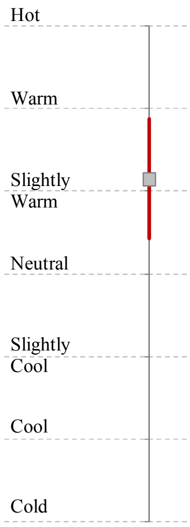
oints of monitoring
ed stars)

Figure 1.1.00.1/2 – Room 1.1.00 evidenced on the Ground floor (1) and position of the occupants that filled the questionnaires (2).



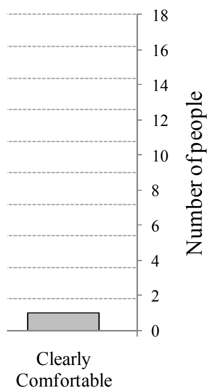
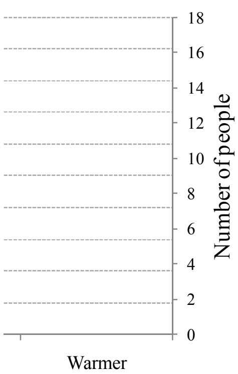


Figure 1.1.00.1/2 – Thermal sensation (1) and Average thermal indoor climate in the room (2).



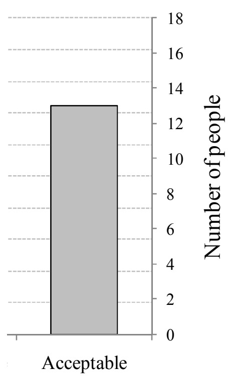


Figure 1.1.00.3/4 – Preference of thermal indoor climate in the room (3) and assessment of the thermal environment (4).

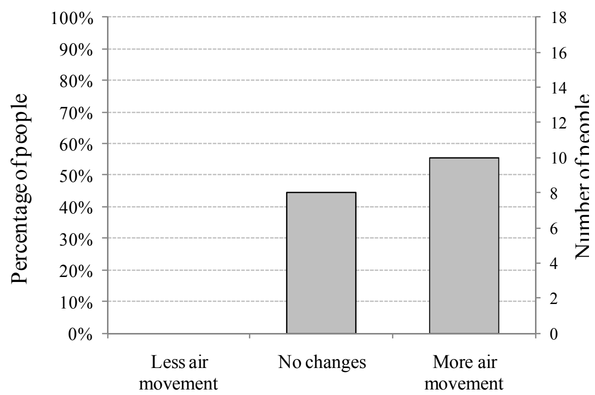


Figure 1.1.00.5 – Preference of air movement around the occupants.

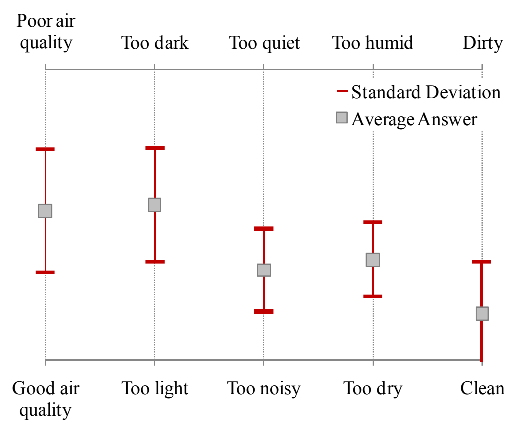


Figure 1.1.00.6 – Environment factors perceived by the occupants in the room.

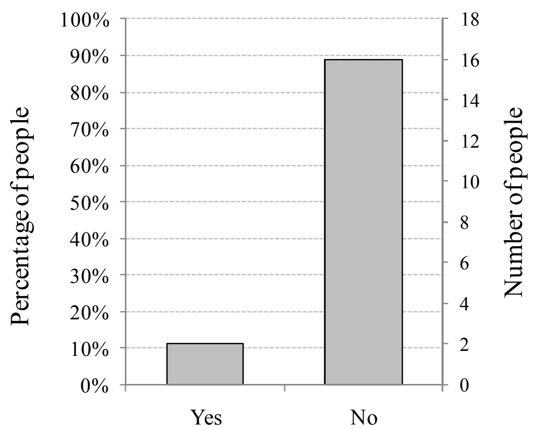


Figure 1.1.00.7 – Occupants affected by respiratory disorders.

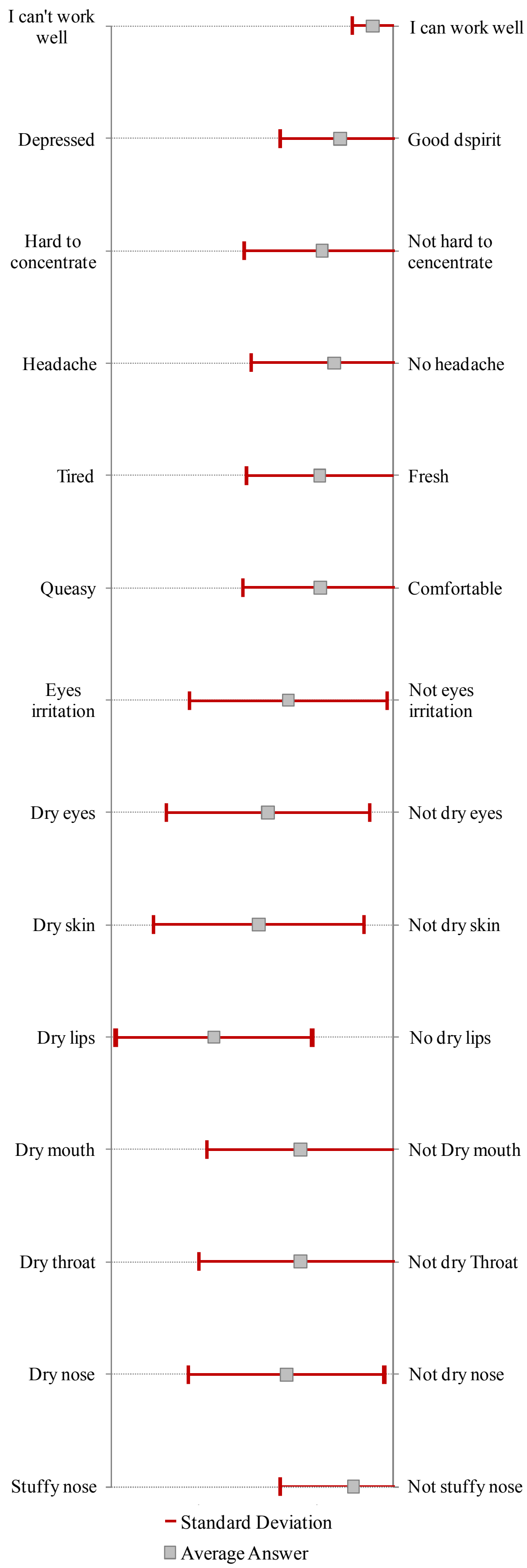


Figure 1.1.00.8 – Symptoms perceived by the occupants in the room.

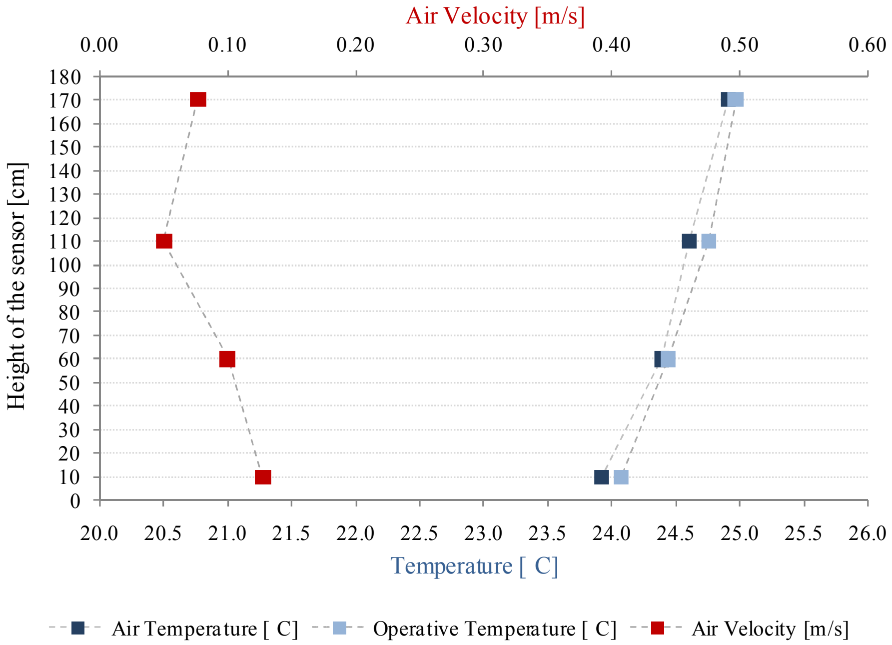


Figure 1.1.00.9 – Average value of Air Temperature, Operative Temperature and Air Velocity at different heights in the analyzed room.

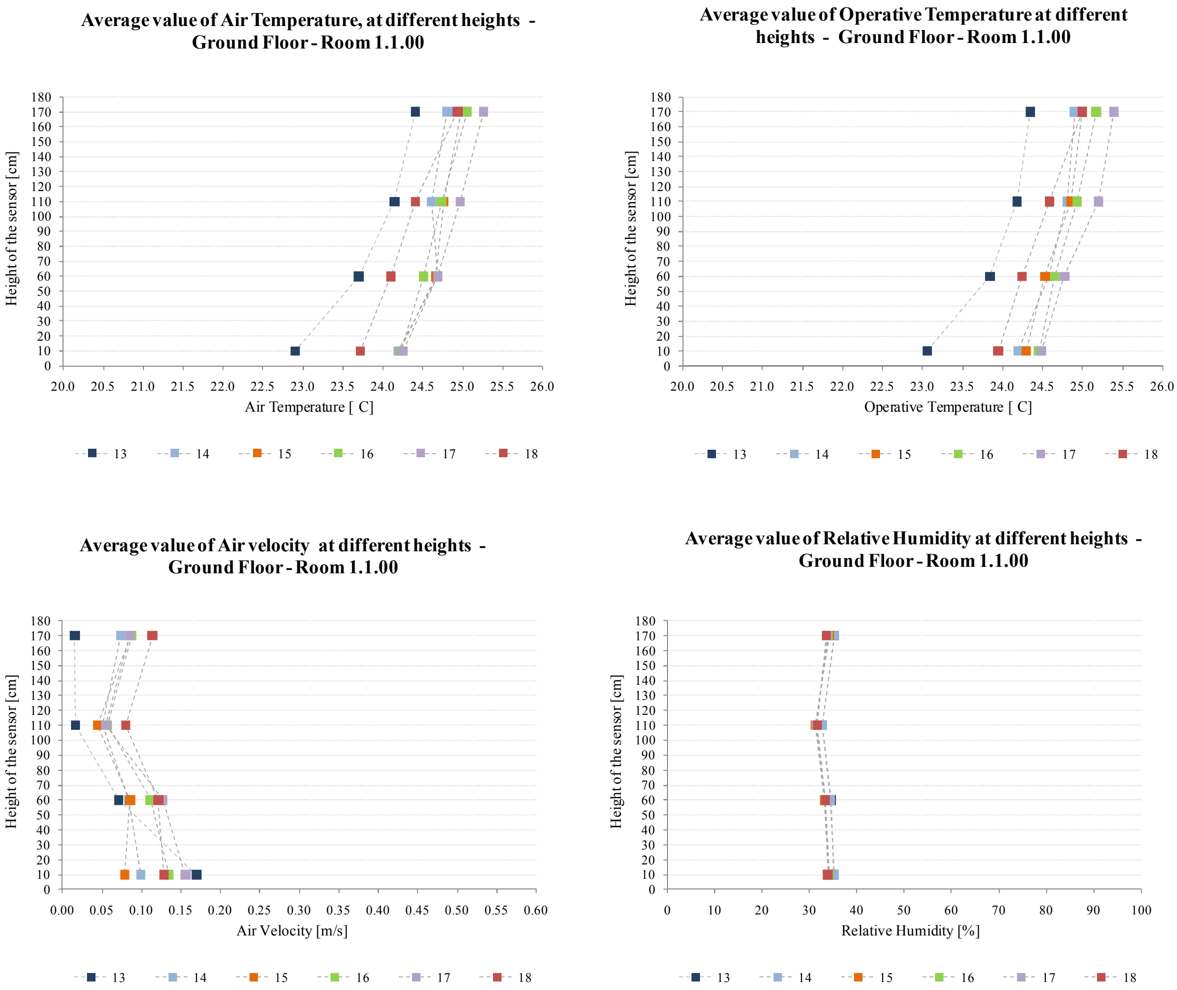


Figure 1.1.00.10 – Average value of Air Temperature, Operative Temperature, Air Velocity and Relative at different heights for the monitored points.

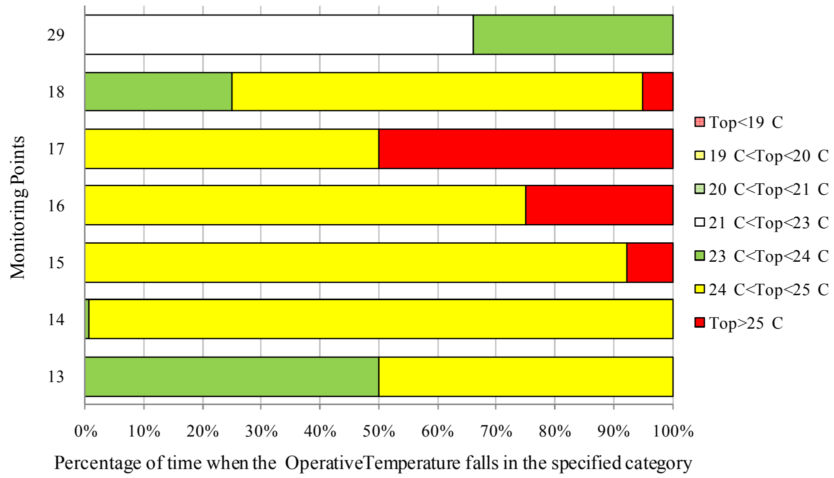


Figure 1.1.00.11 – Percentage of time when the Operative Temperature falls in the specified categories.

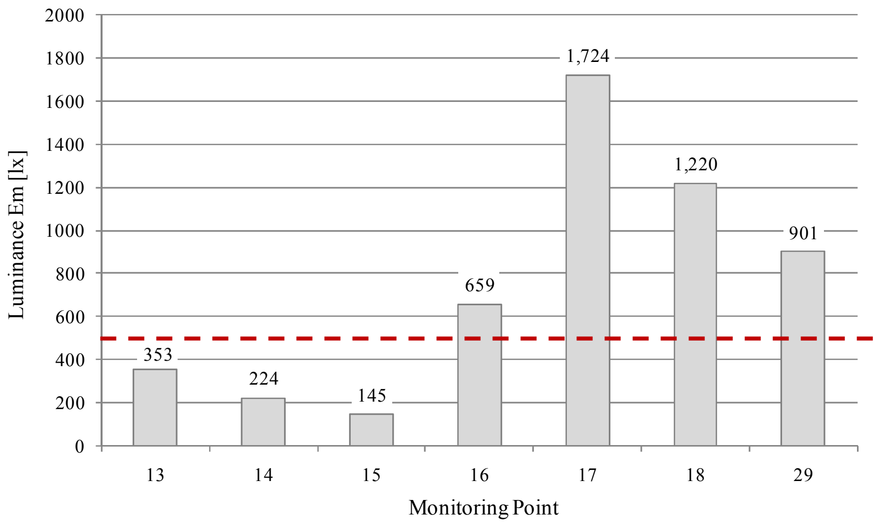


Figure 1.1.00.12 – Average value of Luminance monitored in the analyzed room.

Comments of the occupants

- The temperature rise during the day and it is cause of discomfort.
- More ventilation and fresh air are required.
- The air is very dry

Ground floor - Room 1.4.00

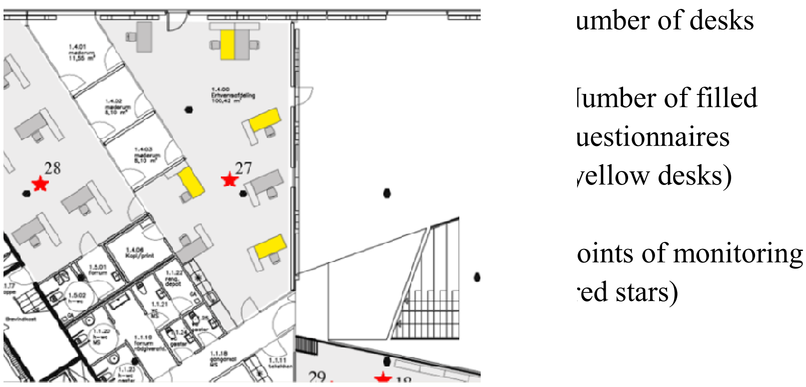
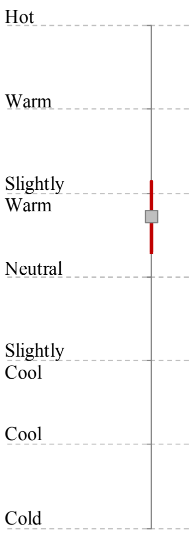


Figure 1.4.00.1/2 – Room 1.4.00 evidenced on the Ground floor (1) and position of the occupants that filled the questionnaires (2).



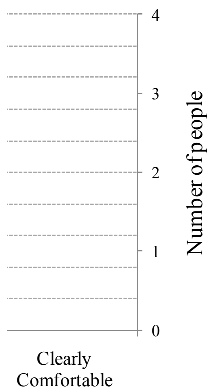
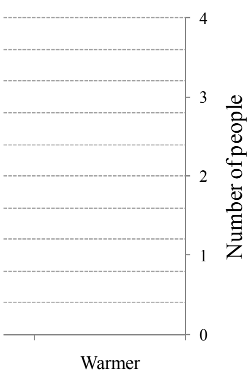


Figure 1.4.00.1/2 – Thermal sensation (1) and Average thermal indoor climate in the room (2).



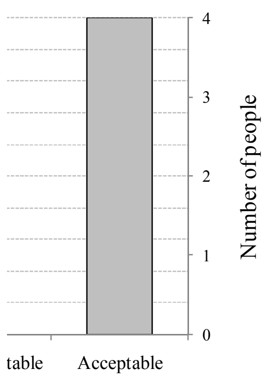


Figure 1.4.00.3/4 – Preference of thermal indoor climate in the room (3) and assessment of the thermal environment (4).

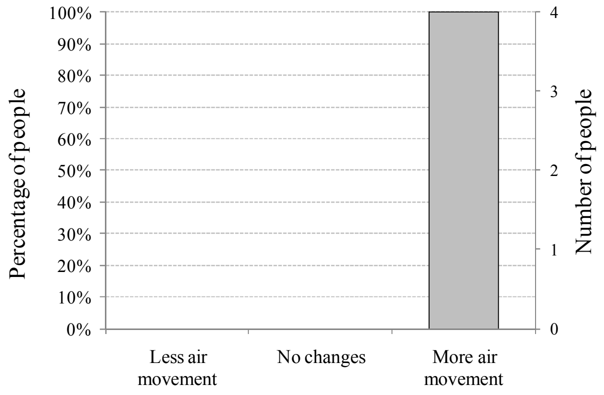


Figure 1.4.00.5 – Preference of air movement around the occupants.

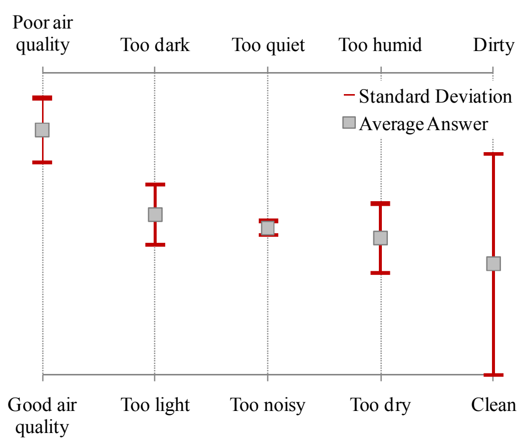


Figure 1.4.00.6 – Environment factors perceived by the occupants in the room.

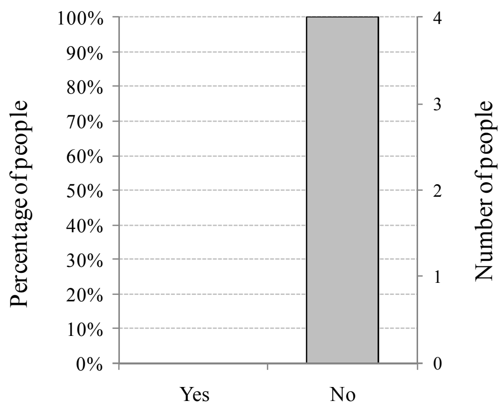


Figure 1.4.00.7 – Occupants affected by respiratory disorders.

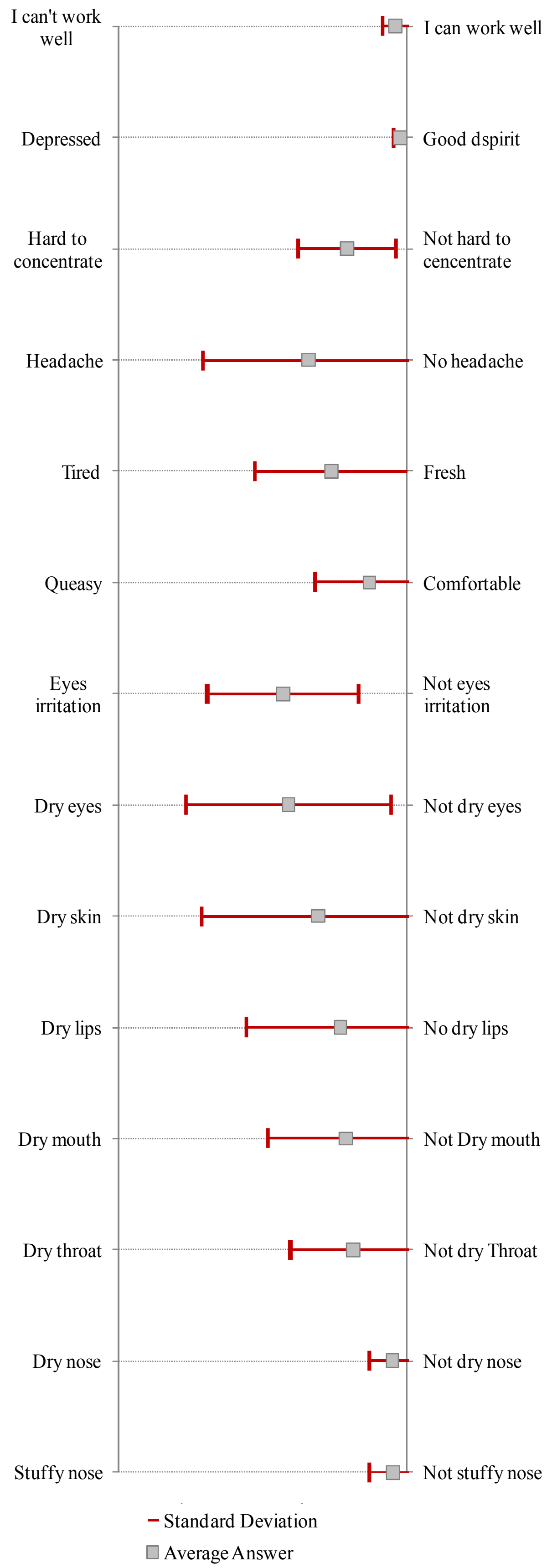


Figure 1.4.00.8 – Symptoms perceived by the occupants in the room.

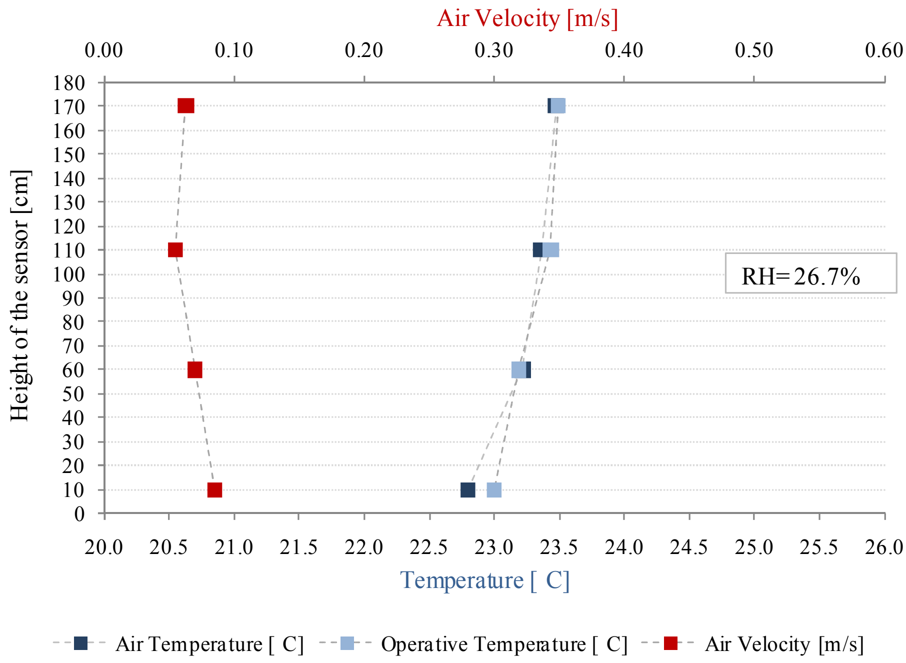


Figure 1.4.00.9 – Average value of Air Temperature, Operative Temperature and Air Velocity at different heights in the analyzed room.

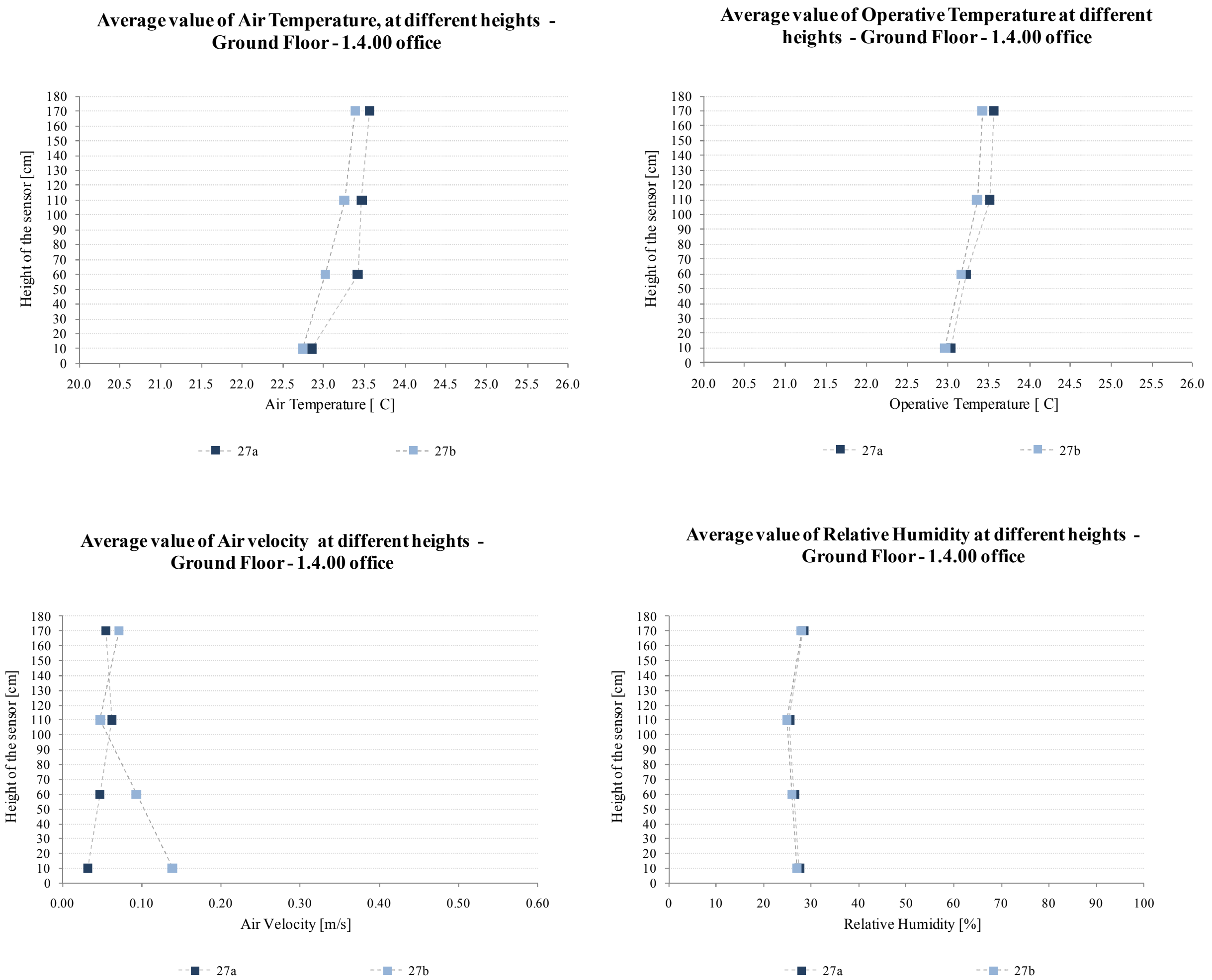


Figure 1.4.00.10 – Average value of Air Temperature, Operative Temperature, Air Velocity and Relative at different heights for the monitored points.

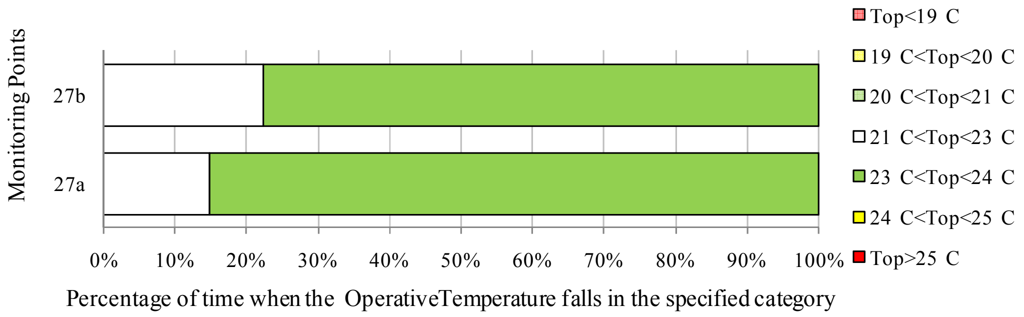


Figure 1.4.00.11 – Percentage of time when the Operative Temperature falls in the specified categories.

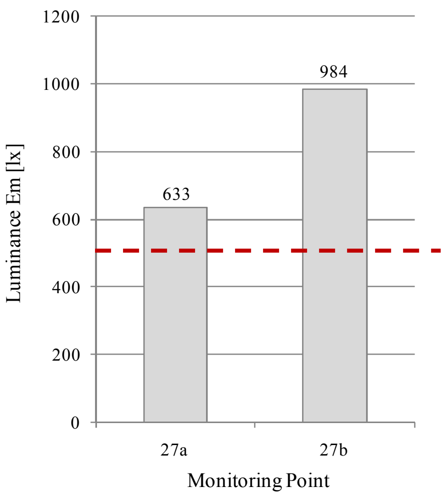


Figure 1.4.00.12 – Average value of Luminance monitored in the analyzed room.

Comments of the occupants

- There are large deviations of temperature during the course of the working week.
- Bad air quality during from midday until the end of the working day. Smell of food during the afternoon.

First Floor - Room 2.1.23 (Plateau 1)

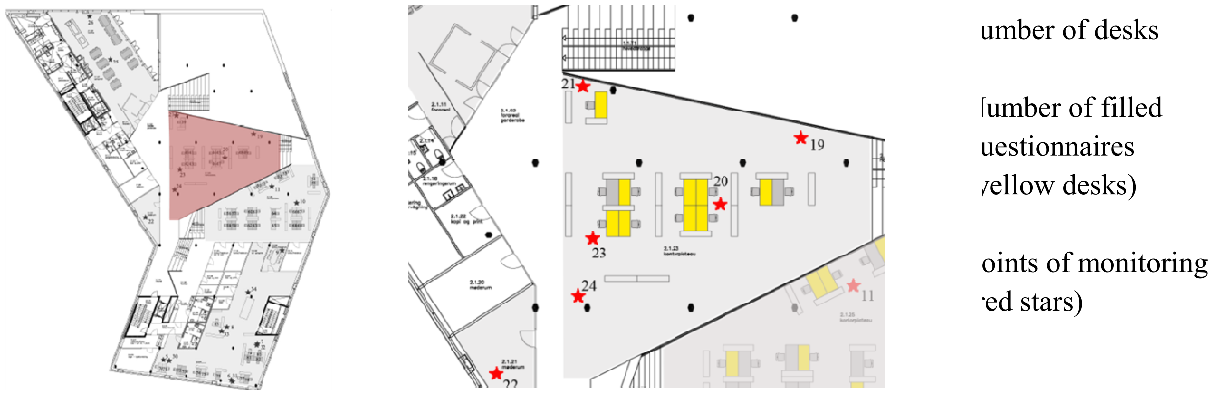


Figure 2.1.23.1/2 – Room 2.1.23 evidenced on the First floor (1) and position of the occupants that filled the questionnaires (2).

Figure 2.1.23.1/2 – Thermal sensation (1) and Average thermal indoor climate in the room (2).

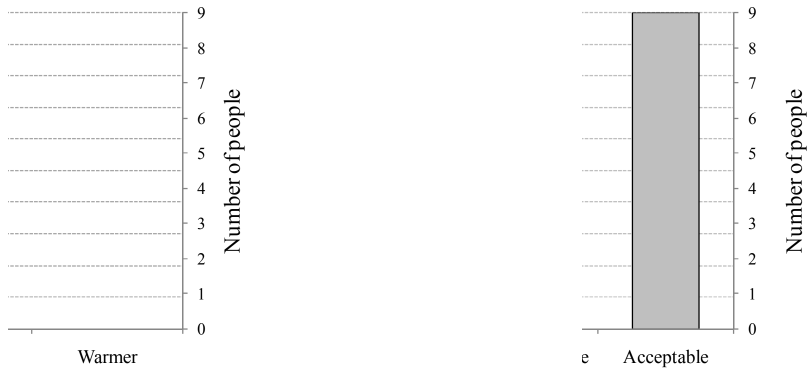


Figure 2.1.23.3/4 – Preference of thermal indoor climate in the room (3) and assessment of the thermal environment (4).

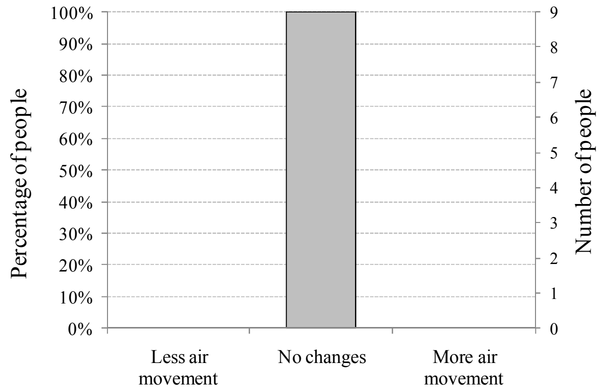


Figure 2.1.23.5 – Preference of air movement around the occupants.

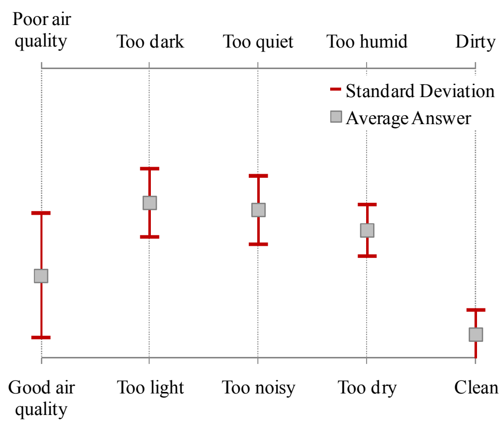


Figure 2.1.23.6 – Environment factors perceived by the occupants in the room.

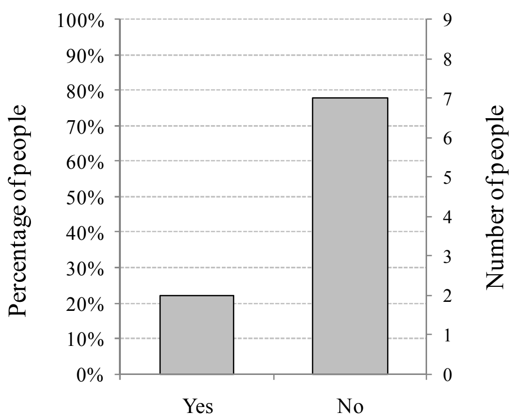


Figure 2.1.23.7 – Occupants affected by respiratory disorders.

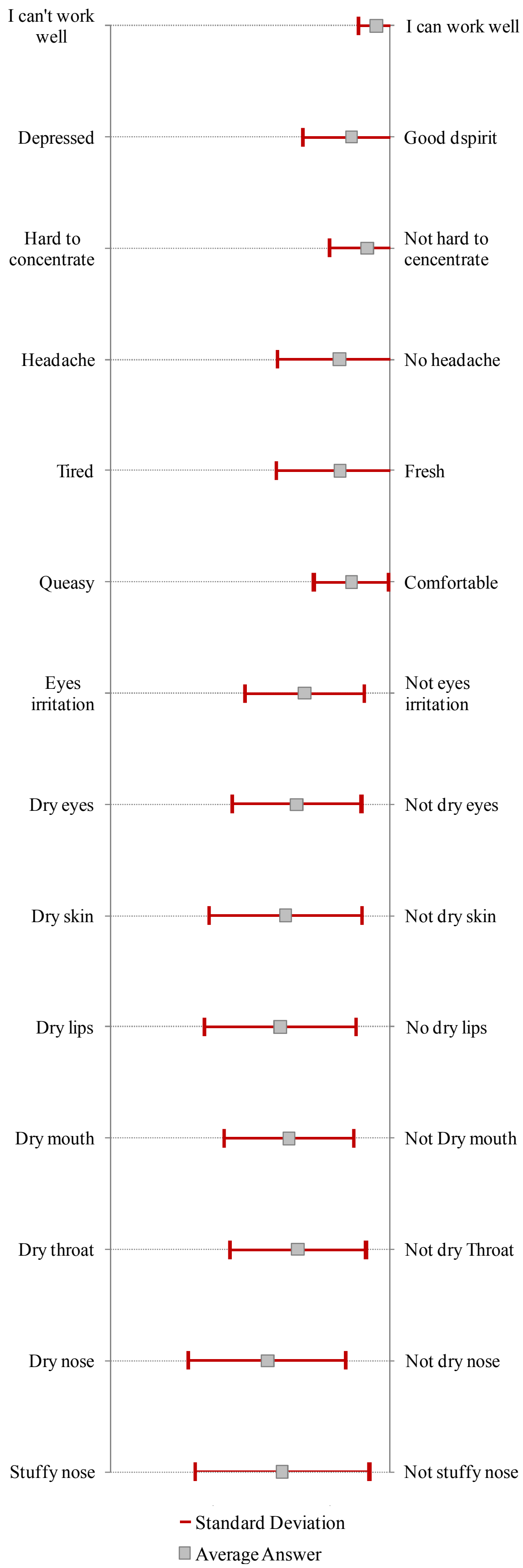


Figure 2.1.23.8 – Symptoms perceived by the occupants in the room.

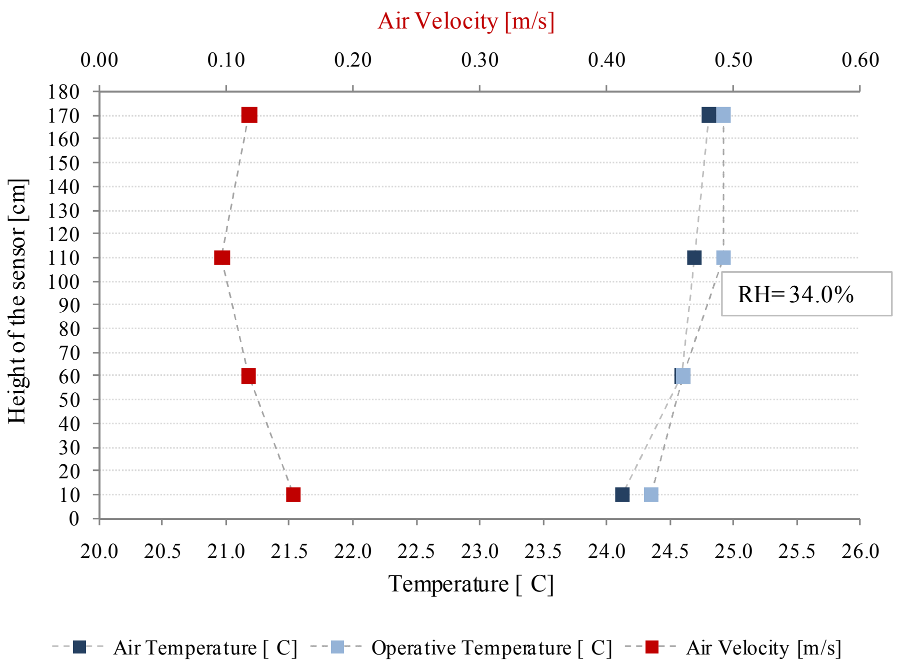
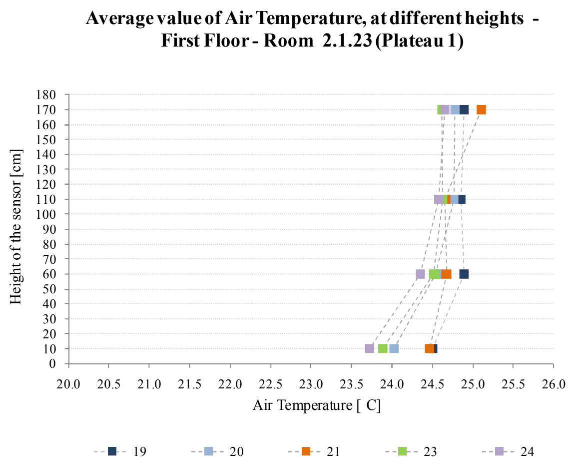
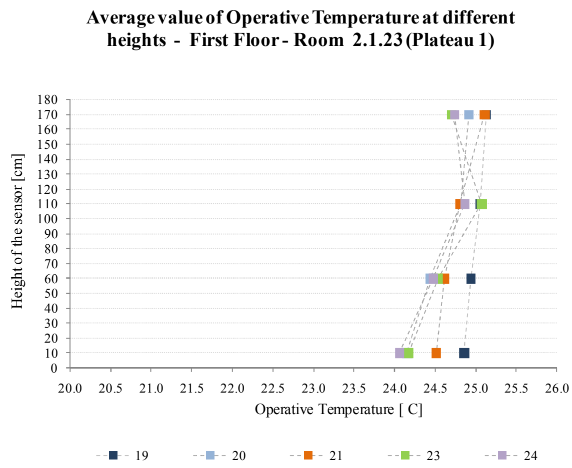
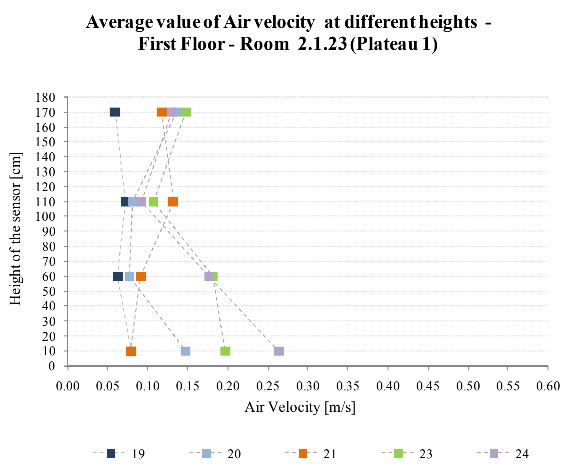


Figure 2.1.23.9 – Average value of Air Temperature, Operative Temperature and Air Velocity at different heights in the analyzed room.







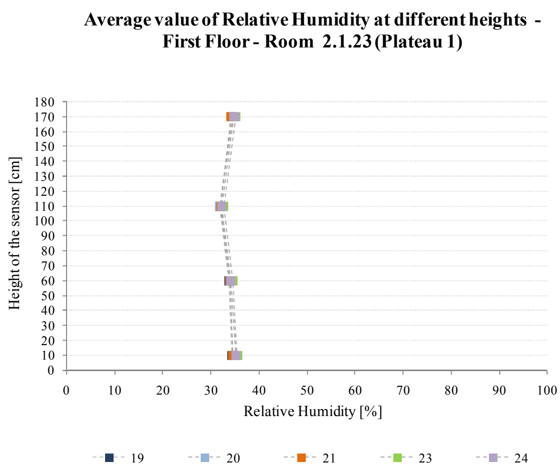


Figure 2.1.23.10 – Average value of Air Temperature, Operative Temperature, Air Velocity and Relative at different heights for the monitored points.

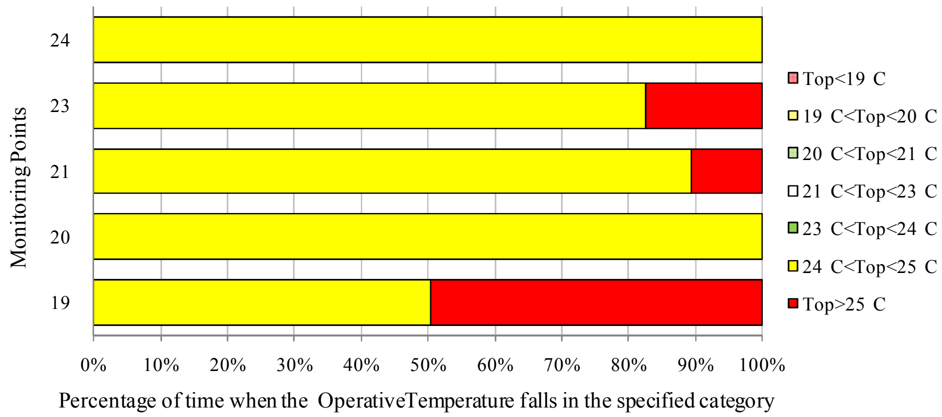


Figure 2.1.23.11 – Percentage of time when the Operative Temperature falls in the specified categories.

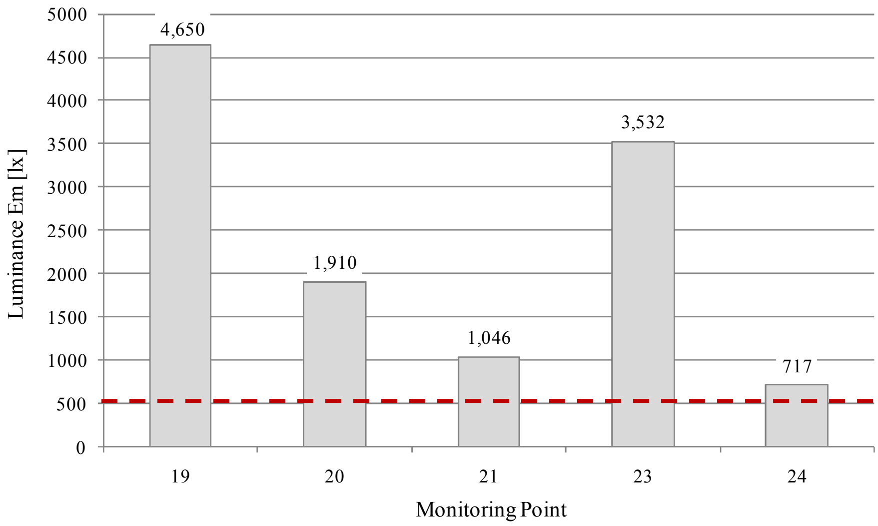


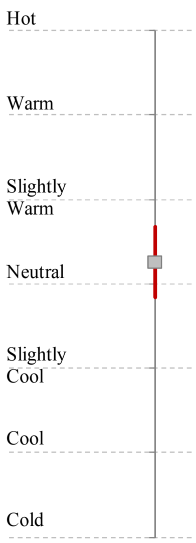
Figure 2.1.23.12 – Average value of Luminance monitored in the analyzed room.

<u>Comments of the occupants</u>

- The situation in March is very different than in December.
- The inside temperature vary a lot according to the outside temperature.

First Floor - Room 2.1.25 (Plateau 2)

Figure 2.1.25.1/2 – Room 2.1.25 evidenced on the First floor (1) and position of the occupants that filled the questionnaires (2).



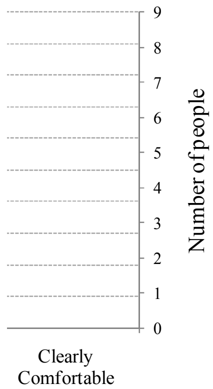
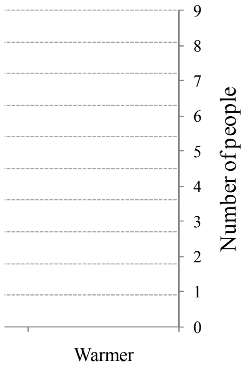


Figure 2.1.25.1/2 – Thermal sensation (1) and Average thermal indoor climate in the room (2).



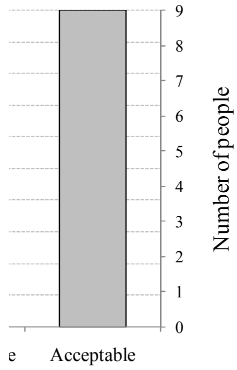


Figure 2.1.25.3/4 – Preference of thermal indoor climate in the room (3) and assessment of the thermal environment (4).

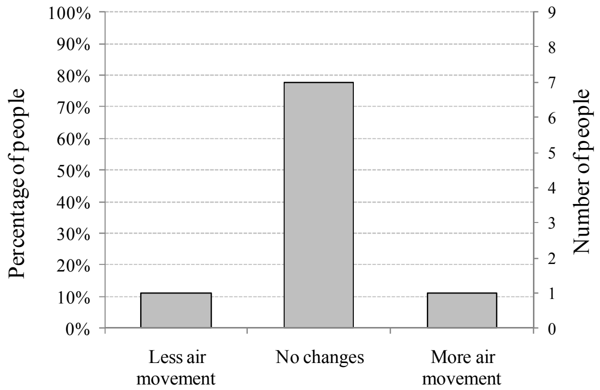


Figure 2.1.25.5 – Preference of air movement around the occupants.

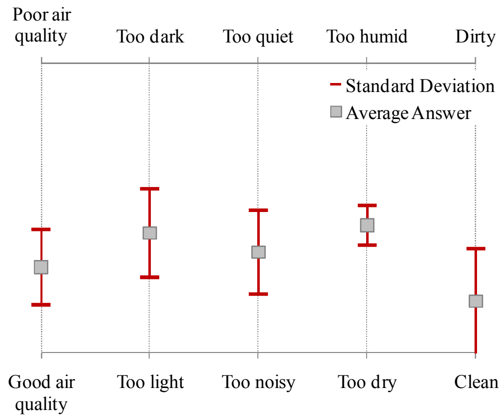


Figure 2.1.25.6 – Environment factors perceived by the occupants in the room.

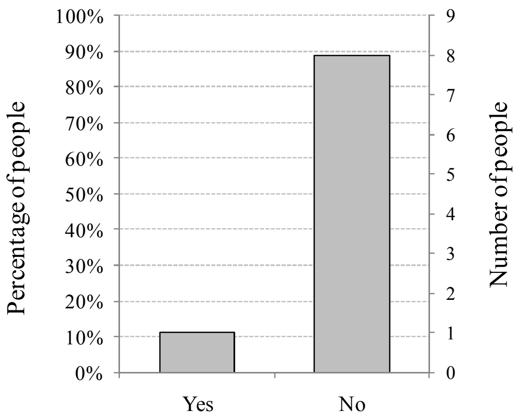


Figure 2.1.25.7 – Occupants affected by respiratory disorders.

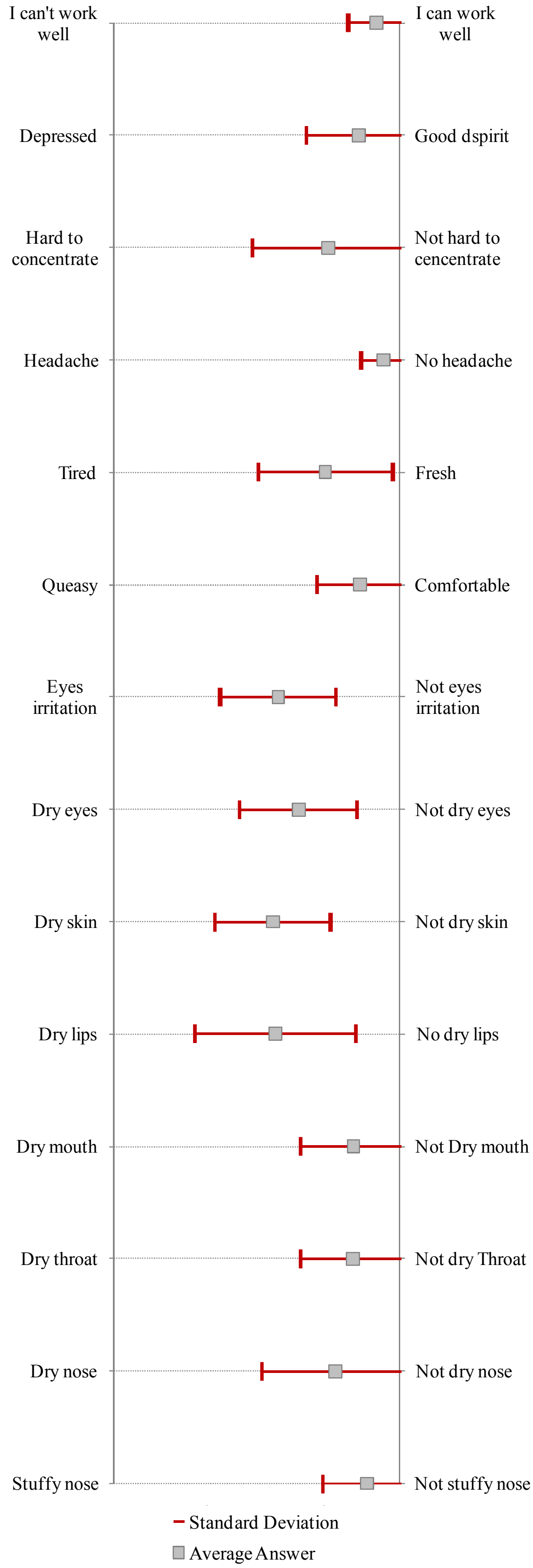


Figure 2.1.25.8 – Symptoms perceived by the occupants in the room.

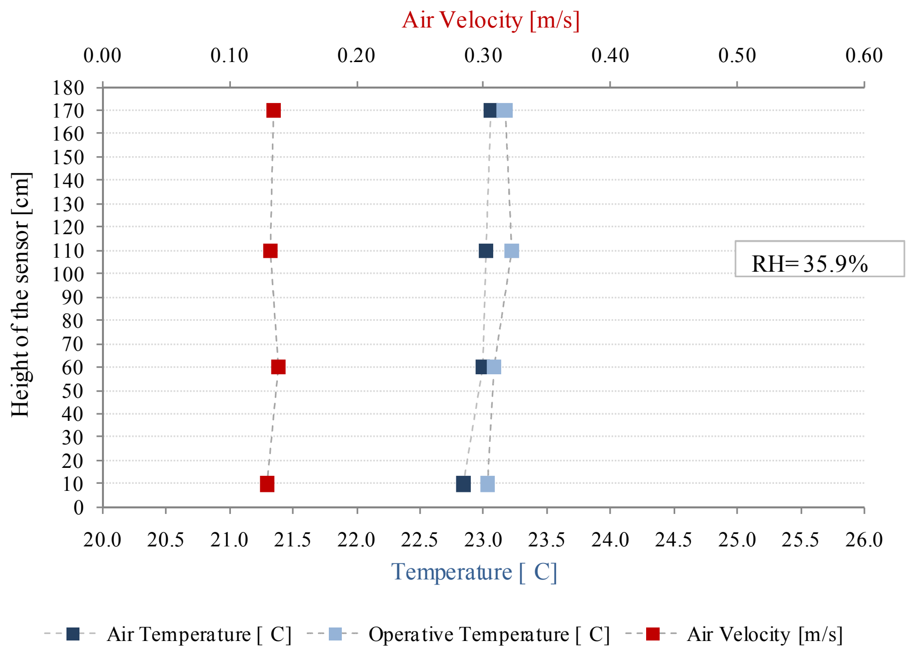


Figure 2.1.25.9 – Average value of Air Temperature, Operative Temperature and Air Velocity at different heights in the analyzed room.

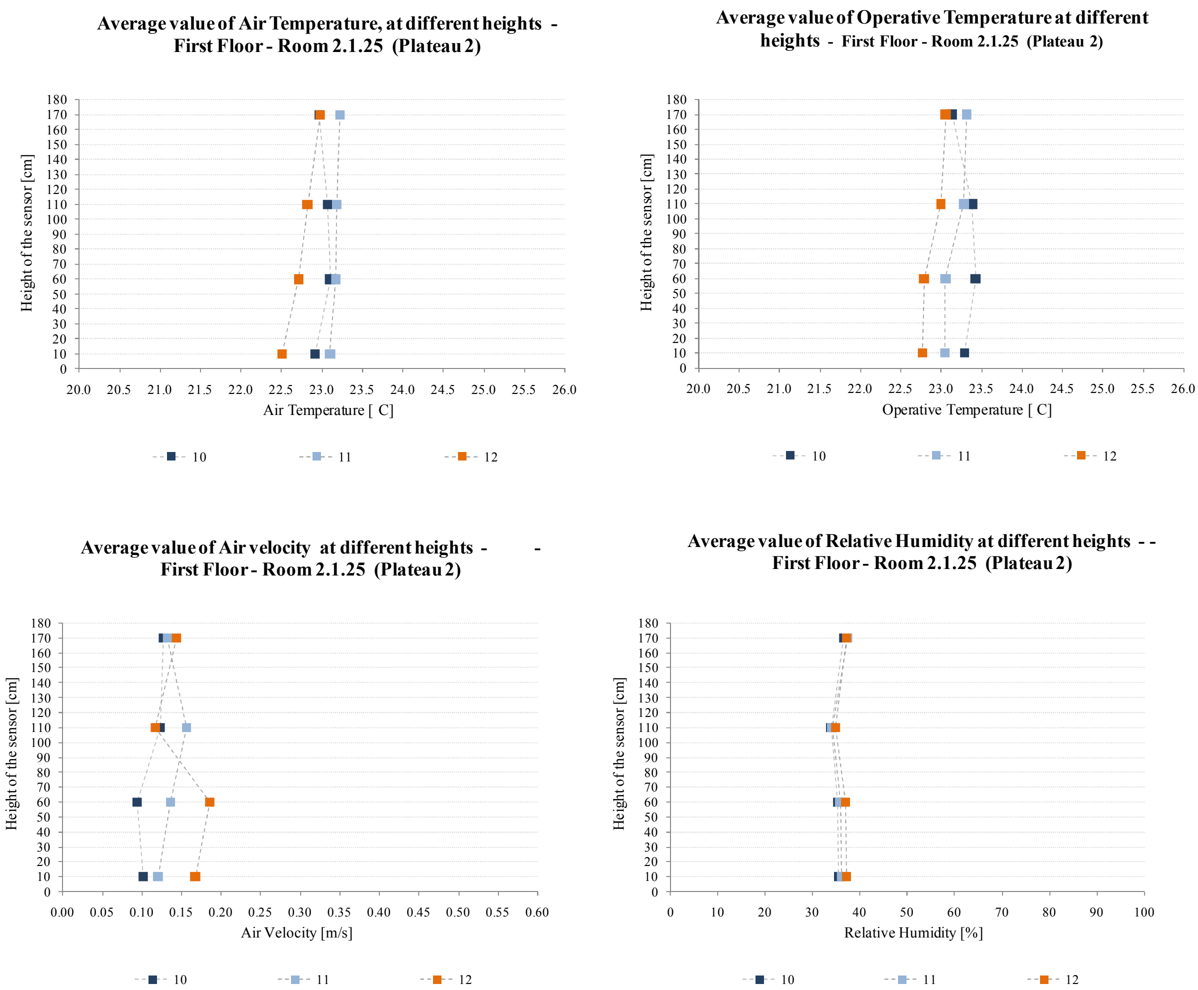


Figure 2.1.25.10 – Average value of Air Temperature, Operative Temperature, Air Velocity and Relative at different heights for the monitored points.

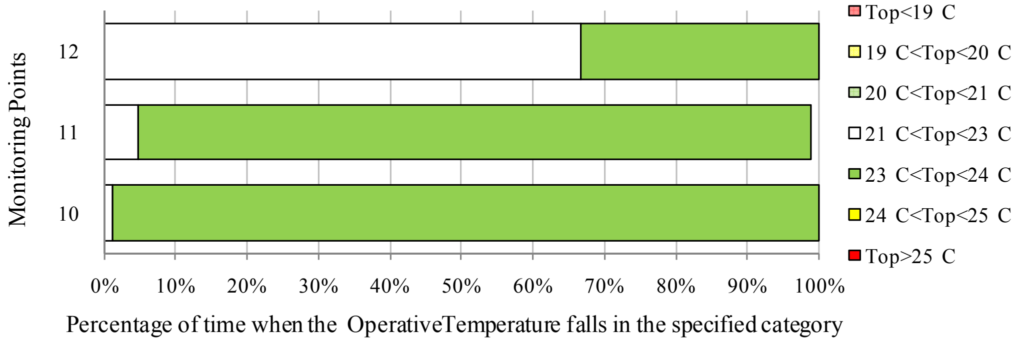


Figure 2.1.25.11 – Percentage of time when the Operative Temperature falls in the specified categories.

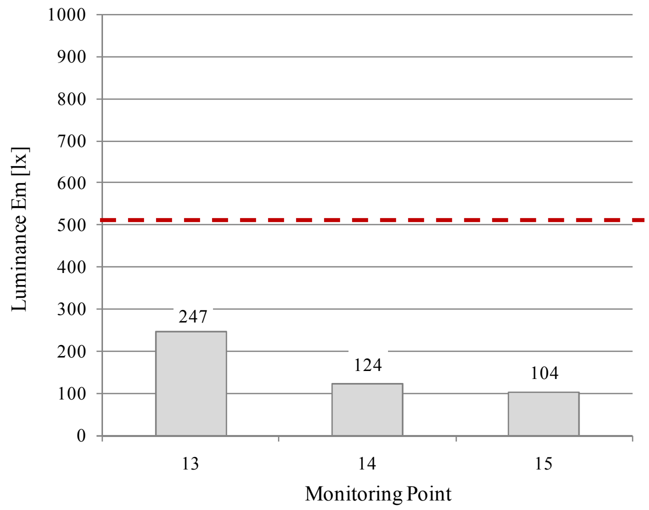


Figure 2.1.25.12 – Average value of Luminance monitored in the analyzed room.

<u>Comments of the occupants</u>

No comments.

First Floor - Room 2.2.00

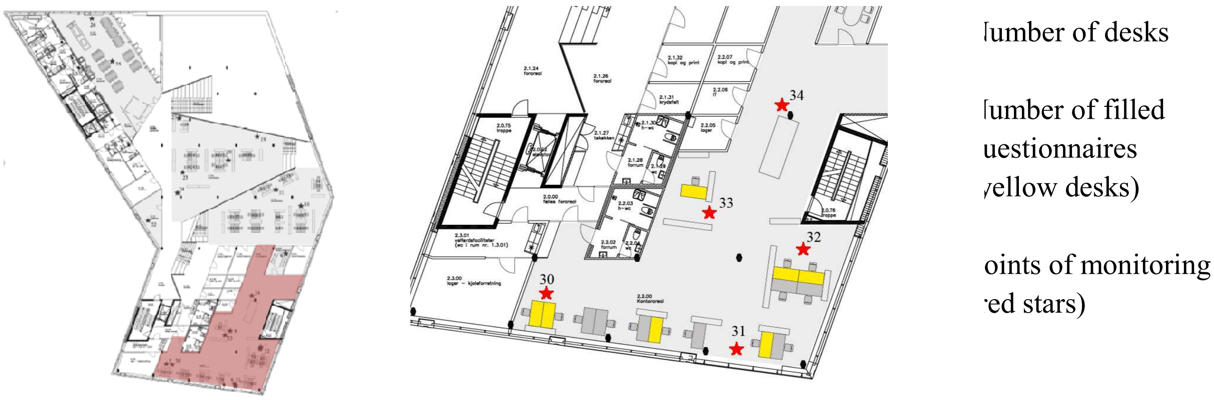


Figure 2.2.00.1/2 – Room 2.2.00 evidenced on the First floor (1) and position of the occupants that filled the questionnaires (2).

Figure 2.2.00.1/2 – Thermal sensation (1) and Average thermal indoor climate in the room (2).

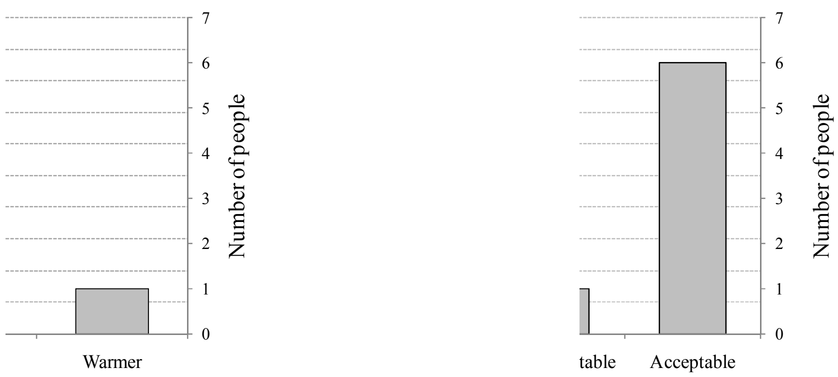


Figure 2.2.00.3/4 – Preference of thermal indoor climate in the room (3) and assessment of the thermal environment (4).

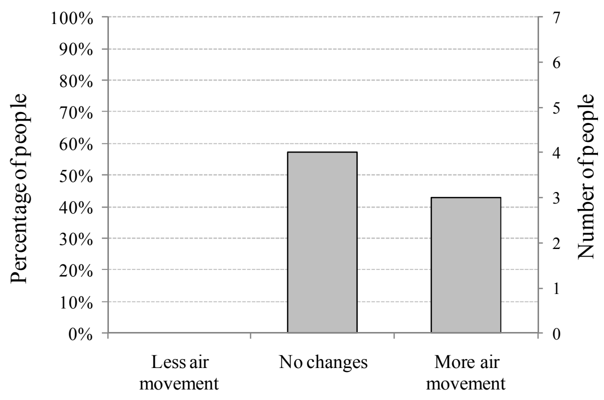


Figure 2.2.00.5 – Preference of air movement around the occupants.

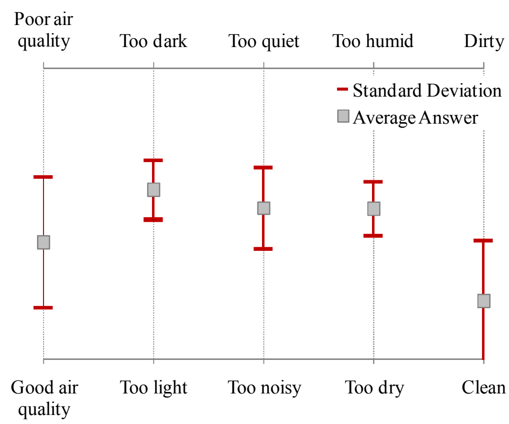


Figure 2.2.00.6 – Environment factors perceived by the occupants in the room.

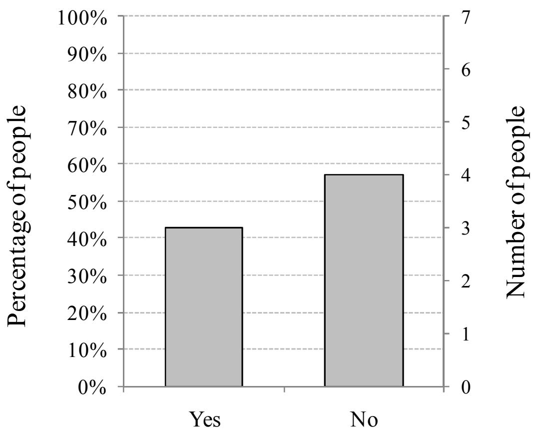


Figure 2.2.00.7 – Occupants affected by respiratory disorders.

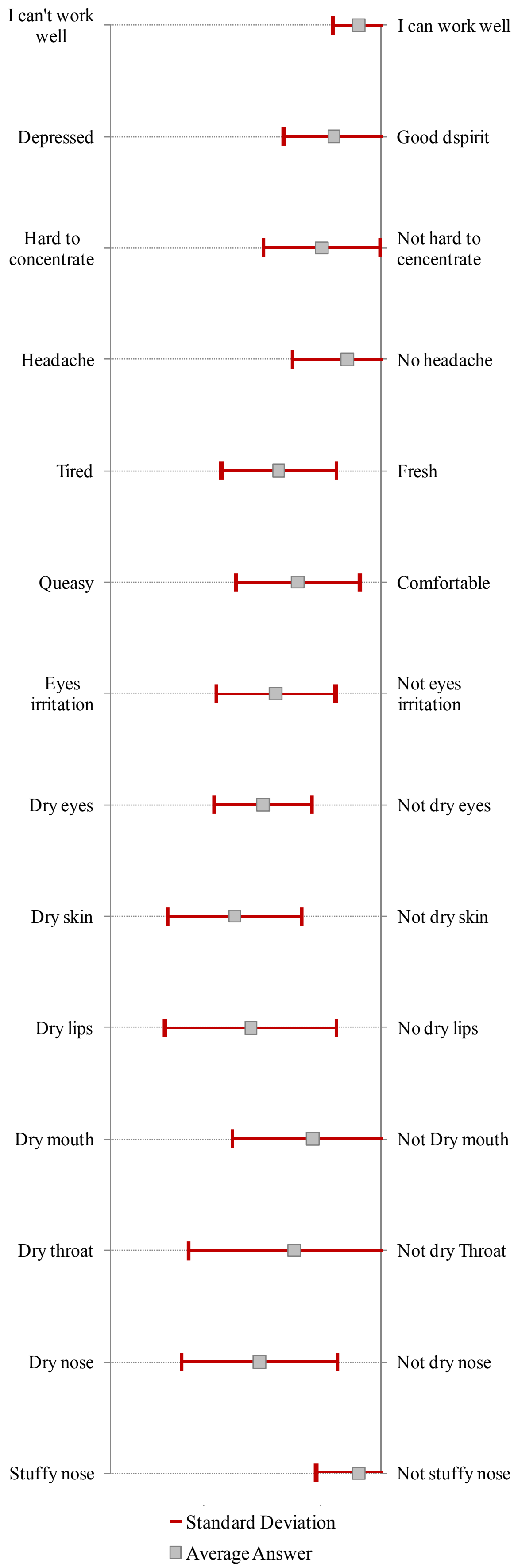


Figure 2.2.00.8 – Symptoms perceived by the occupants in the room.

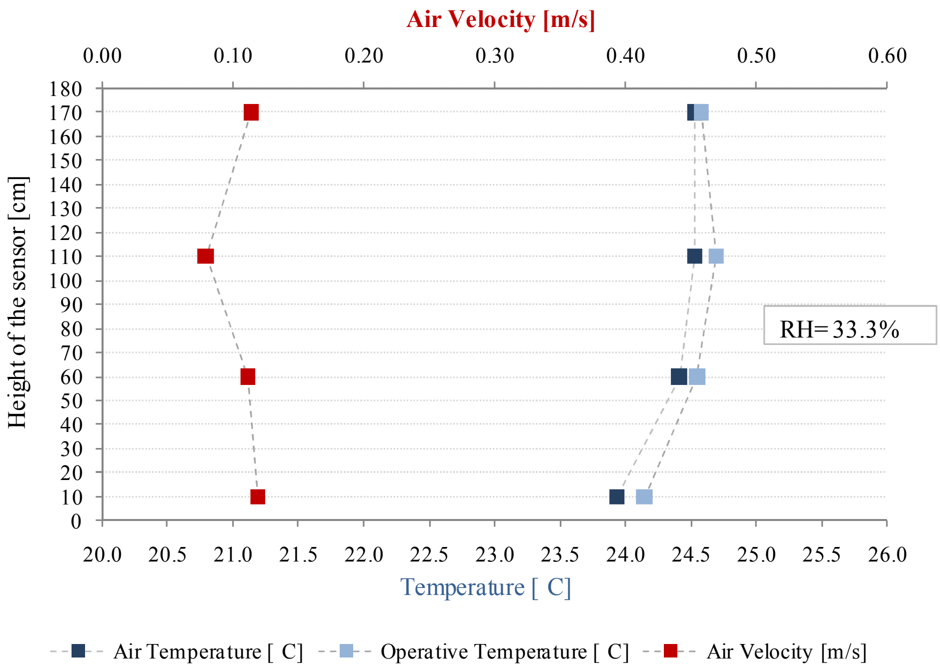


Figure 2.2.00.9 – Average value of Air Temperature, Operative Temperature and Air Velocity at different heights in the analyzed room.

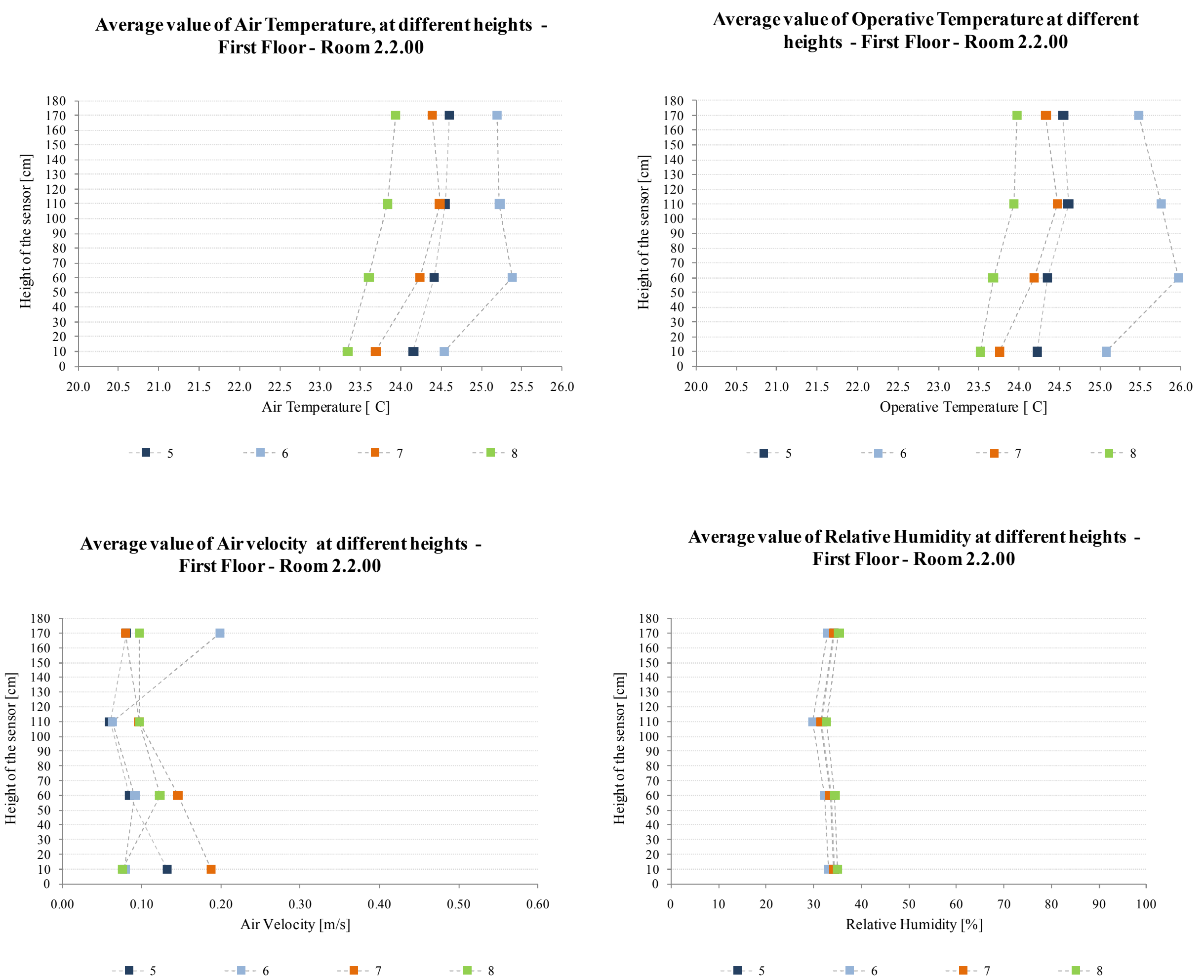


Figure 2.2.00.10 – Average value of Air Temperature, Operative Temperature, Air Velocity and Relative at different heights for the monitored points.

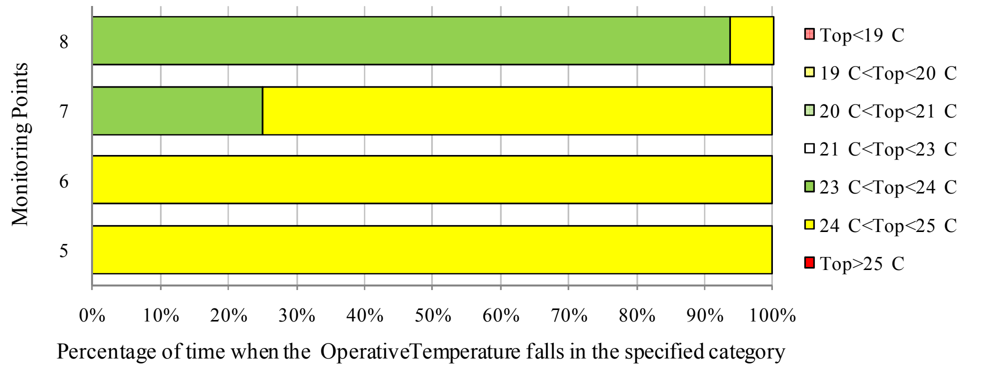


Figure 2.2.00.11 – Percentage of time when the Operative Temperature falls in the specified categories.

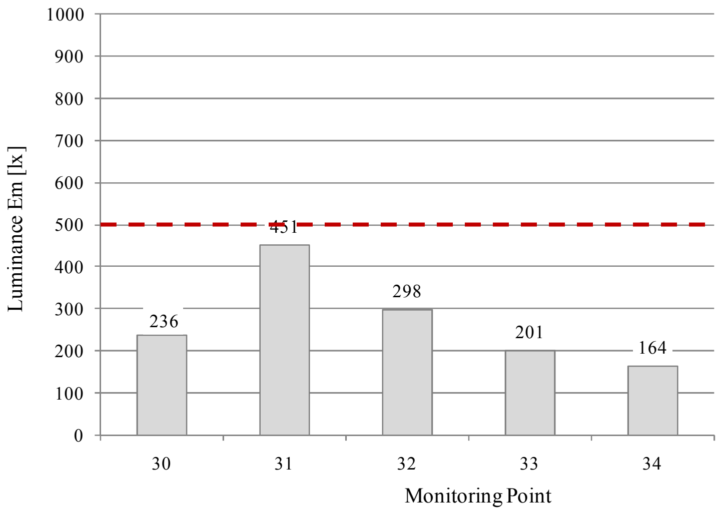


Figure 2.2.00.12 – Average value of Luminance monitored in the analyzed room.

Comments of the occupants

- Smell of food in the office

Second Floor - Room 3.1.16 (Plateau 4)

Figure 3.1.16.1/2 – Room 3.1.16 evidenced on the Second floor (1) and position of the occupants that filled the questionnaires (2).

Figure 3.1.16.1/2 – Thermal sensation (1) and Average thermal indoor climate in the room (2).

Figure 3.1.16.3/4 – Preference of thermal indoor climate in the room (3) and assessment of the thermal environment (4).

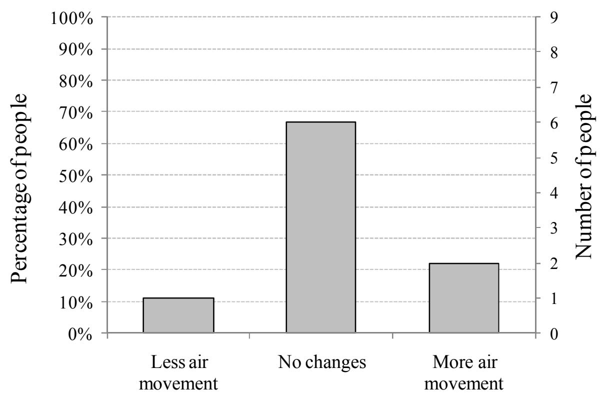


Figure 3.1.16.5 – Preference of air movement around the occupants.

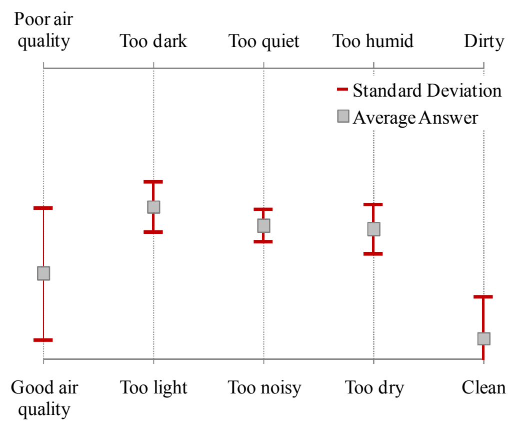


Figure 3.1.16.6 – Environment factors perceived by the occupants in the room.

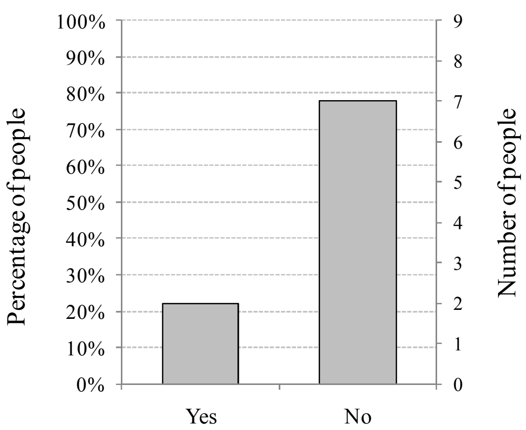


Figure 3.1.16.7 – Occupants affected by respiratory disorders.

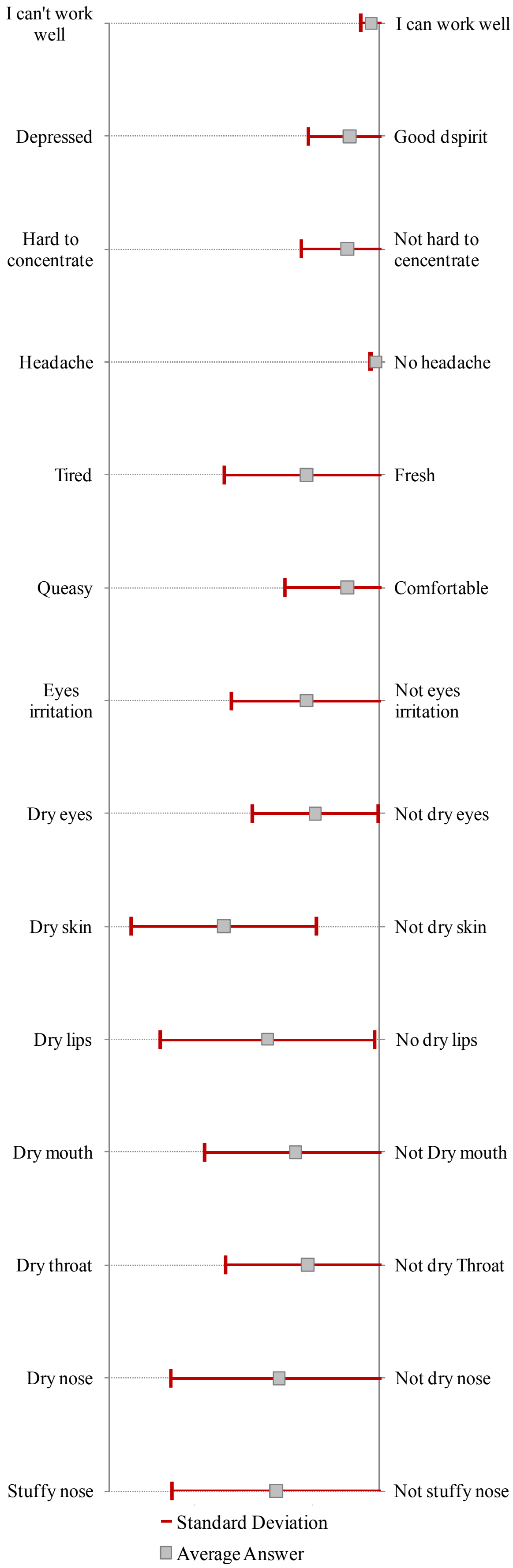


Figure 3.1.16.8 – Symptoms perceived by the occupants in the room.

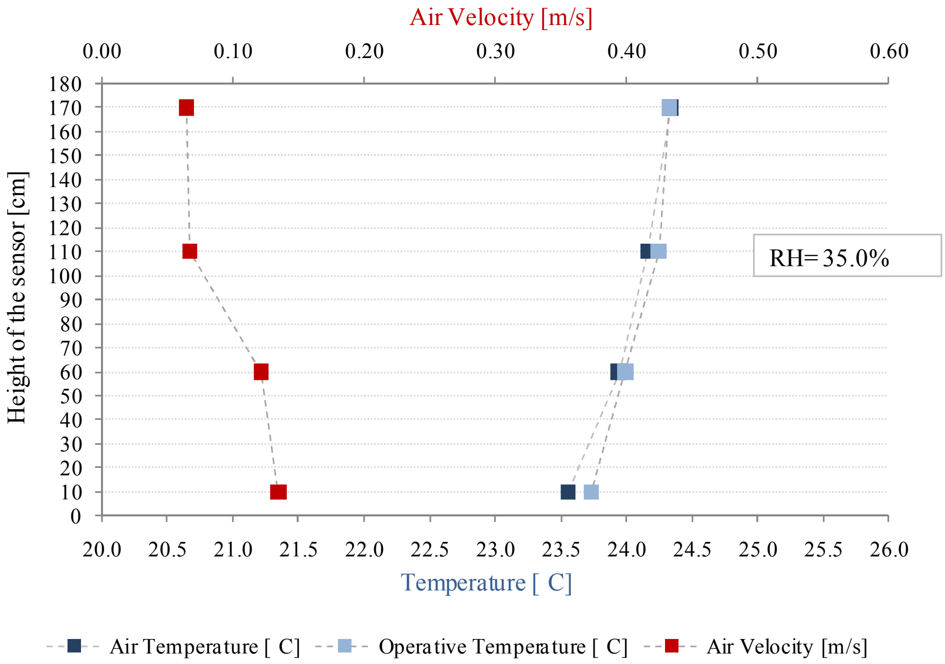


Figure 3.1.16.9 – Average value of Air Temperature, Operative Temperature and Air Velocity at different heights in the analyzed room.

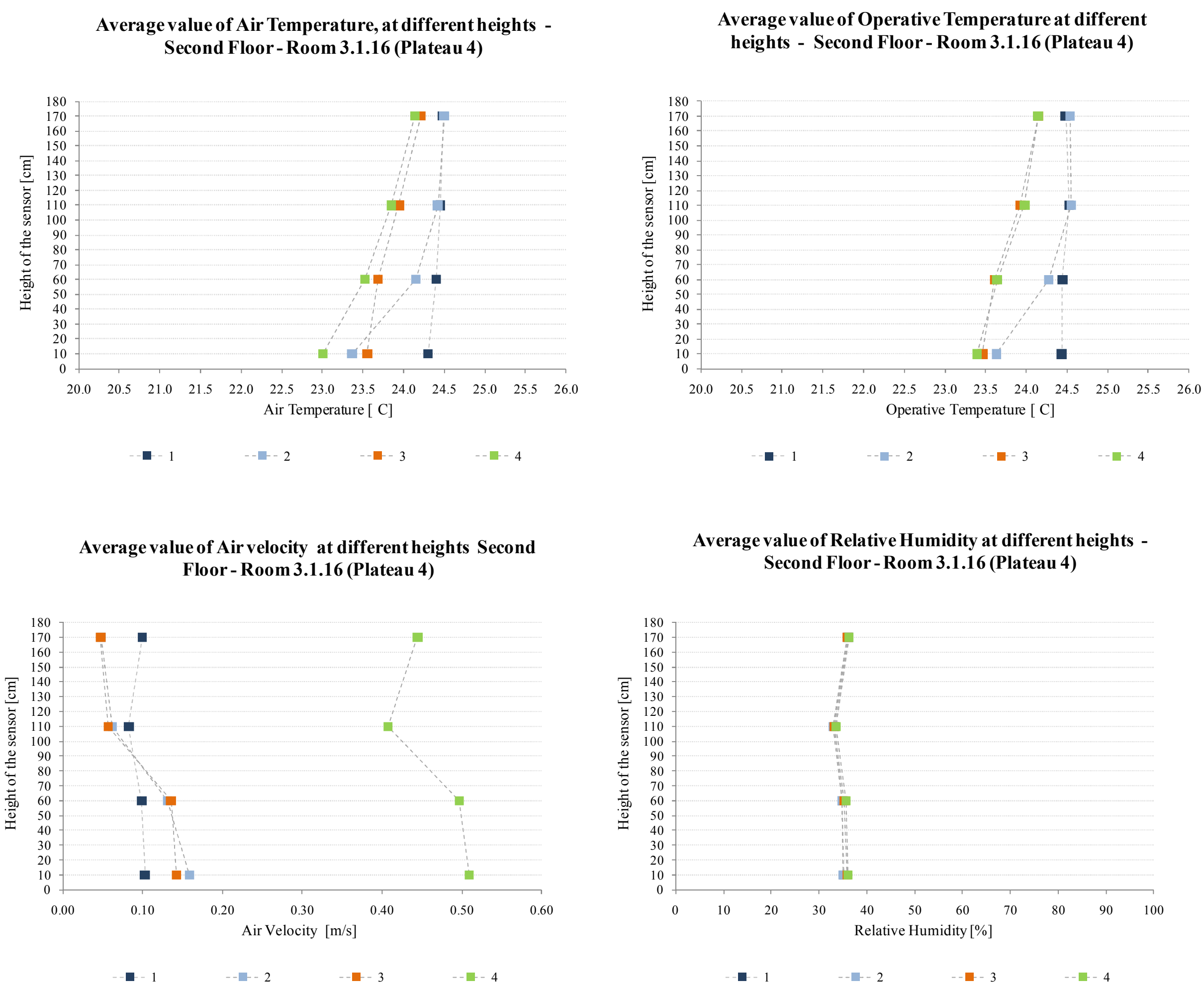


Figure 3.1.16.10 – Average value of Air Temperature, Operative Temperature, Air Velocity and Relative at different heights for the monitored points.

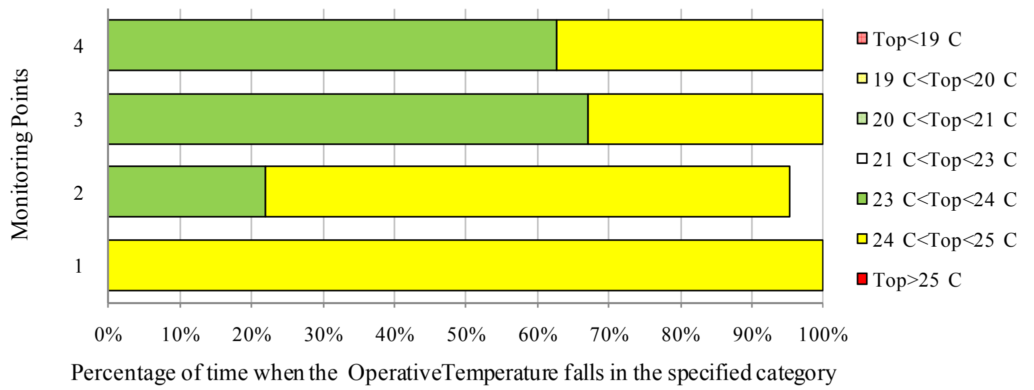


Figure 3.1.16.11 – Percentage of time when the Operative Temperature falls in the specified categories.

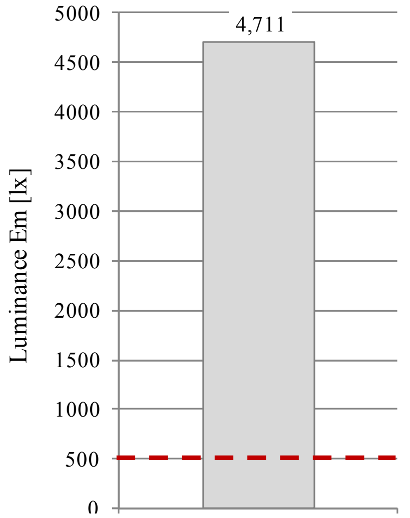


Figure 3.1.16.12 – Average value of Luminance monitored in the analyzed room.

Comments of the occupants

- The lighting level is too low.
- The air is too dry.

The level of light in the room has been monitored in a secondary moment respect to the other measurements. The high luminance level showed by figure 3.1.16.12 does not represent the average value of luminance of the room. Being the room an open space on the last floor, can be that a natural light beam affected the measurement.

Annex b

Summary of all the room where spot measurements were conducted.

Floor	Room	Data and hour of monitoring	Number of monitored points	Height of the sensor	Average Values: Air Temperature [°C]	Average Values: Operative Temperature [°C]	Average Values: Air Velocity [m/s]	Average Values: RH [%]
Ground Floor	1.1.00 Office open space	23/03/2011 From 09:16 To 10:44	6 (13÷18)	170 cm	24.91	24.97	0.08	0.34
				110 cm	24.60	24.76	0.05	0.32
				60 cm	24.39	24.44	0.10	0.34
				10 cm	23.92	24.07	0.13	0.34
	1.1.00 Desk close to the door	23/03/2011 From 14:20 To 14:30	1 (29)	170 cm	23.35	23.57	0.16	0.28
				110 cm	22.48	22.99	0.08	0.25
				60 cm	21.85	22.48	0.17	0.26
				10 cm	21.34	21.97	0.25	0.28
	1.4.00 Office	23/03/2011 From 13:21 To 14:09	1 (27)	170 cm	23.47	23.49	0.06	0.28
				110 cm	23.36	23.43	0.05	0.25
				60 cm	23.22	23.19	0.07	0.26
				10 cm	22.80	23.00	0.09	0.27
	1.5.00 Office	23/03/2011 From 14:11 To 14:17	1 (28)	170 cm	23.41	23.42	0.02	0.27
				110 cm	23.30	23.38	0.02	0.25
				60 cm	23.11	23.19	0.04	0.26
				10 cm	22.89	22.99	0.05	0.27
Firs t Floor	2.1.23 Plateau 1	23/03/2011 From 10:46 To 12:01	5 (19÷21, 23-24)	170 cm	24.81	24.92	0.12	0.35
				110 cm	24.70	24.92	0.10	0.32
				60 cm	24.60	24.60	0.12	0.34
				10 cm	24.12	24.35	0.15	0.35
	2.1.25 Plateau 2	23/03/2011 From 08:29 To 9:14	3 (10÷12)	170 cm	23.06	23.17	0.13	0.37
				110 cm	23.02	23.22	0.13	0.34
				60 cm	22.99	23.09	0.14	0.36
				10 cm	22.84	23.03	0.13	0.36
	2.1.24 Meeting room	23/03/2011 From 11:32 To 11:43	1 (22)	170 cm	22.48	22.42	0.04	0.34
				110 cm	22.34	22.25	0.05	0.32
				60 cm	22.23	22.06	0.04	0.34
				10 cm	21.84	22.12	0.11	0.35
	2.2.00_a Office	22/03/2011 From 14:24 To 16:27	5 (5÷9)	170 cm	24.53	24.58	0.11	0.34
				110 cm	24.53	24.69	0.08	0.31
				60 cm	24.41	24.55	0.11	0.33
				10 cm	23.93	24.15	0.12	0.34
	2.2.00_b Office	23/03/2011 From 14:24 To 16:27	5 (5÷9)	170 cm	23.96	23.99	0.09	0.27
				110 cm	23.89	24.03	0.07	0.24
				60 cm	23.65	23.76	0.10	0.26
				10 cm	23.21	23.49	0.13	0.27
	2.1.00 Canteen	23/03/2011 From 13:34 To 13:59	2 (25-26)	170 cm	25.08	25.13	0.08	0.33
				110 cm	24.89	25.02	0.06	0.30
				60 cm	24.68	24.69	0.08	0.31
				10 cm	24.23	24.39	0.10	0.32
Second Floor	3.1.16 Plateau 4	22/03/2011 From 13:18 To 15:37	5 (30÷34)	170 cm	24.33	24.33	0.07	0.36
				110 cm	24.17	24.25	0.07	0.33
				60 cm	23.94	23.99	0.12	0.35
				10 cm	23.56	23.73	0.13	0.36

Undersøgelse af indeklimaet i Middelfart Sparekasse, 11. juni 2007 til 3. juli 2007

Målerapport

Center for Indeklima og Energi
Institut for mekanik, Energi og konstruktion
Danmarks Tekniske Universitet

19. september 2007

Indhold

I det følgende præsenteres resultaterne af undersøgelsen af indeklimaet i Middelfart Sparekasse.

Undersøgelsen blev gennemført for at kortlægge indeklimaet i den eksisterende bygning forud for opførelsen af det nye domicil, hvor en tilsvarende undersøgelse vil blive gennemført som grundlag for en sammenligning af indeklimaet i de to bygninger.

Undersøgelsen var sammensat af fire elementer:

- Kontinuert måling af temperatur, luftfugtighed og luftens CO_2-koncentration igennem hele undersøgelsesperioden fra den 11. juni til den 29. juni 2007.

- Kortlægning af brugernes generelle oplevelse af indeklimaet i løbet af den sidste måned (regnet fra midten af juni).

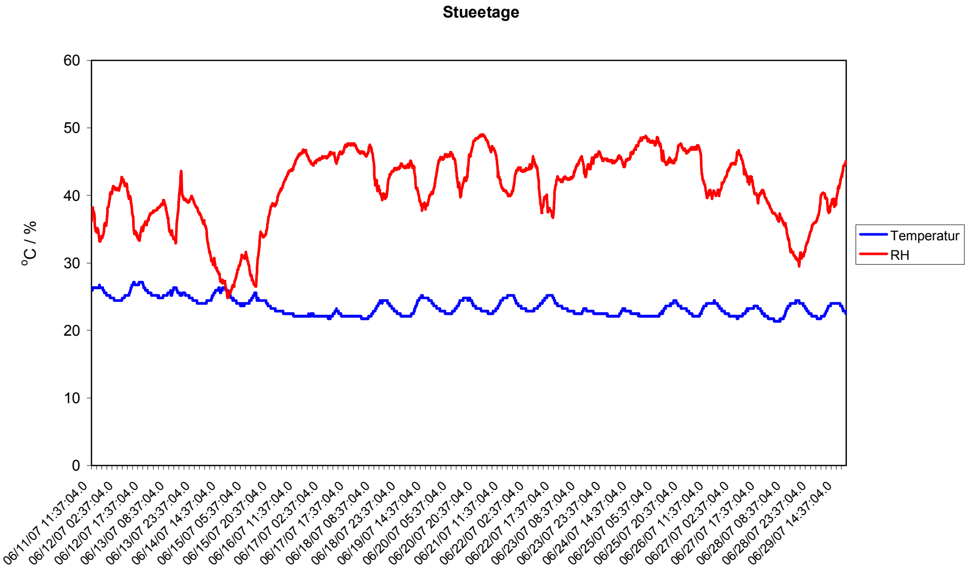
- Detaljerede målinger af temperaturer og lufthastighed i løbet af en udvalgt dag, den 3. juli 2007.

- Øjebliksbesvarelser af brugernes aktuelle oplevelse af indeklimaet den 3. juli 2007.

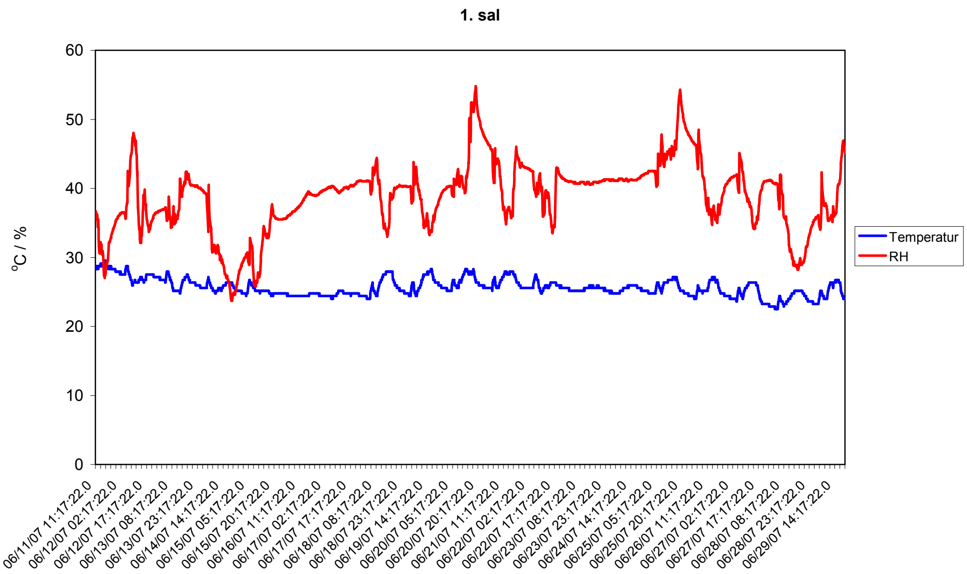
De to sidste elementer er målrettet en sammenligning af indeklimaet i den nuværende og den fremtidige bygning og har først egentlig værdi efter at undersøgelsen er gentaget i den nye bygning. Måleresultater og spørgeskemabesvarelser er medtaget i denne rapport for fuldstændighedens skyld.

Fysiske målinger fra den 11. juni til den 29. juni 2007

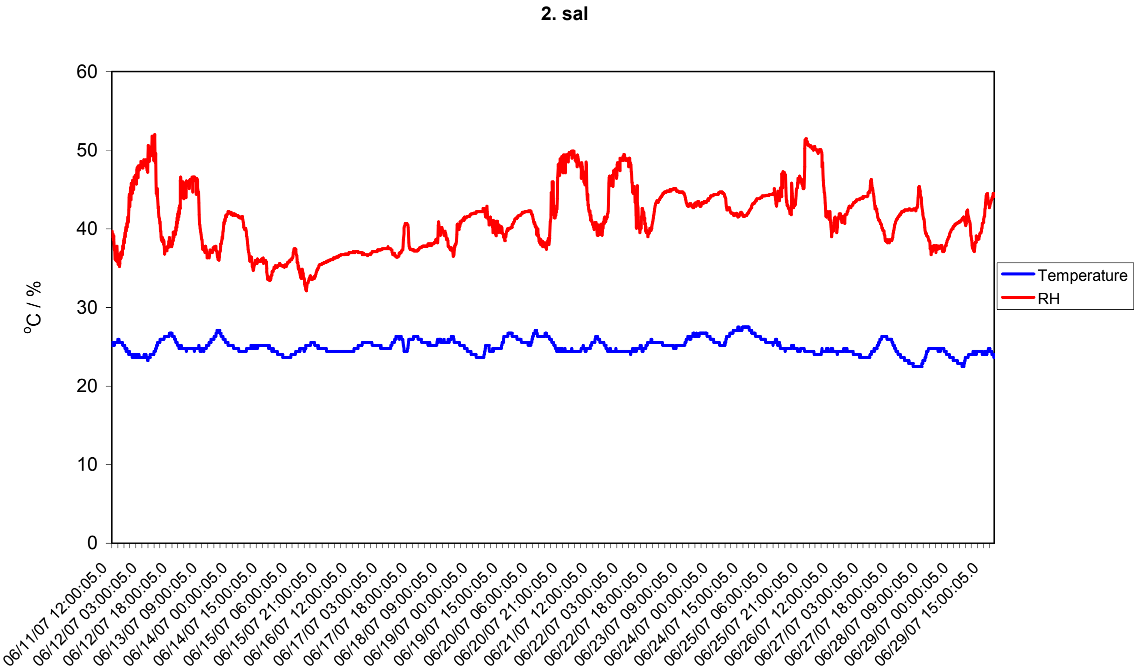
Figur 1, 2 og 3 viser lufttemperatur og relativ luftfugtighed målt i stueetagen, på første sal og på anden sal. Særligt i den tidlige del af måleperioden overstiger temperaturen i sidste halvdel af arbejdsdagen de 26^{o}C, som typisk anbefales i indeklimastandarder som en øvre grænse for termisk komfort (e.g. DS474 1995). Det målte temperaturforløb inden døre er i overensstemmelse med udetemperaturens variation (Figur 4).



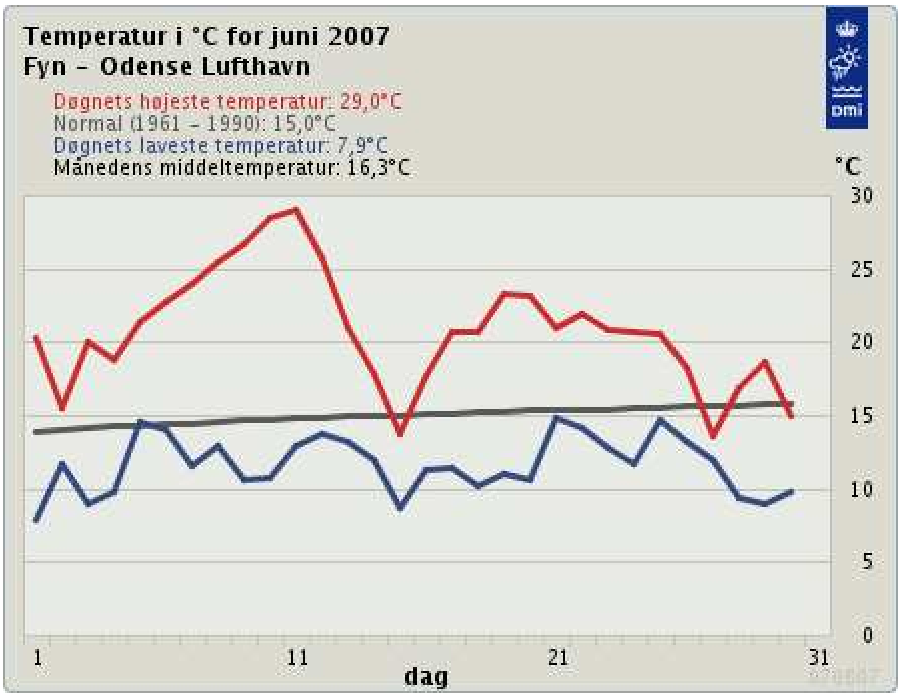
Figur 1. Lufttemperatur og luftfugtighed målt i stueetagen fra 11. juni til 29. juni.



Figur 2. Lufttemperatur og luftfugtighed målt på 1. sal fra 11. juni til 29. juni.



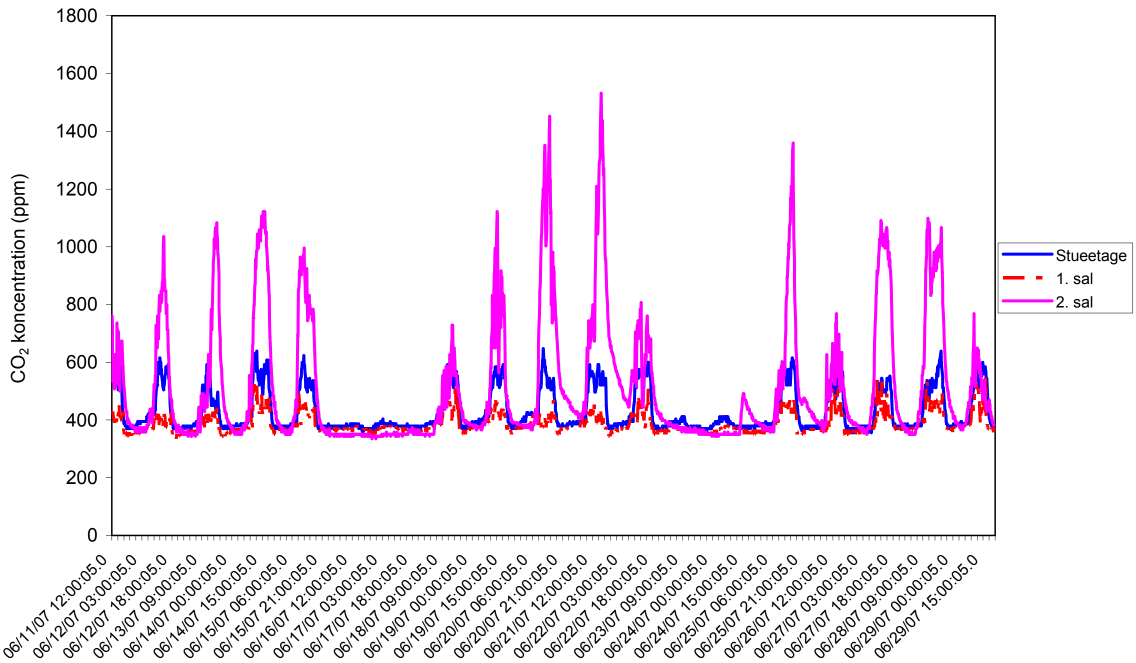
Figur 3. Lufttemperatur og luftfugtighed målt på 2. sal fra 11. juni til 29. juni.



Figur 4. Udetemperaturen på Fyn i juni måned.

De højeste temperaturer blev målt på første sal, hvorimod den lokale køling på anden sal har forhindret tilsvarende høje temperaturer, som ellers kunne forventes på denne etage.

Den relative luftfugtighed varierede kun lidt mellem kontorer og lå typisk mellem 30% og 50%. Typisk er det anbefalede interval i indeklimastandarder mellem 30% og 70%.



Figur 5. Luftens CO2 koncentration målt i stueetagen, på første og på anden sal.

Figur 5 viser luftens koncentration af CO_2 i måleperioden. CO_2 udåndes af mennesker og anvendes som en indikator for forurening afgivet af mennesker og som et udtryk for ventilationen set i forhold til persontætheden i et lokale. I stueetagen og på første sal var den højeste CO_2 koncentration omkring 600 ppm (parts per million), hvilket indikerer, at ventilationen på disse etager var tilstrækkelig til at fortynde forureningen fra personerne. På anden sal nåede CO_2 - koncentrationen på visse dage niveauer omkring 1400-1500 ppm. Dette er højere end anbefalet i indeklimastandarder og kan resultere i oplevelsen af dårlig lugt og indelukket luft og for nogle personer øge intensiteten af indeklimasymptomer.

Spørgeskemaer, baggrund

56 personer (32 kvinder, 23 mænd, 1 ikke angivet) har besvaret det lange spørgeskema svarende til ca. 75% af de personer, der modtog en invitation per mail til at udfylde skemaet. Dette anses for tilfredsstillende og repræsentativt for brugernes oplevelse af bygningen. Der var 20 besvarelser i stueetagen, 28 på første sal og 8 på anden sal.

Spørgeskemaet kan ses på www.ie.dtu.dk/midspar

De vigtigste resultater af spørgeskemaundersøgelsen omfatter forekomsten af bygningsrelaterede symptomer og forekomsten af klager over indeklimaet. Begge prevalenser vil blive sammenlignet med tilsvarende værdier baseret på et stort antal bygninger (CIS 2000).

Tabel 1 viser forekomsten af bygningsrelaterede symptomer, forekomsten af symptomer uafhængigt af om de er bygningsrelaterede samt median og 90 % fraktiler for tilsvarende prevalenser i normalmaterialet hørende til Glostrupskemaet, som det aktuelt anvendte skema er baseret på (CIS 2000).

Bygningsrelaterede symptomer er symptomer, hvis intensitet mindskes når bygningen forlades. Symptomforekomsterne i Tabel 1 svarer til, at hyppigheden af symptomet er ofte (ugentlig) eller daglig. Eksempelvis følte 25 % af personerne træthed ugentligt eller dagligt, mens 14 % følte træthed mens de var i bygningen, men at trætheden blev mindre når de forlod bygningen.

Symptom	Bygningsrelateret forekomst (%)	Forekomst (%)	Glostrup median (%)	Glostrup 90% fraktil (%)
Træthed	14	25	12	19
Tung i hovedet	13	16		
Hovedpine	4	4	11	17
Koncentrationsbesvær	9	9	4	10
Søvnig	2	2		
Problemer med at fokusere	4	7		
Kløe eller irritation i øjnene	4	7	6	16
Irriteret, tilstoppet eller løbende næse	5	7	12	16
Hæs, tør hals	0	6	3	7
Hoste	0	2	7	10
Tør, kløende hovedbund eller hud på øre	2	4		
Tør, kløende hud på hænderne	0	2		
Andet	6	6		

Tabel 1. Forekomsten af symptomer, der er til stede flere gange ugentligt eller dagligt.

Kategorien ”Andet” omfatter andre symptomer der især fokuserer på gener forårsaget af varme og støj.

Normalmaterialet til sammenligning (Glostrup) stammer fra 41 tilfældigt udvalgte virksomheder fordelt over hele landet. Omtrent 2/3 af besvarelserne er fra kvinder, hvilket stemmer nogenlunde overens med kønsfordelingen i denne undersøgelse. Medianen angiver, at halvdelen af virksomhederne ligger under denne værdi, mens

90%-fraktilen angiver, at 90 % af virksomhederne ligger under denne værdi dvs. at de ansatte her har det bedre. Som retningslinie bør man ikke ligge over 90%-fraktilen, men såfremt man ønsker en høj kvalitet i sit arbejdsmiljø, kan man tilstræbe at nærme sig eller komme under værdien for medianen (CIS 2000).

Sammenlignet med normalmaterialet er der nogenlunde samme eller lavere forekomst af både specifikke (øjne, næse, hals, hud) og generelle (træthed, hovedpine, koncentrationsbesvær) symptomer end i gennemsnittet af danske kontorbygninger.

Symptomerne med den højeste prevalens fordeler sig på etager som vist i Tabel 2.

Symptom	Stueetage (%)	Første sal (%)	Anden sal (%)
Træthed	25	18	50
Tung i hovedet	11	14	25
Koncentrationsbesvær	10	7	13

Tabel 2. Fordeling af udvalgte generelle symptomer på etager.

Særligt på anden sal er der en høj prevalens af de generelle symptomer, men tallene baserer sig på kun 8 besvarelser og er derfor forholdsvis usikre.

Tabel 3 viser forekomsten af klager over indeklimaet for gener, der er til stede ugentligt eller dagligt.

Faktor	Forekomst (%)	Glostrup median (%)	Glostrup 90% fraktil (%)
Høj temperatur	48	10	20
Varierende temperatur	23	16	30
Lav temperatur	7	9	18
Træk	18	15	29
Indelukket luft	39	17	27
Tør luft	25	23	39
Støj	34	28	42
Lys	18	10	20

Tabel 3. Forekomst af klager over indeklimaet for gener, der er til stede ugentligt eller dagligt.

Især høj temperatur, indelukket luft og støj er faktorer, som forårsager gener og for to af disse overstiger 90 % fraktilen i normalmaterialet (høj temperatur og støj).

Besvarelsesfordelingen for spørgsmålet ”Hvor tilfreds er du med indeklimaet i bygningen kan ses i Tabel 4.

	Klart utilfreds	Netop utilfreds	Netop tilfreds	Klart tilfreds
Antal besvarelser	10	13	24	8

Tabel 4. Fordeling af besvarelser for den generelle tilfredshed med indeklimaet i bygningen.

Flertallet af besvarelserne indikerede tilfredshed med indeklimaet, men samtidig var der også en ikke ubetydelig del, som ikke var tilfreds med de nuværende forhold.

Opsummering
Målinger af lufttemperaturen i løbet af en tre-ugers periode viste, at temperaturen var højere end anbefalet i indeklimastandarder – særligt om eftermiddagen og når udetemperaturen var høj. Den periodevis høje temperatur i lokalerne resulterede i, at den hyppigste klage over indeklimaet var høj temperatur. En høj lufttemperatur medfører ofte en oplevelse af dårlig luftkvalitet. Den næsthyppigste gene var indelukket luft, som kan være afledt af temperaturforholdene i bygningen. Yderligere var støj på kontoret et forholdsvist omfattende problem.

I stueetagen og på anden sal blev der målt lave CO_2-koncentrationer, der indikerede, at ventilationen var tilstrækkelig til antallet af personer i lokalerne. På anden sal blev der målt ret høje CO_2 koncentrationer, som oversteg anbefalinger i indeklimastandarder. Niveauet af ventilationsraten på anden sal kunne således også bidrage til oplevelsen af indelukket luft.

Forekomsten af symptomer var typisk på niveau med eller lavere end gennemsnitsforekomsten i kontorbygninger i Danmark, og således ikke alarmerende.

Fysiske målinger gennemført den 3. juli 2007

På denne dato blev gennemført øjebliksmålinger på de tre etager af operativ temperatur (t_o), lufttemperatur (t_a), lufthastighed (v_a), turbulensintensitet (Tu) og strålingstemperaturasymmetri (Δt_{pr}). Målingerne er gengivet i følgende tabel 5.

PMV indekset i tabellen er beregnet udfra t_o, v_a, luftfugtighed samt beklædningsisolans og aktivitetsniveau, og udtrykker hvordan en gruppe af mennesker vil føle sig tilpas i termisk henseende i forhold til 7-pkt. skalaen (-3: kold, -2: kølig, -1 let kølig, 0: neutral, 1: let varm, 2: varm, 3 hed). I beregningerne i Tabel 5 er det antaget, at beklædningsisolansen svarer til ca. 0.6 clo (sommerbeklædning) og aktivitetsniveauet til 1.2 met (typisk for kontorarbejde).

Vurdering af trækrisiko foretages på baggrund af trækmodellen, som beregner den forventede andel af utilfredse p.g.a. træk (DR) udfra v_a, Tu og t_a. Modellen gælder for stillesiddende personer klædt i normal indendørs beklædning. Lidt varmere end neutral medfører mindre følsomhed overfor luftbevægelser (behagelig konvektiv afkøling) og omvendt, lidt køligere end neutral medfører større følsomhed overfor luftbevægelser.

Målested	Punkt	Tidspunkt	Målehøjde (m)	t_o (°C)	t_a (°C)	v_a (m/s)	Tu (%)	Δt_{pr} (°C)	PMV	DR (%)
Stue-etage	1	10:43	0.1		23.7	0.03	100			<10
			0.6	23.3		0.08	2	0.8	-0.1[3)]	
			1.1		23.9	0.07	5			<10
	2	10:54	0.1		23.5	0.13	46			14
			0.6	23.3		0.09	67	<0.6	-0.1	
			1.1		23.7	0.09	67			<12
	3	11:03	0.1		23.5	0.08	50			<10
			0.6	23.3		0.10	77	0.2	-0.2	
			1.1		23.8	0.08	100			<15
	4	11:15	0.1		23.5	0.10	100			17
			0.6	23.4		0.09	78	<0.3	-0.2	
			1.1		24	0.07	86			<14
1. sal	1	11:25	0.1		23.5	0.05	60			<16[1)]
			0.6	23.6		0.05	60	<0.3	-0.1	
			1.1		24.7	0.01	0.02			
	2	11:42	0.1		24.9	0.06	67			<12
			0.6	24.9		0.15	33	<0.8	0.1	
			1.1		26.1	0.17	59			18
	3	11:52	0.1		23.9	0.06	50			<13
			0.6	24.6		0.08	63	0.2	0.2	
			1.1		24.4	0.08	63			<12

Måle-sted	Punkt	Tids-punkt	Måle-højde (m)	t_o (°C)	t_a (°C)	v_a (m/s)	Tu (%)	Δt_{pr} (°C)	PMV	DR (%)
2. sal	1	12:50	0.1							
			0.6	21.9		0.25	48	0.1	-1	44 2)
			1.1		21.9	0.14	57			
	2	13:00	0.1		22.9	0.16	19			24
			0.6	22.9		0.10	45	<0.3	-0.2	
			1.1		23.5	0.06	67			<13

1) Hvor lufthastigheden blev målt til <0.1 m/s skønnes trækrisikoen for en lufthastighed på 0.1 m/s

2) Dette målepunkt var ved en arbejdsplads placeret umiddelbart under indblæsningen fra en lokal køleunit.

3) En beklædningsisolans på 0.6 clo og et aktivitetsniveau på 1.2 met er antaget ved beregning af PMV.

Tabel 5: Øjebliksmålinger af fysiske indeklimaparametre i stueetage, på 1. og på 2. sal.

Turbulensintensiteten er beregnet som forholdet mellem standardafvigelsen af lufthastigheden og middellufthastigheden hvorfor Tu særligt ved lave lufthastigheder når op på 100%. Den høje tu er formentlig et udtryk for kortvarige høje lufthastigheder, når ansatte eller kunder bevægede sig rundt i lokalet i nærheden af måleudstyret.

Generelt overholder de målte termiske forhold standardernes krav til temperatur og lufthastighed og kun i et enkelt målepunkt blev der registreret samtidig lav lufttemperatur og høj lufthastighed, som forventeligt vil forårsage trækgener for den person, der sidder direkte under indblæsningen på 2. sal. (DS 474-1995).

Udvalgte øjebliksbesvarelser den 3. juli 2007

Spørgeskemaet, som blev anvendt til at måle de ansattes øjeblikkelige oplevelse af indeklimaet indeholdt hovedsagelig kontinuerte VAS (Visual Analogue Skalaer) skalaer med værdier fra 0 ved venstre endepunkt til 100 ved højre endepunkt. En persons votering på skalaen varierer meget mellem individer, og besvarelserne kan derfor kun anvendes til at sammenligne større gruppers voteringer i to situationer, f.eks. før og efter en renovering. Besvarelserne er medtaget i det følgende for fuldstændighedens skyld.

I alt 34 personer har besvaret et eller flere spørgsmål i det spørgeskema, som blev udfyldt den 3. juli, 15 i stueetagen, 12 på første sal og 7 på anden sal.

Spørgeskemaet kan ses på www.ie.dtu.dk/midspar/tirsdag

Middelværdien af de observerede besvarelser på den termiske 7 pkt. skala er vist i Tabel 6:

Stueetage	1. sal	2. sal
-1.9	0.6	-0.6

Tabel 6. Middelværdi af medarbejdernes votering på 7 pkt. skalaen.

Hyppigheden af medarbejdernes subjektive oplevelse af det termiske indeklima er vist i Tabel 7.

	Klart behageligt	Netop behageligt	Netop ubehageligt	Klart ubehageligt
Stueetage	1	10	1	3
1. sal	0	7	0	5
2. sal	1	3	2	1

Tabel 7: Hyppighed af personer, der besvarede spørgsmål om behagelighed af det termiske indeklima, fordelt på etager.

Tabel 8 viser middelværdien fordelt på etager af oplevelsen af forskellige faktorer med forbindelse til indeklimaet.

Faktor	Endepunkter	Stueetage	1. sal	2. sal
Luftkvalitet	0=dårlig 100=god	39	32	47
Lys	0=for mørkt 100=for lyst	34	42	46
Støj	0=for stille 100=for støjende	63	59	42
Luftfugtighed	0=fugtig luft 100=tør luft	54	48	50
Rengøring	0=snavset 100=rent	59	75	73

Tabel 8. Middelværdier af de ansattes oplevelser af forskellige faktorer med forbindelse til indeklimaet, fordelt på etager.

Tabel 9 viser middelværdien af intensiteten af forskellige indeklimasymptomer.

Skala endepunkter	Stueetage	1. sal	2. sal
0=tør hals, 100=ikke tør hals	56	51	79
0=tør mund, 100=ikke tør mund	58	57	79
0=tørre læber, 100=ikke tørre læber	53	40	69
0=tør hud, 100=ikke tør hud	60	58	61
0=tørre øjne, 100=ikke tørre øjne	59	52	77
0=irriterede øjne, 100=ikke irriterede øjne	55	54	65
0=utilpas, 100=veltilpas	63	60	80
0=træt, 100=frisk	59	49	69
0=kraftig hovedpine, 100 = ingen hovedpine	74	81	88

0=koncentrationsbesvær, 100=ikke koncentrationsbesvær	66	67	69
0=deprimeret, 100=ikke deprimeret	73	71	84
0=kan arbejde 0%, 100=kan arbejde 100%	86	85	87

Tabel 9. Middelværdier af de ansattes oplevelser af intensiteten af forskellige indeklimasymptomer, fordelt på etager.

De følgende kommentarer til indeklimaet blev registreret via spørgeskemaet og er kopieret fra databasen:

- Jeg sidder lige under air condition'en og derfor trækker det meget på mig. De andre i afdelingen har det ofte for varmt, mens det er koldt hos mig - især på den side, hvor den kolde luft rammer.

- På min plads er der altid meget varmt.

- Der er for meget støj

- Lige nu er temperaturen ok. Det er en undtagelse, og skyldes, at airconditionen er tændt lige nu. Der er normalt alt for varmt, fordi airconditionen som regel er slukket, da den generer meget (træk og kulde).

- Der er voldsom træk, hvis døren ikke er lukket (så kraftig, at papirerne blæser ned på gulvet). Derfor lukker jeg den 100 gange om dagen, og generer derved mine kolleger, der jo som regel har det alt for varmt!

- Vi har intet klima anlæg hvor vi sidder - kun en kold og varme blæser.

- Klimaanlægget giver meget træk og meget uensartede temperaturer i lokalet. Man er kold på den ene side og varm på den anden. Samtidig er der fugt fra utæt tag, som muligvis udvikler svampe og sporer.

- Da jeg har astma foretrækker jeg et miljø uden tæpper

- Jeg er lidt forkølet. Plejer aldrig at være det, men sad i telt i regnvejr......

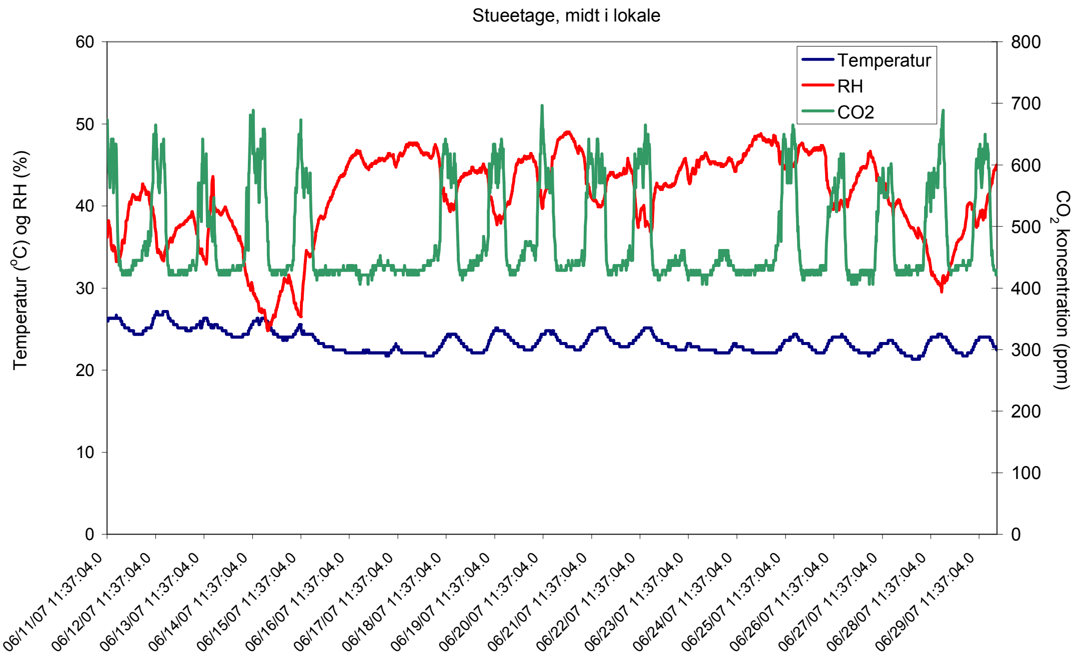
- Ingen frisk luft. Dårlig køle/varmeanlæg. Temperatur altid enten for høj eller lav. Aldrig tilpas.

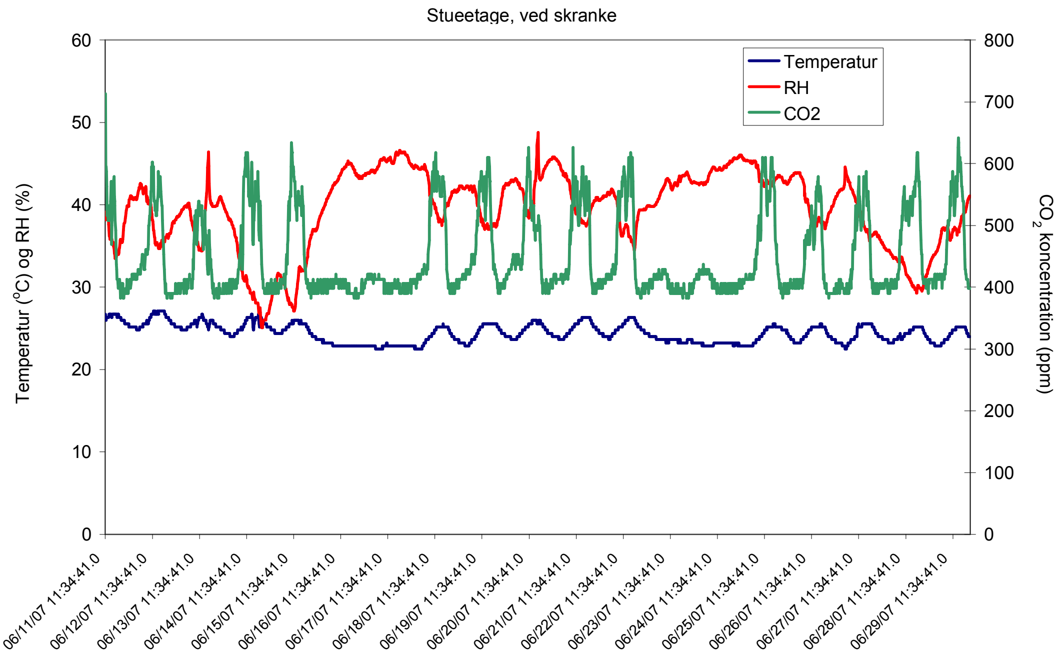
Litteratur

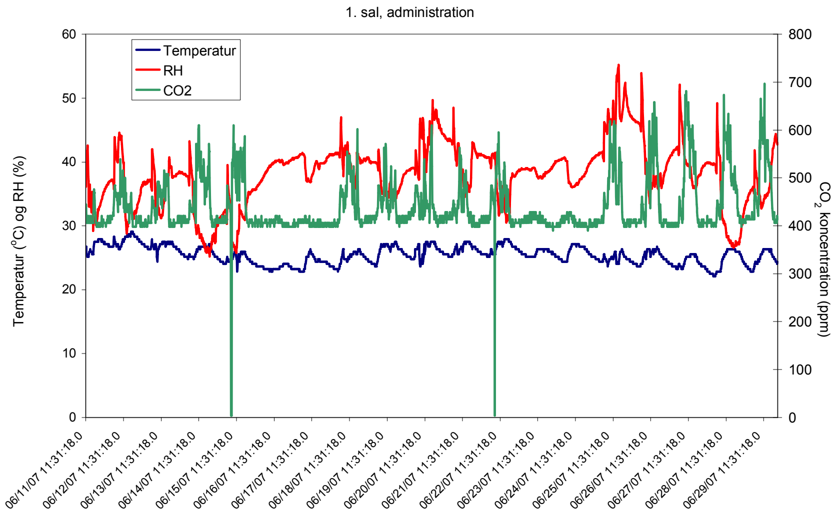
DS 474 1995. Norm for specifikation af termisk indeklima. 1st edition. Dansk Standard

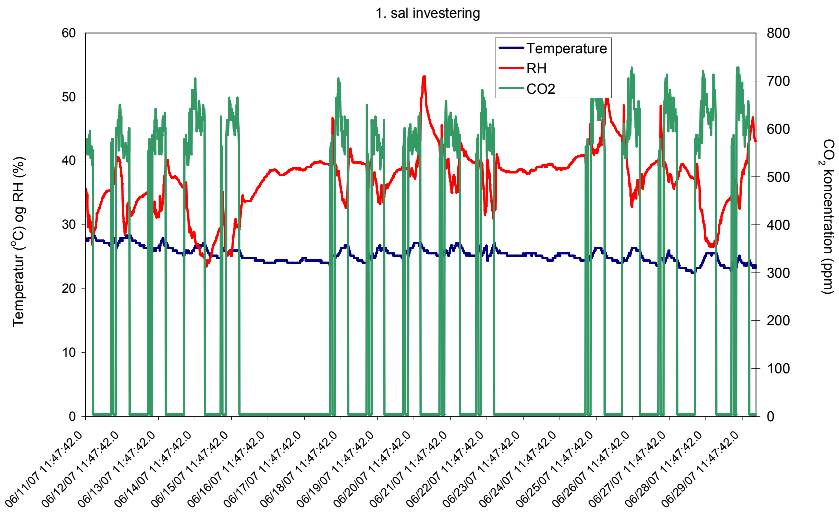
CIS 2000. Center for Indeklima og Stressforskning Spørgeskema. Spørgeskema til kortlægning af en virksomheds indeklimaproblemer og det psykiske arbejdsklima (Glostrupskemaet). http://www.cis.suite.dk/

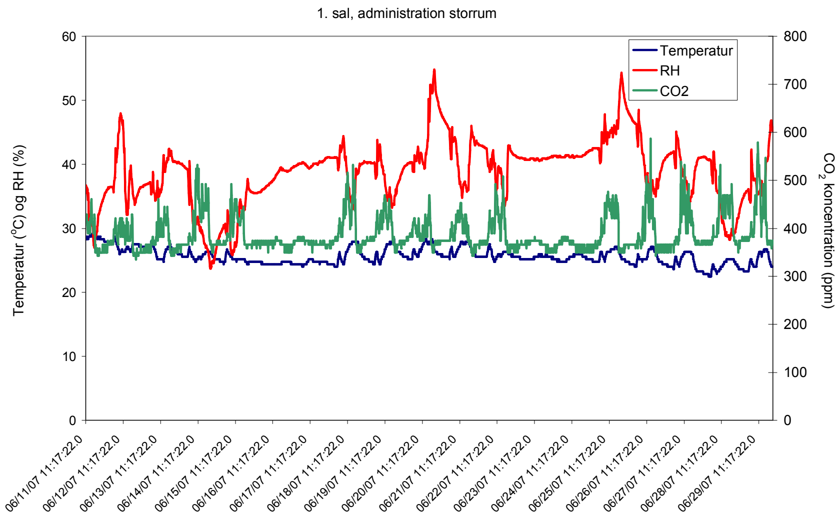
Appendix – Resultater fra samtlige fysiske målinger fra den 11. juni til den 29. juni 2007

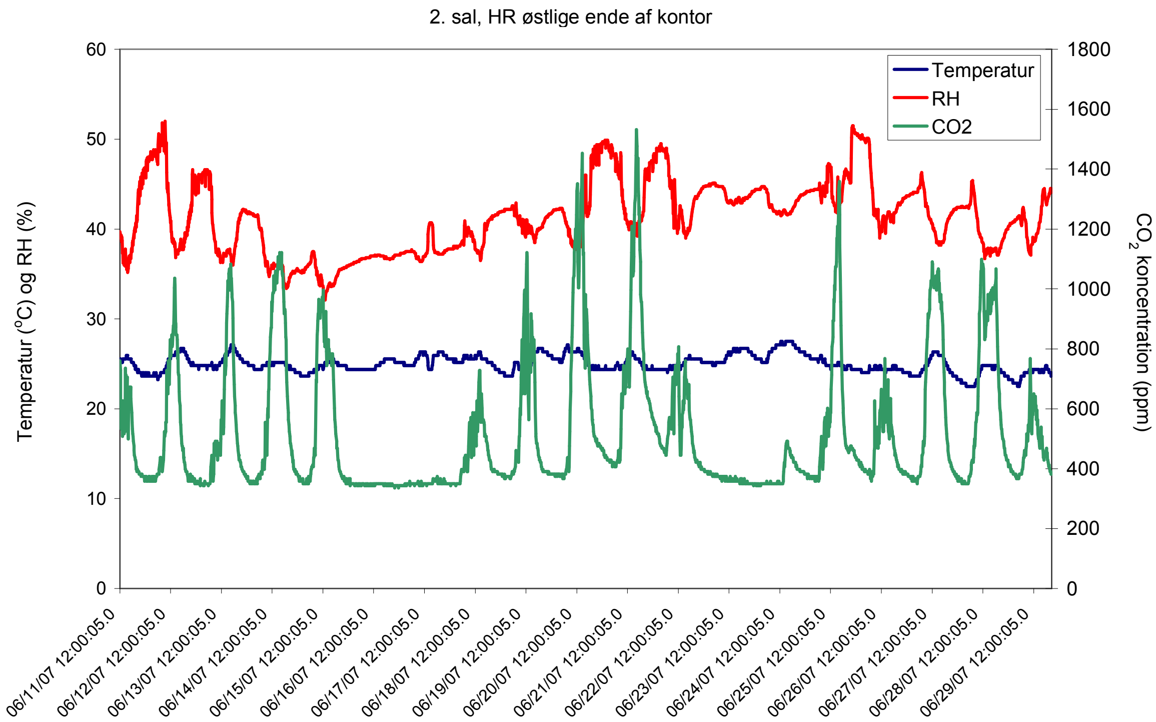





1. sal, administration
Temperatur
RH
CO2
Temperatur (°C) og RH (%)
CO_2 koncentration (ppm)
06/11/07 11:31:18.0 … 06/29/07 11:31:18.0


1. sal investering
Temperature
RH
CO2
Temperatur (°C) og RH (%)
CO_2 koncentration (ppm)
06/11/07 11:47:42.0 … 06/29/07 11:47:42.0


1. sal, administration storrum
Temperatur
RH
CO2
Temperatur (°C) og RH (%)
CO_2 koncentration (ppm)
06/11/07 11:17:22.0 … 06/29/07 11:17:22.0


2. sal, HR østlige ende af kontor
Temperatur
RH
CO2
Temperatur (°C) og RH (%)
CO2 koncentration (ppm)
06/11/07 12:00:05.0
06/12/07 12:00:05.0
06/13/07 12:00:05.0
06/14/07 12:00:05.0
06/15/07 12:00:05.0
06/16/07 12:00:05.0
06/17/07 12:00:05.0
06/18/07 12:00:05.0
06/19/07 12:00:05.0
06/20/07 12:00:05.0
06/21/07 12:00:05.0
06/22/07 12:00:05.0
06/23/07 12:00:05.0
06/24/07 12:00:05.0
06/25/07 12:00:05.0
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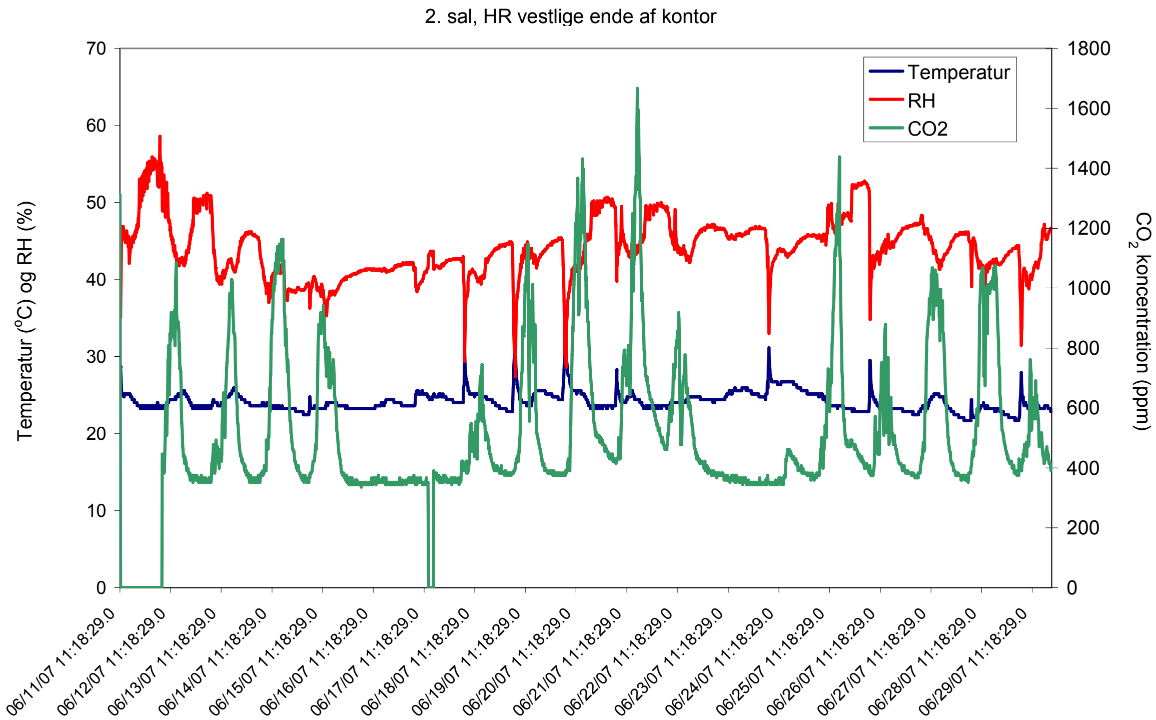
06/29/07 12:00:05.0


2. sal, HR vestlige ende af kontor
Temperatur
RH
CO2
Temperatur (°C) og RH (%)
CO2 koncentration (ppm)
06/11/07 11:18:29.0
06/12/07 11:18:29.0
06/13/07 11:18:29.0
06/14/07 11:18:29.0
06/15/07 11:18:29.0
06/16/07 11:18:29.0
06/17/07 11:18:29.0
06/18/07 11:18:29.0
06/19/07 11:18:29.0
06/20/07 11:18:29.0
06/21/07 11:18:29.0
06/22/07 11:18:29.0
06/23/07 11:18:29.0
06/24/07 11:18:29.0
06/25/07 11:18:29.0
06/26/07 11:18:29.0
06/27/07 11:18:29.0
06/28/07 11:18:29.0
06/29/07 11:18:29.0