



Temperature distribution in Risø Flexhouse Room 3 with different heating control principles

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Angela Simone

Carsten Rode

Technical Report

**Department of Civil Engineering
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Temperature distribution in Risø Flexhouse Room 3 with different heating control principles

Angela Simone and Carsten Rode

DTU Byg

Lyngby, December 2009

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1. Preface

This report presents the measurements of local thermal conditions in one room (“Room 3”) of the so-called “Flexouse” located at Risø DTU. The house is part of Risø DTU’s SYSLAB facility used to study the interaction of different facilities that supply and use energy.

The facility has been used in winter and spring 2009 to study the distribution of local temperatures in the room – particularly with the purpose to compare with the temperature measured and logged by the heating control sensor which was already installed in the room. The measured data shall be used together with mathematical models to predict the overall dynamic thermal properties of the building. The heating control sensor is located within a box (of size 85 x 85 x 25 mm) which is positioned on the wall in the back of the room. The circumstances for measuring the dynamic evolution of the temperature within the box may be different from what can be measured with other sensors located at different positions in the room, and it has been the purpose of the investigation to map these differences during the dynamic experiments.

Actors in the work have been graduate students, B.Sc. Theresa Højland Back, who managed the experimental setup in Flexhouse, and Post. Doc. Angela Simone who compiled the data for the report. Anders Thavlov of Risø DTU and Peder Bacher of DTU IMM facilitated the practical arrangements in Flexhouse. Professor Carsten Rode has been project leader in charge of the project.

The activity has been carried out within the project “Målekampagne i forbindelse med modeller for standby-forbruget samt rådgivning v. modellering”, which is funded by Elsparefonden (The Danish Electricity Saving Trust). The project is part of a wider complex of projects on predicting the electricity and heating energy consumption in dwellings. Partners in the consortium are Department of Mathematical Modelling, Technical University of Denmark (DTU IMM); Danish Technological Institute; ENFOR A/S; the Danish Building Research Institute.

The collaboration with these partners is highly appreciated. The funding of the project by the Danish Energy Saving Trust is thankfully acknowledged.

2. Introduction

The present report deals with analyses of thermal environment measurements carried out in Flexhouse at Risø DTU from February till April 2009. As the objective of the experiments was to provide data for models of the thermal dynamics of the building, the indoor temperature distribution has been analysed. The room have been equipped with the heating system of electrical radiators, which should be able to control the indoor environment to guarantee a desired indoor thermal condition for the occupants [1]. In these experiments, the heating system was used to supply heat energy according to desired load patterns which are described in [2].

Five series of the experiments were run, the details of which are described in Section 3 and in [2]. The temperature condition of Room 3 of the house were analysed in details (Figure 1), by studying the temperature distribution within the enclosed space in different positions.

An investigation of temperature sensors is made focusing on how well the sensor of the house, some additional thermocouple sensors and a HOBO sensor represent the thermal condition of the room. Comparing the measured temperature of the built thermal indoor environment, for five series of experiments, an evaluation of the sensors is made for determination of the best possible heating control sensor for the system.

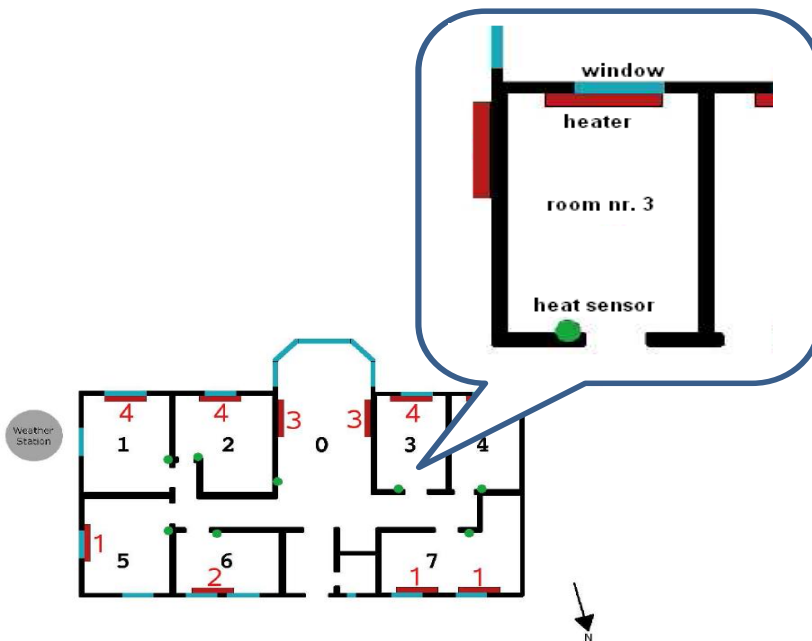


Figure 1. Room nr 3 (the room in which more temperatures measurements have been done).

3. Methods and Set up

The procedure for recording measured data by the central server and by the HOBO sensors is explained in Chapter 4 of [2].

In addition to the recorded data by the central server, temperature measurements at different locations in Room nr 3 were recorded. The measurement period from 29th January till 27th April

included the time of the different series of the experiments under different heating control system modes.

Temperature measurements were carried out in different places of the room. Due to different practical reasons, in the first part of the period (29th January – 19th February) it was possible to measure at only 14 different locations in the room, while in the following period (27th February – 27th April) temperature data at 24 locations in the room were recorded. An overview of the measured locations is shown in Figure 2.

24 thermocouple sensors, connected to a data logger (see Figure 3), were used and placed in the different positions. Air, window and wall temperatures were recorded each five minutes.

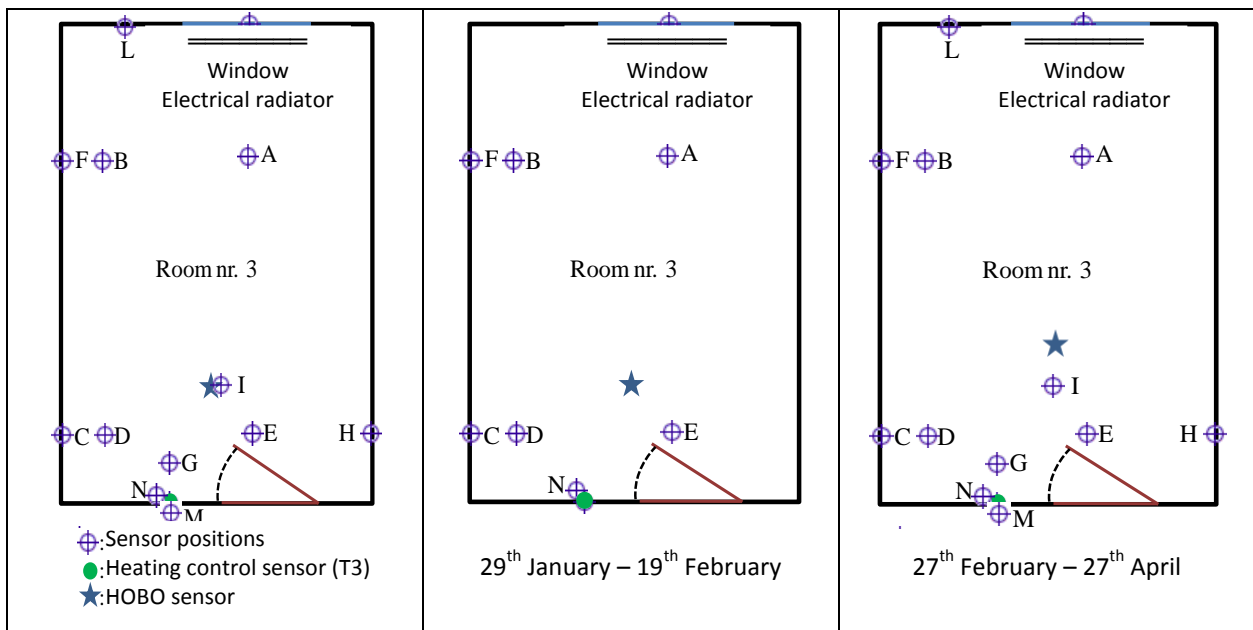


Figure 2. Plan of temperature measuring points: a) first period, b) subsequent periods. More details are reported in Appendix A.1.

The temperature (T_3) measured by the sensor of the house in Room 3 is controlling the heating system; the sensor is located close to the door at around 1.9 m's height above the floor (see Figure 3). More details about T_3 , the HOBO data and other data recorded by the central server are reported in Section 4 and 5.

Three more temperature sensors were located close to the heating control sensor: One (N) on the wall right to side of the heating control box, one (G) in the air 10 cm in front of the box, and the last (M) at the back side in the corridor, at the same height.

The window's temperature was measured in the centre of the pane. The wall's temperature was recorded at two different heights, 0.1m and 1.1m above the floor, at positions L , F , C , H of the external and internal wall from inside (Figure 2). In that way the influence of the surrounding environment could be evaluated. Particular attention was focused on point F , as a consequence of the heat generated by the device located on the opposite side of the wall in room nr 0.

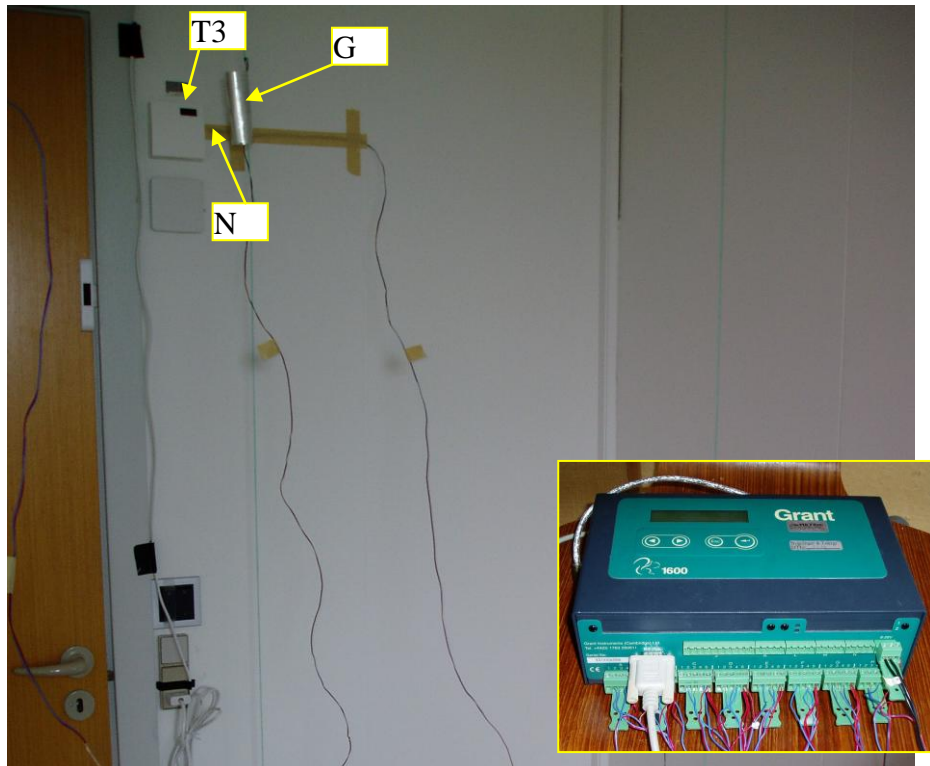


Figure 3. View of data logger and a few of the temperature sensors (*T3*, *N* & *G*) located in Room 3 (picture taken March 16, 2009).

In order to evaluate the influence due to the wall temperature, the air temperature was measured 10 cm from the wall (*B* and *D*) and at the same height above the floor.

With the sensors located at *A*, *B*, *D* and *E*, it was possible to analyse the temperature distribution in the room at 0.1 m and 1.1 m above the floor and, at the same time, to evaluate the generation of non-uniform temperature distribution.

It is common use in an office to locate the desk close the window, at around 1 m distance from it. In the present room, an office condition will see the occupant spending his/her working time mostly at the location *A*. For that reason, the vertical air temperature distribution was measured in location *A* at different heights from the floor to the ceiling (0 m, 0.1 m, 0.6 m, 1.1 m, 1.7 m and 2.5 m). As a consequence of the heating control of the temperature in Room nr.3, a check of the possible occurrence of draft within the room was possible.

In the second time period of the measurements, globe-temperature was measured in point *A* by a characteristic black sphere, at 1.7 m above the floor. The measured air temperatures and, in particular, the globe-temperature gives the possibility to estimate the operative and mean radiant temperatures (according to ISO 7726/94 [3]) as the best room temperature desired.

4. Results and discussion

An estimated average temperature, by the HOBO sensor (*HT3*), the heating control sensor (*T3*), the globe- and the thermocouple-sensors, located approximately at the same height above the floor, are reported in Table 1 for all the experiment series. The values show how well the temperature sensor of the heating control system and the other sensors characterize the thermal condition in the room. Only looking to the average values, there seems to have been a good correspondence between the temperature control sensor and the HOBO sensor. However, as will be seen later, there is quite some difference between how well the sensors have represented the dynamic variations.

The thermocouple sensors (*A – N*) have given a more diversified picture of the temperature distribution within the room, and their results may be slightly more transient due to the smaller heat capacity of the sensor. However, there may have been an issue with solar sensitivity of the thermocouple measuring system which hampers the interpretation of results from those sensors. These problems are mentioned in the next section of the report.

As expected, also the globe sensor shows differences due to the solar radiation directly shining on the black sphere surface.

Table 1. Average of measured temperatures.

Experimental set	$T_{\text{average}} \pm \text{standard deviation}$									
	HT3 (HOBO)	I (1.7m)	T3	G (1.7m)	N (1.7m)	M (1.7m)	A (1.7m)	window	globe	calculated T_r / T_o
	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)
PRBS1 5/02-9/02	19.6±3.5	-	19.7±3.1	-	19.3±3.3	-	19.8±3.7	16.6±4.5	-	
PRBS2 27/02-05/03	20.5±2.5	20.5±2.5	19.8±2.2	20.7±2.7	19.9±2.3	18.3±2.9	20.6±2.8	17.4±4.2	-	
Therm1 16/02-19/02	20.9±1.9	-	20.6±1.7	-	18.2±1.7	-	21.1±2.2	17.3±5.4	-	
Therm2 06/03-20/03	21.7±2.3	21.7±2.3	21.9±2	21.0±2.7	21.7±2.3	20.7±1.4 ^(*)	21.8±2.6	18.3±4.9	23.4±4.2 ^(**)	24.0 / 22.9
Therm3 22/03-11/04	25.4±3.6	25.6±3.7	25.2±3.4	25.0±3.6	24.9±3.5	-	25.4±3.9	21.3±6.7	25.9±4.2	26.1 / 25.7

(*) from 06/03 to 16/03

(**) from 16/03 to 19/03

The following analyses present comparisons of the temperatures measured during the time for the experimental period, highlighting also some particular short time periods. The analysed temperatures, representative of a short period, are chosen to be representative of the working hours, when occupants are supposed to spend their time in the office. However, more results and analyses of the thermal condition of Room 3 are reported in the Appendix, which is divided into subsections according to the different experimental sets.

Evidence from the analyses of the room thermal condition (in PRBS experiments) is the dynamic response of the room to the outside climatic conditions, during the low outside air temperature (lower than 8 °C) combined with the running condition of the heater. It is evident by the window temperature fluctuation, especially when the solar radiation is higher than 400 W/m². For example at noon on 3rd March the air temperature rose by several degrees K when the global solar radiation reached 600 W/m² (see Figure 4). The fact that all the temperatures in the room are increasing or decreasing rather fast can be seen as a sign that the building has a rather low heat capacity.

Focusing on the temperature variations measured by the heating control sensor, an underestimation of the thermal dynamics of the room seems to be the results.

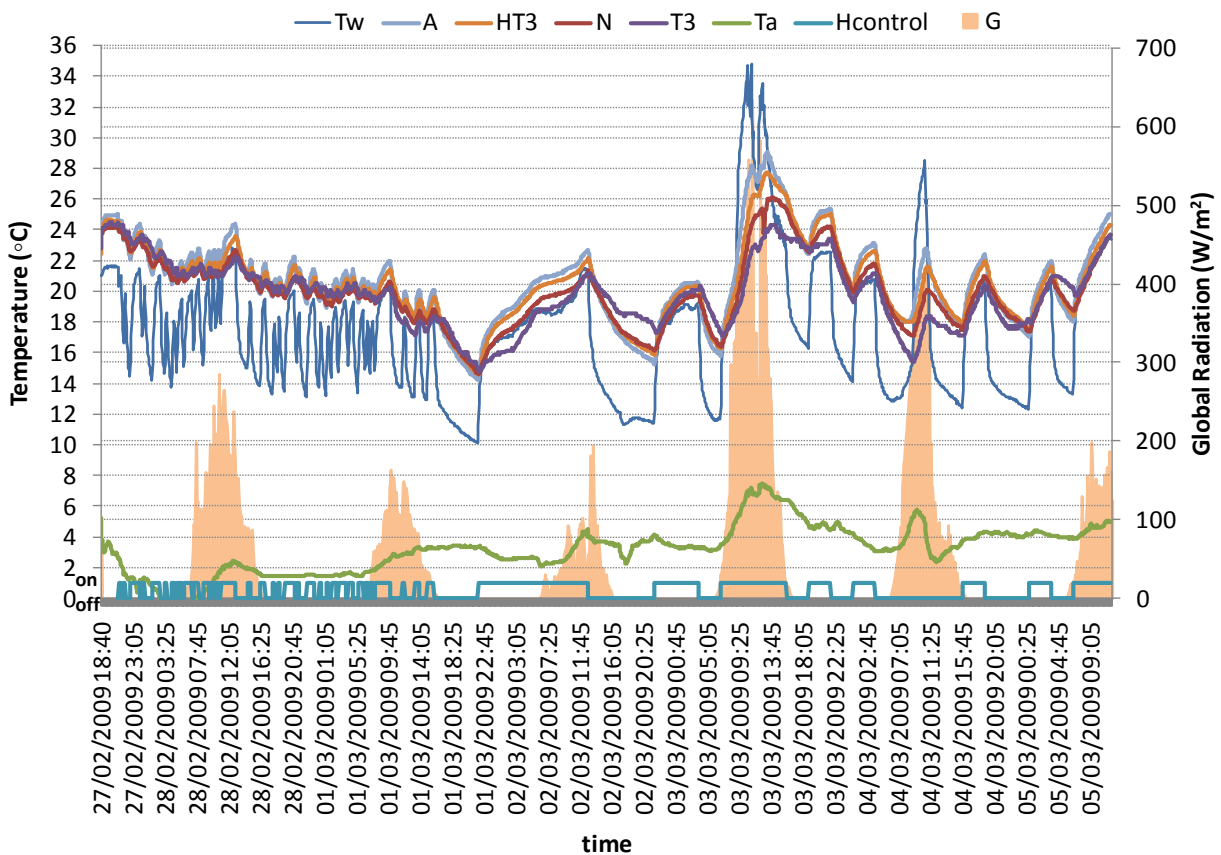


Figure 4. Inside-outside temperature fluctuation. In addition, the running of the heater (on-off) and the global solar radiation is shown (PRBS2). The data labels are explained in Appendix A.1, page 14.

In order to verify if the heating system has been working in compliance with the thermal needs of potential occupants of the room, a comparison has been made between the measured temperatures of the heating control sensor and the HOBO temperature logger. The difference of measured temperatures in the room can be higher than 1 K (see Figure 5) and even more than 2 K when the global solar radiation increased to 600 W/m² (see Figure 6). During the stable room thermal

condition, generated under THERM experiments, the difference between the measured temperature by the heating control sensor and the HOBO sensor was also close to 2 K, as shown in Figure 7.

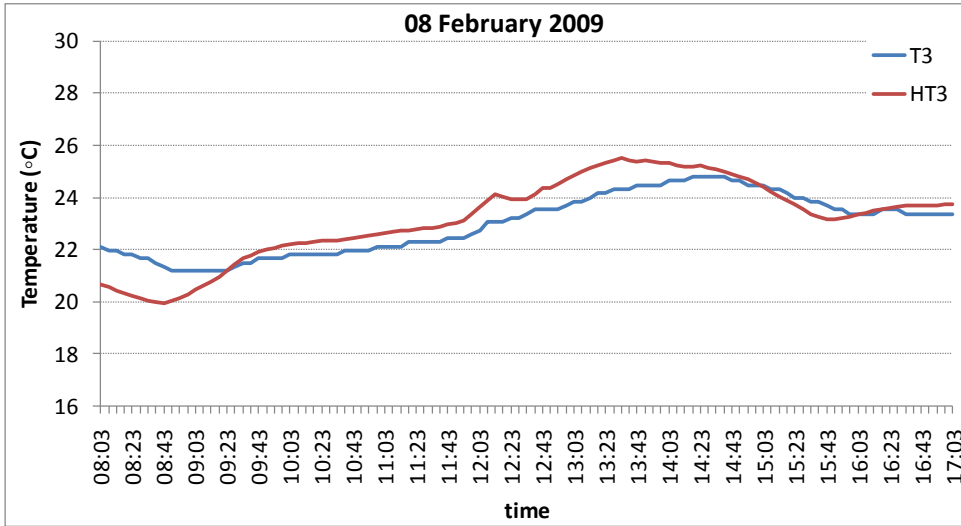


Figure 5. Comparison between the temperature measured by the heating control sensor, $T3$, and the HOBO sensor, $HT3$. (PRBS1).

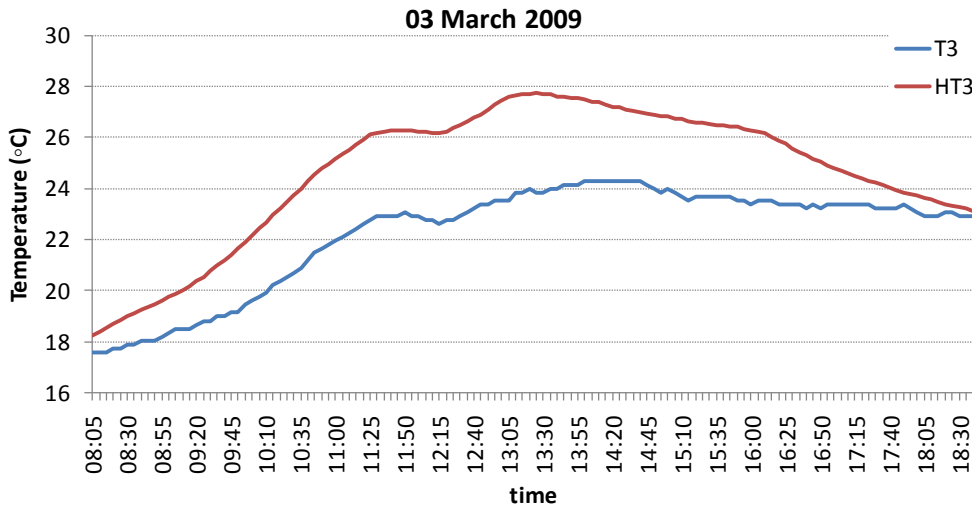


Figure 6. Comparison between the temperature measured by the heating control sensor, $T3$, and the HOBO sensor, $HT3$. (PRBS2).

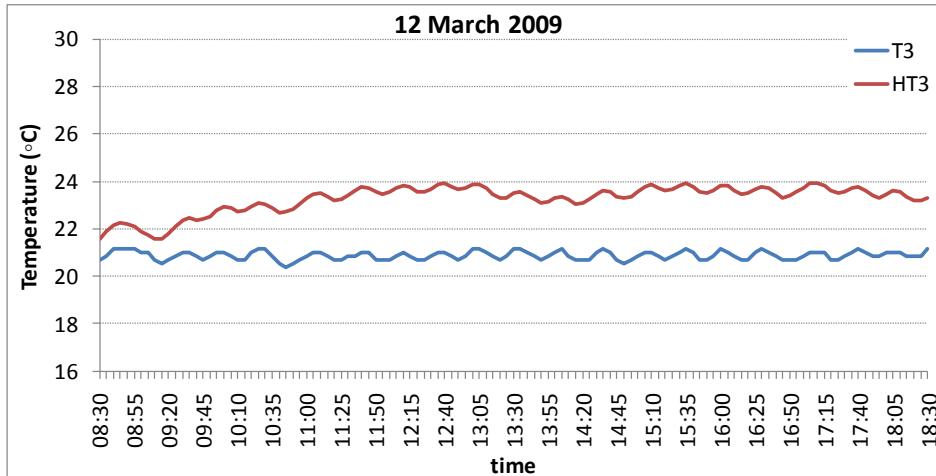


Figure 7. Comparison between the temperature measured by the heating control sensor, *T3*, and the HOBO sensor, *HT3*. (THERM2).

A quite significant temperature difference was noted between the different measuring positions with height measured in location A (see also the Appendix's Figures 13, 22, 31, 46, 47 & 59). The order of magnitude of difference was around 4 K in the daytime on sunny days, around 2-3 K on gray days, and around 1 K at night, and the difference was most pronounced between measuring positions at or near the floor and positions higher in the room. The different measuring positions also showed different sensitivity to incidences such as solar gain or draft from opening of the door to the room.

Results from the temperature measurements at different lateral positions in the room (see the Appendix' Figures 14, 15, 23, 24, 32, 33, 48, 49, 50, 51, 60 and 61) give an indication mainly of how the different measuring positions in the room are affected by the passage of the sun. For most measuring position, this influence is most pronounced at 1.1 m's height compared to the sensitivity at 0.1 m's height.

5. Suspected errors

A sudden increase of temperature at the measuring positions A(0.6 m) and A(1.1. m) from around 10:30 on sunny days could indicate that the thermocouple is hit by the sun. A sudden decrease of all thermocouple measurements from around 13:00 on sunny days could indicate the Grant data-logger, which has an internal temperature reference, was hit by the sun on such days and that the temperature adjustments to the reference was affected by these incidents. Such rather sudden temperature jumps had an order of magnitude between 1 and 4 K.

The measurements with thermocouple *N* seem to have been permanently a couple of degrees K too low during measurement period THERM1 (see also Table 1).

It is recommended therefore to use the thermocouple measurements only by regarding these potential errors. With this is in mind, the thermocouple measurements can be used mainly for relative comparison of the different measuring positions

6. Conclusions

The difference between the measured temperature by the HOBO and the heating control sensor is not negligible. Since the calibration of the HOBO sensors shows a very precise measured temperature, the HOBO sensor should be the reference temperature controlling the heating system of the house.

In addition, when data were available, a comparison between the measured temperatures with the globe-sensor, the vertical temperature profile at the zone of expected occupancy (measurement positions A) and the temperature distribution in the room were analysed. The vertical temperature profiles show notable temperature gradients, especially for the PRBS1 experiment at the occupied zone, and when the solar gain is large, while otherwise the horizontal temperature distribution is more modest.

7. References

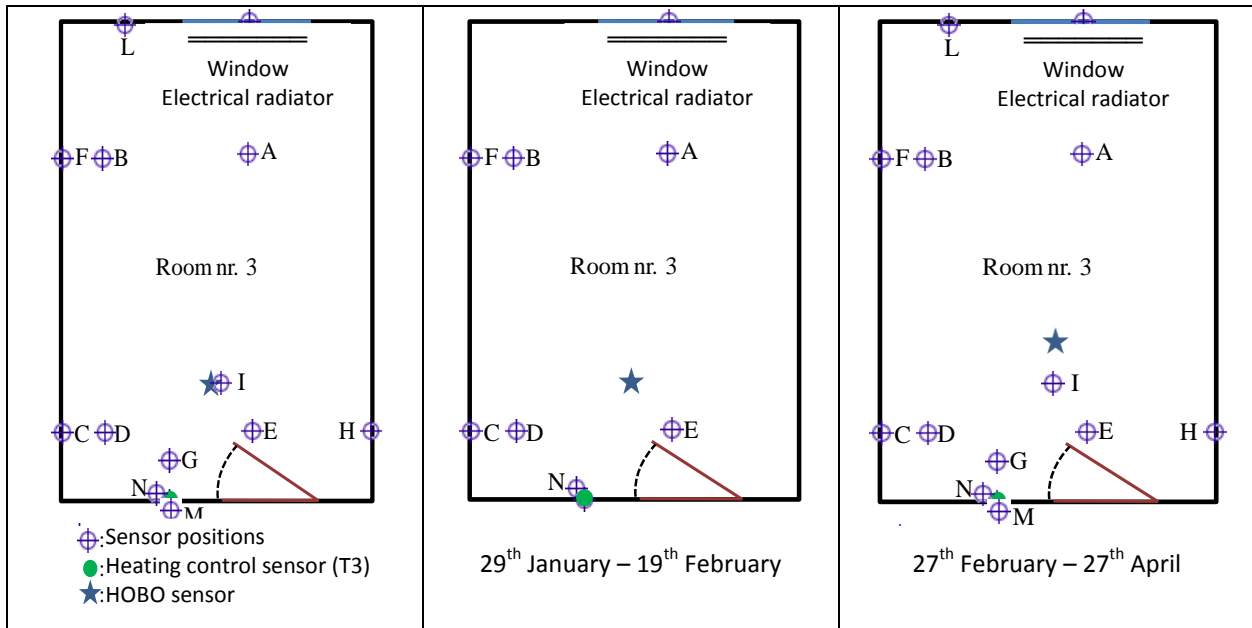
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- [3] ISO 7726 (1998). Ergonomics of the thermal environment - Instruments for measuring physical quantities. Geneva: International Standard Organization for Standardization.

Appendix

In the appendix is reported a list of temperature signals with the abbreviations used in the text. Following different analyses of the measured temperature in Room 3 are reported through the graphs. Those analyses are reported separately per each experimental session.

A.1. List of Signals

The temperatures, in different positions in Room 3, were measured. The plan of temperature measuring points is below reported followed by a list of temperature signal's abbreviations used in the text and in the analysed graphs.



- "HT3": Temperatures measured by the HOBOSensor in Room 3.
- "T3": Temperatures measured by the central server in Room 3 ("Heating control sensor") [°C].
- "Hcontrol": Heating control signal for Room 3 [on – off].
- "G": Global irradiance [W/m²].
- "Ta": Ambient temperature (outside temperature) [°C].
- "Tw": Temperature measured at the window [°C].
- "globe": Temperature measured by globe-sensor in position A [°C].
- "ceiling": Temperature measured at the ceiling in position A [°C].
- "floor": Temperature measured at the floor in position A [°C].
- "A": Temperature measured in position A (*) (at 0.1m, 0.6m, 1.1m, 1.7m above the floor) [°C].
- "B": Temperature measured in position B (*) (at 0.1m and 1.1m above the floor) [°C].
- "C": Wall temperature measured in position C (*) (at 0.1m and 1.1m above the floor) [°C].
- "D": Temperature measured in position D (*) (at 0.1m and 1.1m above the floor) [°C].
- "E": Temperature measured in position E (*) (at 0.1m and 1.1m above the floor) [°C].
- "F": Wall temperature measured in position F (*) (at 0.1m and 1.1m above the floor) [°C].
- "G": Temperature measured in position G, in front at the heating control sensor (same height) [°C].
- "I": Temperature measured in position I close the HOBOSensor [°C].
- "L": Wall temperature measured in position L at 1.1m above the floor [°C].
- "M": Corridor wall temperature, at the opposite side of the heating control sensor position [°C].
- "N": Wall temperature measured close the position of the heating control sensor [°C].

(*) when the height of the measured temperature is not mentioned, it is equal to the other sensors.

A.2. HOBO calibration data

Table 2 shows that the HOBO temperatures are very precise.

The regression line to correct the values is reported too. However it is not necessary to use it because the actual error of the read temperature values is lower than 0.5 K. Moreover, the temperatures values are in the range of the accuracy of the sensor equal to ± 0.35 K (from 0 to 50 °C). The comparison of the HOBOS to one another is documented in more detail in section 5.5.1 of [2].

Table 2. HOBO calibration results.

	HOBO 0	HOBO 1	HOBO 2	HOBO 3	HOBO 4	HOBO 5	HOBO 6	HOBO 7
error	-0.1	+0.2	± 0.1	0.0	+0.3	+0.2	+0.2	+0.1
slope	1.003	1.003	1.016	1.003	1.001	1.012	1.005	1.002
intercept	-0.042	-0.303	-0.405	-0.064	-0.306	-0.408	-0.258	-0.162
RSQ	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

A.3. Results from experiments

The following subsections will present in more detail some selection of results from the different experimental sets:

- A.5 PRBS1 (05-09 February 2009)
- A.6 PRBS2 (27 February – 05 March)
- A.8 THERM1 (16-19 February)A.9THERM2 (06-20 March)
- A.9 THERM2 (06-20 March)
- A.10 THERM3 (22 March – 13 April)

In each subsection is first presented a graph showing the most significant measuring results for the period of the set. The channels presented are:

- T3* Temperature measured by the heating control sensor,
- HT3* Temperature measured by the HOBO data logger,
- A* Temperature measured in room pos. A in same height as the heating control sensor,
- N* Temperature measured at the wall surface next to the heating control sensor
- Tw* Temperature at the inside pane of the window
- Ta* Outside air temperature
- G* outside global solar radiation
- Hcontrol* The control parameter for heating switched on or off.

The second graph shows an excerpt of the results from the first graph, zooming in on the daytime hours of one of the days from the period.

The third and fourth graph show the results of the measurements of the air temperature by the sensors/positions *T3*, *HT3*, *N* and *A*. The first of these two graphs shows the full length of the

experimental set, while the other shows a zoom of the daytime hours of the same day that was shown in the second graph.

The fifth graph shows the same zoom as the fourth graph, but now focusing only on the heating control sensor $T3$ and the HOBO sensor $HT3$ – the purpose being to illustrate how well the two sensors correspond to one another.

The sixth graphs shows again for the daytime of the selected day for the zoom, the results of the temperature in different heights at the measuring position A - the purpose being to illustrate the temperature stratification and how it varies over the daytime.

The seventh graph shows the temperature measured different positions (A , B , C , D and E) in the room at the height 1.1 over the floor – the purpose being to illustrate the lateral daytime distribution of the temperature, and how it varies over the daytime.

The eighth graphs also shows the lateral daytime distribution in the same positions as the previous graph, but now as it has been measured only 0.1 m over the floor.

This set of data is repeated for every experimental set, but sometimes supplemented with results from other channels which are perhaps not represented in all the experimental sets (e.g. the corridor temperature), or with repetition of some of the daytime plots for other another day, e.g. such that results from both a clear and an overcast day are shown in detail.

A.4. PRBS experiments

The temperature measurements in Room 3 were recorded and analyzed, divided in two experimental sessions: experimental session PRBS1 – from 29th January to 09th February; and experimental session PRBS2 – from 27th February to 5th March.

The experiment in the house, with one signal control for all the heaters (PRBS1), was running from the 5th to the 11th of February; while the three signal control (PRBS2) was running from the 27th of February to the 5th of March.

Overlapping the data and the time between the house experiment and the Room nr.3 measurements, it is possible to analyse 5 and 6 days of Room nr 3 thermal conditions for the two PRBS experiments.

The results (see Figure 8 and 16) show that the control of the heaters in the house by the PRBS signal gives a varying temperature in the room. It is evident how the room air temperature fluctuates in response to the outside climatic conditions, with the low outside air temperature (which is lower than 8 °C), and with the running condition of the heater. The dependence of the room temperature fluctuation with the outside temperature, T_a , and the heater is more evident by the window temperature fluctuation, T_w , especially when the solar radiation is higher than 400 W/m². It can be noticed that at noon on the 3rd of March the air temperature is rising more than 3 K when the global solar radiation, even if for a very short time, reached 600 W/m² (see Figure 16). The fact that all the temperatures in the room are increasing or decreasing rather fast can be seen as a sign that the building has a rather low heat capacity.

A.5. PRBS1 (05-09 February 2009)

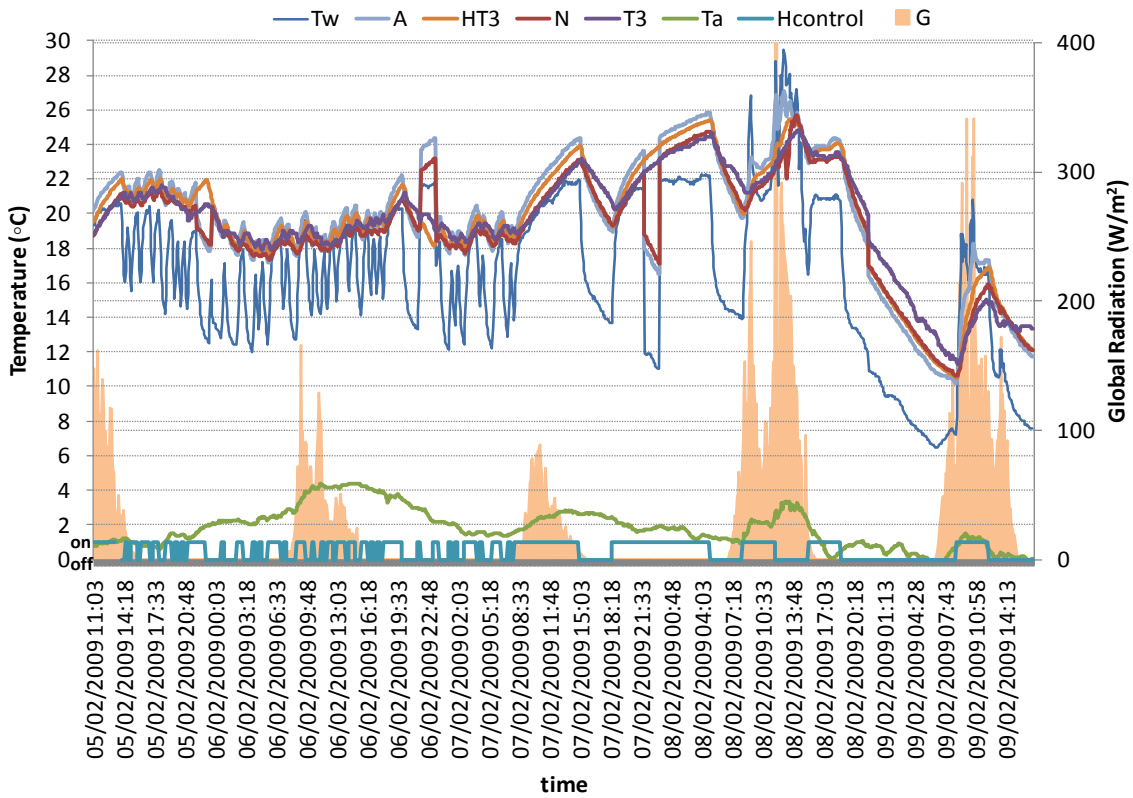


Figure 8. Indoor and outdoor temperature variation, heating control signal (on-off), and global solar radiation (PRBS1).

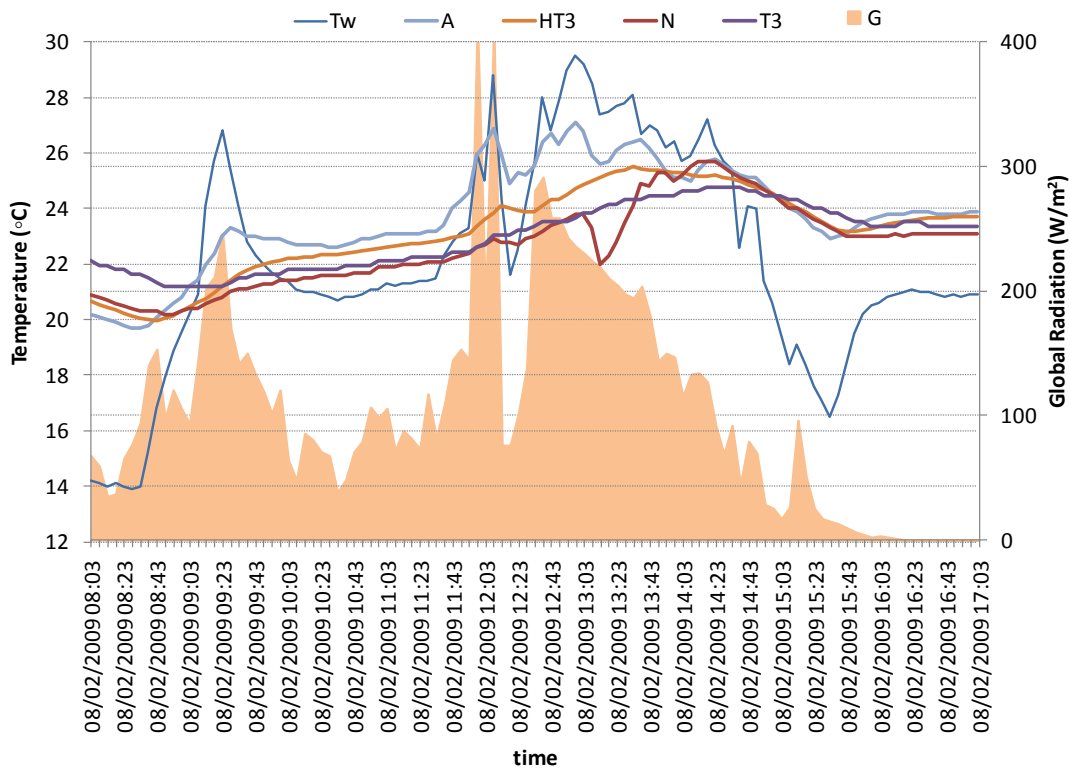


Figure 9. Indoor and outdoor temperature variation and global solar radiation during the working hours of one measured day (PRBS1).

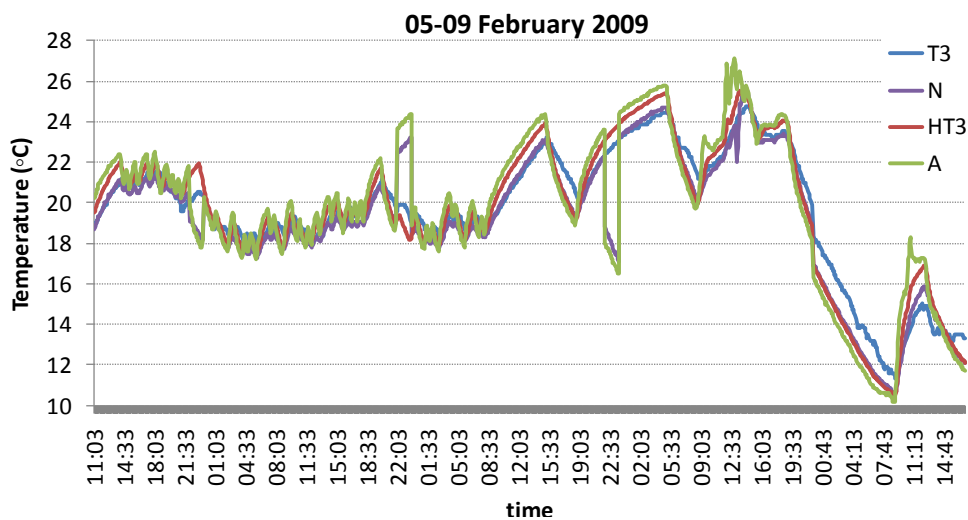


Figure 10. Temperatures measured by the heating control sensor, $T3$, the sensor located on the wall at the same place, N , the HOBO, $HT3$, and the occupied zone, A (PRBS1).

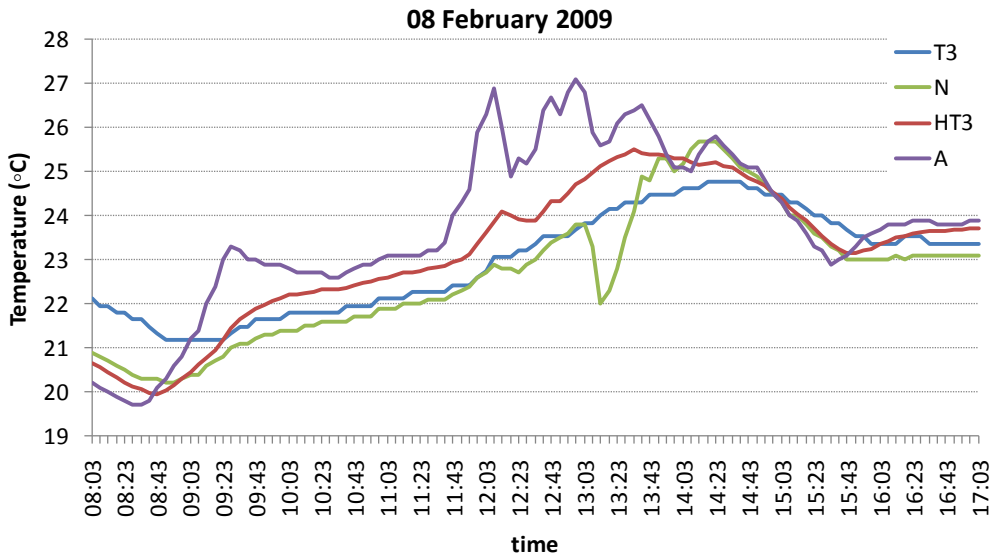


Figure 11. Temperatures measured by the heating control sensor, $T3$, the sensor located on the wall at the same place, N , the HOBO, $HT3$, and the occupied zone, A , during one day of working hours (PRBS1).

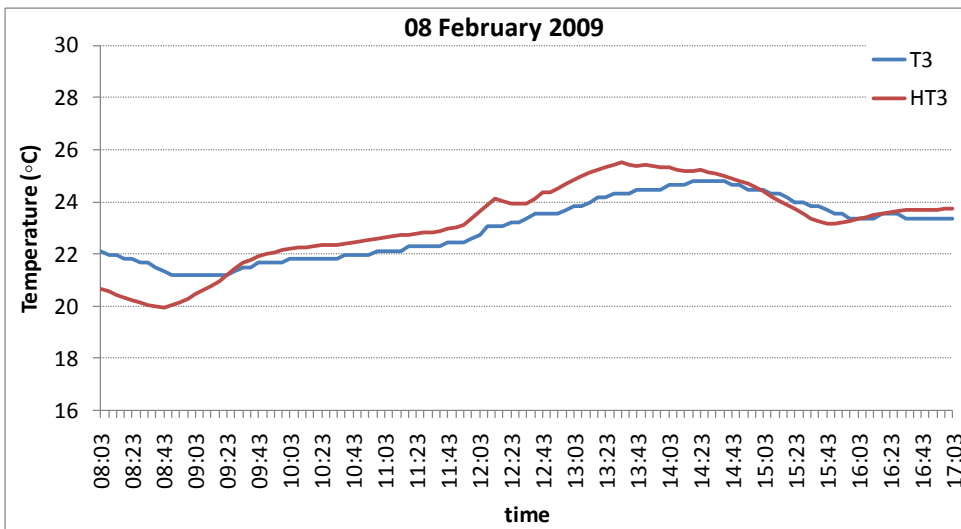


Figure 12. Temperatures measured by the heating control sensor, $T3$, and HOBO, $HT3$ (PRBS1).

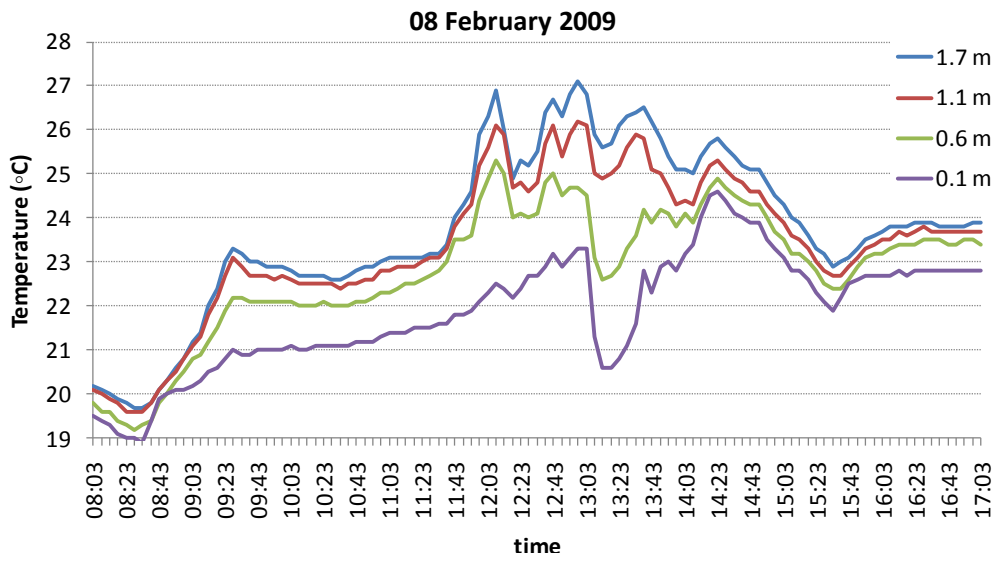


Figure 13. Vertical temperature distribution at 1 m's distance from the window (PRBS1).

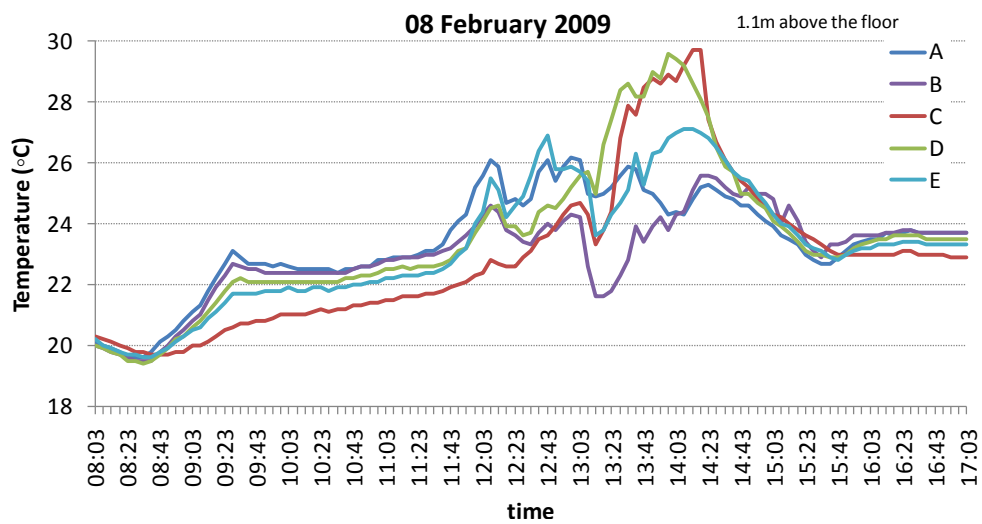


Figure 14. Horizontal temperature distribution 1.1 m above the floor (PRBS1).

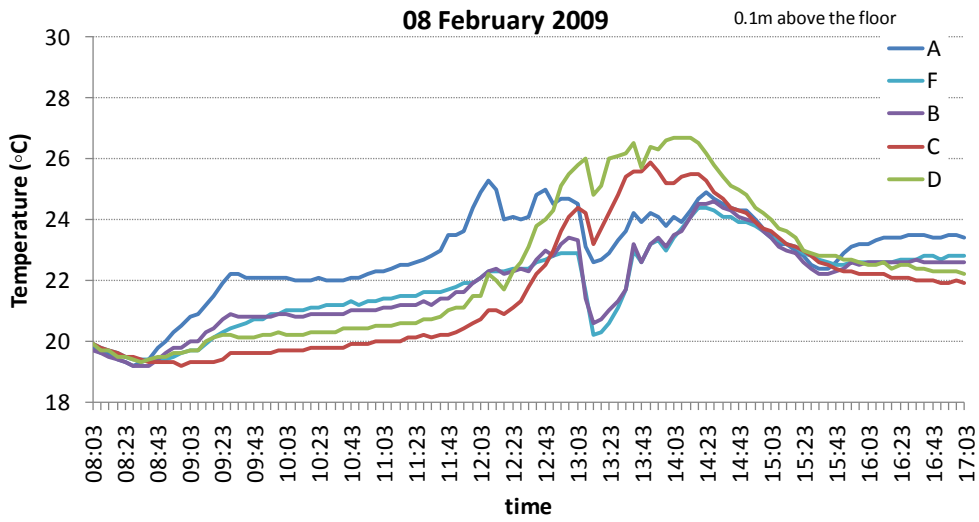


Figure 15. Horizontal temperature distribution 0.1 m above the floor (PRBS1).

A.6. PRBS2 (27 February - 05 March)

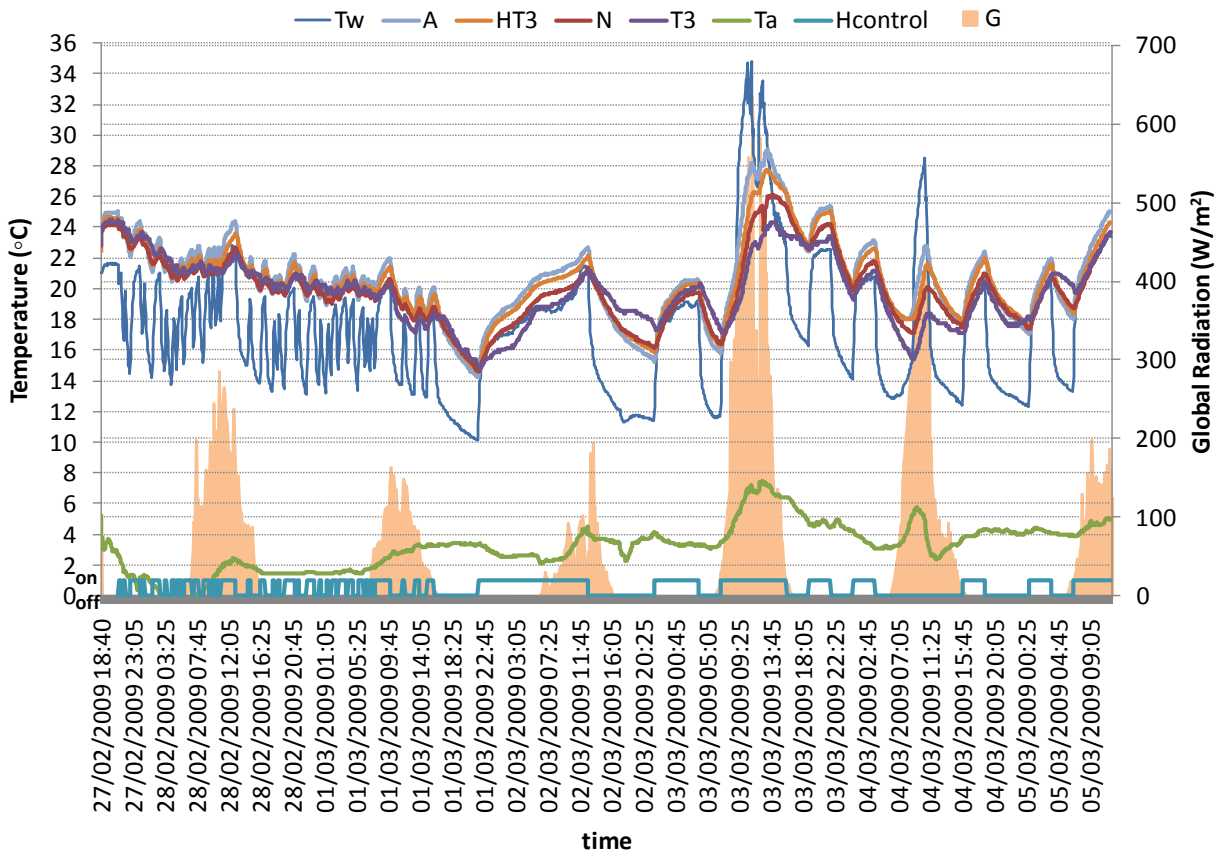


Figure 16. Indoor and outdoor temperature variation, heating control signal (on-off), and global solar radiation (PRBS2).

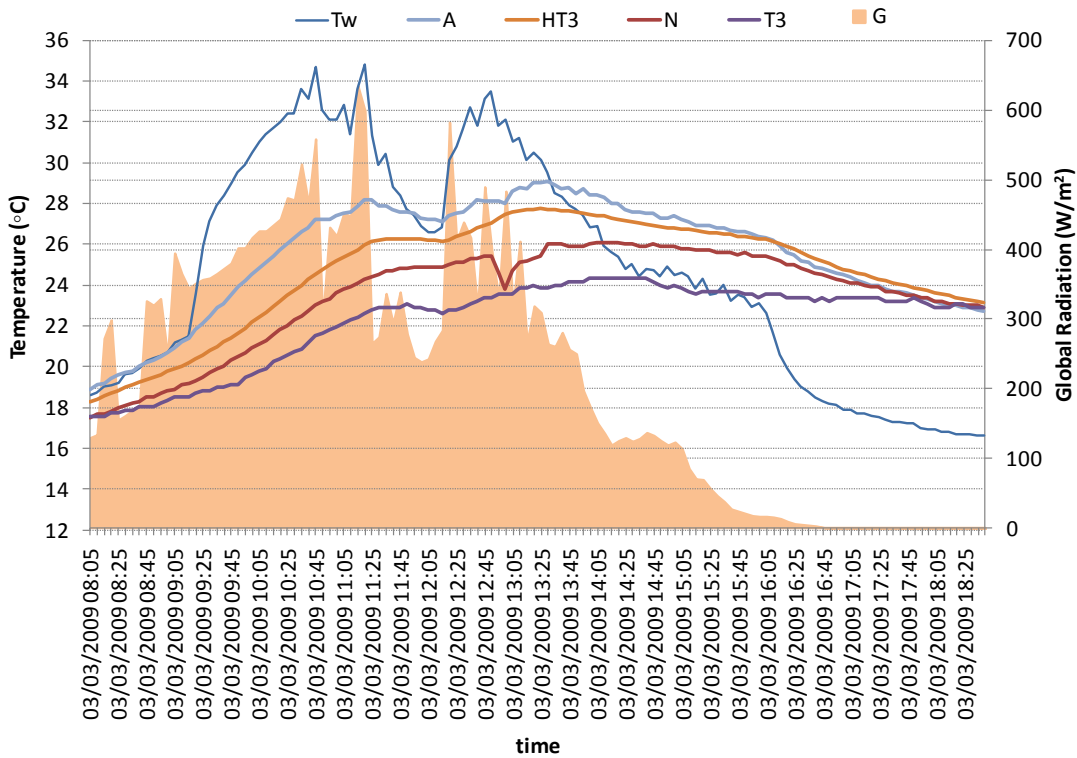


Figure 17. Indoor and outdoor temperature variation and global solar radiation during the working hours of one measured day (PRBS2).

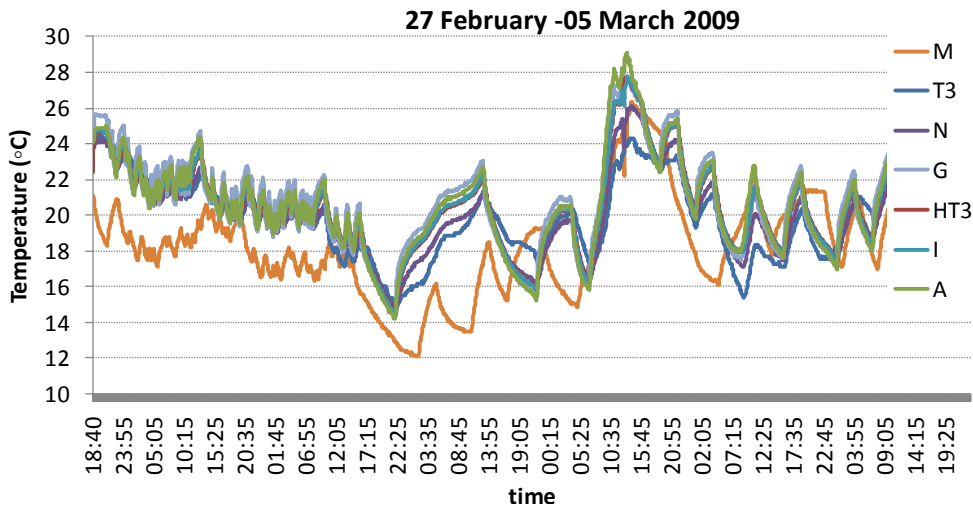


Figure 18. Temperatures measured by the heating control sensor, $T3$, the HOBOSensor, $HT3$, and the sensors located at the same height above the floor in different room positions (PRBS2).

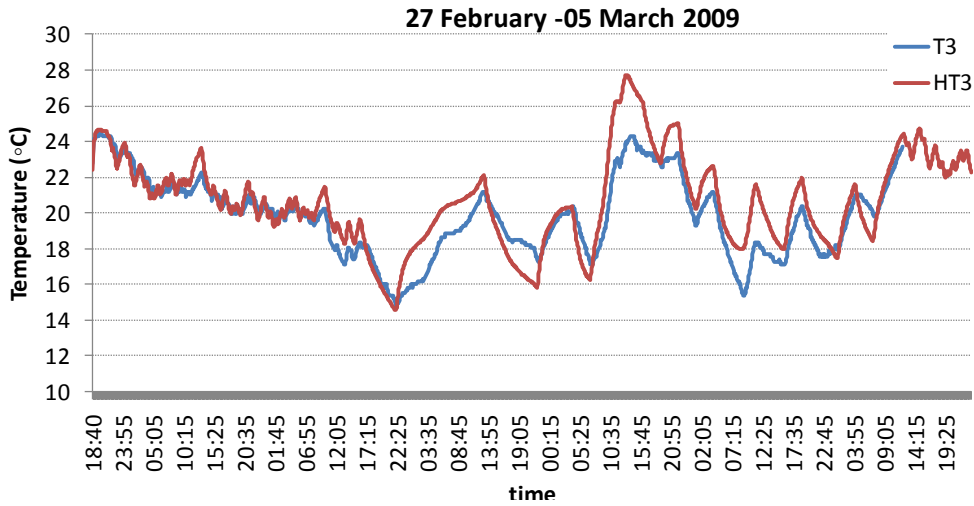


Figure 19. Temperatures measured by the heating control sensor, *T3*, and HOBO, *HT3* (PRBS2).

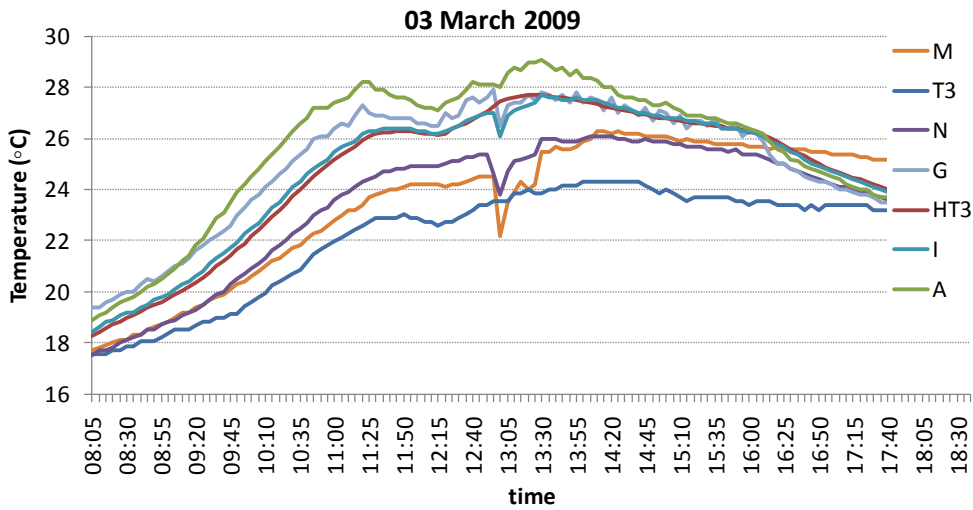


Figure 20. Temperatures measured during one day working hours by the heating control sensor, *T3*, the HOBO, *HT3*, and the sensors located at the same height above the floor in different room positions (PRBS2).

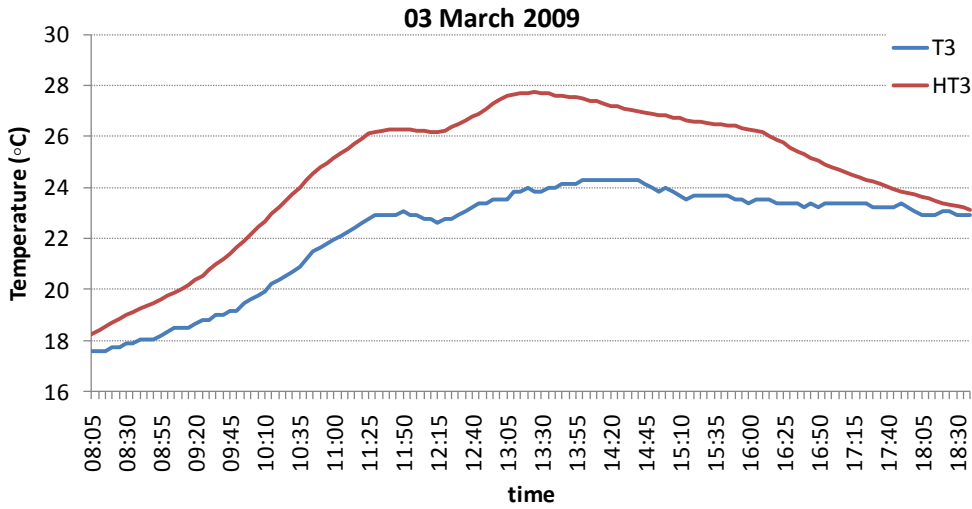


Figure 21. Detailed comparison of the temperature measured by heating control sensor, *T3*, and HOBO, *HT3* (PRBS2).

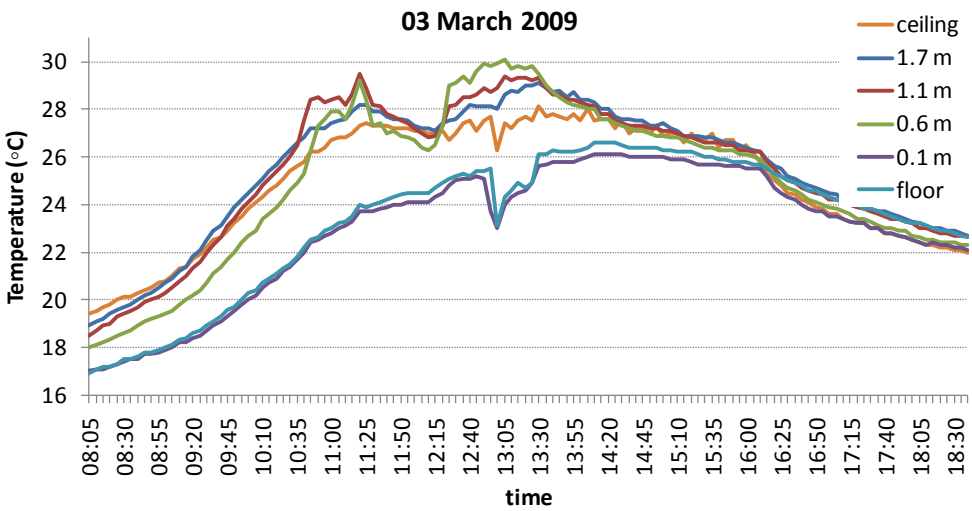


Figure 22. Vertical temperature distribution at 1 m distance from the window (PRBS2).

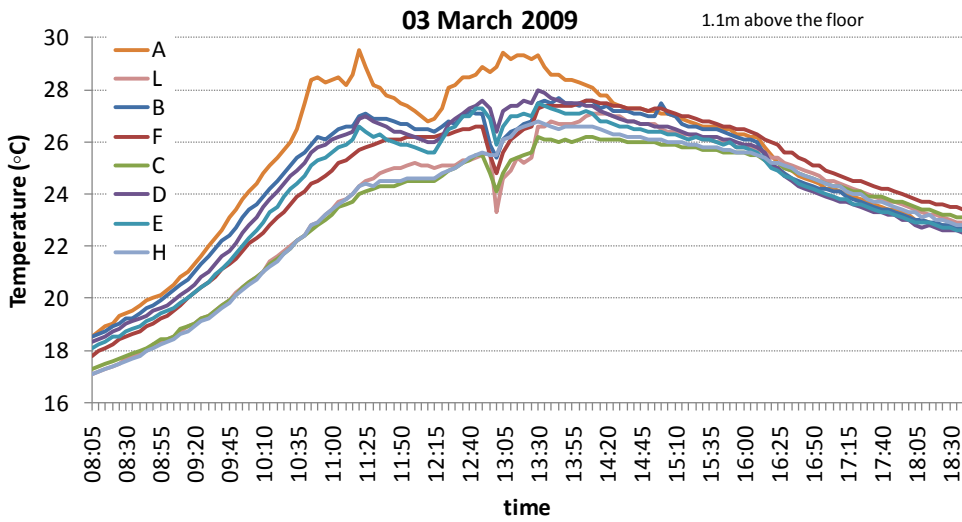


Figure 23. Horizontal temperature distribution 1.1 m above the floor (PRBS2).

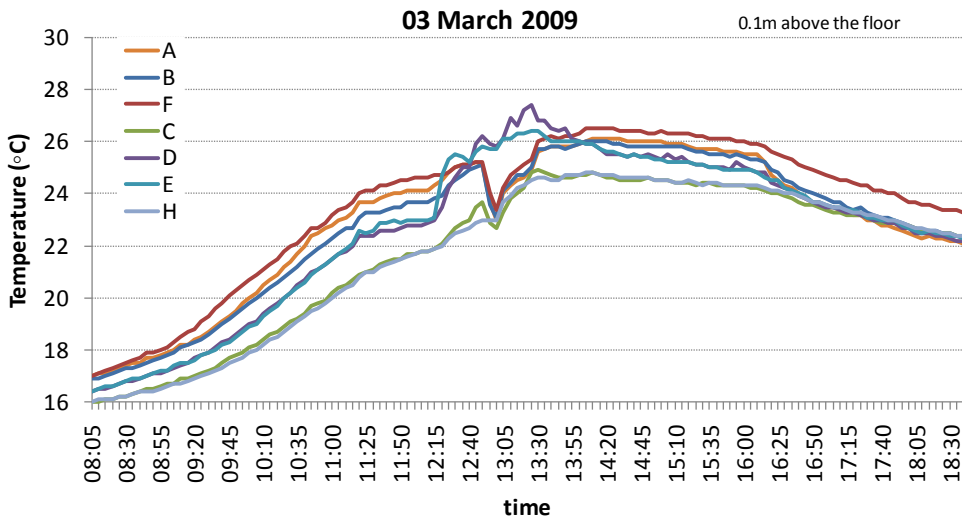


Figure 24. Horizontal temperature distribution 0.1 m above the floor (PRBS2).

A.7. THERM experiments

The experiments in the building with a thermostatic control of the heaters were running from the 16th of February to the 19th of February (THERM1), from the 6th of March to the 20th of March (THERM2), and from the 22nd of March to the 13th of April (THERM3).

Overlapping the data and the time between the house experiment and the room measurements, it is possible to analyse 3, 13 and 22 days of Room 3 thermal conditions for the three THERM experiments. The results (see Figure 25) show that the control of the heaters in the house by THERM control gives a good room temperature control, with a rather constant room temperature, albeit influenced by the solar gains.

Figure 25 is representing the temperature fluctuation at the window, of the heating control sensor and some room locations compared with the running of the heater and the global solar radiation.

According to the results of those days' analyses, for all the three experiments, the thermostatic control of the heaters can ensure a good room thermal condition. However, when the solar radiation is high enough for warming the room air it is important that the heater is not running, but the room air temperature may still be increasing (see Figure 26 and 36).

Moreover, as a consequence of the practical house uses and the weather conditions, for the measurements made in Room 3 it is not possible to notice any differences between the three experimental sessions.

A.8. THERM1 (16-19 February)

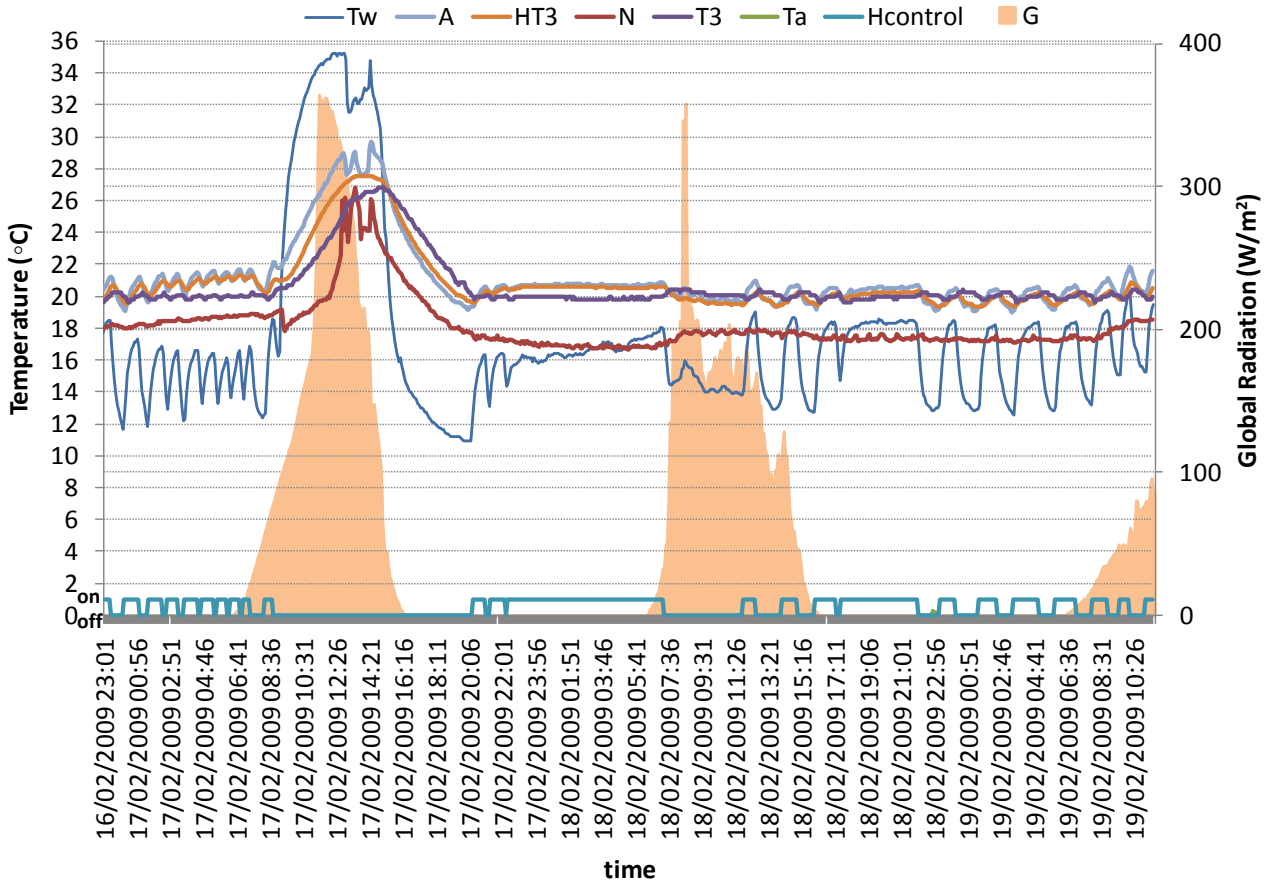


Figure 25. Indoor temperature variation, heating control signal (on-off), and global solar radiation (THERM1). T_a is not visible in the graph (except for one hour on the 18th of February), since the outdoor temperature is below zero during almost the whole period.

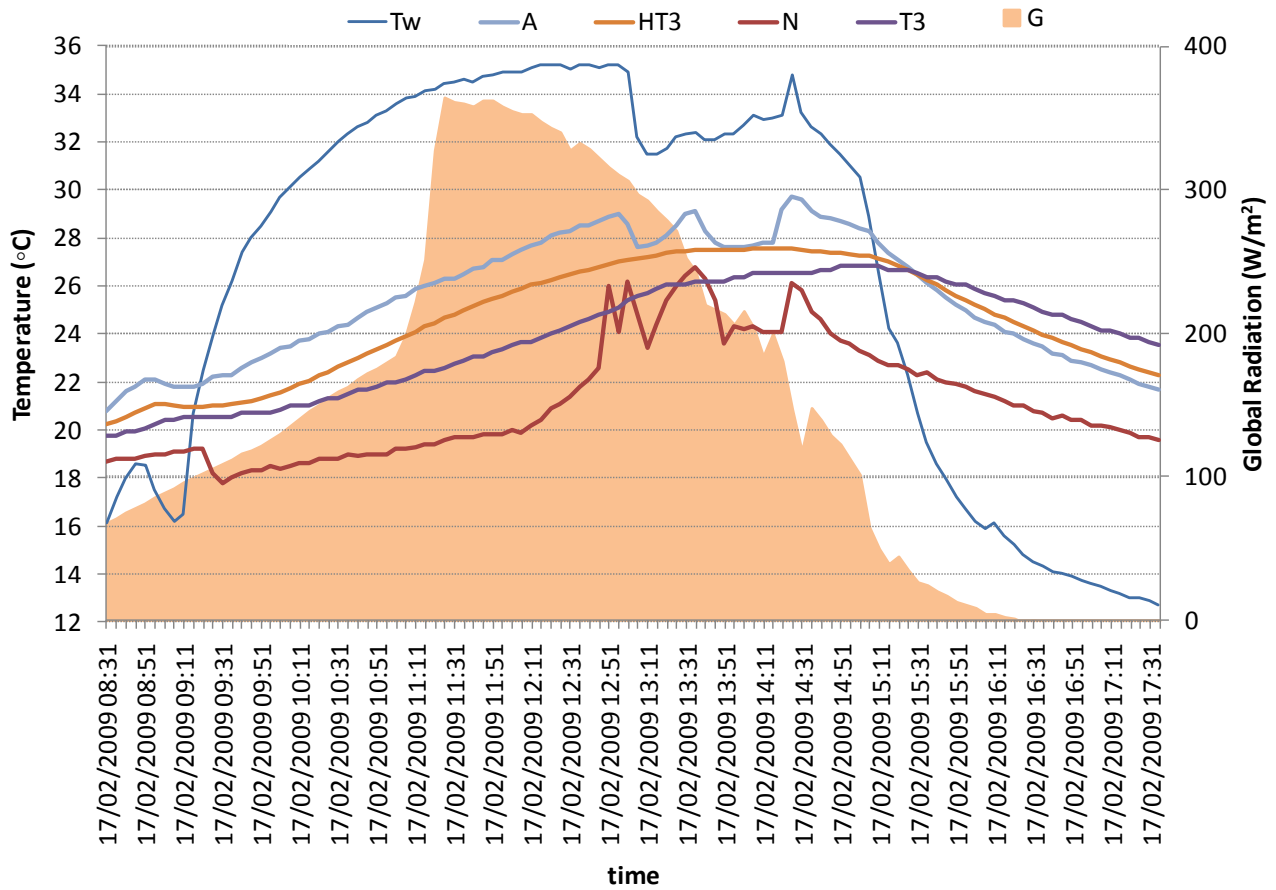


Figure 26. Indoor temperature variation and global solar radiation during the working hours of one measured day (THERM1).

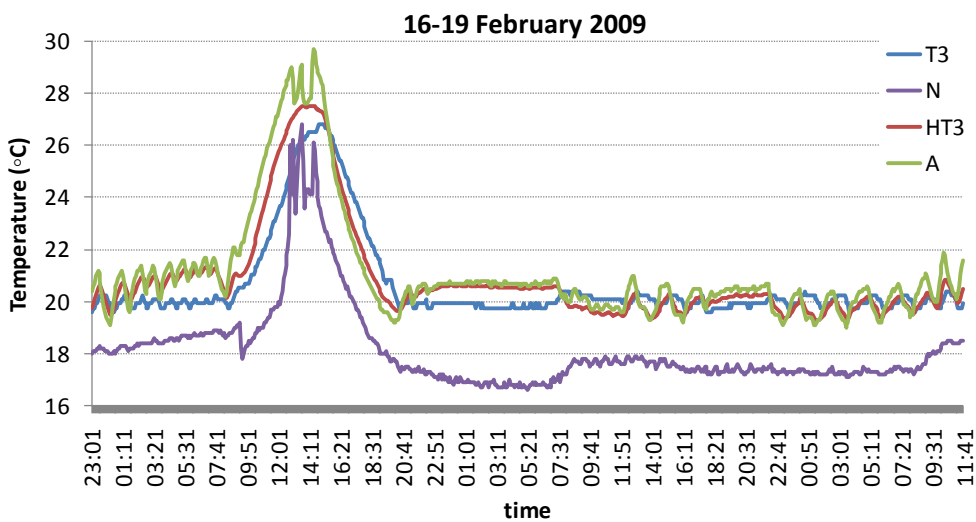


Figure 27. Temperatures measured by the heating control sensor, $T3$, the sensor located at the same place on the wall, N , the HOBO, $HT3$, and the occupied zone, A (THERM1).

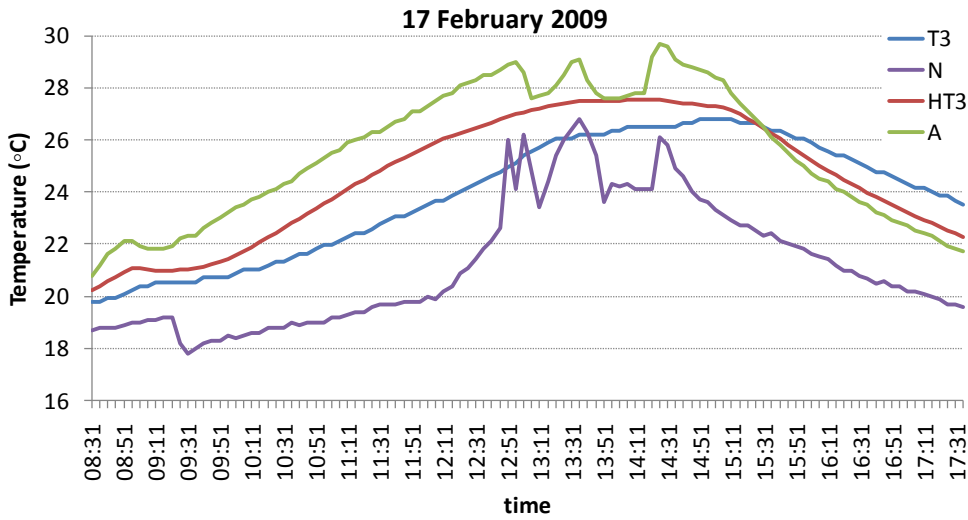


Figure 28. Temperatures measured by the heating control sensor, *T3*, the sensor located at the same place on the wall, *N*, the HOBO, *HT3*, and the occupied zone, *A*, during the working hours of one day (THERM1).

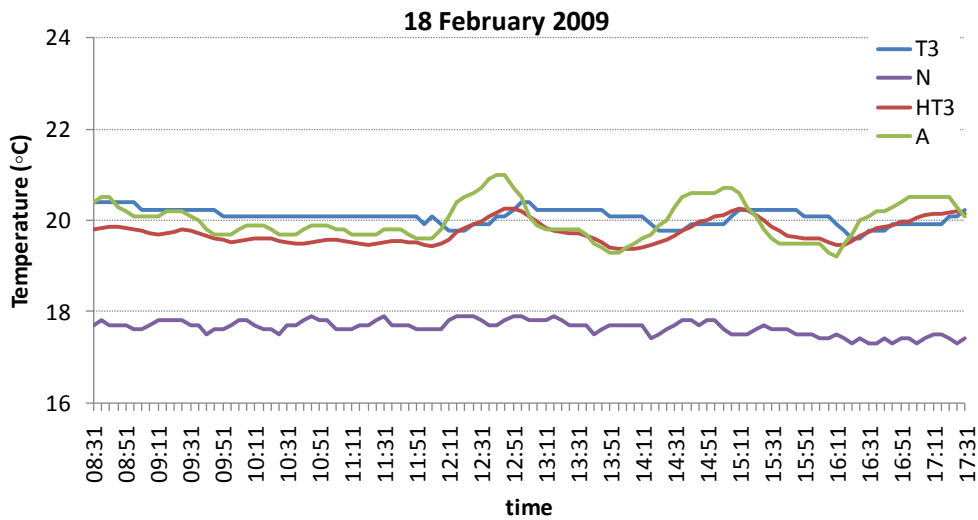


Figure 29. Temperatures measured by the heating control sensor, *T3*, the sensor located at the same place on the wall, *N*, the HOBO, *HT3*, and the occupied zone, *A*, during the working hours of one day (THERM1).

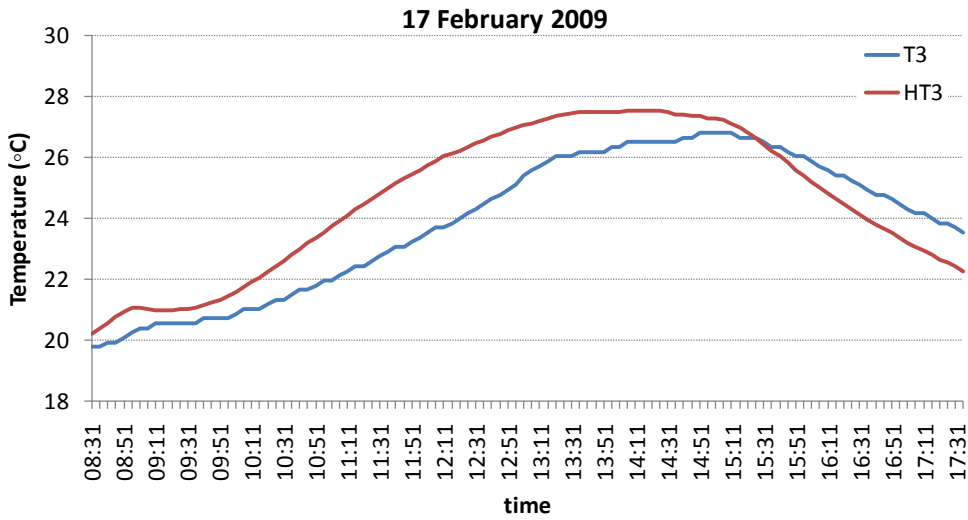


Figure 30. Detailed comparison of the temperatures measured by the heating control sensor, *T3*, and HOBO, *HT3*.

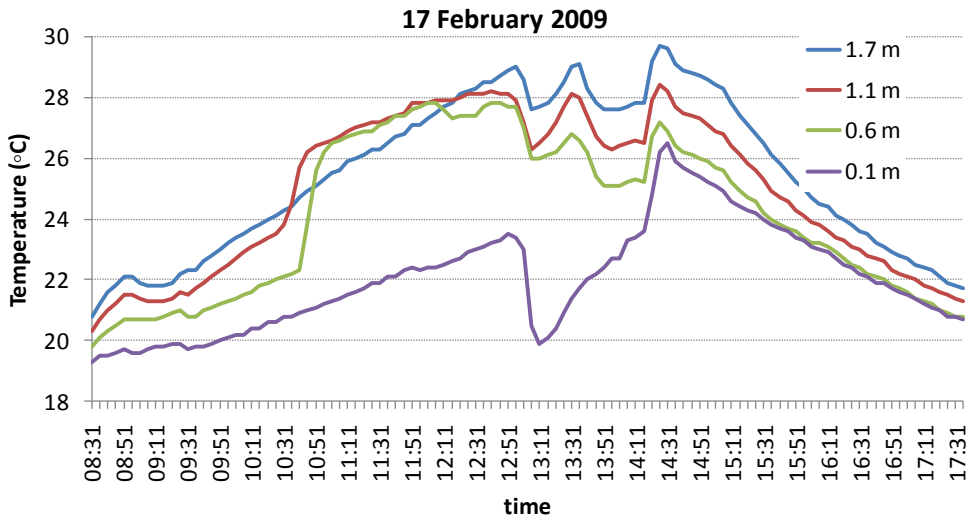


Figure 31. Vertical temperature distribution at 1 m distance from the window (THERM1).

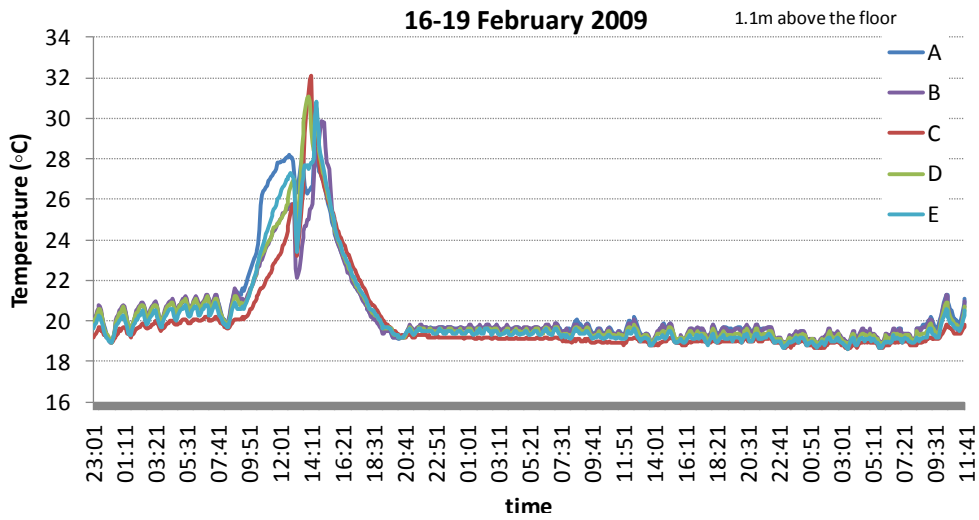


Figure 32. Horizontal temperature distribution 1.1 m above the floor (THERM1).

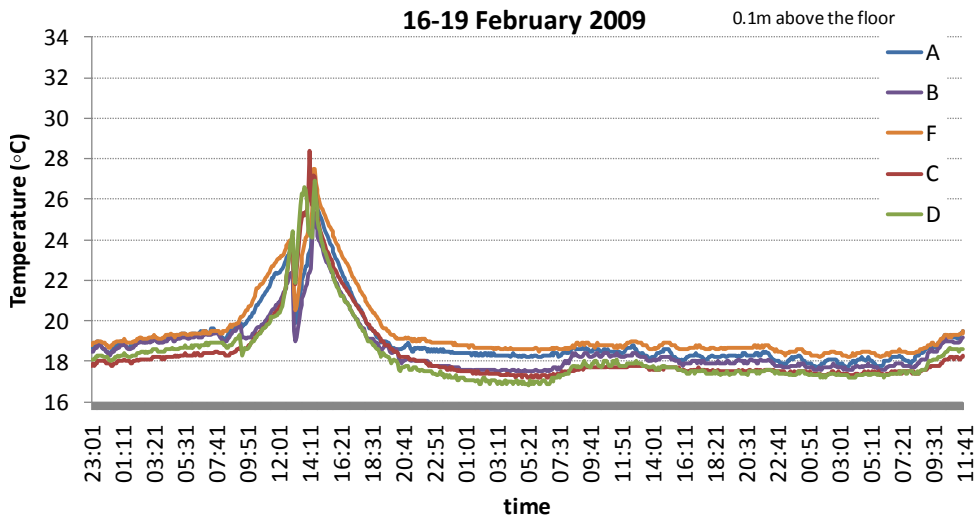


Figure 33. Horizontal temperature distribution 0.1 m above the floor. (THERM1).

A.9. THERM2 (06-20 March)

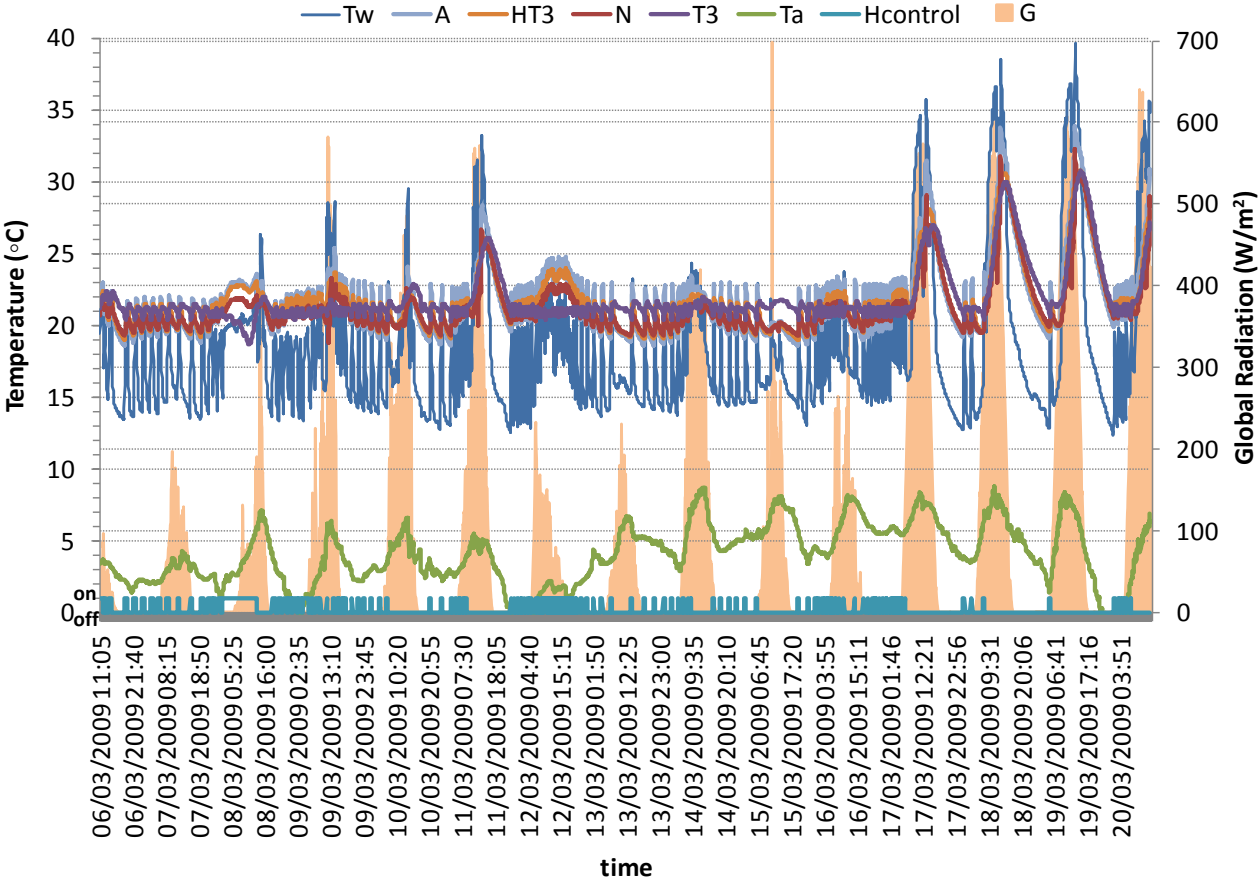


Figure 34. Indoor and outdoor temperature variation, heating control signal (on-off), and global solar radiation (THERM2).

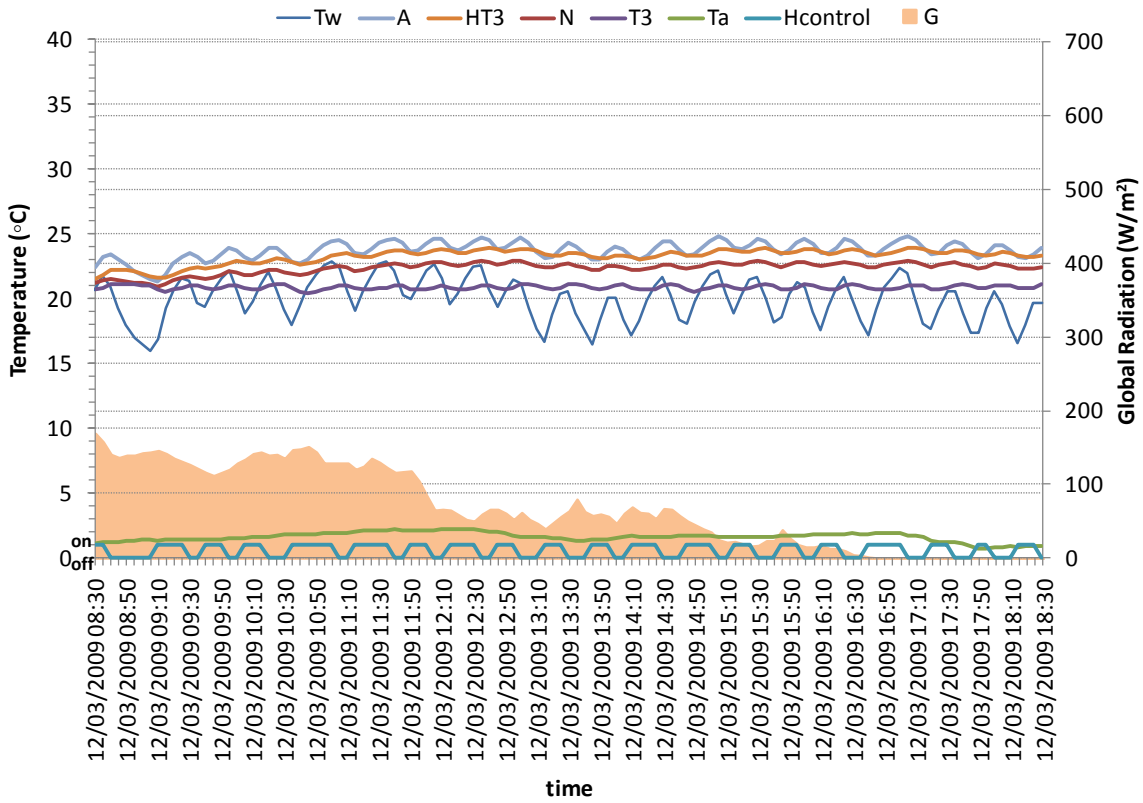


Figure 35. Indoor and outdoor temperature variation, heating control signal (on-off), and global solar radiation (when low) during working hours of one day (THERM2).

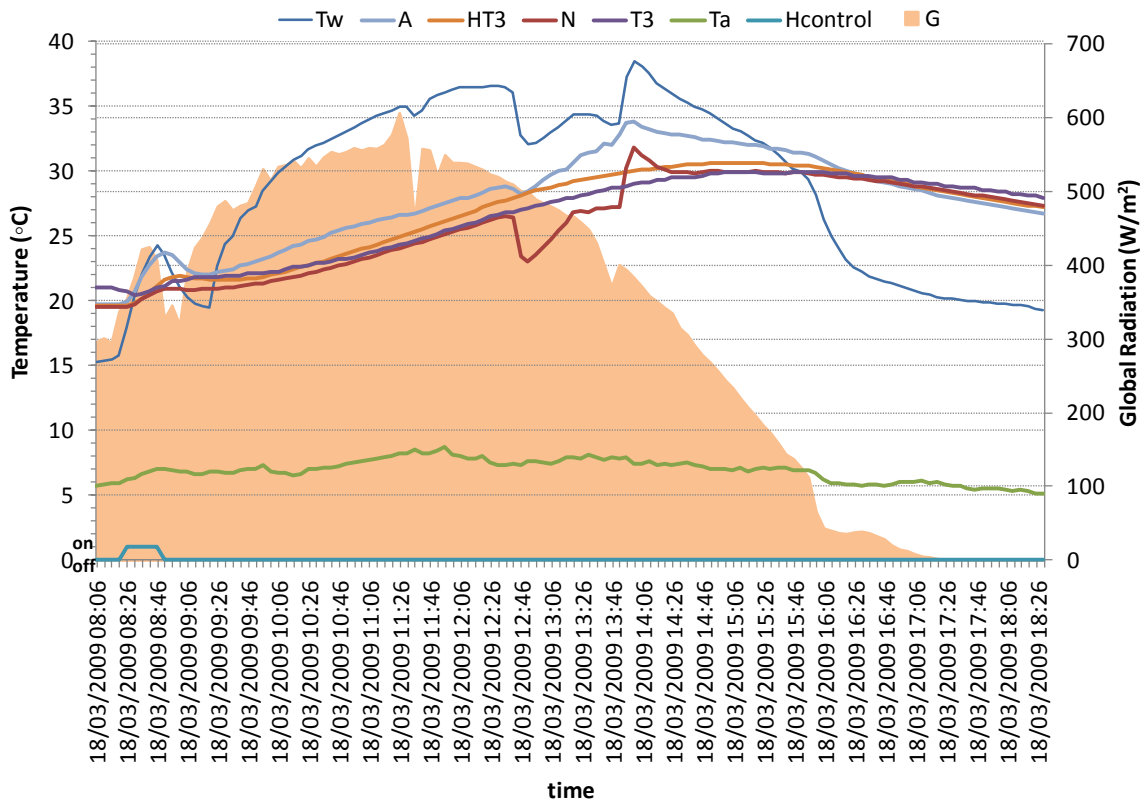


Figure 36. Indoor and outdoor temperature variation, heating control signal (on-off), and global solar radiation (when high) during working hours of one day (THERM2).

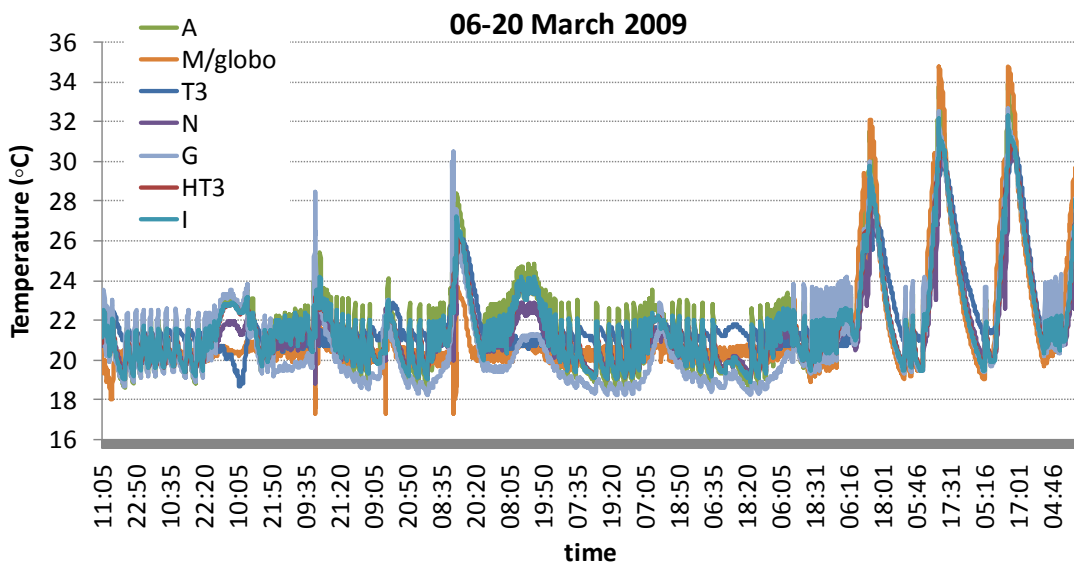


Figure 37. Temperatures measured by the heating control sensor, *T3*, the HOBO, *HT3*, and sensors located at the same height above the floor in different room positions (THERM2).

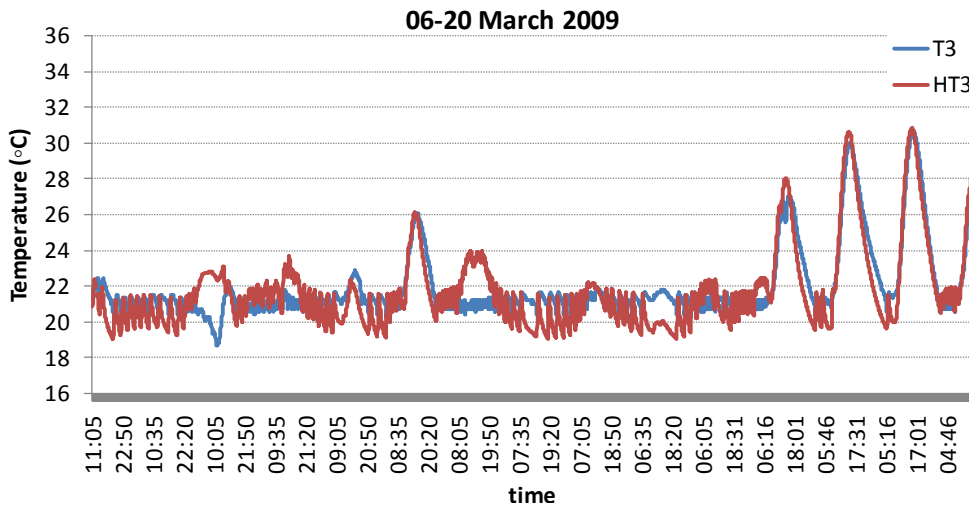


Figure 38. Temperatures measured by the heating control sensor, $T3$, and HOBO, $HT3$ (THERM2).

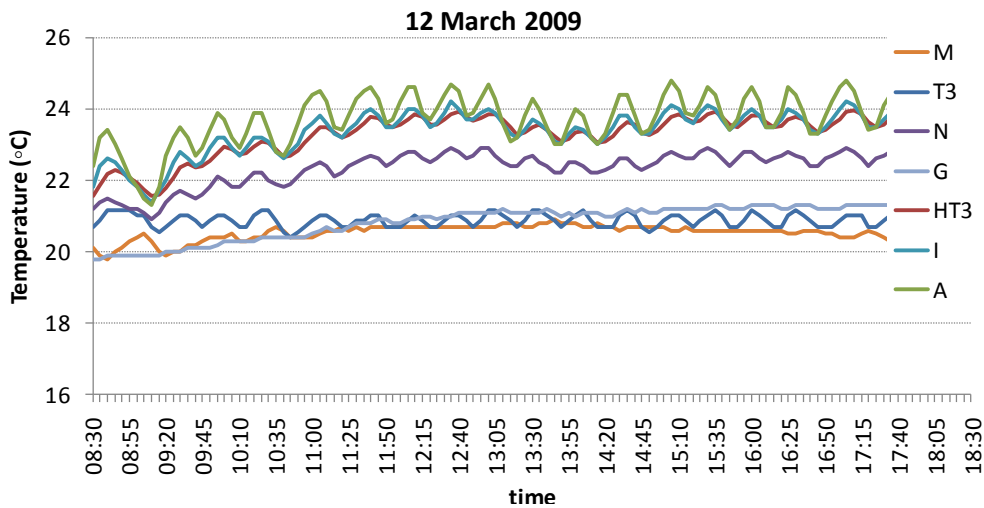


Figure 39. Temperatures measured by the heating control sensor, $T3$, HOBO, $HT3$, and sensors located at the same height in different room positions, during working hours of one day *without* solar radiation influence (THERM2).

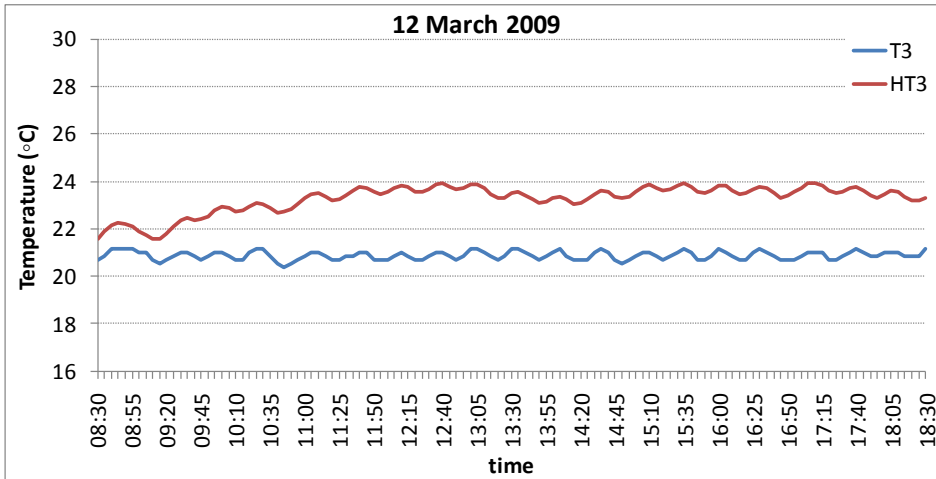


Figure 40. Detailed comparison of temperatures measured by the heating control sensor, $T3$, and HOBO, $HT3$, during working hours of one day *without* solar radiation influence (THERM2).

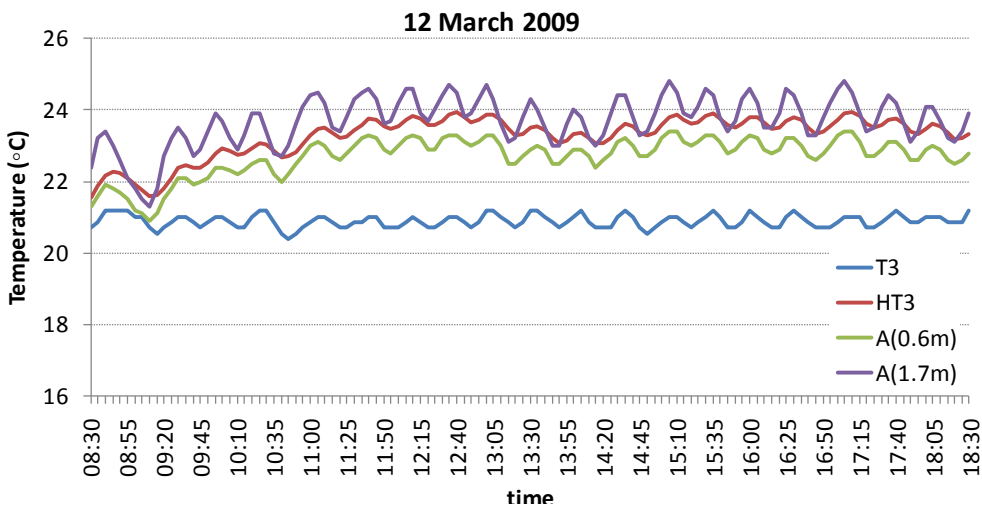


Figure 41. Temperatures measured by the heating control sensor, $T3$, the HOBO, $HT3$, and in the occupied zone, A , during working hours of one day *without* solar radiation influence (THERM2).

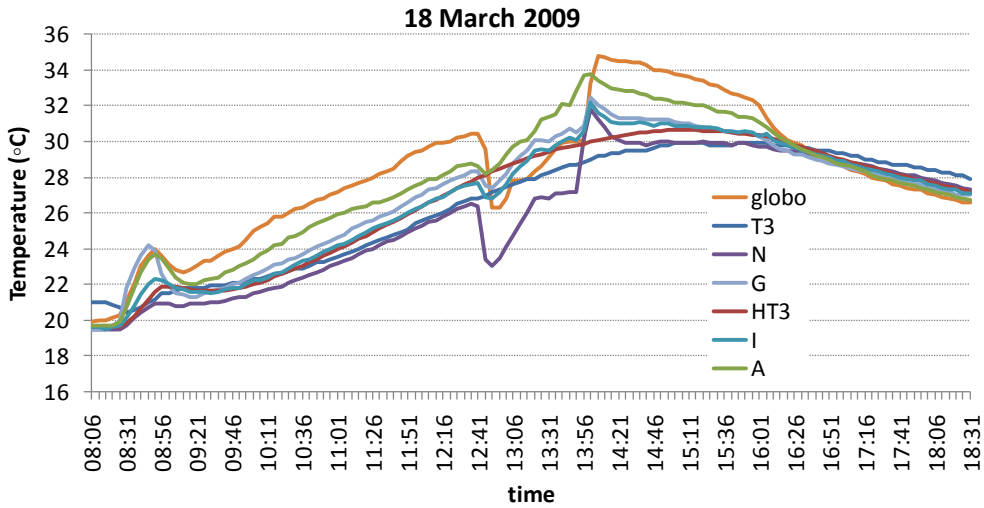


Figure 42. Temperatures measured by the heating control sensor, $T3$, HOBO, $HT3$, and differently placed sensors during working hours of one day *with* solar radiation influence (THERM2).

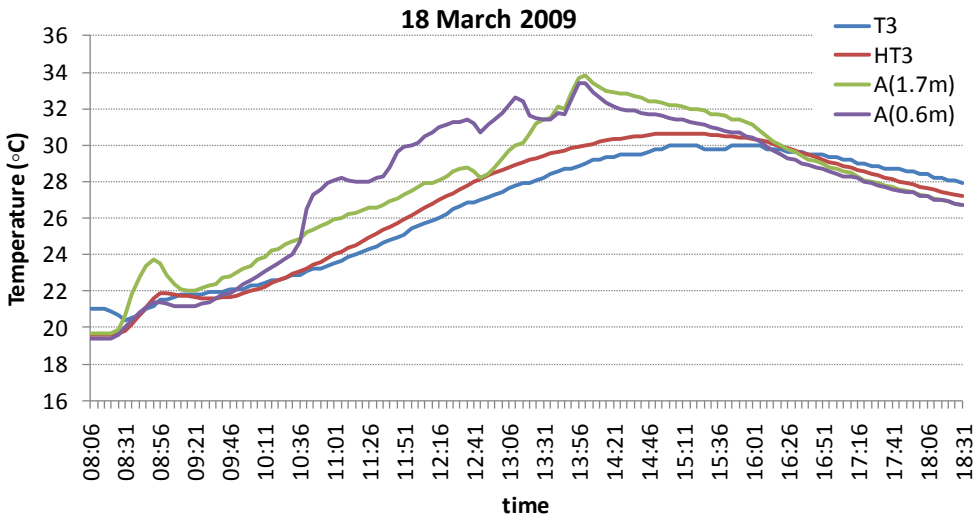


Figure 43. Temperatures measured by the heating control sensor, $T3$, HOBO, $HT3$, and in the occupied zone, A , during working hours of one day *with* solar radiation influence (THERM2).

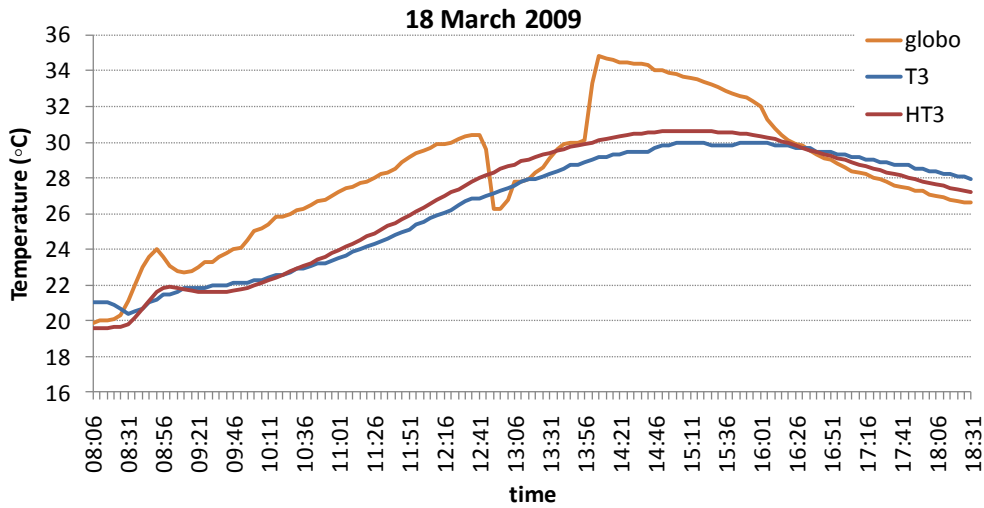


Figure 44. Temperatures measured by the heating control sensor, *T3*, the HOBO, *HT3*, and the globe sensor, during one working hours of day *with* solar radiation influence (THERM2).

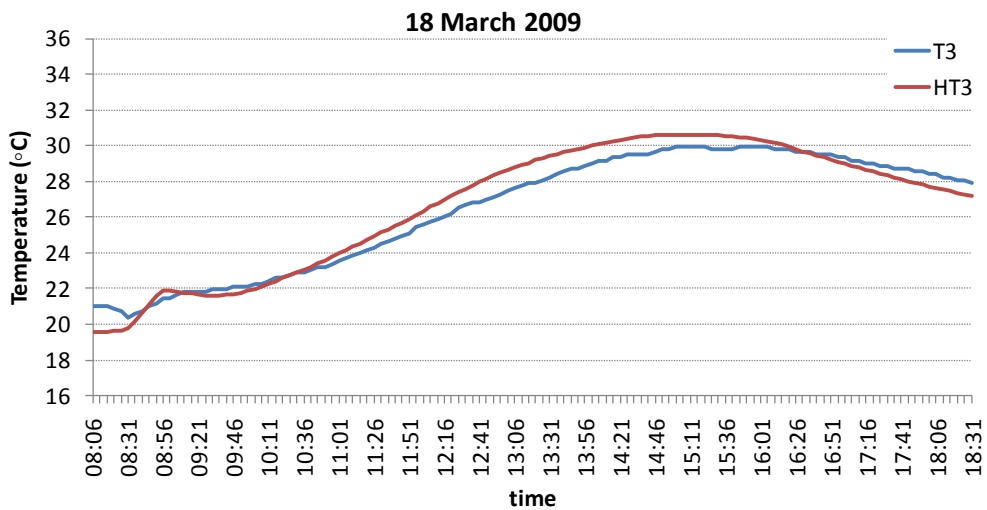


Figure 45. Detailed comparison of the temperature measured by the heating control sensor, *T3*, and HOBO, *HT3*, during working hours of one day *with* solar radiation influence (THERM2).

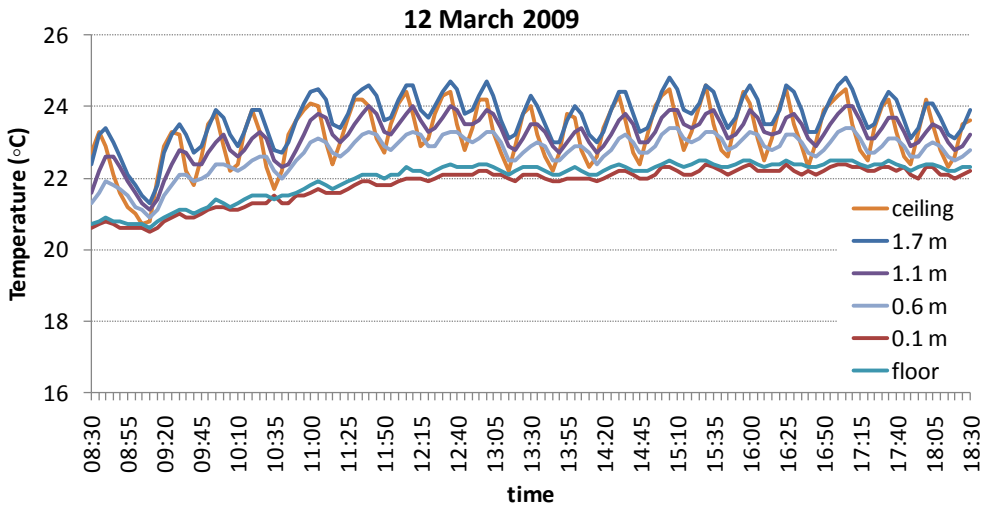


Figure 46. Vertical temperature distribution at 1 m distance from the window *without* solar radiation influence. (THERM2).

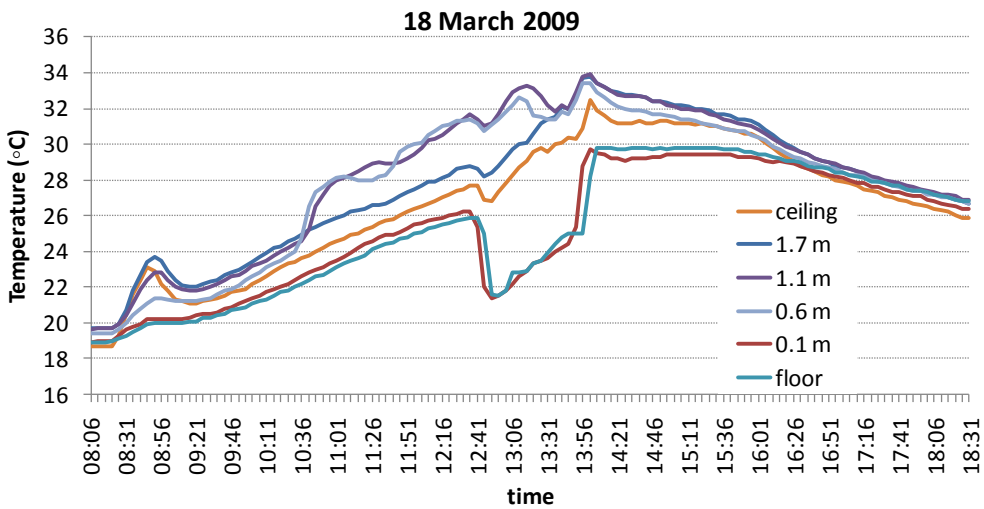


Figure 47. Vertical temperature distribution at 1 m distance from the window *with* solar radiation influence (THERM2).

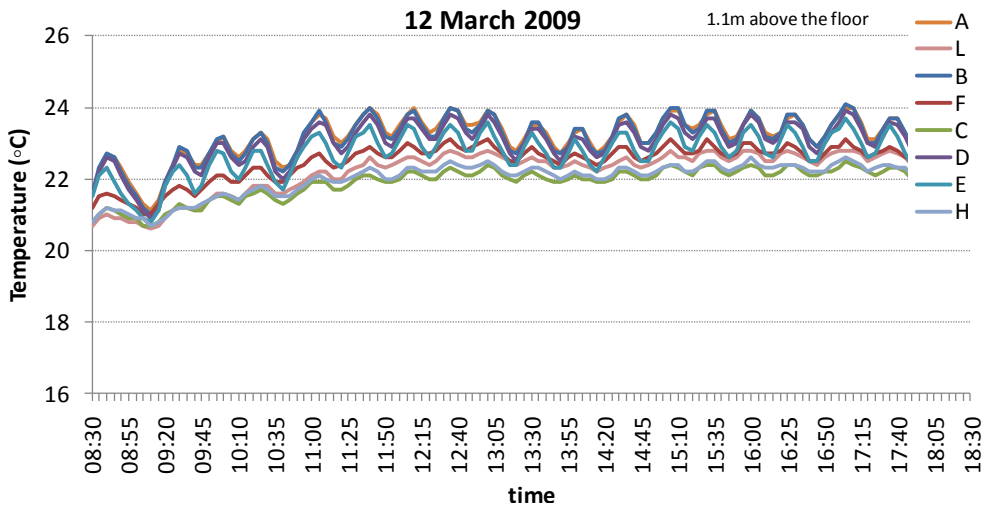


Figure 48. Horizontal temperature distribution 1.1 m above the floor *without* solar radiation influence (THERM2).

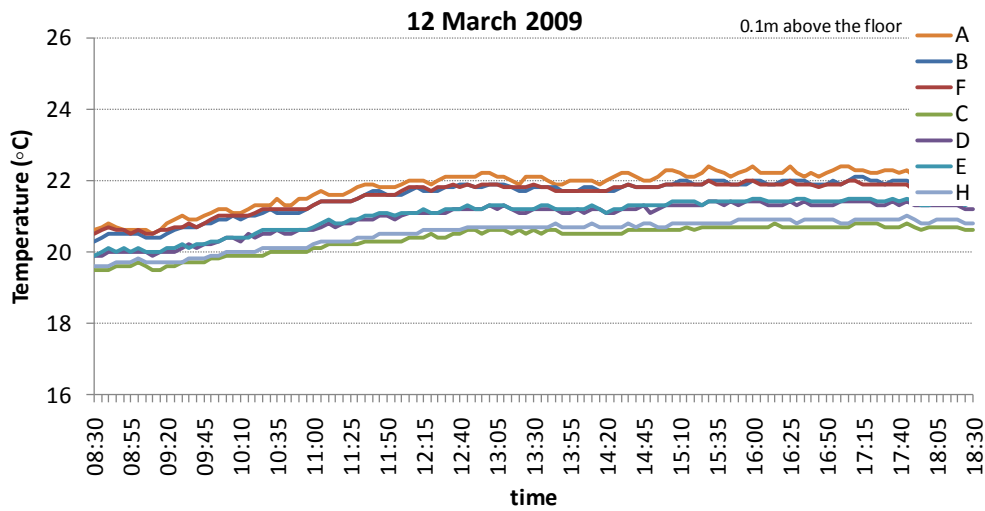


Figure 49. Horizontal temperature distribution 0.1 m above the floor *without* solar radiation influence (THERM2).

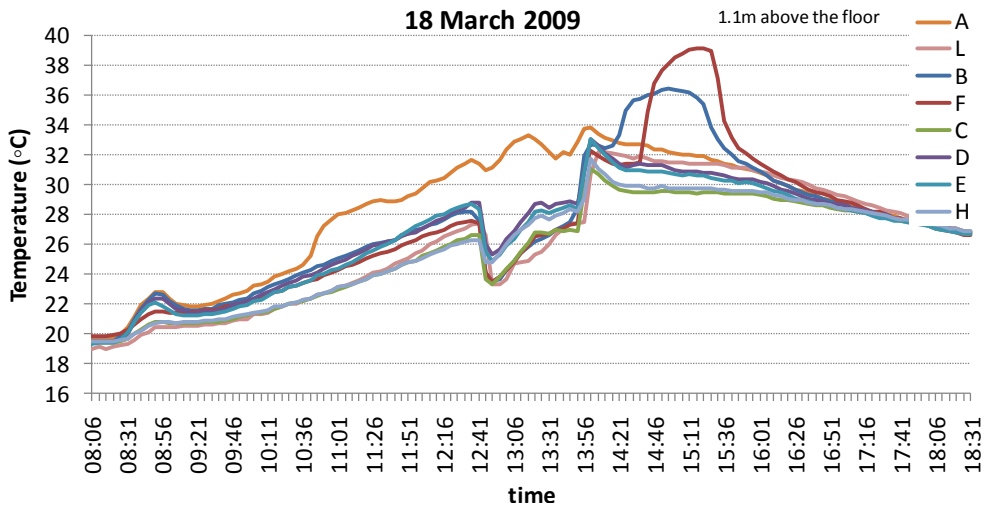


Figure 50. Horizontal temperature distribution 1.1 m above the floor *with* solar radiation influence (THERM2).

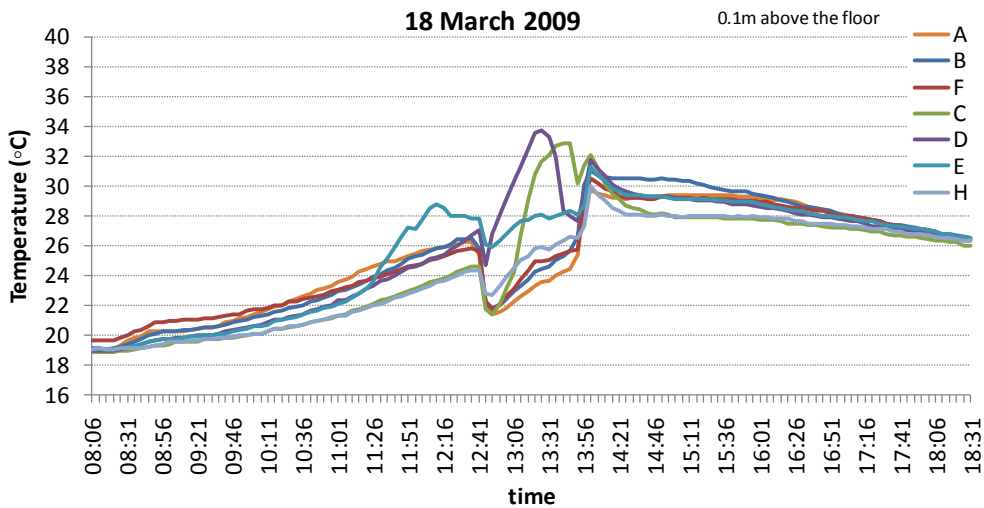


Figure 51. Horizontal temperature distribution 0.1 m above the floor *with* solar radiation influence (THERM2).

A.10. THERM3 (22 March - 13 April)

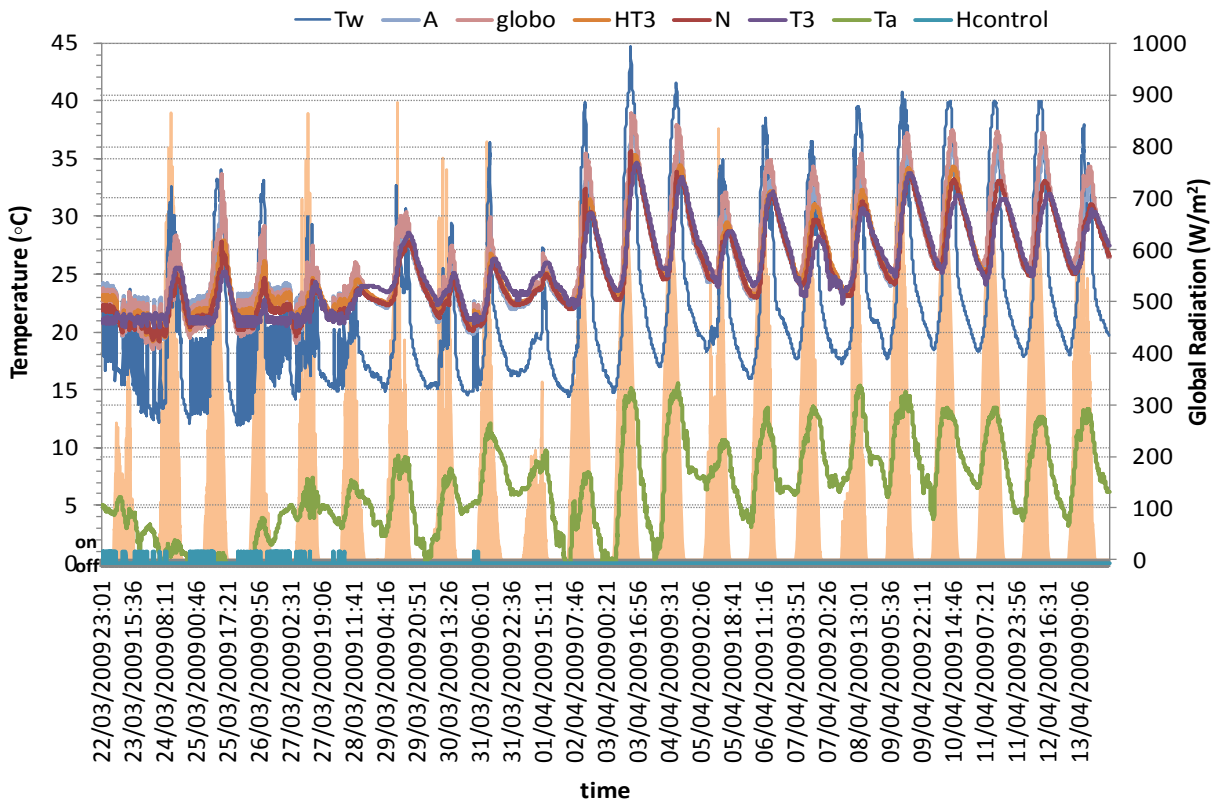


Figure 52. Indoor and outdoor temperature variation, heating control signal, and global solar radiation (THERM3).

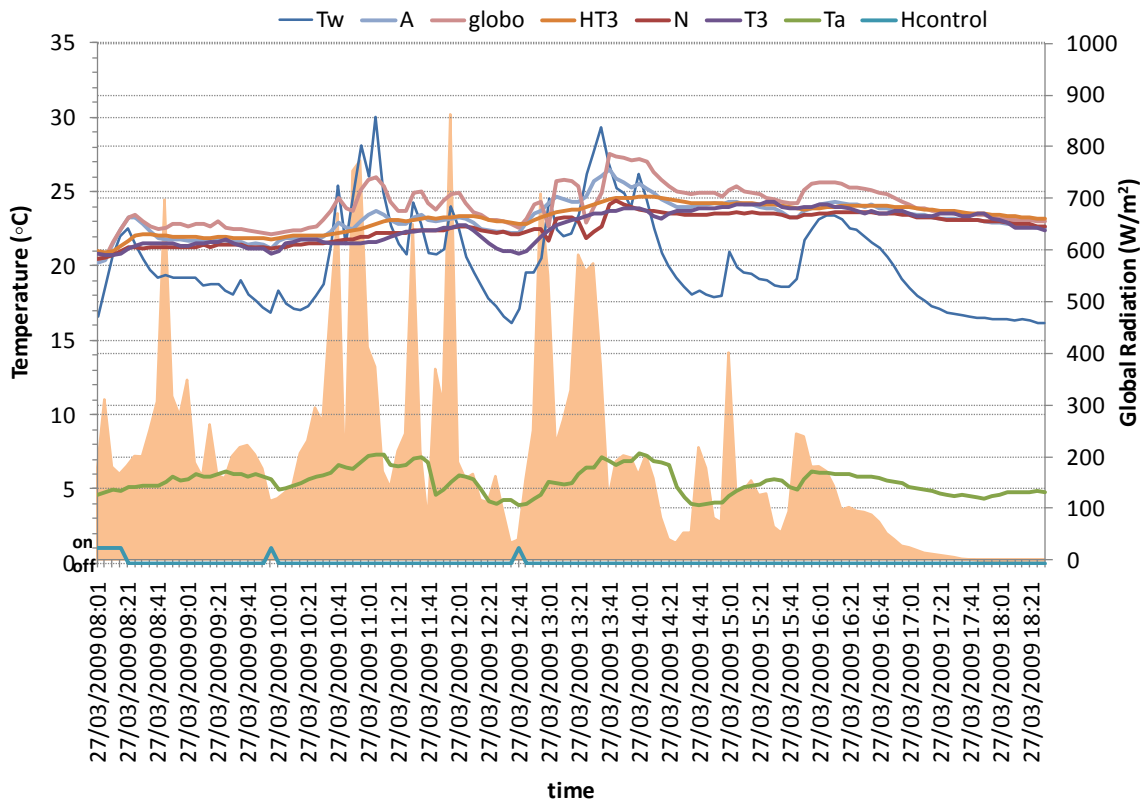


Figure 53. Indoor and outdoor temperature variation, heating control signal (on-off), and global solar radiation during working hours of one day (THERM3).

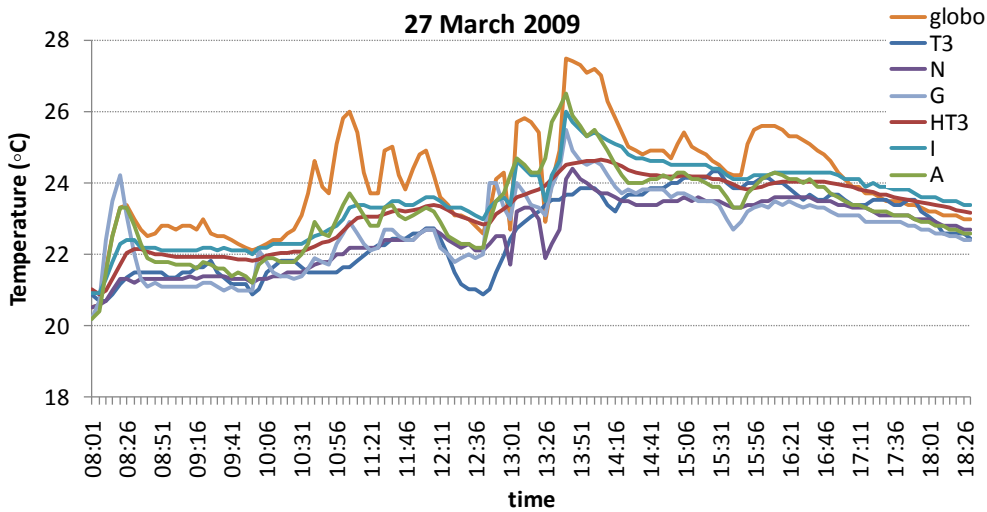


Figure 54. Temperatures measured by the heating control sensor, *T3*, HOBO, *HT3*, globe and differently placed sensors during working hours of one day (THERM3).

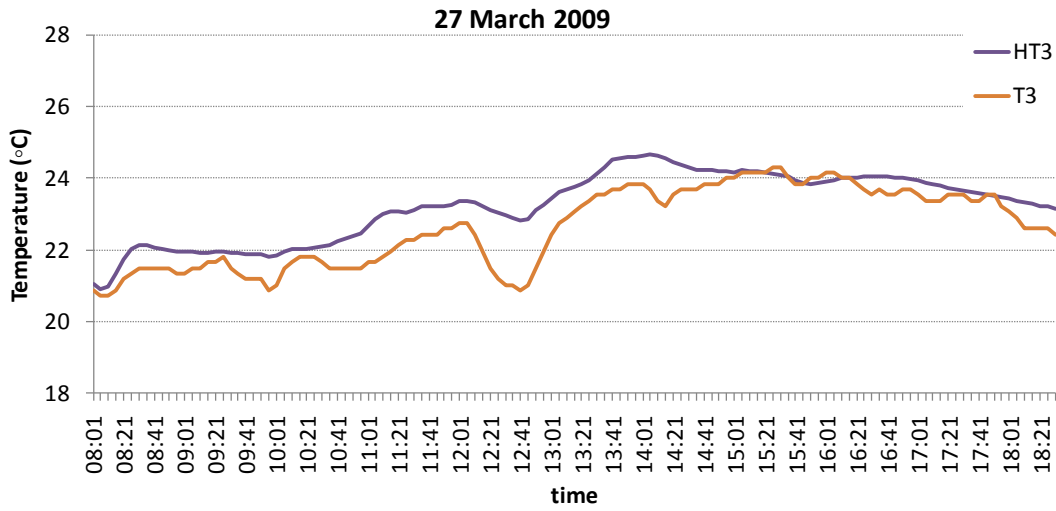


Figure 55. Temperatures of heating control sensor, *T3*, and HOBO, *HT3*, during working hours of one day (THERM3).

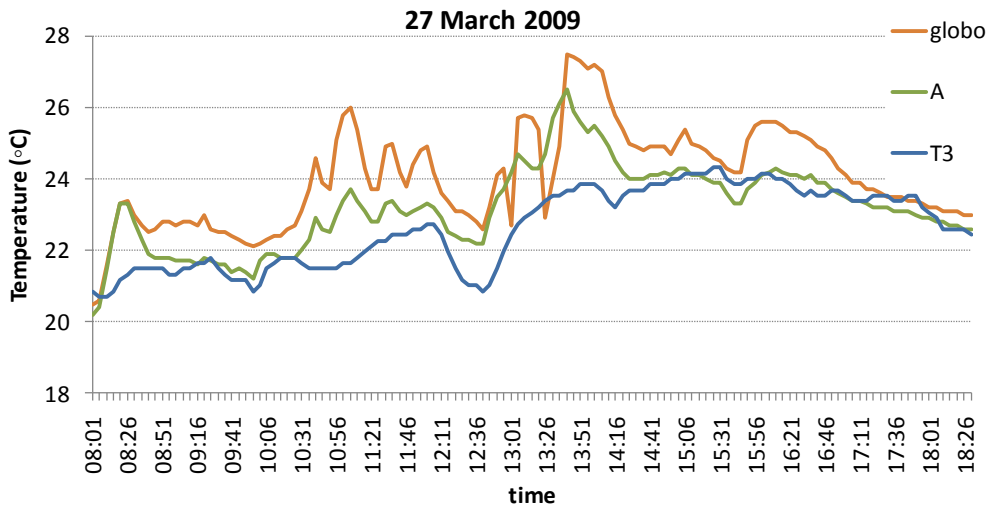


Figure 56. Temperatures measured by the heating control sensor, *T3*, the globe sensor and in the occupied zone, *A*, during working hours of one day (THERM3).

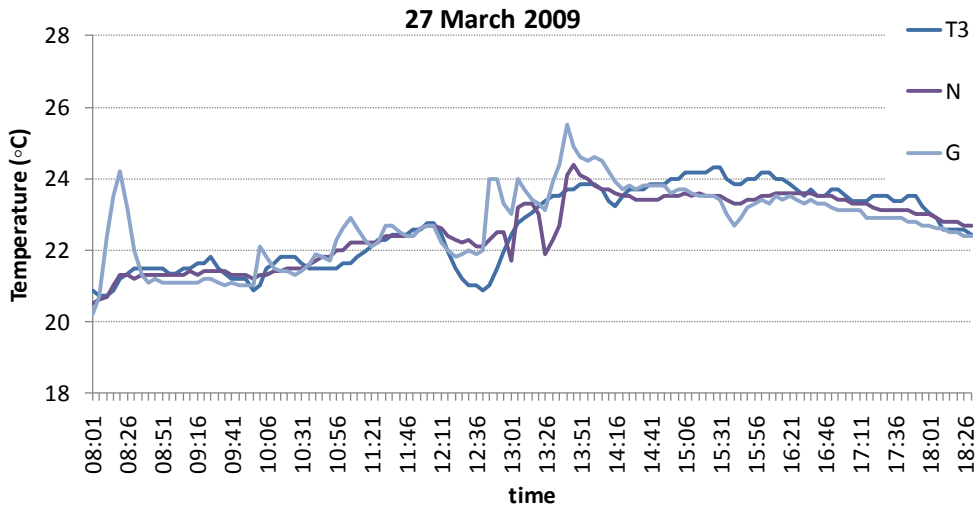


Figure 57. Detailed comparison of the temperature measured by the heating control sensor, $T3$, and thermocouple measurements at the same place on the wall, N , and in the air, G , during working hours of one day (THERM3).

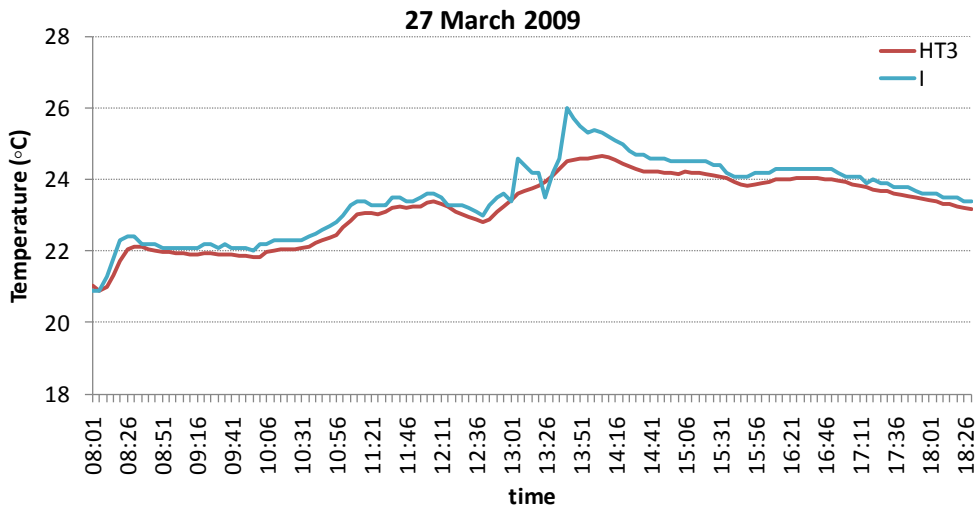


Figure 58. Detailed comparison of the temperatures measured by HOBO, $HT3$, and thermocouple sensor at the same place, I (THERM3).

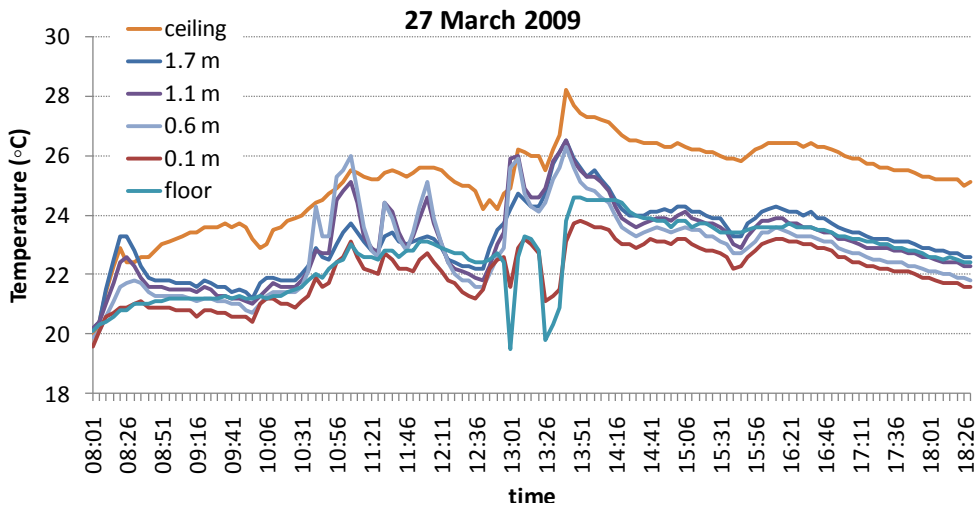


Figure 59. Vertical temperature distribution at 1 m distance from the window (THERM3).

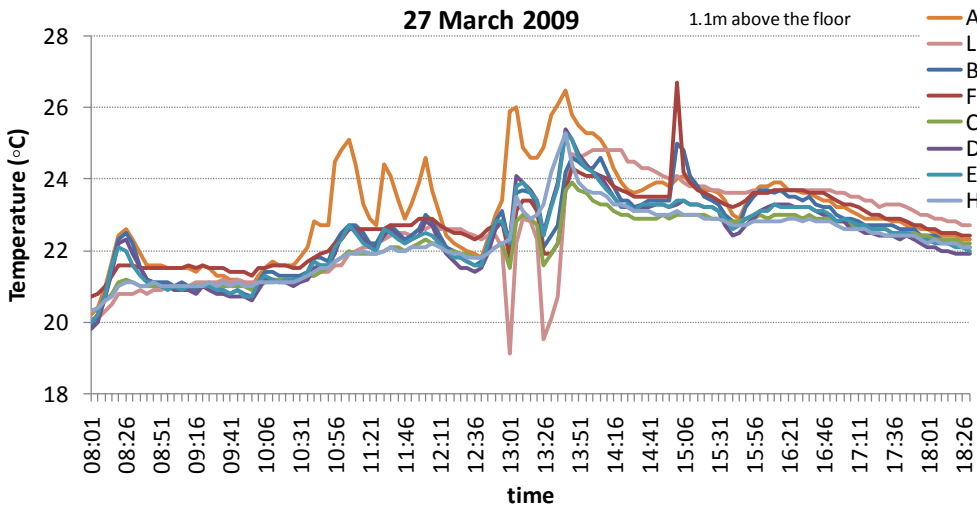


Figure 60. Horizontal temperature distribution 1.1 m above the floor during working hours of one day (THERM3).

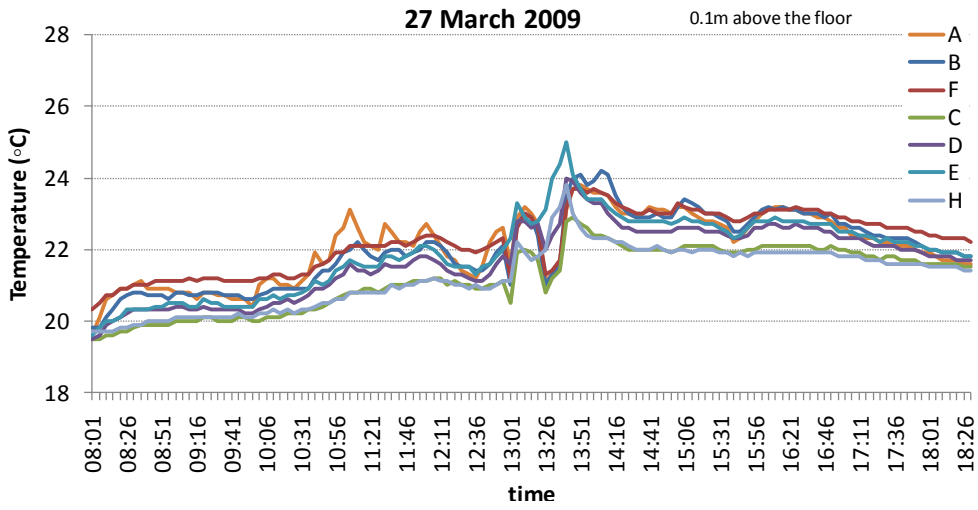


Figure 61. Horizontal temperature distribution 0.1 m above the floor during working hours of one day (THERM3).

The report presents analyses of thermal environment measurements carried out in a south-faced room of the so-called Flexhouse at Risø DTU from February to April 2009. The indoor temperature distribution and different choice of sensor types and locations are analysed with the objective to provide data for models of the dynamic thermal condition of the building. Five series of the experiments were run using either PRBS-signals (Pseudo Random Binary Sequence) or thermostatic control.

An investigation of temperature sensors is made focusing on how well the heating system's wall mounted control sensor represents the thermal condition of the room compared to how the condition is represented by auxiliary sensors and data loggers, which have been positioned at different locations and heights in the room.

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