Contents

B] STRATIFICATION EXPERIMENTS

A general experimental configuration of the stratification experiments carried out in this work and the location of the thermocouples of Th.Set A are shown in Figure 1,

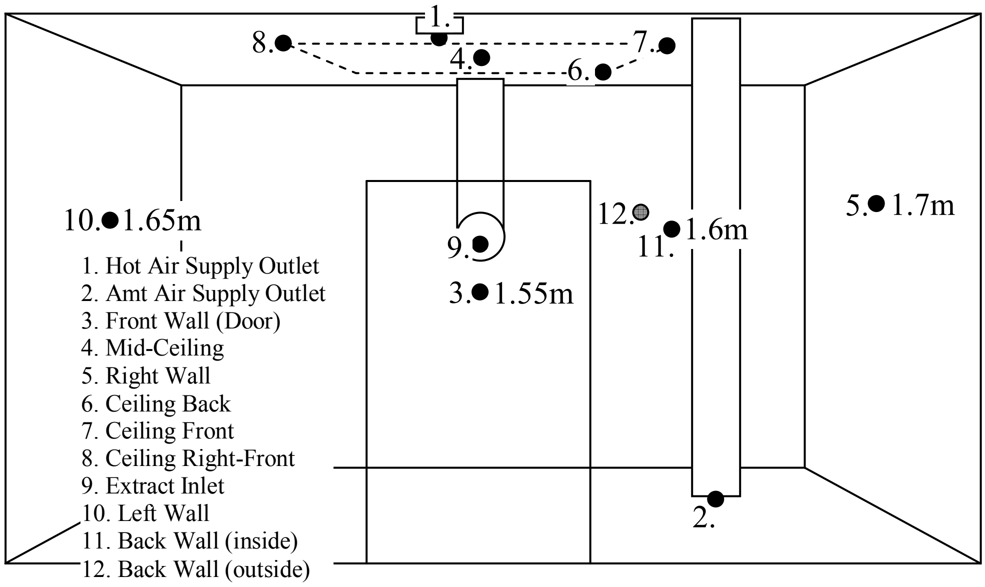


Figure 1: Wall surface and inlet/outlet thermocouple locations of Th.Set A.

1) EXP01(04,06,08)-08-00 – EXPERIMENTS ON MIXING FLOW RATES

The aim of the experimental cases here is to create thermal stratification and find the parameters that affect the stability of stratification. This was done by taking measurements on a 36-nodded grid of 0.9-m apart at 6 sections shown on the grid in Figure 2 below,

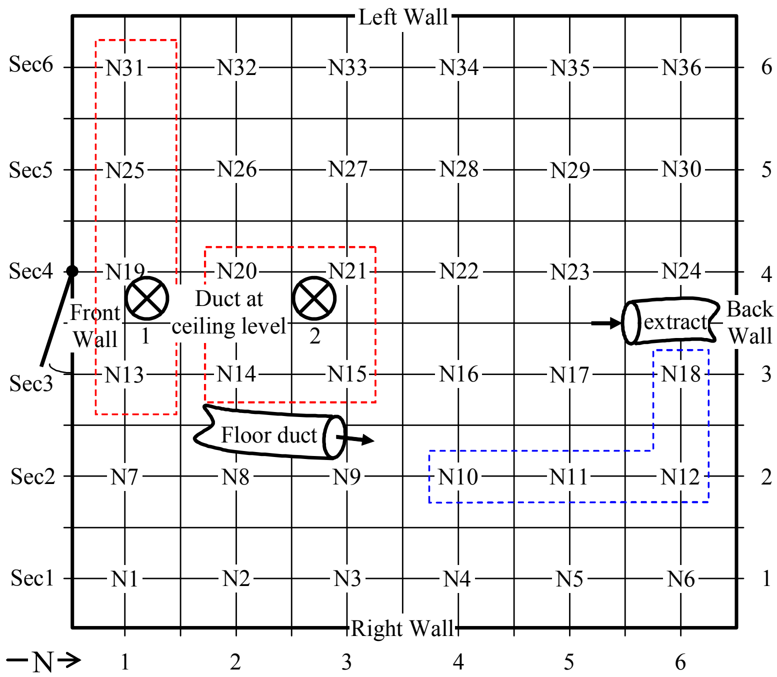


Figure 2: Measuring positions of the two support-rods for Thermocouple Set B and C. The effect of the hot-temperature-air-jet and the ambient-temperature-air-jet is more

significant in the regions defined by the red lines and the blue line respectively. Experiments: EXP-(01,04,06,08)-08-00.

There are four case studies carried out in this section. The first one is at high inlet temperature difference. The second one is for an increased inlet temperature difference and the next two are for reduced inlet temperature differences and reduced inlet flow rates.

There are limitations involved with the experimental apparatus of any experimental investigation. The restrictions encountered in these studies are mention here briefly. The inlet temperatures are coarsely controlled by the air-handling unit in this set of case studies and this introduces a deviation of approximately ±1.5°C around the mean values of the inlet supply temperatures. This limitation does not pose a restriction on the analysis of these case studies because the range of supply temperatures between the ceiling duct and the floor duct is large compared to the error range. These studies aim to converge to an approximate estimation of the temperature changes of the chamber medium with respect to the changes of the inlet temperatures. The heating element has a power output capable to raise the temperature to only a little higher than 40°C at the setting point. This is because the blue-foam connections can undergo permanent deformation if they exert temperatures higher than 50°C. The environmental chamber is reduced to a normal room size 5x5.5x2.5, to economise for energy consumption during testing and reduce the time-scale. The pressure drop over the length of the chamber can be overcome by using an extractor fan at the other end of a duct, located at the back wall. The extractor fan is connected to a closed-loop circuit in the air-handling unit of the experimental facility. The heat recovery duct-work can theoretically recover 70% of the heat for air-to-air systems. This helps to overcome the pressure losses in the chamber and maintain mass balance for the supply flow rates. The fan speed is set to obtain a flow rate at the extract outlet that is equal to the maximum set value, $(Q_{\mathrm{extr}})_v$=0.04m³/s.

The input parameters to the following series of experiments are shown in Table 1 below,

	h_{extr} [m]	$(Q_{\mathrm{HS}})_v$ [m³/s]	$(Q_{\mathrm{CS}})_v$ [m³/s]	$(Q_{\mathrm{in}})_v$ [m³/s]	$(R_{\mathrm{BJ}})_o$ [m⁻³]
EXP01	1.5	0.09	0.07	2×3ACH	0.26
EXP02	1.85	0.09	0.07	2×3ACH	0.33
EXP03	1.85	-	0.07	1×3ACH	0.16
EXP04	1.5	-	0.07	1×3ACH	0.1

Table 1: Input parameters for experiments on mixing flow rates. The time constant for the hot air supply is τ_{HS}=1.4min for the ambient air supply is τ_{CS}=2min. Experiments: EXP-(01,04,06,08)-08-00.

Large inlet flow rates of the order of 3ACH for heavy duty occupancy of large areas where manufacturing, welding and painting are taking place, is suggested by the British Standards in many textbooks. For office rooms, however, infiltration rates used in the natural ventilation of buildings are much lower, starting from approximately 0.1ACH up to a maximum value of 1.5ACH.

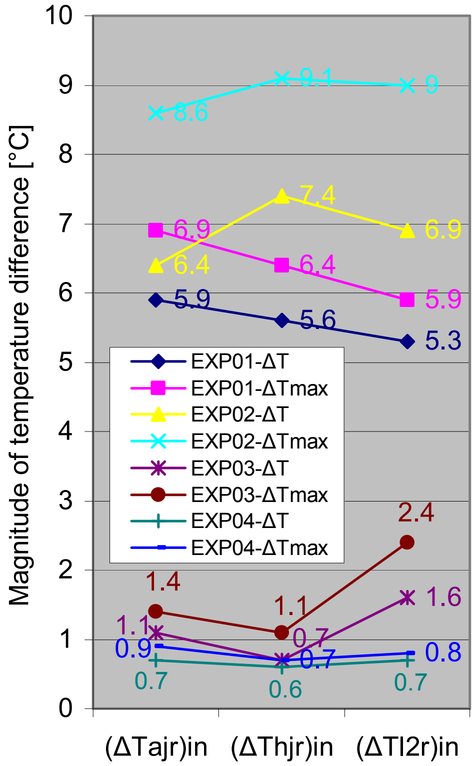


Table 2: Input parameters for experiments on mixing flow rates. Experiments: EXP-(01,04,06,08)-08-00.

The lab temperatures for each experimental case are shown in Figure 3,

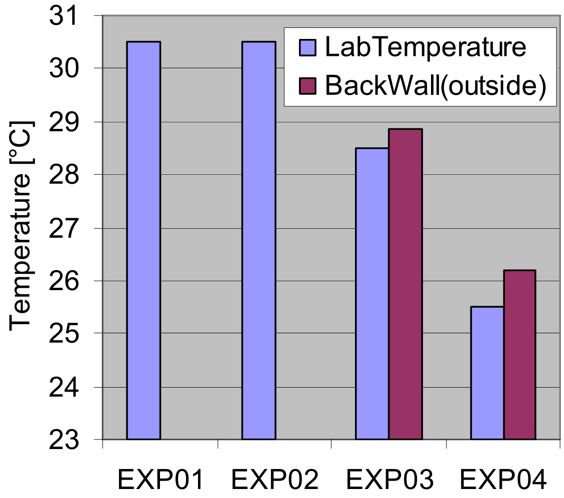


Figure 3: Reference temperature and back wall outside temperature. Experiments: EXP-(01,04,06,08)-08-00.

The reference lab temperature, T_{lab}, affects the temperature of the chamber while heating or cooling. This is shown on the graphs of the difference case studies in Fig.A-1.

a) EXP01: Hot-temperature-air-jet at T_1 & ambient-temperature-air-jet - T_{lab}=30.5°C, Δt=10min, h_{extr}=1.5m

The aim of this experimental case is to “punch a hole“ in the thermally stratified layers if they exist in order to study the stability of thermal stratification. To achieve that, stratification has to be built and this could be assured to some extend by introducing two air supplies at different temperatures in an environmental chamber. The top air supply is pointed downwards in the room from the ceiling and aims to provide the controlling mechanism for disturbing thermal stratification if present. To further enhance any existing stratification, the lower air supply is pointed horizontally towards the lower levels of the chamber medium at the ambient temperature of the outside, supplying the room with cool air. The inlet flow rate for the hot-temperature-air-jet at the supply outlet is $(Q_{HS})_v$=0.09 m³/s and for the cooler ambient-temperature-air-jet this is $(Q_{CS})_v$=0.07m³/s. The lab temperature is T_{lab}=30.5°C. The inlet temperature difference of the stabilised region away from the jet regions is $(\Delta T_{L2R})_{in}\approx$5.3°C. The maximum inlet temperature difference that could be achieved is in the cool-temperature-air-jet region, $(\Delta T_{CJR_max})_{in}\approx$6.9°C. Another parameter that will be varied in the next experimental cases is the extract height that for this case study it is set to h_{extr}=1.5m. These values are shown in Table 1. The results obtained in this case are presented by the temperature contour plot in Figure 11.

b) EXP02: Hot-temperature-air-jet at $T_2>T_1$ & ambient-temperature-air-jet - T_{lab}=30.5°C, Δt=5min, h_{extr}=1.85m

This experimental case is similar to the previous one, but the aim here is to see if there is any difference in the flow patters by using the inlet temperature difference. The flow rates are the same as in the previous case, i.e., the flow rate of the hot-temperature-air-jet $(Q_{HS})_v$=0.09 m³/s and the flow rate of the cooler ambient-temperature-air-jet is $(Q_{CS})_v$=0.07m³/s. The lab temperature is T_{lab}=30.5°C. The inlet temperature over a stable range away from the supplies is $(\Delta T_{L2R})_{in}\approx$6.9°C. The increase in the temperature difference in the medium is the main variable in this case and the maximum value of the magnitude is obtained in the hot-temperature-air-jet region $(\Delta T_{HJR_max})_{in}\approx$9.1°C. Additionally the extract height in this case is now changed to h_{extr}=1.85m. These values are shown in Table 1. The results obtained in this case are presented by a temperature contour plot in Figure 12.

c) EXP03: Only ambient-temperature-air-jet at $(T_3)_{1/2}<T_2$ - T_{lab}=28.5°C, Δt=20min, h_{extr}=1.85m

The aim of this experimental case is to see if the magnitude of the temperature distribution of the chamber medium can be maintained for lower input temperature differences and if it is possible to achieve thermal stratification for the given buoyancy-to-momentum ratio from only the lower duct as in the case of a plume source. The lab temperature in this case is T_{lab}=28.5°C. The flow rate of the cooler ambient-temperature-air-jet is the same as before and approximately half the total value of the previous cases, $(Q_{CS})_v$=0.07m³/s. The inlet temperatures change after having obtained around the first half of the range of values due to the unrefined control over the inlet temperatures from the experimental equipment. Although experimental convergence between supply and medium is not achieved for the new values after the ambient-temperature-air-jet region, these changes do not have any effect on the values of the chamber medium. The temperature difference of the supply air jets is now reduced to $(\Delta T_{AJR})_{in}\approx$0.7°C in the ambient-temperature-air-jet range of values and $(\Delta T_{L2R})_{in}\approx$1.6°C in the last two rows of the grid. The inlet temperature changes that occurred in the chamber medium are small, i.e., $(\Delta T_{HJR_max})_{in}\approx$1.1°C. The temperature differences in the flow field are of the range of ΔT=1.3°C. The extract height in this case is also h_{extr}=1.85m. These values are shown in Table 1. The results obtained in this case are presented by a temperature contour plot in Figure 13.

d) EXP04: Only ambient-temperature-air-jet at $(T_4)1/2<(T_3)1/2$ - T_{lab}=25.5°C, Δt=20min, hextr=1.5m

The aim of this case is to see how the chamber temperature distribution and magnitude changes compared to the previous case for a lower inlet temperature difference by only using the lower duct similar to EXP03, while the magnitude of the lab temperature is reduced, T_{lab}=25.5°C, and for an initial estimation of the calibration offsets. The flow rate of the supply jet is the same as in the previous cases Q_{CS}=0.07m³/s. However, the temperature changes that occurred in the chamber medium are smaller, i.e., $\Delta T_{max}\approx$0.9°C. The extract height in this case is changed back to h_{extr}=1.5m. These values are shown in Table 1. The results obtained in this case are presented by a temperature contour plot in Figure 12.

DISCUSSION

The results obtained by the set of case studies considered here suggest mixed flow and no stratification. However, there are small positive temperature distributions. The inlet temperature difference is equally important to the inlet flow rate. There is almost no stratification when high inlet flow rates are maintained which is evident in all four case studies.

Flow features

To visualise the temperature field inside the chamber, contour plots were made by using MS-XL. The data was arranged in the cells of a spreadsheet in the required order for plotting the values according to height and horizontal location. The value in each cell is based on the average of the neighbouring cells. A continuous contour plot was made of all section planes from all the measurements at each node on the grid to account for the all observations. For experimental case study EXP01 that is shown in Figure 2. Due to the high mixing the interesting flow feature is the jet flow characteristics. The Reynolds number of the hot-temperature-air-jet is approximately *Re*=50,000. Some of the flow features of the case study EXP01 have appeared more clearly in section-6 because the measurements at that section where taken very close to the beginning of the experiment where temperature differences where larger than the following measurements in the middle of the chamber. The middle sections, however, still shows the same flow features but with a little discontinuity and cohesion of a large shear layer region due to smaller ΔT_{in} and interaction on the other side of the jet with the ambient-temperature-air-jet. A finer plot of section-6 is made to observe the flow features more distinctly in Figure 4,

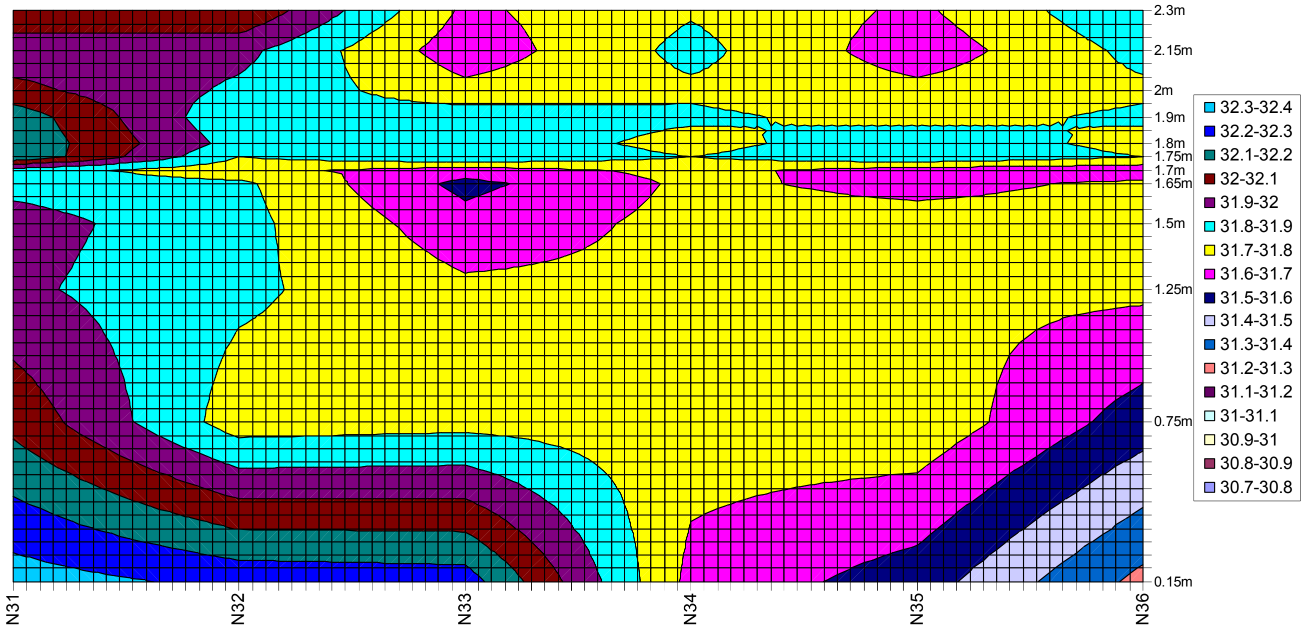


Figure 4: Temperature contours of hot-temperature-air-jet for case study EXP01, section-6, EXP-01-08-00.

The hot-temperature-air-jet is a wall-jet type and impinges and there is flow impingement on the floor. For that reason the wall jet looses most of the input momentum. There is a temperature instability that at around 1.75 and 1.8m (thermocouple 7 and 8). The average temperature difference around the instability is 0.1°C which is relatively small, compared to the larger instantaneous instabilities when obtaining the values and at the different nodes for the same height. The phenomenon of the instability appears at a lower Re probably because the interaction of momentum force with the buoyancy force and the consequent increase of small scale turbulence at that location. A better idea could be obtained comparing the results with the next experimental case.

The flow features of the higher buoyancy-to-momentum ratio of the case study EXP02 are presented by a contour plot of all sections in Figure 12. In section-1, the appearance of plume of mixed fluid flowing below the ceiling is occurring in the cooler surroundings of the chamber. In section-2, rotational flow patterns of mixed fluid are observed due to the cooler flow from the ambient-temperature-air-jet impinging on the back wall. Warm fluid from the ceiling is entrained by the jet increasing the temperature magnitude of the ambient-temperature-air-jet, while there is a small increase in the inlet temperatures. The mixed flow from the ambient-temperature-air-jet mixes with the flow from the hot-temperature-air-jet, which is also observed in section-3. In section-4, the hot-temperature-air-jet is observed impinging on the floor. The colourations of the hot-temperature-air-jet region are very interesting and a finer plot is made to better visualise the flow field, in Figure 5,

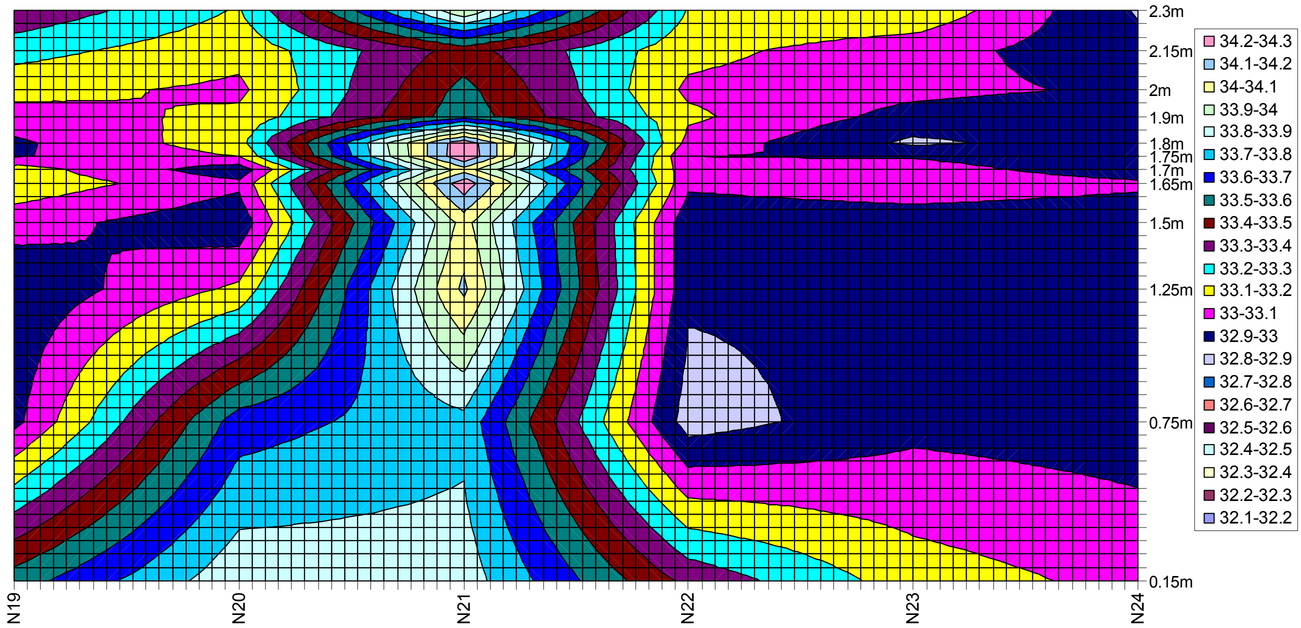


Figure 5: Temperature contours of hot-temperature-air-jet for case study EXP02, section-4, EXP-04-08-00.

The supply temperature in this range has been controlled more steadily than in the rest of the sections. The temperature differences act like a dye and in this case the higher ΔT_{in} makes the regions inside the jet show up more clearly. In the initial jet region, the potential core region is formed. Standard ring vortices (roller-type) are formed which follow a periodical motion. Hotter fluid is pushed down the primary core region due to primary vortex rotation. The rotational phenomenon is reproduced periodically, mixing the local flow field. The outcome of the momentum-buoyancy mechanism is to put the transitional zone into a higher fluctuating motion that an isothermal jet. These are periodical oscillations which result in the appearance of secondary core formations. The potential core contains the highest energy pick that is signified theoretically by a primary frequency. The secondary frequencies of the secondary core formations follow an exponential decay. This adverse sequence of physical phenomena is the source of sound waves, which is a drawback of the mixing ventilation type. The shock wave acts like a carrier phase for the thermal instability which is very weak in this case. However, this can cause problems in the mixing ventilation type by reducing the buoyancy height for the contaminants which can affect the efficiency of the ventilation system. In the case study EXP01, this instability is much thicker because of large-scale circulations above and below and the shear of the jet flow with the front wall. The instability in case study EXP02 is much stronger because of the higher inlet temperature difference with the surrounding environment. In both case studies, EXP01 and EXP02, the instability forms at around the same height, which is observed to occur at 1.65m (thermocouple 5) the and there is an average change of temperatures of 0.3°C. This is because the length of the primary core measures in dimensions of inlet diameters introducing this constant into the formulation of the phenomenon. From the theory of jets, the primary core for a free jet extends up to 4-6 diameters downstream which is 0.9m. Hence, this is the justification for the approximate height. This effect is a measurable quantity of ventilation terminals which is measured by Buildings Services Engineering on a decibel scale.

The jet is closer to the front wall (door), there is a smaller amount of surrounding fluid between the jet and the wall. Hence, the effect of the shear layer attaching to the close-by surface (downstream) makes the surface of the front wall slightly warmer than the rest of the chamber. The flow impingement is also a periodical phenomenon, which is observed by the large changes in magnitude of the temperature distributions close to the floor region. On the other side of the jet, there is a larger amount of fluid constrained between the jet and the back wall than the other side. The thermal shock wave due to the periodical motion of the secondary core formations is more evident on this side of the jet. A stagnant region of fluid due to the impingement is also evident. In section-5, the trailing region of the impinged fluid of warm air is rising up below the ceiling. The temperature magnitude is maintained almost the same up to section-5. Finally, in section-6, the inlet temperature is reduced, which affected the temperature of the medium.

The temperature distributions at different regions in EXP01 show the transient character of the flow at low buoyancy-to-momentum ratios, as shown in Figure 11. It can be seen very clearly here that this is negative close to the hot-temperature-air-jet region. This becomes slightly positive and negative further away from the jet. This high momentum jet impinges on the floor, which results in the average temperatures of the medium at the floor level being slightly higher than the temperature of the medium at the ceiling level. The temperature differences in the case study EXP01 are smaller than in the case study EXP02, consequently the contours of the hot-temperature-air-jet are present in almost all sections of EXP01. Although the input temperatures in EXP02 followed an increase of a parabolic type of curve, the temperature of the hot air supply at the setting point from the start to the end of this case was not varied too much. This is because of heat leaking to the outside of the chamber. Heat conducts from the medium to the walls of the chamber.

In the case of EXP03, the temperature differences are even smaller than in the previous case. The temperature changes are slightly higher if the results of this case were compared qualitatively with the previous cases. For that reason the average values were taken from the two Th.Sets and plotted in sections. Stable temperatures are initially maintained in the chamber medium that can be seen in section-1. However, the air supply temperature follows a linear descent. This is clearer by the contours of section-2, as shown by the less warm plume of the ambient-temperature-air-jet. The outlet flow of the ambient temperature air supply is warmer than the surrounding medium in the chamber at section-2. This is very interesting because although there is very small buoyancy-to-momentum ratio, there is turbulent flow settling below the ceiling in the way of smoke stratification in fire-safety research. This is shown in more detail in Figure 6,

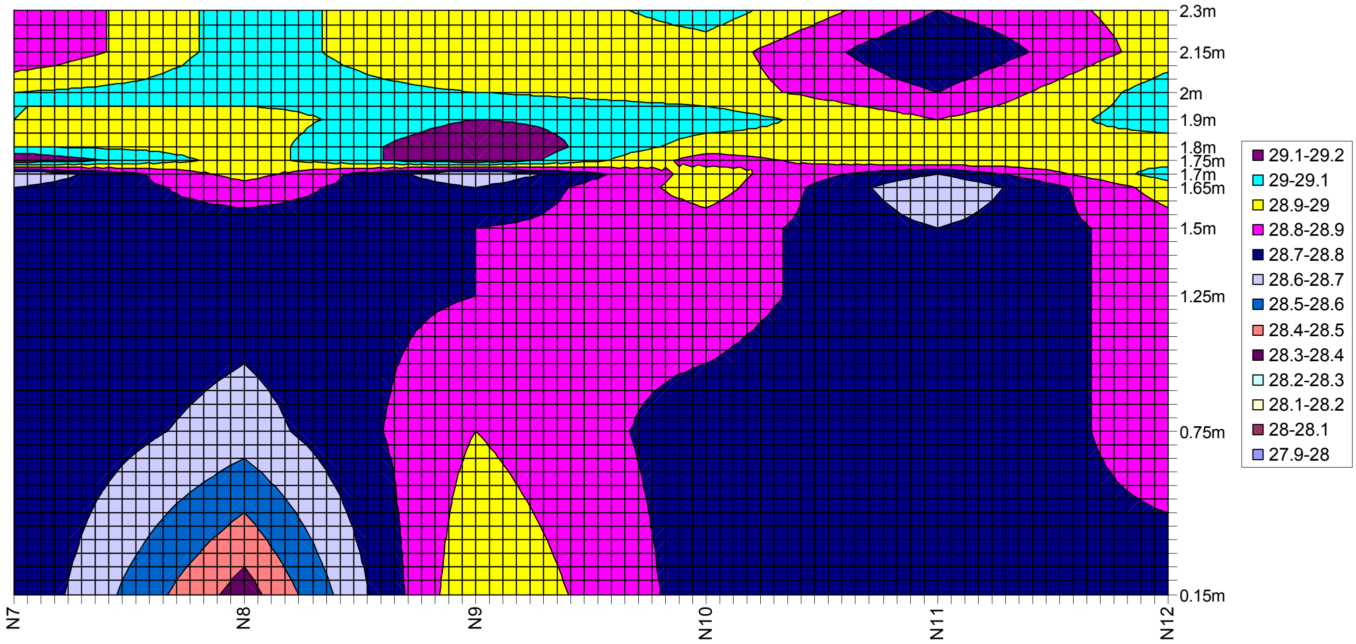


Figure 6: Temperature contours from the flow coming out of the floor air supply for case study EXP03, EXP-06-08-00.

Slight variation in the contours at grid nodes N8 and similarly at N14 and N15 in Figure 13 could have been generated most likely due to the surface radiation of the duct as the floor conducts the heat from the external surface of the duct (verified by personal communication with Prof. Icha Bruno University, Czech Republic).

Warm air pockets that change over time are evident in section-3 and section-4, in the spreading region of the jet below the ceiling. However, since the temperature of the air supply starts descending Figure A-1 (c), colder temperatures are achieved as expected in sections-5 and section-6. The overall stratification obtained in this case is still very weak and the chamber medium is very weakly affected by the inlet temperature changes. The most obvious reasons are the temperature difference between the chamber walls and the chamber medium, i.e., the outside surroundings in the lab, and the inlet velocity, due to the heat flux of the walls and the heat capacity of the chamber.

The ration of buoyancy-to-momentum is small due to the plume rise. Hence, the thermal stratification of a plume rise is different to the stratification that occurs in rooms. When the plume flow stops, the temperature differentials in the chamber will put the medium into a thermally stratified mode as gravity effects become larger. The buoyancy-to-momentum ratios will become larger too, resulting to a larger ΔT with room height with the influence of latent heat.

In EXP04, the chamber medium initially gets to the working temperatures as shown by the contours of section-1 at the lower levels. The temperature is seen to become a little higher in the lower levels of section-2. The temperature above is also a little higher because it was affected by the linear descent of the inlet temperature. Similar to the previous case in section-3 and section-4, there are temporal warmer temperature pockets below the ceiling which is at the same time. In contrast to the previous case, in sections-5 and section-6 the response to the changes of chamber medium is negligible.

Looking at the results obtained from the case studies EXP03 in Figure 13 and EXP04 in Figure 14, the changes that occur to the ambient-temperature-air-jet do not affect the temperature of the chamber medium. This is because the heat value obtained from the flow rates is small compared to the heat value that is needed to warm up the chamber medium and the wall fabric. Hence, it takes much longer for the chamber medium and the wall fabric to respond in contrast to the previous case studies. The input temperature difference taken for the last two rows in the case of EXP03 is for the previously stabilised temperature of the ambient-temperature-air-jet. The overall characteristics of the chamber medium are almost constant.

The extract height does not make any difference to any of the case studies and this is due to the high inlet flow rates and turbulence. There is a slight curvature at the height of 1.7-1.8m, but the change is due to the jet. A higher but realistic, uniform temperature distribution may be maintained for lower flow rates.

Comparing cases EXP01 and EXP02, there is a difference in the flow patterns. In EXP01, the hot-temperature-air-jet is experienced in the entire flow field of the environmental chamber. In EXP02, the hot-temperature-air-jet influences only the area below the supply. For the inlet temperature differences of EXP01 and EXP02, higher temperature ranges could be achieved with occasional hot air pockets but no stratification. The temperature changes are much smaller in the case of EXP03 and EXP04. Thermal stratification is not present in these cases either, but there is a turbulent hot air zone in EXP03 similar to smoke stratification.

Extract height

In the case study EXP01, the magnitude of the temperature of the flow at the extract is slightly higher than of the chamber medium at the same height. This occurs due to the high inlet velocity of the supply jets prevent the build-up of thermal stratification. Any temporal warm air pockets that shear off from the momentum region of the jet are attracted by the extract because of their lighter density. In EXP02, this is not evident because the inlet temperature difference affects the chamber medium temperatures by higher magnitudes. The effect is more pronounced at the nodes N14 and N21 where the hot-temperature-air-jet is discharged. However, these differences are becoming smaller in both cases of EXP03 and EXP04, as it would be expected. This is shown in Figure 7 below,

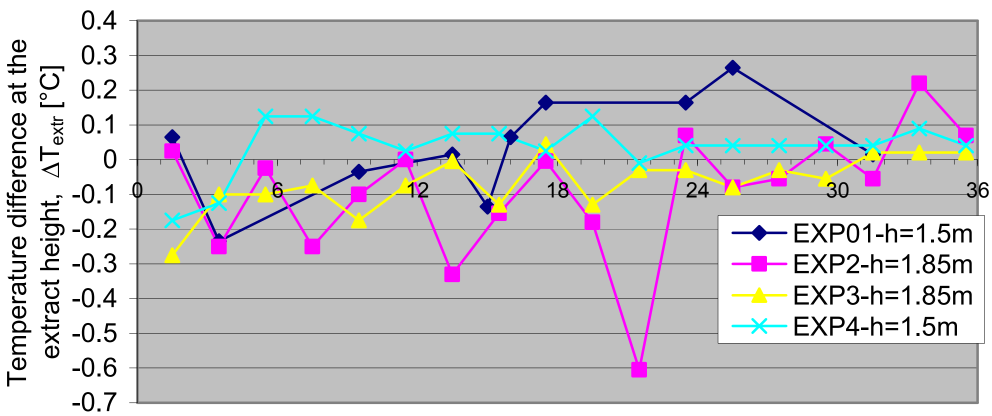


Figure 7: Temperature differences between the extract and the medium at the same height. Experiments: EXP-(01,04,06,08)-08-00.

The extract temperature in EXP01 is close to just being the same value at the same height only in the last two rows of the run. The temperature differences vary from up to a maximum of 0.25°C and from -0.2°C to -0.6°C depending on the location of the measurements in the chamber, i.e., when the Th.Sets are situated close to the air supply jets.

Energy considerations

The temperature changes that occurred in the case studies of this experiment for the given flow rates and temperatures are shown in Figure 8,

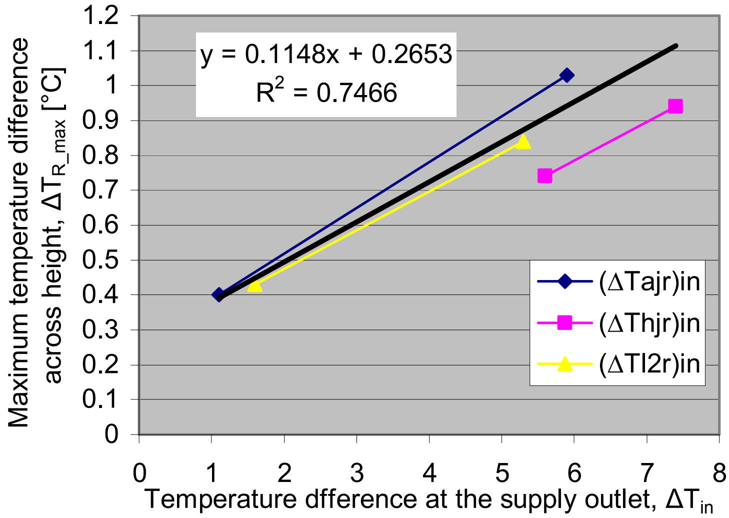
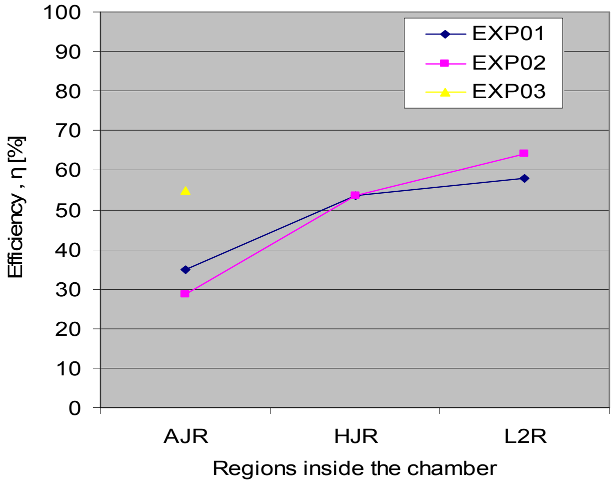


Figure 8: In the process of achieving thermal stratification, the inlet temperature difference ΔT_{in} is the average inlet temperature and ΔT_{max} is the maximum temperature difference that could be achieved in the chamber medium for the corresponding inlet temperatures in the chamber. Experiments: EXP-(01,04,06)-08-00.

The values are obtained mainly from EXP01 and EXP02 and the ambient-temperature-air-jet region from EXP03. The temperature difference in EXP02 in the ambient-temperature-air-jet region is ΔT=1.1°C for an inlet temperature of ΔT_{in}=7.5°C. This occurred because of the high inlet temperature of the hot-temperature-air-jet. In the case of EXP01, the temperature difference is lower and this results in lower temperatures in all three regions. The temperatures reduce even further in the case of EXP03 and EXP04. The inlet temperatures for EXP03 and EXP04 are calculated by using the lower air supply and the ceiling or floor temperature depending on the outlet temperature at the duct.

i) Efficiency

The thermal efficiency measures the ability to heating up the environmental chamber to maintain the temperatures obtained by the jet flow. This is defined as the ratio of average temperature difference from the supply outlets over the average input. The efficiencies calculated for the region of the last two rows on the grid are only for EXP01 and EXP02. The efficiency calculated for the ambient-temperature-air-jet region is for the case study EXP03 that was stabilised for a long time. An additional point was added for hot-temperature-air-jet in the case of EXP03 taking the previously stabilised magnitude of the ambient-temperature-air-jet. This is plotted in Figure 9,



(a) (b)

Figure 9: Thermal efficiency of the environmental chamber. Experiments: EXP-(01,04,06)-08-00.

The thermal efficiency is plotted in Figure 9 for selected regions where stable temperature could be maintained within a small error range in the specified region. The average efficiency in HJR and L2R is approximately 57%. This is a typical value for buildings and indicates that the external temperatures affect the temperature of the chamber medium. This occurs on the one hand, due heat losses which are controlled to a large extent by the insulation of the room and due to the mixing characteristics of the inlet flow rates to conduct the heat to the walls of the chamber by the forced convection and heat exchange by radiation from the jets to the walls. On the other hand, the heating in this case involves the chamber medium and the chamber walls, while there is no thermal stratification. The heat value obtained by the mixing jets conducts to the chamber walls and leaks by surface radiation to the external surroundings in the lab, while some amount of heat leaks normally out of the extract maintaining mass balance and flows back into the system by the closed loop arrangement of the air-handling unit. The effect of the heat flow through the chamber walls can be observed as the average temperature of the chamber increases with time, Figure A-1 (a), (b), (c) and (d). Looking at the chamber temperature, the mean inlet temperatures and the chamber medium temperature in Figure A-1 (a), (b), (c) and (d), it has been quite a difficult task to extract the right values, for stabilised conditions, where changes are small and the difference between average input and output temperatures are more evident from the graphs. This is because of the time taken for the wall fabric to conduct the temperatures.

ii) <u>Performance</u>

Since the variation in the values for EXP03 and EXP04 depend on the inlet flow rate as much as the wall temperatures, another parameter may be introduced. Thermal performance can be defined as the ratio of thermal efficiency over total cost. The heat losses are large when large flow rates are used. There is a decrease in thermal performance by mixing with thermal efficiency as shown in Figure 10,

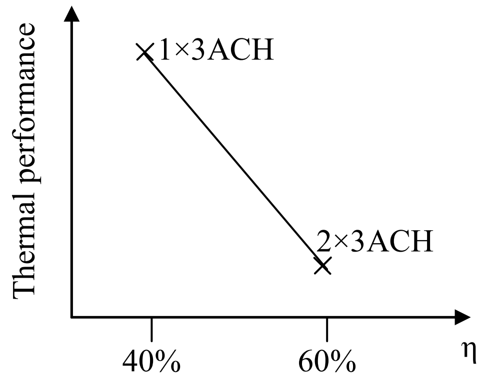


Figure 10: Thermal performance versus thermal efficiency by mixing ventilation.

CONCLUDING REMARKS

The following concluding remarks can be made for the current case studies:

1) Full mixing occurs in EXP01 and EXP02, the flow is of shear layer type. The thermal instabilities can influence the buoyancy height of the indoor contaminants.

2) Full mixing occurs in EXP03 and EXP04, but warm and cool air patches seem to form momentarily. There is a positive temperature distribution but no stratification. There are two zones in EXP03 and smoke-type stratification occurs due to high inlet velocity of the floor duct.

3) The inlet temperatures should be higher than 9°C to achieve stratification with high flow rates. Hence, a higher ratio of buoyancy force to momentum force may be useful as a starting point for producing thermal stratification. For smaller temperature differences, heat losses and capacitance of the chamber fabric may be considerable.

4) The inlet flow rate should be less than $0.07 m^3/s$ in order to achieve thermal stratification or ΔT should be higher.

Comparing the experiments on mixing with the stratification experiments, the major conclusion is that heating up is not very efficient in the mixing cases of high flow rates as it would be expected in stratified cases.

The walls and the external/lab temperature have an influence on the chamber medium temperatures. It takes several minutes to warm up the entire chamber fabric. This is observed by comparing the temperature of the chamber fabric that is taken inside the walls with the average inlet temperature with time.

The wall heat flux contributes significantly to the temperatures of the chamber medium due to mixed flow, while in stratified cases, larger temperature differences could be maintained in the chamber medium with little effect of the wall heat flux. This has an effect in the energy characteristics of the room. The outside temperature always affects the mean temperature of the interior. To better control the mean temperature of the chamber medium with as little as possible influence of the outside of the building and increase thermal efficiency, it can be done by maintaining thermally stratified environment in the chamber.

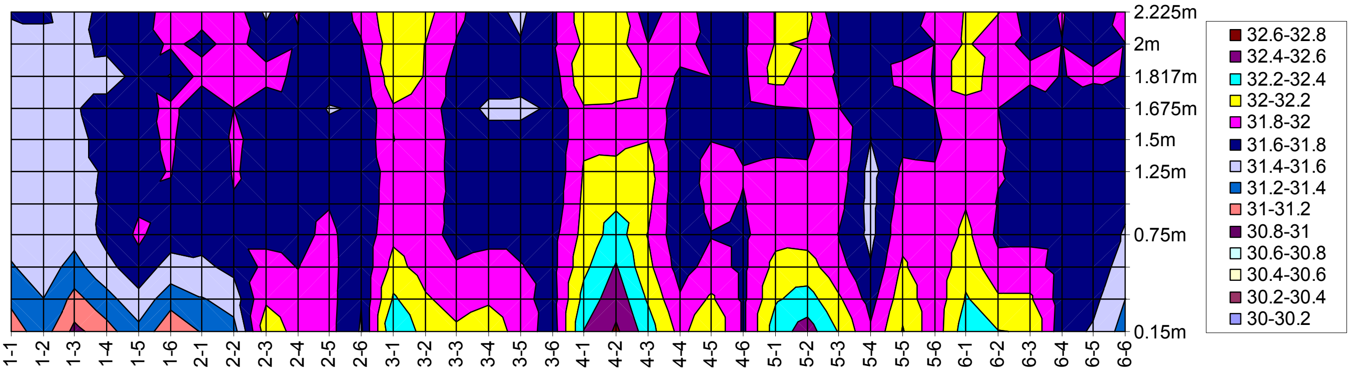


Figure 11: Temperature contour plot of section planes obtained for relatively small temperature difference form the supply outlets. The x-axis is reduced by a factor of 3. from the two air supplies of case study EXP01/EXP01-08-00.

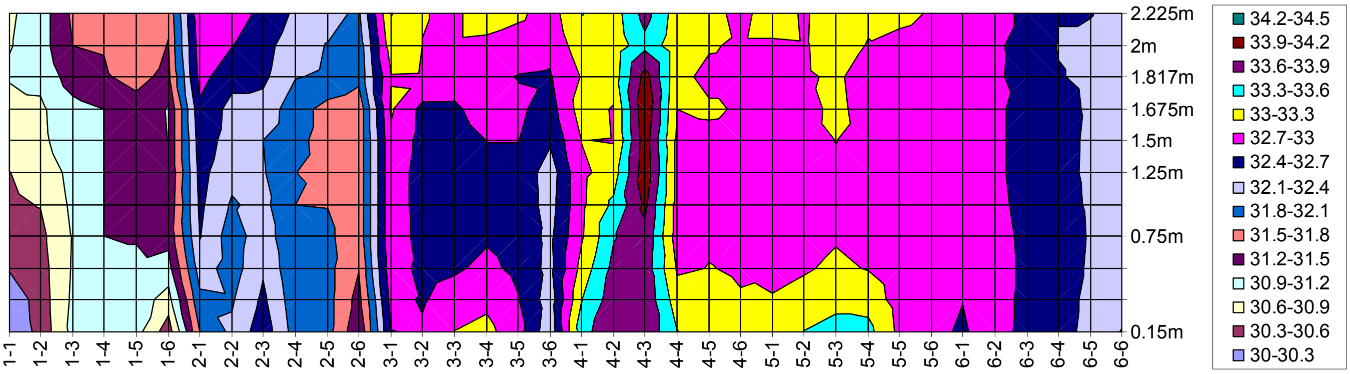


Figure 12: Temperature contour plot of section planes obtained for increased temperature difference of the supply outlets. The x-axis is reduced by a factor 3. Case study: EXP02/EXP04-08-00.

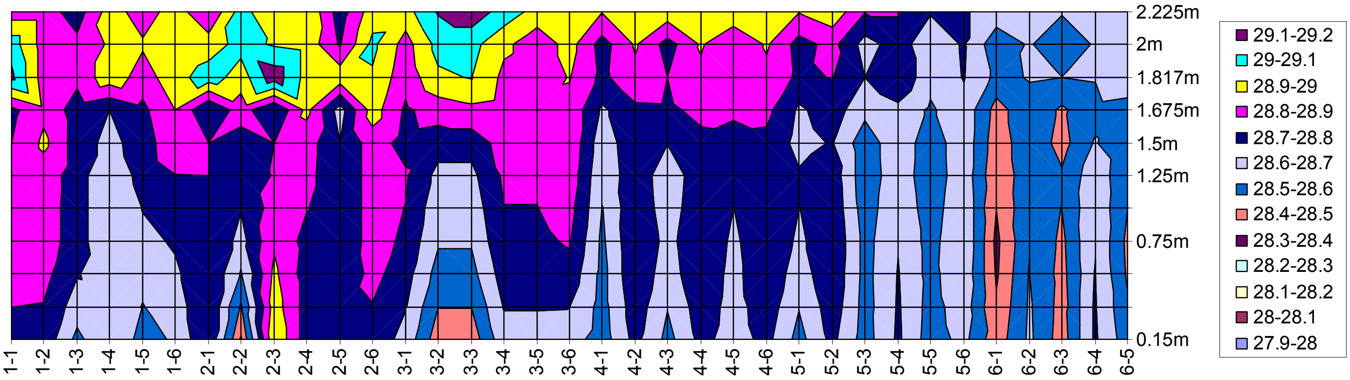


Figure 13: Temperature contour plot of section planes by using only the lower air supply and at smaller supply temperatures, $(T_{in})_{1/2}$. The x-axis is reduced by a factor of 3. Case study: EXP03/EXP06-08-00.

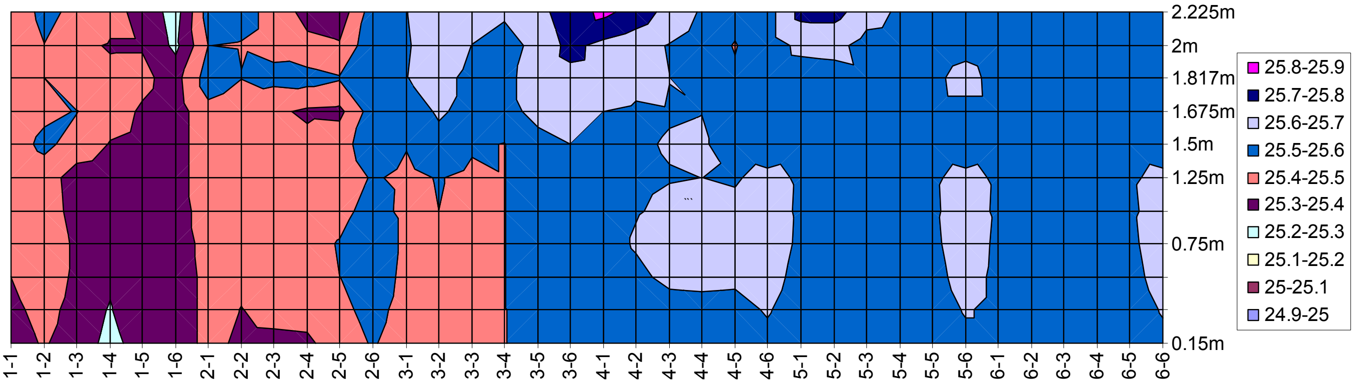


Figure 14: Temperature contour plot of section planes by using only the lower air supply at a further reduction in temperature, $(T_{in})_{1/2}$. The x-axis is reduced by a factor of 3. Case study: EXP08/EXP08-08-00.

2) EXP-14-11-00 Temperature changes with location and the effect solar heating on the chamber - parameters affecting the flow field

A hot air supply unit is now installed in the environmental chamber with control over the supply temperature to ±0.2°C and speed. The highest temperature that can be achieved at the setting point is 40°C.

The graph of surface temperature variation of the wall fabric inside the chamber obtained by Th.Set A in Figure A-2(2) shows that the temperatures of the chamber medium are affected by external heat gains. This is done by solar radiation from the windows.

The experimental configuration for the case studies in this experiment is shown in Figure 15,

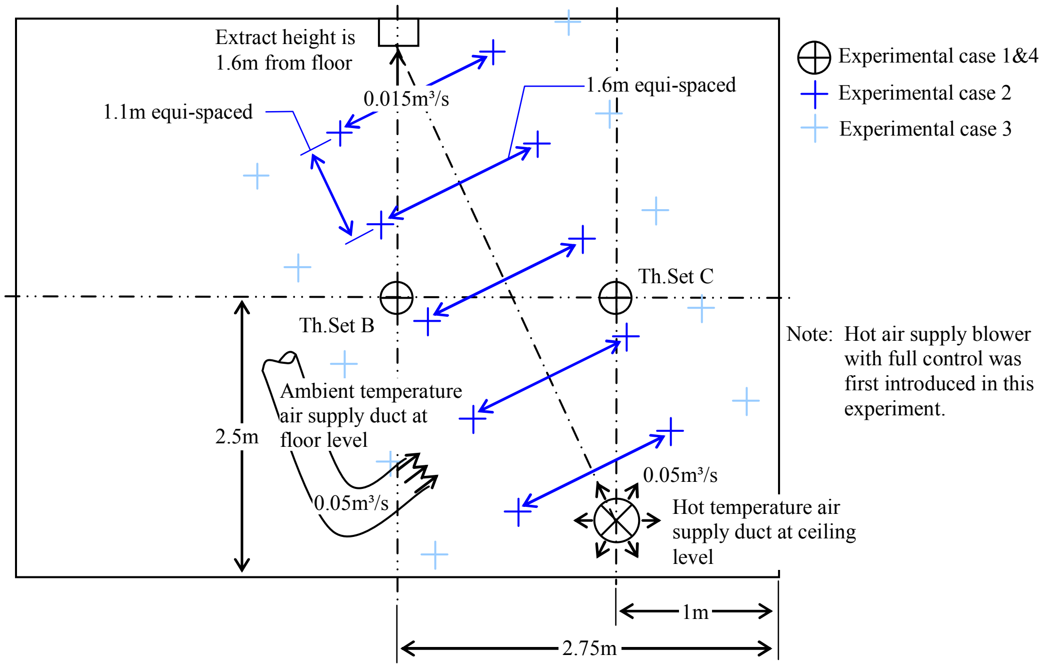


Figure 15: Experimental configuration for producing thermal stratification and with the effect of solar heat gains and measurement grid placed around the areas of interest, EXP-14-11-00.

The aim of this experiment is to see if the temperature distribution is similar with different location in the chamber as well as how much could the sunrays affect the internal temperature distribution. Air at the ambient temperature was used for creating thermal stratification.

The extract setting is low to minimise flow disturbance in the process of building up stratified layers, $(Q_{extr})_v$=0.015m³/s. A lower extract setting was chosen in order not to avoid any effect of the mechanically driven extract on the temperature distribution.

The input parameters to the following series of experiments are shown in Table 3 below,

	h_{extr} [m]	T_{lab} [°C]	T_{HS} [°C]	T_{CS} [°C]	Q_{HS} [m³/s]	Q_{CS} [m³/s]	Air changes per hour	ΔT_{in} [°C]	R_{BJ} [m⁻³]	τ^*_{HS}	τ^*_{CS}
EXP01	1.65	15.7	28.7	16.6	0.048	0.045	1.34×3ACH	12.1	0.965	10	9 2/5
EXP02	1.65	15.9	29	17.2	0.048	0.045	1.34×3ACH	11.84	0.944	5 7/8	5 1/2
EXP03	1.65	16.5	29.3	17.8	0.048	0.045	1.34×3ACH	11.5	0.89	3 1/2	3 2/7
EXP04	1.65	16.7	29.2	17.8	0.048	0.045	1.34×3ACH	11.4	0.714	3 1/2	3 2/7
									Data collection intervals EXP02,03	1 3/7	1 1/3

Table 3: Input parameters for experimental cases of EXP-14-11-00.

a) EXP01: Initial Temperature distribution in the middle of the chamber before solar gains take effect – T_{lab}=15.7°C

The aim of the experimental case here is to measure the initial temperature distribution of the chamber medium when the external heat gains are low. The inlet flow rates are supplied at a constant velocity and temperature. The inlet flow rate for the hot-temperature-air-jet is $(Q_{HS})_v$=0.05m³/s and the inlet temperature is T_{HS}=28.7°C. The inlet flow rate for the ambient-temperature-air-jet is $(Q_{CS})_v$=0.05m³/s and the inlet temperature is T_{CS}=16.6°C. The lab temperature is T_{lab}=15.7°C. These values are shown in Table 3. There were two temperature distributions obtained in this case which are presented in Figure A-2.

b) EXP02: Temperature distribution close to the inlet ducts and extract for continuous solar radiation effect – T_{lab}=15.9°C

The aim of this experimental case is to measure the temperature distribution of the chamber medium with increasing external heat gains. The inlet flow rates are supplied at constant velocity and temperature. The inlet flow rate for the hot-temperature-air-jet is $(Q_{HS})_v$=0.05m³/s and the inlet temperature is T_{HS}=29°C. The inlet flow rate for the ambient-temperature-air-jet is $(Q_{CS})_v$=0.05m³/s and the inlet temperature is T_{CS}=17.2°C. The lab temperature is T_{lab}=15.9°C. These values are shown in Table 3. There were 10 temperature distributions obtained in this case and they are presented in Figure A-2. The results obtained in this case are presented by the temperature contour plot in Figure 16.

c) EXP03: Temperature distribution further away from the ducts for stabilised solar gains effect – T_{lab}=16.5°C

The aim of this experimental case is to measure the temperature distribution of the chamber medium with stabilising external heat gains. The inlet flow rates are supplied at constant velocity and temperature. The inlet flow rate for the hot-temperature-air-jet is $(Q_{HS})_v$=0.05m³/s and the inlet temperature is T_{HS}=29.3°C. The inlet flow rate for the ambient-temperature-air-jet is $(Q_{CS})_v$=0.05m³/s and the inlet temperature is T_{CS}=17.8°C. The lab temperature is T_{lab}=16.5°C. These values are shown in Table 3. There were 10 temperature distributions obtained in this case which are presented in Figure A-2. The results obtained in this case are presented by the temperature contour plot in Figure 17.

d) EXP04: Final distribution in the middle of the chamber for decreasing heat gains – T_{lab}=16.7°C

The aim of this case study is to measure the temperature distribution of the chamber medium at the end of the experiment when the external heat gains are falling. The inlet flow rates are at the constant velocity and temperature set initially. The inlet flow rate for the hot-temperature-air-jet is $(Q_{HS})_v$=0.05m³/s and the inlet temperature is T_{HS}=29.2°C. The inlet flow rate for the ambient-temperature-air-jet is $(Q_{CS})_v$=0.05m³/s and the inlet temperature is T_{CS}=17.8°C. The lab temperature is T_{lab}=16.7°C. These values are shown in Table 3. There were two temperature distributions obtained in this case and they are presented in Figure A-2.

DISCUSSION

The temperature of the chamber fabric is influenced by the solar radiation during the pick hours in the day. The heat capacitance of the chamber fabric increases with solar heat gains. This is similar to the charging cycle of an electronic capacitor. The heat capacity of the fabric follows a similar curve, $T_{rad}e^{-t/\tau}$ and the amount of heat losses become positive increasing the total amount of heat into the chamber. Instead of the internal heat being lost due to heat conduction through the walls and radiation from the outer surface of the chamber to the surroundings of the lab, the opposite effect takes place. The radiative heat from the sun rays heats up the chamber fabric from the outside, it follows a conduction process through the fabric and radiates to the medium inside the chamber (NB. 10W/m².K convection coefficient inside buildings.

The temperature of the chamber increases linearly from 11:00 when the experiment started up to 12:47. The sun came out, but not entirely, it is blocked by some clouds and the sunrays are not aligned with the lab windows to hit on the outside of the chamber directly. A stable temperature is maintained. At 14:00, the effect of the solar radiation becomes much stronger. The top of the chamber at 1m above the windows became very bright. During this time, the temperature values are only slightly higher than the previous values and relatively stable. From 14:00 there is a strong solar radiation again, but at 14:50 the effect reduces as the sunrays are interfered by the clouds. The values of the temperature distribution increase with time because of the sunrays warming up the chamber from the outside. However, at 15:00 the sun becomes blocked until the end of the experiment, which is at 15:47. The temperature values drop but they are relatively stable. The range of values on the walls when the experiments started is much higher than at the end of the experiments. There is an increase of 1.3°C/2h in EXP02 at 1.7m (1.3°C below that and 0.3°C above that).

The magnitude of the hot air supply temperature increased by 0.7°C during the entire experiment. This happened because the control point is away from the chamber. However, these variations are small. Coarser control is applied on the temperature of the ambient-temperature-air-jet and as a consequence this maintains the same variations with the wall surfaces and the chamber medium. The wall surface temperatures were varied by approximately 1.3°C from 1.25m to 1.9m. Similar temperature distribution was obtained throughout the experiment with minor time-dependent variations of an average of ±0.2°C for EXP02 and ±0.3°C for EXP03 with the highest value below the ceiling, ±0.5°C. The deviation also increased slightly from the first case study to the next by ±0.1°C. The temperature in the upper layers changed by 1°C, while the magnitude of the lower layer (occupied zone) below the extract changed by 1.5°C. The temperature increase in lower layer from EXP01 to EXP02 is 0.3°C. There is an increase of 0.4°C in EXP02 and 0.5°C from EXP02 to EXP03. The increase becomes very small in EXP03 which is 0.2°C. Finally, there is a decrease of 0.1°C in EXP04 due to the reduction of the solar heat gains.

Flow features

The flow field is dominated by a thermal stratification similar to a case of displacement ventilation as shown in Figure 16 and Figure 17,

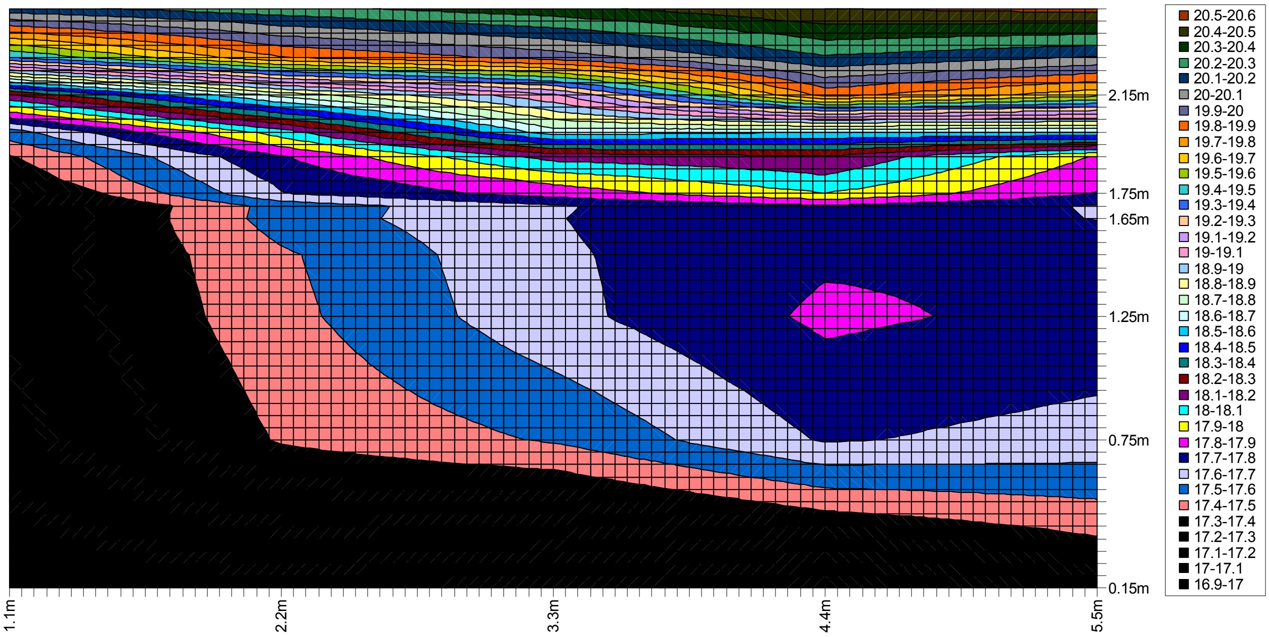


Figure 16: Temperature contour plot along the diagonal of the experimental configuration in the environmental chamber from the inlets to the extract. Stratified layers for experimental case EXP02, affected by increasing solar radiation. Note: each location corresponds to a different timing.

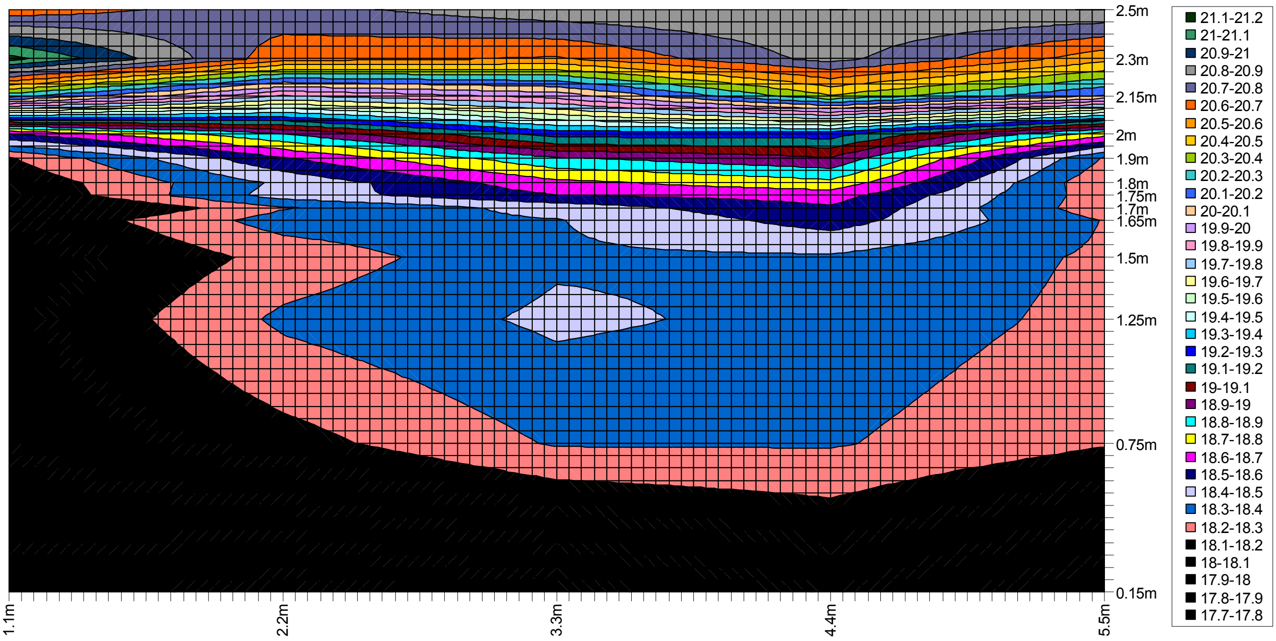


Figure 17: Temperature contour plot along the diagonal of the experimental configuration in the environmental chamber from the inlets to the extract. Stratified layers for experimental case EXP03, affected by stabilising solar radiation. Note: each location corresponds to a different timing.

Stratification is produced for a buoyancy-to-momentum ratio of $0.5<r<0.8$. Although it is customary to install the extract at the ceiling level in order to completely remove the stale, hot air from the upper levels in the room, it may not be energy efficient. The radiative temperature from the heated ceiling provides the room with a recycled heating system. Although this might not have a significant impact for a few hours of operation in a small room, for an industrial hall, the flow rate of the extract and the size may be critical in the energy consumption of the building.

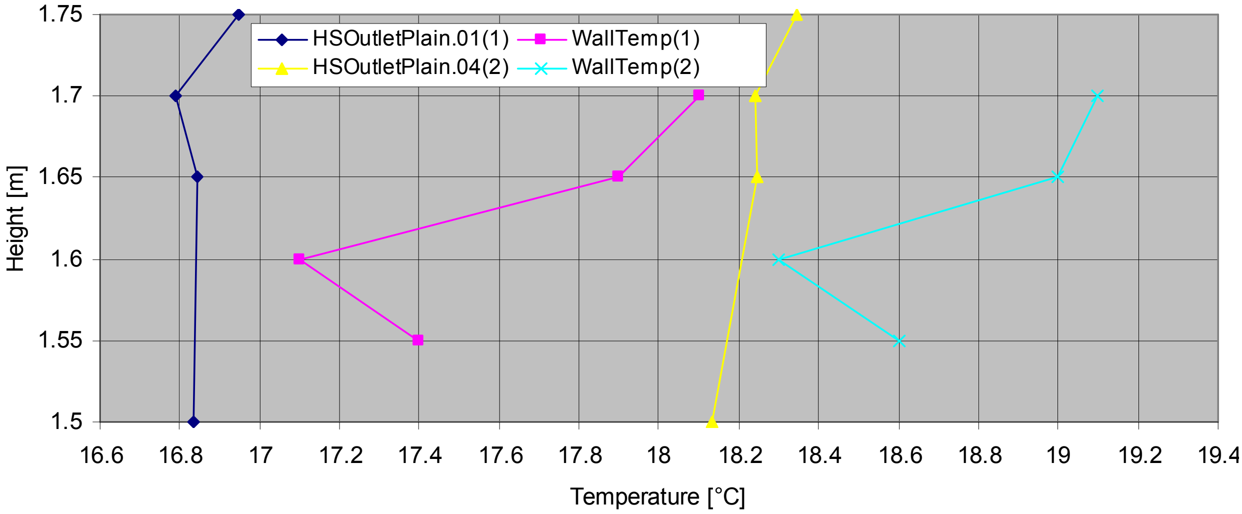
The extract in this case study did not make any obvious changes to the temperature distributions.

i) **Graph of extract height:**

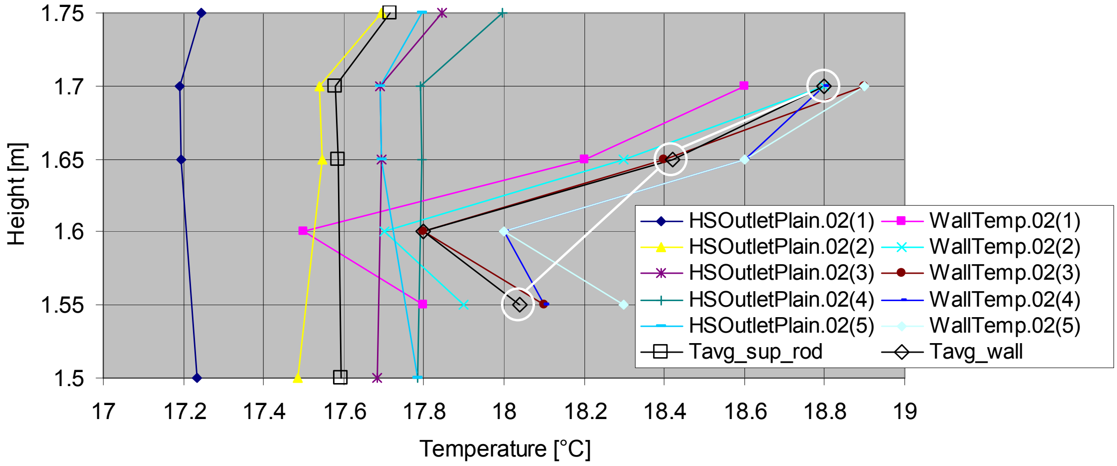
The wall temperatures are affected by the solar radiation which increased the temperature of the front and the right walls. At the extract height, which is at 1.6m, the temperature of the extract is the same as the thermocouple of the back wall. This wall is not affected by the solar radiation. Likewise, the supported ceiling below the chamber ceiling is not affected by the solar radiation either. The temperatures are maintained almost the same. This is because of the thermal stratification of the medium inside the chamber. The same, however, does not occur in the lower zone which experiences similar temperature increase with the walls, 1.3°C.

ii) **Wall surface temperatures:**

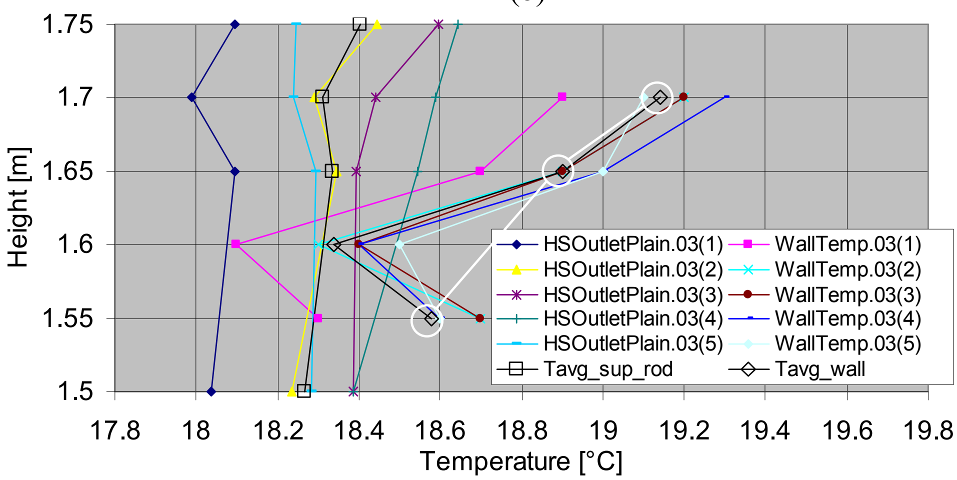
The wall temperature is the primary variable that describes the heat gains or losses through the wall fabric into and out of the chamber. This is very interesting because it reflects to the integrity of the testing facility and repeatability of the experiments. The temperatures of the wall surfaces inside the chamber in comparison with the temperatures of the chamber medium are shown in Figure 18 below,



(a)



(b)



(c)

Figure 18: Comparison between wall temperatures and chamber medium temperatures at the same heights for EXP-14-11-00. In (a), case studies EXP01 and EXP04, i.e., initial case and final case. In (b), case study EXP02, increasing solar radiation effect. In (c), case study EXP03, stabilising solar heat gains.

The temperature of the wall fabric is higher than the temperature of the chamber medium. The slope of the wall temperatures is higher in EXP02, because of increasing solar radiation, as shown in Figure 18 (b). However, this decrease for the case of stabilising solar heat gains, EXP03, which also follows an increase in the temperatures of the chamber medium is shown in Figure 18 (c). The temperature of the back wall is the only value that stays approximately the same as the temperature of the chamber medium, which is more obvious in the latter case. This is because the wall façade is used to reduce the size of the chamber and it is not directly affected by the solar radiation effect.

iii) Efficiency

Although the supply temperature set for the ambient and the hot temperature air supplies were set to provide a temperature difference of approximately, $(\Delta T_{set})_{in}$=40°C at the setting points, the actual average output temperature difference delivered by the outlets was three times smaller, $(\Delta T_{max})_{in}$=12°C. The outside temperature is close to 0°C. Any amount of extra heat value obtained from the experiment would be due to solar radiation.

3) <u>EXP-30-11-00 Hot-temperature-air-jet at T_{set}=25°C</u>

The aim of this experiment is to see the effect of the downward oriented duct of the hot-temperature-air-jet for a relatively low ΔT_{in}. The experimental configuration for this experiment is shown in Figure 19,

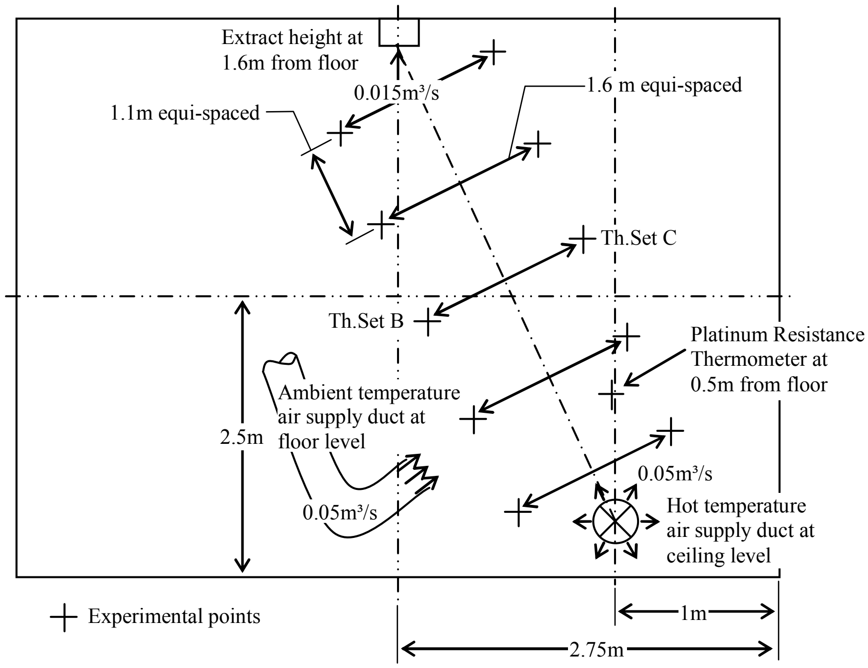


Figure 19: Experimental case for plain hot-temperature-air-supply outlet configuration and measurement grid placed around the areas of interest. Experiment: EXP-30-11-00.

Similar to the previous experiment, a low extract setting is used to minimise flow disturbance to the temperature distribution, $(Q_{extr})_v$=0.015m³/s.

DISCUSSION

The results of this experiment are presented by a temperature contour plot in Figure 20,

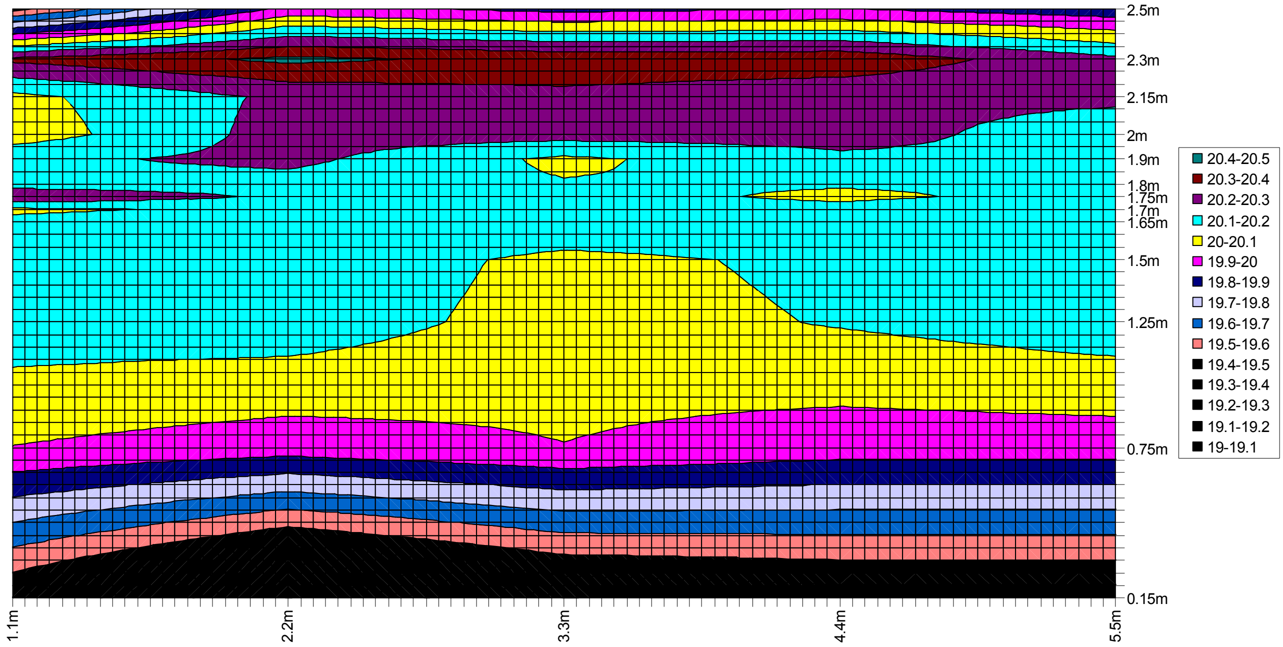


Figure 20: Temperature contour plot along the diagonal of the experimental configuration in the environmental chamber from the inlets to the extract. Stratified layers in experimental case for a lower hot temperature air supply, T_{set}=25°C.

The temperature of a large hot air region below is mixed due to the low hot air temperature. However, looks as if the thermal stratification has moved closer to the floor. This could be an effect from the smaller buoyancy-to-momentum ratio associated with the low supply hot air temperatures.

i) <u>Wall surface temperatures:</u>

There is a small temperature rise due to the small increase in the hot air supply temperature. That was recorded at the height of 1.7m to 1.9m only in the first section, equal to 0.3°C from Th.Set B and C. This is recorded as 0.4°C from Th.Set A.

Nevertheless, the temperature remains constant in the next 4 sections.

In contrast to the previous experiment, the wall temperatures are increasing due to the heat value obtained from the chamber medium. This is shown in Figure 21,

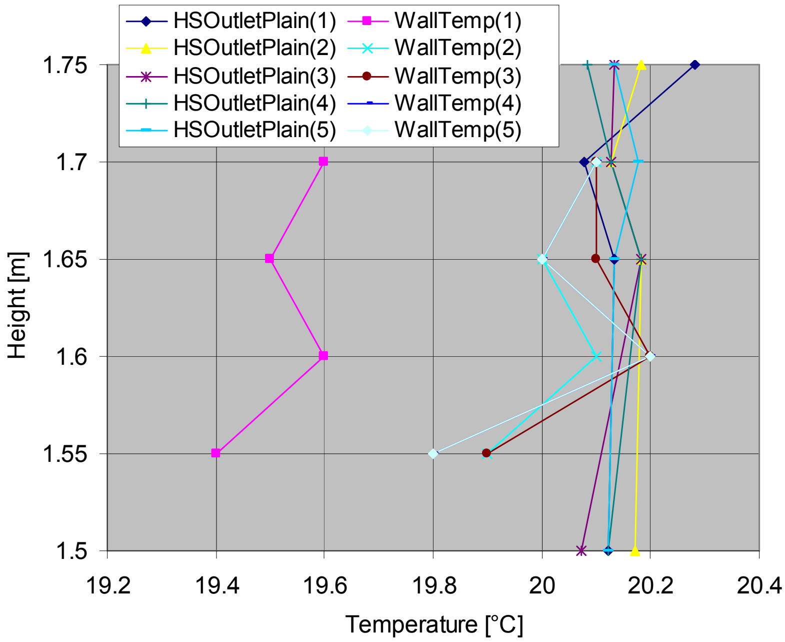


Figure 21: Comparison between wall temperatures and chamber medium temperatures at the same heights for EXP-30-11-00.

There are heat losses through the walls and this is shown from Figure A-3 (a). The external, lab temperature remains almost constant because the lab volume is 3 times larger than the chamber volume (5 times when considering the reduced space only). The temperature on the other side of the wall façade increases with respect to the surface temperature on the other side of the wall.

ii) <u>Graph of extract height:</u>

Similar to the previous experiment, the extract temperature is almost identical to the temperature of the back wall at 1.6m. The temperatures of the other walls are almost equal as expected due to mixing at that height, except at the door that is ~0.2°C lower than the rest of the walls. This is because this thermocouple is located at 1.55m and although the temperature suggests a constant temperature due to mixing, there is still a small stratification. In addition to that, opening the door has also affected its temperature. The outside temperature is ~2°C less than the temperature of the inside at the same height. The temperature of the other walls are also smaller than expected by ~0.1°C. For this reason, the wall temperature seems to be smaller than the temperature of the extract at 1.6m.

4) EXP-01-12-00 Hot-temperature-air-jet at T_{set}=30°C plain and carton below the hot air supply configuration (continuation of 30-11-00)

A plain hot-temperature-air-supply outlet configuration was used as an initial case to compare with a deflector outlet configuration for a higher ΔT_{in} than in the previous experiment. A carton deflector was used at 20cm height under the hot-temperature-air-supply outlet to reduce the impingement height in order to observe any difference on the temperature distribution due to reduced mixing effect of the jet with height.

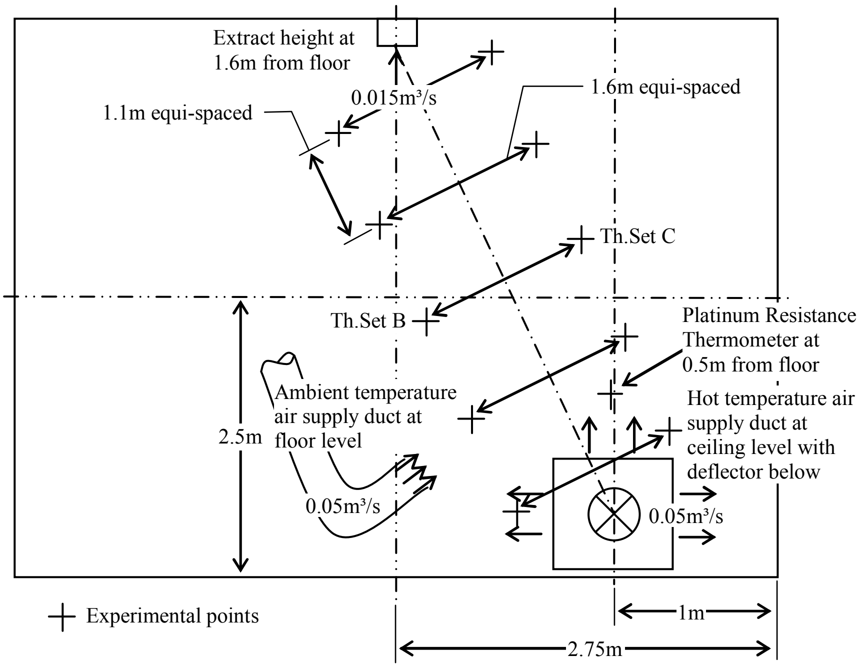


Figure 22: Experimental configuration for deflector hot temperature air supply outlet configuration and measurement grid placed around the areas of interest. Experiment: EXP-01-12-00.

Similar to the previous experiment, a low extract setting is used to minimise flow disturbance to the temperature distribution, $(Q_{extr})_v$=0.015m³/s.

DISCUSSION

The results from the case study on the plain hot-temperature-air-supply outlet configuration EXP01 are presented by a temperature contour plot in Figure 23,

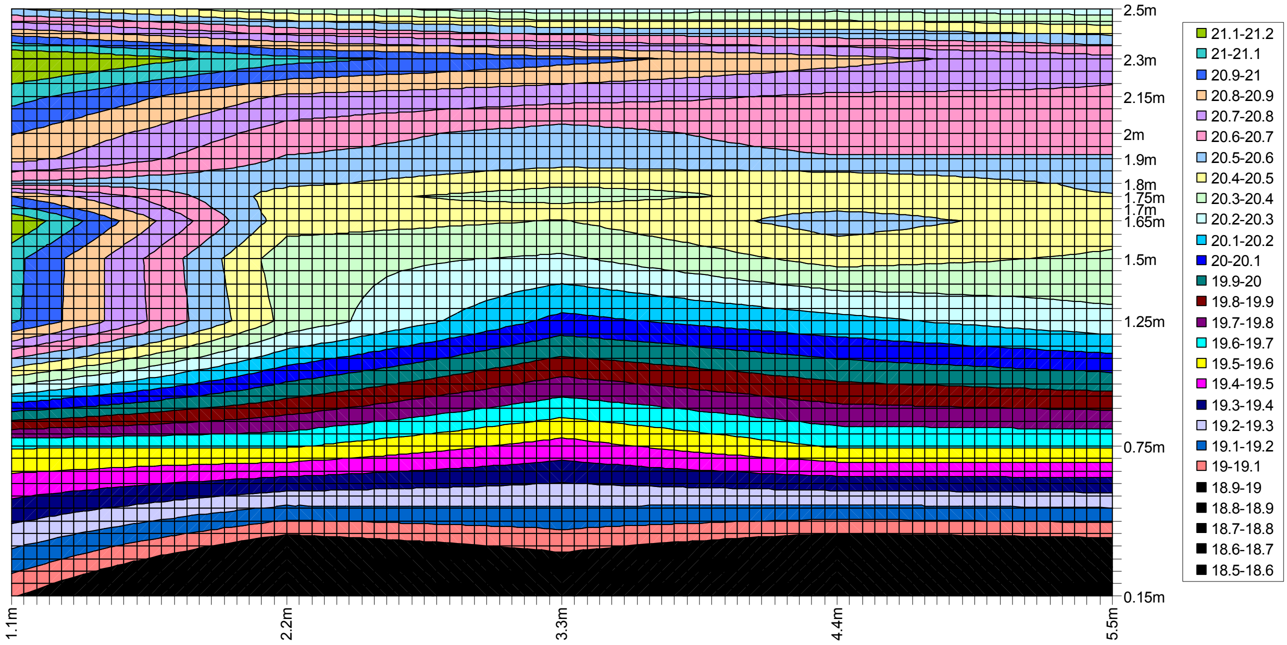


Figure 23: Temperature contour plot along the diagonal of the experimental configuration in the environmental chamber from the inlets to the extract. Stratified layers in experimental case for plain hot temperature air supply outlet configuration, T_{set}=40°C.

Although the temperature of the hotter region is mixed because of the hot-temperature-air-jet there is still thermal stratification.

The results for the deflector outlet case EXP02 are presented by a temperature contour plot in Figure 24,

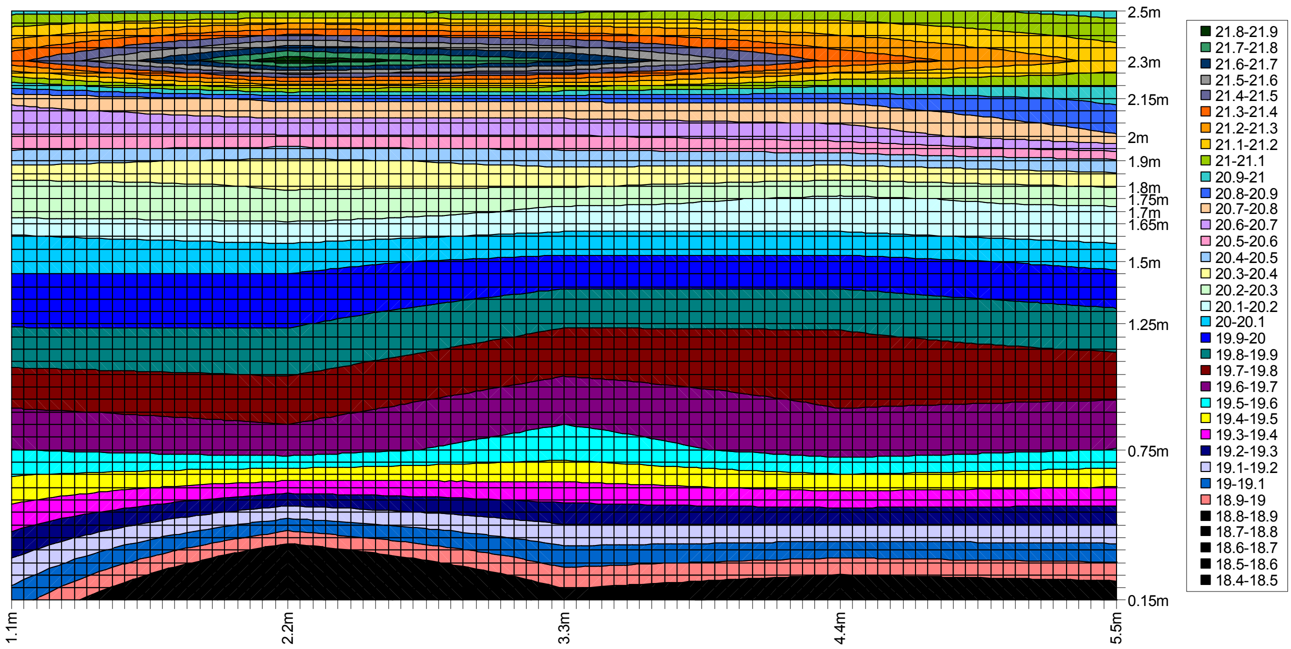


Figure 24: Temperature contour plot along the diagonal of the experimental configuration in the environmental chamber from the inlets to the extract. Stratified layers for experimental case with carton below the hot-temperature-air-jet, T_{set}=40°C.

The hot-temperature-air-jet in this case does not affect the hot air region and there is much more thermal stratification that in case study EXP01.

Looking at the changes that occur between the two temperature distributions with room height, the temperature characteristics in both case studies EXP01 and EXP02 stay the same. Hence, irrespective of the direction of the jet, the temperature distribution is modified in such a way so that the heat distribution stays the same in the entire room.

i) Wall surface temperatures:

By comparing the values obtained in EXP02 with EXP03, it can be seen that the accuracy is especially good. The temperature differences between Th.Set B, C and Th.Set A are very consistent. In the case of plain hot-temperature-air-supply outlet configuration the temperature by Th.Set A, B and C at 1.6m is 20.5°C. In the case of hot-temperature-air supply outlet with deflector configuration, the temperature is the same at 1.6m by all readers again, which is equal to 20.1°C.

The wall surface temperature is seen to be reaching the point of stabilisation in the case study EXP02 in Figure 25 (a). This is more evident with the value of the wall surface at 1.55m obtained from the thermocouple on the front wall. The wall surface temperatures in case study EXP03 in Figure 25 (b) show that the temperatures have achieved the same values as the chamber medium.

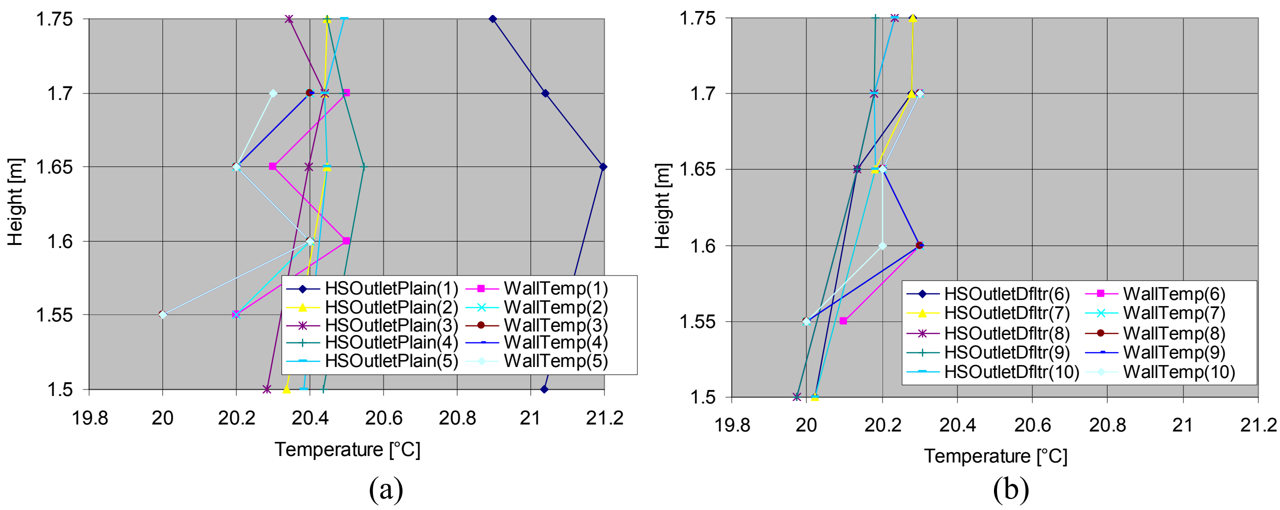


Figure 25: Comparison between wall temperatures and chamber medium temperatures at the same heights for EXP-01-12-00. In (a), plain hot temperature air supply outlet configuration. In (b), configuration of carton deflector positioned at 20cm perpendicularly below the outlet of the hot air supply.

The wall temperature at the fist measurement point between the wall surface of the chamber and the chamber medium in Figure 25 shows that there is a disparity of 0.6°C in the values. The contours in Figure 23 show that the hot-temperature-air-jet is not buoyed to the height of the interface. The corresponding temperature distribution if compared with the rest of distributions of the same case, and other sets of distributions obtained from similar cases in this work, such as experiment EXP-14-11-00 and measurements close to the walls in EXP-11-12-00, the disparity is not present. Looking at results obtained a little later in this work, also show this disparity but to a lesser extent. This shows that because the measurement at that location was taken a little earlier, there was not enough time for the chamber to stabilise completely and the jet to receive enough damping from the buoyancy field.

ii) Graph of extract height:

Although the extract temperature is the same as the temperature of the same height on the thermocouple support-rod in both data sets, at 1.6m, all temperature values are very close. This is because there is only 0.8°C of thermal stratification at the height of the thermocouples and the difference between the inside and the outside temperature is only ~1°C. Additionally the temperature differences between 1^{st} and the 2^{nd} data sets is less than >0.5°C.

5) EXP-05-12-00 High inlet speed of hot-temperature-air-jet – 2SD

This experiment was performed to achieve the highest possible temperature difference across the height of the room. The experimental configuration of this experiment is shown in Figure 26,

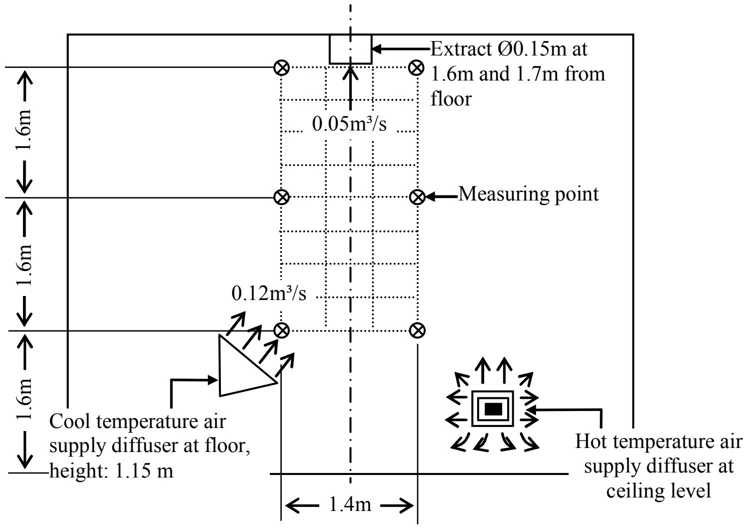


Figure 26: Experimental configuration during experiment of high inlet speed of hot-temperature-air-jet and measurement grid around the areas of flow disturbance, EXP-05-12-00.

A 4-way ceiling air diffuser is introduced at the hot-temperature-air-supply outlet. The size of the outlet face of the diffuser is reduced down to 2 square slots. The extract setting is higher than the previous cases because of the higher supply flow rates, $(Q_{\mathrm{extr}})_v$=0.05m³/s.

The input parameters are shown in Table 4,

	h_{extr} [m]	T_{lab} [°C]	T_{HS} [°C]	T_{CS} [°C]	$(Q_{HS})_v$ [m³/s]	$(Q_{CS})_v$ [m³/s]	Air changes per hour	R_{BJ} [m⁻³]	τ_{HS}^*	τ_{CS}^*
EXP01	1.6	20.43	26	16.3	0.065	0.064	2.3×3ACH	2.522	13 3/5	13 2/5
EXP02	1.6	20.33	32.5	8.2	0.065	0.064	2.3×3ACH	2.724	5	5
EXP03	1.7	20.1	32.4	8.3	0.065	0.064	2.3×3ACH	2.869	3 2/5	3 2/5
EXP04	1.7	20.02	32.3	8.3	0.1	0.064	2.9×3ACH	1.236	5 1/5	3 2/5
EXP05	1.6	20.23	32.1	8.2	0.1	0.064	2.9×3ACH	1.281	5 1/5	3 2/5
								Data collection intervals EXP01-03	1 2/3	1 2/3
								EXP04,05	2 3/5	1 2/3

Table 4: Input parameters for the case studies in EXP-05-12-00.

a) EXP01: Perforated diffusers – h_{extr}=1.6m,T_{lab}=18°C

The aim of this case study is to produce thermal stratification with practical-to-make diffusers. In this case study, two perforated plastic bags were used tighten firmly on the outlets of the hot-temperature-air-supply duct and the cool-temperature-air-supply duct. The flow rate before the blockage effect from the perforated diffusers of the hot-temperature-air-supply outlet is $(Q_{\mathrm{HS}})_v$=0.07m³/s and cooler, ambient-temperature-air-supply outlet is $(Q_{CS})_v$=0.07m³/s. The flow rate after the hand-made diffusers is around Q_v=0.01-0.015m³/s. The extract height is h_{extr}=1.6m. The lab temperature in this case is T_{lab}=18°C. These values are shown in Table 4.

b) EXP02: High inlet speed of hot temperature air supply HSK4 – Ceiling & floor diffuser, h_{extr}=1.6m,T_{lab}=18.8°C

The aim of this case study is to produce thermal stratification for a larger inlet temperature range by reducing the outlet blockage. This was done by using air terminals similar to those provided by ventilation suppliers. These terminals were made available for testing the performance characteristics in the environmental chamber. The same inlet parameters were used in this case as in the previous experimental case. The ceiling air diffuser is a commonly used air terminal in office rooms that was used in this case to provide the chamber with air at a hotter temperature than the ambient room temperature. To keep the temperature of the room at a desirable level, a displacement-type floor air diffuser was used. The flow rate of the hot-temperature-air-supply outlet is $(Q_{HS})_v$=0.07m³/s. The flow rate of the cooler, ambient-temperature-air-supply outlet is $(Q_{CS})_v$=0.07m³/s. The extract height is h_{extr}=1.6m. The lab temperature in this case is T_{lab}=18.8°C. These values are shown in Table 4. The results obtained in this case are presented by a temperature contour plot in Figure 27.

c) EXP03: High inlet speed of hot temperature air supply HSK4 – Ceiling & floor diffuser, h_{extr}=1.7m,T_{lab}=18.25°C

The aim of this case study is to observe any changes on thermal stratification when changing the extract height. The height of the extract was raised to h_{extr}=1.7m. Similar to the previous case, this test was run with both diffusers and with the same inlet parameters as the previous two cases. The flow rate of the hot-temperature-air-supply outlet is $(Q_{HS})_v$=0.07m³/s. The flow rate for the cooler, ambient-temperature-air-supply outlet is $(Q_{CS})_v$=0.07m³/s. The lab temperature in this case is T_{lab}=18.25°C. These values are shown in Table 4.

d) EXP04: High inlet speed of hot temperature air supply HSK6 – Ceiling & floor diffuser, h_{extr}=1.7m,T_{lab}=18°C

The aim of this case study is to observe the changes on thermal stratification by changing the inlet flow rate while keeping the extract the same as the previous case. The flow rate of the hot-temperature-air-supply outlet is $(Q_{HS})_v$=0.1m³/s. The flow rate for the cooler ambient-temperature-air-supply outlet is $(Q_{CS})_v$=0.07m³/s. The extract height is h_{extr}=1.7m. The lab temperature in this case is T_{lab}=18°C. These values are shown in Table 4.

e) EXP05: High inlet speed of hot temperature air supply HSK6 – Ceiling & floor diffuser, h_{extr}=1.6m,T_{lab}=18.15°C

The aim of this case study is to observe any changes on thermal stratification by changing the extract to the original height for the current setting of the hot-temperature-air-supply flow rate. The extract height is h_{extr}=1.6m. The flow rate of the hot-temperature-air-supply outlet is $(Q_{HS})_v$=0.1m³/s. The flow rate of the cool-temperature-air-supply outlet is $(Q_{CS})_v$=0.05m³/s. The lab temperature in this case is T_{lab}=18.15°C. These values are shown in Table 4.

DISCUSSION

The result of EXP01 is that the temperature of the hot-temperature-air-supply outlet was reduced and the temperature of the cold-temperature-air-supply outlet was increased, reducing the overall temperature range of this experiment. This is shown in Figure A-5.

The results obtained form case study EXP02,03 and EXP04,05 are shown in the contour plot of Figure 27 and Figure 28 respectively,

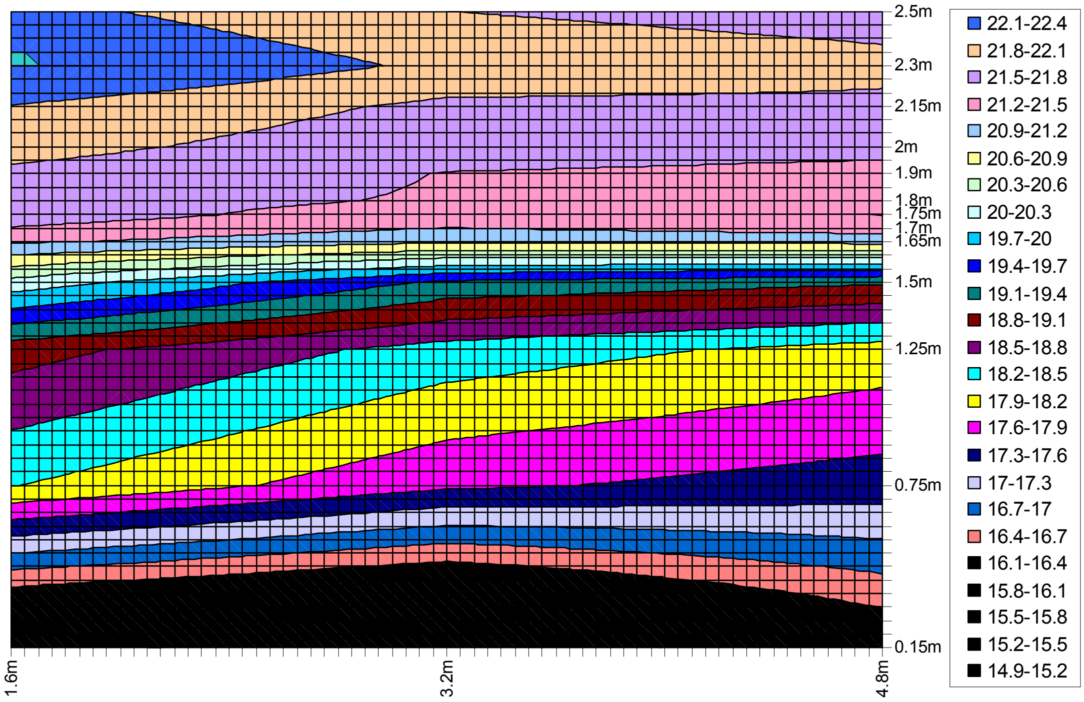


Figure 27: Temperature contour plot along the middle plane of the experimental configuration in the environmental chamber from the inlets to the extract. Stratified layers for experimental case EXP02 (EXP03 is similar) show the influence of high supply flow rates but also high supply temperatures.

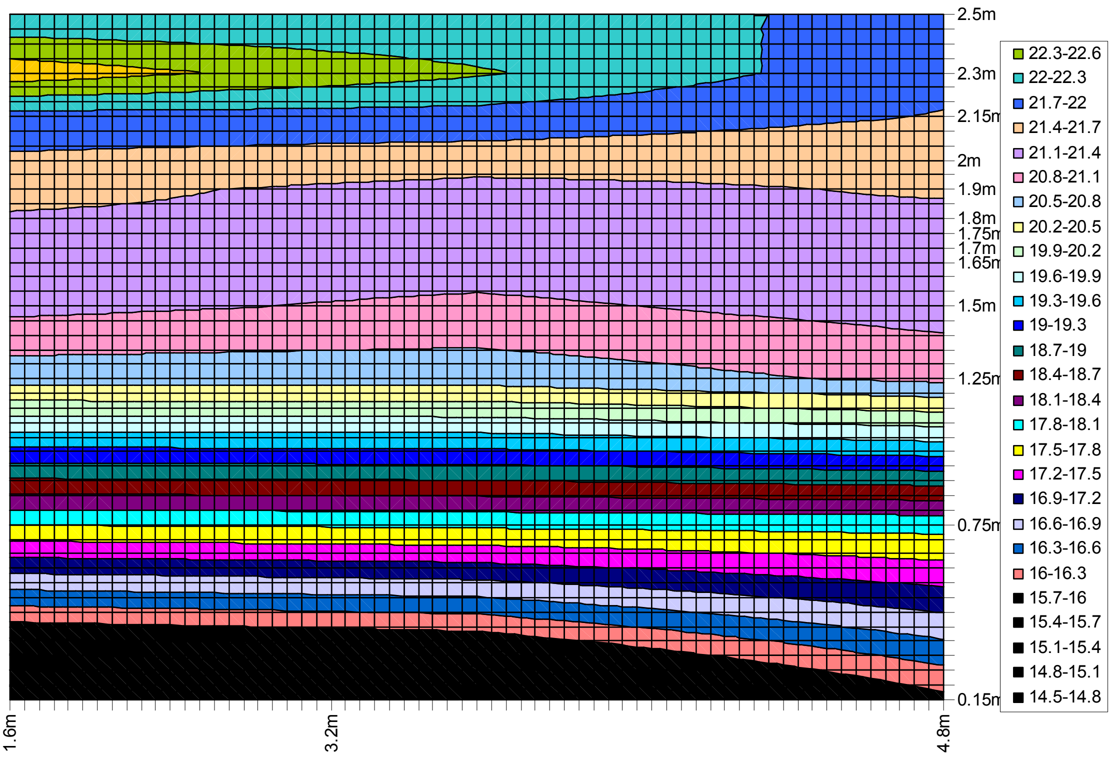


Figure 28: Temperature contour plot along the middle plane of the experimental configuration in the environmental chamber from the inlets to the extract. Stratified layers for experimental case EXP05 (EXP04 is similar) show the influence of high supply flow rates but also high supply temperatures.

In the case study EXP02 and EXP03, the isotherms are higher than in the case study EXP04 and EXP05. The isotherms are also thicker at higher levels. In that region, the temperature distribution is small due to mixed flow. Since in EXP04 and EXP05 the inlet flow rate is higher by a factor of two, this region is thicker than in the cases EXP02 and EXP03.

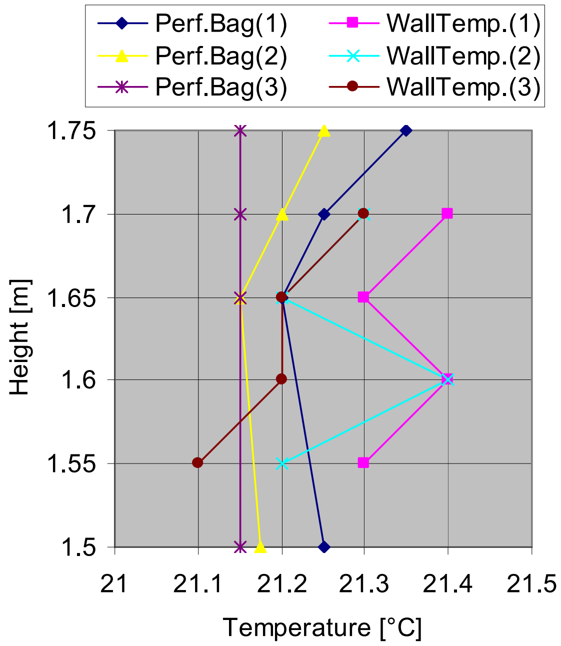
i) **Wall temp.'s and reference temperature:**

The difference in the mean temperature distributions of EXP02 and the EXP03 are attributed to the slight change of the lab temperature outside the chamber. Not in the change made to the extract height. The average lab temperature is 18.25°C in EXP02 which is equal to the temperature inside the chamber around mid-height (~1.3m). The average lab temperature in EXP03 is 18.8°C. The difference in the temperature of the chamber medium is around 0.55°C, which is the same as the increase in the lab temperature (i.e., similar to EXP-14-11-00). When this value is added on the mean distribution of EXP02, it matches the distribution of EXP03 with negligible difference. Additionally, the distribution of EXP04 and EXP05 match each other, in which cases the lab temperatures stay constant.

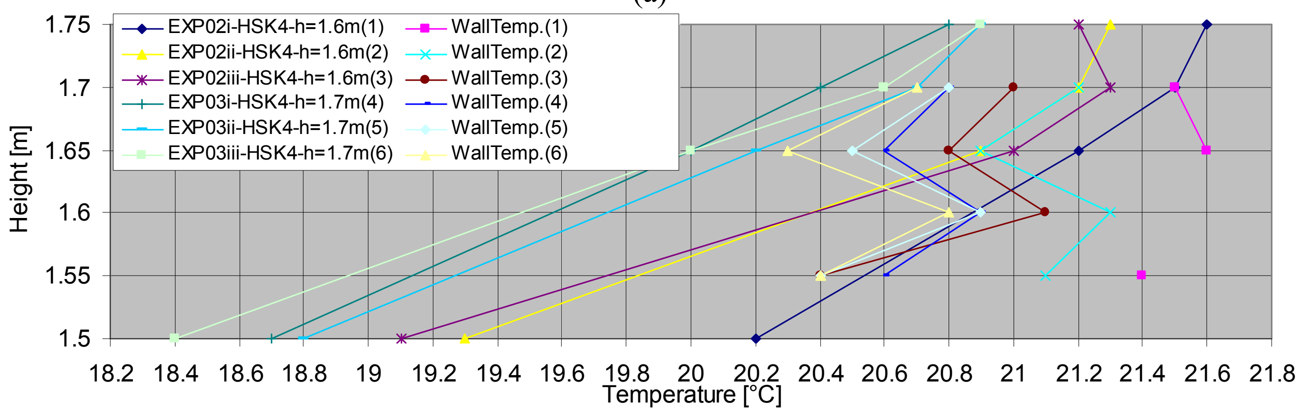
The wall temperatures are a little higher than the temperatures of the chamber at the same height. This occurs in the cases EXP02 and EXP03, where the external temperatures changed by 1°C. This could have probably happened from solar radiation, the time and magnitude is similar to the experiment EXP-14-11-00 on the effect of solar radiation. Although the sunrays warm up the chamber until 14:00, the air temperature is still low and gets lower as the time progresses.

In the next two cases, EXP04 and EXP05, the front wall (door) temperature is affected because the hot air terminal is close to the front wall which results in the hot air jet washing down on the door. The temperature of the left wall and right wall are lower than the extract temperature because it is affected by the lower external temperatures.

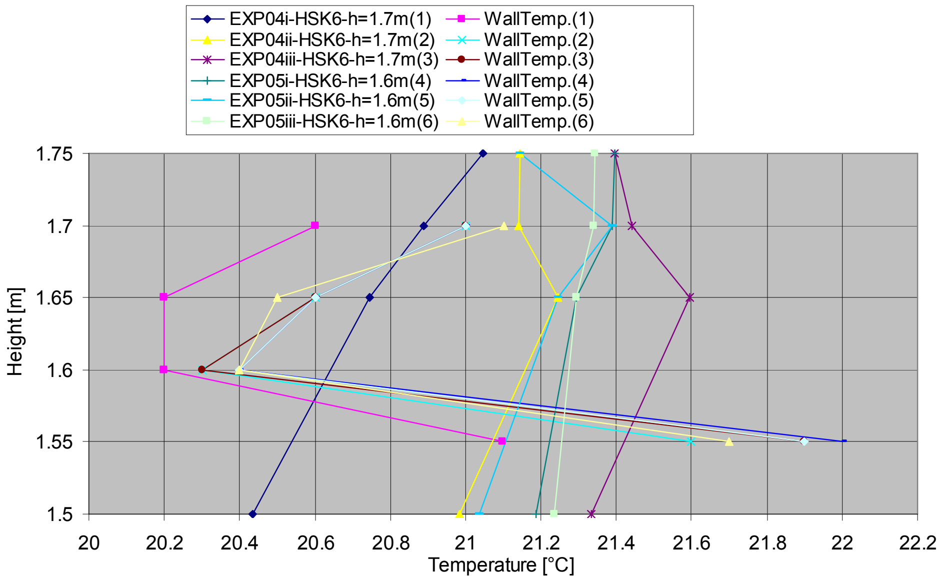
A comparison between wall and chamber medium temperatures is presented in Figure 29,



(a)



(b)



(c)

Figure 29: Comparison between wall temperatures and chamber medium temperatures at the same heights for EXP-05-12-00. In (a) case study with perforated bag at the outlet ducts. In (b), case study of high inlet flow rates. In (c), case study of higher flow rates.

ii) Extract height:

In the case of the perforated bag, EXP01, all thermocouples show close temperature values because of the mixing and the reduced inlet parameters. The temperature of the extract in EXP01 is a little higher than at the same level. This implies that the extract "prefers" fluid from a little higher level in the room. This is illustrated in Figure 30,

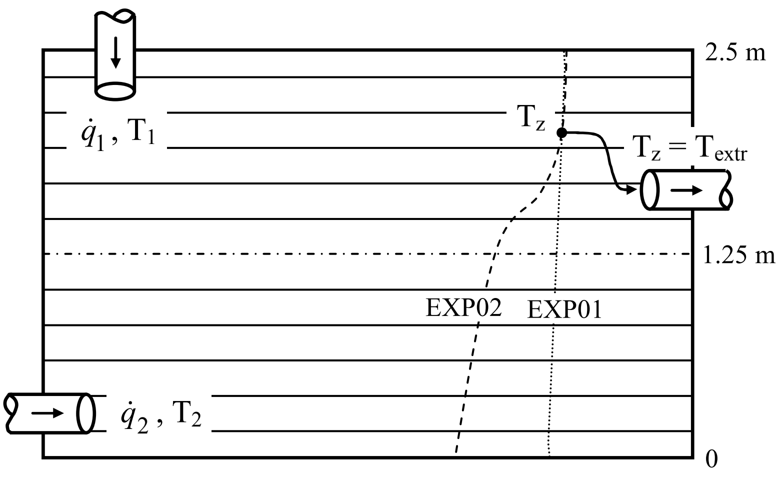
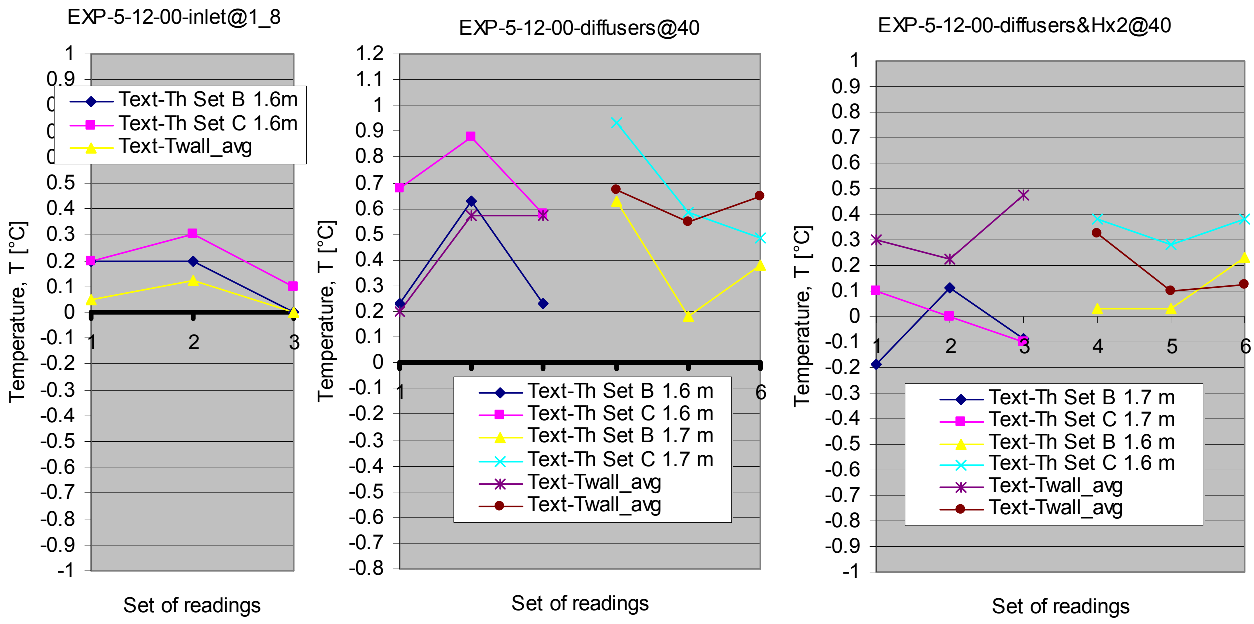


Figure 30: Temperature distribution across the height of the entire room becomes uniform for certain configuration of supply outlet and inlet parameters.

A comparison between extract, wall and chamber medium temperatures is shown in Figure 31,



(a) (b) (c)

Figure 31: Temperature differences between extract versus chamber medium and wall fabric, EXP-5-12-00.

The main conclusion here is that when the thermal stratification is weak, the temperature at the extract tends to become higher. This is because of selective withdrawal of the fluid. The ratio of dT/dz is small and therefore the buoyancy force is small to keep the extraction of the air at the preset level. Thinner air from the top layers is of a smaller viscosity and therefore, there is less friction than the lower more viscous fluid. Hence, the selective withdrawal of fluids in liquids is seen to occur in gases too. This will also be seen to occur in EXP-11-12-00, but for a relatively high extract rate.

6) EXP-08-12-00 High hot-temperature-air-jet speed and effect of lights – 2SD

Several tests are taking place to check whether a higher difference in Temperature is achieved between the upper and the lower zone by only changing the flow rates. The experimental configuration for this experiment is shown in Figure 32,

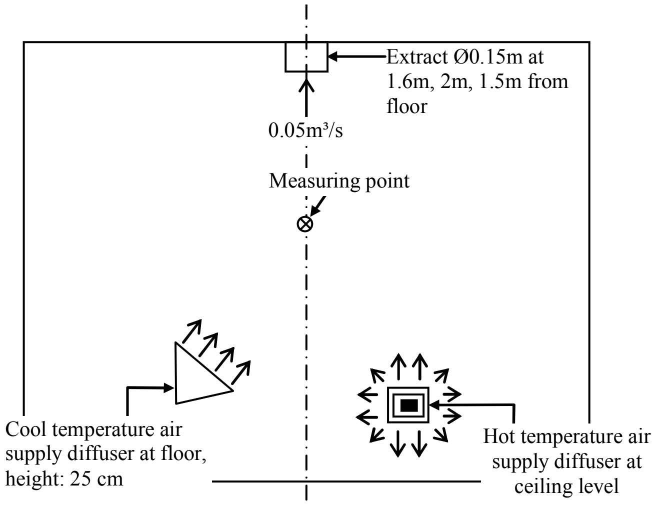


Figure 32: Experimental configuration during experiment of low and high inlet speed of hot-temperature-air-jet, EXP-08-12-00.

Similar to the previous experiment, the size of the outlet face of the hot-temperature-air-diffuser is reduced down to 2 square slots. The face area of the floor air-diffuser was also reduced. The extract setting is also the same as in the previous experiment because of the higher supply flow rates, $(Q_{\mathrm{extr}})_v$=0.05m³/s.

The input parameters are shown in Table 5,

	h_{extr} [m]	T_{lab} [°C]	T_{HS} [°C]	T_{CS} [°C]	$(Q_{\mathrm{HS}})_v$ [m³/s]	$(Q_{\mathrm{CS}})_v$ [m³/s]	Air changes per hour	R_{BJ} [m⁻³]	τ_{HS}^* [min]	τ_{CS}^* [min]
EXP01	1.6	18.1	33.2	14.4	0.0346	0.026	1.1×3ACH	5.9822	11	8
EXP02i	2.2	18.1	32.2	14.7	0.0693	0.026	1.7×3ACH	1.2742	3 3/5	1 1/3
EXP02ii	2.2	18.1	32	15	0.1039	0.026	2.3×3ACH	0.482	5 2/5	1 1/3
EXP02iii	2.2	18.1	32.2	15.3	0.1385	0.026	2.9×3ACH	0.2237	7 2/7	1 1/3
EXP02iv	2.2	18.1	32.3	15.6	0.1731	0.026	3.5×3ACH	0.1685	9	1 1/3
EXP03	2.2	18.25	32.1	12.4	0.1039	0.106	3.7×3ACH	0.7486	11	11
EXP04	1.5	18.25	33.3	9.8	0.039	0.144	3.2×3ACH	7.2212	4	15
EXP05	1.5	18.55	33.1	9.05	0.039	0.064	1.8×3ACH	7.7126	1	1 2/3
							Data collection intervals	EXP01	5 2/5	1 1/3
								EXP02	3 3/5	1 1/3
								EXP05	1	1 2/3

Table 5: Input parameters for case studies in EXP-08-12-00.

a) EXP01: Low hot air supply flow rates

The aim of this experimental case is to study the effect of extract height. The flow rate of the hot-temperature-air-supply outlet is $(Q_{HS})_v$=0.04m³/s. The flow rate of the cool-temperature-air-supply outlet is $(Q_{CS})_v$=0.03m³/s. The extract height is h_{extr}=1.6m. The lab temperature in this case is T_{lab}=18.1°C. These values are shown in Table 5.

b) EXP02: Increasing hot air supply flow rates

The aim of this experimental case is to study the effect of increasing the flow rate of the hot-temperature-air-supply. The error deviation in these cases is much higher than any other case. The flow rate of the hot-temperature-air-supply outlet is $(Q_{HS})_v$=0.07m³/s. The flow rate of the cool-temperature-air-supply outlet is $(Q_{CS})_v$=0.03m³/s. The extract height is h_{extr}=2.2m. The lab temperature in this case is T_{lab}=18.1°C. These values are shown in Table 5.

c) EXP03: Increasing cold air supply flow rate

Curve 8,9-12; both varied speeds and temperatures varied, trying to achieve the maximum ratio of $\Delta T_{out}/\Delta T_{in}$. The ratio of $\Delta T_{out}/\Delta T_{in}$ is the same.

The increase in the cold air supply velocity gives a proportional increase in the temperature of the cold air zone. The height of the extract removes more hot air.

Almost the same flow rates are maintained between the hot and cool-temperature-air-supply outlet, $(Q_{HS})_v$=0.11m³/s and $(Q_{CS})_v$=0.11m³/s. The extract height is h_{extr}=2.2m. The lab temperature in this case is T_{lab}=18.25°C. These values are shown in Table 5.

d) EXP04: Further increasing cold air supply flow rate & setting hot air supply to EXP02ii

The aim of this experimental case is to study the increase in both hot and cold air supply flow rate. The flow rate of the hot-temperature-air-supply outlet is $(Q_{HS})_v$=0.04m³/s. The flow rate of the cool-temperature-air-supply outlet is $(Q_{CS})_v$=0.14m³/s. The extract height is changed back to approximately the same initial height, h_{extr}=2.2m. The lab temperature in this case is T_{lab}=18.25°C. These values are shown in Table 5.

e) EXP05: Air supply is set to produce a low flow rate case with and without the effect of lights and location for EXP-5-12-00

The aim of this experiment is to do a lower hot air supply velocity case for EXP-05-12-00. Additionally, the thermocouple support-rod was moved to a different location.

T_{HS}=40°C and Cold in mid-position (this must also be around 10m/s same as EXP-5-12-00 because there is some qualitative comparison between the curves and in EXP-5-12-00 Cold setting mid-position “but 10m/s in the next experiment”, this means that the way the lever was turned is for 10m/s). The position of the leaver puts the cold speed close to the max value).

The flow rate of the hot-temperature-air-supply outlet is $(Q_{HS})_v$=0.04m³/s. The flow rate of the cool-temperature-air-supply outlet is $(Q_{CS})_v$=0.07m³/s. The extract height is changed back to approximately the same initial height, h_{extr}=2.2m. The lab temperature in this case is T_{lab}=18.25°C. These values are shown in Table 5. The results obtained in this case are presented by a temperature contour plot in Figure 33.

DISCUSSION

By the results obtained from experimental case EXP05 a contour plot can be drawn shown in Figure 33,

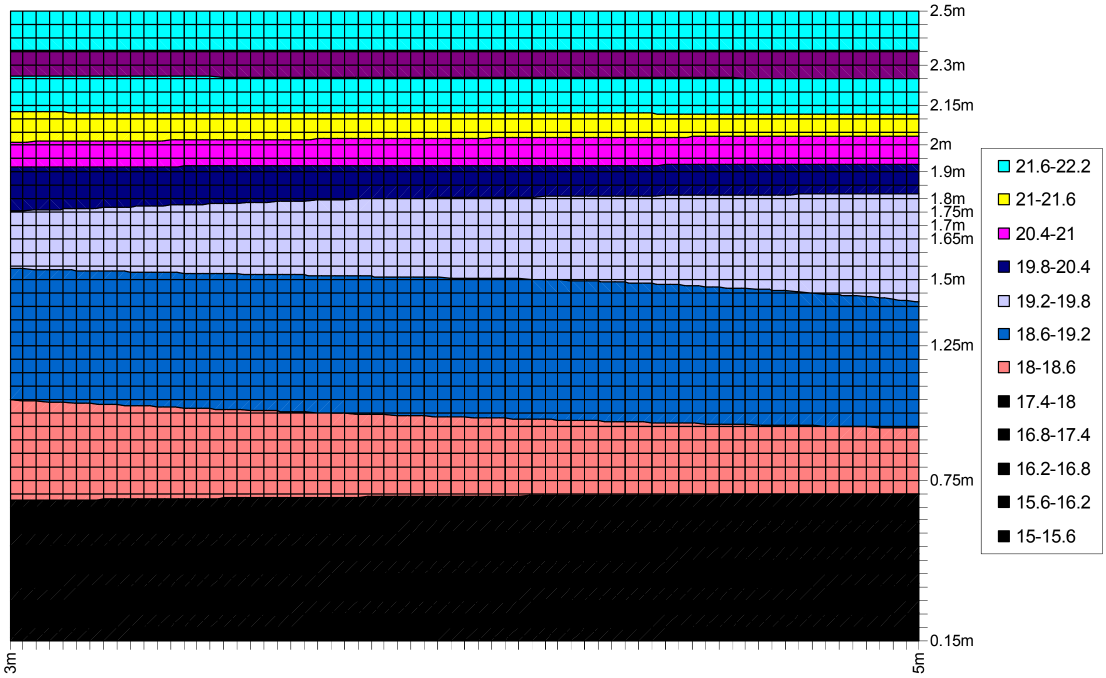


Figure 33: Temperature contour plot along the middle plane of the experimental configuration in the environmental chamber from the inlets to the extract. Stratified layers for experimental case EXP05 show the influence of high supply flow rates but also high supply temperatures.

By looking at the statistical analysis, the deviations are large and hence turbulence is large too. This could be due to the reduction in the area of the diffusers and the high input parameters at the supply outlets. The reduction in this creates a jet that fluctuated along the longitudinal axis at higher wave frequency. The extract height does not make much difference, because of the turbulence. There is still a little stratification. Hence, it is not a strong parameter in influencing stratification.

Initially it seems that the extract height was changed from 1.6m to 2.2m and all values are very close after the data set No.2, because they are affected by the mixing.

The right and left walls never acquire the temperatures at the same height with the thermocouple support-rod inside the chamber but they follow the same curve as the other temperatures. This is because the external temperature is much lower and they need more time to achieve the expected temperatures that they should have. This is the case until data set No.8 where the temperatures fall closer to the external temperature, i.e., 18.5°C, minimising this gap and all these thermocouples show the expected temperatures and because all these cases are well-stratified cases.

Turbulence suppresses/destroys the stratification pattern.

(1) The inlet size did not make much difference in this case.

(2) The vertical diffusion increases with higher speed of hot-temperature-air-jet in EXP02. This is understood by the looking at the temperatures of the cool-air-zone in Figure A-6. This is because of the turbulent diffusion with height becomes larger with higher speed of hot-temperature-air-supply. The temperature of the cool-temperature-air-supply in EXP02 is slightly affected from the higher temperatures of the zone, as shown in Figure A-6, which slightly increases with time.

The low flow rates in EXP01 and EXP02 shows that there is a straight line between the layers that are formed from the hot and the cold air jets, due to the low initial flow rates compared to the large increments. Although there are not as many thermocouples in the cool air region close to the floor as in the hot air region, the existing thermocouples still show that the cool air region is similarly stratified.

The increments show that the filling box mechanism still occurs. This is up to curve 6.

Curve number 7 shows that higher temperatures are achieved in the air region by increasing the supply flow rate of cold air.

Curve number 1 and curve number 2 are similar to curve number 8 which is stretched out from the furthest point closer to the cool air region. It is more evident here in curve number 8 when the supply rates are very high and both jets diffuse equally into each other. That would imply that if we increased the temperature instead of velocity, the F/M ratio would put through a reverse change in magnitude.

and this means that the model will not work for very high supply flow rates because the similarity (1,2 are similar to curve number 8) is affected by the orientation of the jets (refer to the initial simulations where the supply flow rates were increased equally). These changes are direct (1:1 for supply velocity and temperature) and the changes from the opposite supplies are indirect by diffuser across the height. The indirect changes depend on the size of the inlet and the current state of the temperature distribution (height of the hot air interface if the hot air supply is the modifier).

For changes in the flow $0.05 m^3/s$ (curve number 7 and 8) or even less, there is a noticeable difference in the temperature of the supply outlet. This is because of the heat from the flow in the pipe increases compared to the external value and this affects the temperature at the supply point. The extreme temperatures on the temperature distribution are also affected which influences the relationship of the buoyancy-to-momentum. Comparing with the similar temperatures at the supply outlet of EXP-5-12-00, the supply temperature is a linear function of velocity and flow rate for the range of room temperatures,

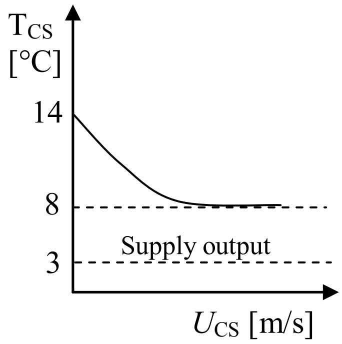


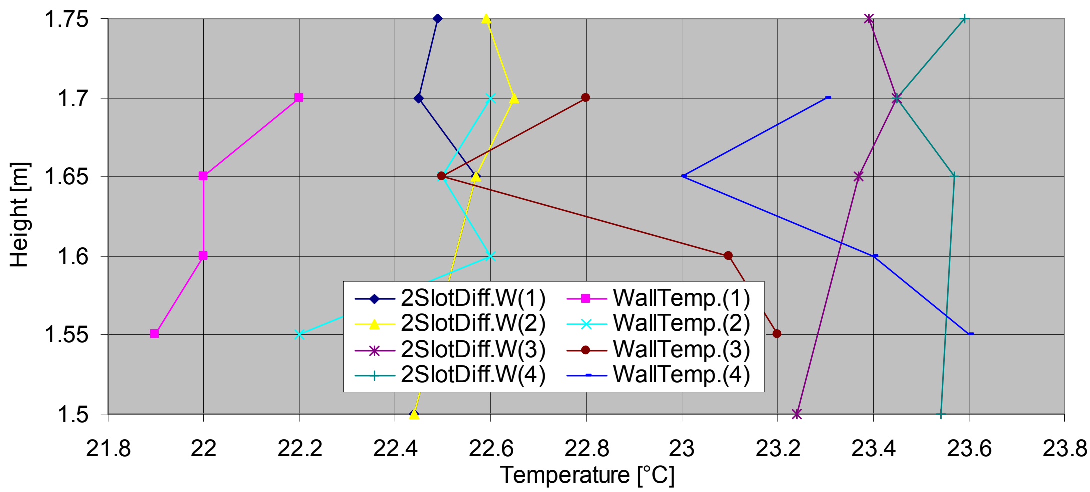
Figure 34: Linear response of supply outlet temperature versus duct velocity for flow rates higher than 0.025m³/s.

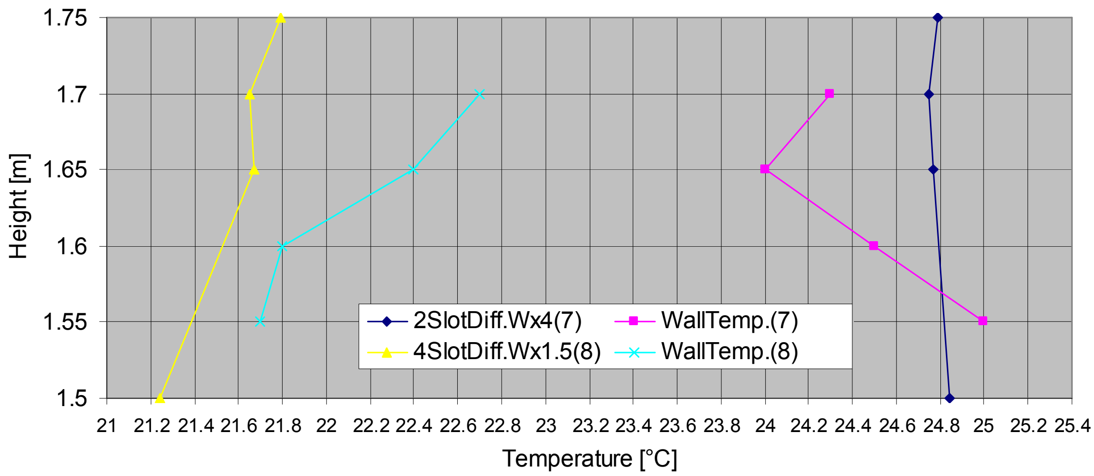
The higher velocities, on the other hand, mix the chamber medium that also slightly affect back the supply outlet temperatures. However, these changes are linear.

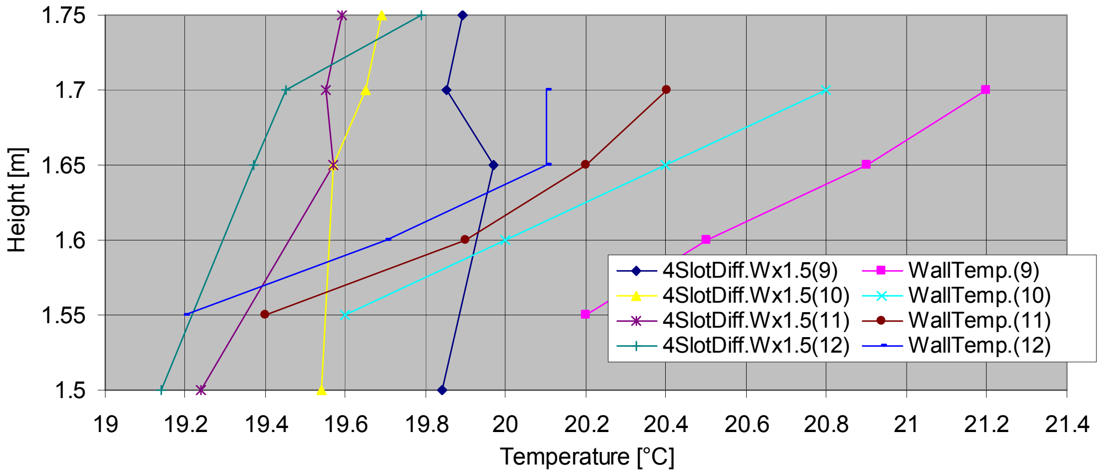
The initial change of the extract affects very little the supply temperatures. However, the supply temperature of the hot air is increased by 1°C when the extract was moved from close to the ceiling to the middle of the room.

The lights did not affect the temperature distribution of the final case study EXP05. The changes are due to the low. The change is due to the wall fabric taking a long time to acquire the same temperature and heat.

i) Wall surface temperatures:







Height [m]
Temperature [°C]
4SlotDiff.Wx1.5(9)
4SlotDiff.Wx1.5(10)
4SlotDiff.Wx1.5(11)
4SlotDiff.Wx1.5(12)
WallTemp.(9)
WallTemp.(10)
WallTemp.(11)
WallTemp.(12)

7) EXP-11-12-00 Lower speeds of hot-temperature-air-jet and different extract height – 2SD

This experiment was carried out to see the effect of (1) increasing the temperature, (2) changing the extract height for a good stratification case (3) measure and compare the homogeneity of stratification close to the walls and (4) make regular checks to see how the stratification is maintained during the experiment for the same settings. The experimental configuration of this experiment is shown in Figure 35,

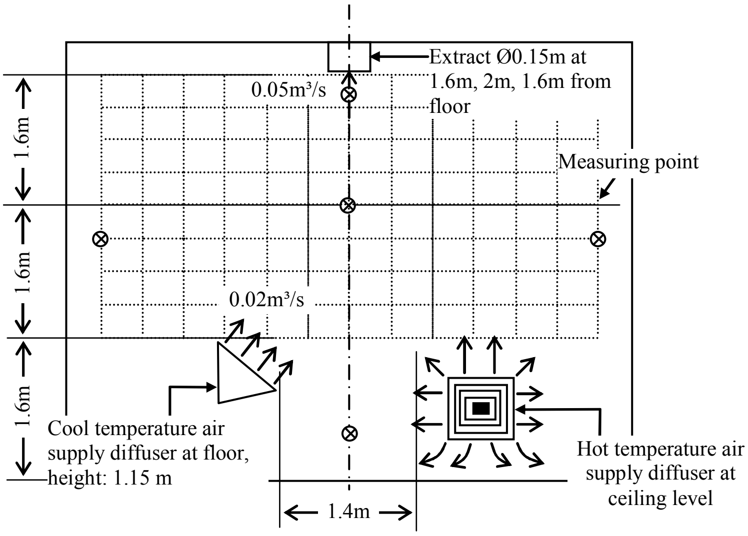


Figure 35: Experimental configuration during experiment of high inlet speed of hot-temperature-air-jet.

The total area is used for the hot-temperature-air-supply diffuser in this experiment. The cold-temperature-air-supply rate is constant in all the case studies of this experiment, $(Q_{CS})_v$=0.03m³/s, and similarly the extract rate, $(Q_{extr})_v$=0.05m³/s. The input parameters are shown in Table 6,

	h_{extr} [m]	T_{lab} [°C]	T_{HS} [°C]	T_{CS} [°C]	$(Q_{HS})_v$ [m³/s]	$(Q_{CS})_v$ [m³/s]	Air changes per hour	R_{BJ} [m⁻³]	τ_{HS}^*	τ_{CS}^*
EXP01i	1.6	18.6	32	13.8	0.0301	0.026	1×3ACH	17.03	18 8/9	16 1/9
EXP01ii	1.6	18.6	31.8	13.8	0.0395	0.026	1.1×3ACH	10.78	2 1/9	1 1/3
EXP01iii	1.6	18.25	31.6	14.1	0.0489	0.026	1.3×3ACH	7.288	2 3/5	1 1/3
EXP01iv	1.6	18.25	31.6	14.3	0.0583	0.026	1.5×3ACH	5.293	3 1/9	1 1/3
EXP02	1.6	18.45	31.6	14.2	0.0583	0.026	1.5×3ACH	5.32	6	2 5/7
EXP03	1.6	18.93	31.7	14.3	0.0583	0.026	1.5×3ACH	5.304	6	2 5/7
EXP04	1.6	19.4	31.5	14.3	0.0583	0.026	1.5×3ACH	5.242	3 1/9	1 1/3
EXP05	1.6	19.4	29.6	14.3	0.0395	0.026	1.1×3ACH	9.14	2 1/9	1 1/3
								Average data collection interval	3 1/9	1 1/3

Table 6: Input parameters for case studies in EXP-08-12-00.

a) EXP01: Increasing inlet flow rates – HSK1.5,HSK2,HSK2.5,HSK3

The aim of this experimental case is to study the effect of varying the flow rate by making small incremental steps, $(Q_{\mathrm{step}})_v$=0.01m³/s, on the temperature distribution. The flow rate of the hot-temperature-air-supply outlet is $(Q_{\mathrm{HS}})_v$=0.03m³/s. The flow rate for the cool-temperature-air-supply outlet is $(Q_{\mathrm{HS}})_v$=0.03m³/s. The extract height is h_{extr}=1.6m. The lab temperature was not varied too much, T_{lab}=18.6°C to T_{lab}=18.25°C.

b) EXP02: Varying the extract height – HSK3:h_{extr}=2.2m,h_{extr}=0.8m,h_{extr}=1.6m-check1

The aim of this experimental case is to study the effect of changing the extract height on the temperature distribution for the lower values of inlet flow rates used in this experiment. The flow rates were not varied in this case study. The flow rate of the hot-temperature-air-supply outlet is $(Q_{\mathrm{HS}})_v$=0.06m³/s. The flow rate for the cool-temperature-air-supply outlet is $(Q_{\mathrm{HS}})_v$=0.03m³/s. The extract height is h_{extr}=1.6m. The lab temperature is T_{lab}=18.45°C.

c) EXP03: Temperature distribution close to the chamber walls – Back Wall, Left Wall, Right Wall, Front Wall

The aim of this experimental case is to study the difference in the temperature distribution very close to the walls. The inlet flow rates were not varied in this case study. The flow rate of the hot-temperature-air-supply outlet is $(Q_{\mathrm{HS}})_v$=0.06m³/s. The flow rate for the cool-temperature-air-supply outlet is $(Q_{\mathrm{HS}})_v$=0.03m³/s. The extract height is h_{extr}=1.6m. The lab temperature is T_{lab}=18.9°C.

d) EXP04: Repeatability check for h_{extr}=1.6m EXP01iv-HSK3-check2

The aim of this experimental case is to do a second test to the temperature distribution of h_{extr}=1.6m for HSK3. The flow rates were not varied in this case study. The flow rate at the hot-temperature-air-supply outlet is $(Q_{\mathrm{HS}})_v$=0.06m³/s. The flow rate at the cool-temperature-air-supply outlet is $(Q_{\mathrm{HS}})_v$=0.03m³/s. The extract height is h_{extr}=1.6m. The lab temperature is T_{lab}=19.4°C.

e) EXP05: Repeatability check for EXP01ii-HSK2-check-1

The aim here is to obtain a distribution to check with EXP01ii-HSK2. The flow rate at the hot-temperature-air-supply outlet is $(Q_{\mathrm{HS}})_v$=0.04m³/s. The flow rate at the cool-temperature-air-supply outlet is $(Q_{\mathrm{HS}})_v$=0.03m³/s. The extract height is h_{extr}=1.6m. The lab temperature is T_{lab}=19.4°C.

DISCUSSION

(1) The second setting was done for a lower flow rate than the first to check the response of the chamber to achieve the same stratification with the chamber medium (the sampling time is t=2τ which is yields approximately 80%). As it would be

expected, the consequent reduction in heat would cause the temperatures to reduce. Hence, the wall temperatures do not respond as fast as the thermocouple support-rod temperatures. Compare to other cases of a good stratification with height, it is obvious that the wall temperatures are affected at a higher rate when there is not much stratification.

(2) The temperatures at the height of 2.2m is the same as the temperature of the extract. The temperature at 1 m is the same as the temperature of the extract.

(3) There is a constant temperature distribution at the back of the chamber, close to the extract. On the one hand, this is because the extract gets some lighter/warmer fluid as well as heavier/colder fluid at the same height. This occurs in regular pulses, getting the colder fluid at the same height or warmer fluid closer to the ceiling. On the other hand, the fluid that is below the ceiling advances much faster than the cooler fluid below the extract inlet making this effect show up.

(4) The checks that have been carried out at the end of this experiment show that the temperature of the hot-temperature-air-supply decreases affecting all the other temperatures in the chamber. The outside temperature in the lab increases by a little over a half of a degree Celsius. The decrease in the flow rate could have caused overheating in the hot air supply unit making the controller to lower the supply temperature.

Especially good is the accuracy of the values of this experiment too. The cases where the values obtained from Th.Set A (back, front, left and right) are exactly the same with the values at the same height obtained on the thermocouple support-rod (height of Th.Set B). For example, the temperature of the extract which is at 1.6m, is the same with the temperature on the thermocouple support-rod at 1.6m.

This is equal to 22.4°C.

The experimental case check-EXP02-h1.6m has slightly larger temperature than EXP02. This is because the heat capacity of the wall surface did not fully converge to the new settings.

The results of the case study EXP03 are shown in Figure 36,

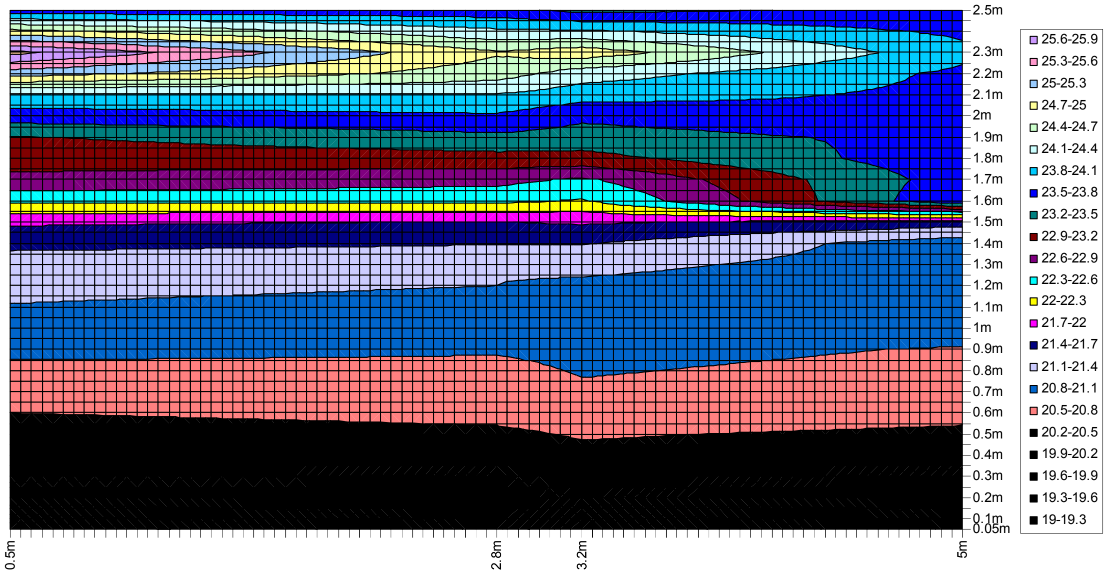


Figure 36: Temperature contour plot along the middle plane of the experimental configuration in the environmental chamber from the inlets to the extract. Stratified layers for experimental case EXP03 show the influence of low supply flow rate and high supply temperature difference.

The contours in the region of hot air close to the extract are more mixed. This is because of the turbulence of the extract.

i) Wall stratification

The temperature distribution at the chamber walls follows the same function of the chamber medium, when there is little influence from outside and a good stratification inside. This is shown in Figure 37 (a).

The higher temperature of the upper part of the walls due to the change in the extract height has slightly affected the wall temperature profile, however, this is rather within the error margins of the temperature readers. This is shown in Figure 37 (b). The rest of the cases are for different heights, in which the distribution is the same, except when the thermocouple support-rod was located close to the extract. At that place, there is a temperature increase due a minor wash-down of warm air. That could be attributed to upper thinner air being withdrawn in the preference of warmer air. Similarities with the wall profile can be observed with the one obtained from the support-rod at the extract location.

The temperature profile when the chamber is at a constant thermal stratification is also very similar. The temperature of the thermocouple at the back wall is again a little higher than the temperature of the thermocouple support-rod for the same reason as explained in the previous paragraph. This is shown in Figure 37 (c).

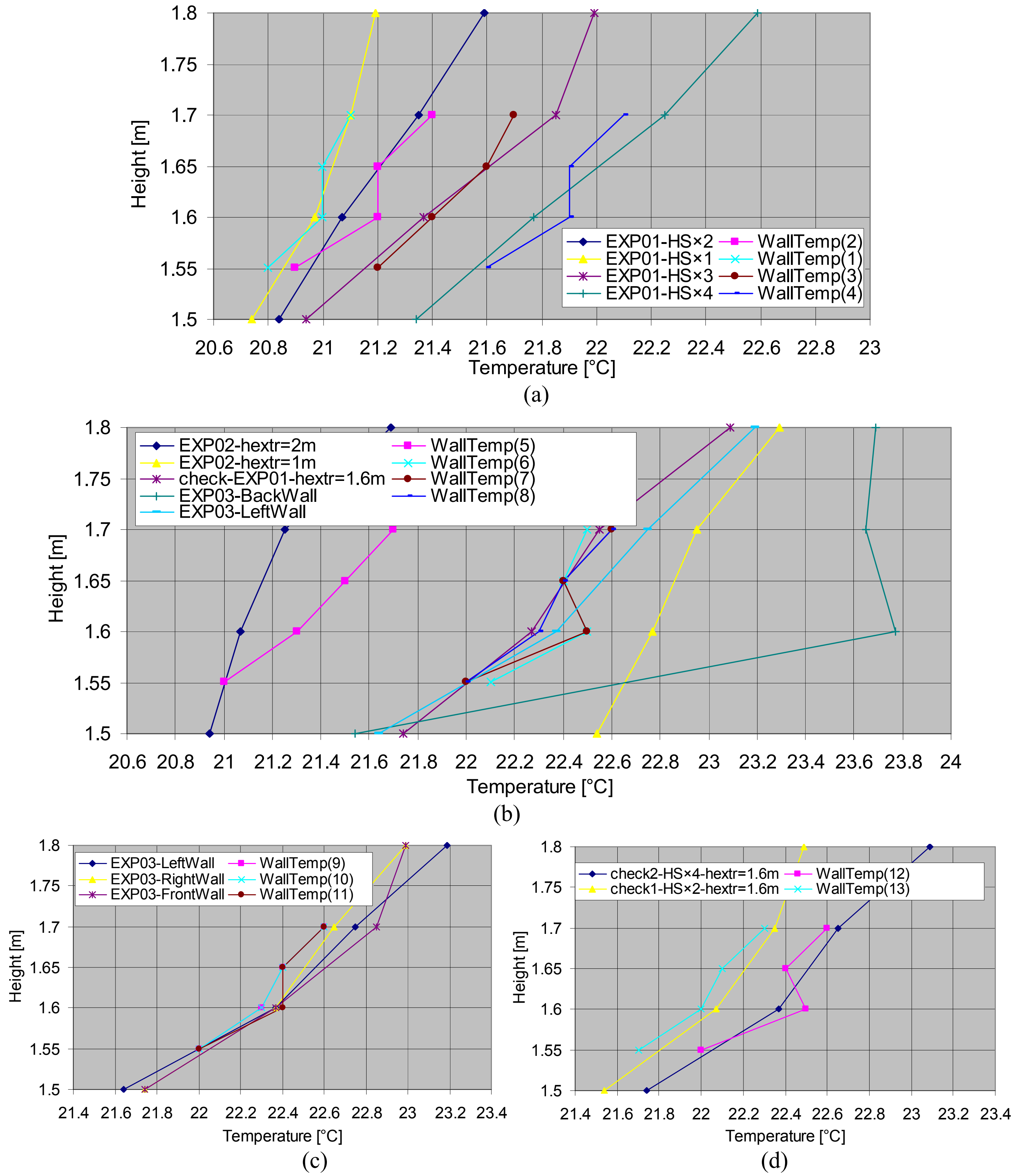


Figure 37: Wall temperatures and chamber medium temperatures at the same height. In (a), first four experiments are obtained for increasing inlet flow rate. In (b), measurements with different extract height, a different location of support rod and close to the extract (back wall). In (c), measurements with location of support rod at the right and left walls and close to the front wall (door). In (d), measurements in the middle of the chamber of repeatability checks.

The selective withdrawal occurs appears in the temperature distribution of the back wall. The different curvature of the back wall appears periodically. This is illustrated in Figure 38,

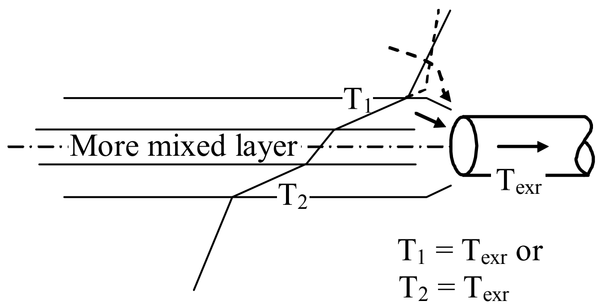


Figure 38: Local temperature distribution affected by the turbulence of the extract.

The average values are very close to the values obtained form the layer at the same height shown in Figure 39,

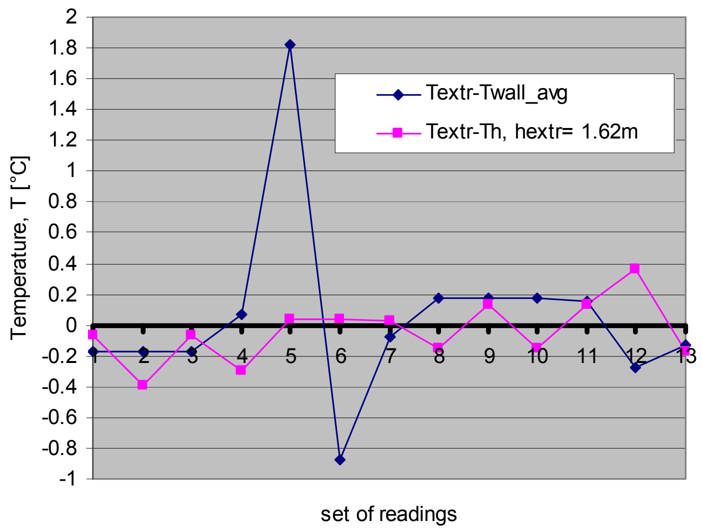


Figure 39: Temperature differences between extract versus chamber medium and wall fabric, EXP-11-12-00.

GENERAL DISCUSSION

The small difference between the case studies EXP02i-HS4-1-1.6m and EXP02ii-HS4×1-1.7m in EXP-05-12-00 is because of the external temperature rise, which is 1°C. This difference is very small (~0.2°C) on the temperature distribution. This is confirmed by case studies EXP03i-HSK6-1.7m and EXP03ii-HSK6-1.6m because the outside temperature is kept the same during the experiment and the temperatures of the distributions do not show any difference. Comparing with the EXP-8-12-00, the temperature distribution is affected by the hot-temperature-air-supply jet similar to this case. Therefore, the effect of the extract on the temperature distribution can only be seen at very low speeds where there is not much turbulence and dynamic pressure heads to modify the pressure level, as in the experiment EXP-11-12-00.

The difference in the inlet size is not so evident except that the extract has an effect on the slope at the height that it is located, which is noticed previously by the variation in the extract height of EXP-11-12-00. A lesser cold air supply rate (set to 5m/s) means a lesser effect of the cool-temperature-air-jet on the cold air zone. However, the range of ΔT_{in} is the same. To observe the comparison directly is not very obvious. The lab temperature is slightly different by 0.3°C. Thus by offsetting the results in Figure 40,

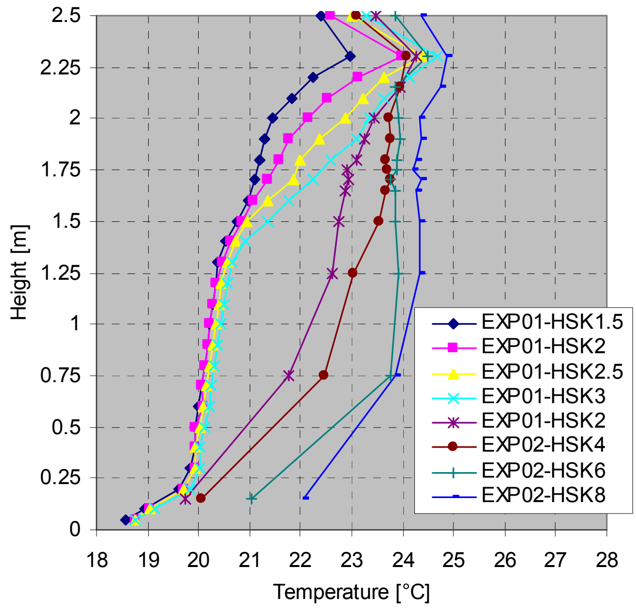


Figure 40: Possible changes defined by offsetting data from other experimental cases.

The cold is 5 times higher than EXP-11-12-00 due to the linear relation with inlet temperature there should be 5°C added in order to match. On the other hand, the hot is 1/4 higher, hence in this case the curve should be reduced by 1°C. Therefore, the values of the EXP-5-12-00 should be increased by around 4°C (NB. both experiments are for the same T_{lab}). Additionally the values of EXP-5-12-00 should be for a normalised range so that the temperature range also reduces by 2°C to match the temperature range of EXP-11-12-00 because of the different ΔT_{in}. Thus by offsetting the results in ,

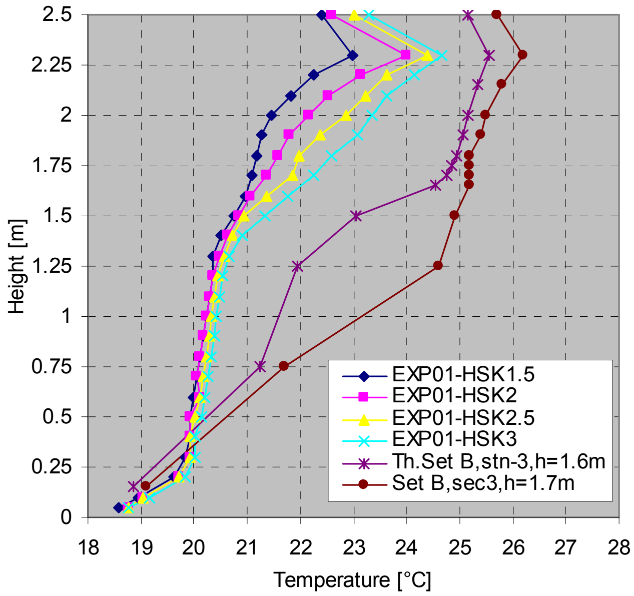


Figure 41: Possible changes defined by offsetting data from other experimental cases.

In the cases of EXP03 and EXP04 because of using only the floor supply, the time-scale is higher by a factor of 2. Hence it takes 20min for the temperature changes to occur in EXP03 and EXP04 compared to the EXP01. On the contrary, the slightly higher temperatures involved in EXP02 compared to EXP01, required a reduction in the time-scale by a factor of 2. Therefore, the most important variation in the temperature gradient can be identified below,

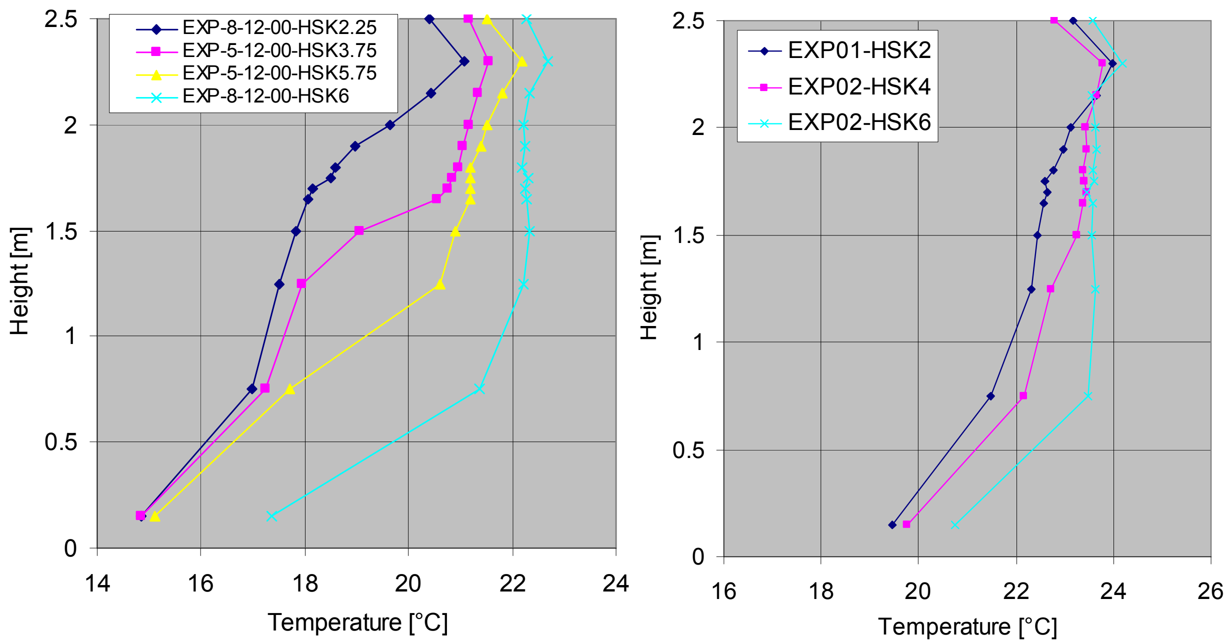


Figure 42: Variations of the temperature gradient by increasing the hot air supply flow rate.

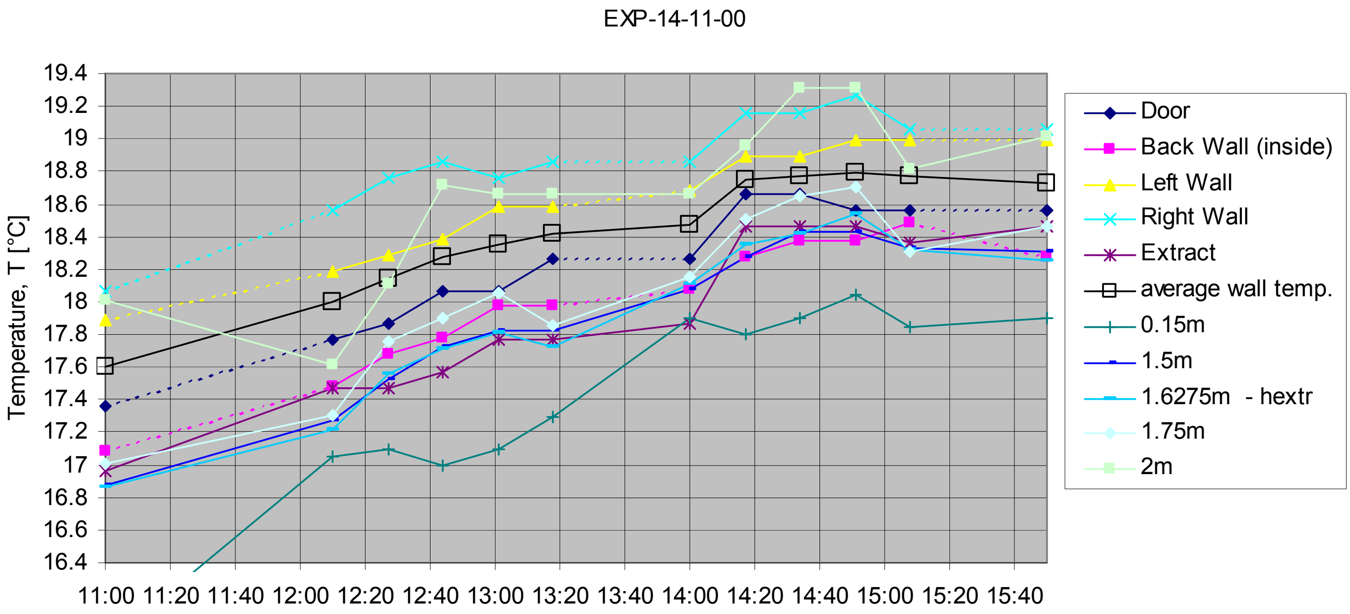
General commends

Stratification range

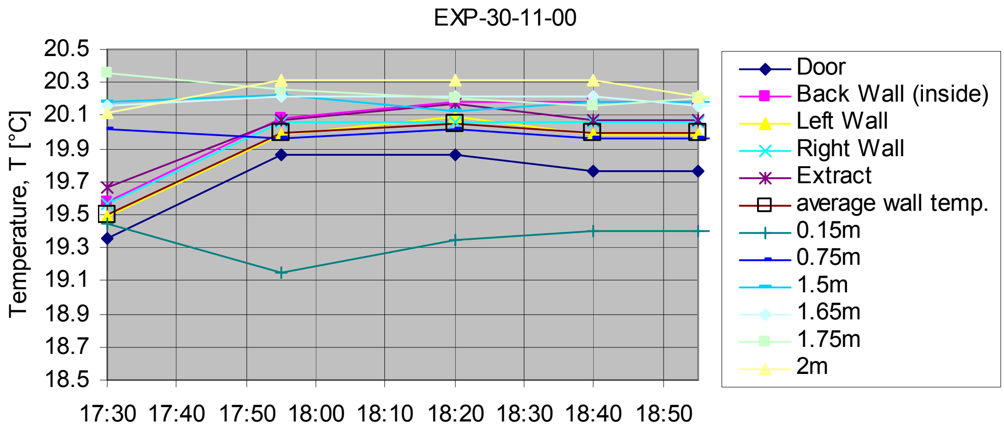
Overall the temperatures have a preference to perform in a close range of 20°C(mid) +/- 4°C(max range). This also depends on the turbulence from the supply outlet and the supply temperature difference.

Chamber temperatures affected by external temperatures

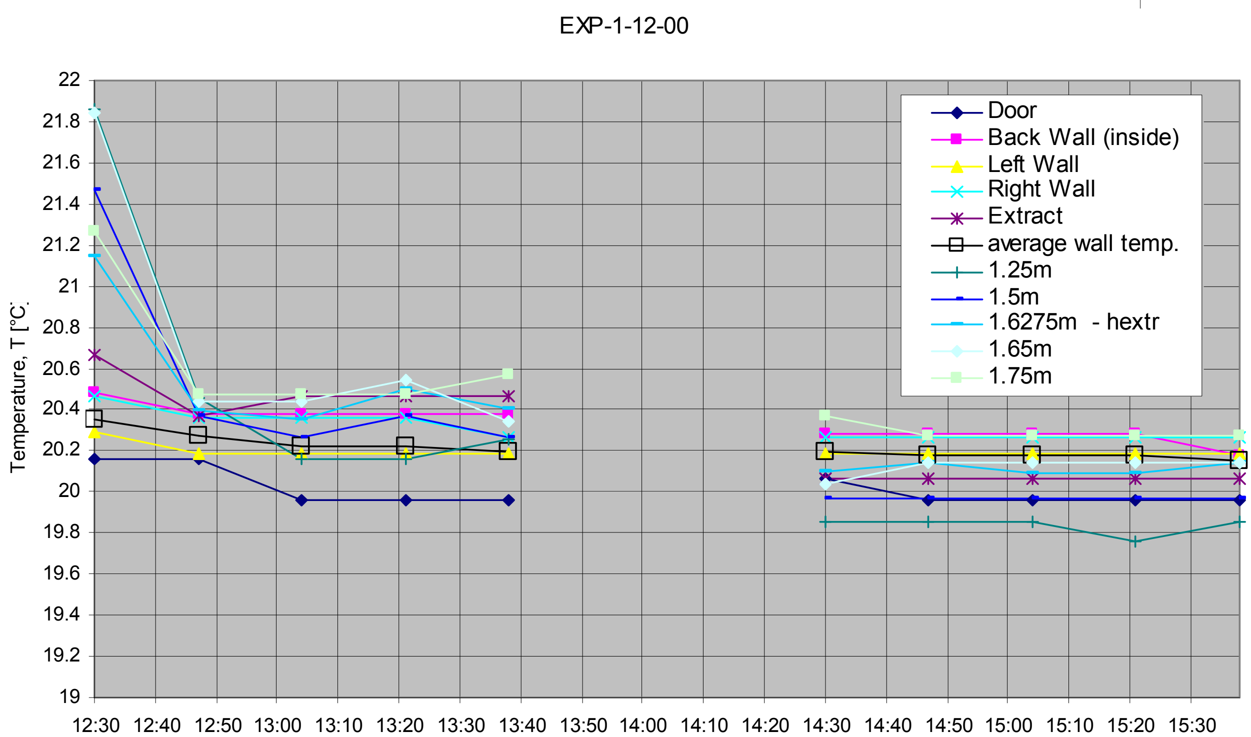
The lab and the chamber fabric temperatures, outside of the chamber, are affected by the solar radiation and latent heat. The lab temperature is only increased after long hours of operation. It is, however, very little affected. Temperature fluctuations of a maximum range of 1°C were recorded in 12hours of operation (EXP-11-12-00).



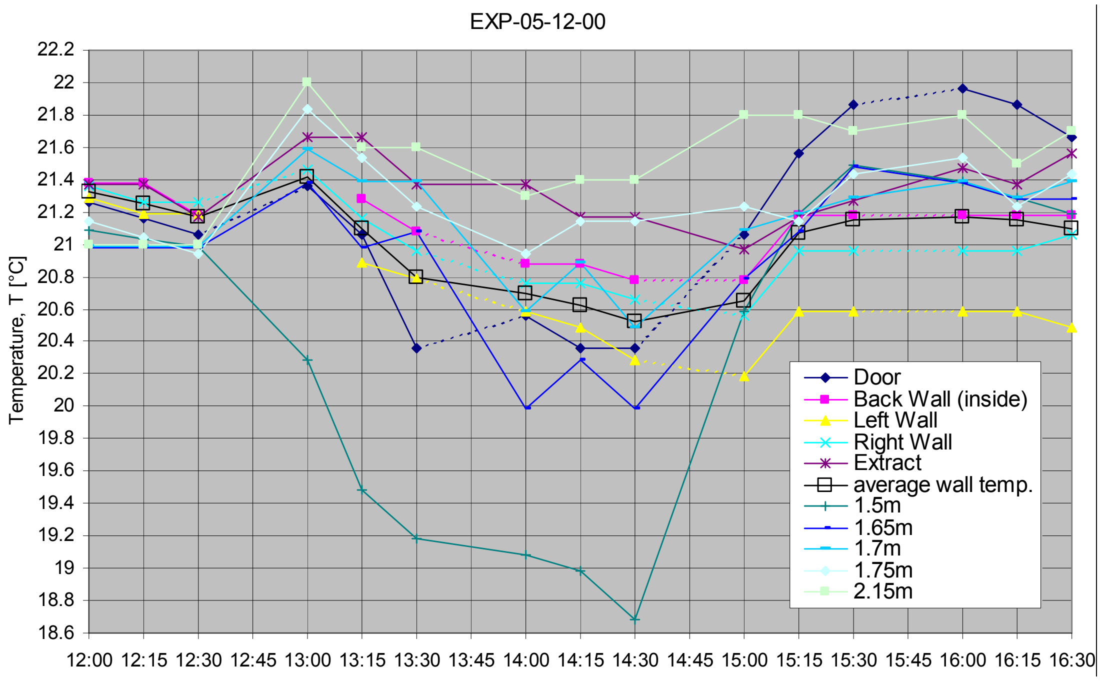
EXP-14-11-00
Temperature, T [°C]
19.4
19.2
19
18.8
18.6
18.4
18.2
18
17.8
17.6
17.4
17.2
17
16.8
16.6
16.4
11:00 11:20 11:40 12:00 12:20 12:40 13:00 13:20 13:40 14:00 14:20 14:40 15:00 15:20 15:40
Door
Back Wall (inside)
Left Wall
Right Wall
Extract
average wall temp.
0.15m
1.5m
1.6275m - hextr
1.75m
2m

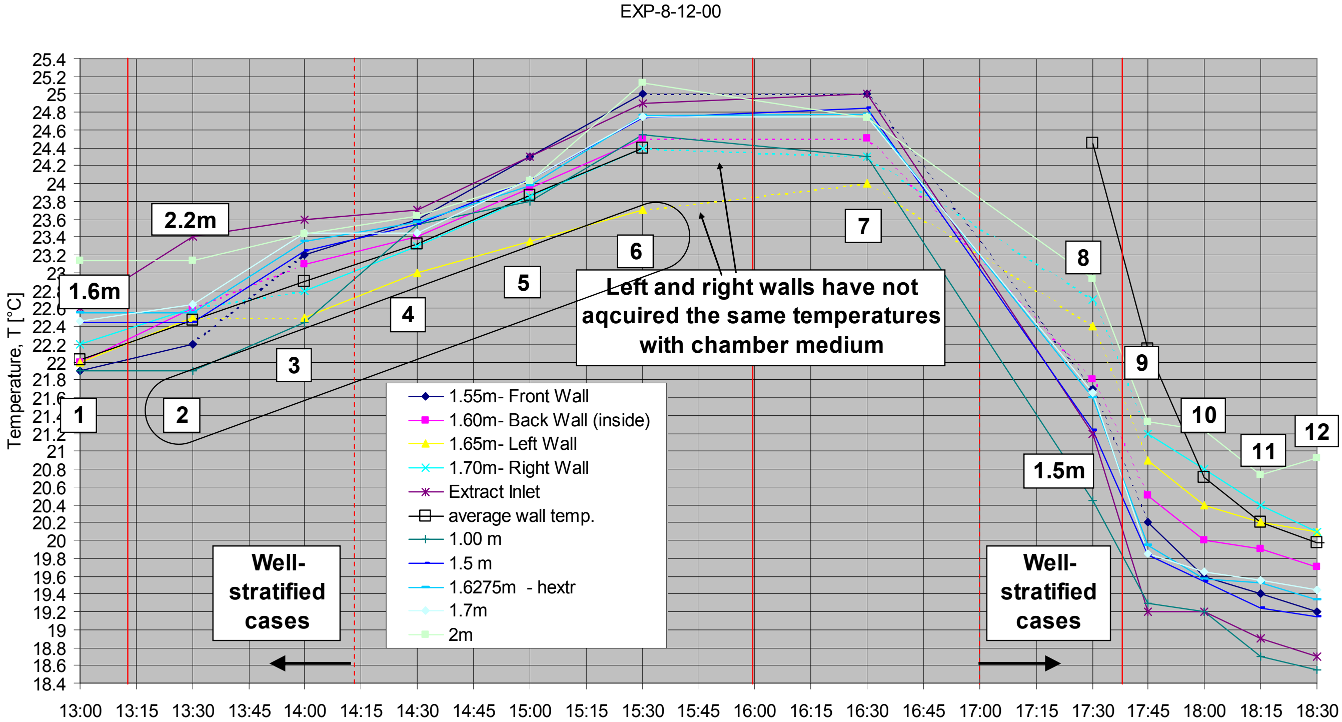


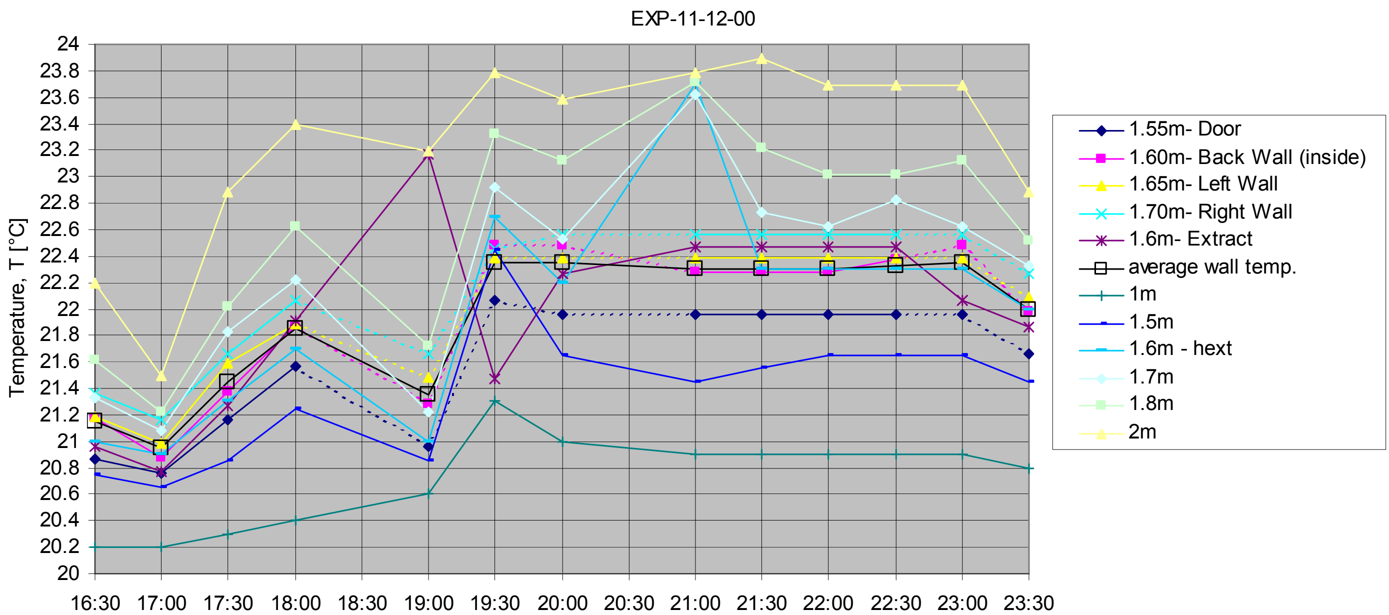
EXP-30-11-00
Temperature, T [°C]
20.5
20.3
20.1
19.9
19.7
19.5
19.3
19.1
18.9
18.7
18.5
17:30 17:40 17:50 18:00 18:10 18:20 18:30 18:40 18:50
Door
Back Wall (inside)
Left Wall
Right Wall
Extract
average wall temp.
0.15m
0.75m
1.5m
1.65m
1.75m
2m



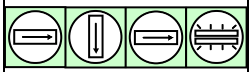
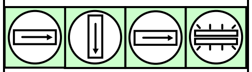
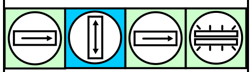
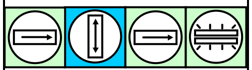
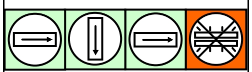
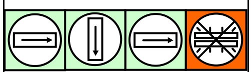
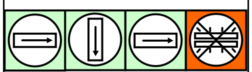
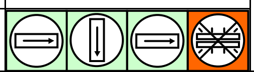
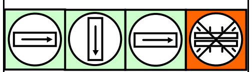
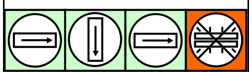
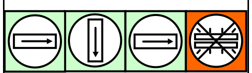
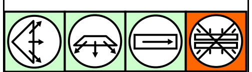
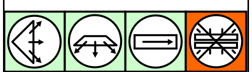
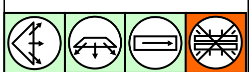
EXP-1-12-00
Temperature, T [°C]
22
21.8
21.6
21.4
21.2
21
20.8
20.6
20.4
20.2
20
19.8
19.6
19.4
19.2
19
12:30 12:40 12:50 13:00 13:10 13:20 13:30 13:40 13:50 14:00 14:10 14:20 14:30 14:40 14:50 15:00 15:10 15:20 15:30
Door
Back Wall (inside)
Left Wall
Right Wall
Extract
average wall temp.
1.25m
1.5m
1.6275m - hextr
1.65m
1.75m


EXP-05-12-00
Temperature, T [°C]
Door
Back Wall (inside)
Left Wall
Right Wall
Extract
average wall temp.
1.5m
1.65m
1.7m
1.75m
2.15m


EXP-8-12-00
Temperature, T [°C]
2.2m
1.6m
1.5m
1
2
3
4
5
6
7
8
9
10
11
12
Left and right walls have not aqcuired the same temperatures with chamber medium
Well-stratified cases
Well-stratified cases
1.55m- Front Wall
1.60m- Back Wall (inside)
1.65m- Left Wall
1.70m- Right Wall
Extract Inlet
average wall temp.
1.00 m
1.5 m
1.6275m - hextr
1.7m
2m


EXP-11-12-00
Temperature, T [°C]
1.55m- Door
1.60m- Back Wall (inside)
1.65m- Left Wall
1.70m- Right Wall
1.6m- Extract
average wall temp.
1m
1.5m
1.6m - hext
1.7m
1.8m
2m

1. TABLE OF EXPERIMENTS

Experiment	No.	U_{CS} [m/s]	U_{HS} [m/s]	h_{extr} [m]	Details	Times	Period	Configuration	Additional information
08-00	1.1	4.16	10	1.5	Hot and ambient temperature air measr./10 min	14:00-20:00	6:00		Warming up since 10:00, i.e., 4:00
	1.2	4.16	10	1.85	Hot and ambient temperature air (measurements taken /5 min)	14:30-17:30	3:00		Warming up since 13:50, i.e., 0:40
	1.3	4.16	10	1.85	Only ambient temperature air	14:30-19:30	5:00		Warming up since 12:00, i.e., 2:30
	1.4	4.16	10	1.5	Only ambient temperature air	14:00-20:00	6:00		Warming-up time not recorded
14-11-00	2.1	2.4	3	1.6	Temperature changes with location–middle–pressure measured	11:47	0:47		Warming up earlier than 11:00 but switched on at that time. Real warming-up time is 1:10
	2.2	2.4	3	1.6	Temperature changes with location – curve-1– pressure measured	12:10-13:18	1:08		
	2.3	2.4	3	1.6	Temperature changes with location – curve-2– pressure measured	14:00-15:08	1:08		
	2.4	2.4	3	1.6	Check with initial temperature distr.	15:50	0:42		
30-11-00	3	8.0	3	1.6	Stratification achieved by minimising jet effects (Ths_set=25°C and measr./20 min	17:30-18:55	1:25		Warming up since 16:30, i.e., 2:00
1-12-00	4	1.5	1.5	1.6	Similar but Carton under the hot air supply (Ths_set=30°C and measr./17 min)	12:30-15:40	3:10		Warming up for 2:30
5-12-00	5.1	2.2	2.8	1.6	Perforated bags used on hot/cold supplies to make stronger srtat.	12:00-12:30	0:30		Warming up from 10:00, i.e. 2:30
	5.2	2.2	2.8	1.6	High input rates, h_{ext}-1, vel-1	13:00-13:30	0:30 +0:30		
	5.3	2.2	2.8	1.7	High input rates, h_{ext}-2, vel-1	14:00-14:30	0:30 +0:30		
	5.4	3	2.8	1.7	High input rates, h_{ext}-2, vel-2	15:00-15:30	0:30 +0:30		

	5.5	3	2.8	1.6	High input rates, hext-1, vel-2	16:00-16:30	0:30 +0:30		
	6.1	2.35	2.35	1.6	Varying supply rates – repeatability check – EXP01	13:00-13:30	0:30		
	6.2	2.35	4.7	2.2	Reduced diffuser – 4 different hot air speeds – EXP02i	13:30-14:00	0:30		
	6.3	2.35	7	2.2	Hot air speed is up by 2 turns – EXP02ii	14:00-14:30	0:30		
8-12-00	6.4	2.35	9.4	2.2	Hot air speed is up by another 2 turns – EXP02iii	14:30-15:00	0:30		Warming up since 10:00, i.e., 3:00
	6.5	2.35	11.74	2.2	Hot air speed is up by another 2 turns – EXP02iv	15:00-15:30	0:30		
	6.6		7	2.2	EXP03 – varying cold speed	15:30:16:30	1:00		
	6.7			2.2	EXP04 – varying both speeds	16:30-17:30	1:00		
	6.8	2.35	7	1.5	Lights and location EXP05i /15 min	17:45-18:30	15:00 +45:00		
	6.9	2.35	7	1.5	EXP05ii				
	7.0	2.35	7	1.5	EXP05iii				
	7.1	2.35	7	1.5	EXP05iv				
11-12-00	7.1				Low input rates – Varying hot air supply – lines EXP1-4	16:30-18:00	1:30		Warming up since 10:30, i.e., 6 hours from start
	7.2				Low input rates – Extract height h_{extr}=2.2m	18:00-19:00	1:00		
	7.3				Low input rates – Extract height h_{ext}=0.8m	19:00-19:30	0:30		

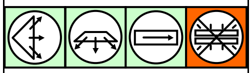
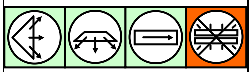
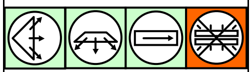
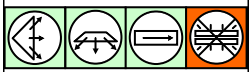
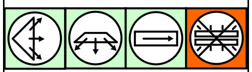
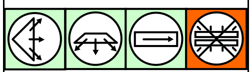
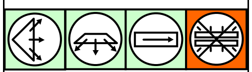
	7.4				Low input rates – Extract hext=1.6m check with line EXP4	19:30-20:00	0:30		
	7.5				Low input rates – Location of Th.Set-support-rod –back room side	20:00-21:00	1:00		
	7.6				Low input rates – Varying hot air supply – left room side	21:00-21:30	0:30		
	7.7				Low input rates – Varying hot air supply – right room side	21:30-22:00	0:30		
	7.8				Low input rates – Varying hot air supply – left room side	22:00-22:30	0:30		
	7.9				Low input rates – Varying hot air supply – check 2 EXP01iv	22:30-23:00	0:30		
	7.10				Low input rates – Varying hot air supply – check 1 EXP01ii	23:00-23:30	0:30		

Table 2: Summary table of experiments.

Dimensional graphs

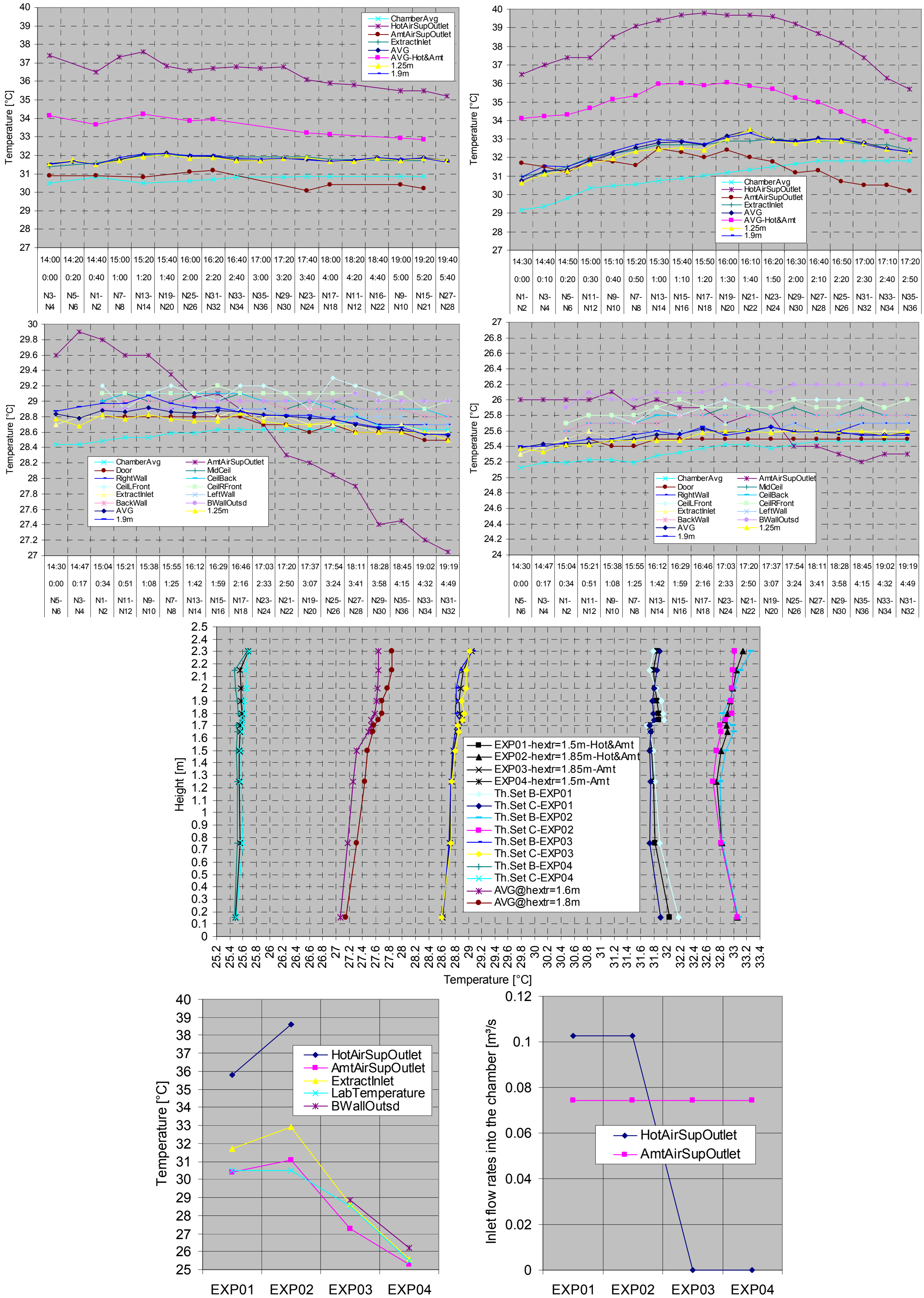


Figure A-1: EXP01, EXP02 EXP03, EXP04-08-00.

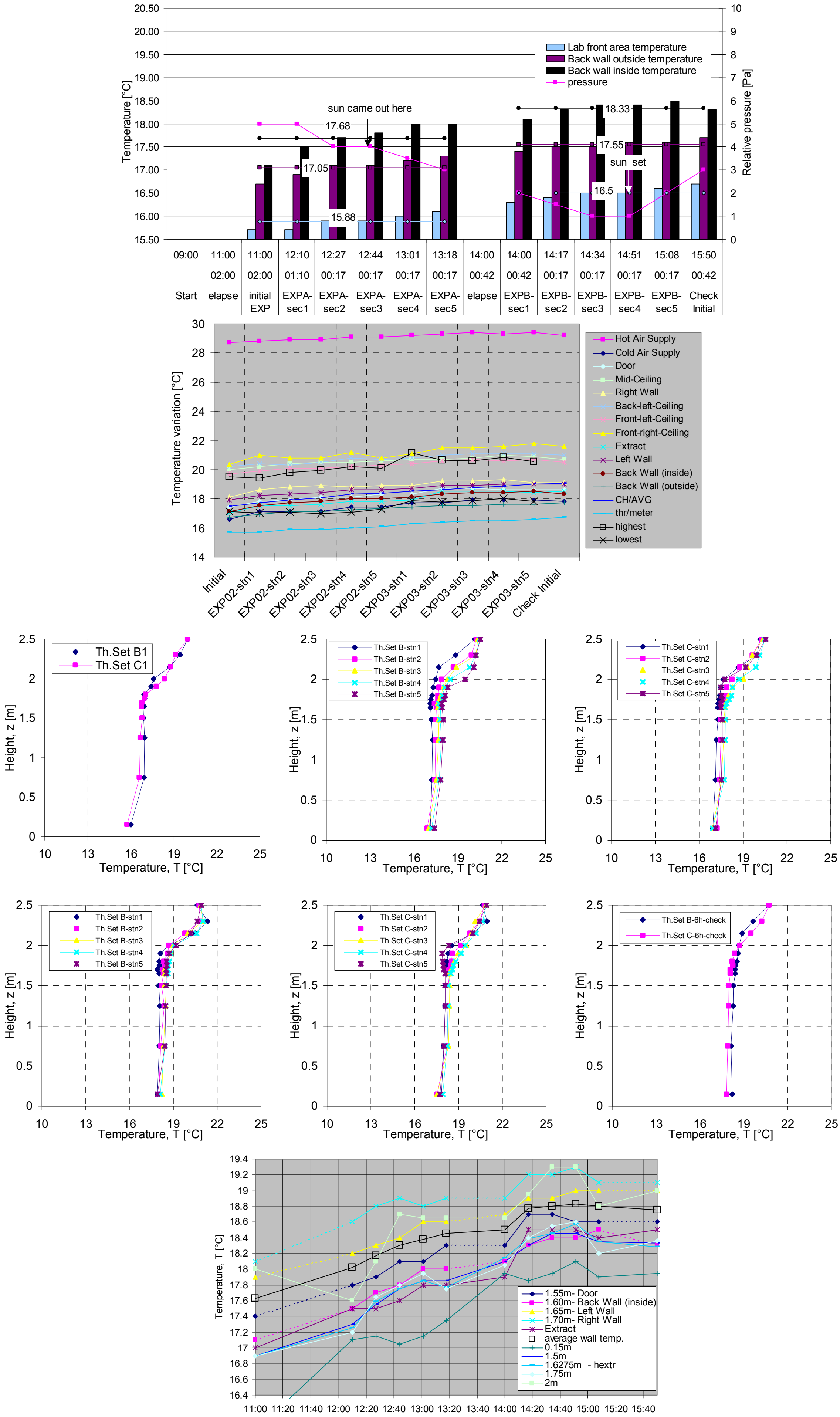


Figure A-2: EXP-14-11-00

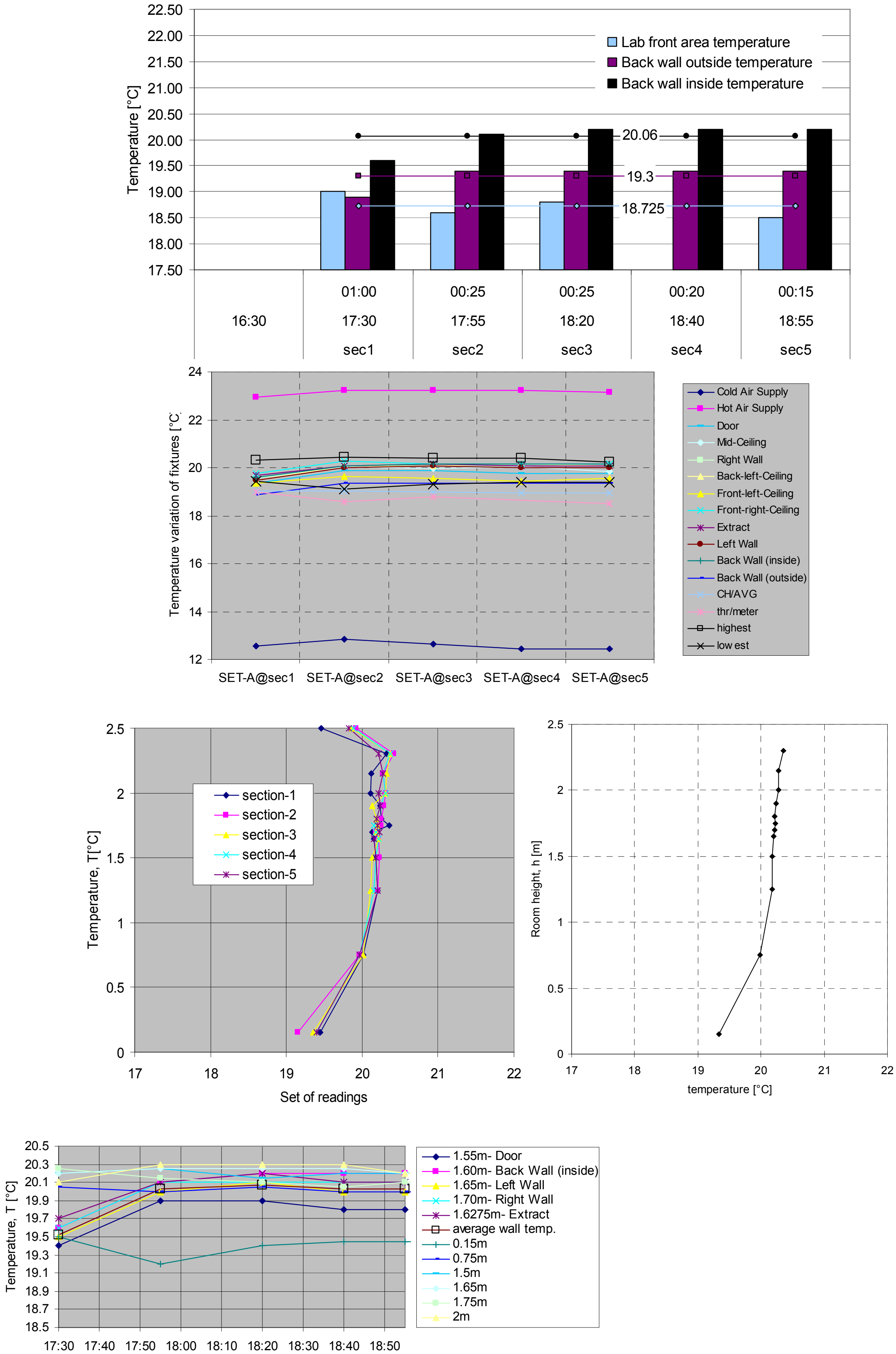


Figure A-3: EXP-30-11-00

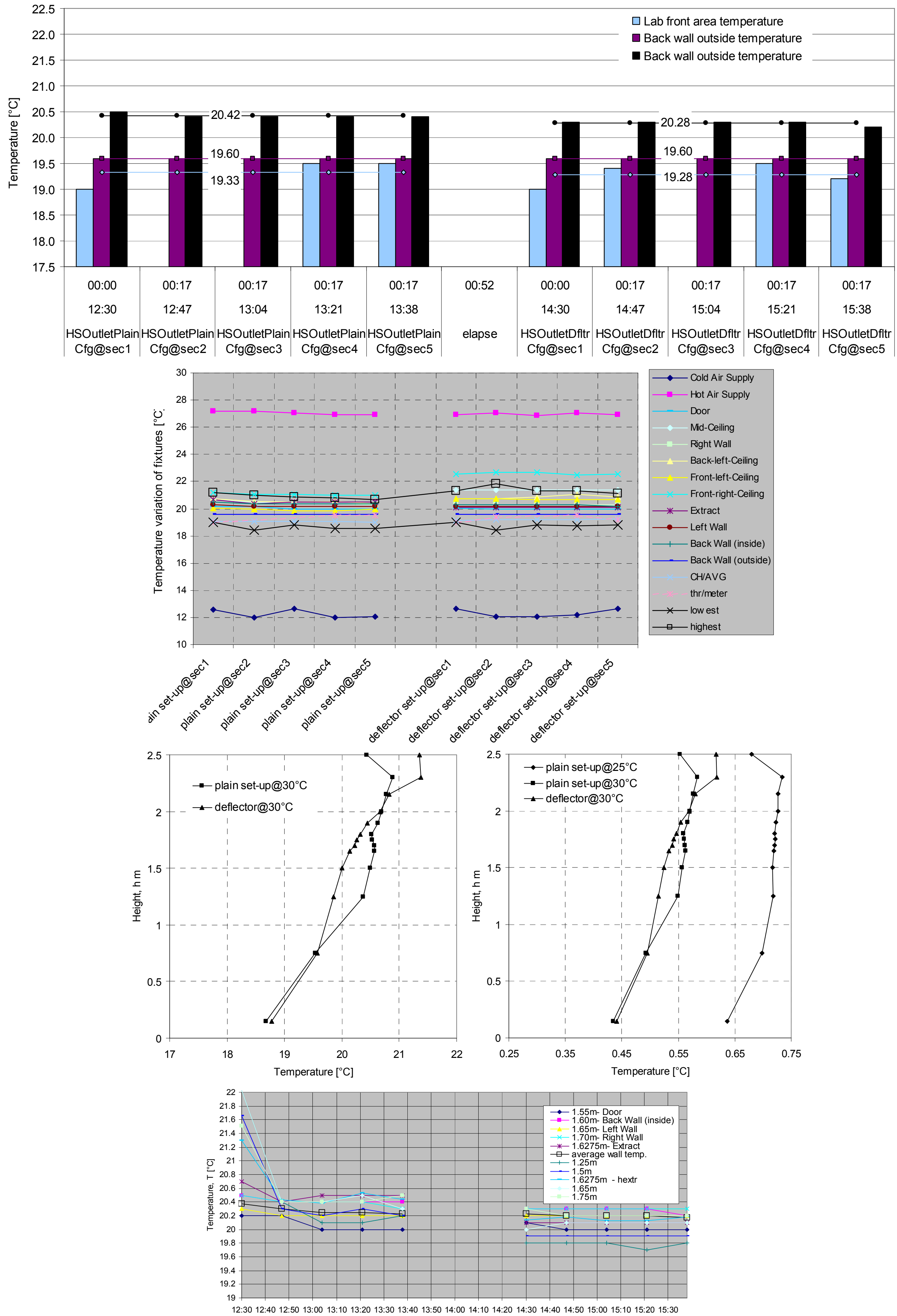


Figure A-4: EXP-01-12-00

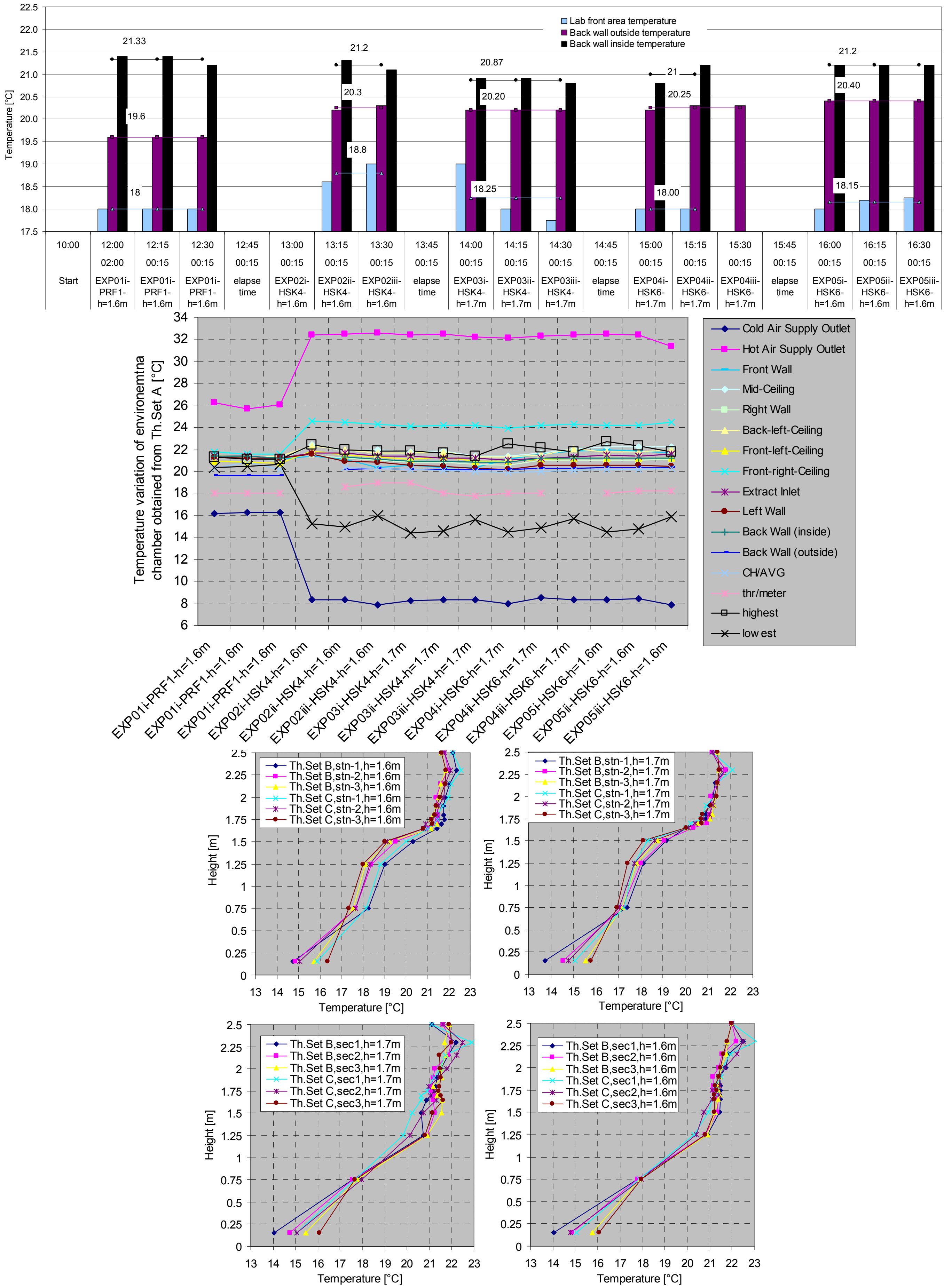


Figure A-5: EXP-5-12-00

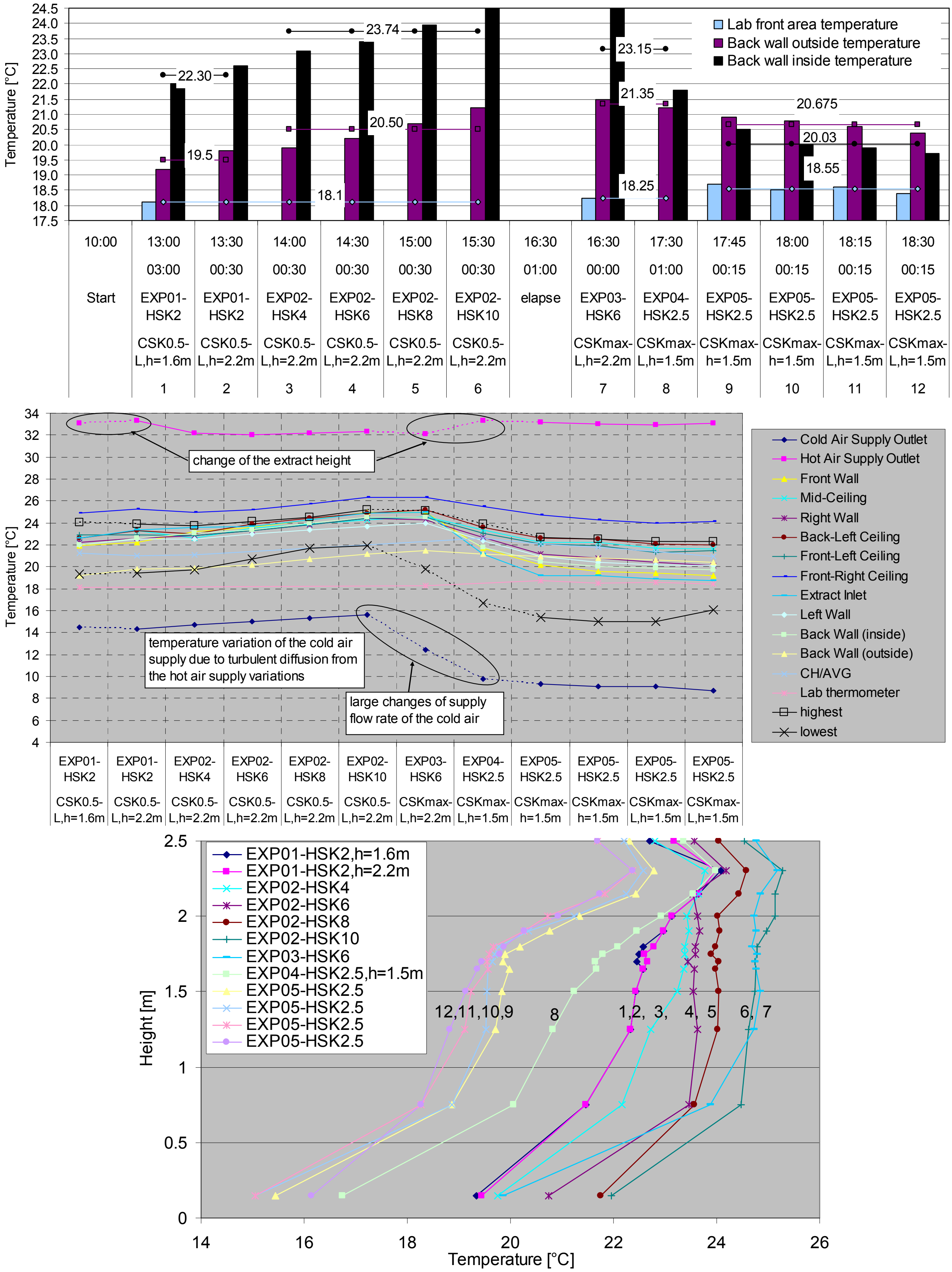


Figure A-6: 8-12-00

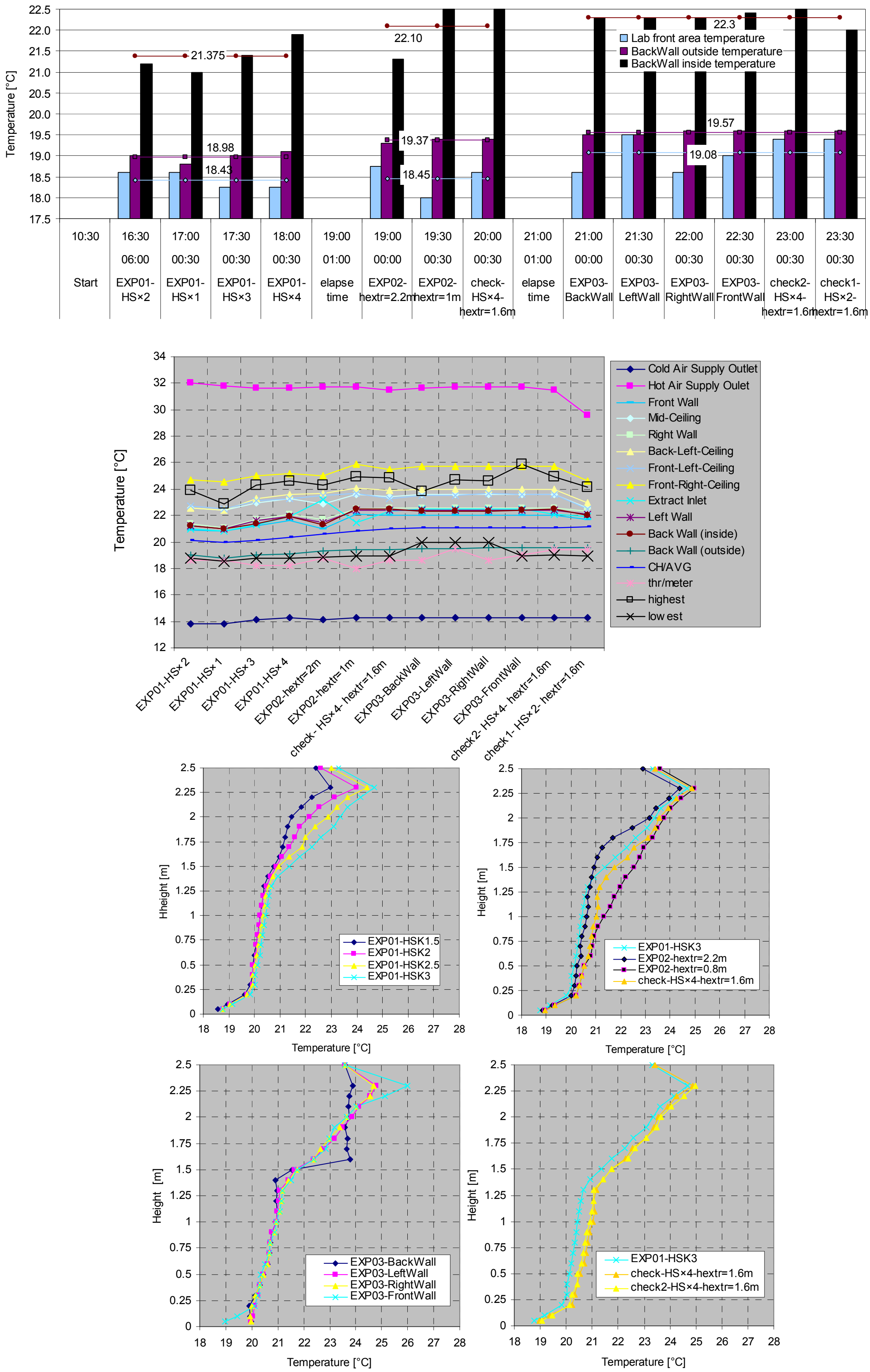


Figure A-7: EXP-11-12-00