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TEMPERATURE DISTRIBUTION IN A LARGE LIVESTOCK BUILDING

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SUMMARY

Chicken for meat production (broilers) are normally raised in large, open spaced buildings where the birds are free to move around on the floor. The ventilation system are designed as one system controlled with a single thermostat placed in the middle of the room, assuming this place to be representive for the whole animal zone.

In order to check this assumption, data on temperature was recorded in a 96 x 19 m. broiler house with wall height 3 m. and roof/ceiling slope 25°. The house contained 50000 broilers at their final stage, giving an estimated heat production of 670 kw, which should be removed by the ventilation system. The building was ventilated by an negative pressure ventilation system. Exhaust fan units were placed in the ridge. Wall inlets were installed behind wind-breaks under the overhangs.

The temperature distribution was measured with 15 thermocouples placed in 5 cross-sections of the room. During a recording time of 9 day, the ventilation system was able to maintain the room temperature at the thermostat within ±0.5°C of the set point value provided the outside temperature were below design value. The maximum temperature difference between the 15 measurements points was 4°C and less then 3°C for 98% of the time.

At an outside temperature of 20°C the maximum recorded room temperature was 25°C at the control sensor. The design criteria was thus met perfectly by the ventilation system.

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INTRODUCTION

Commercial production of broilers normally takes place in large open spaced buildings, where the broilers are free to move around on the floor. Temperature is important for the production result [1,2,3], and broiler producers strive to maintain indoor temperature differences within narrow limits. Previous research work has shown that in small buildings, small temperature differences can be achieved in a horizontal plane near the animal zone [4,5]. One measuring point could thus be found to be representative for the overall temperature. Within large buildings the interest of controlling the overall temperature within narrow limits is still the same, but it may be harder to achieve.

The traditional ventilation of broiler houses is to supply outside air directly into the room air space without preheating and recirculation. In order to keep the indoor temperature at set-point when the outdoor temperature decreases, the air flow rate is reduced. The adjustment of ventilation air flow rate is carried out according to the indoor temperature set-point. This is usually performed by controller with a single control sensor placed in the middle of the building, assuming this place to be representative for the whole occupied zone.

The maximum design air flow rate for the ventilation system design is computed using a steady-state heat balance for the building, where the heat load from the broilers is the only heat source [6,7]. A design temperature of 25°C at an out door temperature of 20°C is normally chosen. Due to temperature dependence of the sensible heat from animals, this is equivalent to a design indoor, which corresponds to an indoor temperature of 30°C at an outdoor temperature of 27°C. In Denmark, an outdoor temperature higher than 27°C occurs only about 1%, according to the reference year [8].

In order to find out how representative the sensor temperature was in a large building, temperature distribution was recorded in a commercial broiler house. The measured indoor temperatures at high outdoor temperatures were compared with the commonly used design criteria, using a temperature lift.

FACILITY

Building:

The broiler house was situated on a farm in the mid-east of mainland Denmark. It was an insulated steel-frame building with brick walls and light gray asbestos-concrete plate covered roof. The floor area was 96m x 19m = 1.825m², wall height 3.0 m and roof slope of 25°. The south wall and west gable end were facing open fields, the north wall was partly facing open field and partly shielded by a neighbouring building. The east gable end was shielded by a wood nearby.

Ventilation System:

The house was ventilated by an automatically controlled, negative pressure system. Exhaust fan units were placed in the ridge and inlets behind wind-breaks under the overhangs, figure 1.

Fig. 1. Photo of the broiler house seen from south-west.

Outside air was supplied through wall inlets, figure 2. The casing and flap were made of polyurethan foam with hardened surfaces. The maximum opening area was 0.1 m^2. The air flow rate at 10 Pa pressure difference was 1075 m^3/h [9,10]. The total number of inlets was 144. Exhaust fans were installed in Ø650mm fibre glass chimneys with outlet diffusers extending above the roof. The number and the performance of the exhaust fan gives 155000 m^3/h calculated maximum supply air flow rate at 10 Pa pressure difference.

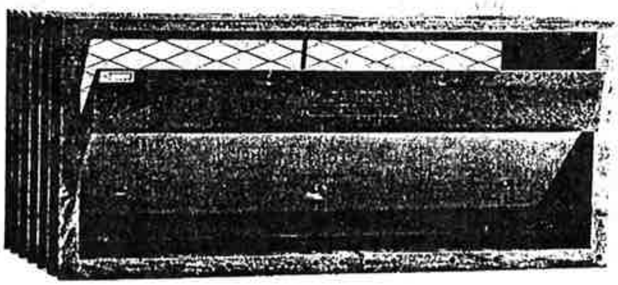

Fig. 2. Close-up of a wall inlet seen from the room side.

Control System:

The inlet and exhaust units were controlled by a climatic computer. Inputs to the computer came from a temperature sensor (the control sensor) and a humidity sensor placed in the middle of the center section.

The opening area and the air jet direction from the inlet was controlled by a flap that was hinged at the bottom edge. The flap was pulled open by a wire, and it was closed by a spring as the wire pull was released. Inlet flap position was controlled by wire-and-rod connection to a powered winch. The exhaust units had fan speed control and sliding dampers to take over control at low fan speeds.

MEASUREMENTS

Period:

Temperature recording started at 9 P.M. on 19 August 1991 and terminated at 5 P.M. on 28 August 1991. The broilers were in their final stage of brooding when the recording started, and the recordings continued until delivery.

Procedure:

A total of 15 T-type NKT copper/constantan thermocouples was placed 0.5 m above the floor. The sensors were placed in 5 cross-sections of the house, two at 8 m from the gable ends and the remaining three at 20 m distances in between.

In addition to the room temperatures, air supply temperatures were measured in the inlets on both sides of the centre cross-section. The outside temperature was measured under the overhang near the north-east corner of the house.

The thermocouples were connected to a data taker type DT-100 version 3.5 from Data Electronics. A temperature sensor, type AD590 from Analog Device was used for the reference junction.

All sensor signals were scanned every 5 minutes and average values were calculated and saved every hour. The measured data were saved in the datalogger and later downloaded to a PC.

Weather Data:

Only outside temperatures were recorded on the site. Other weather data were available from the weather station at NIAE,SjF-Bygholm approximately 10 km to the north-east.

RESULTS AND DISCUSSION

Weather:

The temperature varied from 9.4°C to 26.0°C with an average of 16.1°C. Midday irradiation values were between 300 W/m² and 500 W/m². Sunny days and clear nights have resulted in 24 hour temperature fluctuations of 5-15°C.

The weather was fairly calm with an hourly average of 3.7 m/s and a maximum of 7.9 m/s. The winds were from west the first few days, then turned south east for a couple of days and ended up north-westerly for the remaining days.

Supply Air Temperatures:

The supply air temperatures were measured in the center inlet of the south and the north sidewalls. The difference between the supply and the outside air temperature is shown in figure 3.

The supply temperatures were equal to the outside temperatures within ± 2°C. Supply temperatures higher than the outside temperature occurred only for the inlet in the south wall, and only at midday. It is reasonable to assume that the temperature lift was the consequence of solar heating of the sidewall. The peaks were only present at the beginning and at the end of the measuring period. The reason is probably that the wind direction was west to north-west during these days, so the south wall was allowed to warm up, while on the other days, the wind removed the heat.

Supply temperatures were equal or lower than the outside temperature all the time for the north wall inlet and most of the time for the south wall inlet. It looks as though southern winds tended to create a negative supply temperature lift. This can be explained by the slight heating of the air at the sensor due to transmission heat losses from the broiler house. No temperature measurements were made in a free standing weather station on the site, so no data are available to evaluate this as a probable cause.

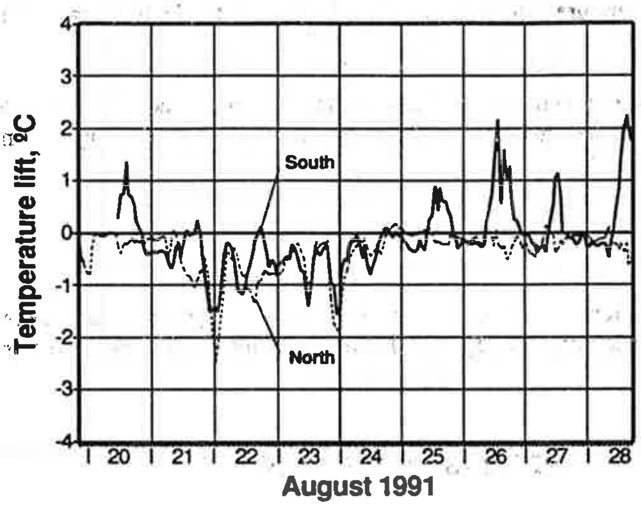

Fig. 3. Differences between outside temperature and supply air temperature for the center inlet in the south and north facing sidewalls.

Except for two negative peaks at night with nearly no wind, supply air temperatures where within 0°C to -1°C of the measured outside air temperature.

Room Temperature at the Control Sensor

The room air temperature in the middle of the centre section of the house has a special significance, because it represents the temperature at the control sensor. The ventilation and control systems tried here to maintain the room temperature at the set-point value. Analysis of temperature variations at this location will thus reflect the quality of system control.

The heat produced by the broilers was grabbed as a temperature rise in the ventilation air and exhausted from the house. A certain temperature increase is therefore to be accepted. The recommended design value is an acceptable room temperature of 25°C at an outside temperature of 20°C. When the outside temperature rises above the value at which the ventilation system runs at design/maximum air flow rate the room temperature will also rise.

The variation of the outside temperature and the temperature at the control sensor is shown through the measurement period is shown in figure 4. Most of the time the room temperature was slightly above 20°C. During midday the outside temperature became too high for the system to be able to maintain a room temperature at the set-point value.

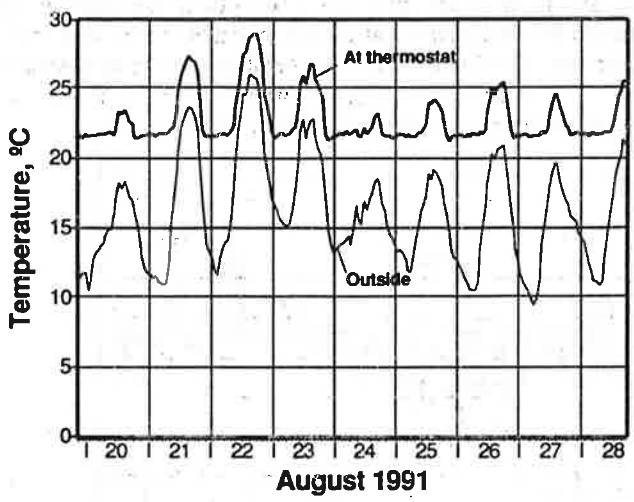

Fig. 4. Variations of outside temperature and temperature at the control sensor.

System Control:

The performance of the system control is shown in figure 5, where the temperature at the control sensor is plotted as a function of the outdoor temperature. The room temperature was maintained at a constant level at outside temperatures below 16°C. As the outside temperature increased above this value, the room temperature followed suit.

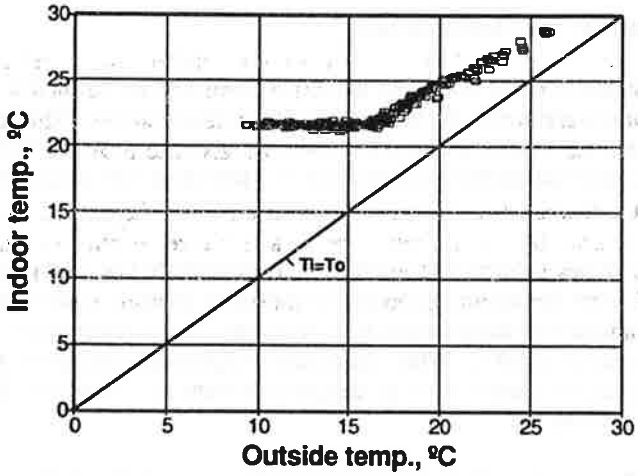

Fig. 5. Temperature variation at the control sensor as a function of outside temperature.

When the ventilation system was in control, the set-point value was kept at 21.5°C which the system was able to maintain within ± 0.5°C. At outside temperatures above 16°C, the ventilation system was running at maximum capacity. Further increases in outside temperatures resulted in higher room temperatures, figure 6. At an outside temperature of 20°C it is seen that the maximum recorded room temperature was 25°C. The design criteria was thus met perfectly by the ventilation system.

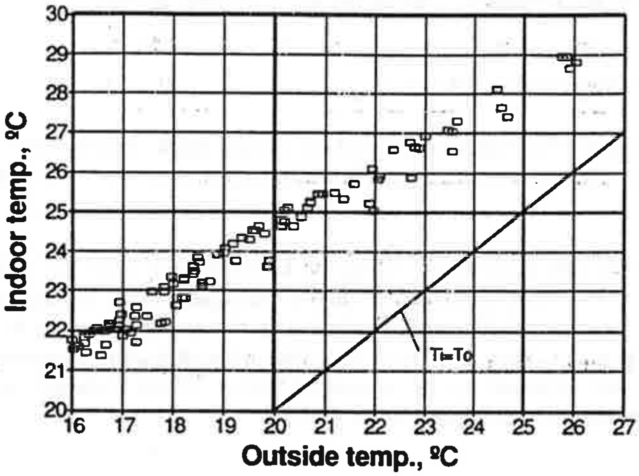

Fig. 6. Temperature at the control sensor as a function of the outside temperature for hours when the outside temperatures were too high for the ventilation system to be in control.

The following two things are worth noting:

- Firstly, the temperature lift decreases as outside temperature increases, e.g. from 5°C at 20°C to 3.5°C at 25°C. This is according to the theory [7,11]. The amount of sensible heat from the animals decreases at increasing temperature, and consequently the temperature lift will also decrease.

- Secondly, the temperature lift was in many cases lower than specified above. The reason is probably that the wind created an increased ventilation, resulting in a reduced temperature lift. This is supported by the fact that peaks in wind velocity often occurred simultaneously with peaks in outside temperature and solar irradiation.

ROOM TEMPERATURE DISTRIBUTION IN THE HOUSE

The ventilation system had only direct information of the room temperature at the control sensor. Temperatures elsewhere in the house depend on factors such as distribution and adjustment of inlets, solar heating of the supply air and movements of birds within the building, e.g. during inspection.

The measured room temperatures are discussed below as absolute values and as differences relative to the temperature measured at the control sensor.

Maximum Room Temperature Differences:

The variation of the absolutly highest and absolutly lowest room temperature is given in figure 7. The room temperatures ranged from extremely low, 20°C to extremely high, nearly 30°C.

In general the maximum and minimum temperatures followed each other at a difference of 2°C. There were a few exceptions, though. There was a peak in the maximum room temperature on the morning of 20 August, which was not accompanied by a similar peak in the minimum curve. There are also a few dips in the minimum temperature on 23 and 24 August, not followed by the maximum curve. These instances take the maximum differences in room temperatures to 4°C.

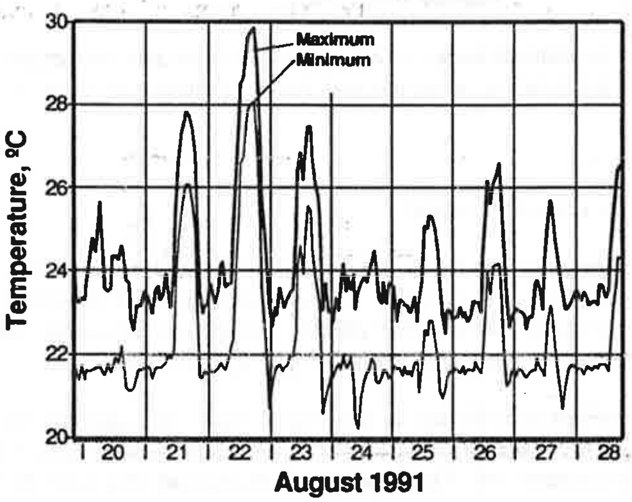

Fig. 7. Variation of the temperature at the warmest and the coldest measuring point in the house.

Plotting the room temperatures as a function of the outside temperatures gives a clearer picture of the general trend, figure 8. The atypically high and low room temperatures are seen to occur at outside temperatures of 12-16°C. The general difference of 2°C is clearly visible.

A frequency distribution of the difference between the absolute maximum and absolute minimum hourly room temperature is given in figure 9. For 55% of the time the maximum difference was less than 2°C and for 98% of the time less than 3°C.

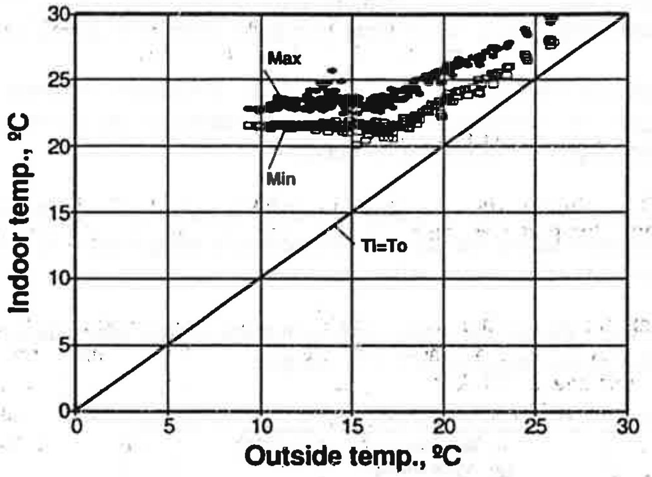

Fig. 8. Temperature at the warmest and the coldest measurering point as a function of the outside temperature.

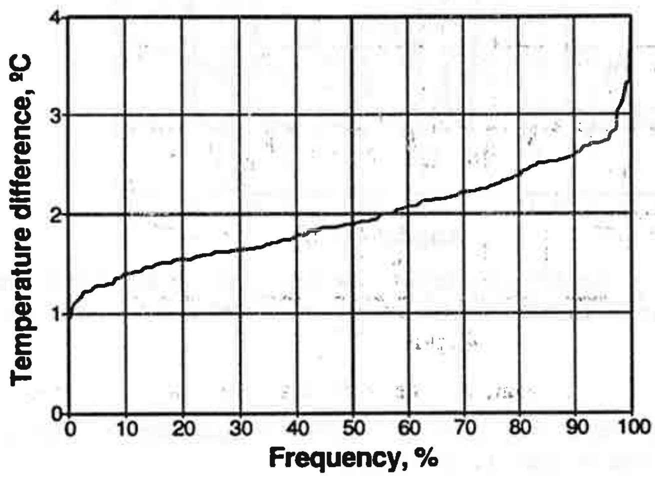

Fig. 9. Frequency distribution of the temperature difference between the warmest and the coldest measuring point.

Differences Between Maximum, Average and Minimum Room Temperatures and the Temperature at the Control Sensor:

The temperature at the room control sensor was shown above to be closely controlled by the ventilation system. The question is then how representative the temperature at the control sensor is for the different measurement points in the room.

During the nights, the trends was that temperature at the control sensor was 1 °C lower than the average room temperature, while there was good agreement during day.

These trends are clearly seen in figure 10, where the differences between maximum/average/minimum room temperatures and the temperature at the control sensor are shown. The following conclusions can be drawn:

- The temperature at the control sensor was fairly representative of the average room temperature during the day, with temperatures being from 1 °C colder to 1-2 °C warmer at other places within the room.

- During the night the control sensor represented the coldest spot with temperatures at other places being up to 1-2 °C warmer.

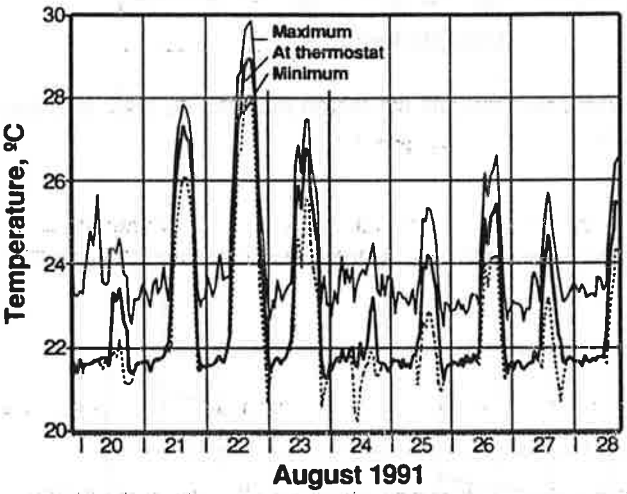

Fig. 10. Variation in the difference between the temperature at the control sensor and the temperatures in the warmest and the coldest spot as well as the average of all room temperatures.

On a diurnal basis these conclusions may further be quantified by looking at the frequency distribution in figure 11. It is seen that:

- it was slightly warmer at the control sensor (up to 0.5 °C) than the average for 30% of the time. It was colder (down to 1.5 °C) for the remaining 60%.

- it was slightly warmer at the control sensor (up to 1.5 °C) than at the coldest spot for 50% of the time. The control sensor place was representative of the coldest spot for the rest of the time

- it was colder at the control sensor (at least 0.5 °C) than at the warmest spot all the time and at least 1.5 °C colder for more than 50% of the time.

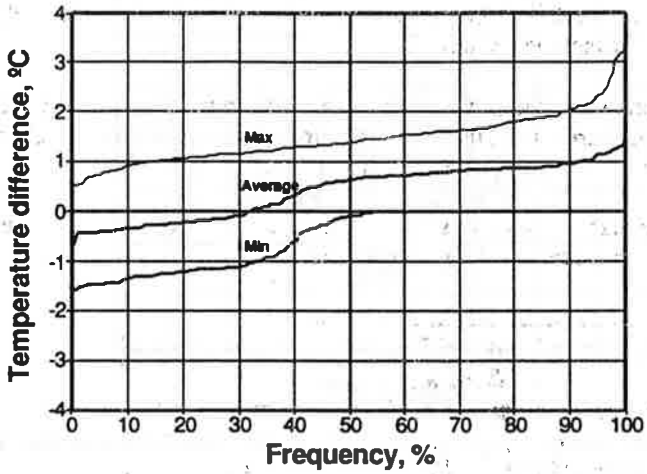

Fig. 11. Frequency distribution of the maximum, average and minimum temperature differences between all measurement points and the temperature at the control sensor.

Variations Across the House:

Room temperature variations across the house are illustrated by the conditions at the center cross section, figure 12. The general trend is that:

- during day it was 1 °C colder near the side walls than in the middle.

- at night it was 0.5 °C warmer near the side walls than in the middle.

The trends are the same in other cross-sections, but variations along the building tend to blur the general picture.

Variations along the house:

Room temperature variations along the house is illustrated by the conditions at the middle of the house, figure 13. The general trend is that the room temperatures are slightly higher at the two gable ends than at the center section of the house.

The peak warm deviation from the temperature at the control sensor took place near the eastern gable in the morning of 20 August. The extreme cold deviation from the temperature at the control sensor took place near the western gable end during the day on 24 August. These atypical temperature peaks may be due to the birds being disturbed and concentrating in one end of the house.

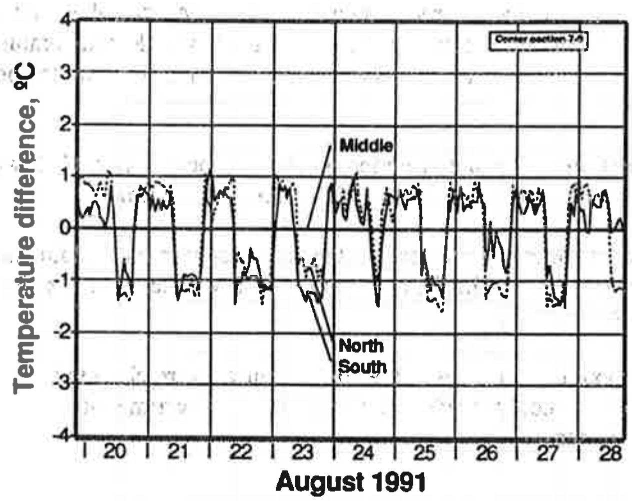

Fig. 12. Differences between room temperatures in the center cross-section and the temperature at the control sensor.

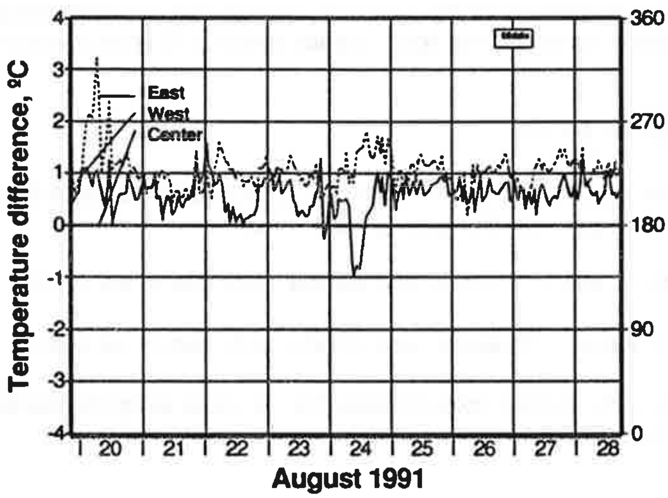

Fig. 13. Differences between room temperatures along the middle of the house and the temperature at the control sensor.

CONCLUSIONS

At an outside temperature of 20°C the maximum recorded room temperature was 25°C at the control sensor. The design criteria was thus met perfectly by the ventilation system.

The system was able to maintain a room temperature at the control sensor within ±0.5°C at outside temperatures below 16°C. At higher outside temperatures the ventilation system was running at maximum capacity, and the room temperature increased.

The maximum temperature difference recorded within the house was 4°C. It was less than 3°C for 98% of the time and less than 2°C for 55% of the time.

In general, the room control sensor represented the coldest spot in the building at night. Temperature differences were small, though, being 0.5°C warmer near the side walls than at the control sensor.

During the days the room temperatures at the control sensor were close to the building average. It was 1°C colder near the side walls and 1.0-1.5 °C warmer at the two gable ends than at the control sensor.

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