BSRIA

uilding services technology

NIGHT COOLING CONTROL STRATEGIES - SITE MONITORING RESULTS

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1. INTRODUCTION

This report is the second in a series produced as part of project 11621 entitled "Night Cooling Control Strategies". Night cooling is a technique of utilising the diurnal ambient air temperature swing to cool the fabric of a building. The thermal mass of the cooled fabric acts as a store until the following day where it becomes a heat sink and assists in offsetting heat gains and limiting the temperature rise. Night cooling, in conjunction with other measures eg solar shading, has been demonstrated to be very effective in limiting temperature rise (peak temperatures can be up to 5-6K below the outside air temperature). However, although the technique itself is known to be effective, the buildings currently utilising it apply different techniques to control night cooling eg variable floor slab temperature setpoint, degree hours or daytime outside air temperature exceeding a fixed limit. The controls could potentially vary from a simple time clock to complex algorithms that predict the required night cooling based on recent history and prevailing conditions. It has not been established whether simple or complex controls are more effective. Therefore the project objective was to produce practical guidance on the application of control strategies for night cooling.

This report details the results of site monitoring in five buildings that use night cooling. The buildings were selected because each applied a different night cooling control strategy and used a combination of natural and mechanical ventilation. The five buildings included were the Inland Revenue building at Durrington, Inland Revenue buildings B and F at Nottingham, Ionica building at Cambridge and PowerGen building at Coventry. The buildings were monitored during spring to autumn 1995 and the analysis was concentrated on the summer period when peak night cooling was required. The monitored data comprised points logged by the building management system (BMS) of the particular building. The analysis investigated the operation and effectiveness of each night cooling control system and the correlation between night cooling and factors that could influence its performance.

2. DESCRIPTION OF BUILDINGS

2.1 INLAND REVENUE BUILDING DURRINGTON

2.1.1 General Building Description

Age:	Built 1993
Use:	Offices
Occupancy:	07:00-18:00 (Mon-Fri)

2.1.2 Construction

Exposed mass:	Flat exposed ceiling soffit (all floors).
Wall construction:	100mm brick, 50mm cavity, 50mm insulation, 190mm concrete block 12mm plaster.
Ceiling construction:	Flat exposed concrete soffit.
Floor construction:	Solid concrete carpeted floor.
Percentage/ type of glazing:	Approximately 30% of the facade was glazing of the clear type.
Solar shading:	External light shelves and internal blinds.
No of floors:	4
Central atrium?	Yes
Layout:	Open plan on two sides and cellular offices on two sides.
Floor area:	7500m^2

2.1.3 HVAC System

Ventilation:	A mixed mode system was used with natural ventilation from automatically controlled external casement vents and air extracted via internal vents to the central atrium and atrium vents. Mechanical ventilation was from a two speed supply fan (1.5 ac/h or 4 ac/h) to the zone and two speed extract fans in the atrium roof. The windows could also be manually operated to increase ventilation.
Heating:	The heating comprised of perimeter heating and a thermal wheel and heater batteries in the supply AHU's.
Cooling:	No mechanical cooling was available.

2.1.4 Daytime and night time ventilation controls

The building was divided such that each floor had four zones, (NE, NW, SE, SW) making a total of 16 zones. The setpoints for heating and cooling varied from month to month as follows:

	OAT heating enable (°C)	Heating setpoint (°C)	Cooling setpoint (°C)	Minimum permitted slab setpoint (°C)
Jan	18	21	23	19
Feb	18	21	23	19
Mar	18	21	23	19
Apr	17	21	23	18
May	17	21	22.5	17
Jun	16	20	22	16
Jul	15	20.5	22	15
Aug	16	20.5	22	14
Sep	17	20.5	23	15
Oct	18	21	23	17
Nov	18	21	23	18
Dec	18	21	23	19

OAT = Outside air temperature

Occupied heating

A deadband of 1K was applied, centred on the setpoint. If the average temperature fell below the setpoint minus half the deadband the AHU supplied air at the setpoint temperature. When the heating was on, the outer windows and atrium vents shut and the atrium windows opened. If the average temperature exceeded the setpoint plus half the deadband the heating switched off.

Perimeter heating was also available and was on only if the outside air temperature was below the heating enable setpoint.

Optimum start heating

If night cooling took place, the perimeter heating was inhibited until the building was occupied. If night cooling did not occur the perimeter heating was enabled according to an optimum start algorithm.

Occupied cooling

A deadband of 1K was applied, centred on the setpoint. If the temperature of a zone exceeded the cooling setpoint plus half the deadband the automatic windows of that zone opened. If the temperature of a zone fell below the cooling setpoint minus half the deadband the outer windows of that zone shut.

If the average room temperature exceeded the cooling setpoint by 1K the supply fans operated at low speed and continued to operate until the average temperature fell 0.5K below the setpoint. If the average temperature rose 2K above the setpoint the supply fans switched to high speed and remained at high speed until the temperature fell to 1K above the setpoint when it reverted to low speed operation. The following illustrates the heating and cooling setpoints, with deadbands, for July:

Temperature increasing		Temperature falling
High speed fans on	24	
	23.5	
Low speed fans on	23	High speed fans off
Cooling on (windows open)	22.5	
	22	
	21.5	Cooling off (windows shut/low speed fans off)
Heating off	21	
	20.5	
	20	Heating on.

Night cooling

At the end of occupancy the cooling by natural ventilation was maintained as required, for 1.5 hours. Following this, and provided the building was occupied within 24 hours ie not Friday night or Saturday night, night cooling was applied by opening the automatic windows and atrium vents for cooling by natural ventilation. This continued until the slab setpoint was achieved at which time the windows and vents were shut. If the slab setpoint was not achieved by the start of the low electricity tariff, the latest start time for mechanical night cooling to achieve the setpoint was calculated. The fans were only operated during the low tariff period. The windows remained open and the fans operated for the calculated period, or until the setpoint was achieved. The calculation included the basic cooling rate, temperature differentials between the slab and outside air and a factor for high wind speeds.

Slab temperature setpoint

The extent of night cooling was limited by the slab temperature setpoint and was off if the slab temperature fell below this level. The setpoint was automatically adjusted according to a series of rules (a weighting factor could be applied to all stages of calculation to include the relative importance of each one).

- Rule 1 This calculated the difference between the room setpoint and slab at the end of occupancy with the aim of both being equal. An offset was applied such that the winter aim was for the slab temperature to be higher than the room setpoint and lower in summer.

- Rule 2 This calculated the difference between the room setpoint and the room temperature at the end of occupancy, again with the aim of both being equal.

- The results of rules 1 and 2 were summed and referred to as the self learning value for that day.

- The self learning value was reduced if the slab temperature was significantly above the setpoint at the end of night cooling. For example the following illustrates the percentage of the self learning value to be applied at 100% weighting (full weighting).

ΔT (slab-slab setpoint) at end of night cooling	0	1	2	3	4	5
% of self learning value	100	20	5.9	2.7	1.5	1

- The self learning value was multiplied by the above percentage, the result being an adjusted self learning value that accounted for the success of night cooling the previous night.

- The self learning value was then added to the previous learning value and the result was the new self learning value. This calculation step was included to reduce the effect of, unusual days and to reflect trends. The limits on this addition were user adjustable and vary from 100% of the current days learning to 33% of the most recent learning added to 66% of the previous learning.

- The new learning value was added to the slab setpoint resulting in the new slab setpoint.

2.2 INLAND REVENUE BUILDING B NOTTINGHAM

2.2.1 General Building Description

Age:	Built 1994
Use:	Offices
Occupancy:	08:00-18:00 (Mon-Fri)

2.2.2 Construction

Exposed mass:	A "waveform" ceiling (not on the top floor)
Wall construction:	This was limited to brick load bearing piers.
Ground floor doors:	There were glazed doors 2.4m x 1.2m that could tilt by 5° or slide open. The doors had an integral blind.
Ceiling construction:	An exposed "waveform" concrete slab of 200-250mm depth.
Floor construction:	A carpeted raised floor, with the waveform concrete slab.
Percentage/type of glazing:	The proportion of glazing was approximately 75% and used triple glazing (U valve 1.2 W/m^2K).

Solar shading:	There was structural shading from the windows being recessed between deep load bearing piers and also light shelves. Automatic blinds were used and these shut overnight to minimise solar gains from the sun rising. The blinds were also re-positioned at 45° twice each day.
No of floors:	3
Central atrium?	No
Layout:	The building shape was a quadrangle with the central courtyard open to the ambient conditions.
Floor area:	$8500m^2$

2.2.3 HVAC System

Ventilation:	A mixed mode system was used with ventilation from openable windows and a four speed mechanical supply via a floor void. The air was extracted from (termed "towers") in each corner of the building (four in total). The stairwell roofs could raise and lower to vary the extract area and thus the ventilation rate. Also the stairwells were partially glazed to encourage ventilation from the stack effect. The extract from the top floor was via manually controlled motorised roof vents and not the stairwells.
Heating:	Perimeter heating was controlled locally.
Cooling:	There was no mechanical cooling.

2.2.4 Daytime and night time HVAC controls

The daytime tower enable was "on" providing the following conditions were satisfied:

- occupied period
- no security or fire alert
- wind speed < 8m/s
- temperature at top > 27°C
- average corridor temperature > 25°C
- outside air temperature > 12°C
- rain intensity < intermediate.

If the above conditions were satisfied the tower roof would raise and lower to vary the ventilation extract area and thereby control the ventilation. The tower opening (%) was varied between 0-100% depending on the tower temperature. The actual opening (m) was also variable and controlled from a combination of outside air temperature, wind speed and direction and rain intensity. Therefore the actual opening could vary although the tower temperature called for the same percentage opening. Wind speed and rain were combined in one lookup table such that worsening rain at one wind speed or increasing wind speed at a particular rain intensity resulted in the opening being reduced. There was also a scaling factor applied depending on the wind direction and outside air temperature. If the wind was from the South West then the scaling factor was 1 ie the tower height was 100% of that determined by the combination of tower temperature, wind speed and rain. If the wind was from the North, South, West or South West the scaling factor was 0.95 and from the East, North East or North West 0.9. A scaling factor was also calculated according to outside air temperature. For example if the outside air temperature was 12-14°C the scaling factor was 0.85, 14-16°C 0.9, 16-20°C 0.95 and above 20°C 1.0. The lower scaling factor between wind direction and outside air temperature was multiplied by the tower opening to provide the actual tower opening.

Daytime ventilation control of ridge vents

The ridge vents (for top floor extract) were enabled during the daytime for local control provided:

- it was the occupied period
- the outside air temperature >10°C
- the wind speed <8 m/s
- the rain intensity < intermediate
- there was no security or fire alert

Daytime ventilation control of supply fans

The mechanical supply fans were enabled for daytime local control provided:

- it was the occupied period
- the outside air temperature >6°C
- the wind speed < 15 m/s.

Night cooling control

Night cooling was enabled providing the average outside air temperature that day between 12.00-17.00 exceeded 18°C. The night cooling was then operational if the following criteria were satisfied:

- night cool period
- outside air temperature >12°C
- inside air temperature > outside air temperature
- inside air temperature > 15.5°C with a 3K deadband centred on the setpoint.

The wind speed, rain, security and fire interlocks used for daytime control also applied.

If all of the above controls were satisfied the stairwell tower opened fully, the supply fans were on and the ridge vents opened.

2.3 INLAND REVENUE BUILDING F NOTTINGHAM

2.3.1 General Building Description

Age:	Built 1994
Use:	Offices
Occupancy:	08:00-18:00 (Mon-Fri)

2.3.2 Construction

Exposed mass:	See 2.2.2.
Wall construction:	See 2.2.2.
Ceiling construction:	See 2.2.2.
Floor construction:	See 2.2.2.
Percentage/ type of glazing:	See 2.2.2.
Solar shading:	See 2.2.2.
No of floors:	4
Central atrium?	No
Layout:	The building was L shaped
Floor area:	5700m^2 (approx)

2.3.3 HVAC System

See 2.2.3 (building B description). Three ventilation extract towers were used in the L shaped buildings, one main tower and two slave towers that operated under the control of the main tower.

2.3.4 Daytime and night-time HVAC controls

See 2.2.4

2.4 IONICA BUILDING CAMBRIDGE

2.4.1 General Building Description

Age:	Built 1994
Use:	Offices
Occupancy:	08:00-18:00

2.4.2 Construction

Exposed mass:	Coffered concrete ceiling on all floors.
Wall construction:	The construction varied between the North and South facades with 100mm brick, 50mm cavity, 25mm insulation, 150mm block on the North facade and a lightweight curtain wall on South facade.
Ceiling construction:	Exposed concrete ceiling with a slab depth of 250mm.
Floor construction:	Carpeted raised floor with hollow core floor slab.
Percentage/ type of glazing:	Glazing accounted for approximately 60% of the South facade.
Solar shading:	Sunshade louvres and internal blinds.
No of floors:	3
Central atrium?	Yes
Layout:	Cellular offices and open plan on North side, open plan on South side.
Floor area:	4000m^2

2.4.3 HVAC System

Ventilation:	The cellular offices had mechanical supply and extract. The open plan areas were naturally ventilated with motorised casement vents on the external facade and air exhausted through wind towers on the atrium roof. The operation of casement vents was manually controlled during the day and automatically controlled at night for night cooling. In addition to the casement vents the windows could be opened manually. The open plan areas could also be mechanically ventilated if required. The mechanical ventilation was a displacement system with air supplied to the room via a hollow core slab and floor void. Only the South West zone operated a mixed mode system with the other three zones (South East, North West and North East) being mechanically ventilated.
Heating:	Perimeter heating was supplied scheduled on the outside air temperature. The mechanical system included frost protection, a thermal wheel, heat pump and electric reheater to supply at a constant temperature of 18°C.

Cooling:	There was evaporative cooling on the mechanical extract before a thermal wheel between the supply and extract The heat pump could also be used for cooling but its operation had to be manually initiated.

2.4.4 Daytime and Night time HVAC Controls

South West zone (mixed mode)

The operation of the HVAC plant (day or night) was divided into 11 modes.

Mode	Period (day, night, any)	Did the control apply if night cooling was "on" (Yes/No/NA)	Control setpoint	Control action
0	-	-	-	Plant off
1	Night	No	Average zone < 19°C	Heating optimum start - perimeter heating on, AHU on full recirculation
2	Night	Yes	Average zone > 20°C	Cooling optimum start - natural ventilation
3	Any	No	Average zone <18°C	Emergency heating - perimeter heating on, AHU + heating constitutes [(1)] on
4	Night	No	Average zone <19°C	Winter night operation - AHU on full recirculation
5	night	No	Average zone >19°C, outside air <7°C outside air periods day <24°C	Mid season night operation - plant off
6	Night	No	Average zone >19°C, outside air > 7°C, outside air previous day < 24°C	Summer night operation - plant off.
7	Night	NA	Average zone >19°C, outside air > 7°C, Zone air previous day > 24°C	Night cooling - natural ventilation
8	Day	Yes	Outside air < 14°C	Winter day operation - perimeter heating on, AHU + heating constituents [(1)] on (to supply 18°C)
9	Day	Yes	Average zone <26°C, outside air > 14°C	Mid season day operation - natural ventilation
10	Day	Yes	Average zone >26°C, outside air > 14°C	Summer day operation - AHU[(1)] and cooling [(2)] constituents on (18°C supply)

(1) Frost heater, thermal wheel, heat pump, electric reheat.
(2) Evaporative cooler, heat pump (heat pump cooling must be manually initiated).

Other zones (mechanical ventilation)
The South East, North West and North East zones operated in a similar manner to the South West but did not have natural ventilation available. For example under mode 2 the control setpoint was the same but the AHU, thermal wheel and evaporative cooler were on. Mode 7 in these zones also operated the AHU, thermal wheel and evaporative cooler and the South East also had the heating constituents on and supplied at 18°C but the North West and North East operated under the control of a self learning algorithm. The daytime operation of the South East, North East and North West was to supply at 18°C with all plant on, except heat pump cooling which was manually initiated. The priority sequence of heating plant operation, to maintain the 18°C supply temperature, was thermal wheel, heat pump Stage 1, heat pump Stage 2 then electric re-heat. The cooling plant sequence was evaporative cooler, heat pump Stage 1 then heat pump Stage 2.

Natural Ventilation Operation (South West only)

Modes 7 and 9 operated the South West zone under natural ventilation. High level motorised windows were manually controlled (one controller per bay) and linked to the two other windows per bay. Other windows could also be manually opened. The atrium rooflights and wind tower doors were automatically controlled with the roof lights divided into North and South and the six wind towers individually controlled. Their operation (once initiated by mode 7 or 9) was dependant on the wind speed and direction and rain. Rain inhibited the rooflights from opening. At low wind speeds (< 5.75m/s) both roof lights and tower doors were open. At higher speeds (up to 38 m/s) the roof lights shut and two wind towers opened (selected according to wind direction) and at speeds over 38 m/s all rooflights and tower doors were shut.

Night Cooling control (South West Zone)

The need for night cooling was determined by a degree hours calculation on the slab temperature. The degree hours were calculated by assuming the slab was at a fixed temperature of 21°C and measuring the deviation of the zone temperature from this limit. If the net degree hours at the end of occupancy was positive it was assumed that this proportion of heat had been absorbed. The zone air temperature was also monitored during the day and only if it exceeded 24°C for more than 1 hour was night cooling permitted. The night cool period was 9pm to 6am and operated until the heat extracted from the slab matched the heat absorbed by the slab during the day. The criteria to measure the night degree hours was different to the day. During the day the degree hours calculation included both heat gain and heat loss from the slab, i.e. zone temperature above and below 21°C to determine night cooling target. At night only the heat loss was calculated ie zone temperature below 21°C and periods where the zone temperature exceeded 21°C were ignored. A self learning algorithm calculated the target proportion of heat to be extracted from the slab under night cooling. The rate of heat absorbed during the day to target heat loss was generally 1:1 but could be varied depending on the deviation of the average zone temperature from the zone setpoint. The change was 2.5% per K deviation up to a maximum of 20% ie

Zone one - zone setpoint	Ratio of heat absorbed: heat extracted
-8	1:0.8
-4	1:0.9
0	1:1
+4	1:1.1
+8	1:1.2

2.5 POWERGEN BUILDING COVENTRY

2.5.1 General Building Description

Age:	Built 1994
Use:	Offices
Occupancy:	08:00 - 17:30

2.5.2 Construction

Exposed mass:	Coffered concrete ceiling on all floors.
Wall construction:	The wall construction was a 100mm brick panel, 25mm air gap and 80mm mineral fibre insulation with a 175mm cast in-situ concrete upstand and dry lining finish.
Ceiling construction:	Coffered concrete ceiling with lighting in the recesses. The slab depth was approximately 180mm in recessed areas and 720mm between recesses.
Floor construction:	Raised floor with a 410mm air gap and the concrete floor slab. The ground floor was above an underground car park.
Percentage/ type of glazing:	Double glazing accounting for approximately 55% of the South facing facade.
Solar shading:	External overhangs on South facing facade and roller blinds
No of floors:	3
Central atrium?	Yes
Layout:	Open plan North and South with some cellular offices at East and West ends.
Floor area:	-

2.5.3 HVAC System

Ventilation:	A mixed mode system was used with natural ventilation from automatically controlled top ribbon windows. The air was extracted via two rows of automatically controlled windows in the atrium roof. The windows in the occupied areas could also be opened manually. Mechanical ventilation was provided from four supply and extract fans which operated at two speeds (1.5 ac/h or 3 ac/h), with the air supplied via the floor void.
Heating:	There was perimeter heating and also heater batteries in the mechanical supply for pre-heat and main heat.
Cooling:	Ceiling fan coil units were located in six business areas on each floor. The business areas contained a concentration of office equipment. Cellular offices also had fan coil units.

Heat pumps were used for both heating and cooling and the waste heat from the cooling was supplied to radiators in the atrium roof to assist ventilation via the stack effect.

2.5.4 Daytime and night time HVAC controls

Daytime natural ventilation

The following describes the operation of the ventilation system during the day:

Event	Action
Zone temperature (any zone) >23°C	Natural ventilation operated. The windows in that zone opened together with the atrium windows on opposite to provide cross ventilation.

The natural ventilation operation was subject to the interlocks described below:

Event	Action
Outside air temperature > zone temperature (any zone)	The windows in that zone closed. The atrium windows were only shut when the temperature of all three zones of the particular facade were less than the outside air temperature.
Windward wind speed (measured by pressure) > 2.5 m/s	The windward zone and atrium windows were closed.
Windward wind speed > 5m/s	The leeward zone windows were closed.
Windward wind speed > 10m/s	The leeward atrium windows were closed.
Rain	All windows were closed.

Daytime heating

All automatic windows were closed.

Daytime mechanical cooling

If the zone temperature exceeded 25°C the windows were shut and the mechanical ventilation and cooling system was enabled.

Night cooling

Night cooling was utilised providing the following conditions were satisfied:-

Average daytime zone temperature at the end of occupancy > 23°C.
Outside air temperature the previous day > 21°C.
Heating system off for the summer.

If the above criteria were satisfied night cooling operated by fully opening all office and atrium windows. During the night cool period the operation was subject to the interlocks described below:

Event	**Action**
Zone temperature (any zone) < outside air temperature	The windows of that zone were closed.
Zone temperature (any zone) < 18°C	The windows of that zone were closed.
Rain	The windward office and atrium windows were closed.
Wind speed of 5-15 m/s	The windward office and atrium windows were progressively closed (all closed at 15 m/s).
Wind speed > 20 m/s	The leeward windows were closed.

3. RESULTS

3.1 OVERVIEW

The data collected was from the building management system (BMS) of each building. There were a number of problems with the data which limited the scope of the analysis and the following is a summary of the problems:-

- The data supplied to BSRIA from PowerGen recorded temperatures only with no plant data or record of wind speed/direction.
- At the Inland Revenue, Nottingham, some files were deleted on site by a third party. Also a lack of computer storage capacity on site resulted in the logs stopping when the capacity was reached.
- The data supplied to BSRIA from Ionica had many gaps and there was little crossover between the period covered by the mode and temperature data.

Data for three of the five buildings was supplied by the BMS contractor for the site. At PowerGen the contractor could only provide temperature data because setting up additional logging was not feasible. At Ionica the contractor had difficulties with saving logged data.

The analysis of the data included investigating the relationship between different variables. Regression and correlation analyses were performed using an EXCEL spreadsheet. The regression analysis calculated the best linear fit using the least squares method. It included the coefficient of determination (r^2) which is a measure of the relationship between the variables (o = no relationship, 1 = perfect correlation). The correlation coefficient (r) was also calculated and again a figure of zero demonstrated no correlation but the value could vary between ±1. A correlation coefficient of +1 indicated a perfect correlation with a positive slope and -1 a perfect correlation with a negative slope. The coefficient of determination and correlation coefficient are separate statistical functions but for linear regressions the coefficient of determination is the square of the correlation coefficient.

If there is no correlation between the two variables it is still possible that a falsely high correlation (positive or negative) could occur by chance. This was tested for by the following calculation:-

$$\frac{r\sqrt{(n-2)}}{\sqrt{(1-r^2)}} \geq t_{\alpha/2,n-2}$$

r = correlation coefficient
n = sample size
t = t - distribution.

The following table illustrates the critical correlation coefficient value for different sample sizes for $t_{0.025, n-2}$:

Sample size	Critical r value
5	0.75
10	0.58
15	0.48
20	0.42
25	0.38
30	0.35
50	0.27
100	0.20

The highest critical r value is 0.75 for a sample of five and below this limit the result may be due to chance. A r value of 0.75 was too small to be considered significant for this project and was not included in the data analysis. Therefore it can be assumed that the correlations investigated were genuine and not due to chance.

The criteria for success of night cooling was the zone temperature drop during the night cool period. The alternative was slab temperature change, but this was not measured at every site and the daily changes were generally very small.

The accuracy of the outside air temperature sensors was checked at each site. The sensors were found to be within ±1K of the actual reading with the exception of the Inland Revenue at Nottingham which was reading high:

Date	5/9/95
Time	15:00
	Outside air temperature (°C)
BMS	19.4
BSRIA Spot check	16.3

3.2 INLAND REVENUE BUILDING, DURRINGTON

The data from the Inland Revenue Building at Durrington was the most complete of the monitored sites and included zone, slab and outside air temperatures, mode of operation for the heating and ventilating system and wind speed and direction. The results from the Inland Revenue Building, Durrington are provided in Appendix A1.

3.2.1 Building Performance

One technique to assess a building performance in summer is to calculate the number of occupied hours above selected temperature limits and this is illustrated in Figures A1.1 and A1.2 (August and September respectively). August was a very hot month compared to September. In August nearly two thirds of the outside air temperature hours were above 22°C compared to approximately 7% in September and the peak August temperature was 37°C, 12K higher than the peak September temperature. In contrast the internal temperature peak in August was 28.5°C only 4.5K above the September peak. The temperature limit at which the outside air temperature hours exceeded the zone hours was 25°C in August and amounted to approximately 50% of the total hours. An indication of the good performance achieved at Durrington was that a zone temperature of 26°C was exceeded on less than 20% of occupied hours. Also the point at which the outside air temperature hours above fixed temperature limits exceeded those of the zone air temperature was similar for August and September (25°C and 24°C respectively) although the conditions between the two months varied greatly.

Figure A1.3 demonstrates graphically the good performance achieved at Durrington. This figure illustrates an example week in which the outside air temperature exceeded 28°C each day, peaking at 34°C. It shows that the zone temperature peaked 4K below the outside air even though it was subjected to casual and solar heat gains and heat conduction in addition to the hot outside air being circulated in the zone (the mechanical ventilation system operated if the zone temperature was above 23°C in June, July or August and the automatic windows opened at 22.5°C). Table A1.1 provides information on the alternative modes of operation. The mode operation illustrates that mechanical ventilation was used almost exclusively during the daytime due to the high zone temperatures. It also shows the effectiveness of night cooling in reducing the zone temperature by approximately 4K. Each night both natural and mechanical ventilation were applied and the use of mechanical ventilation did not result in a change in the rate of cooling. Figure A1.4 shows the relationship between the success of night cooling (zone temperature drop) against the ratio of night cooling by natural ventilation to total night cooling hours. The bad weather condition prevented some night cooling and therefore the graph includes two plots, one for 6-9 hours total night cooling and the other 10-13 hours. The graphs show a wide scatter of results with no discernible pattern. This demonstrates that night cooling was not more successful with a high proportion of natural ventilation or mechanical ventilation.

Figure A1.5 shows the same period as Figure A1.3 but includes the change in slab temperature. Over the 5 day working week the slab temperature rose by over 2K as it absorbed the heat gains in the zone. Night cooling was not successful in reducing the slab temperature and merely prevented further increase. During each daytime period the temperature rose by approximately 0.5K before stabilising on the Friday. Towards the end of the week the daytime slab temperature approached but never exceeded the average zone temperature. This figure shows the importance of considering trends over periods greater than the previous day when considering night cooling control. It also demonstrates that the slab was capable of significant temperature changes over a short period when subjected to a change in ambient conditions.

Figure A1.6 shows an example week in autumn. Night cooling was still being carried out as the slab setpoint was 18.5°C compared to an actual slab temperature of 22-23°C. The figure shows that the effectiveness of night cooling (zone temperature drop) under natural and mechanical ventilation was similar on two days and more effective with mechanical ventilation on two days. This indicates that natural ventilation was effective but could be beneficially supplemented with mechanical ventilation. On the Thursday evening the effect of a bad weather condition can clearly be seen. The zone temperature fell with night cooling but then began to rise when a bad weather condition shut the vents. It continued to rise until mechanical ventilation was utilised.

The requirement for pre-heating following night cooling is shown in Figure A1.7. This typically occurred when night cooling was applied on a Sunday evening following a prolonged (weekend) off period. The zone temperature was cooled from 23°C to 20°C with natural ventilation, followed by a 1K rise with a bad weather condition and a 2K drop with mechanical ventilation. Over cooling occurred and, at the beginning of occupancy, heating was required for 2 hours. The temperature increased by 2K during heating. The outside air temperature was below the perimeter heating enable setpoint and therefore both perimeter and AHU heating would have operated. The slab temperature was above the air temperature and would also have contributed heat to the space. Therefore it is not clear why it took two hours to achieve a modest temperature rise. One possible explanation was that the zone temperature shown was the average of all the zones and at the beginning of heating there was a 5.3K difference between the hottest and coldest zones. Therefore although the average was increased by only 2K, some zones required more heating than others. It should be noted that the need for heating was minimal (6 hours) for the monitoring period of 18 June-17 October 1995.

3.2.2 Summary of daily temperature data and building mode of operation

Tables A1.2 to A1.4 show a daily summary of the building mode and temperature conditions. The tables are divided into June to July data (A1.2), August data (A1.3) and September to October data (A1.4). Table A1.2 shows that night cooling by natural and mechanical ventilation were used equally (92 and 86 hours respectively) although the bad weather condition (60 hours) prevented a much greater use of natural ventilation. In August (Table A1.3) the bad weather condition occurred more frequently (83 hours) and limited the natural ventilation use to 52 hours compared to 123 for mechanical ventilation. In September and October the bad weather condition hours exceeded both natural and mechanical night cooling. The bad weather was detrimental to energy use because the fans operated. The excessive use of the bad weather interlock indicates that the limits for wind speed and direction and rain limits may have been set too low. Other sites did not experience similar bad weather periods. The peak night cooling achieved (all periods) was a 4K drop in zone temperature but a figure of 1.5-2.5K was more typical. Night cooling was assisted by the average temperature difference between inside and outside overnight typically being 5-7K but this figure did vary between 2.1K (1 August) and 14.4K (29 September). The external conditions that occurred in summer 1995 were very unusual. CIBSE Guide A table A2.8 shows banded weather data for Kew 1959-68. The peak dry bulb temperature was in July (29°C) and the banded average that included this temperature, occurred on only 1.6% of the month ie one day every two years. However as Tables A1.2 and

A1.3 show this temperature was regularly exceeded during June, July and August 1995. In June and July, 29°C was exceeded on eight out of 25 days and in August on 14 out of 31 days and the peak temperature reached 37.3°C. This comparison demonstrates the extreme nature of the summer in 1995 when compared to a typical year. In contrast the peak zone temperature was 28.3°C, which occurred the day after the peak outside air temperature, and the peak zone temperature was typically 3-5K lower than the peak outside air temperature. The swing in daytime zone temperature varied from 0.9K to 3.2K and was typically 1.5-2.5K. This compares to the swing in outside air temperature which varied from 1.8K to 18.9K and was generally around 10K.

Table A1.5 illustrates the monthly variation in slab temperature and slab temperature setpoint. The average slab temperature increased by 2.4K from June to August and fell 3.1K from August to October and shows how the slab was influenced by the trend in ambient conditions. The slab setpoint demonstrated little variation over this period with the average setpoint only changing by 0.2K between August to September and 0.1K September to October. The difference between the maximum and minimum setpoint from August to October was only 0.7K. The small change in setpoint was due to the calculations involved. If the setpoint was not attained at the end of night cooling, the permitted change in setpoint was limited. Table A1.5 shows that the setpoint was not attained at any time and the minimum difference was during June (1.2K) and this month also demonstrated the largest change in setpoint (1.3K). From August to October the setpoint was maintained at 18°C-19°C and the difference between slab temperature and setpoint was high (maximum 7.8K). It only reduced as the average slab temperature reduced over these months.

3.2.3 Correlations between variables

Tables A1.6 to A1.8 illustrate the correlations between different variables for weekdays, Mondays and weekends respectively. Correlation coefficients vary between ±1 with +1 indicating a perfect correlation with a positive slope and -1 indicating a perfect correlation with a negative slope. Table A1.6 shows that a correlation (r=0.87) existed between the peak outside air temperature and the peak average zone temperature during the occupied period. Weaker correlations existed between the peak average zone temperature and the use of natural and mechanical ventilation. These correlations were expected because the daytime control changed from no controlled ventilation to natural ventilation and then mechanical ventilation as the zone temperature increased. There was also a weak correlation between the peak zone temperature and the wind direction. However the other factors investigated did not demonstrate a significant correlation. Therefore although the zone maximum was influenced by the outside air temperature it was not significantly affected by wind speed or direction. Wind speed and direction would have influenced the ventilation rates through particular zones but the most significant factor was the temperature of the ventilation air. Also the success of night cooling (measured by the zone temperature drop) was not significantly influenced, individually, by any of the following:

wind speed
wind direction
outside air temperature
temperature difference (zone - outside)
bad weather mode conditions
mechanical ventilation use.

In practise the success of night cooling would be governed by a combination of factors and the above demonstrates that no single factor could be identified as the primary influence.

Most of the correlation coefficients ranged between ±0.3 but there was a very weak correlation between the success of night cooling (zone temperature drop) and the application of natural ventilation (hours)(r=0.452). Table A1.7 (Monday data) shows the same results as the whole weekday data but the relationship between the success of night cooling and the application of natural ventilation at night is slightly stronger (r=0.55). However both of these correlations were too small to be significant and it was likely that this actually correlated the success of night cooling with the hours of night cooling, not specifically natural ventilation.

The relationship between the peak average zone temperature and peak outside air temperature is illustrated in Figure A1.8. It shows an intercept (outside air temperature 0°C) of 18.8°C, which would be consistent with heating, although the peak outside air temperature did not fall below 22°C during the period investigated. The coefficient of determination (r^2) was 0.724 and the correlation coefficient (r) 0.851.

Figures A1.9 and A1.10 show the seasonal variation of slab temperature with outside air temperature. The slab temperature can be seen to follow the variation in average daily outside air temperature. In August there were three peaks in average daily outside air temperature and these were followed by changes in the slab temperature. Towards the end of August the average daily outside air temperature fell, again matched by a fall in slab temperature. The correlation coefficient between peak outside air temperature and peak slab temperature was 0.727. If a lag was introduced, i.e. the peak outside temperature compared to the peak slab temperature of future days, the correlation improved:-

Lag	r
1 day	0.797
2 days	0.832
3 days	0.830

Figure A1.10 shows a regression analysis on the weekly average outside air temperature against weekly average slab temperature. The coefficient of determination (r^2) was 0.68 (r=0.825) indicating weak correlation although the data was limited to only 14 points. The relationship had an intercept of 17.5°C which shows the minimum that the slab temperature may be expected to fall to.

Table A1.10 shows the correlation between the peak zone temperatures on each floor and the outside air temperature. A strong correlation existed between each of the 16 zones and the outside air. However it was significantly lower on the ground and first floors of the south-west and south east facades indicating that these areas were less influenced by the outside air temperature. It may be that the ventilation of these areas was higher than other areas because of the beneficial combination of stack effect (when the inside temperature was greater than the outside) and prevailing wind direction. The correlation did not improve if a lag was introduced between the outside air day and zone day, unlike the slab temperature (see above). The variation of different zones with outside air temperature is also shown in Figures A1.11 to A1.14 which represent the north west, north east, south west and south east facades respectively. The data shows quite a large scatter but a linear regression was included in the plots. The north west facade (Figure A1.11) demonstrated that the peak zone temperature varied from approximately 21°C to 28°C. At the peak outside air temperature (28°C) the ground floor temperature could be expected to be 3-5K lower (24.5°C) and the third floor temperature 2.5K lower (25.5°C). Each floor shows the same slope of temperature increase with the exception of the first floor which became hotter than the second floor at elevated temperatures. However the first and second floor temperatures were very similar. The north east facade (Figure A1.12) was very similar to the north west with a 1K increase between the ground and third floors and a 3.5K difference between the ground floor zone temperature and outside air temperature at elevated temperatures (28°C outside air temperatures). Figure A1.13 shows the south west facade. The data for the south west facade showed less variation between floors. The regression demonstrated less than 0.5K difference between the ground and third floors. The difference between peak zone temperature and peak outside air temperature was 2.5K, 1K lower than the northern facade. The south east facade (Figure A1.14) followed the pattern set by the northern facade with a 1K difference between the ground and third floors and a 3K difference between ground floor peak and an outside air peak of 28°C. The first and second floor temperatures were similar. The differences in temperatures can be explained by the differences in thermal mass and probably ventilation. The temperature increase between floors may have been due to the stack effect having greater influence than wind on that facade. When the inside temperature was hotter than the outside there would be greater ventilation (and cooling) through the ground floor than the third floor. Conversely during periods where the outside temperature exceeded the inside temperature the ventilation may have acted in reverse, cooling the hot outside air. The cooling effect on the air would have been greater for the lower floors resulting again in cooler zone temperatures. The ground floor also had improved thermal effects from the ceiling slab and ground floor heat loss and was therefore the coolest. The first and second floors had similar thermal influences and demonstrated similar temperatures. This indicates the need for individual night cooling control to be applied to each zone.

Table A1.10 shows the results of linear regression analyses on the individual zone temperatures. The table is divided into three sections calculating the relationship between:-

- the outside air temperature and each average floor or facade temperature
- the ground floor on each facade to other floors
- the night cooling temperature of the ground floor of each facade to other floors.

As previously shown in Figures A1.11 to A1.14 there was a correlation between the peak zone temperatures and the peak outside air temperature. Table A1.10 demonstrated a significant correlation for the average of each floor and the average of each facade. The correlation was stronger for the northern facades than the southern and for higher floors than lower. This was particularly the case for the top floor (third) where the coefficient of determination (r^2) was 0.936. There was also a strong correlation between the peak temperature on the ground floor and that on other floors, particularly for the northern facades. The relationships developed in Table A1.10 demonstrated that the northern facade showed a temperature increase from lower to upper floors but this was much less defined for the southern facade. Table A1.10 also showed the night cooling temperature drop on the ground floor to the other floors. The northern facades demonstrated a significant correlation with the temperature drop diminishing from the lower to upper floors. The southern facade did not show a significant relationship between the ground floor temperature drop and the other floors. The explanation for this and difference in daytime correlations for north and south facades may be wind direction. If the wind direction was primarily onto the southern facade the ventilation (and therefore temperature) in the southern zones may have been less governed by the stack effect and more influenced by wind pressure. This would explain similar temperatures being experienced on all floors. By contrast the northern facade ventilation may have been more influenced by stack effect resulting a significant temperature gradient between the floors. One unusual result of the analysis was that the third floor north temperatures sometimes exceeded the third floor south. Table A1.11 provides a summary of the occurrences and shows that the temperature of the third floor north regularly exceeded that of the south during occupancy but not at all during night cooling. If it is assumed that both areas are subjected to similar casual heat gains the imbalance must be the result of ventilation. It could be further evidence of the different natural ventilation influences on the south and north facades, with the south benefiting from wind pressure effects and the north relying on the stack effect. There may also have been some cross ventilation if the stack effect driving forces were minimal on the third floor. In this case, hot atrium air could have exhausted though the third floor vents on the north side.

3.2.4 Weekend tests

The building was subjected to two weekend tests where the vents in some areas were manually shut and others were allowed to operate under night cooling control. Table A1.12 shows the night cooling performance for the first test (4-7 August) and also the peak zone temperatures for the Monday following the test and the Monday one week later. The zones on the northern facade showed a clear distinction between the floors with and without night cooling. For example the north-east demonstrated temperature drops of 3.1-3.4K in the areas night cooled but only 0.4-0.7K in the no night cooling areas. The same distinction could not be made for the south facade zones. Comparison of the Monday peak temperatures following the test and the next week (no test) did not provide a conclusion about the effectiveness of night cooling. The temperature difference between the first floor (night cooling) and second floor (no night cooling) for the north west and north east zones was 0K and -0.3K respectively. This compared to the next Monday when the temperature difference was 0K and 0.7K. Therefore the north-west demonstrated no advantage and the north east actually improved when night cooling was prevented. Figures A1.15 to A1.18 show the temperature profiles for each of the sixteen zones over the test weekend. The effect of night cooling can be seen in figures A1.15 and A1.16 (north west and north east respectively), however it was not clear exactly what was happening. For example on the Friday evening the night cool areas demonstrated a dramatic temperature drop of 3K until midnight followed by an equally dramatic temperature rise back to the level of the no night cool areas. There was a further fall from 4 to 8 am. One potential explanation was that a bad weather condition caused the vents to shut between midnight and 4am. However the building mode data was not available. The following day night cooling did not apply until midnight and then only for one hour. On Monday morning night cooling was permitted in all areas, and those zones cooled over the weekend did not appear to benefit significantly. This was probably because, as previously shown, one additional night of cooling would not have a significant effect on the slab temperature. The no night cool zones demonstrated relatively stable temperatures over the weekend. Figures A1.17 and A1.18 show the test weekend for the south west and south east zones respectively. Although the night cool zones (second and third floors) demonstrated similar temperature changes to the northern areas, the no night cool areas were very variable. The temperatures in the no night cool areas cycled by 2-3K approximately every 6 hours and the reason for this variation was not known. Figure A1.19 shows the wind speed and direction for the test period and although the wind speed was quite variable the wind direction remained relatively stable throughout the test.

Table A1.13 contains temperature data from a second test at the Inland Revenue building at Durrington (1-4 September). For this test night cooling was applied to selected zones for the Sunday evening/Monday morning period only. Normal operation was applied to all zones from Friday to Sunday evening. Figures A1.20 to A1.23 illustrate the test period for the north west, north east, south west and south east areas respectively. Once again the northern zones clearly distinguished between the night cool and no night cool areas. The no night cool zones showed a relatively stable temperature until normal control was re-established at 6am Monday morning. The night cool zones were cooled by 3K followed by an increase of 1.5K, a fall of 1.5K and an increase of 2K. These changes in temperature may have been due to bad weather conditions opening and shutting vents but this cannot be proven. Between 6-8am on Monday, when night cooling was re-established for all areas, the no night cool zones cooled to achieve similar zone temperatures to the night cool test areas. Also, during Monday the areas subjected to full night cooling on Sunday did not demonstrate any measurable benefit over those limited to 2 hours night cooling. This was probably due to the thermal storage of the slab being relatively unaffected by the reduction night cooling on only one night. Figures A1.22 and A1.23 shows the south west and south east zones and, similarly to the first test, the temperatures in the no night cooling zones were very variable making a comparison difficult. Figure A1.24 shows the wind speed and direction for the second test period and similarly from the wind direction was relatively constant (although opposite from the first test) whereas the wind speed was very variable.

3.3 INLAND REVENUE BUILDING B, NOTTINGHAM

Data from the Inland Revenue Building B at Nottingham was limited to July 1995. However this did allow some comparison with Building F on the same site and the other buildings. The results are provided in Appendix A2.

3.3.1 Building performance

Figure A2.1 shows the performance of the south and west zones subjected to hot ambient conditions. The outside air temperature exceeded 26°C on each day and 30°C on two days but the zone temperature maintained a 3K temperature difference on the two peak days and was under 26°C on the other days. The performance of night cooling was demonstrated and resulted in zone temperature drops of between 3-4.5K.

3.3.2 Summary of daily temperature data and building mode of operation

Table A2.1 illustrates temperature data and Table A2.2 mode data for July. The mode data showed that night cooling was applied each night including weekends, and generally operated for 9-12 hours. The criteria for night cooling to operate were satisfied on each day and this was shown in Table A2.1. The average outside air temperature during the afternoon always exceeded 18°C (21.5°C minimum), the zone temperature never approached the minimum permitted of 14°C during night cooling and the outside air temperature was generally cooler than the zone temperature overnight. However, at the beginning of the night cool period the zone temperature was occasionally cooler than the outside air due to the extreme nature of the 1995 summer. On two days the outside air temperature fell below the minimum permitted (12°C) and this would have restricted night cooling. The only other condition which may have affected night cooling was a bad weather condition, but this was not logged because, unlike Durrington, it did not have a specific bad weather mode. The success of night cooling (zone temperature drop) varied from 0.7K to 5.7K. The average temperature difference (zone - outside air) during night cooling varied from 0.3K to 6.0K and was typically 2K-5K which demonstrated that favourable conditions existed, but it was lower than the Inland Revenue Building at Durrington.

3.3.3 Correlations between variables

Table A2.3 illustrates the correlations between different variables. A weak correlation existed between the maximum zone temperature and maximum outside air temperature ($r = 0.732$ south, $r = 0.761$ west) but was weaker than the Inland Revenue Building at Durrington. There were several factors that may have been relevant to night cooling performance but, when tested individually, did not show a significant correlation and were not shown to be more important than other factors. These were:

- average outside air temperature
- operation of local fans (not a central system)
- operation of ridge vents
- operation of the ventilation towers.

The exception was the temperature difference between the zone and outside air during night cooling. The south zones demonstrated a very weak correlation coefficient (r) of 0.669 and the west zones 0.638. This contrasts with the Inland Revenue at Durrington where the temperature difference did not produce a significant correlation.

Figure A2.2 shows a linear regression between the peak zone and outside air temperatures. Although the data was scattered ($r = 0.762$ west, $r = 0.735$ south) it does illustrate the performance of the system. For example a peak outside air temperature of 30°C may result in a peak zone temperature below 26°C. The south and west zones demonstrated very similar relationships.

3.4 INLAND REVENUE BUILDING F, NOTTINGHAM

The second building to be studied at the Inland Revenue site in Nottingham was Building F. The data available was more detailed than for Building B and covered a longer period (July to September). The results of the data analysis are in Appendix A3.

3.4.1 Building performance

Figure A3.1 and A3.2 illustrate the occupied hours that the outside air and zone air exceeded selected temperature limits for July and August respectively. Figure A3.1 also includes data for Building B. The outside air temperature for July was very hot, peaking at 35°C and with over 25% of monitored occupied hours over 30°C. However it should be noted that the outside air temperature sensor was found to be reading high when checked (see 3.1). Under these extreme conditions the zone temperatures were still maintained at acceptable levels. Building F peaked at 27°C and there was little difference between the north and west zones. Building B peaked at 30°C and 27°C was exceeded for over 20% of the monitored period. The Building B south and west temperatures were similar. The performance curves were calculated from the second floor temperatures and for Building B this was the top floor but for Building F it was a lower floor. It would be expected that Building B would be higher, particularly as the top floors of the Nottingham building did not have a concrete exposed ceiling. The temperature at which the outside air temperature hours were greater than the zone hours was 24-25°C, which was consistent with other monitored sites. The external temperatures in August were even greater than those in July, peaking at 37°C with nearly half the monitored hours over 30°C. The peak zone temperature was 29°C and this temperature was exceeded by ambient conditions on over 50% of the hours. The temperature at which the outside air hours exceeded the zone hours was 23.5-24°C.

Figures A3.3 and A3.4 illustrate the variation of zone temperature and outside air temperature on selected hot weeks. The first figure shows that the peak zone temperature (27°C) being 4-6K below the outside air temperature. Night cooling produced a 3-4K zone temperature drop. Towards the end of the week, as the outside air temperature peaks dropped to 28-29°C the maximum zone temperature fell to 25°C. Figure A3.4 shows that a second hot week where the outside air temperature exceeded 30°C on four of the five working days. Although the zone temperature reached 30°C on each of these days the building still maintained a temperature differential 3-6K with the outside air. Night cooling achieved an impressive 4K drop in zone temperature. At the end of the week the outside air temperature dropped and was matched by the zone temperature which gradually cycled down to a more acceptable peak of 26°C.

Figures A3.5 and A3.6 show the temperature difference between the ground floor high and low level sensors and the third floor high and low level sensors respectively. During the daytime there was a temperature gradient of up to 4.5K from low level to high level sensors in a zone. The reason for this difference could relate the effectiveness of ventilation and the production of causal heat gains. The application of night cooling resulted in the temperature gradient being reduced to 0-1K. There was some evidence that ventilation may be reduced due to partitioning of areas designed to be open plan. If this was the case the heat gains from lights, office equipment and people may be creating a reservoir of hot stagnant air. It may also be imposing an unnecessary thermal load on the ceiling slab.

3.4.2 Summary of daily temperature data and building mode of operation

Tables A3.1 to A3.4 show the daily temperature data for July and August/September and the mode data for July and August/September respectively. Table A3.1 and A3.2 show whether the criteria for night cooling were satisfied. The average 12.00-17.00 outside air temperature was above 18°C every day in July and ranged from 21.5°C to 36.7°C and in August it was below 18°C on only one occasion (29th). The outside air temperature minimum was below 12°C on two days in July (22nd, 23rd) and three days during August (9th, 28th, 30th) and one in September (3rd). The zone air never attained the minimum permitted of 14°C with the minimum in July being 20.7°C, August being 19.8°C and September 18.2°C. The mode data indicated a significant reduction in night cooling but this did not correlate with the temperature data, which could have reduced night cooling on only a limited number of occasions. The night cooling mode data for the zones ie local fan operation or ridge vent operation was related to the operation of the ventilation towers (data available for 11-26 July only). The only factors that could have prevented night cooling were the prevailing weather conditions or outside air temperature exceeding zone temperature. The peak night wind speed was 6.4 m/s, lower than the 8 m/s limit. The wind direction only affected the opening of the ventilation tower. The other potential reduction in night cooling, from prevailing weather, was rain intensity. The tower shut with a wind speed of 7 m/s and an intermediate rain intensity or a wind speed of 4 m/s with a high rain intensity. However, as the wind speed did not exceed 7 m/s it was only a high rain intensity that could have limited night cooling. The average night rain intensity was 1.9 from 11-26 July but it did vary from 0 to 70.8. The rain intensity range was at least 0-70 but with an average of only 1.9 it was unlikely that the high intensity limit would have been regularly exceeded to prevent night cooling. The other option was that the outside air temperature exceeded the zone air temperature during the night cooling enable period from 16.30-07.45. In the extreme conditions experienced in July and August the outside air temperature often exceeded the zone temperature until 19.30-20.00 with the longest period being up to 21.45 (11 August).

The drop in zone temperature achieved each night ranged from 0.6K to 5.1K but was typically 2-4K. Although the outside air temperature sometimes exceeded the zone temperature there was always a positive average differential over the night cooling period. This ranged from 0.5K to 6.9K and was typically 3-5K.

3.4.3 Correlations between variables

Tables A3.5 and A3.6 show the results of correlations between different variables. There was a weak correlation between the peak average zone temperature and peak outside air temperature (north r = 0.872, west r = 0.849). This was similar to both building B at Nottingham and the Inland Revenue building at Durrington. There was also a weak correlation between the outside air temperature swing and the zone temperature swing (north r = 0.682, west r = 0.635). The success of night cooling (zone temperature drop) did not show significant correlations with any of the following individual variables which indicates that no one factor had overriding influence:

average temperature difference (zone - outside)
average outside air temperature (v.weak (r) = 0.389)
average wind speed (v.weak (r) = 0.440)
average wind direction
average rain intensity
night cool local fan operation
night cool ridge vent operation
night cool ventilation tower operation.

There were two weak correlations that may have demonstrated the effect of night cooling. The first was between the zone daytime maximum temperature and the success of night cooling measured by zone temperature drop (north r = 0.648, west r = 0.641) and the second was between the zone daytime maximum and the zone night minimum temperatures. Table A3.6 shows the correlations between different floors of a particular facade. There was a strong correlation between the maximum temperatures on each floor and with the outside air. This was particularly true for the third floor where the correlation with the outside air temperature was 0.932 north facade and 0.922 west facade. In the northern zones a correlation existed between the success of night cooling on different floors and although it was also the case for the western zones the correlation was significantly lower.

Figures A3.7 and A3.8 illustrate linear regressions on the variation of peak zone temperature with peak outside air temperature These graphs show that similar conditions existed in the north and west zones. At a peak outside air temperature of 30°C the zone temperature could be expected to be limited to 27°C on the top floor and 25°C on the ground floor. The top floor was considerably hotter than the other floors through a combination of lower ventilation and thermal mass. At the extreme conditions experienced (36°C) the change in peak temperature between ground and second floor was only 1K but between ground and third floor it was 3.5K.

Figure A3.9 shows the relationship between the average peak north and west temperatures and the peak outside air temperature. At an outside air temperature of 30°C the average of the floors could be expected to peak at less than 26°C producing a good temperature differential between inside and outside. The coefficient of determination (r^2) was 0.76 (r = 0.872) for the north and 0.72 (r = 0.849) for the west. Comparison of this figure and a similar one for the Inland Revenue at Durrington (Figure A1.7) showed that the slope at Nottingham was greater. This indicated that the Inland Revenue Building F at Nottingham was more influenced by outside air temperature than the Inland Revenue Building at Durrington. For example the outside air temperature range of 22°C to 30°C would produce an expected increase in the peak zone temperature at Durrington of 2K but at Nottingham it would be 3K.

Table A3.7 shows the results of a number of regression analyses on different parameters. The relationships between the peak zone and peak outside air temperature demonstrate that the correlations were significant, particularly on the top floor. Night cooling on the north facade ground floor was weakly related to night cooling on other floors. On the west facade this relationship was not significant.

3.5 IONICA BUILDING, CAMBRIDGE

The Ionica data covered the period from March to September 1995 and included temperature and building mode of operation data. The full results are in Appendix A4.

3.5.1 Building performance

Figures A4.1 to A4.3 compare the number of hours that the average zone and outside air temperatures exceeded fixed limits for July, August and September respectively. The outside air was relatively cool when compared to the Inland Revenue Building at Nottingham, although it peaked at 37°C in both July and August. For example 30°C was only exceeded on approximately 8% of the monitored hours in July and 16% in August, compared to approximately 30% for both months at Nottingham. However the Nottingham readings were high (see 3.4.1). The August levels were similar to those experienced at Inland Revenue, Durrington. The temperature at which the number of outside air hours exceeded the zone hours was 25.5°C in July and 23.5°C in August which was similar to the other monitored sites. The September data (Figure A4.3) shows that the outside air peaked at 23°C and the zone air 24.5°C.

Figure A4.4 shows a hot early summer week when night cooling criteria were satisfied but the system did not operate. The outside air temperature exceeded 25°C on six consecutive days and peaked at over 30°C. The zone temperature exceeded the control limit of 24°C on each of these days and never fell below 19°C (minimum permitted) or 21°C (degree hours calculating limit) and the outside air minimum was above the 7°C limit, but night cooling (mode 7) did not operate. During the day the building operated under mode 9 (mid season) because the outside air was above 14°C but the zone air below 26°C. At night the modes were 0 (plant off), 6 (summer) and mode 2 (cooling optimum start). Mode 6 applied when the zone temperature in the day did not exceed 24°C but the temperature data (also from the BMS) showed that 24°C was exceeded. The need for night cooling was highlighted because the cooling optimum start mode was used on three nights (mechanical ventilation and evaporative cooling on). Figure A4.5 shows a second example week where night cooling did not operate although the criteria were again satisfied. Mode 6 was applied overnight although the daytime zone temperature exceeded 24°C. Consultation with the BMS contractor confirmed that the mode number and setpoints were correct but failed to provide a solution to why the night cooling mode did not operate.

3.5.2 Summary of daily temperature data and building mode of operation

Tables A4.1 to A4.7 show daily temperature and mode data. Table A4.1 shows a brief summary for March to May. During this period the criteria for night cooling was only satisfied during one week (see Figure A4.4). The zone temperature varied from 19.5°C to 25.8°C compared to an outside air variation of 1.6°C to 29.7°C. From July to September the success of night cooling (zone temperature drop) ranged from -0.6K to 3.3K and only exceeded 2K on six out of 77 nights. The average night cooling (July to September) was only 0.97K for weekdays and 0.93K for weekends. The night cooling control limit of 24°C was exceeded on 42 out of 77 days (including weekends) between July and September. If only those days when the night cooling control criteria were satisfied are considered the average zone temperature drop was 1.8K for weekdays and 1.5K for weekends. These temperature drops were probably higher than could be expected from the natural temperature swing alone, but were still lower than other sites. Also, the mode data indicated that night cooling was not applied. Table A4.5 shows a summary of all the mode data from March to August. The night cooling (mode 7) did not operate at any time. The daytime operation was shared mainly between the winter and mid-season modes with summer mode only applied manually for six consecutive days. The night time operation was also shared between winter, mid-season and summer operation between March to May although with the winder mode (full recirculation to extract heat from the floor slab) being extensively applied. During July to August the night-time operation was limited to mode 6 (summer operation) which indicated that night cooling (mode 7) could have been extensively applied. The criteria for mode 6 and 7 are the same except that for mode 7 to apply the zone air temperature must exceed 24°C for at least one hour the previous day. However, as previously stated, 24°C was exceeded on 42 out of 77 days between July and September and it is not known why night cooling was not applied.

Tables A4.6 and A4.7 show the mode data for July to August for each of the AHU's. This data was very limited, particularly in July. Details of the different modes are shown with the summary data in Table A4.5. The building had ten different modes but tended to operate only five of them. There were four main night time modes (winter, mid-season, summer, night cooling) and three main daytime modes (winter, mid-season and summer). Although each of the main daytime modes was applied only one night time mode was applied (summer night operation). The other mode was a plant off condition that was applied at the end of occupancy for two hours each day. Table A4.6 shows that the system was manually overridden to operate mode 10 (cooling enabled) continuously between 11-16 August to cool the floor slab.

3.5.3 Correlations between variables

Table A4.8 shows the correlations between different variables. The most significant correlation was between the zone maximum and outside air maximum temperature ($r = 0.675$). This correlation did not exist for weekend data. The correlation was lower than the Inland Revenue buildings at Nottingham and Durrington probably due to evaporative cooling being available at Ionica.

Figures A5.8 to A5.11 illustrate regression analyses on the variation of peak zone temperature for each level with peak outside air temperature for north west, north east, south west and south east facades respectively. These graphs do not show the expected relationship of increasing temperature (particularly on the top floor) with height. Although the data was very scattered, the third floor temperatures were consistently lower on the north west and south east facades than the other floors. One possible explanation was that level 1 of these facades was subjected to higher casual gains. A small power loads assessment was made but only included selected areas. The third floor north west was one of the areas chosen and the estimated heat gain was 23.6W/m^2 . This compared to the south west level 2 of 36W/m^2 and north east level 1 of 38.1W/m^2 . The north east and south west behaved more as expected with the level 1 and level 2 demonstrating similar peak temperature and level 3 1-2K higher. At elevated ambient temperatures the peak temperatures of each level converged, probably due to the use of mechanical cooling.

Figure A5.12 illustrates a regression analysis on the peak outside air and zone temperatures (average of all zones). This regression demonstrated a good coefficient of determination ($r^2 = 0.819$) and a similar performance to the Inland Revenue building at Durrington. The following shows a comparison of the buildings using the regression equations:-

Peak outside air temperature (°C)	Peak zone temperature PowerGen	Peak zone temperature IR, Durrington	Peak zone temperature IR, Nottingham	Peak zone temperature Ionica
22.0	24.2	23.6	23.0	24.0
30.0	26.0	25.4	26.1	25.1
8K rise	1.8K rise	1.8K rise	3.1K rise	1.1K rise
r^2	0.819	0.724	0.720	0.456
r	0.905	0.851	0.849	0.675

Table A5.6 details regression analyses showing the relationship between temperatures on different floors of each facade. The coefficients of determination were good for the daytime data (r^2 range was 0.923 to 0.945). The relationships confirm that the peak temperatures on the north west and south east facades actually became cooler between levels 1 and 3. The success of night cooling on different floors did not appear to be related and had only very weak coefficients of determination (r^2 range was 0.192 to 0.727).

3.7 SITE COMPARISON

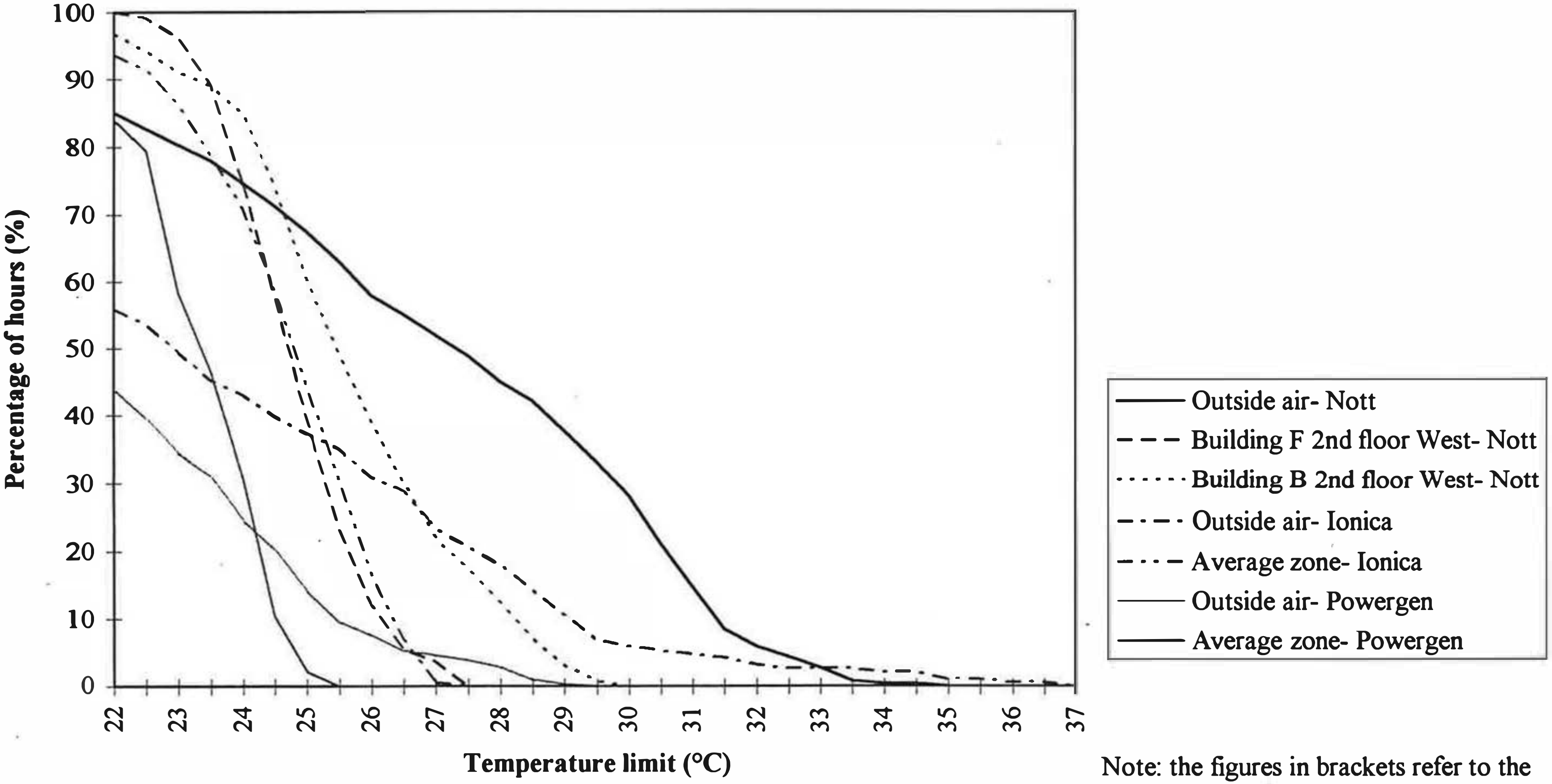
Results from the different sites have been compared in Figures 1 and 2, which illustrate the number of hours that average zone temperatures and outside air temperatures exceeded fixed temperature limits at each site for July and August 1995. It should be noted that the sample sizes were very variable, Nottingham data was a selected zone not the average for the entire building and Ionica and PowerGen buildings had mechanical cooling available. Figure 1 shows July data but does not include the Inland Revenue Building at Durrington (no data was available). The PowerGen building produced the best performance and the zone temperature did not exceed 25.5°C although the outside air temperature was also the coldest, peaking at 29.5°C and with only 45% of occupied hours above 22°C. The worst performance was from Nottingham building B which was 2-3K higher than Nottingham building F, but building B zone temperature was from the top floor temperature and therefore it would be expected to be hotter. The performance of the Nottingham buildings was good compared to the outside air temperature as this was consistently hotter than the other sites. For example approximately one third of the recorded outside air temperature readings, during the occupied period, were above 30°C compared to around 5% at Ionica and none at PowerGen. It should be noted that the location and accuracy of the sensors may have influenced the outside air temperature readings and the Nottingham sensor was shown to be reading high (see 3.1). Nottingham building F performed similarly to the Ionica building, although no mechanical cooling was available at Nottingham and mechanical cooling was enabled for 170 hours at Ionica during July and August. Another performance indicator was the temperature limit at which the proportion of outside hours exceeded was higher than the internal hours and this was very similar for each of the sites (24-25°C).

Figure 2 illustrates the data for August and includes the Inland Revenue Building at Durrington. Once again the Nottingham site experienced the hottest conditions with 70% of occupied hours above 22°C and a peak temperature of 37°C (see 3.1) and PowerGen was the coldest with 35% of hours above 22°C and 31°C peak temperature. This was reflected in the zone temperatures with Nottingham the hottest (29.5°C peak) and PowerGen the coldest (27°C peak). The Nottingham, Durrington and Ionica buildings demonstrated similar performance curves compared to PowerGen which had a large reduction in the proportion of hours that the temperature limits were exceeded (100% at 22°C to only 20% at 24°C). This may indicate that mechanical cooling was in use but as previously stated only temperature data was logged. Ionica demonstrated the next best performance, but this may also have been due to mechanical cooling. The temperature limit at which the proportion of outside hours exceeded the zone hours ranged from 23.5°C (Ionica) to 25°C (PowerGen and Durrington).

Overall, each of the buildings and particularly Nottingham and Durrington where no mechanical cooling was available, were very successful in limiting the peak internal daytime temperatures during the extreme conditions experienced in summer 1995. For example in August at Durrington the peak zone temperature in occupied hours was 28.5°C compared to 37°C for the outside air temperature. The outside air temperature was also above 28.5°C (peak zone temperature) for 30% of the occupied hours.

Figure 1

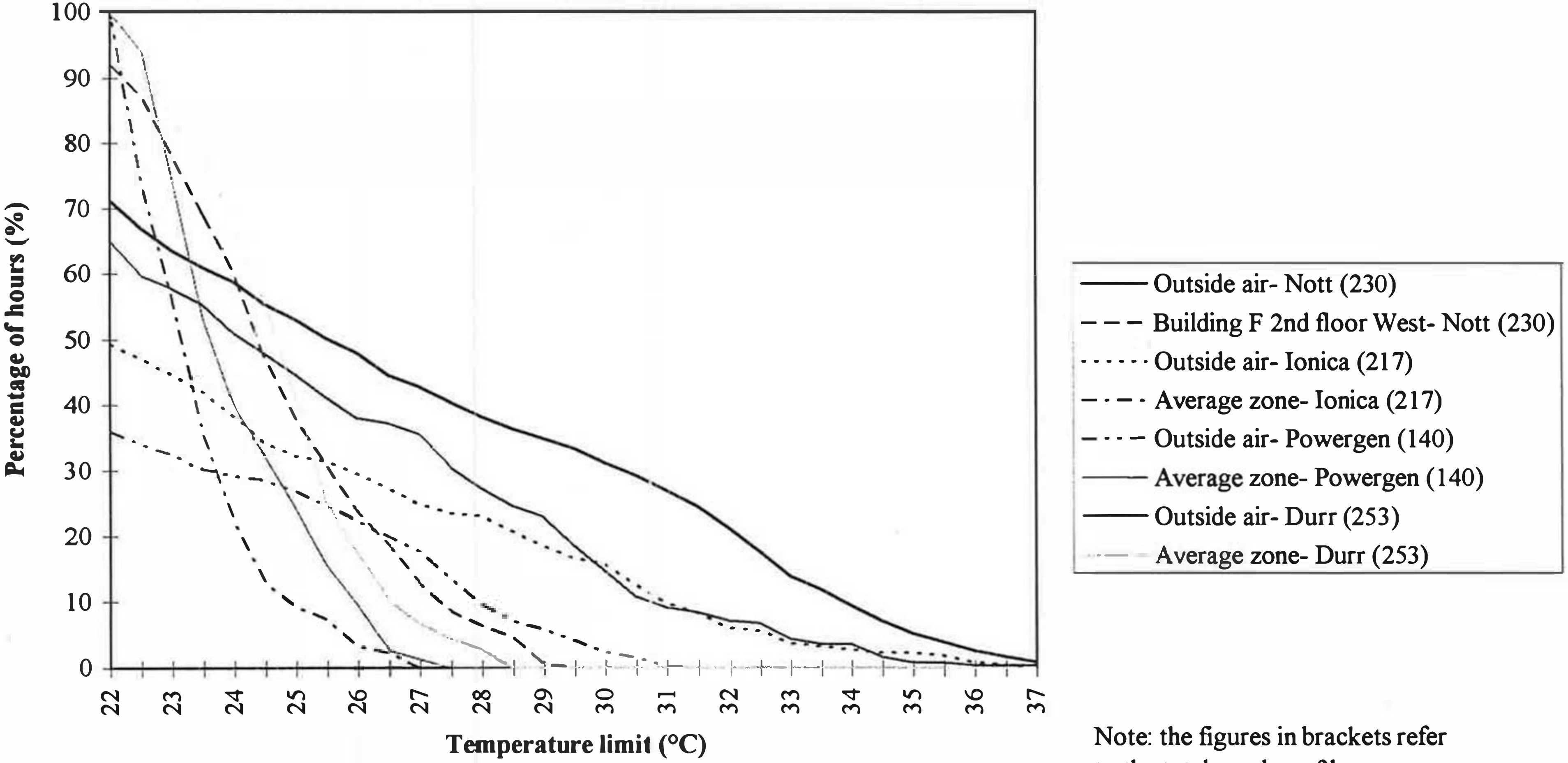
COMPARISON OF SITES- PERCENTAGE OF OCCUPIED HOURS ABOVE SPECIFIED TEMPERATURE LIMITS JULY 1995



Note: the figures in brackets refer to the total number of hours

Figure 2

COMPARISON OF SITES- PERCENTAGE OF OCCUPIED HOURS ABOVE SPECIFIED TEMPERATURE LIMITS AUGUST 1995



Note: the figures in brackets refer to the total number of hours.

4. CONCLUSIONS

4.1 INLAND REVENUE, DURRINGTON CONTROL (SLAB TEMPERATURE SETPOINT)

1) The slab setpoint was never attained during night cooling. The slab temperature only approached the set point as it reduced with the trend in average outside temperature. The minimum temperature difference was 1.2K and the maximum 7.8K during the August to October period.

2) The setpoint change was very limited (0.7K between August to October) considering the complex nature of the algorithms involved. The algorithms only permitted minimal change in the setpoint if it was not successful the previous night. Therefore the setpoint changed very little.

3) The minimum permitted slab setpoint was unrealistically low. A regression analysis between the outside air and slab temperatures suggested the slab temperature would not fall below 18°C. Also the minimum slab setpoint would have caused serious heating problems if ever achieved as the heating setpoints were 2-6.5K above the minimum slab setpoint.

4) The control strategy resulted in very high night cooling utilisation, even in the marginal months of September and October. It was only the bad weather mode that prevented further night cooling. Bad weather operated for 158 hours in September and October compared to only 109 hours for night cooling by natural ventilation.

5) There was not generally a significant difference in the cooling rates between night cooling with mechanical ventilation and natural ventilation.

6) The night cooling control, although successful in helping to maintain a satisfactory environment, was over utilised. In theory the night cooling technique was sound because it included two important parameters (slab and zone temperatures). However in practise the algorithms created unrealistic targets because the zone and slab temperatures were expected to achieve the cooling setpoint which was set too low eg 22°C in July. This compares, for example to Ionica where the zone temperature had to exceed 24°C for night cooling to take place. As previously shown the peak zone temperatures are related to the peak outside air temperature and a low energy design (no mechanical cooling) can only expect to temper this by 3-4K. Therefore 22°C would be rarely achieved in peak summer. The slab temperature also followed trends in outside air temperature but was expected to be actually cooler than the cooling setpoint. The algorithms assumed the slab would demonstrate significant temperature changes but in practise this only occurred at the beginning or end of a hot spell of weather. One sensible precaution was the interlock that minimised setpoint change if night cooling did not succeed the previous night. This prevented even more unrealistic targets being set. The night control also included a minimum setpoint limit, which should have prevented it being set too low. However the actual limits were unrealistic and would have caused heating problems if ever achieved (see conclusion (3)).

4.2 INLAND REVENUE, NOTTINGHAM CONTROL (MINIMUM AVERAGE AFTERNOON OUTSIDE AIR TEMPERATURES)

1) The minimum permitted night cooling zone temperature of 14°C was not approached during July to September. The minimum zone temperatures were 20.7°C in July, 19.8 °C in August and 18.2 °C in September. The night cooling technique in use at Nottingham allows the air temperature to cool to 14°C before the system switches off. The fabric is then expected to heat the air to 17°C when night cooling is again applied. This technique, although valid in theory, does not work in practise because to cool the zone air temperature to 14°C requires an unrealistic temperature drop of 8-10K.

2) The criteria that the average afternoon outside air temperature must exceed 18°C for night cooling to be permitted was satisfied throughout July and August. It was not a particularly extreme condition to satisfy.

3) The minimum outside temperature of 12 °C was another sensible precaution and would only have limited night cooling on 6 occasions between July and September.

4) The wind speed interlock did not prevent night cooling

5) Similarly to Durrington the night cooling control was generally successful as part of an overall low energy strategy. The minimum outside air temperature average was a good criteria to include because, as previously shown, the zone and outside peak temperatures are related. It was also sensible for the limit to be an afternoon average rather than peak because a peak may not represent the entire day. The limit was 18°C which was not very high and probably resulted in over utilisation in marginal seasons. The 14°C minimum zone temperature was set far too low and would not have been achieved in practise. It also may result in the need for heating at occupancy. However, generally the control was successful but did include unrealistic factors.

4.3 IONICA, CAMBRIDGE CONTROL (MINIMUM ZONE TEMPERATURE AND DEGREE HOURS)

1) The night cooling mode did not operate throughout the March to September monitoring period although the criteria for its operation were satisfied on numerous occasions. Consultation with the BMS contractor failed to provide an explanation for this.

2) The criteria for night cooling (daytime zone temperature >24 °C) was satisfied on 42 out of 77 days between July and to September. The other night cooling criteria were satisfied throughout July to August and it is not know why night cooling was not applied.

3) Although night cooling did not operate in practise it is still possible to infer the potential of the control strategy. The criteria for night cooling to be permitted was if the zone temperature exceeded 24°C. If this was satisfied, night cooling was carried out until the degree hours heating matched the degree hours cooling with a base of 21°C (for a detailed explanation see 2.4.4). The general results have demonstrated that night cooling could achieve a zone temperature drop of 3-4K. If the zone temperature did exceed 24 °C during the day it would be unlikely to fall below 21°C during night cooling. Therefore, in theory, if night cooling was permitted it would probably operate for the entire night period. The 24°C is a sensible inclusion to prevent unnecessary night cooling although it may be set slightly too high. The degree hours calculation, although valid in theory, is not practical at the current setpoint of 21°C. If the setpoint is increased it may actually influence night cooling operation but will also prevent beneficial utilisation. Also, the control calculates the net daytime degree hours ie periods above and below 21°C both count. However the night cooling degree hours calculation only includes the period when the zone air temperature is below 21°C and not above 21°C when, in theory, it would still be heating the slab. The night cooling control includes an interlock that increases the target cooling degree hours by up to 20% if the daytime zone temperature is too hot but this will not be achieved in practise. As shown above, it is unlikely to achieve the original target degree hours even without an extra 20%. Overall, the control is potentially successful, but does include unrealistic factors. However, as previously stated, night cooling was not actually used during the monitoring period.

4.4 POWERGEN, COVENTRY CONTROL (MINIMUM OUTSIDE AIR TEMPERATURE AND MINIMUM AVERAGE ZONE TEMPERATURE)

1) The 21 °C minimum outside air temperature limit for night cooling to apply was exceeded on 24 out of 29 days in July and August.

2) The 23 °C minimum average zone temperature limit for night cooling to apply was exceeded on 23 out of 29 days in July and August

3) When night cooling was permitted it probably operated for the entire night period. The explanation for this is similar to conclusion 4.3(3). The average daytime zone temperature must exceed 23 °C for night cooling to be permitted and if this were the case it is unlikely that the zone temperature would fall below the 18 °C minimum setpoint at night.

4) The PowerGen night cooling control was the most simple of the four strategies but was potentially the most successful. It did not include complex algorithms that had little practical benefit but it did include the most sensible control feature. The minimum average zone temperature interlock prevented night cooling unless it was necessary. Once that interlock had been satisfied, there was maximum night cooling permitted with a simple zone temperature minimum to prevent over cooling. However, as conclusion (3) shows, although this was a sensible precaution night cooling would be unlikely to cool to the zone minimum.

4.5 POTENTIAL NIGHT COOLING OPERATION OF ALTERNATIVE CONTROL STRATEGIES APPLIED TO THE SAME BUILDING

The only limiting factor for the Durrington control was a bad weather mode because the slab setpoint was never achieved. However if a comparison is made on the effect of applying the other controls at Durrington the night cooling utilisation would have been different, particularly in the marginal months of September and October. Conclusions (1) to (4) compare the potential application of each strategy at Durrington during September and October.

1) The zone temperature at Durrington did not exceed 24 °C and there would have been no night cooling if the Ionica control had applied.

2) The average afternoon outside air temperature exceeded 18 °C on 31 days out 47 at Durrington during September and October. Therefore the Inland Revenue, Nottingham control would have restricted night cooling by one third.

3) The average zone temperature exceeded 23 °C on only 12 days out 47 at Durrington during September and October. The outside air temperature exceeded 21 °C on 20 days out of 47 at Durrington. The two limits combined were only satisfied on 7 days out of 47 at Durrington and this is the number of days that night cooling would have been applied with the PowerGen control.

4) The alternative control techniques would have resulted in wide variation in utilisation, particularly in marginal months, e.g. Inland revenue, Durrington, September to October. The following summarises the findings from the previous conclusions:-

Control type	September to October Utilisation (maximum = 47 days)
Slab set point (IR. Durrington)	47 days
Average afternoon OAT (IR. Nottingham)	31 days
Average zone temperature + peak OAT (PowerGen)	7 days
Peak zone temperature + degree hours (Ionica)	0 days

4.6 GENERAL CONCLUSIONS

1) There was generally a weak correlation between the peak zone temperature and the peak outside air temperature (0.724 at Inland Revenue, Durrington, 0.720 at Inland Revenue, Nottingham, 0.819 at PowerGen, 0.456 at Ionica).

2) There was a correlation between the ground floor peak temperature and the other floors. For all buildings, excluding Ionica, there was a temperature increase of approximately 2K between the ground and top floors.

3) There was no lag between the peak zone temperature and the peak outside temperature from day to day. If Durrington was used as an example the correlation between the peak temperatures was 0.849 with no lag, 0.806 with a one day lag and 0.710 with a two day lag. Only the Durrington control, based on slab temperature, accounted for this lag and continued to night cool. The Nottingham and PowerGen controls would be off at the end of a hot spell because they both include minimum outside air temperature interlocks. The Ionica control would probably also be off at the end of a hot spell because it included a minimum zone temperature interlock.

4) The floor slab temperature demonstrated a significant correlation with the outside air temperature and followed its trends. For example at Durrington the weekly average slab temperature rose by 2.4K between June to August and then fell by 3.1K to October.

5) There was a significant lag between the peak daily slab temperature and peak daily outside temperature. At Durrington the correlation was 0.727 with no lag, 0.797 with a one day lag, 0.832 with a two day lag and 0.830 with a three day lag. This indicates that there was a lag of approximately two days between the outside air temperature and slab temperature.

6) Slab temperature changes were generally small but could be significant when ambient conditions suddenly altered, e.g. the start or end of a hot spell. For example the slab temperature at Durrington increased by 2K in a one week period.

7) Over cooling was generally not beneficial. Night cooling in peak ambient conditions did not cool the zone to the heating setpoint. The zone temperature typically fell from, e.g. 26 °C to 22-24 °C. In marginal conditions, over cooling is possible and the requirement for night cooling is also reduced. Consequently overcooling is not beneficial and night cooling control should include a minimum zone temperature setpoint that is related to the heating setpoint.

8) Night cooling was applied at weekends at some of the sites and this is recommended particularly for peak ambient conditions. A minimum zone temperature setpoint should prevent over cooling in marginal conditions.

9) Bad weather interlocks can potentially be very disruptive to the utilisation of night cooling. Their use needs to be carefully considered and not over specified.

10) There was no one overriding factor that influenced the success of night cooling (measured by zone temperature drop) over any other tested. This included wind speed, wind direction, night-time outside air temperature or the temperature difference between inside and outside.

11) The correlation between peak daytime zone temperature on different floors did not extend to night cooling success where there was no correlation between floors.

12) Different facades may demonstrate different temperature patterns between floors. For example, at Durrington the northern facades showed a temperature increase from ground to top floor, but the southern did not. This indicated that different natural ventilation driving forces may have applied. Night cooling should, where possible, have individual control for zones with the building divided by floor and facade.

13) There was generally a significant temperature difference between inside and outside during night cooling. However, during peak conditions a positive differential may not occur until late evening, e.g. Inland Revenue, Nottingham, was up to 21.45. Therefore night cooling should monitor the temperature differential between inside and outside and prevent operation if the outside exceeds the inside. This practise, although commony used, is not universal.

5. NIGHT COOLING CONTROL STRATEGY

The previous section detailed the conclusions from the site monitoring study. Each of the control strategies was successful in helping to produce a satisfactory thermal environment, as part of an overall low energy strategy. However as conclusions 4.1(6), 4.2(5) and 4.4(3) show the use of complex algorithms may not be necessary in practise. These conclusions also show the daytime criteria to permit night cooling eg peak zone temperature often exclude the night criteria being satisfied. This was because the difference between day and night setpoints was too large. For example at Ionica the daytime zone temperature must exceed 24°C and a calculation of net degree hours is performed. However, the night cooling degree hours are unlikely to attain their target (match daytime heating degree hours) because the zone temperature must fall by at least 3K before the cooling degree hours are registered.

The different night cooling control strategies resulted in a wide variation in utilisation in the marginal summer months. It ranged from no night cooling with the Ionica control, to maximum night cooling with the Inland revenue, Durrington control (conclusion 4.5(4)). During peak summer periods each control would be applied for the maximum period. The results also show that, once initiated, each control would operate for the entire night cooling period:-

Inland Revenue, Durrington	- slab setpoint was never obtained
Inland Revenue, Nottingham	- zone temperature would not fall to 14 °C
Ionica, Cambridge	- night cooling degree hours unlikely to match daytime heating degree hours
PowerGen, Coventry	- zone temperature unlikely to fall to 18 °C if daytime average exceeded 23 °C

Each of the strategies was based on sound principles but, as the above shows, the daytime criteria to permit night cooling appears to exclude the possibility of less than maximum night cooling. Therefore the important difference between strategies was the specification of daytime conditions to permit night cooling.

Although some of the complex night cooling algorithms appear to be redundant in practise it is sensible to include simple controls to predict the need for night cooling. The most obvious indicators are the zone or outside air temperatures. A correlation was demonstrated between daytime peak zone and outside air temperatures (conclusion 4.6(1)). Therefore the use of either as a control limit should be applicable. If the zone temperature was used, either peak or average would be applicable because relatively small temperature changes are experienced. If the outside air temperature is used it should be an average to prevent temperature spikes, not representative of the day, influencing the results. The zone temperature limits applied at Ionica and PowerGen may be slightly too high in practice and prevent some beneficial night cooling. The outside air control at Inland Revenue, Nottingham, may conversely be slightly too low.

The slab temperature at the Inland Revenue, Durrington was weakly correlated to peak outside air temperature but demonstrated a lag of approximately two days (conclusions 4.6(3) and 4.6(5)). Therefore it may be applicable to operate night cooling for an additional two days after a prolonged hot period. This would not be necessary where night cooling was only utilised occasionally.
Over cooling was generally not beneficial (conclusion 4.6(7)). A minimum zone temperature setpoint, related to the heating setpoint, should therefore be specified.

The peak zone temperatures were dependent upon the floor and facade (conclusions 4.6(12)). The building should be zoned between floors and facades with individual night cooling control in each zone.

The results demonstrated that during peak conditions the outside air temperature may exceed the zone temperature until late evening (conclusion 4.6(13)). Therefore night cooling should only be permitted provided the zone temperature (each zone) exceeds the outside air temperature. It is probably beneficial to include a small temperature difference, e.g. 2K, to account for sensor accuracy and location.

The addition of a minimum outside air temperature limit, e.g. 12 °C, should be included (conclusion 4.2(3)). This would reduce the possibility of condensation occurring. It should not affect the operation of night cooling during peak conditions because the outside air would be unlikely to fall below this level.

Night cooling by mechanical ventilation was typically no more successful than natural ventilation, (conclusion 4.1(5)), and also imposed a significant energy penalty. Fan energy was not measured but an indication of likely cost can be derived from the Inland Revenue at Durrington. A simple calculation indicates that electrical power to the night cooling supply fans would have been approximately 144KW. The cost of their operation from midnight to 7.00am is £50 per night (5p/KWh). Therefore, its use could be restricted to bad weather conditions when natural ventilation was not feasible.
Night cooling by natural ventilation could be applied from the end of occupancy, providing the interlocks, discussed above, are applied. Night cooling should also be applied at weekends (conclusion 4.6(8)) provided a minimum zone temperature setpoint has been specified.

The above discussion indicates the type of night cooling control that could be applied in practice. The following summarises those recommendations, but further reference should be made to the thermal simulation study (report 11621/3).

Night cooling enable

Days - 7 days per week
Time - entire non-occupied period
Lag - operate night cooling for an additional two nights following the night cooling criteria no longer being satisfied. This only applies if night cooling operated for a minimum of the five previous consecutive nights.

Daytime activation requirement

Peak zone temperature (any zone) > 23 °C
Average zone temperature (any zone) > 22 °C
Average afternoon outside air temperature > 20 °C

Select any one of the above or a combination.

Night-time activation requirement

Zone temperature (any zone) > outside air temperature + 2K
Zone temperature (any zone) > heating setpoint
Outside air temperature > 12 °C

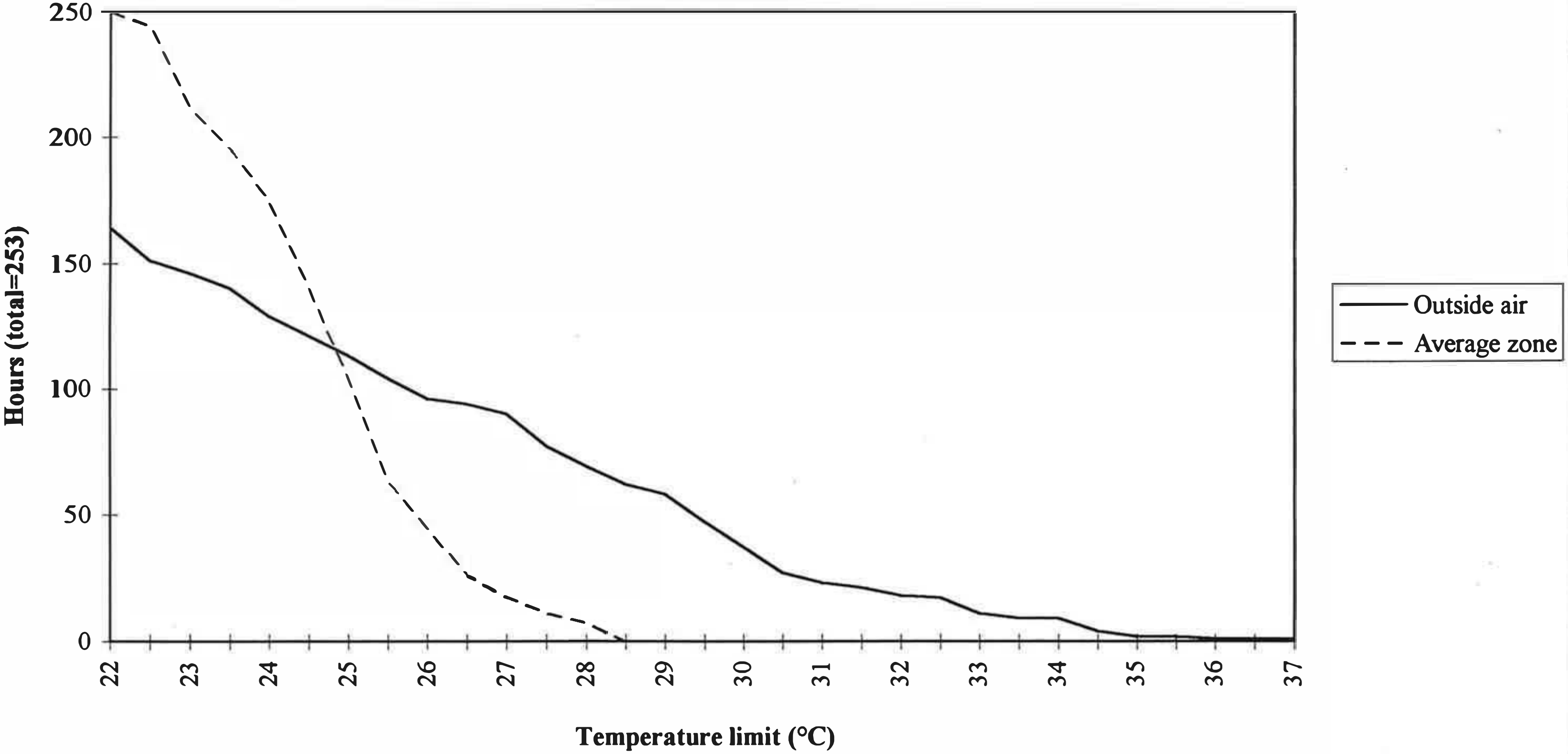
APPENDIX A1

RESULTS FROM THE INLAND REVENUE BUILDING, DURRINGTON

No. of pages: 36

INLAND REVENUE, DURRINGTON- OCCUPIED HOURS ABOVE TEMPERATURE LIMITS- AUGUST (1/8-31/8)

Figure A1. 1



INLAND REVENUE, DURRINGTON- OCCUPIED HOURS ABOVE TEMPERATURE LIMITS- SEPTEMBER (1/9-30/9)

Figure A1. 2

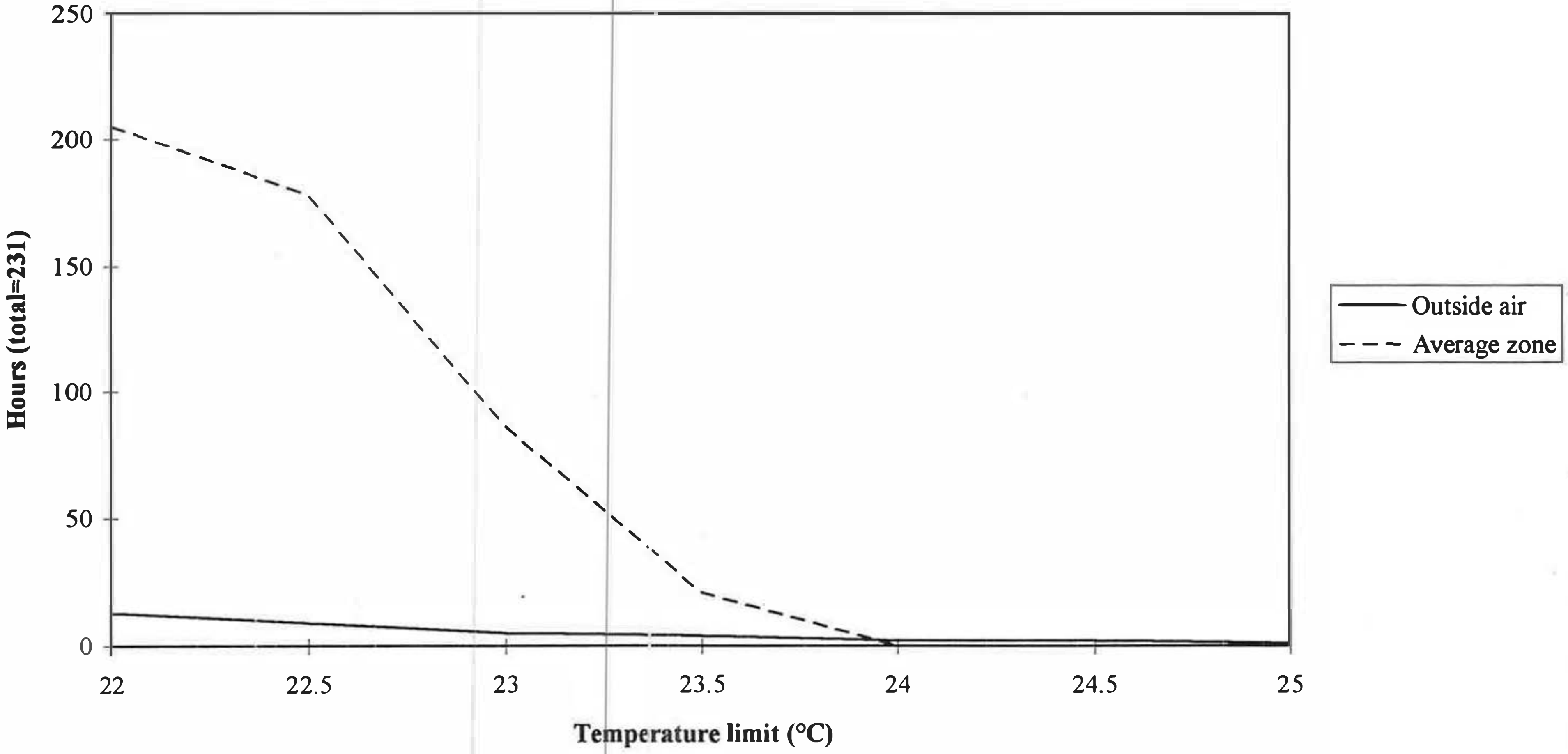


Figure A1. 3

INLAND REVENUE, DURRINGTON- EXAMPLE HOT WEEK (26/06/95-02/07/95)

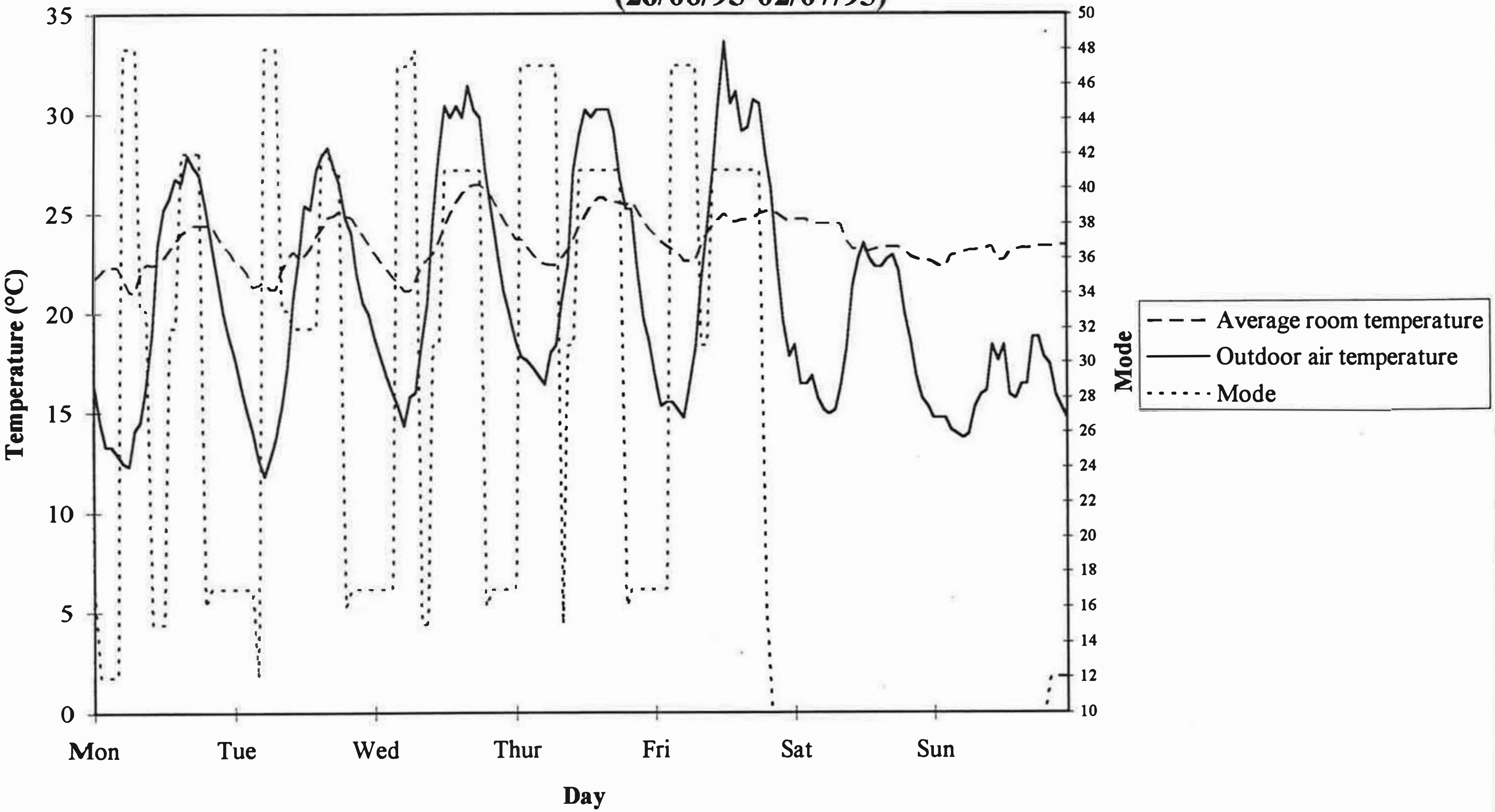


Figure A1. 4

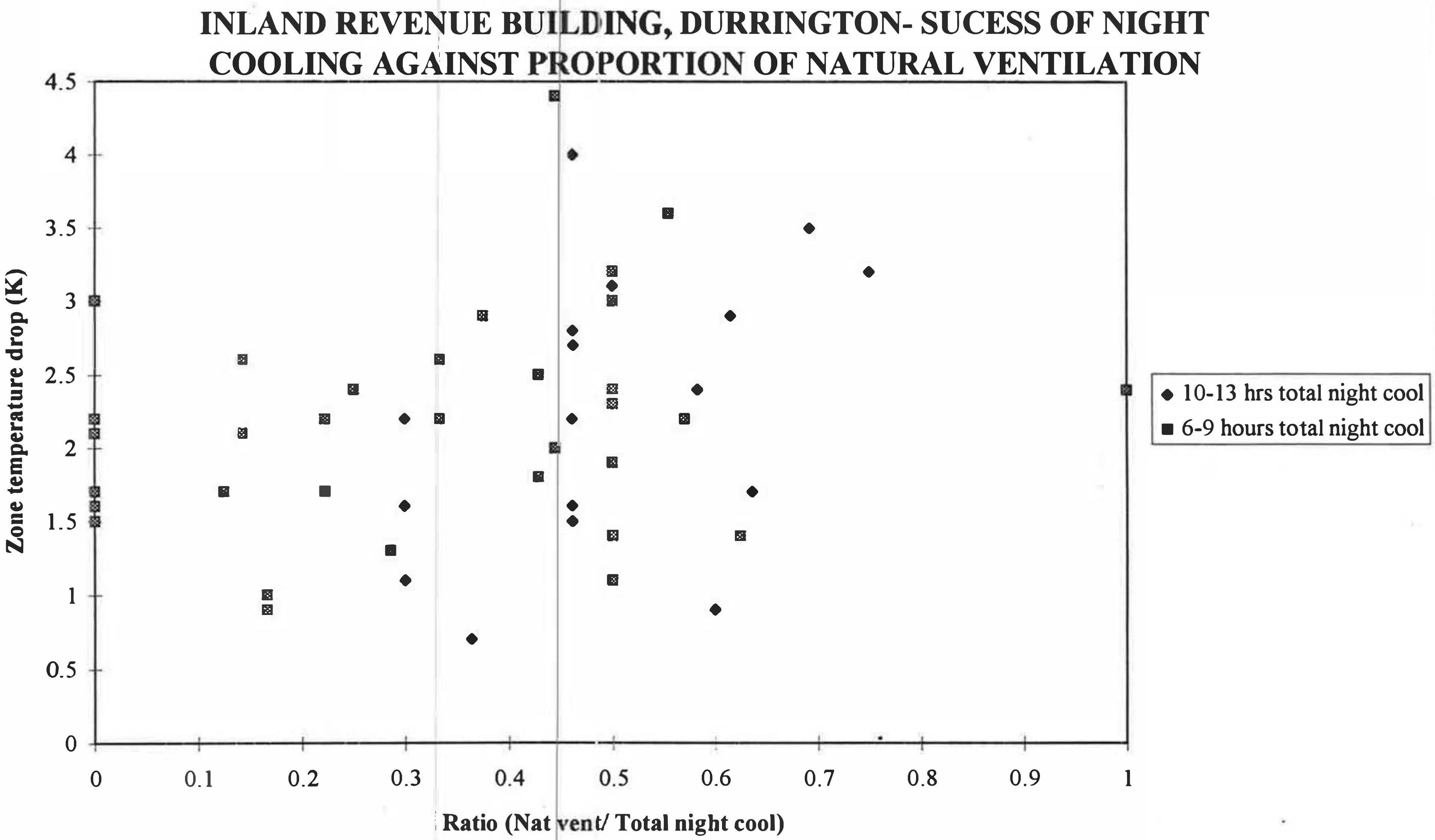
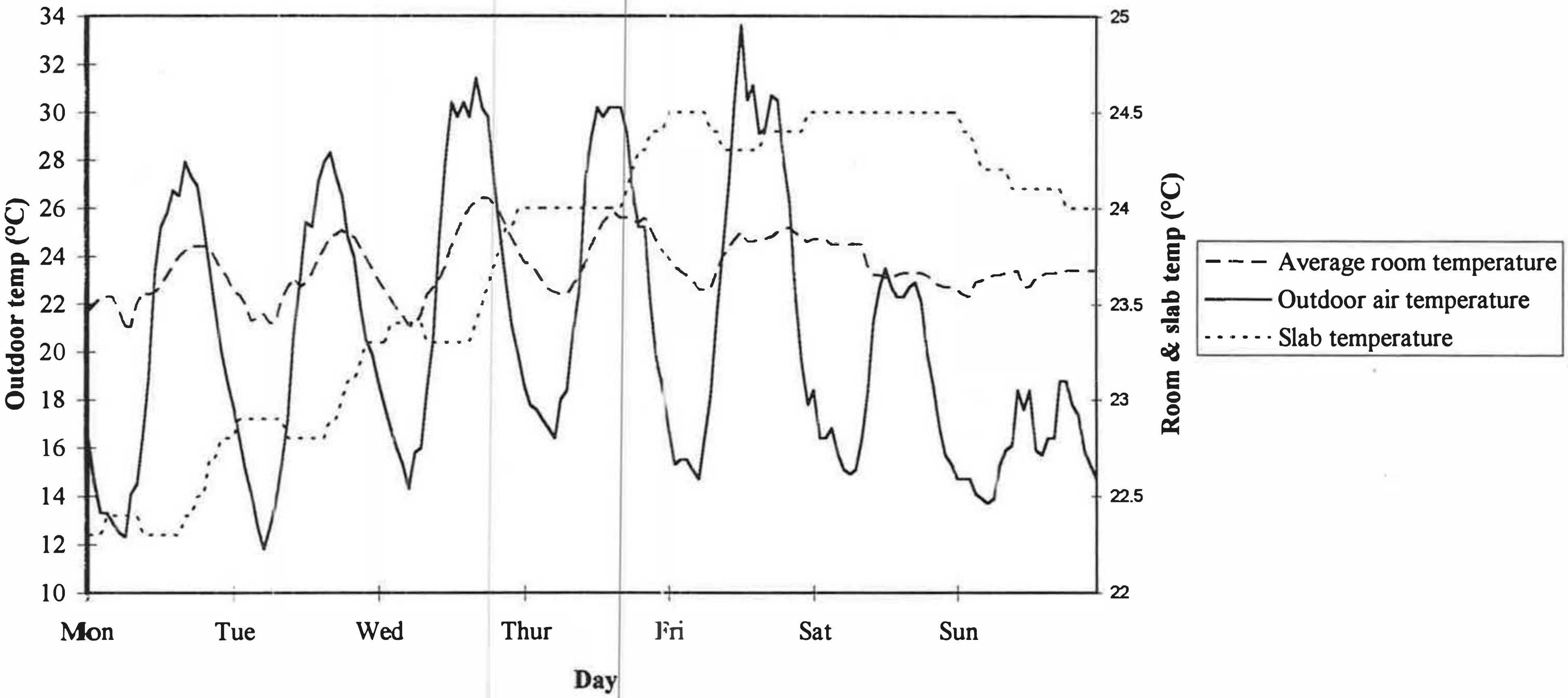

INLAND REVENUE BUILDING, DURRINGTON- SUCESS OF NIGHT COOLING AGAINST PROPORTION OF NATURAL VENTILATION
Zone temperature drop (K)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Ratio (Nat vent/ Total night cool)
10-13 hrs total night cool
6-9 hours total night cool

Table A1. 1 - Inland Revenue Building, Durrington. Building Control Modes

Mode		
Fans Off		
0	Plant off	
1	Mains failed	
2	Fireman's extract	
3	Fireman's off	
4	Fire alarm	
5	AHU hold Off	(fault eg FrostStatTrip)
10	Extended shut down	(plant off > 24 hours)
11	Slab free cooling not required (slab temp < setpoint)	
12	Slab free cooling held off due to bad weather	
13	Slab cooling terminated due to end of low tariff period	
14	Slab cooling completed (ie setpoint attained)	
15	Free cooling during occupation period	
16	Free cooling run on after end of occupation	
17	Slab free cooling	
20	Awaiting LPHW to reach setpoint before going into 21	
Low speed Fans		
21	Heating	
31	Cooling using supply fan on low speed	
32	Cooling using extract fan on low speed	
33	Bad weather cool using extract fan on low speed (instead of 15/16)	
34	Bad weather both fans on low speed (instead of 31 and 32)	
37	Slab cooling supply fans on low speed	
38	Bad weather slab cooling both fans low speed (instead of 37)	
High speed Fans		
41	Cooling using supply fan on high speed	
42	Cooling using extract fan on high speed	
43	Bad weather cool using extract fan on high speed (instead of 15)	
44	Bad weather both fans on high speed (instead of 41 and 42)	
47	Slab cooling supply fans on high speed	
48	Bad weather slab cooling both fans high speed (instead of 47)	

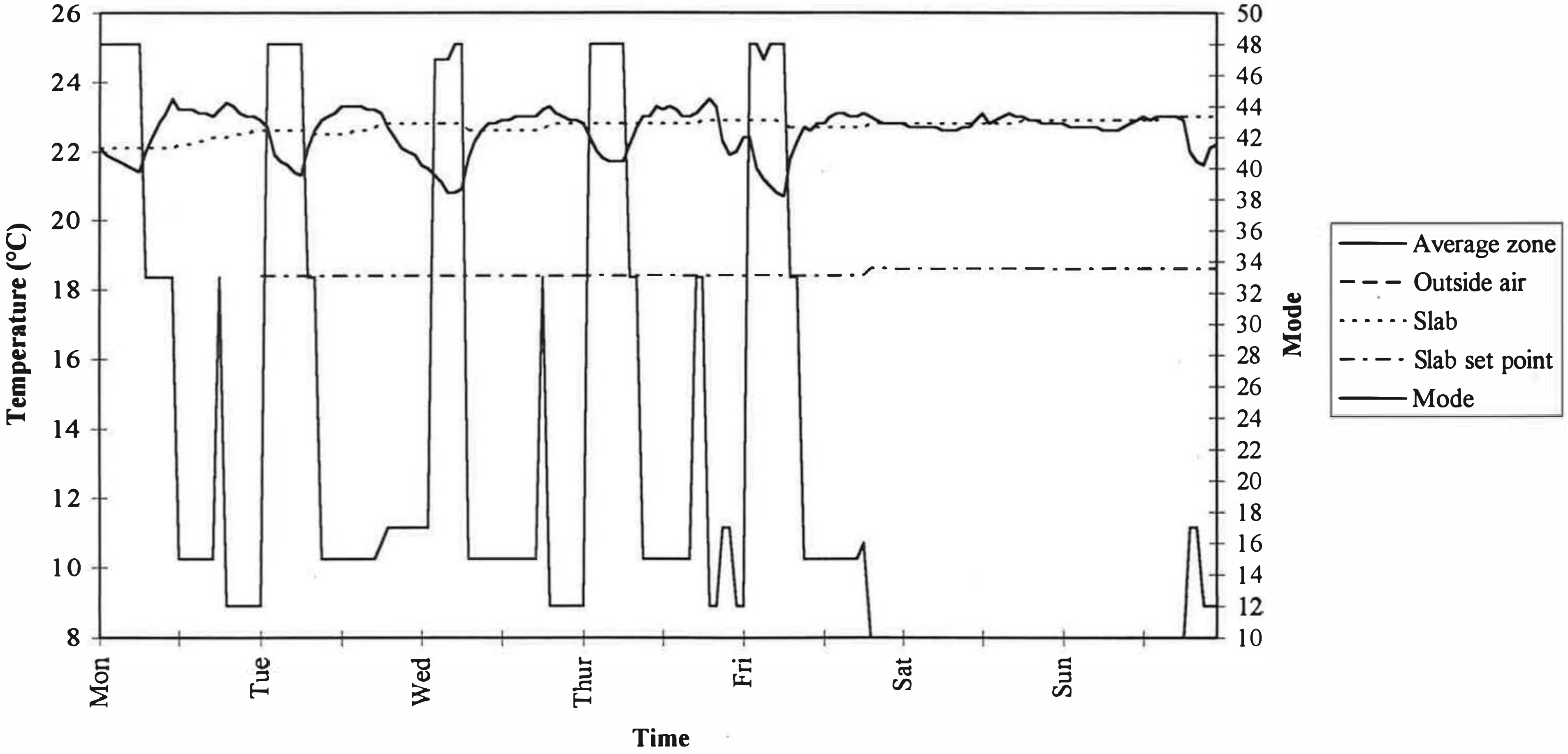
INLAND REVENUE, DURRINGTON- EXAMPLE HOT WEEK (26/06/95-02/07/95) DEMONSTRATING THE CHANGE IN SLAB TEMPERATURE

Figure A1. 5



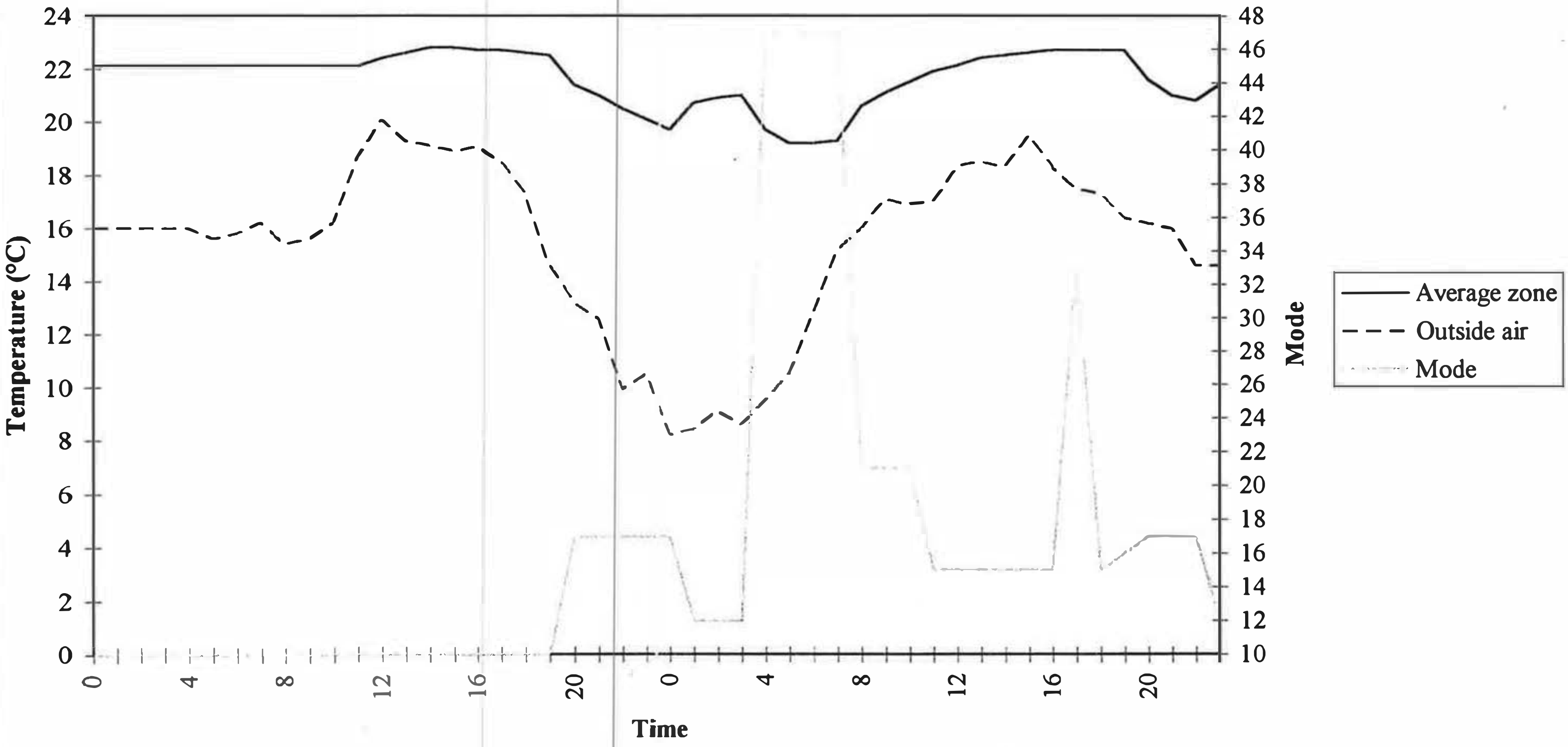
INLAND REVENUE, DURRINGTON- EXAMPLE AUTUMN WEEK (9/10/95-15/10/95)

Figure A1. 6



INLAND REVENUE, DURRINGTON- EXAMPLE OF HEATING BEING REQUIRED FOLLOWING NIGHT COOLING (Sun 1/10/95- Mon 2/10/95)

Figure A1. 7



	Date	Night cool operation (18 to 08)				Daytime operation (08 to 18)					Peak	Peak	Daily IAT	Daily OAT	Night cool	Ave
		NV (hrs)	NV stop	MV	MV (bad	NV (hrs)	MV (hrs)	MV (hrs)	MV (bad	Daytime	average	OAT (°C)	swing (K)	swing (K)	delta T	Zone- OAT
			(bad wea)	(hrs)	wea) (hrs)		(low speed)	(hi speed)	wea) (hrs)	MV total	IAT (°C)				(18 to 08)	(18 to 08)
		Mode16,17	Mode 12	Mode 47	Mode 48	Mode 15	Mode31,32	Mode 41	Mode 33,34							
Sun	18-Jun	2	7	1	2	0	0	0	0	0	23	21.8	1.2	10.3		-
Mon	19-Jun	3	6	1	3	4	3	0	4	7	23.8	22	2.7	11.5	2.5	6.6
Tue	20-Jun	3	7	0	3	11	0	0	0	0	22.8	25.8	1.6	12.2	1.1	6.6
Wed	21-Jun	4	6	0	3	5	5	0	0	5	23.6	26	2.3	12.3	2.2	8.4
Thur	22-Jun	3	7	0	3	9	0	0	2	2	22.7	24	1.9	14	1.4	8.7
Fri	23-Jun	1	0	0	0	6	3	0	2	5	23.4	24.4	2.6	14.4	-0.1	8.4
Sat	24-Jun	0	0	0	0	0	0	0	0	0	22.5	20.6	0.3	10	-0.1	9.0
Sun	25-Jun	5	4	0	3	0	0	0	0	0	22.8	27.3	0.7	15.3	1.4	5.0
Mon	26-Jun	9	1	0	3	3	2	0	2	4	24.4	27.9	3.4	15.6	3.2	4.7
Tue	27-Jun	9	0	3	1	0	5	2	2	9	25.1	28.3	3.9	16.5	3.5	3.8
Wed	28-Jun	6	0	7	0	2	2	7	0	9	26.4	31.4	5.3	17.1	4	3.5
Thur	29-Jun	8	0	5	0	1	2	8	0	10	25.8	30.2	3.4	13.8	2.9	5.0
Fri	30-Jun	1	0	0	0	0	2	9	0	11	25.2	33.6	2.6	18.9	0.5	5.2
Sat	01-Jul	0	0	0	0	0	0	0	0	0	24.7	23.5	2	8.6	0.1	6.9
Sun	02-Jul	0	8	0	4	0	0	0	0	0	23.4	18.8	1.1	5.1	1.6	8.6
Mon	03-Jul	3	6	0	4	3	5	0	3	8	23.4	24.3	1.6	12.1	1.8	8.8
Tue	04-Jul	5	0	0	0	4	0	0	7	7	23.8	24.1	2.5	13.2	2	5.1
Mon	24-Jul	7	1	4	1	6	5	0	0	5	23.5	30.6	2.2	18.3	-	-
Tue	25-Jul	6	0	7	0	2	2	7	0	9	26.1	29.6	4.5	14.9	2.7	2.6
Wed	26-Jul	3	3	4	3	0	2	7	0	9	24.5	29.5	1.3	12.3	2.2	4.3
Thur	27-Jul	3	3	0	7	3	8	0	0	8	24	25.5	1.7	8.4	1.1	4.3
Fri	28-Jul	1	0	0	0	1	4	4	2	10	24.5	27	2.2	9.4	0.6	5.7
Sat	29-Jul	0	0	0	0	0	0	0	0	0	23.9	28.7	0.8	13.8	0.4	5.0
Sun	30-Jul	4	1	3	4	0	0	0	0	0	24	35.1	1.7	20.8	0.7	3.1
Mon	31-Jul	6	0	7	0	0	1	10	0	11	26.7	35.9	3.4	17.9	2.2	3.3
	Total	92	60	42	44	60	51	54	24	129						

Heating mode (21) did not operate

Key to tables A 1.2 to A 1.4
NV = Natural ventilation
MV = Mechanical ventilation
(bad wea) = Bad weather condition
OAT = Outside air temperature
IAT = Indoors air temperature

Table A1.2 - Inland Revenue Building, Durrington mode of operation and temperature data (June-July)

	Date	Night cool operation (18 to 08) NV (hrs) Mode16,17	NV stop (bad wea Mode 12	MV (hrs) Mode 47	MV (bad wea) (hrs) Mode 48	Daytime operation (08 to 18) NV (hrs) Mode 15	MV (hrs) (low speed) Mode31,32	MV (hrs) (hi speed) Mode 41	MV (bad wea) (hrs) Mode 33,34	Daytime MV total	Peak average IAT (°C)	Peak OAT (°C)	Daily IAT swing (K)	Daily OAT swing (K)	Ave Zone- OAT (18 to 08)
Tue	01-Aug	6	0	7	0	0	0	11	0	11	27.2	37.3	2.7	18.5	2.1
Wed	02-Aug	6	0	7	0	0	0	11	0	11	28.3	34.3	2.8	12.8	3.8
Thur	03-Aug	5	0	0	0	0	0	11	0	11	28.2	32.8	3	13.4	2.2
Fri	04-Aug	1	0	6	1	0	0	11	0	11	26.1	29.6	0.9	15.1	-
Sat	05-Aug	0	0	0	0	0	0	0	0	0	26.3	28.3	0.5	12.3	7.9
Sun	06-Aug	0	5	0	0	0	0	0	0	0	25.4	25.7	1.5	10.2	7.5
Mon	07-Aug	0	6	0	6	0	0	0	1	1	24	22.4	2.4	7.9	7.0
Tue	08-Aug	0	7	0	5	0	0	0	11	11	24.9	28.7	2.6	14.2	8.6
Wed	09-Aug	0	8	0	4	0	0	0	5	5	25.9	31	2.8	14.2	6.2
Thur	10-Aug	6	0	0	7	0	0	3	2	5	26.3	33.5	2.6	14.9	4.1
Fri	11-Aug	1	0	7	0	0	0	11	0	11	25.7	27.1	0.9	11.3	6.7
Sat	12-Aug	0	0	0	0	0	0	0	0	0	26	29.5	0.6	13.1	6.5
Sun	13-Aug	0	5	0	0	0	0	0	0	0	25.2	28.3	1.6	12.7	6.8
Mon	14-Aug	0	6	0	6	0	0	0	1	1	25.5	30.1	1.9	13.2	7.0
Tue	15-Aug	0	6	0	6	0	0	0	2	2	25.7	32	2.4	15	6.1
Wed	16-Aug	2	4	0	7	0	0	10	1	11	25.7	30.1	1.9	12.8	5.7
Thur	17-Aug	3	3	0	7	0	1	10	0	11	26.6	35.6	2.5	17.7	5.5
Fri	18-Aug	1	0	0	7	0	0	10	0	10	26.2	34.7	1.5	16.7	4.5
Sat	19-Aug	0	0	0	0	0	0	0	0	0	26.1	31.4	1.4	13	4.4
Sun	20-Aug	3	2	0	0	0	0	0	0	0	26.5	31.2	2.8	14.6	5.1
Mon	21-Aug	2	4	3	4	0	0	9	0	9	25.2	27.9	1.5	11.5	6.5
Tue	22-Aug	1	5	0	7	0	0	7	1	8	25.3	25.4	1.8	8.4	7.0
Wed	23-Aug	0	6	0	6	0	0	7	2	9	24.8	24.1	2.1	10.6	8.7
Thur	24-Aug	1	7	0	5	0	3	3	1	7	25.3	25.5	1.5	7	4.4
Fri	25-Aug	1	0	0	7	0	0	7	0	7	23.9	25.2	1.5	9.8	6.3
Sat	26-Aug	0	0	0	0	0	0	0	0	0	23.9	23.4	1	6.8	5.6
Sun	27-Aug	0	0	0	0	0	0	0	0	0	23.2	22.3	0.6	11.9	9.8
Mon	28-Aug	5	0	0	0	0	0	0	0	0	23.4	20.2	3.3	7.4	7.2
Tue	29-Aug	0	0	0	0	0	0	0	0	0	23.4	20.2	3.3	7.4	-
Wed	30-Aug	2	6	3	1	2	2	0	8	10	23	24	2.2	12.4	9.0
Thur	31-Aug	6	3	0	4	6	4	0	1	5	22.9	21.7	1.1	5.7	4.7
	Total	52	83	33	90	8	10	121	36	167					

Heating mode (21) did not operate

Table A1.3 - Inland Revenue Building, Durrington mode of operation and temperature data (August)

	Date	Night cool operation (18 to 08)				Daytime operation (08 to 18)					Peak	Peak	Daily IAT	Daily OAT	Night cool	Ave	
		NV (hrs)	NV stop	MV	MV (bad	NV (hrs)	MV (hrs)	MV (hrs)	MV (bad	Daytime	average	OAT (°C)	swing (K)	swing (K)	delta T	Zone- OAT	
			(bad wea)	(hrs)	wea) (hrs)		(low speed)	(hi speed)	wea) (hrs)	MV total	IAT (°C)				(18 to 08)	(18 to 08)	Heating (hrs)
		Mode16,17	Mode 12	Mode 47	Mode 48	Mode 15	Mode31,32	Mode 41	Mode 33,34								Mode 21
Fri	01-Sep	6	0	4	3	4	6	0	1	7	23.4	20.3	2.1	5.8	1.6	4.8	0
Sat	02-Sep	1	0	1	6	9	0	0	2	2	23.1	21.7	0.2	8	0.5	6.9	0
Sun	03-Sep	0	0	0	0	0	0	0	0	0	23.2	24.9	0.4	14.9	0.2	10.5	0
Mon	04-Sep	3	2	0	0	0	0	0	0	0	23	26.4	2.5	14.7	2.6	10.2	0
Tue	05-Sep	4	5	0	4	9	0	0	2	2	23.6	23.2	3	11.5	2.4	8.2	0
Wed	06-Sep	4	4	0	4	4	0	0	8	8	23.1	23.6	2.7	10.5	3.2	7.8	0
Thur	07-Sep	1	6	5	0	10	0	0	2	2	24	22.6	1.8	6.2	0.9	5.6	0
Fri	08-Sep	1	6	1	5	0	0	0	11	11	24	21.3	2.3	5.5	2.1	6.9	0
Sat	09-Sep	1	2	3	2	1	4	0	6	10	23.6	22.9	0.7	9.4	0.4	7.7	0
Sun	10-Sep	0	0	0	0	0	0	0	0	0	23.2	19.2	0	3.9	-0.3	6.9	0
Mon	11-Sep	0	5	0	0	0	0	0	0	0	24	21.7	3.2	8.1	2.4	6.4	0
Tue	12-Sep	6	1	3	3	6	0	0	5	5	23.5	21.8	2.8	10.3	3.1	6.5	0
Wed	13-Sep	3	5	1	4	4	0	0	7	7	23.3	24.7	3	14.5	2.9	9.5	0
Thur	14-Sep	4	5	0	4	8	0	0	3	3	23.6	20.9	2.8	8.2	2.3	9.2	0
Fri	15-Sep	4	4	0	4	4	0	0	8	8	23.3	24	2.7	10.6	3	7.9	0
Sat	16-Sep	1	0	2	4	8	0	0	4	4	22.9	21	0.3	8.8	0.6	10.8	0
Sun	17-Sep	0	0	0	0	0	0	0	0	0	22.9	22	0.4	9.4	0.4	9.5	0
Mon	18-Sep	0	5	0	0	0	0	0	0	0	23.5	18.1	2.4	3.9	1.7	9.2	0
Tue	19-Sep	2	6	0	4	1	0	0	11	11	23.4	21.8	2.1	6.8	2.2	8.0	0
Wed	20-Sep	4	4	0	5	8	0	0	3	3	22.9	20.1	4	10.3	4.4	7.4	1
Thur	21-Sep	7	2	3	1	8	0	0	2	2	23	20.9	1.8	13.7	1.7	10.8	0
Fri	22-Sep	3	10	0	0	9	0	0	2	2	23	22.3	2.7	11.5	2.7	9.4	0
Sat	23-Sep	1	2	0	5	8	0	0	3	3	22.6	21.8	1.5	9.2	0.3	7.4	0
Sun	24-Sep	0	0	0	0	0	0	0	0	0	22.5	16.9	0.4	3.7	0	7.4	0
Mon	25-Sep	3	2	0	0	0	0	0	0	0	22.8	19	2	12.8	1.7	11.4	0
Tue	26-Sep	8	5	0	0	9	0	0	2	2	23.1	19.8	2.7	3.9	2.4	4.9	0
Wed	27-Sep	1	5	4	2	3	0	0	9	9	23.2	17.5	2.8	4.9	2.6	7.9	0
Thur	28-Sep	4	4	0	5	3	0	0	8	8	22.9	16	1.8	9.6	2	12.6	0
Fri	29-Sep	1	12	0	0	8	0	0	3	3	23.2	18.5	1.4	13.8	1.1	14.4	0
Sat	30-Sep	1	7	0	0	7	0	0	4	4	22.3	17.3	0.1	3.9	0.9	12.5	0
Sun	01-Oct	0	0	0	0	0	0	0	0	0	22.8	20.1	0.7	4.7	0.1	7.0	0
Mon	02-Oct	5	0	0	0	0	0	0	0	0	22.7	19.5	3.4	4.3	3.3	9.1	3
Tue	03-Oct	4	5	4	0	7	0	0	1	1	23.2	17.7	2.4	2.5	1.9	5.7	0
Wed	04-Oct	0	7	0	5	2	0	0	10	10	23.4	18.7	1.8	2.9	1.6	6.0	0
Thur	05-Oct	5	4	0	4	0	0	0	11	11	23.2	17.9	3.4	6.2	3.6	6.1	1
Fri	06-Oct	7	1	2	3	4	0	0	6	6	23.1	17.5	2.6	3.1	2.4	6.2	1
Sat	07-Oct	1	2	0	4	0	0	0	11	11	22.2	19.7	0.6	3.1	1.4	5.3	0
Sun	08-Oct	0	0	0	0	0	0	0	0	0	22.8	21.6	0.9	6.4	0.3	6.4	0
Mon	09-Oct	0	5	0	0	0	0	0	0	0	23.5	21.3	2.1	6.3	1.2	5.6	0
Tue	10-Oct	0	5	0	7	6	0	0	6	6	23.3	21.6	2	6.4	1.7	7.4	0
Wed	11-Oct	6	1	0	6	9	0	0	2	2	23	17	2.1	1.8	2.3	6.5	0
Thur	12-Oct	2	5	3	2	11	0	0	1	1	23.3	21.1	1.6	4.7	1.3	7.1	0
Fri	13-Oct	2	4	0	6	8	0	0	4	4	23.1	18.9	2.4	5.8	2.4	6.9	0
Sat	14-Oct	1	1	1	5	9	0	0	2	2	23.1	20.1	0.5	5.3	0.4	7.6	0
Sun	15-Oct	0	0	0	0	0	0	0	0	0	23	19.1	0.4	3.7	0.4	8.4	0
Mon	16-Oct	2	3	0	0	0	0	0	0	0	23.1	19.9	2.1	5.5	2	6.1	0
Tue	17-Oct	0	6	0	6	7	0	0	5	5	23.5	20.3	1.9	5.1	1.5	7.0	0
	Total	109	158	37	113	194	10	0	165	175							6

Table A1.1 Inland Revenue Building, Durrington mode of operation and temperature data (Sept-Oct)

Table A1. 5 - Inland Revenue Building Durrington - Comparison of Slab temperature and Slab temperature setpoint

	Slab temperature			Slab setpoint			Δ T (Slab - setpoint)		
	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave
June (1)	24.5	22.1	22.9	21.3	20.0	20.6	4.5	1.2	2.2
July (2)	24.4	22.7	23.4	-	-	-	-	-	-
Aug	26.7	23.5	25.3	19.0	18.4	18.7	7.8	5.1	6.6
Sept	24.0	22.1	22.9	18.8	18.3	18.5	5.6	3.7	4.4
Oct (3)	23.0	21.6	22.4	18.9	18.4	18.6	4.4	3.0	3.8

(1) from 19 June to 30 June
(2) 3 July, 4 July and 24 July-31 July
(3) from 1 October to 17 October

Table A1. 6 - Inland Revenue Building Durrington - Correlation between variables (weekday data)

Variable 1	Variable 2	Correlation coefficient (r)
OAT occ max	Zone occ max	0.870
OAT occ swing	Zone occ swing	0.196
Wind speed occ	Zone occ max	-0.309
Wind dir occ	Zone occ max	0.443
NV hrs occ	Zone occ max	-0.540
MV hrs occ	Zone occ max	0.551
Bad weather hrs occ	Zone occ max	-0.331
MV hi speed hrs occ	Zone occ max	0.800
NV hrs night	Night cool Δ T	0.457
MV hrs night	Night cool Δ T	0.132
Bad weather hrs night	Night cool Δ T	-0.075
Ave temp diff (zone - OAT) night	Night cool Δ T	-0.035
Wind speed night	Night cool Δ T	0.069
Wind dir night	Night cool Δ T	-0.037
Average OAT night	Night cool Δ T	-0.065
Night cool Δ T	NV hrs occ	-0.085
Night cool Δ T	MV hrs occ	0.011

Key to table

OAT	=	outside air temperature
max	=	maximum temperature
swing	=	temperature swing
wind dir	=	wind direction
night	=	night cooling period
occ	=	occupied period
Bad weather	=	bad weather mode
NV	=	natural ventilation
MV	=	mechanical ventilation
Night cool Δ T	=	zone air temperature change during night cooling
hi speed	=	high speed mechanical ventilation (4 ac/h)

Table A1.7- Inland Revenue Building Durrington - Correlation between variables (Monday data)

Variable 1	Variable 2	Correlation coefficient (r)
OAT occ max	Zone occ max	0.871
OAT occ swing	Zone occ swing	0.030
Wind speed occ	Zone occ max	-0.306
Wind dir occ	Zone occ max	0.438
NV hrs occ	Zone occ max	-0.034
Bad weather hrs occ	Zone occ max	-0.022
MV hi speed hrs occ	Zone occ max	0.750
NV hrs night	Night cool Δ T	0.550
MV hrs night	Night cool Δ T	0.022
Bad weather hrs night	Night cool Δ T	-0.190
Ave temp diff (zone-OAT) night	Night cool Δ T	-0.087
Wind speed night	Night cool Δ T	-0.210
Wind dir night	Night cool Δ T	-0.133
Night cool Δ T	NV hrs occ	0.200
Night cool Δ T	MV hrs occ	0.019

Key to table

OAT = outside air temperature
max = maximum temperature
swing = temperature swing
wind dir = wind direction
night = night cooling period
occ = occupied period
Bad weather = bad weather mode
NV = natural ventilation
MV = mechanical ventilation
Night cool Δ T= zone air temperature change during night cooling
hi speed = high speed mechanical ventilation (4 ac/h)

Table A1. 8- Inland Revenue Building Durrington - Correlation between variables (weekend data)

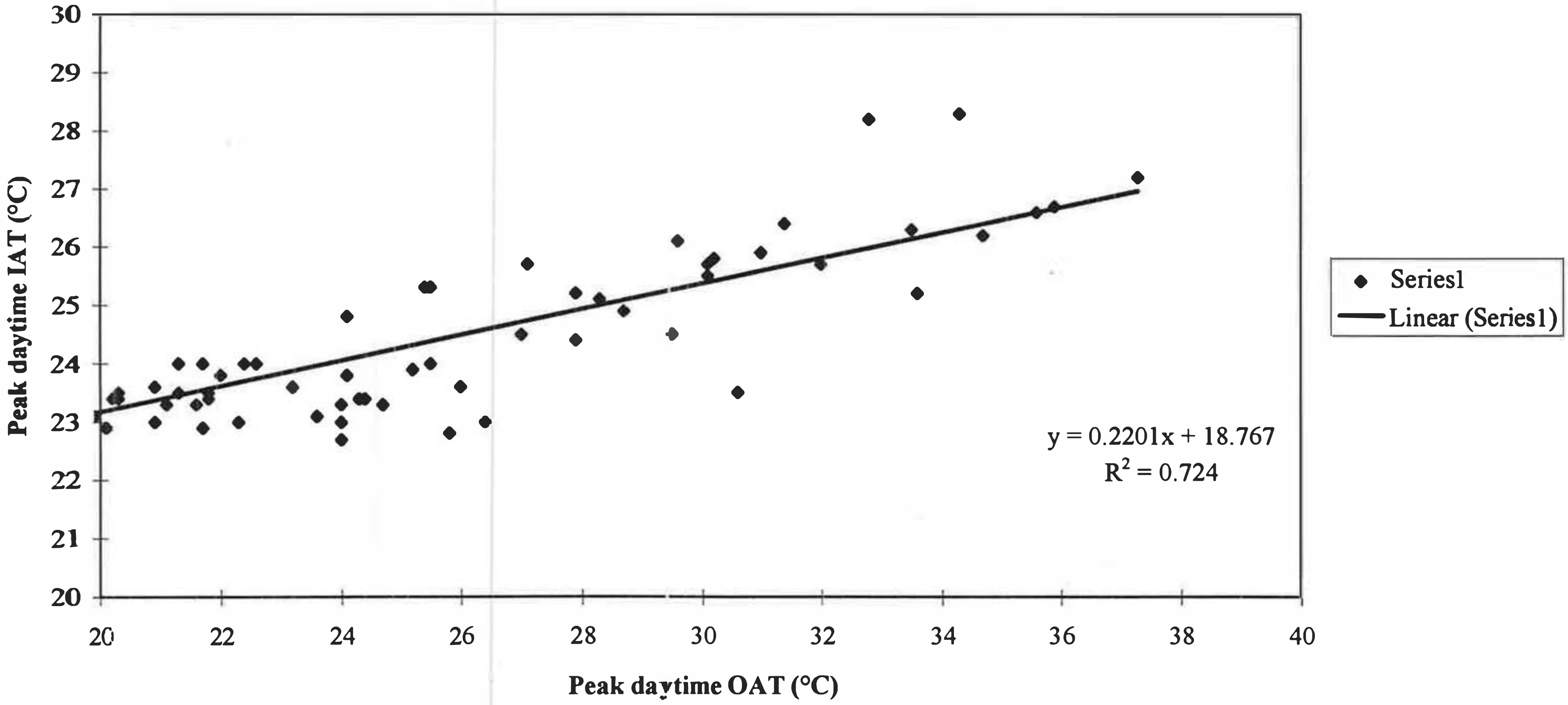
Variable 1	Variable 2	Correlation coefficient (r)
OAT occ max	Zone occ max	0.752
OAT occ swing	Zone occ swing	0.446
Wind speed occ	Zone occ max	-0.298
Wind dir occ	Zone occ max	0.379
NV hrs occ	Zone occ max	-0.312
MV hrs occ	Zone occ max	-
Bad weather hrs occ	Zone occ max	-0.352
MV hi speed hrs occ	Zone occ max	-0.310
NV hrs night	Night cool Δ T	0.316
MV hrs night	Night cool Δ T	-0.070
Bad weather hrs night	Night cool Δ T	0.728
Ave temp diff (zone-OAT) night	Night cool Δ T	-0.135
Wind speed night	Night cool Δ T	0.085
Wind dir night	Night cool Δ T	0.331
Night cool Δ T	NV hrs occ	-0.090
Night cool Δ T	MV hrs occ	0.0798

Key to table

OAT = outside air temperature
max = maximum temperature
swing = temperature swing
wind dir = wind direction
night = night cooling period
occ = occupied period
Bad weather = bad weather mode
NV = natural ventilation
MV = mechanical ventilation
Night cool Δ T= zone air temperature change during night cooling
hi speed = high speed mechanical ventilation (4 ac/h)

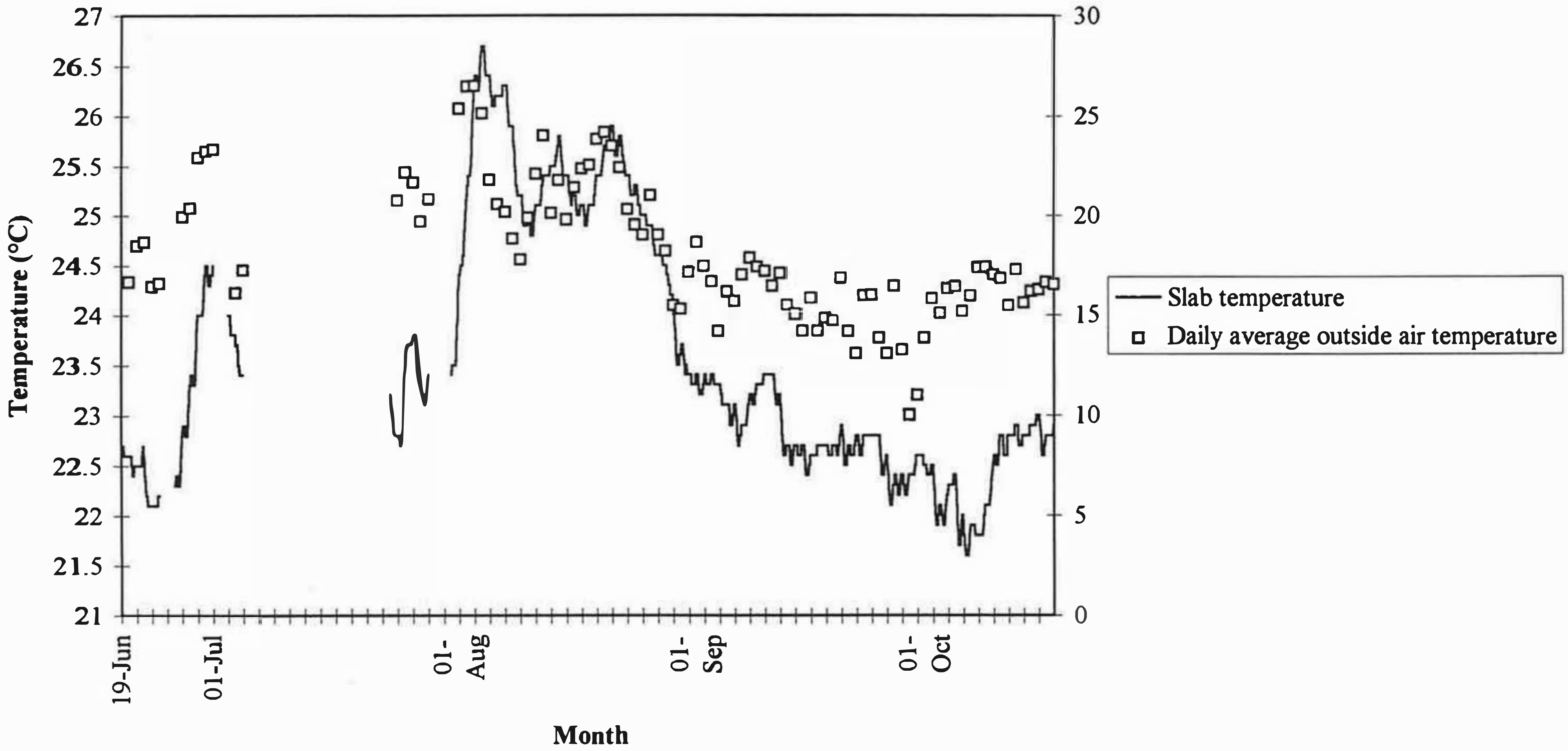
INLAND REVENUE, DURRINGTON- CORRELATION TESTS (WEEKDAY DATA)

Figure A1. 8



INLAND REVENUE BUILDING DURRINGTON- SEASONAL VARIATION IN SLAB TEMPERATURE

Figure A1. 9



INLAND REVENUE, DURRINGTON- RELATIONSHIP BETWEEN AVERAGE WEEKLY OUTSIDE AIR TEMPERATURE AND AVERAGE WEEKLY SLAB TEMPERATURE

Figure A1. 10

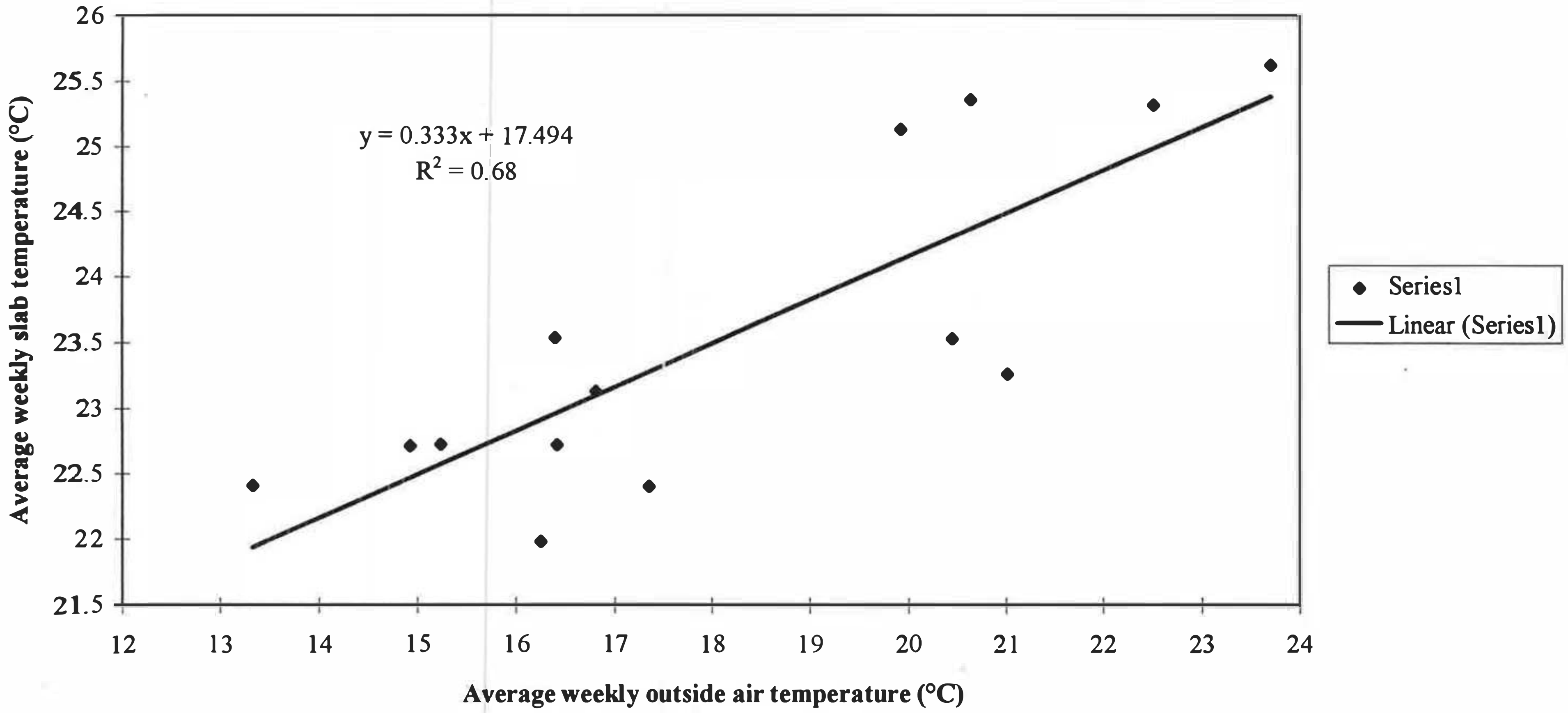


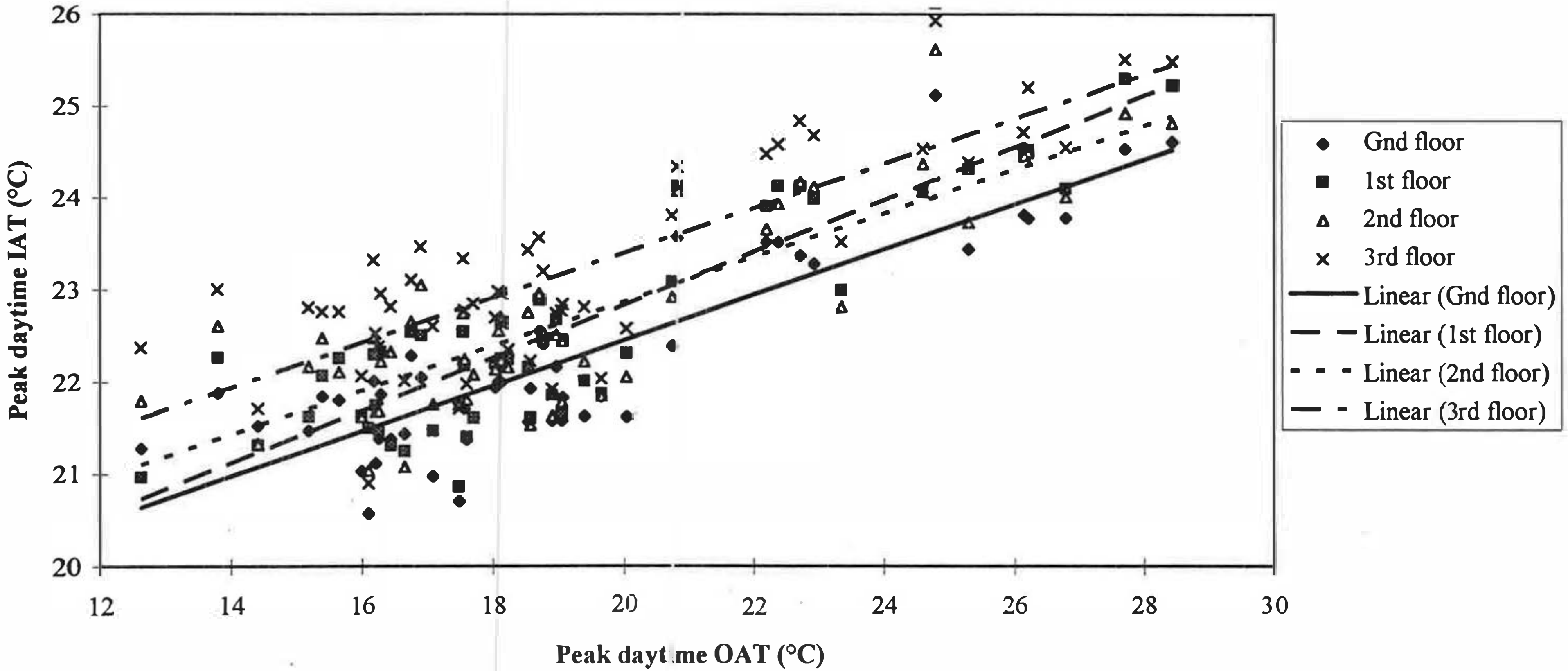
Table A1. 9 - Inland Revenue Building, Durrington -

correlation (r) between peak daytime point temperatures and peak daytime outside air temperature

	North East	North West	South East	South West
Ground floor	0.868	0.888	0.782	0.794
1st floor	0.863	0.896	0.775	0.757
2nd floor	0.866	0.830	0.860	0.857
3rd floor	0.850	0.832	0.848	0.858

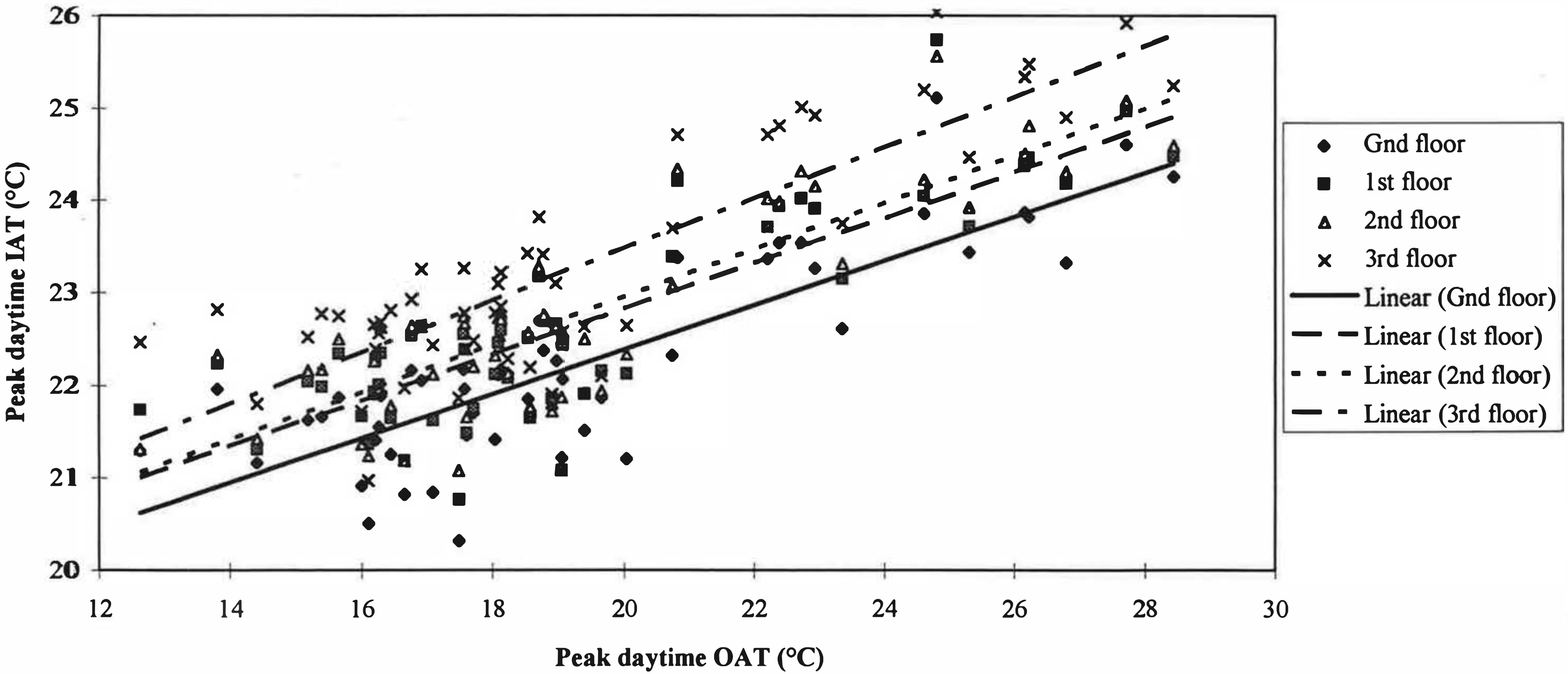
INLAND REVENUE, DURRINGTON- VARIATION OF PEAK DAYTIME INSIDE AIR TEMPERATURE (NW) WITH PEAK OUTSIDE AIR TEMPERATURE

Figure A1. 11



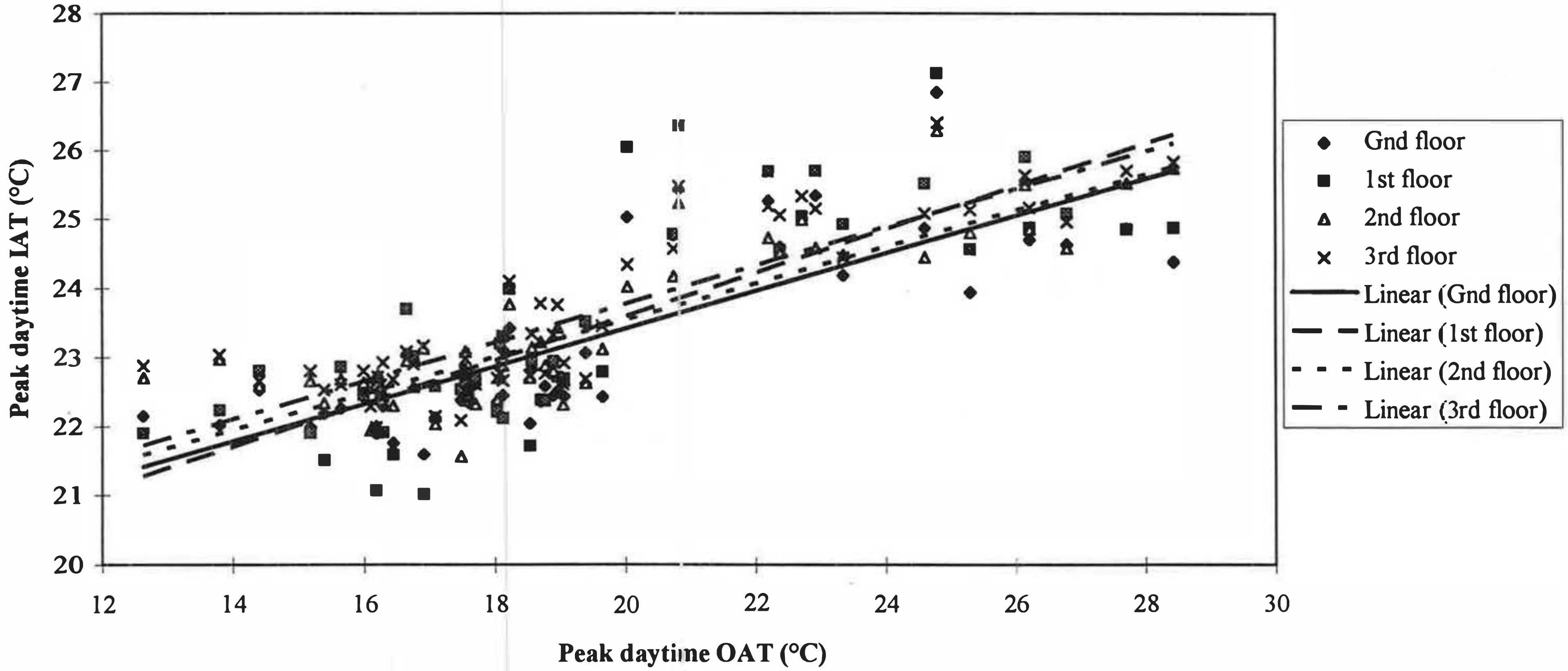
INLAND REVENUE, DURRINGTON- VARIATION OF PEAK DAYTIME INSIDE AIR TEMPERATURE (NE) WITH PEAK OUTSIDE AIR TEMPERATURE

Figure A1. 12



INLAND REVENUE, DURRINGTON- VARIATION OF PEAK DAYTIME INSIDE AIR TEMPERATURE (SW) WITH PEAK OUTSIDE AIR TEMPERATURE

Figure A1. 13



INLAND REVENUE, DURRINGTON- VARIATION OF PEAK DAYTIME INSIDE AIR TEMPERATURE (SE) WITH PEAK OUTSIDE AIR TEMPERATURE

Figure A1. 14

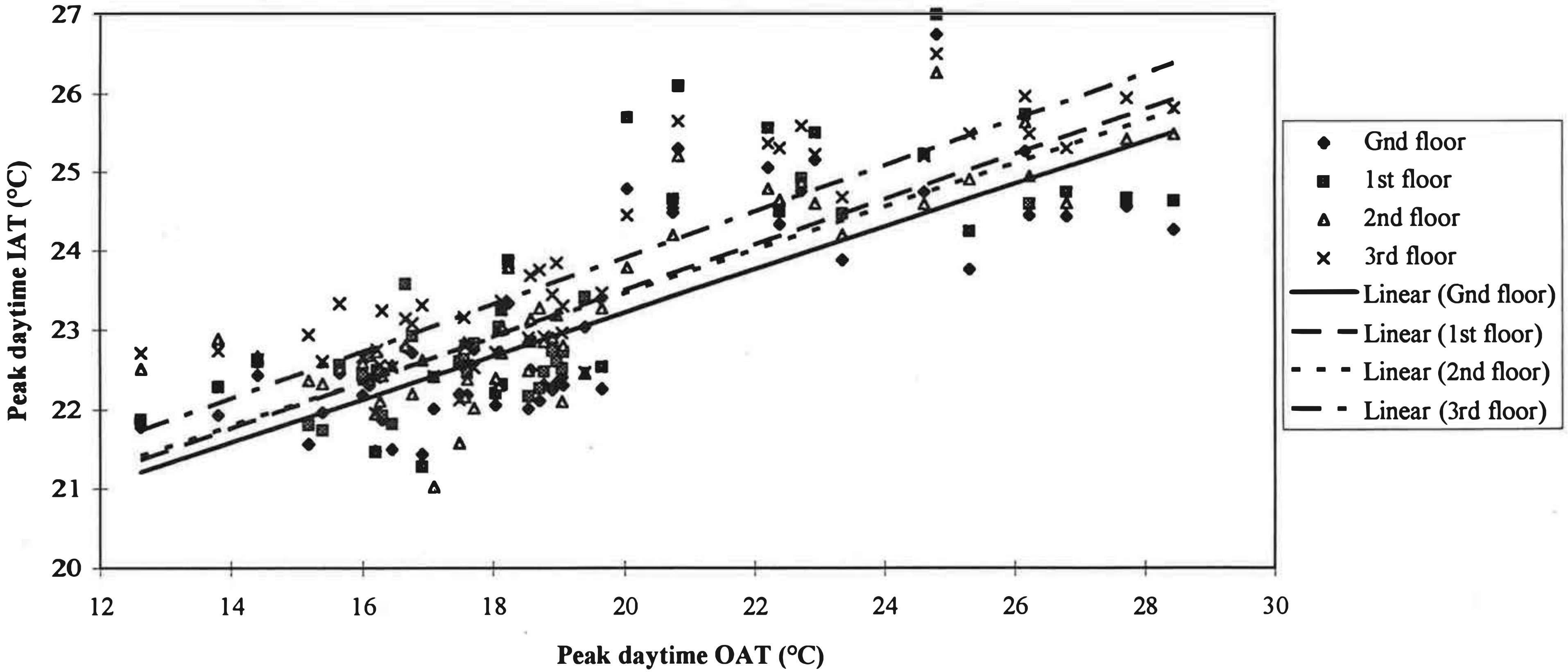


Table A1. 10 - Inland Revenue Building, Durrington - Point temperature regression analysis

1 Daytime outside air temperature v daytime point temperatures

	R^2	
Max occ OAT v Ave max occ Gnd	0.756	T = 0.2098 OAT + 18.91
Max occ OAT v Ave max occ 1st	0.758	T = 0.2396 OAT + 18.61
Max occ OAT v Ave max occ 2nd	0.781	T = 0.2033 OAT + 19.35
Max occ OAT v Ave max occ 3rd	0.936	T = 0.3687 OAT + 15.66
Max occ OAT v Ave max occ NE	0.753	T = 0.2083 OAT + 18.96
Max occ OAT v Ave max occ NW	0.769	T = 0.2078 OAT + 19.02
Max occ OAT v Ave max occ SE	0.708	T = 0.2216 OAT + 19.28
Max occ OAT v Ave max occ SW	0.699	T = 0.2258 OAT + 19.19

2 Daytime ground floor temperature v daytime other floor temperature

	R^2	
NE Gnd to other floors	0.921	T = 1.0705 Tg + 0.2689F - 1.445
NW Gnd to other floors	0.895	T = 1.0476 Tg + 0.2764F - 0.986
SE Gnd to other floors	0.805	T = 0.8780 Tg + 0.0528F + 3.100
SW Gnd to other floors	0.810	T = 0.8805 Tg + 0.0104F + 3.050
Ave (NE, NW, SE, SW) Gnd to other floors	0.878	T = 1.1751 Tg + 0.0191F - 3.831

3 Night cooling ground floor temperature drop v other floors night cooling temperature drop

	R^2	
NE Gnd to other floors	0.672	ΔT = 0.7170 ΔTg - 0.1077F + 0.7934
NW Gnd to other floors	0.578	ΔT = 0.7982 ΔTg - 0.0231F + 0.6206
SE Gnd to other floors	0.183	ΔT = 0.1266 ΔTg + 0.6096F - 0.0160
SW Gnd to other floors	0.310	ΔT = 0.1472 ΔTg + 0.7932F - 0.4960
Average Gnd to other floors	0.382	ΔT = 0.6325 ΔTg + 0.3180F - 0.2660

T = Maximum point temperature (°C)
OAT = Maximum outside air temperature (°C)
Tg = Maximum ground floor temperature for particular facade
F = Floor number (other than ground)
ΔT = Night cooling temperature drop (K)
ΔTg = Night cooling temperature drop of ground floor for particular facade (K)

Table A1.11 - Summary of hours when third floor north temperature exceeded the third floor south temperature (August-October)

	Occupied period (hrs)	Night cooling period (hrs)
NE>SE	110.25	0
NW>SW	136	0
NE>SW	127	0
NW>SE	416	0
Total available hours	440	616

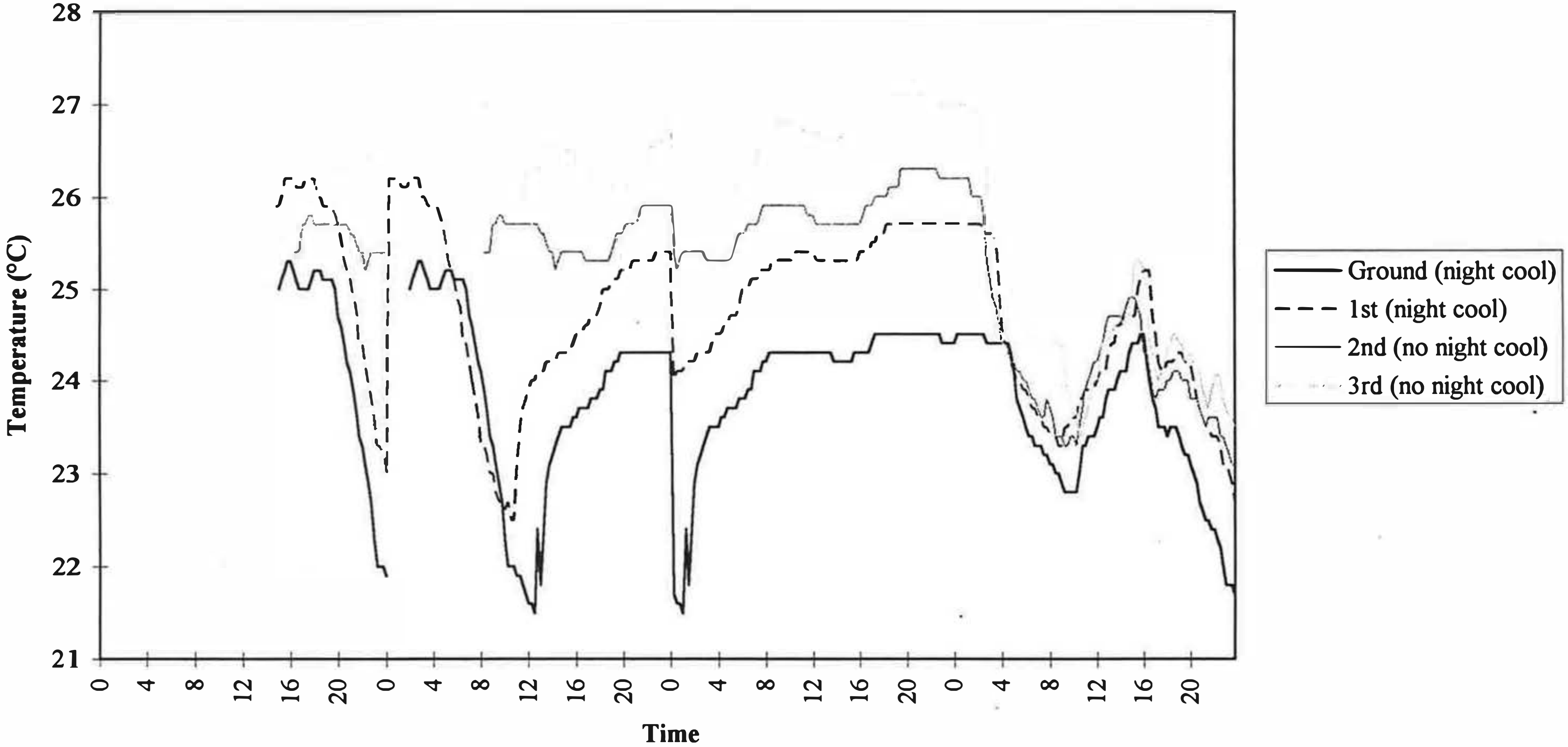
		NEGnd	NE1st	NE2nd	NE3rd	NWGnd	NW1st	NW2nd	NW3rd	SEGnd	SE1st	SE2nd	SE3rd	SWGnd	SW1st
		Night	Night	No cool	No cool	Night	Night	No cool	No cool	No cool	No cool	Night	Night	No cool	No cool
		cool	cool			cool	cool					cool	cool		
Fri	18.00 temp	25.2	25.8	25.6	26.1	25.2	26.2	25.7	26	26.1	26.5	26.5	26.7	26.4	26.7
Sat	07.00 temp	22.2	23.8	25.5	26.1	24.7	24.2	25.7	26	27.6	28.1	26.7	26.6	25.8	28.1
Fri-Sat	temp change	3	2	0.1	0	0.5	2	0	0	-1.5	-1.6	-0.2	0.1	0.6	-1.4
Fri-Sat	max-min(18-7)	3.3	3.1	0.4	0.7	3.4	3.2	0.5	0.6	4.1	4.7	1.2	1.3	2.9	4.1
Sat	18.00 temp	24.2	24.6	25.3	26.2	23.9	24.8	25.3	26.1	25.5	25.9	26	26.8	28.3	26.7
Sun	07.00 temp	24.3	24.3	25.4	26.5	24.1	25.1	25.7	26.3	27	25.3	26.3	26.7	25	25.5
Sat-Sun	temp change	-0.1	0.3	-0.1	-0.3	-0.2	-0.3	-0.4	-0.2	-1.5	0.6	-0.3	0.1	3.3	1.2
Sat-Sun	max-min(18-7)	0.7	3.2	0.6	0.8	2.8	1.4	0.7	0.7	3.9	3.4	1.9	1.5	3.5	3.4
Sun	18.00 temp	24.4	25.3	25.8	27	24.5	25.6	26	27	25.2	25.9	26.7	27.2	25.6	26
Mon	07.00 temp	23.4	23.5	24	24.5	23.3	23.6	23.7	24.4	25.6	24.2	24.4	25.3	25.5	24.8
Sun-Mon	temp change	1	1.8	1.8	2.5	1.2	2	2.3	2.6	-0.4	1.7	2.3	1.9	0.1	1.2
Sun-Mon	max-min(18-7)	1.2	2	2	2.6	1.2	2.1	2.6	2.7	3.9	4.3	2.7	2.2	5	3.8
Mon 7Aug	Peak outside	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.7
Mon 7Aug	Peak zone	24.2	25.1	25.1	25.4	24.5	25.2	24.9	25.3	26.2	26.8	26	26.3	26.4	27
Mon 14Aug	Peak outside*	28.3	28.3	28.3	28.3	28.3	28.3	28.3	28.3	28.3	28.3	28.3	28.3	28.3	28.3
Mon 14Aug	Peak zone*	24.1	24.9	24.9	25.7	24.4	24.8	25.5	26.4	26.1	26.6	25.7	26	26.6	26.7

* Used for comparison only- normal weekend controls applied

Table A1.12 - Inland Revenue Building, Durington - Weekend test 1 (4/8/95 - 7/8/95)

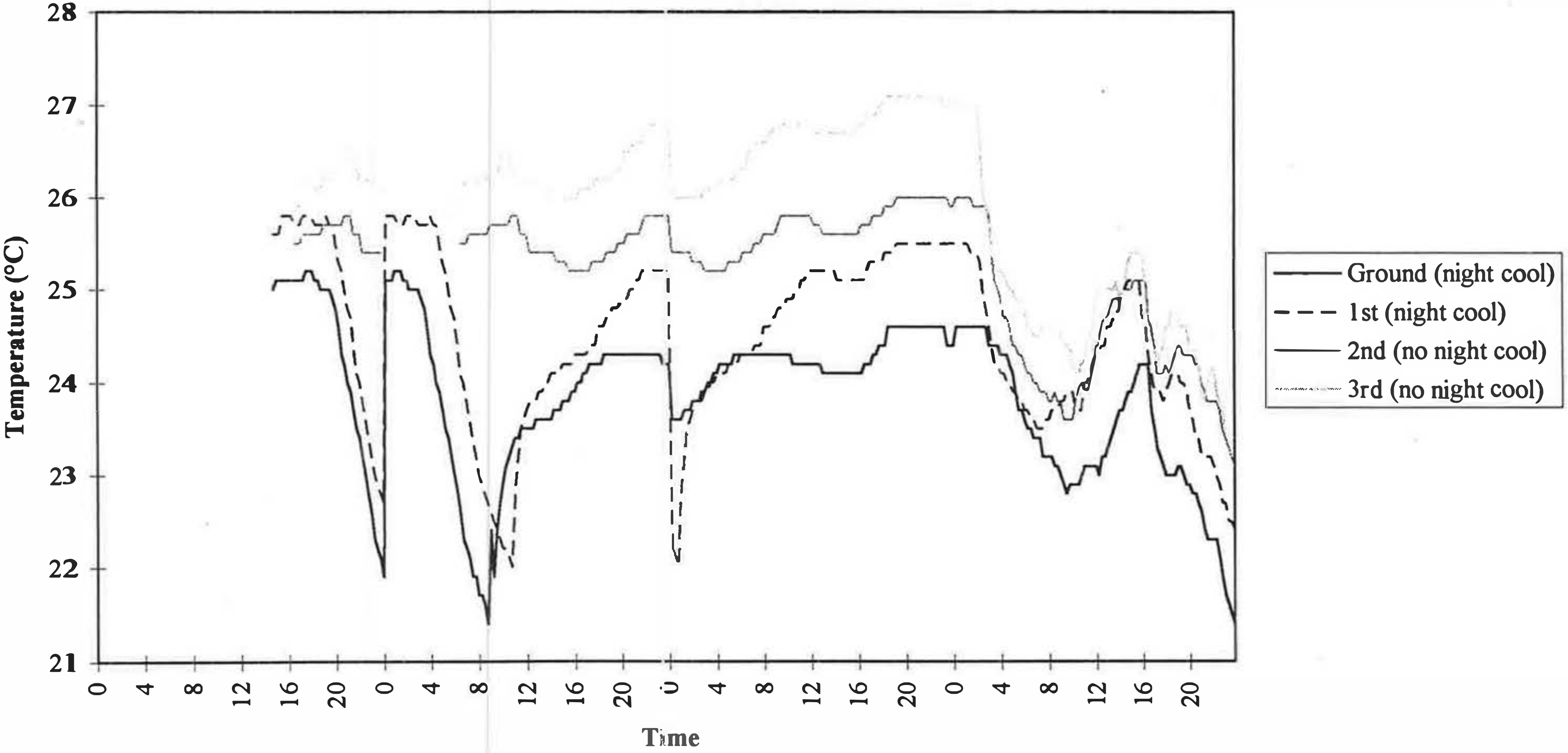
INLAND REVENUE, DURRINGTON TEST- NORTH WEST TEMPERATURES (4/8/95-7/8/95)

Figure A1. 15



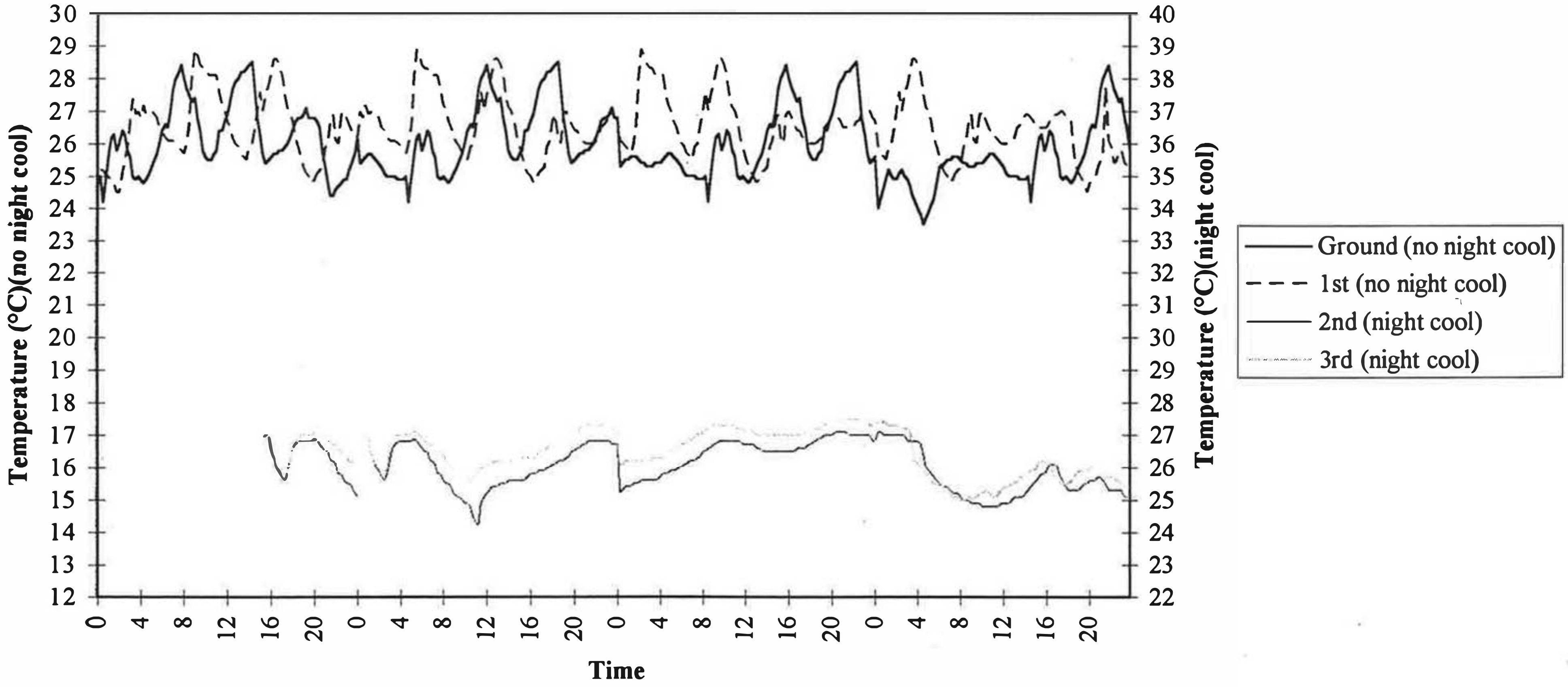
INLAND REVENUE, DURRINGTON TEST- NORTH EAST TEMPERATURES (4/8/95-7/8/95)

Figure A1. 16



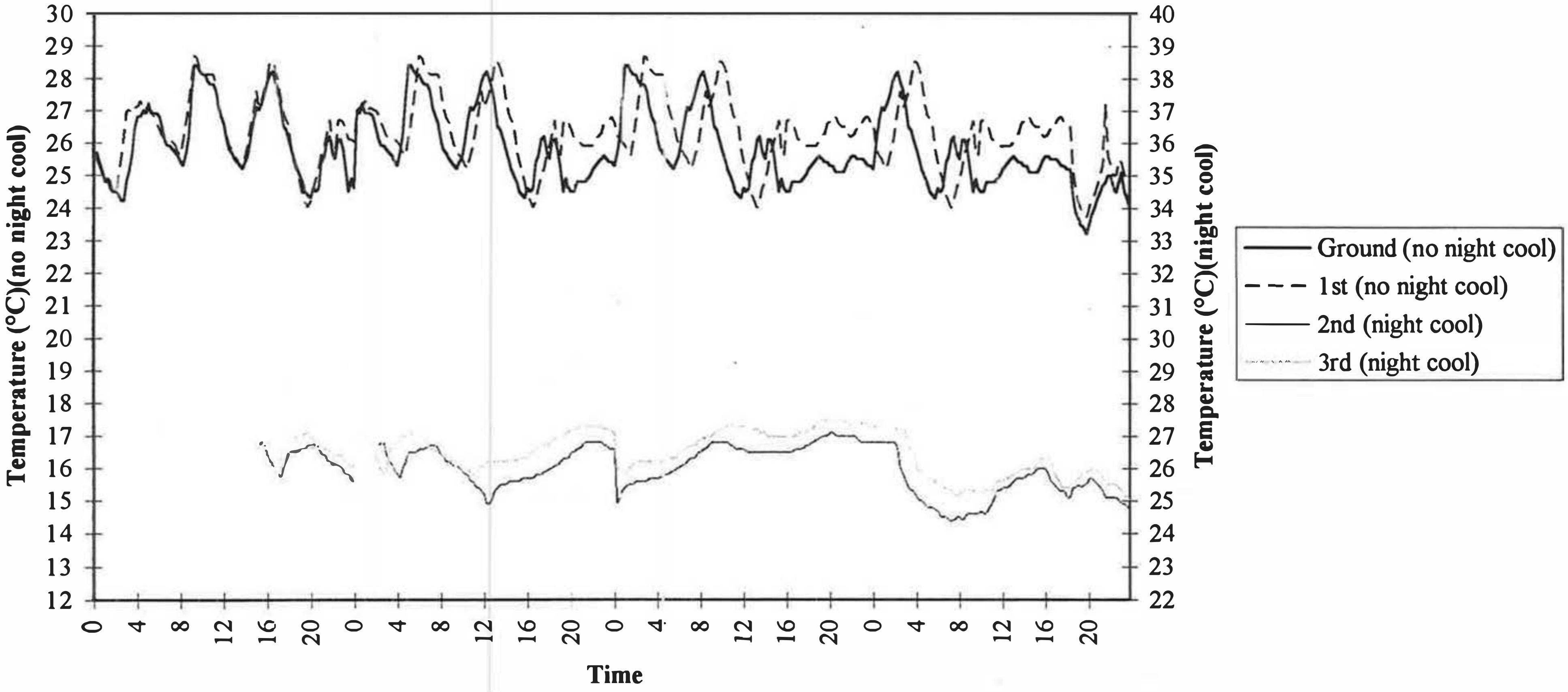
INLAND REVENUE, DURRINGTON TEST- SOUTH WEST TEMPERATURES (4/8/95-7/8/95)

Figure A1. 17



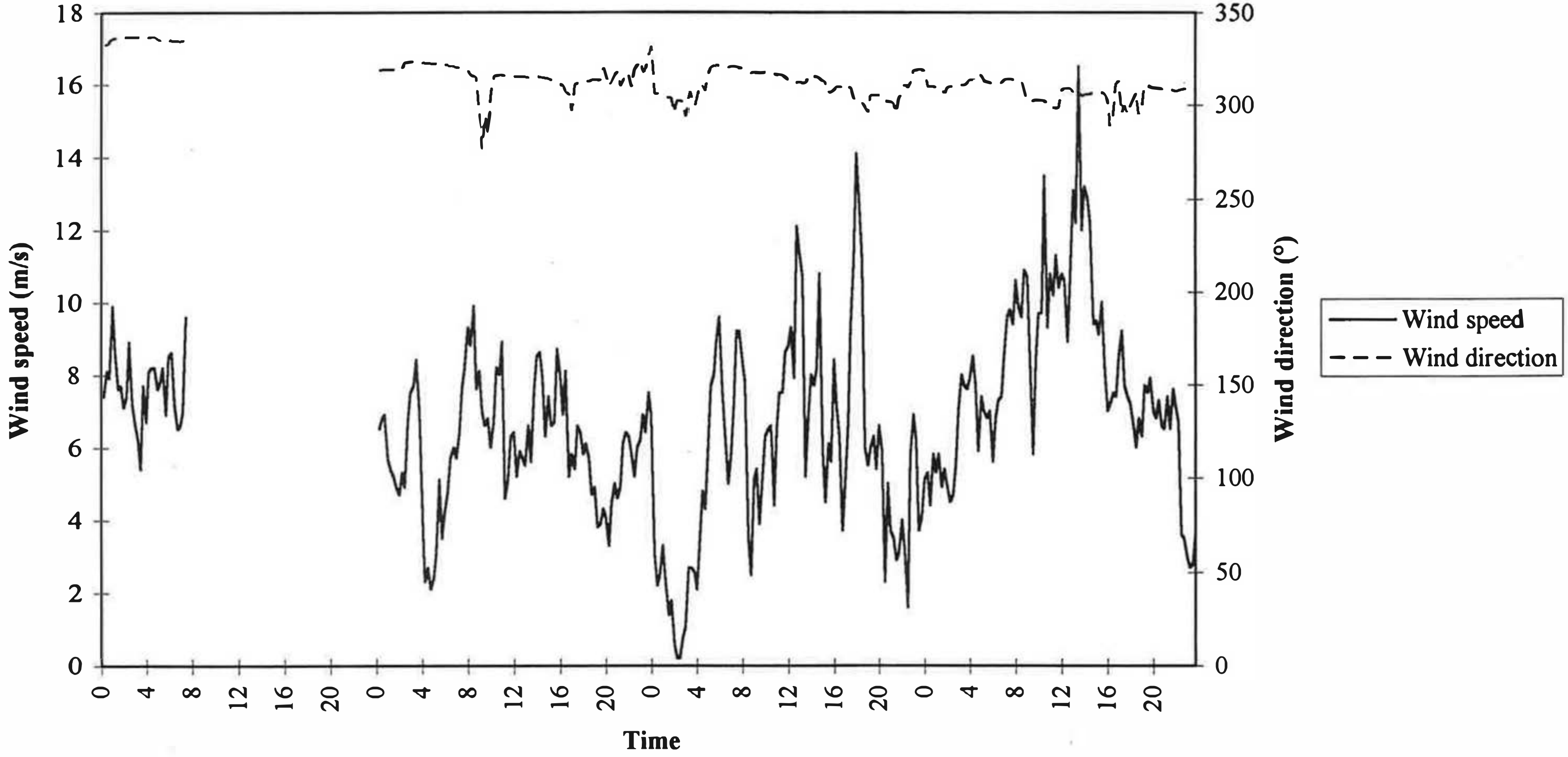
INLAND REVENUE DURRINGTON TEST- SOUTH EAST TEMPERATURES (4/8/95-7/8/95)

Figure A1. 18



INLAND REVENUE, DURRINGTON TEST- WIND SPEED AND DIRECTION (4/8/95-7/8/95)

Figure A1. 19

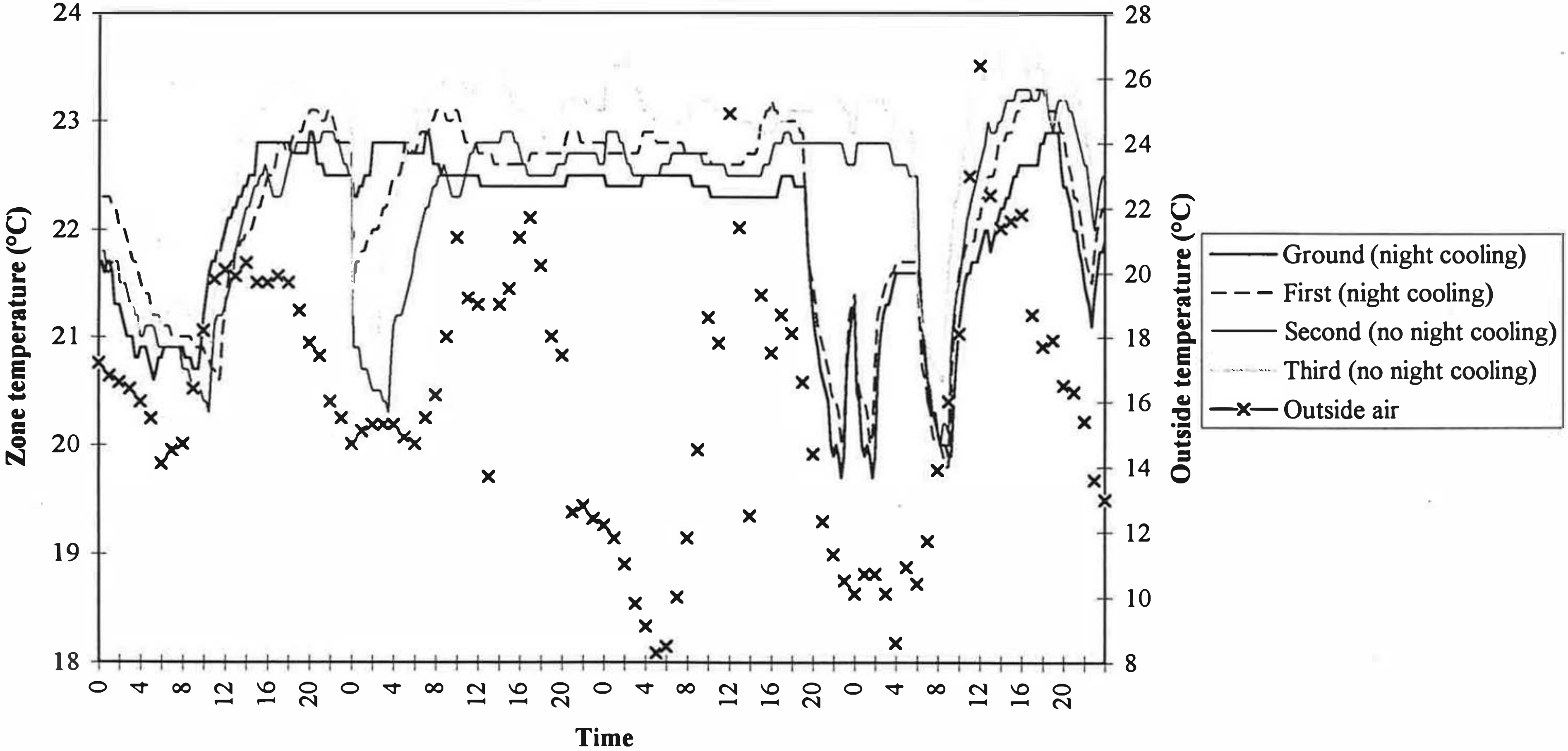


		NEGn	NE1st	NE2nd	NE3rd	NWGnd	NW1st	NW2nd	NW3rd	SEGnd	SE1st	SE2n	SE3r	SWGn	SW1st	SW2nd	SW3rd
		Night	Night	No cool	No cool	Night	Night	No cool	No cool	No cool	No cool	Night	Night	No cool	No coo	Night	Night
		cool	cool			cool	cool					cool	cool			cool	cool
Fri	18.00 temp	22.8	22.8	22.7	22.8	22.4	22.7	23.3	23.1	22.5	22.6	23.7	23.7	22.6	23.4	24.1	24.2
Sat	07.00 temp	22.5	22.9	22.2	22.6	22.9	22.9	22.6	23.8	22.9	22.2	23.6	22.9	23.5	23.1	22.9	23.2
Fri-Sat	temp change	0.3	-0.1	0.5	0.2	-0.5	-0.2	0.7	-0.7	-0.4	0.4	0.1	0.8	-0.9	0.3	1.2	1
Fri-Sat	max-min(18-	0.3	0.6	3.4	3.1	1.8	1.6	4	2.6	0.8	2.6	1.3	1.3	2.5	2.7	1.8	1.7
Sat	18.00 temp	22.6	22.4	22.7	23.4	22.5	22.7	23.2	23.1	22.5	22.5	23.3	23.5	23.1	23	23.2	23.4
Sun	07.00 temp	22.5	22.5	21.6	22.3	22.6	22.8	21.7	23.3	22.6	22.7	23.1	23.2	23.1	23	23.2	23.3
Sat-Sun	temp change	0.1	-0.1	1.1	1.1	-0.1	-0.1	1.5	-0.2	-0.1	-0.2	0.2	0.3	0	0	0	0.1
Sat-Sun	max-min(18-	0.1	0.1	3.3	2.8	0.3	0.2	3.7	2.6	0.2	0.4	0.8	1	0.5	0.6	1.1	0.9
Sun	18.00 temp	22.6	22.5	23.2	23	22.8	23	23.7	23.8	22.5	22.8	23.4	23.3	23.2	23.1	23.4	23.2
Mon	07.00 temp	20.9	20.6	22.4	22	20.3	20.4	21.4	23.2	20.6	20.6	20.9	21.3	21.2	20.9	22.5	21.7
Sun-Mon	temp change	1.7	1.9	0.8	1	2.5	2.6	2.3	0.6	1.9	2.2	2.5	2	2	2.2	0.9	1.5
Sun-Mon	max-min(18-	3.4	2.8	2	1.6	3.7	3	2.6	2.3	2.1	2.2	2.5	2.1	2.1	2.3	1.4	1.5
Mon 4 Se	Peak outside	26.4	26.4	26.4	26.4	26.4	26.4	26.4	26.4	26.4	26.4	26.4	26.4	26.4	26.4	26.4	26.4
Mon 4 Se	Peak zone	22.6	22.8	23.7	23.7	23	23.3	24.1	24.1	23.5	23.3	23.5	23.4	23.5	23.7	23.5	23.7

Table A1.13 - Inland Revenue Building, Durrington - Weekend test 2 (1/9/95 - 4/9/95)

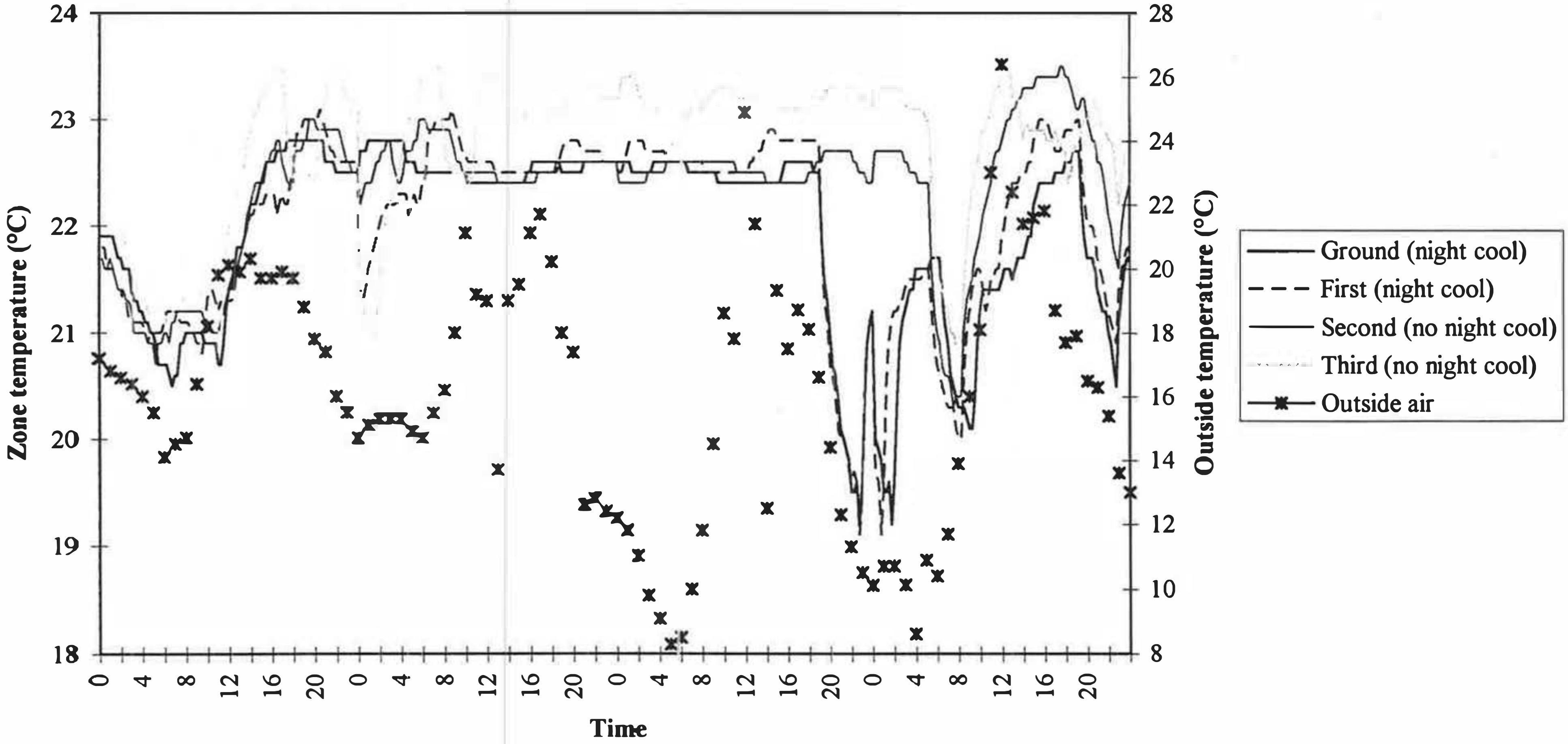
INLAND REVENUE, DURRINGTON TEST- NORTH WEST TEMPERATURES (1/9/95-4/9/95)

Figure A1. 20



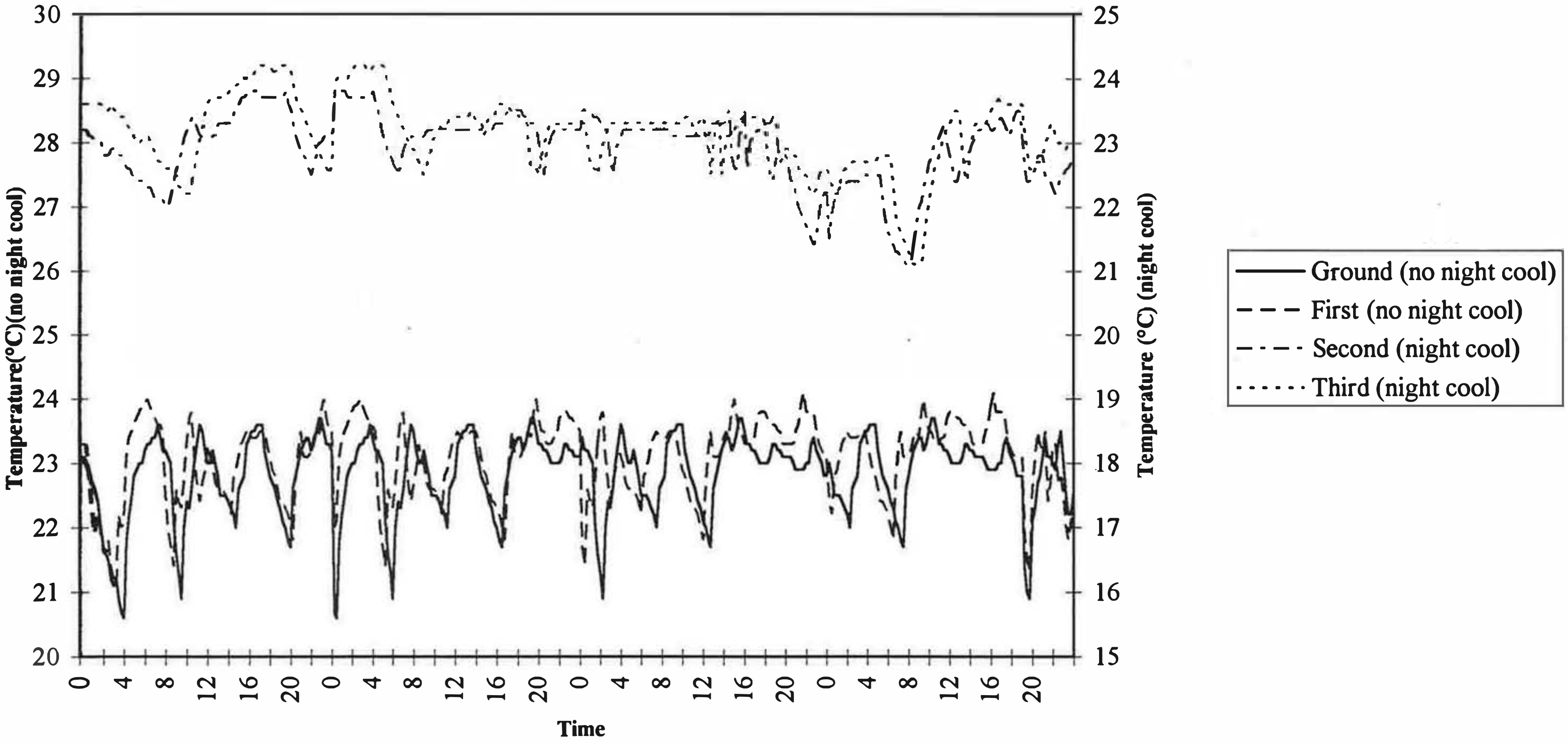
INLAND REVENUE, DURRINGTON TEST- NORTH EAST TEMPERATURES (1/9/95-4/9/95)

Figure A1. 21



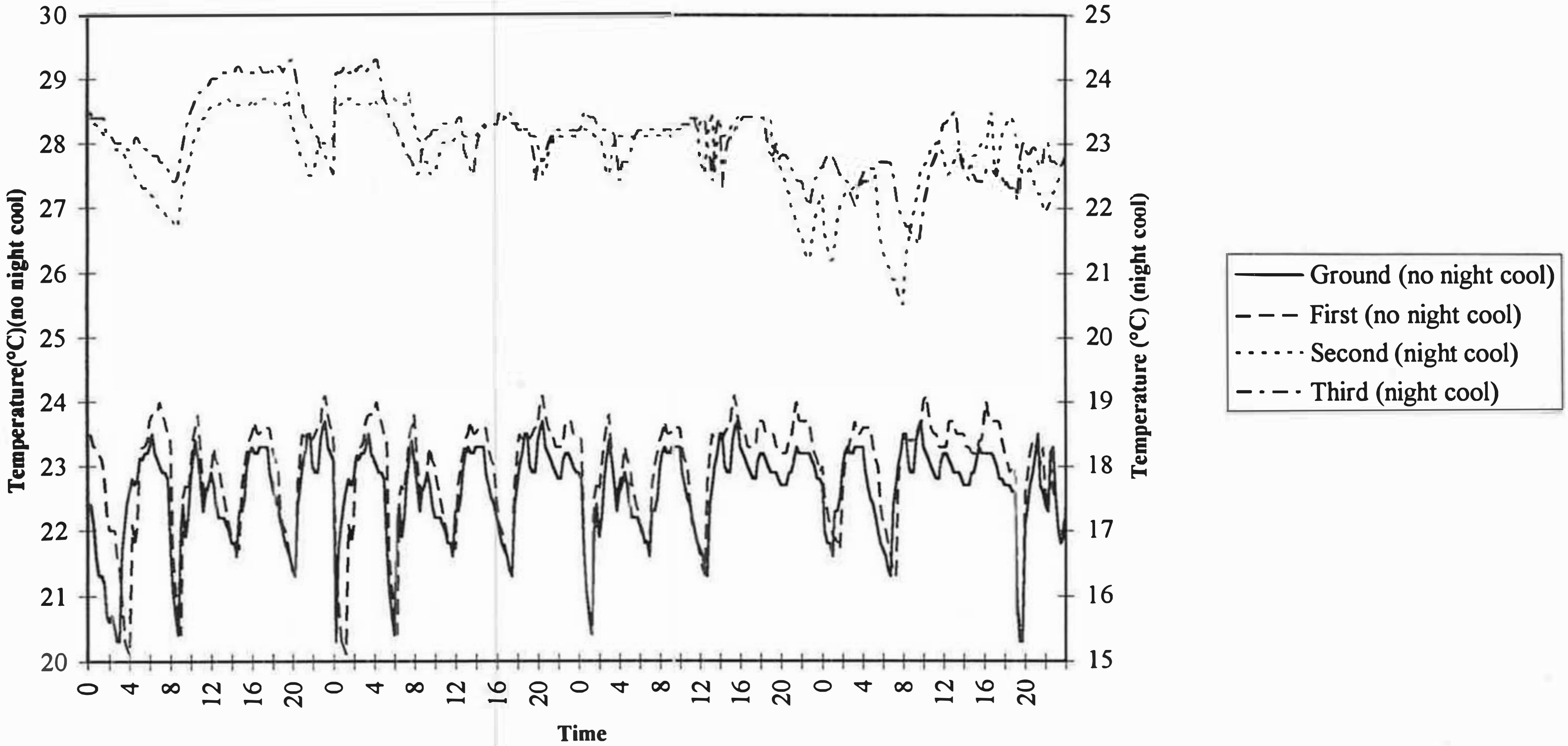
INLAND REVENUE, DURRINGTON TEST- SOUTH WEST TEMPERATURES (1/9/95-4/9/95)

Figure A1. 22



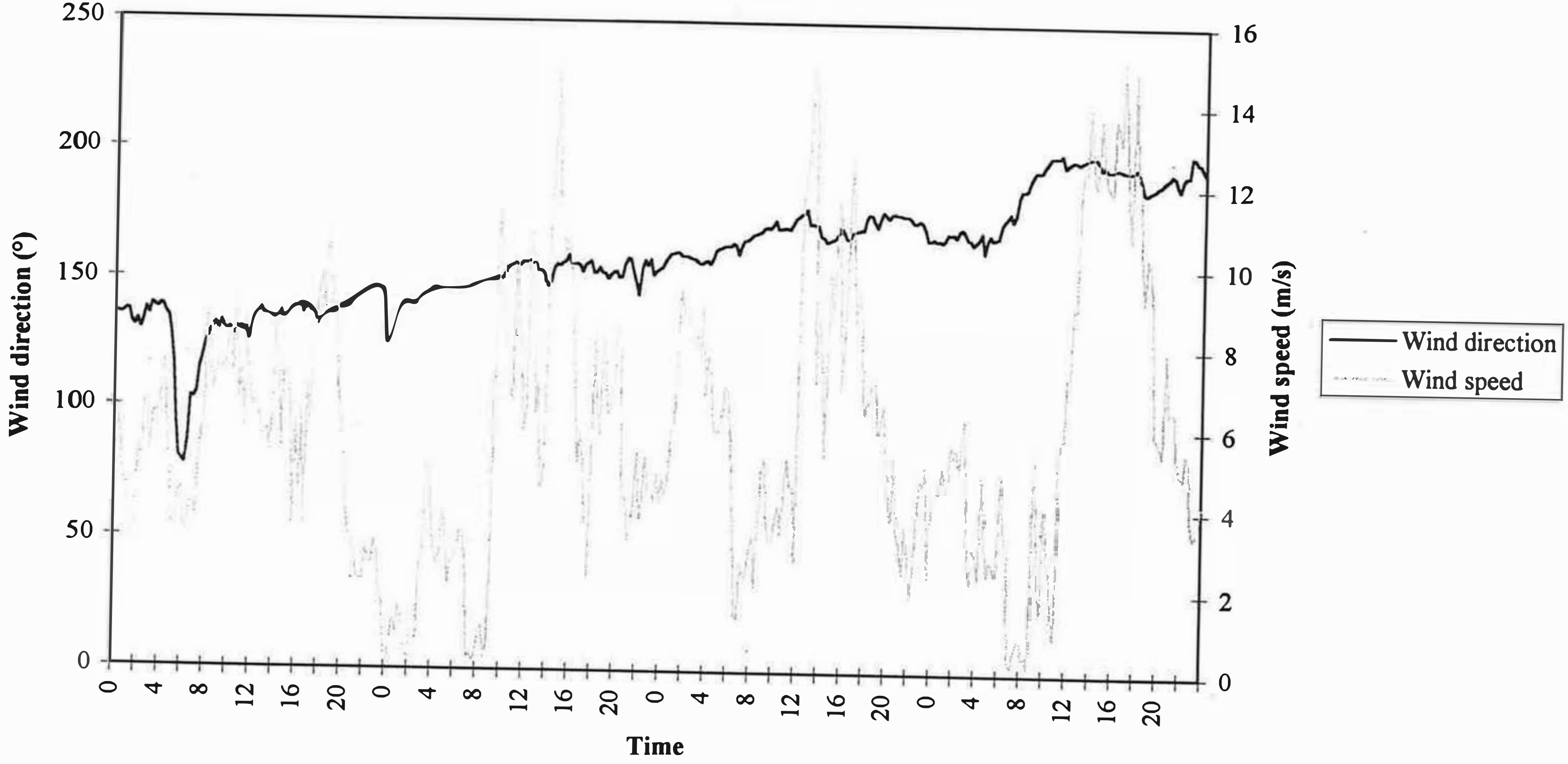
INLAND REVENUE, DURRINGTON TEST- SOUTH EAST TEMPERATURES (1/9/95-4/9/95)

Figure A1. 23



INLAND REVENUE, DURRINGTON TEST- WIND SPEED AND DIRECTION (1/9/95-4/9/95)

Figure A1. 24



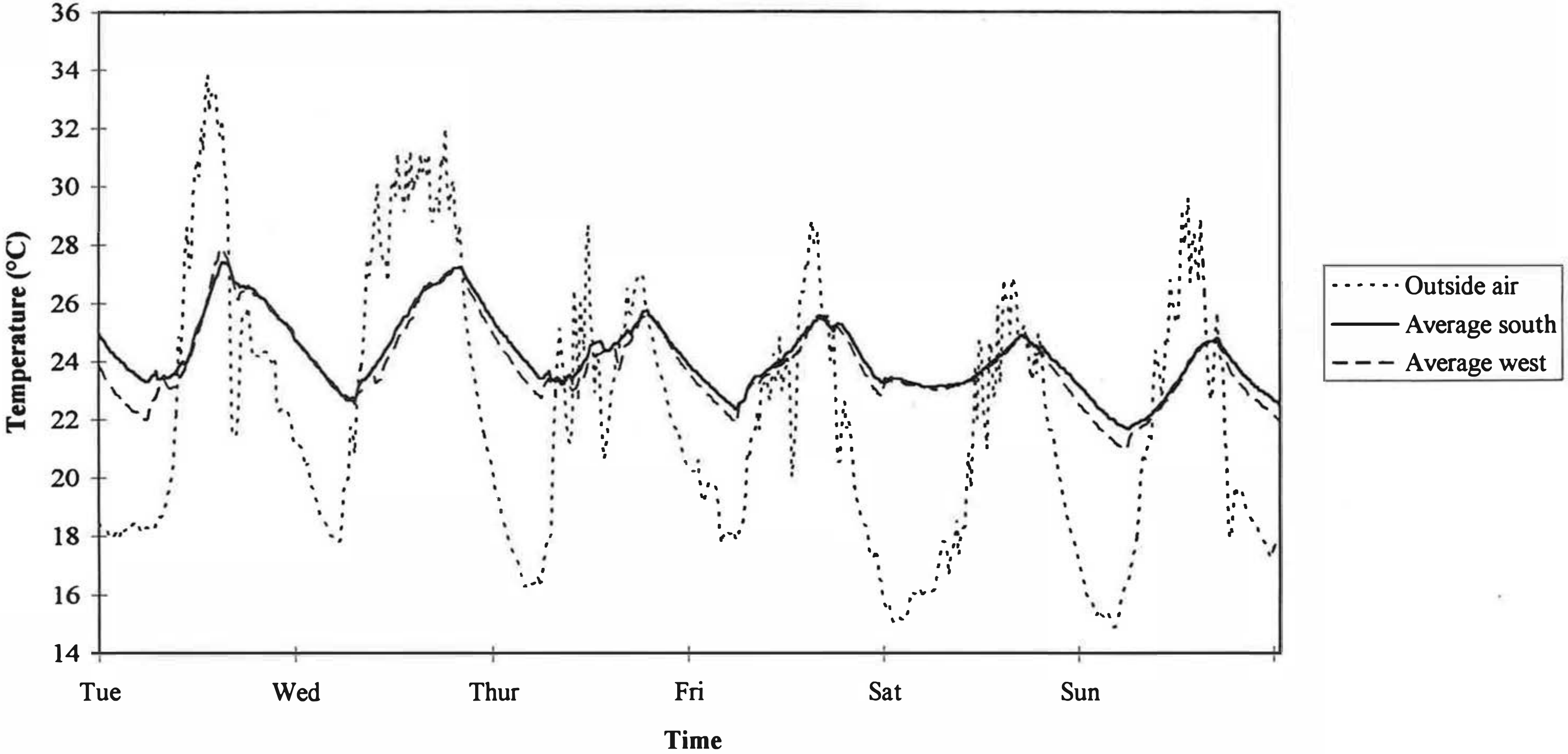
APPENDIX A2

RESULTS FROM THE INLAND REVENUE BUILDING B, NOTTINGHAM

No. of pages: 5

INLAND REVENUE, NOTTINGHAM BUILDING B- EXAMPLE HOT WEEK (11/7/95-16/7/95)

Figure A2. 1



		Ave S	Ave S	Ave S	Ave S	Ave S	Ave S	Night ave	Ave W	Ave W	Ave W	Ave W	Ave W	Ave W	Night ave	Occ	Occ	Occ	"12-17	Occ	Night	Night
		occ	occ	occ	occ	night	night	d T	occ	occ	occ	occ	night	night	d T	OAT	OAT	OAT	OAT	OAT	OAT	OAT
Date	Day	max	min	ave	swing	d T	min	S-OAT	max	min	ave	swing	d T	min	W-OAT	max	min	ave	ave	swing	ave	min
11-Jul	Tue	27.4	23.4	25.5	4.0	4.2	23.3	4.5	27.9	23.1	25.5	4.9	4.1	22.0	3.6	33.8	18.8	27.1	29.7	15.0	20.4	17.9
12-Jul	Wed	26.8	23.3	25.2	3.5	3.2	22.5	3.1	26.9	22.9	25.0	4.0	3.5	22.4	3.1	31.2	23.8	29.1	30.1	7.4	21.4	17.8
13-Jul	Thur	25.4	23.2	24.3	2.2	3.4	23.3	3.9	25.3	22.9	24.0	2.4	3.5	22.7	3.6	28.7	20.6	24.3	23.8	8.1	21.2	16.2
14-Jul	Fri	25.5	23.3	24.5	2.1	2.0	22.3	2.8	25.6	23.1	24.3	2.5	2.1	21.8	2.5	28.8	20.0	24.5	25.6	8.8	21.1	17.7
15-Jul	Sat	24.9	23.2	23.9	1.7	1.8	23.1	6.2	24.8	23.1	23.8	1.8	2.1	22.7	6.0	26.9	16.7	22.6	24.6	10.2	17.5	15.0
16-Jul	Sun	24.8	21.9	23.5	2.8	2.7	21.6	4.6	24.7	21.8	23.4	2.9	2.6	20.9	4.1	29.6	20.6	25.0	26.5	9.0	18.3	14.9
17-Jul	Mon	23.8	21.4	22.6	2.4	2.9	21.1	4.6	23.6	21.4	22.5	2.2	2.7	20.6	4.0	26.9	19.7	22.6	23.8	7.2	17.9	15.8
18-Jul	Tue	25.2	21.3	23.4	3.9	2.4	20.1	2.9	25.2	21.1	23.1	4.1	2.3	19.6	2.5	29.2	18.7	25.2	27.3	10.6	18.7	16.0
19-Jul	Wed	26.3	23.1	24.8	3.2	1.9	23.1	0.5	26.4	23.3	24.7	3.2	1.9	22.9	0.3	31.1	24.8	28.4	29.5	6.3	23.5	21.4
20-Jul	Thur	27.9	23.6	25.6	4.3	2.8	23.3	2.3	28.0	23.5	25.6	4.5	2.9	22.8	2.1	33.6	23.8	30.3	32.2	9.7	22.5	17.5
21-Jul	Fri	24.9	23.7	24.4	1.3	3.2	23.6	1.9	24.3	23.7	24.0	0.7	3.7	23.8	2.1	26.8	18.5	22.7	21.5	8.3	23.7	19.3
22-Jul	Sat	24.6	21.7	23.3	3.0	2.8	21.3	6.8	24.4	20.7	22.7	3.7	3.6	19.5	5.6	24.3	18.6	21.8	22.6	5.7	15.9	11.4
23-Jul	Sun	25.1	21.5	23.2	3.5	2.7	21.2	6.3	25.1	20.7	22.8	4.4	3.2	19.5	5.2	27.8	19.0	24.9	26.1	8.8	16.1	11.4
24-Jul	Mon	25.8	21.6	23.9	4.2	3.5	21.3	3.9	25.8	21.5	23.8	4.3	3.6	19 7	2.9	35.3	24.2	30.3	31.2	11.1	19.0	14.6
25-Jul	Tue	27.9	22.4	25.6	5.5	3.4	21.9	2.5	28.0	22.3	25.6	5.7	3.5	21 9	2.2	31.5	21.9	28.6	30.4	9.7	21.8	17.1
26-Jul	Wed	27.3	23.1	25.6	4.2	4.7	21.8	4.4	27.1	22.7	25.3	4.4	4.9	22 2	4.6	31.6	20.6	28.4	30.4	11.0	19.8	16.9

Key to table

Ave S occ max = Maximum air temperature during the occupied period of averaged southern facade sensors
(min, ave, swing refer to minimum temperature, average temperature and temperature swing respectively)

Ave W occ max = As above but the western facade

Ave S night dt = Zone air temperture drop during night cooling from the average of the southern facades
(min refers to the minimum zone air temperture during night cooling)

Ave S night dt = As above but the western facade

Night ave S-OAT = Average temperature difference between the average of the southern facade zone air temperatures and the outside air temperature during night cooling

Night ave W-OAT = As above but the western facade

Occ OAT max = Maximum outside air temperature during the occupied period
(min, ave, 12-17 ave, swing refer to minimum temperature, average temperature, average temperature between 12.00-17.00 and temperature swing respectively)

Night OAT ave = Average outside air temperature during night cool period
(min refers to minimum temperature)

Table A2.1 - Inland Revenue Building B, Nottingham temperature data (oC) July

Date	Day	Gnd BST-S (hrs)	Gnd BST-W (hrs)	2nd BST-S (hrs)	2nd BST-W (hrs)	2nd LOC-S (hrs)	2nd LOC-W (hrs)	2nd OPN-S (hrs)	2nd OPN-W (hrs)	TB1 SYST (hrs)	TB1 COOL "-ENA (hrs)	TB3 TMP Occ max (°C)	TB3 TMP Occ ave (°C)	TB4 TMP Occ max (°C)	TB4 HI-AVE Occ max (°C)	TB4 TMP Occ ave (°C)	TB4 HI-AVE Occ ave (°C)
11-Jul	Tue	11.0	11.0	12.0	12.0	9.0	0.0	12.0	12.0	21.0	11.0	30.0	25.7	31.9	26.8	26.6	24.9
12-Jul	Wed	10.5	10.5	11.0	11.0	9.5	18.5	11.0	11.0	20.5	10.5	28.6	26.1	29.0	26.0	26.1	24.4
13-Jul	Thur	10.5	10.5	11.0	11.5	9.5	0.0	11.0	11.5	21.0	11.0	25.8	23.9	26.3	30.0	24.2	23.9
14-Jul	Fri	11.0	11.0	12.0	12.0	9.5	19.5	12.0	12.0	21.0	11.0	26.4	23.8	25.0	25.0	22.3	24.3
15-Jul	Sat	5.0	5.0	6.0	5.0	0.0	0.0	6.0	5.0	5.0	5.0	27.8	23.1	27.7	24.4	23.2	24.1
16-Jul	Sun	12.5	12.5	13.0	13.0	0.0	19.5	13.0	13.0	12.3	12.3	30.7	26.5	30.3	24.0	26.1	23.5
17-Jul	Mon	11.0	11.0	12.0	12.0	9.5	0.0	12.0	12.0	21.0	11.0	24.1	22.1	23.2	23.1	20.1	22.5
18-Jul	Tue	9.5	9.5	10.5	10.5	9.5	19.5	10.5	10.5	19.3	9.3	26.4	22.8	27.2	24.3	23.7	23.0
19-Jul	Wed	9.0	9.0	9.5	9.5	9.5	0.0	9.5	9.5	18.8	8.8	27.7	25.5	27.5	25.4	25.2	24.1
20-Jul	Thur	8.5	8.5	9.5	9.5	9.5	0.0	9.5	9.5	18.5	8.5	30.6	26.8	29.7	26.6	26.5	24.8
21-Jul	Fri	11.0	11.0	12.0	12.0	9.5	0.0	12.0	12.0	21.0	11.0	24.7	23.1	25.1	24.4	23.1	23.8
22-Jul	Sat	11.0	11.0	11.5	11.0	0.0	0.0	11.5	11.0	11.3	11.3	30.0	25.9	27.8	24.2	24.7	23.4
23-Jul	Sun	9.0	9.0	10.0	10.0	0.0	0.0	10.0	10.0	8.8	8.8	31.4	26.8	30.1	24.2	26.5	23.0
24-Jul	Mon	9.0	9.0	10.0	10.0	9.5	19.5	10.0	10.0	19.0	9.0	29.3	26.3	30.3	24.5	26.9	23.3
25-Jul	Tue	10.5	10.5	11.5	12.0	9.5	0.0	11.5	12.0	20.3	10.3	31.5	27.6	31.4	26.8	27.3	24.7
26-Jul	Wed	10.0	10.0	10.5	10.5	9.5	19.5	10.5	10.5	19.3	9.3	28.9	26.5	29.4	26.5	26.6	25.1

Key to table

Gnd BST-S = Ground floor fans of southern facade in night cooling mode
(2nd refers to second floor)

Gnd BST-W = As above but western facade

2nd LOC-S = Second floor fans of southern facade in local (daytime) mode

2nd LOC-W = As above but western facade

2nd OPN-S = Second floor ridge vents of southern facade in local (daytime) mode (ridge vents exhaust air from the t floor)

2nd OPN-W = As above but western facade

TB1 SYST = Tower 1 total system operation

TB1 COOL-ENA = Tower 1 night cool enable

TB3 TMP occ max = Maximum temperature of tower 3 during the occupied peri (TB4 and ave refer to Tower 4 and average temperature respectively)

TB4 HI-AVE occ max = Maximum temperature of tower 4 high level sensors during the occupied period (ave refers to average temperature)

Table A2.2 - Inland Revenue Building B, Nottingham mode of operation (July)

INLAND REVENUE, NOTTINGHAM BUILDING B- CORRELATION TESTS (WEEKDAY DATA JULY)

Figure A2. 2

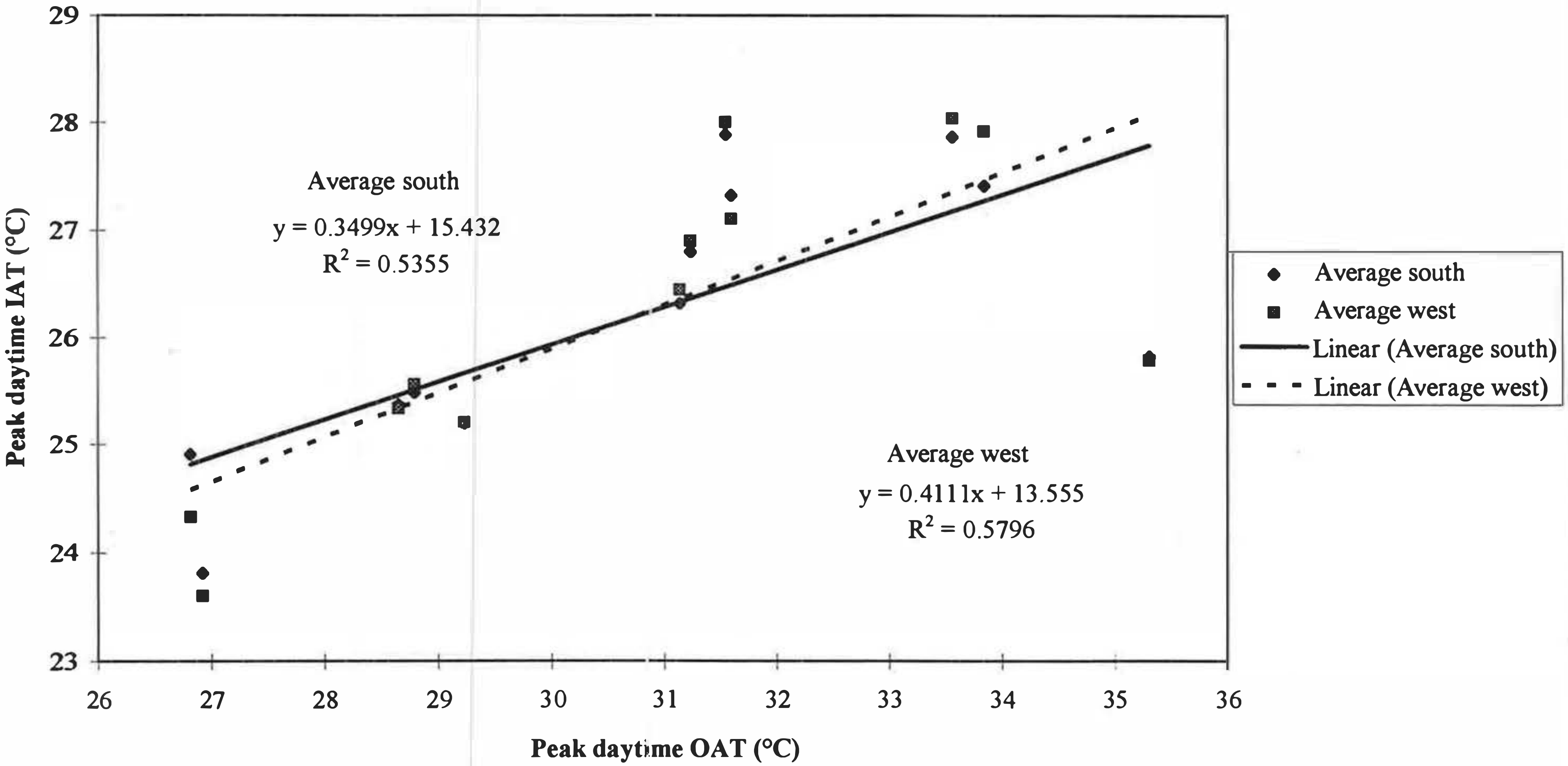


Table 2.3 - Inland Revenue Building B, Nottingham correlations between difference variables (weekdays July)

Variable 1	Variable 2	Correlation coefficient (r)
Ave S occ max	OAT occ max	0.732
Ave S occ min	OAT occ min	0.074
Ave S occ ave	OAT occ ave	0.621
Ave S occ swing	OAT occ swing	0.482
Ave S night cool ΔT	Ave night temp diff (ave S-OAT)	0.669
Ave S night cool ΔT	OAT night ave	-0.227
Ave S occ max	Ave S night cool ΔT	0.381
Ave S occ max	Ave S night min	0.311
Ave W occ max	OAT occ max	0.761
Ave W occ min	OAT occ min	0.130
Ave W occ ave	OAT occ ave	0.664
Ave W occ swing	OAT occ swing	0.556
Ave S occ max	Ave W occ max	0.989
Ave W night cool ΔT	Ave night temp diff (ave W-OAT)	0.638
Ave W night cool ΔT	OAT night ave	-0.080
Ave W occ max	Ave W night cool ΔT	0.326
Ave W occ max	Ave W night min	0.250
Ave S night cool ΔT	Tower 1 pre-cool hrs	0.149
Ave W night cool ΔT	Tower 1 pre-cool hrs	0.139
Ave S night cool ΔT	S ridge vent pre-cool hrs	0.190
Ave W night cool ΔT	W ridge vent pre-cool hrs	0.182
Ave S night cool ΔT	S 2nd floor fans pre-cool hrs	0.190
Ave W night cool ΔT	W 2nd floor fans pre-cool hrs	0.182

Key to table

Ave S	=	average southern facade
Ave W	=	average of western facade
occ	=	occupied period
max	=	maximum temperature
min	=	minimum temperature
ave	=	average temperature
swing	=	temperature swing
night cool ΔT	=	zone temperature drop during night cooling
OAT	=	outside air temperature

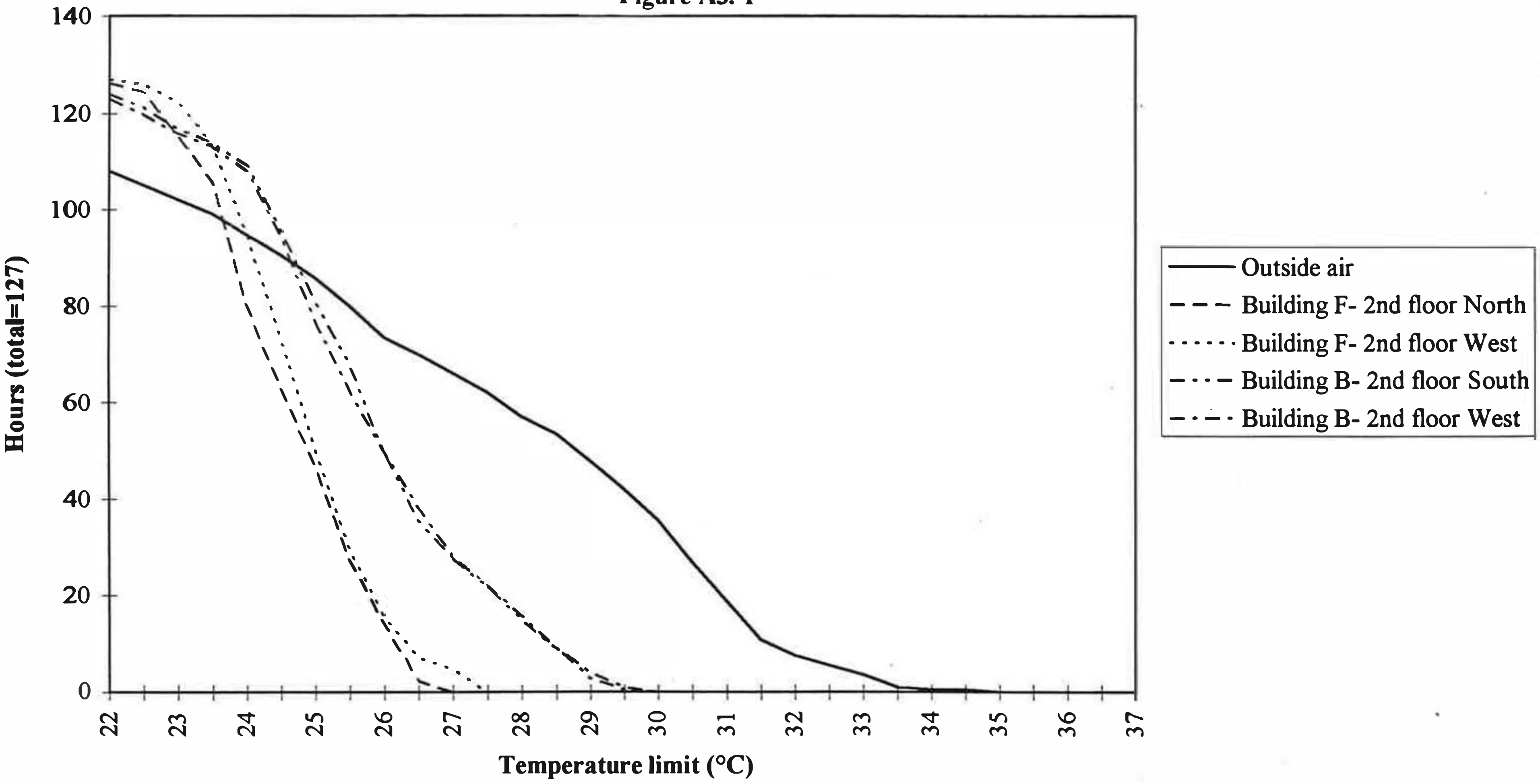
APPENDIX A3

RESULTS FROM THE INLAND REVENUE BUILDING F, NOTTINGHAM

No. of pages: 16

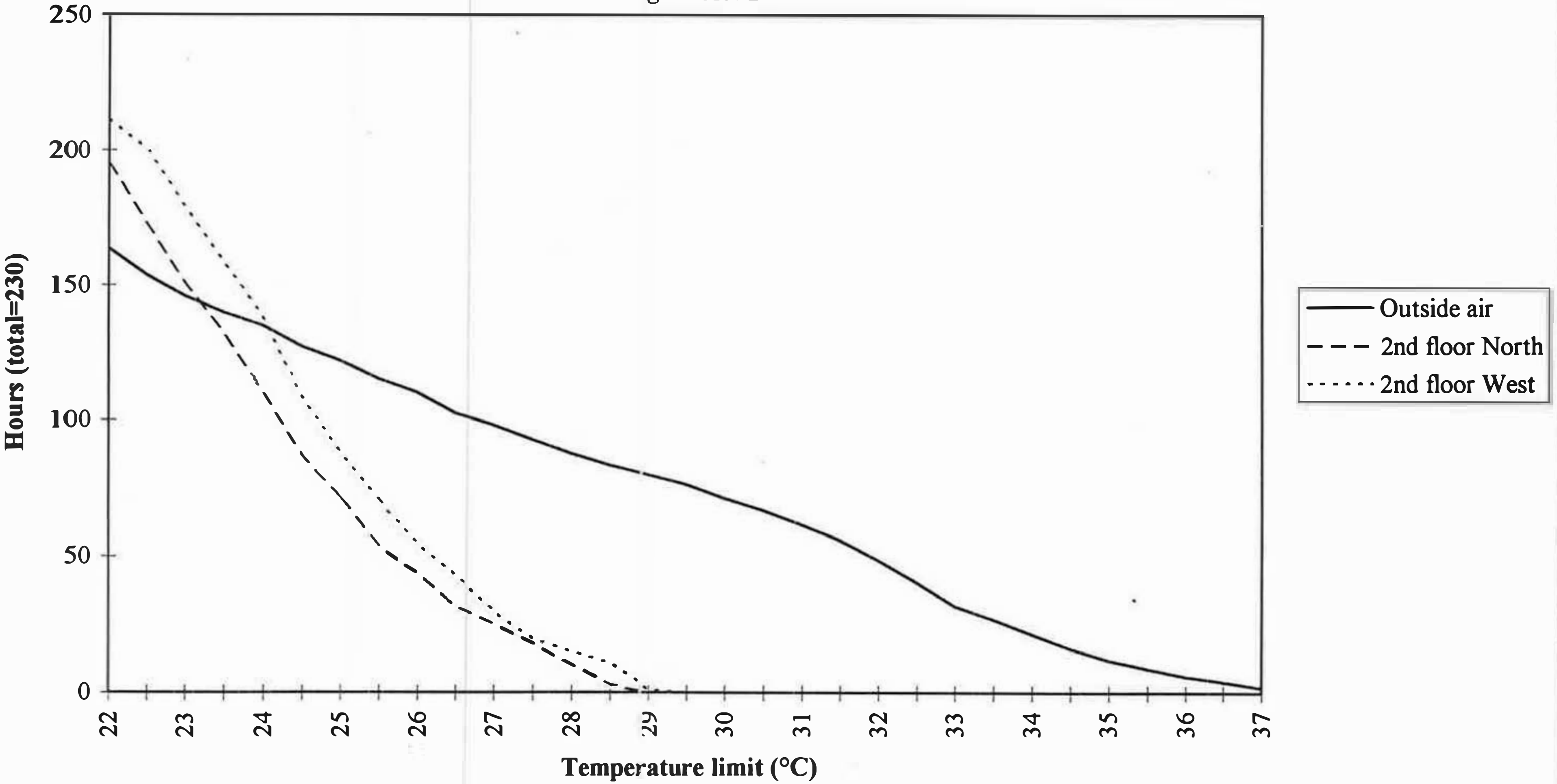
INLAND REVENUE, NOTTINGHAM- HOURS ABOVE SPECIFIED TEMPERATURE LIMITS- JULY (10/7/95-27/7/95)

Figure A3. 1



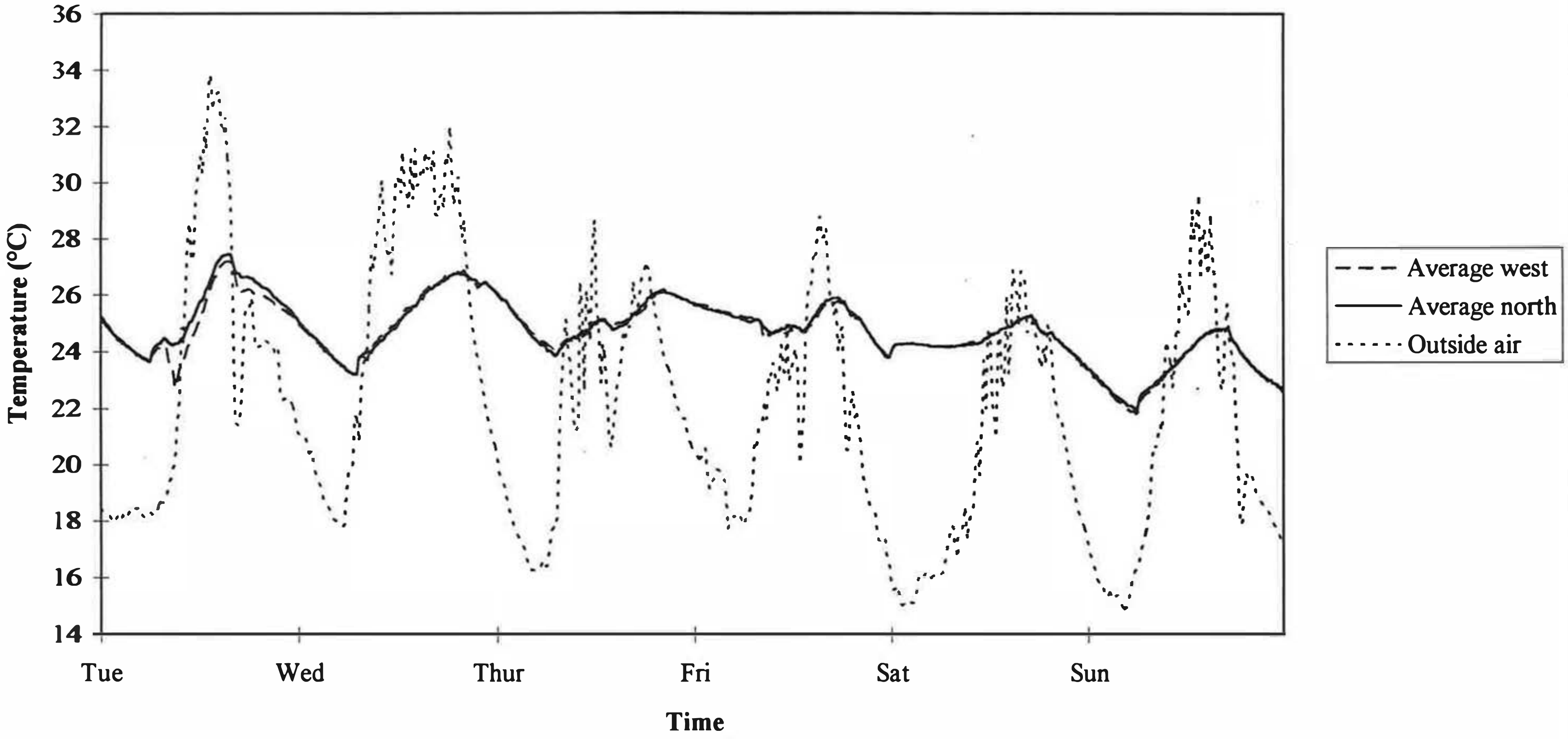
INLAND REVENUE, NOTTINGHAM BUILDING F- HOURS ABOVE SPECIFIED TEMPERATURE LIMITS- AUGUST (1/8/95-31/8/95)

Figure A3. 2



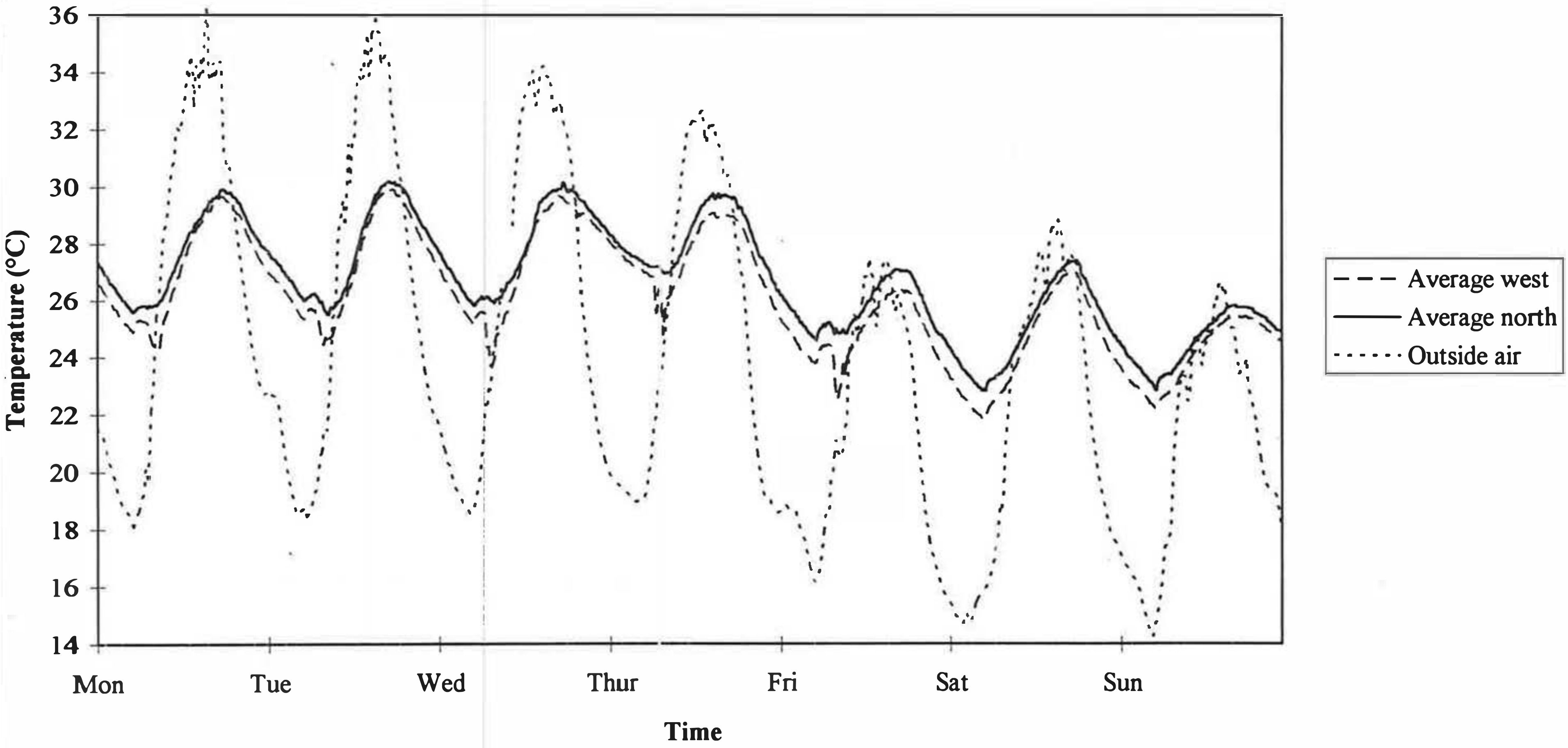
INLAND REVENUE, NOTTINGHAM BUILDING F- EXAMPLE HOT WEEK (11/7/95-16/7/95)

Figure A3. 3



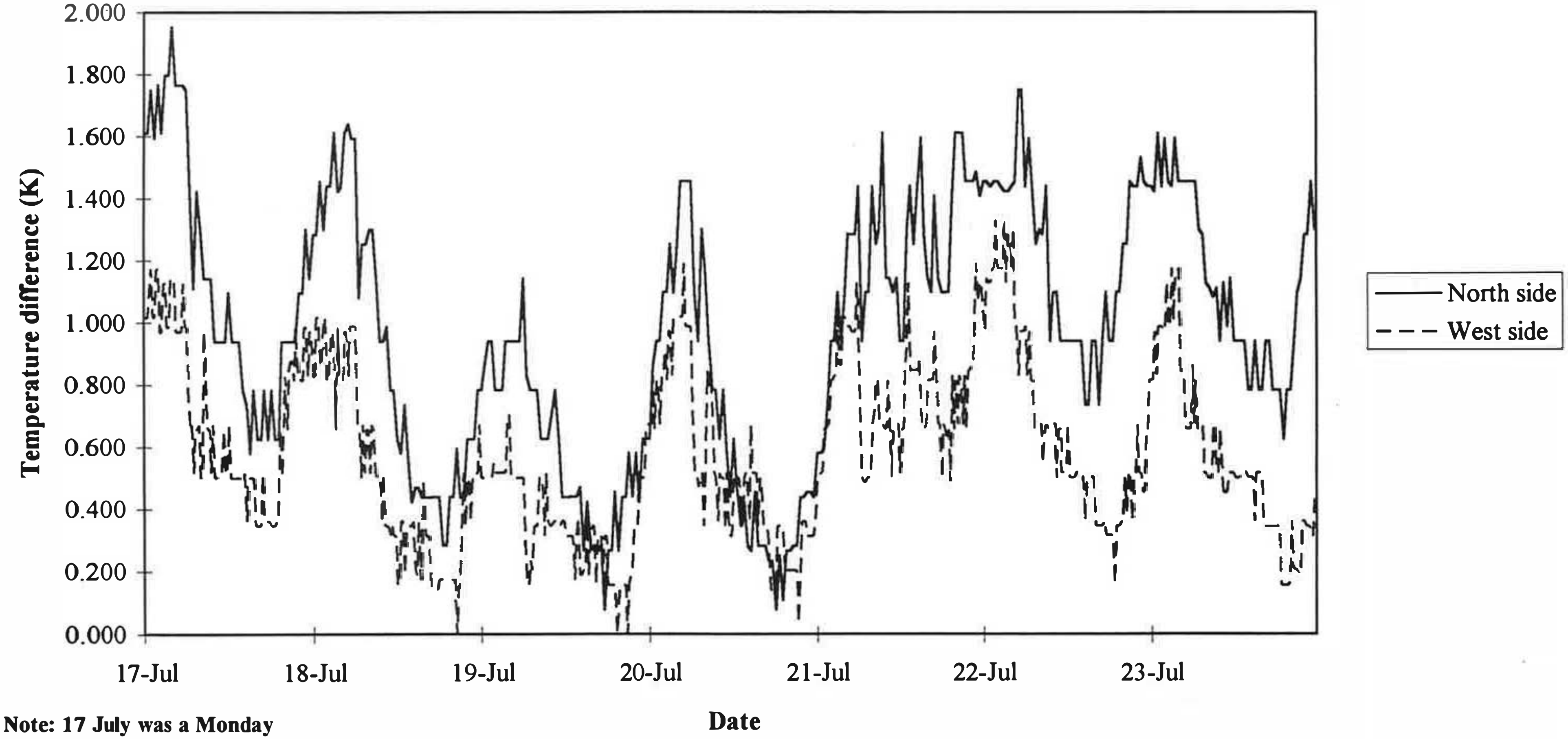
INLAND REVENUE, NOTTINGHAM BUILDING F- EXAMPLE HOT WEEK (31/7/95-6/8/95)

Figure A3. 4



INLAND REVENUE, NOTTINGHAM- BUILDING F GROUND FLOOR HIGH/LOW SENSOR TEMPERATURE DIFFERENCE

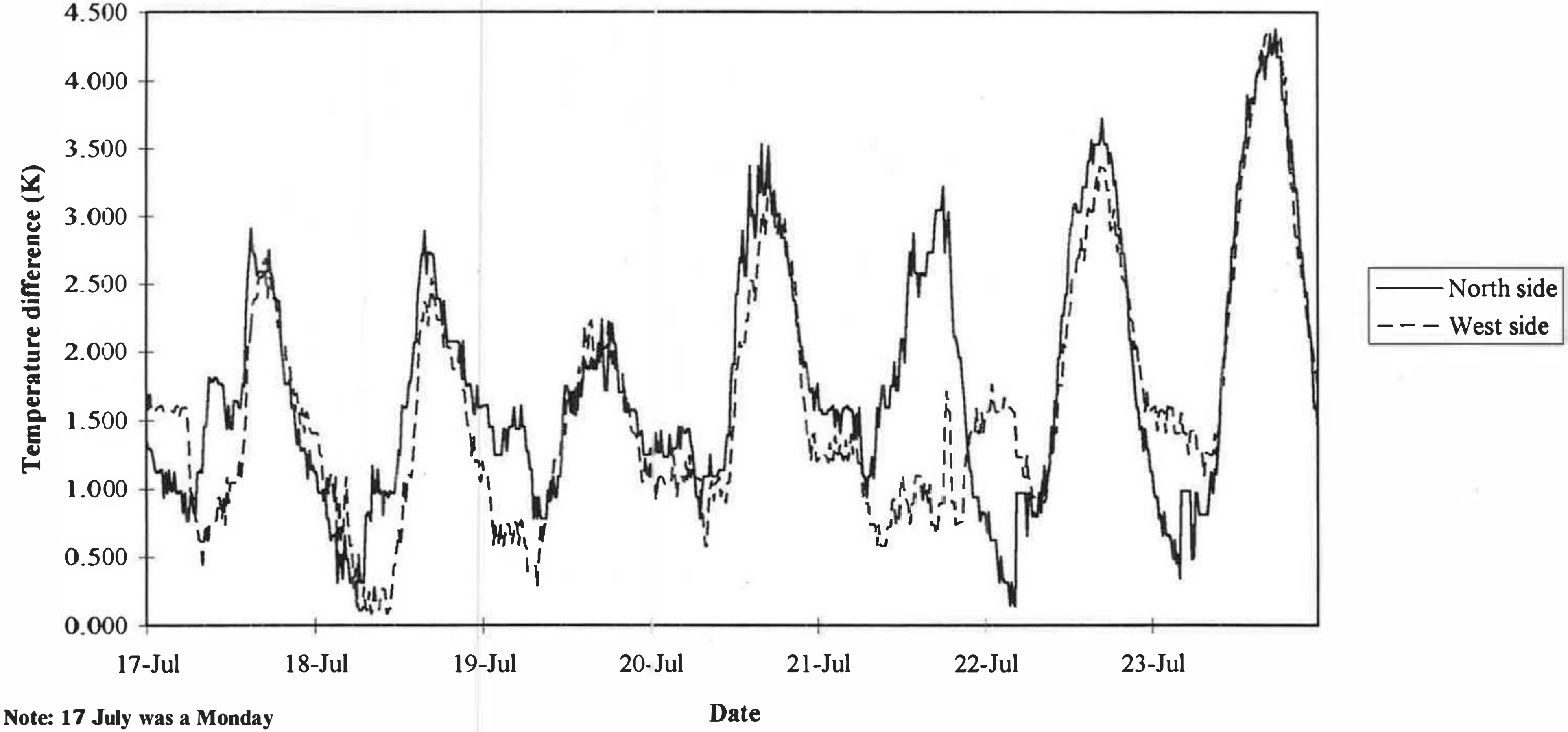
Figure A3. 5



Note: 17 July was a Monday

INLAND REVENUE, NOTTINGHAM- BUILDING F THIRD FLOOR HIGH/LOW SENSOR TEMPERATURE DIFFERENCE

Figure A3. 6



Note: 17 July was a Monday

Date	Day	Ave N occ max	Ave N occ min	Ave N occ ave	Ave N occ swing	Ave N night delta T	Ave N night min	Night delta T N-OAT	Ave W occ max	Ave W occ min	Ave W occ ave	Ave W occ swing	Ave W night delta T	Ave W night min	Night delta T W-OAT	Occ OAT max	Occ OAT min	Occ OAT ave	"12-17 OAT ave	Occ OAT swing	Night OAT ave	Night OAT min
11-Jul	Tue	27.2	22.7	25.4	4.5				27.5	24.2	26.0	3.2				33.8	18.8	27.1	29.7	15.0		
12-Jul	Wed	26.7	23.7	25.4	3.0	2.4	23.2	3.2	26.6	23.9	25.3	2.7	2.7	23.2	3.4	31.2	23.8	29.1	30.1	7.4	21.4	17.8
13-Jul	Thur	25.6	24.3	24.9	1.3	2.4	24.0	4.3	25.7	24.2	24.9	1.5	2.4	23.8	4.3	28.7	20.6	24.3	23.8	8.1	21.2	16.2
14-Jul	Fri	25.8	24.5	25.0	1.2	0.6	25.0	4.5	25.9	24.6	25.1	1.3	0.7	25.0	4.5	28.8	20.0	24.5	25.6	8.8	21.1	17.7
15-Jul	Sat	25.2	24.2	24.7	1.0	1.5	23.8	6.9	25.3	24.2	24.7	1.1	1.5	23.8	6.9	26.9	16.7	22.6	24.6	10.3	17.5	15.0
16-Jul	Sun	24.8	22.7	24.0	2.1	2.1	21.8	4.9	24.8	22.8	24.1	2.0	2.0	22.0	5.0	29.6	20.6	25.0	26.5	9.0	18.3	14.9
17-Jul	Mon	24.1	22.4	23.3	1.6	1.8	21.4	4.6	24.2	22.5	23.4	1.7	1.7	21.5	4.7	26.9	19.7	22.6	23.8	7.2	17.9	15.8
18-Jul	Tue	24.8	22.2	23.5	2.6	1.8	21.5	4.0	24.8	22.2	23.5	2.5	1.9	21.3	3.9	29.2	18.7	25.2	27.3	10.6	18.7	16.0
19-Jul	Wed	26.0	23.7	24.8	2.3	1.0	23.2	0.5	26.0	23.6	24.7	2.3	1.0	23.0	0.4	31.1	24.8	28.4	29.5	6.3	23.5	21.4
20-Jul	Thur	27.0	23.6	25.3	3.4	2.3	23.1	2.2	27.0	23.6	25.2	3.4	2.2	23.2	2.2	33.6	23.8	30.3	32.2	9.7	22.5	17.5
21-Jul	Fri	24.5	23.7	24.0	0.7	2.5	24.1	1.9	24.7	23.9	24.2	0.9	2.4	24.1	1.9	26.8	18.5	22.7	21.5	8.3	23.7	19.3
22-Jul	Sat	24.3	22.2	23.5	2.0	2.2	21.1	6.6	24.3	22.3	23.5	2.0	2.4	21.1	6.6	24.3	18.6	21.8	22.6	5.7	15.9	11.4
23-Jul	Sun	24.2	21.7	23.1	2.5	2.3	20.7	6.0	24.2	21.6	23.1	2.6	2.2	20.6	5.9	27.8	19.0	24.9	26.1	8.8	16.1	11.4
24-Jul	Mon	25.3	21.6	23.9	3.7	2.6	20.9	3.4	25.3	21.8	23.9	3.5	2.4	20.7	3.3	35.3	24.2	30.3	31.2	11.1	19.0	14.6
25-Jul	Tue	26.6	22.0	24.9	4.6	2.9	22.1	2.0	26.6	22.9	24.9	3.7	2.4	22.2	2.1	31.5	21.9	28.6	30.4	9.7	21.8	17.1
26-Jul	Wed	26.5	21.8	24.7	4.7	4.6	21.8	3.8	26.4	22.7	24.9	3.7	3.9	22.1	4.0	31.6	20.6	28.4	30.4	11.0	19.8	16.9
27-Jul	Thur	27.9	23.6	26.1	4.3	2.5	23.4	2.2	27.6	24.1	26.0	3.4	2.2	23.4	2.2	33.2	25.2	29.8	30.4	8.0	22.7	18.0
28-Jul	Fri	27.1	23.7	25.4	3.5	4.2	23.7	3.2	27.1	24.5	25.6	2.6	2.7	24.6	3.4	32.3	22.4	27.6	30.0	9.9	22.7	19.0
29-Jul	Sat	29.9	25.3	27.9	4.6	1.8	24.7	2.0	30.0	25.5	27.9	4.5	1.6	25.2	2.2	36.9	25.7	34.0	35.1	11.3	24.1	20.4
30-Jul	Sun	30.3	26.0	28.2	4.3	3.9	25.4	2.5	30.5	26.3	28.3	4.3	3.7	25.9	2.8	39.2	23.5	34.4	36.7	15.6	25.1	18.4
31-Jul	Mon	29.6	24.2	27.1	5.4	5.1	24.9	4.1	29.7	25.7	27.7	4.0	4.8	25.6	4.7	36.4	19.8	30.9	33.7	16.6	23.0	18.0

Key to table

Ave N max = Average of north sensors maximum temperature during occupied period

Ave N night delta T = Average of north sensors - temperature drop overnight

Night ave delta T N-OAT = Average of north sensors - temperature difference between the north temperatures and the outside air temperature during the night

Occ OAT max = Maximum outside air temperature during occupied period

12-17 OAT ave = Average outside air temperature between 12:00 to 17:00

Table A3.1 - Inland Revenue Building F, Nottingham temperature data (July)

		Ave N	Ave N	Ave N	Ave N	Ave N	Ave N	Night	Ave W	Ave W	Ave W	Ave W	Ave W	Ave W	Night	Occ	Occ	Occ	"12-17	Occ	Nigh	Night
		occ	occ	occ	occ	night	night	delta T	occ	occ	occ	occ	night	night	delta T	OAT	OAT	OA	OAT	OAT	OAT	OAT
Date	Day	max	min	ave	swing	delta	min	N-OAT	max	min	ave	swing	delta T	min	W-OA	max	min	ave	ave	swin	ave	min
01-Aug	Tue	30.0	24.4	27.1	5.5	4.2	25.3	3.7	30.2	25.5	27.7	4.7	3.6	26.0	4.2	35.9	20.0	30.2	33.7	15.9	23.6	18.4
02-Aug	Wed	29.7	23.7	27.3	6.0	5.6	24.3	3.9	29.9	25.9	27.9	4.0	4.1	25.8	4.5	34.2	22.8	31.0	33.3	11.4	23.4	18.5
03-Aug	Thur	29.1	24.8	27.8	4.4	3.2	25.5	5.2	29.8	26.9	28.6	2.8	2.7	27.2	5.6	32.7	23.1	30.0	31.9	9.6	22.8	19.0
04-Aug	Fri	26.4	22.5	25.0	3.9	4.5	23.8	5.6	27.1	24.8	25.9	2.3	4.4	24.6	6.4	27.5	19.7	24.8	26.5	7.8	20.3	16.2
05-Aug	Sat	27.1	22.7	25.1	4.4	3.7	21.9	6.0	27.4	23.4	25.5	4.0	3.6	22.8	6.9	28.9	18.6	25.7	27.4	10.3	17.8	14.7
06-Aug	Sun	25.5	22.8	24.5	2.6	4.2	22.2	5.3	25.9	23.4	24.9	2.4	4.0	22.9	6.0	26.7	18.0	24.1	25.3	8.7	18.8	14.2
07-Aug	Mon	23.7	21.1	23.0	2.6	3.0	22.4	5.7	24.5	23.6	24.1	0.9	1.8	23.9	6.1	22.9	19.3	21.5	22.0	3.6	18.7	16.1
08-Aug	Tue	24.5	21.4	23.0	3.2	1.0	22.3	6.6	24.8	22.5	23.7	2.3	1.6	22.7	7.0	25.4	16.1	21.7	23.6	9.3	16.5	14.4
09-Aug	Wed	25.3	21.0	23.2	4.3	3.3	20.7	7.0	25.9	21.9	23.9	3.9	2.8	21.5	7.7	30.3	16.3	24.9	27.5	14.0	15.2	9.6
10-Aug	Thur	26.6	20.9	24.4	5.7	4.4	20.6	3.8	26.8	22.3	24.7	4.4	3.5	21.7	4.5	31.0	20.5	28.2	30.2	10.5	19.1	13.8
11-Aug	Fri	28.2	21.4	24.9	6.8	5.1	21.4	3.2	28.0	22.9	25.4	5.1	3.9	22.5	4.0	35.2	19.7	30.1	33.7	15.5	20.4	16.4
12-Aug	Sat	28.0	24.8	26.7	3.2	3.1	24.3	1.1	28.2	25.1	26.9	3.1	2.9	24.8	1.5	32.9	24.8	30.1	31.8	8.0	25.0	19.4
13-Aug	Sun	25.8	24.8	25.3	1.1	3.0	24.8	5.9	25.9	24.9	25.4	1.0	3.1	24.9	6.1	27.1	20.7	23.8	24.5	6.4	20.2	16.1
14-Aug	Mon	25.3	21.3	23.8	4.0	4.1	21.1	5.0	25.4	22.7	24.2	2.7	2.9	22.1	5.5	29.8	19.0	26.2	27.6	10.8	18.1	14.8
15-Aug	Tue	26.7	21.0	24.6	5.8	4.3	20.5	4.8	26.7	22.5	24.7	4.2	2.9	21.7	4.9	34.4	21.1	31.2	33.0	13.3	18.6	14.6
16-Aug	Wed	26.7	22.4	25.0	4.3	4.3	22.2	3.2	26.9	22.7	24.9	4.3	4.0	22.4	3.3	32.8	23.3	30.7	32.0	9.5	20.8	16.0
17-Aug	Thur	26.9	21.8	25.0	5.1	4.9	21.5	2.6	27.4	23.5	25.7	3.9	3.4	23.2	2.8	32.8	21.2	29.3	31.7	11.6	22.0	17.9
18-Aug	Fri	26.8	23.0	25.0	3.8	3.8	23.1	3.2	27.5	24.0	25.8	3.5	3.3	24.0	3.6	33.6	20.5	28.7	31.6	13.1	21.8	19.2
19-Aug	Sat	26.2	23.7	25.1	2.5	3.1	22.9	3.4	26.6	24.1	25.4	2.5	3.3	23.5	3.9	33.5	19.1	28.4	31.8	14.4	21.2	18.3
20-Aug	Sun	26.0	23.5	24.9	2.6	2.8	22.8	3.1	26.3	23.9	25.2	2.4	2.6	23.3	3.5	33.6	16.9	28.9	32.4	16.8	21.2	16.7
21-Aug	Mon	27.5	22.9	25.6	4.5	3.1	22.5	3.1	27.8	23.0	25.7	4.8	3.3	23.0	3.4	36.4	24.4	33.1	35.1	12.0	20.9	16.0
22-Aug	Tue	28.2	23.7	26.5	4.5	3.8	23.3	2.4								38.1	25.3	34.8	36.7	12.8	23.1	17.1
23-Aug	Wed	25.6	24.5	24.9	1.1	3.5	24.8	2.2	25.8	24.5	25.0	1.2	3.6	25.0	2.4	27.2	17.6	22.2	22.4	9.6	24.3	19.9
24-Aug	Thur	24.6	21.7	23.4	2.9	3.9	21.5	6.2	24.4	22.6	23.4	1.8	3.2	21.9	6.4	24.8	16.5	21.9	23.7	8.3	17.2	13.7
25-Aug	Fri	24.5	22.8	23.7	1.6	1.5	22.8	3.6	24.6	22.8	23.7	1.8	1.2	22.7	3.4	25.9	19.5	23.0	24.6	6.3	20.0	18.9
26-Aug	Sat	23.5	22.2	23.1	1.4	2.0	21.5	5.1	23.5	22.2	23.1	1.3	1.8	21.5	5.0	25.9	17.5	21.9	22.8	8.4	17.6	15.4
27-Aug	Sun	23.2	22.7	22.9	0.5	0.8	22.7	6.0	23.2	22.7	22.9	0.5	0.8	22.7	5.9	20.0	16.3	18.0	18.5	3.6	17.1	14.9
28-Aug	Mon	22.7	20.9	22.0	1.9	1.3	21.7	9.3	22.7	20.9	21.9	1.9	1.8	21.4	9.4	20.6	13.7	18.5	19.4	6.8	13.2	11.3
29-Aug	Tue	21.9	20.4	21.3	1.6	2.3	19.8	5.6	22.0	20.5	21.4	1.5	2.3	19.7	5.3	17.6	14.2	15.9	16.1	3.4	15.5	13.8
30-Aug	Wed	23.0	21.0	22.4	2.0	0.9	20.9	7.4	22.9	21.0	22.2	1.8	0.9	20.9	7.5	25.6	17.2	22.7	23.2	8.4	14.1	11.2
31-Aug	Thur	22.7	20.9	21.9	1.8	2.0	20.4	3.1	22.6	21.0	21.9	1.6	1.9	20.4	2.9	22.3	18.1	20.4	20.9	4.2	18.4	16.7
01-Sep	Fri	22.8	20.6	22.0	2.2	2.1	19.9	3.6	22.8	20.6	21.9	2.2	2.0	20.0	3.6	25.2	17.0	21.2	22.6	8.2	17.5	15.5
02-Sep	Sat	21.8	20.8	21.3	0.9	1.9	20.2	3.4	21.8	20.9	21.3	0.9	1.9	20.4	3.4	21.8	15.1	18.4	19.7	6.7	18.0	14.8
03-Sep	Sun	21.2	19.7	20.5	1.5	1.5	19.4	7.1	21.3	19.9	20.6	1.4	1.3	19.5	7.1	22.4	12.5	18.7	20.7	9.9	13.0	9.7
04-Sep	Mon	22.6	19.0	21.0	3.6	1.7	18.2	4.5	22.5	19.0	21.0	3.4	1.7	18.4	4.6	27.3	14.8	21.5	23.7	12.6	14.8	12.5

(For key to headings see Table A3.1)

Table A3.2 - Inland Revenue Building F, Nottingham temperature data (August-September)

Date	Day	Gnd ENA-N hours	Gnd BST-N hours	Gnd BST-W hours	1st BST-N hours	1st BST-W hours	2nd BST-N hours	2nd BST-W hours	3rd BST-N hours	3rd BST-W hours	3rd ENA-N hours	3rd ENA-W hours	3rd LOC-N hours	3rd LOC-W hours	3rd OPN-N hours	3rd OPN-W hours	TWR 1 PRE-COL	TW1 COOL-ENA	TWR 1 W-DIRECT Occ ave	TWR 1 W-SPEED Occ ave	TWR 1 RAIN-I Occ ave	TWR W-DIR night ave	TWR 1 W-SPEED night ave	TWR 1 RAIN-I night ave	TWR 1 TMP Occ max	TW1 HI-AVE Occ max	TWR 1 TMP Occ ave	TW1 HI-AVE Occ ave
11-Jul	Tue	9.8	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	9.8	9.8	9.3	9.3	12.0	12.0	13.0	12.0	115.4	1.8	6.6				32.2	26.9	27.5	25.8
12-Jul	Wed	9.8	7.3	7.3	7.5	7.5	7.5	7.5	7.8	7.8	9.8	9.8	9.8	9.8	7.8	7.8	8.0	6.5	242.9	2.2	0.5	-179.0	-0.7	0.3	29.8	26.2	27.8	25.4
13-Jul	Thur	9.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.8	9.8	9.8	9.8	0.0	0.0	0.3	0.0	189.4	1.6	1.8	2.1	0.7	-0.4	28.1	25.6	25.0	25.0
14-Jul	Fri	9.8	5.8	5.8	5.5	5.5	5.5	5.5	5.8	5.8	9.8	9.8	9.8	9.8	5.8	5.8	6.8	5.5	183.0	4.0	1.8	0.0	-2.0	-0.5	27.6	25.7	25.0	25.3
15-Jul	Sat	0.0	6.3	6.3	6.0	6.0	6.0	6.0	6.3	6.0	0.0	0.0	0.0	0.0	6.3	6.0	7.5	7.0	252.5	3.2	1.7	-49.3	0.1	-1.5	28.8	25.1	24.2	24.9
16-Jul	Sun	0.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	0.0	0.0	0.0	0.0	13.0	13.0	13.0	13.0	266.6	2.3	2.7	-40.3	0.6	-0.4	31.4	24.5	27.4	24.2
17-Jul	Mon	9.8	11.0	11.0	11.0	11.0	11.0	11.0	12.0	12.0	9.8	9.8	9.8	9.8	12.0	12.0	13.0	11.0	267.5	3.3	0.8	-139.4	-1.6	11.6	24.7	24.1	22.4	23.6
18-Jul	Tue	9.8	9.5	9.5	9.5	9.5	9.5	9.5	10.0	9.8	9.8	9.8	9.8	9.8	10.0	9.8	13.0	9.5	267.1	4.4	1.6	19.0	-1.0	-3.5	29.6	24.4	24.3	23.7
19-Jul	Wed	11.0	9.0	9.0	9.0	9.0	9.0	9.0	9.8	9.5	11.3	11.3	10.0	9.8	9.8	9.5	13.0	9.0	258.4	2.7	0.6	27.1	2.4	-0.1	30.9	25.5	26.6	24.6
20-Jul	Thur	9.8	8.5	8.5	8.5	8.5	8.5	8.5	9.5	9.5	9.8	9.8	9.8	9.8	9.5	9.5	13.0	8.5	259.3	2.5	0.3	2.8	0.1	-0.3	33.9	26.3	28.4	25.1
21-Jul	Fri	9.8	11.0	11.0	11.0	11.0	11.0	11.0	12.0	12.0	9.8	9.8	9.8	9.8	12.0	12.0	13.0	11.0	262.1	2.2	0.9	-13.0	1.6	-1.9	25.8	24.9	24.1	24.2
22-Jul	Sat	0.0	11.3	11.3	11.0	11.0	11.0	11.0	11.3	11.5	0.0	0.0	0.0	0.0	11.3	11.5	13.0	11.0	290.9	3.5	0.5	-6.5	-2.1	-0.3	30.5	24.0	27.3	23.7
23-Jul	Sun	0.0	8.8	8.8	9.0	9.0	9.0	9.0	9.5	9.5	0.0	0.0	0.0	0.0	9.5	9.5	13.0	9.0	259.3	3.5	0.4	42.0	0.5	-0.6	32.3	23.6	28.0	23.2
24-Jul	Mon	9.8	9.0	9.0	9.0	9.0	9.0	9.0	9.8	9.5	9.8	9.8	9.8	9.8	9.8	9.5	13.0	9.0	210.4	1.2	0.2	-34.5	2.7	-0.5	35.5	24.5	29.6	23.7
25-Jul	Tue	9.8	10.0	10.0	10.0	10.0	10.0	10.0	10.0	11.0	9.8	9.8	9.8	9.8	10.0	10.8	13.0	10.0	136.0	3.2	0.2	56.8	0.4	-0.7	33.0	25.9	28.9	24.8
26-Jul	Wed	9.8	9.3	9.3	9.5	9.5	9.5	9.5	10.5	10.5	9.8	9.8	9.8	9.8	10.5	10.5	13.0	9.5	139.8	3.1	2.0	8.6	1.9	-3.6	30.2	25.9	27.6	24.9
27-Jul	Thur						9.0	9.0					9.8	9.8	11.3	10.5												
####	Fri						7.5	7.5					9.8	9.8	10.5	10.5												
####	Sat						8.0	8.0					0.0	0.0	9.3	9.3												
####	Sun						9.5	9.5					0.0	0.0	11.0	11.3												
####	Mon						9.0	9.0					9.8	9.8	9.8	10.3												

Key to table

Gnd ENA - N = Ground floor north fans in local mode (daytime)
Gnd BST - N = Ground floor north fans in pre-cool mode
3rd LOC - N = Third floor north ridge vent in local mode (daytime)
3rd OPN - N = Third floor north ridge vent in pre-cool mode
TWR1 PRE-COL = Tower 1 pre-cool mode
TWR1 W-DIRECT occ ave = Tower 1 wind direction average during occupancy
TWR1 SPEED occ ave = Tower 1 wind speed average during occupancy
TWR1 Rain-I occ ave = Tower 1 rain intensity average during occupancy
TWR1 TMP occ ave = Tower 1 maximum occupied temperature
TW HI - AVE occ max = Tower 1 high level temperature occupied maximum

Table A3.3 - Inland Revenue Building F, Nottingham mode of operation data (July)

		Gnd	Gnd	Gnd	1st	1st	2nd	2nd	3rd	3rd	3rd	3rd	3rd	3rd	3rd	3rd
		ENA-N	BST-N	BST-W	BST-N	BST-W	BST-N	BST-W	BST-N	BST-W	ENA-N	ENA-W	LOC-N	LOC-W	OPN-	OPN-W
Date	Day	hours	hours	hours	hours	hours	hours	hours	hours	hours	hours	hours	hours	hours	hours	hours
01-Aug	Tue						9.5	9.5					10.8	10.8	10.3	10.3
02-Aug	Wed						6.5	6.5					10.8	11.0	6.3	6.3
03-Aug	Thur						4.5	4.5					11.8	11.8	4.8	4.8
04-Aug	Fri						11.0	11.0					11.8	11.8	11.0	11.0
05-Aug	Sat						11.0	11.0					0.0	0.0	11.0	11.0
06-Aug	Sun						6.5	6.5					0.0	0.0	6.3	6.3
07-Aug	Mon						0.0	0.0					11.8	11.8	0.0	0.0
08-Aug	Tue						4.5	4.5					11.8	11.8	4.8	4.8
09-Aug	Wed						7.0	7.0					11.8	11.8	7.5	7.5
10-Aug	Thur						10.0	10.0					11.3	11.3	10.3	10.5
11-Aug	Fri						7.0	7.0					11.8	11.8	9.3	9.0
12-Aug	Sat						6.5	6.5					0.0	0.0	6.3	6.3
13-Aug	Sun						6.5	6.5					0.0	0.0	6.8	6.8
14-Aug	Mon						11.0	11.0					11.8	11.8	11.0	11.0
15-Aug	Tue						10.0	10.0					11.8	11.8	10.3	10.3
16-Aug	Wed		2.8	14.8			9.5	9.5					11.8	11.8	10.5	10.3
17-Aug	Thur		2.3	14.0			10.0	10.0					11.8	11.8	11.0	11.0
18-Aug	Fri		1.5	13.3			11.0	11.0					11.8	11.8	11.0	11.0
19-Aug	Sat		14.0	14.0			10.0	10.0					0.0	0.0	10.8	10.8
20-Aug	Sun		14.0	14.0			10.0	10.0					0.0	0.0	10.8	11.0
21-Aug	Mon		3.0	14.8			9.5	9.5					11.8	11.8	10.0	10.0
22-Aug	Tue		3.5	15.3			9.0	9.0					11.8	11.8	10.3	10.3
23-Aug	Wed		1.3	13.0			11.0	11.0					10.8	10.8	11.0	11.0
24-Aug	Thur		1.3	13.0			11.0	11.0					11.5	11.5	11.0	11.0
25-Aug	Fri		1.3	13.0			11.0	11.0					11.8	11.8	11.0	11.0
26-Aug	Sat		5.0	17.3			6.5	6.5					0.0	0.0	6.3	6.3
27-Aug	Sun		0.0	24.0			0.0	0.0					0.0	0.0	0.0	0.0
28-Aug	Mon		0.3	19.8			4.5	4.5					11.8	11.8	4.8	4.8
29-Aug	Tue		6.0	17.3			6.5	6.5					11.8	11.8	6.3	6.3
30-Aug	Wed		7.5	19.8			4.5	4.5					11.8	11.8	4.8	4.8
31-Aug	Thur		1.3	13.0			11.0	11.0					11.8	11.8	11.0	11.0
01-Sep	Fri		1.3	13.0			11.0	11.0					11.8	11.8	11.0	11.0
02-Sep	Sat		11.3	11.0			13.0	13.0					0.0	0.0	12.8	12.8
03-Sep	Sun		16.3	16.5			7.5	7.5					0.0	0.0	7.8	7.8
04-Sep	Mon		1.3	13.0			11.0	11.0					11.8	11.8	8.0	8.0

(For key to table see Table A3.3)

Table A3.4 - Inland Revenue Building F, Nottingham mode of operation (August-September)

Table A3.5 - Inland Revenue Building F, Nottingham correlation between different variables (Weekdays July-Sept)

Variable 1	Variable 2	Correlation coefficient (r)
Ave N occ max	Ave W occ max	0.992
Ave N occ max	OAT occ max	0.872
Ave N occ min	OAT occ min	0.333
Ave N occ ave	OAT occ ave	0.796
Ave N occ swing	OAT occ swing	0.682
Ave N occ max	Ave N night cool ΔT	0.648
Ave N occ max	Ave N night cool min	0.651
Ave N night cool ΔT	Ave N night temp diff (N-OAT)	-0.167
Ave N night cool ΔT	OAT night ave	0.389
Ave N night cool ΔT	Ave night wind dir	0.045
Ave N night cool ΔT	Ave night wind speed	0.440
Ave N night cool ΔT	Ave night rain	-0.292
Ave W occ max	OAT occ max	0.849
Ave W occ min	OAT occ min	0.191
Ave W occ ave	OAT occ ave	0.750
Ave W occ swing	OAT occ swing	0.635
Ave W occ max	Ave W night cool ΔT	0.641
Ave W occ max	Ave W night cool min	0.781
Ave W night cool ΔT	Ave night temp diff (W-OAT)	-0.02
Ave W night cool ΔT	OAT night ave	0.375
Ave W night cool ΔT	Ave night wind dir	-0.07
Ave W night cool ΔT	Ave night wind speed	0.391
Ave W night cool ΔT	Ave night rain	-0.310
Ave N night cool ΔT	Tower 1 pre-cool hrs	0.168
Ave W night cool ΔT	Tower 1 pre-cool hrs	0.085
Ave N night cool ΔT	N ridge vent pre-cool	0.295
Ave W night cool ΔT	W ridge vent pre-cool	0.321
Ave N night cool ΔT	N 2nd floor fans pre-cool	0.223
Ave W night cool ΔT	W-2nd floor fan pre-cool	0.264

Key to tables A3.5 and A3.6

Ave N	=	average of north facade	wind dir	=	wind direction
Ave W	=	average of west facade	night cool ΔT	=	night cooling zone air temperature drop
occ	=	occupied period	rain	=	rain intensity
max	=	maximum temperature	tower 1	=	ventilation tower 1
min	=	minimum temperature	gnd	=	ground floor
ave	=	average tempertaire	1st	=	first floor
swing	=	temperature swing	2nd	=	second floor
OAT	=	outside air temperature	3rd	=	third floor

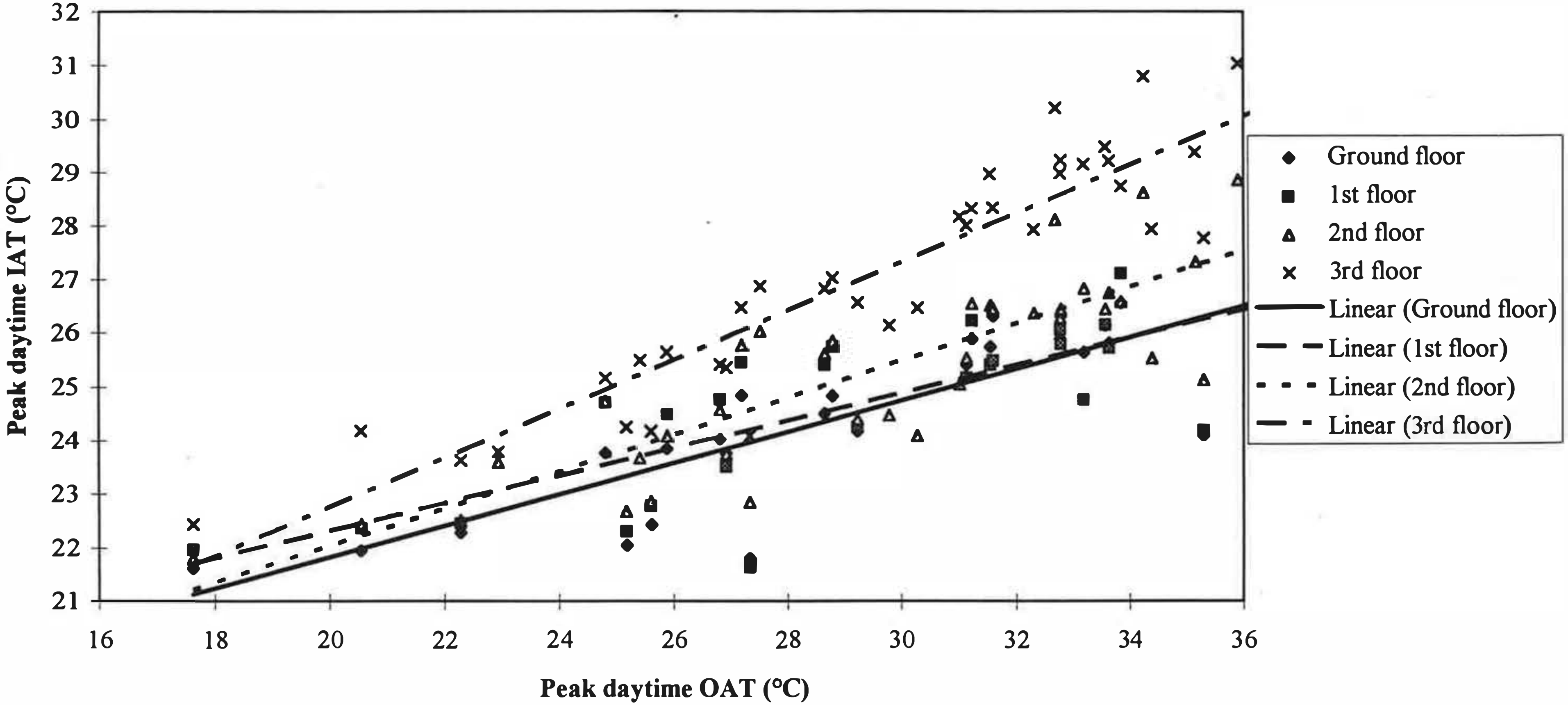
Table A3.6- Inland Revenue Building F, Nottingham correlation between north and west point temperatures (weekday July-Sept)

Variable 1	Variable 2	Correlation coefficient (r)
Gnd N occ max	1st N occ max	0.955
Gnd N occ max	2nd N occ max	0.968
Gnd N occ max	3rd N occ max	0.959
Gnd N occ max	OAT occ max	0.865
1st N occ max	OAT occ max	0.793
2nd N occ max	OAT occ max	0.871
3rd N occ max	OAT occ max	0.932
Gnd N night cool ΔT	1st N night cool ΔT	0.797
Gnd N night cool ΔT	2nd N night cool ΔT	0.707
Gnd N night cool ΔT	3rd N night cool ΔT	0.760
Gnd N night cool ΔT	OAT night ave	0.284
1st N night cool ΔT	OAT night ave	0.401
2nd N night cool ΔT	OAT night ave	0.373
3rd N night cool ΔT	OAT night ave	0.379
Gnd N occ max	Gnd N night cool ΔT	0.493
Gnd N occ max	Gnd N night min	0.471
3rd N occ max	3rd N night cool ΔT	0.581
3rd N occ max	3rd N night min	0.635
Gnd N occ max	Gnd W occ max	0.968
3rd N occ max	3rd W occ max	0.994
Gnd N night cool ΔT	Gnd W night cool ΔT	0.742
Gnd N night min	Gnd W night min	0.773
3rd N night cool ΔT	3rd W night cool ΔT	0.958
3rd N night min	3rd W night min	0.983
Gnd W occ max	1st W occ max	0.975
Gnd W occ max	2nd W occ max	0.960
Gnd W occ max	3rd W occ ;max	0.935
Gnd W occ max	OAT occ max	0.837
1st W occ max	OAT occ max	0.853
2nd W occ max	OAT occ max	0.811
3rd W occ max	OAT occ max	0.922
Gnd W night cool ΔT	1st W night cool ΔT	0.736
Gnd W night cool ΔT	2nd W night cool ΔT	0.549
Gnd W night cool ΔT	3rd W night cool ΔT	0.605
Gnd W night cool ΔT	OAT night ave	0.246
1st W night cool ΔT	OAT night ave	0.453
2nd W night cool ΔT	OAT night ave	0.252
3rd W night cool ΔT	OAT night ave	0.370
Gnd W occ max	Gnd W night cool ΔT	0.469
Gnd W occ max	Gnd W night min	0.735
3rd W occ max	3rd W night cool ΔT	0.609
3rd W occ max	3rd W night min	0.703

See table A3.5 for key

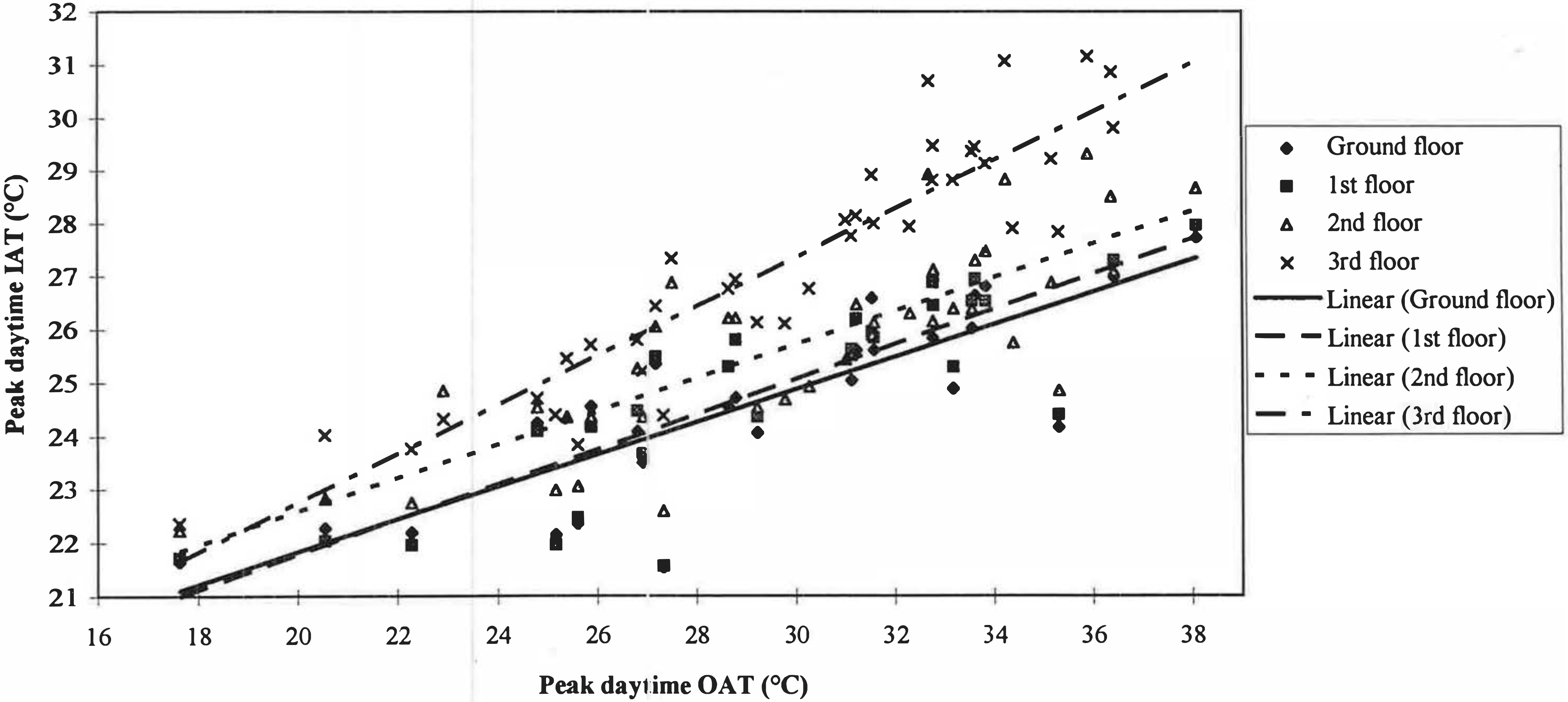
INLAND REVENUE, NOTTINGHAM BUILDING F- VARIATION OF PEAK INSIDE AIR TEMPERATURE (NORTH) WITH PEAK OUTSIDE AIR TEMPERATURE

Figure A3. 7



INLAND REVENUE, NOTTINGHAM BUILDING F- VARIATION OF PEAK INSIDE AIR TEMPERATURE (WEST) WITH PEAK OUTSIDE AIR TEMPERATURE

Figure A3. 8



INLAND REVENUE, NOTTINGHAM BUILDING F- CORRELATION TESTS (WEEKDAY DATA JULY-SEPT)

Figure A3. 9

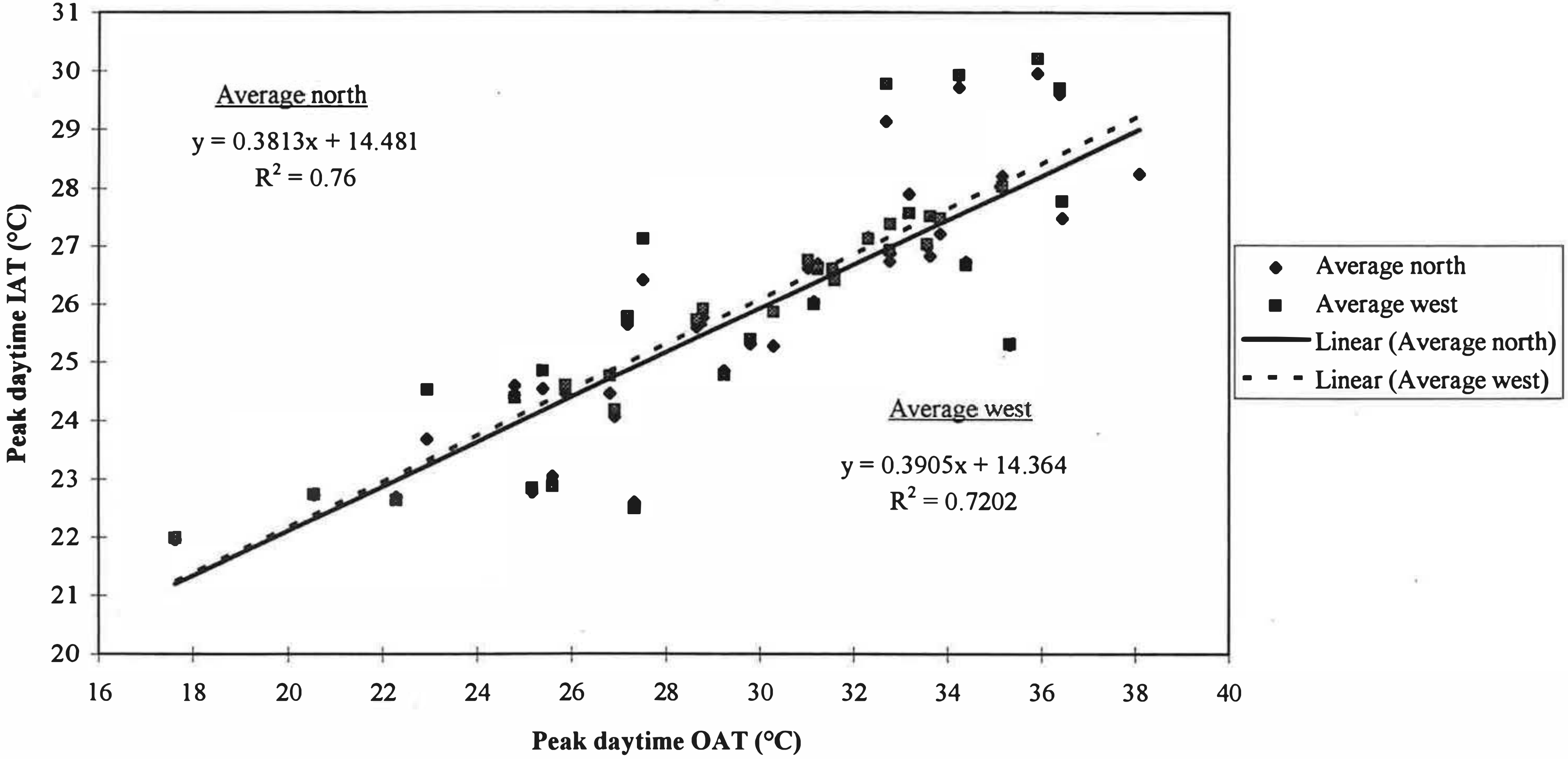


Table A3.7 - Inland Revenue Building F, Nottingham - Regression analysis (Weekday data July-Sept)

1 Occupied period

	R^2	
Comparison of peak North Gnd to other floors	0.900	T = -3.437 + 0.0919 Tg + 1.227F
Comparison of peak West Gnd to other floors	0.900	T = -2.023 + 1.0383 Tg + 1.0388F
Comparison of peak North Gnd to peak OAT	0.749	T = 0.2921 To + 15.978
Comparison of peak North 1st to peak OAT	0.629	T = 0.2576 To + 17.161
Comparison of peak North 2nd to peak OAT	0.759	T = 0.3449 To + 15.137
Comparison of peak North 3rd to Peak OAT	0.868	T = 0.4568 To + 13.62
Comparison of peak West Gnd to peak OAT	0.7005	T = 0.3054 To + 15.713
Comparison of peak West 1st to peak OAT	0.7282	T = 0.3299 To + 15.175
Comparison of peak West 2nd to peak OAT	0.6581	T = 0.3143 To + 16.3
Comparison of peak West 3rd to peak OAT	0.8509	T = 0.4612 To + 13.52

2 Night period

	R^2	
Comparison of night cool gnd N to other floors	0.658	ΔT = -0.7106 + 0.6281 ΔTg + 1.0157F
Comparison of night cool gnd W to other floors	0.421	ΔT = -0.3644 + 0.6817 ΔTg + 0.7448F

T = peak temperature on a particular floor (°C)
Tg = peak ground floor temperature (°C)
To = peak outside air temperature (°C)
F = Floor number
ΔTg = Ground floor temperature drop (K)
ΔT = Floor temperature drop [not ground] (K)

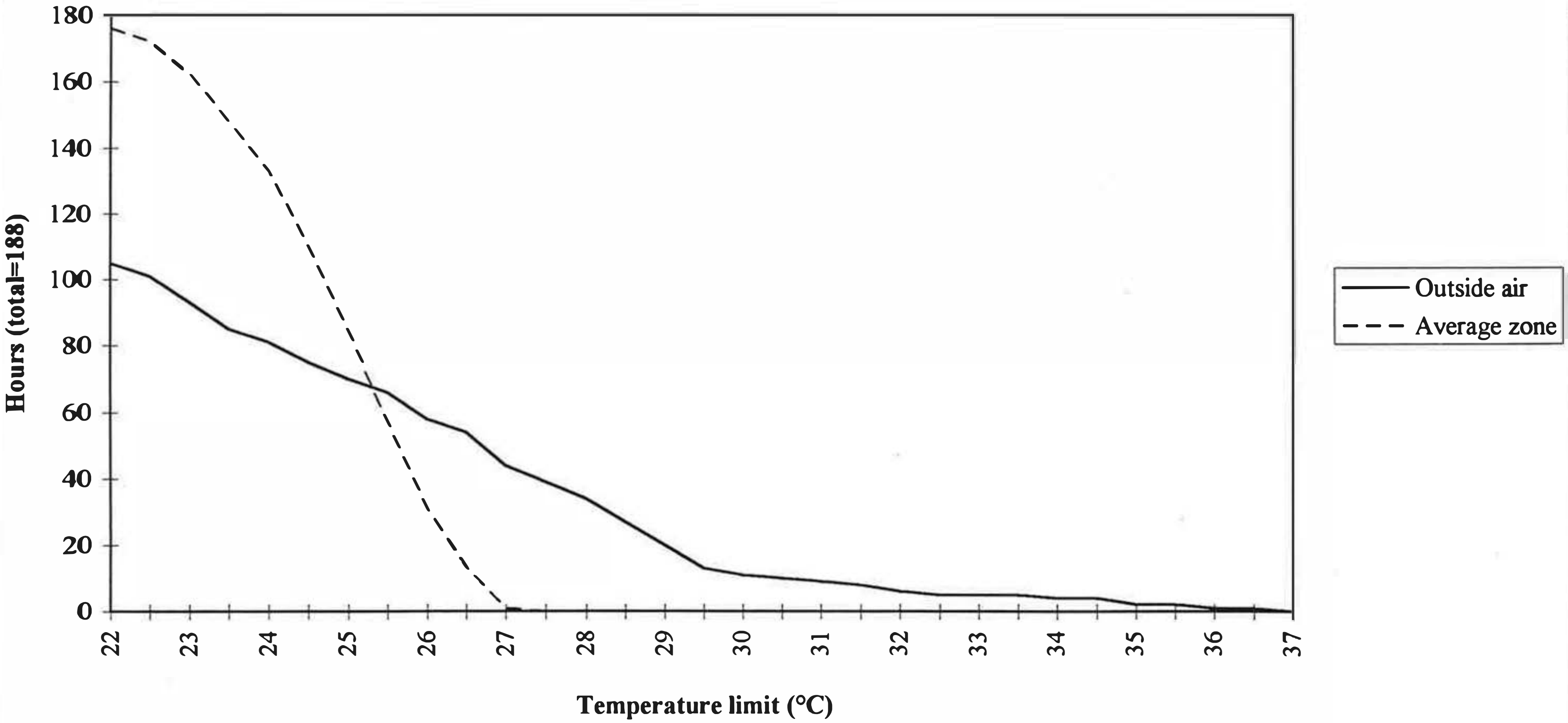
APPENDIX A4

RESULTS FROM THE IONICA BUILDING, CAMBRIDGE

No. of pages: 15

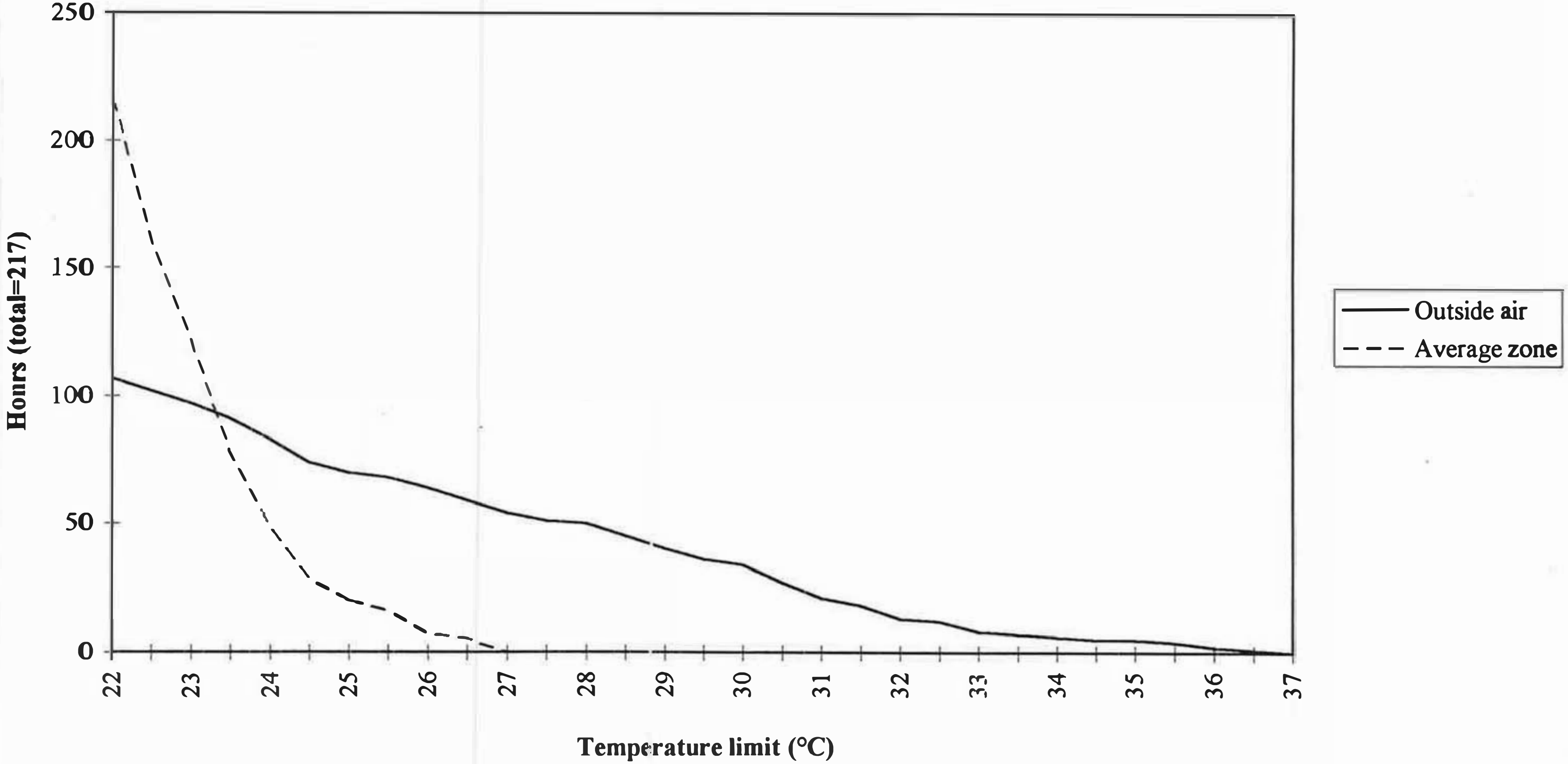
IONICA BUILDING- OCCUPIED HOURS ABOVE TEMPERATURE LIMITS- JULY(3/7-31/7)

Figure A4. 1



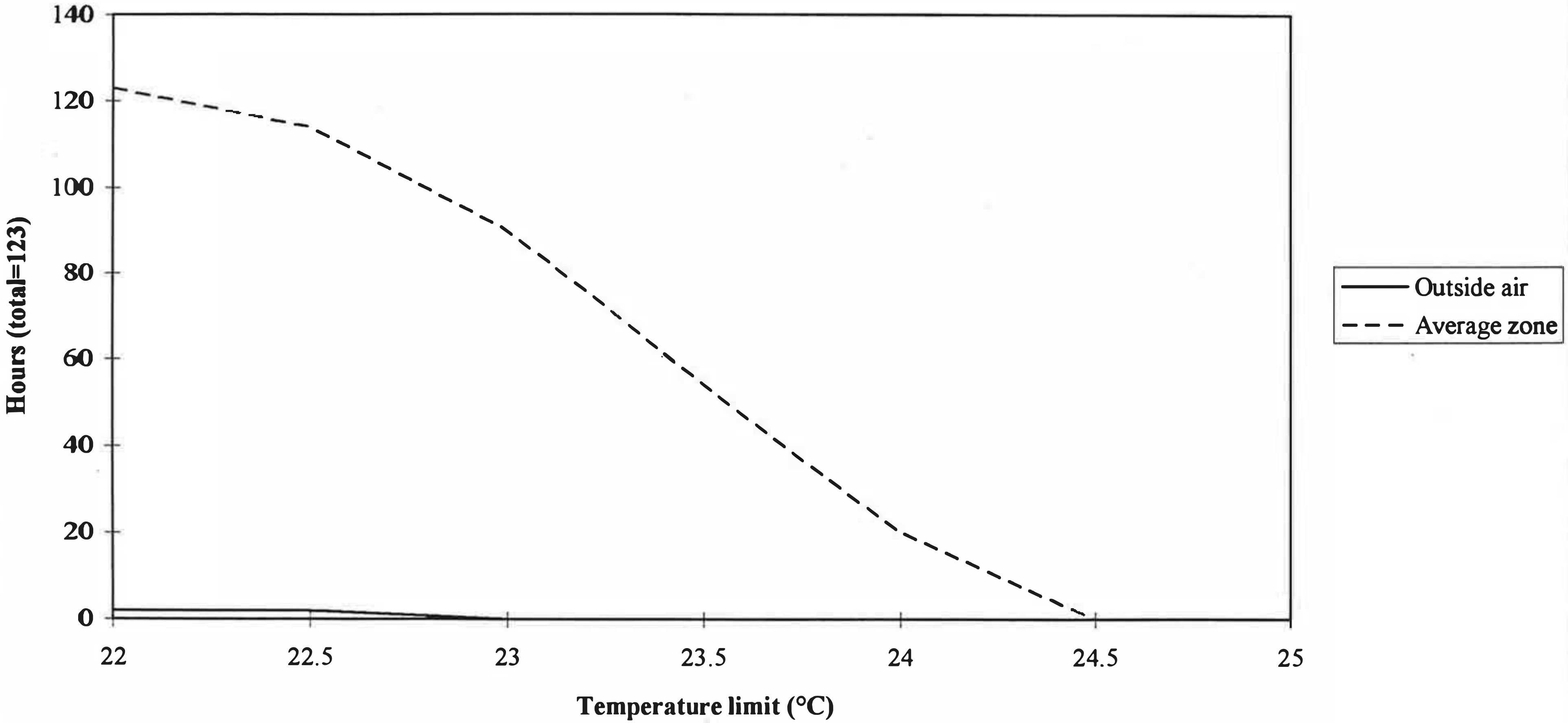
IONICA BUILDING- OCCUPIED HOURS ABOVE TEMPERATURE LIMITS- AUGUST (1/8-31/8)

Figure A4. 2



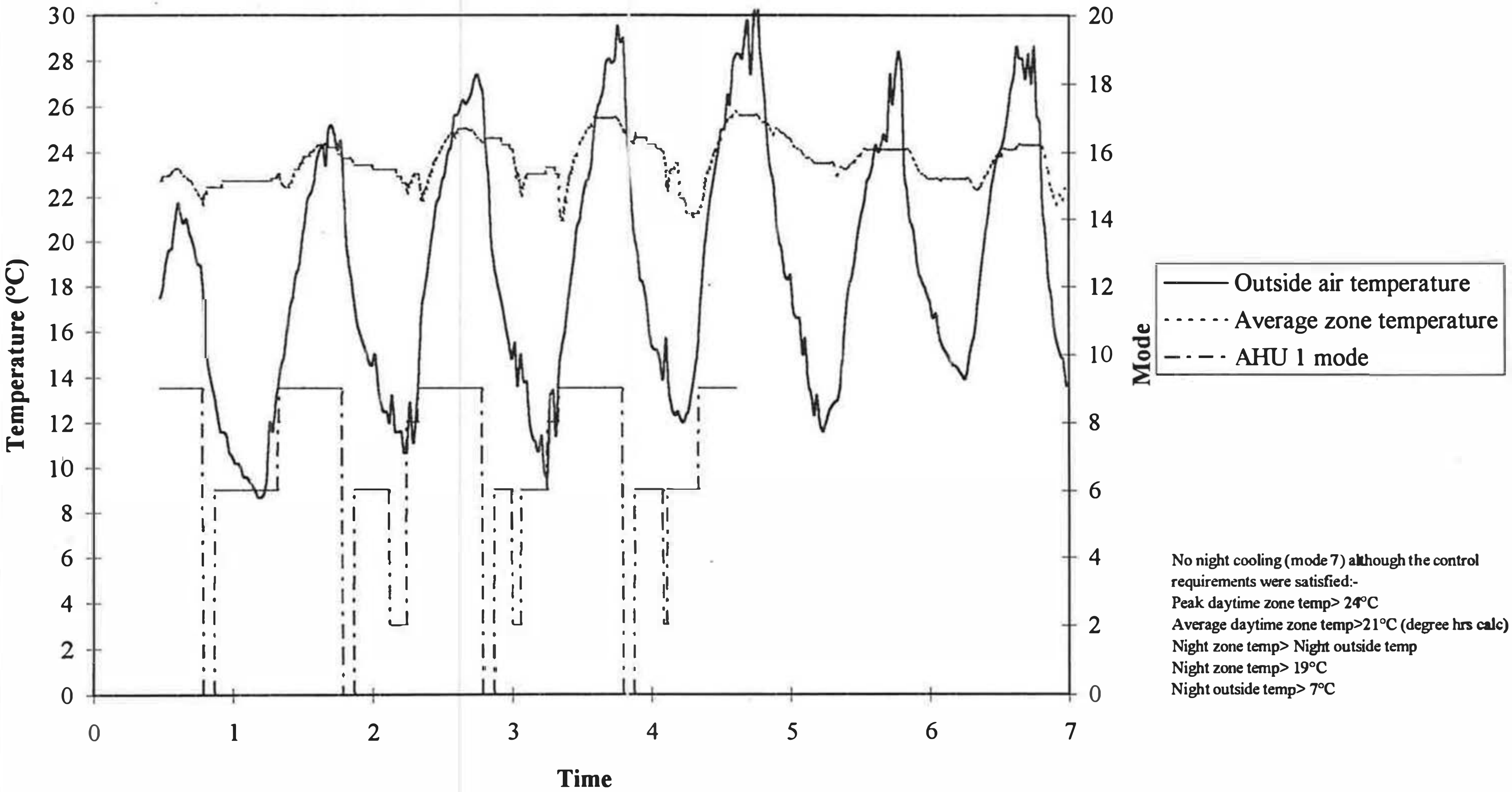
IONICA BUILDING- OCCUPIED HOURS ABOVE TEMPERATURE LIMITS-SEPT(1/9-19/9)

Figure A4. 3



IONICA BUILDING- EXAMPLE WEEK (1/5/95-7/5/95)

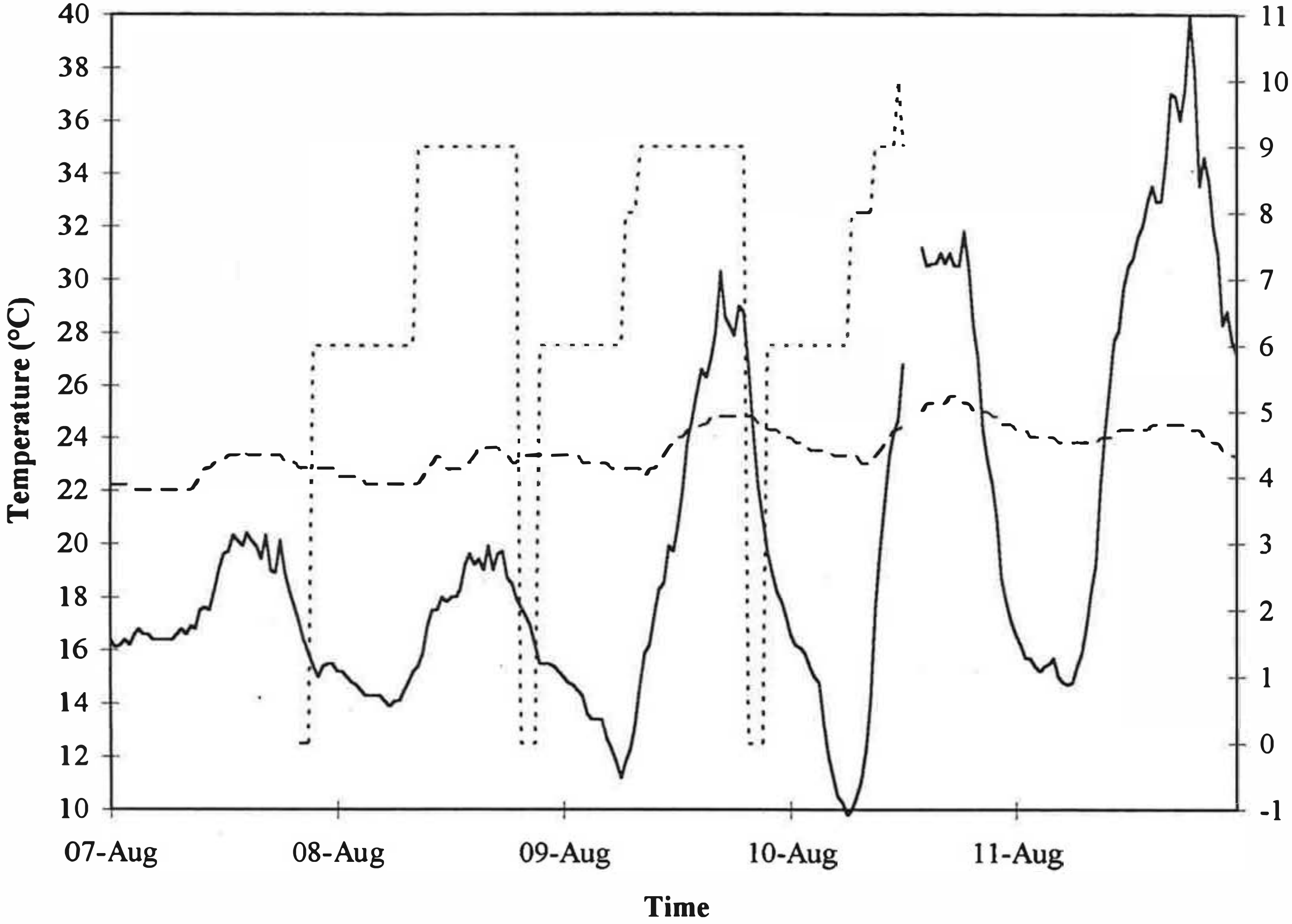
Figure A4. 4



No night cooling (mode 7) although the control requirements were satisfied:-
Peak daytime zone temp> 24°C
Average daytime zone temp>21°C (degree hrs calc)
Night zone temp> Night outside temp
Night zone temp> 19°C
Night outside temp> 7°C

IONICA- EXAMPLE PERIOD (MON 07/08/95- FRI 11/08/95)

Figure A4. 5



No night cooling (mode 7) although the control requirements were satisfied:-
Peak daytime zone temp> 24°C
Average daytime zone temp>21°C (degree hrs calc)
Night zone temp> Night outside temp
Night zone temp> 19°C
Night outside temp> 7°C

	Zone (°C)	Outside (°C)
Maximum	25.8	29.7
Minimum	19.5	1.6
Average	22.8	13.7

Table A4. 1 - Ionica data - summary of occupied temperatures for March to May

	Date	Zone Occ max	Zone Occ min	Zone Occ ave	Zone Occ swing	Night cool delta T (21-08)	Outside Occ max	Outside Occ min	Outside Occ ave	Outside Occ swing
Mon	03-Jul	21.8	20.5	21.1	1.3	-	15.3	14.2	14.7	1.1
Tue	04-Jul	23.5	21.5	22.8	2	0	20.5	13.1	17.7	7.4
Wed	05-Jul	24.5	22	23.2	2.5	1.2	27.3	14	21.1	13.3
Thur	06-Jul	26.1	22.5	24.1	3.6	1.8	29.8	16.7	22.5	13.1
Fri	07-Jul	25.6	22.4	24.3	3.2	1.4	30.4	19.3	24.8	11.1
Sat	08-Jul	24.8	22.6	24.1	2.2	2.5	27.1	17.7	23.4	9.4
Sun	09-Jul	24.3	20.8	23.2	3.5	2.5	27.3	15.1	21.8	12.2
Mon	10-Jul	26.6	23.5	24.9	3.1	0.8	35.2	16.2	24.8	19
Tue	11-Jul	26.1	24.3	25.5	1.8	1.8	31.6	21.3	27.3	10.3
Wed	12-Jul	26.1	24	25.4	2.1	1.8	32.9	20.4	26.6	12.5
Thur	13-Jul	25.8	23	24.6	2.8	1.5	32.5	20.4	25.3	12.1
Fri	14-Jul	25.9	24.8	25.0	1.1	0.7	26.5	18.7	23.2	7.8
Sat	15-Jul	25.1	24.6	24.8	0.5	1	22.9	16.1	19.5	6.8
Sun	16-Jul	24	24	24.0	0	0.8	23.8	16.4	19.8	7.4
Mon	17-Jul	25.1	23.8	24.5	1.3	0	24.8	16.2	21.7	8.6
Tue	18-Jul	26.1	24.3	25.1	1.8	0.8	29.7	16.1	23.3	13.6
Wed	19-Jul	26.1	24.5	25.5	1.6	1.3	30.5	21.7	27.2	8.8
Thur	20-Jul	25.6	24	25.0	1.6	1.3	36	23.8	29.1	12.2
Fri	21-Jul	24	23	23.6	1	1.8	29.2	21.5	24.9	7.7
Sat	22-Jul	23	22.5	22.8	0.5	1.3	22	14.5	18.7	7.5
Sun	23-Jul	23	22.3	22.8	0.7	0.7	27.7	17.5	23.1	10.2
Mon	24-Jul	25.1	22.5	24.3	2.6	0.8	31.6	17.8	24.4	13.8
Tue	25-Jul	26.6	21.5	25.1	5.1	3.3	30.3	18.5	25.9	11.8
Wed	26-Jul	27.2	22.5	25.3	4.7	0.5	29.2	20.8	25.6	8.4
Thur	27-Jul	25.7	22.7	24.9	3	0.8	29.5	21.3	25.6	8.2
Fri	28-Jul	26.9	24.3	25.5	2.6	0.9	29.5	21	26.3	8.5
Sat	29-Jul	25.8	24.8	25.5	1	1	32.3	21.1	28.1	11.2
Sun	30-Jul	25.1	24.8	25.0	0.3	0.8	33.3	22.4	29.0	10.9
Mon	31-Jul	27.2	23	26.0	4.2	2.1	36.6	19.4	28.8	17.2

Average night temperature drop (July - Sept) Weekday 0.97K
Weekend 0.93K

Table A4.2 - Ionica temperature data (July)

Key to table

Zone occ max = Maximum zone air temperature during the occupied period (min, ave, swing refer to minimum temperature, average temperature and temperature swing respectively).

Outside occ max = Maximum outside air temperature during the occupied period (min, ave, swing are same as zone)

Night cool delta T (21-08) = Zone temperature drop during night cool period of 21.00-08.00.

						Night cool				
		Zone	Zone	Zone	Zone	delta T	Outside	Outside	Outside	Outside
	Date	Occ max	Occ min	Occ ave	Occ swing	(21-08)	Occ ma	Occ min	Occ ave	Occ swing
Tue	01-Aug	26.8	23	26.0	3.8	3.1	36.5	19.6	30.0	16.9
Wed	02-Aug	25.6	24	25.4	1.6	2.3	32.9	20.3	29.3	12.6
Thur	03-Aug	24.8	23.3	24.2	1.5	1.2	32.7	21.3	28.5	11.4
Fri	04-Aug	23.8	23	23.5	0.8	1.3	22.9	16.9	20.6	6
Sat	05-Aug	22.5	22	22.2	0.5	1.1	27.5	15.4	21.9	12.1
Sun	06-Aug	22.8	22.2	22.4	0.6	0.6	22.9	15.2	20.3	7.7
Mon	07-Aug	23.5	22	23.0	1.5	0.5	20.4	16.6	18.9	3.8
Tue	08-Aug	23.6	22.2	22.9	1.4	0.6	19.9	15.2	18.2	4.7
Wed	09-Aug	24.8	22.5	23.3	2.3	0.5	30.3	14.7	22.6	15.6
Thur	10-Aug	25.6	23	24.5	2.6	1.5	31.2	12.3	25.3	18.9
Fri	11-Aug	24.5	23.8	24.1	0.7	1.2	37	18.2	29.8	18.8
Sat	12-Aug	22.2	22.2	22.2	0	1.6	34.5	21.5	30.1	13
Sun	13-Aug	21.7	21.7	21.7	0	0.5	24.1	18.2	21.9	5.9
Mon	14-Aug	23	21.2	22.3	1.8	0.3	24.3	15.4	20.9	8.9
Tue	15-Aug	23.5	21.7	22.8	1.8	0.8	30.6	15.9	24.1	14.7
Wed	16-Aug	24	21.7	23.2	2.3	1.3	28.4	17.3	23.9	11.1
Thur	17-Aug	24	22.8	23.3	1.2	0.7	30.5	16.4	25.5	14.1
Fri	18-Aug	23.8	22.2	23.2	1.6	1.3	31.8	18	26.2	13.8
Sat	19-Aug	22	21.7	21.9	0.3	1.6	31.8	15.9	24.7	15.9
Sun	20-Aug	21.7	21.5	21.5	0.2	0.2	27.4	15.7	23.7	11.7
Mon	21-Aug	23.3	21.2	22.4	2.1	0.5	32	15.7	24.4	16.3
Tue	22-Aug	23.5	21.2	22.7	2.3	1.6	34.5	19.9	27.3	14.6
Wed	23-Aug	22.8	22	22.3	0.8	1	22.7	14.5	19.2	8.2
Thur	24-Aug	23.8	21.5	22.8	2.3	1	24.8	15.5	21.3	9.3
Fri	25-Aug	24.3	23	24.0	1.3	0.5	25	20.1	23.3	4.9
Sat	26-Aug	23.3	21.6	22.6	1.7	1.9	22.7	15.5	19.8	7.2
Sun	27-Aug	22.5	22.1	22.4	0.4	0.5	17.8	13.2	16.5	4.6
Mon	28-Aug	22	21.6	21.9	0.4	0.7	17.1	11.2	15.4	5.9
Tue	29-Aug	22.8	21.5	22.2	1.3	-0.2	16.2	11.6	14.2	4.6
Wed	30-Aug	23.8	22.1	23.1	1.7	0.5	20.4	10	17.0	10.4
Thur	31-Aug	23.8	22.3	23.1	1.5	1	19.7	14.8	17.5	4.9

Key to table

Zone occ max = Maximum zone air temperature during the occupied period (min, ave, swing refer to minimum temperature, average temperature and temperature swing respectively).

Outside occ max = Maximum outside air temperature during the occupied period (min, ave, swing are same as zone)

Night cool delta T (21-08) = Zone temperature drop during night cool period of 21.00-08.00.

Table A4.3 - Ionica temperature data (August)

						Night cool				
		Zone	Zone	Zone	Zone	delta T	Outside	Outside	Outside	Outside
	Date	Occ max	Occ min	Occ ave	Occ swing	(21-08)	Occ max	Occ min	Occ ave	Occ swing
Fri	01-Sep	23.5	22.7	23.2	0.8	0.5	18	14.1	16.7	3.9
Sat	02-Sep	22.2	21.4	22.0	0.8	0.8	18	14.1	15.3	3.9
Sun	03-Sep	22.1	21.6	21.9	0.5	-1	19	11.2	16.3	7.8
Mon	04-Sep	24	22.3	23.3	1.7	-0.2	19.9	12.2	16.9	7.7
Tue	05-Sep	23.8	23	23.4	0.8	0.8	20.6	12	16.6	8.6
Wed	06-Sep	23.2	21.9	22.8	1.3	0.7	22	13.9	18.4	8.1
Thur	07-Sep	24.1	22.3	23.3	1.8	0.5	20.3	17.3	18.6	3
Fri	08-Sep	24.3	23.3	24.0	1	0.8	18.5	14.8	16.6	3.7
Sat	09-Sep	23.8	22.8	23.4	1	0.6	22.4	14.1	19.0	8.3
Sun	10-Sep	22.8	22.5	22.7	0.3	0.1	21	12.5	17.7	8.5
Mon	11-Sep	24.2	22.5	23.5	1.7	0	19.9	13.9	16.9	6
Tue	12-Sep	24.5	23	24.0	1.5	0.8	20.3	13.4	17.9	6.9
Wed	13-Sep	24.5	23	23.9	1.5	1.3	22.6	12	18.3	10.6
Thur	14-Sep	24.5	23	23.9	1.5	1	22.9	13.9	19.1	9
Fri	15-Sep	24	23.3	23.6	0.7	0.5	14.5	12.7	13.6	1.8
Sat	16-Sep	22.8	22.2	22.6	0.6	0.8	18.2	12.7	15.6	5.5
Sun	17-Sep	22.4	21.5	22.0	0.9	0.5	18.5	12.9	15.1	5.6
Mon	18-Sep	23.8	21.9	23.2	1.9	-0.6	21.5	13.6	18.7	7.9
Tue	19-Sep	22.8	22.4	22.6	0.4	0.4	16.2	15.4	15.6	0.8

Table A4.4 - Ionica temperature data (September)

Key to table

Zone occ max = Maximum zone air temperature during the occupied period (min, ave, swing refer to minimum temperature, average temperature and temperature swing respectively).

Outside occ max = Maximum outside air temperature during the occupied period (min, ave, swing are same as zone)

Night cool delta T (21-08) = Zone temperature drop during night cool period of 21.00-08.00.

Table A4.5 - Ionica Summary of modes of operation (hrs)

	AHU1		AHU2		AHU4		AHU5	
Mode	Mar-May	Jul-Aug	Mar-May	Jul-Aug	Mar-May	Jul-Aug	Mar-May	Jul-Aug
0	214.1	25.7	548.8	24.2	545.0	25.8	544.3	25.7
1	0	0	0	0	0	0	0	0
2	5.5	0	0.3	0	14.0	0	2.0	0
3	0	0	2.4	0	0	0	7.3	0
4	0.3	0	383.2	0	358.3	0	379.2	4.0
5	229.6	0	28.0	0	29.8	0	29.5	0
6	287.7	127.3	44.8	114.2	33.8	126.3	44.6	123.3
7	0	0	0	0	0	0	0	0
8	401.0	7.0	167.1	6.9	187.8	7.3	168.3	7.1
9	191.4	113.8	155.0	136.6	160.8	117.0	154.3	124.0
10	0	169.3	0	161.3	0	166.8	0.1	159.0

Mode description:

0 Plant off
1 Heating optimum start
2 Cooling optimum start
3 Emergency heating
4 Winter night operation (full mechanical recirculation to remove heat from slab)
5 Mid-season night operation (plant off)
6 Summer night operation (plant off)
7 Night cooling
8 Winter day operation (natural ventilation off)
9 Mid-season operation (natural ventilation)
10 Summer day operation (mechanical cooling enabled)

	AHU1	AHU2	AHU4	AHU5	AHU1	AHU2	AHU4	AHU5	AHU1	AHU2	AHU4	AHU5	AHU1	AHU2	AHU4	AHU5	AHU1	AHU2	AHU4	AHU5
	Mode	Mode	Mode	Mode 0	Mode	Mode	Mode 6	Mode 6	Mode	Mode 8	Mode 8	Mode 8	Mode 9	Mode 9	Mode 9	Mode 9	Mode1	Mode10	Mode10	Mode10
03-Jul	2.0	2.0	2.0	2.0	3.0	3.0	2.8	2.9	0.3	0.2	0.1	0.0	8.9	9.0	9.3	9.3	0.0	0.0	0.0	0.0
04-Jul	2.0	2.0	2.0	2.0	10.9	10.8	10.8	7.1	0.5	0.5	0.5	0.3	10.5	10.6	10.6	10.6	0.0	0.0	0.0	0.0
05-Jul	2.0	2.0	2.0	2.0	9.0	8.9	8.9	8.9	1.5	1.5	1.8	2.0	11.5	11.6	11.3	11.1	0.0	0.0	0.0	0.0
06-Jul	0.0	0.0	0.0	0.0	6.2	6.3	6.2	6.2	0.5	0.5	0.5	0.5	7.5	7.4	7.5	7.5	0.0	0.0	0.0	0.0
07-Jul	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
08-Jul	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
09-Jul	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10-Jul	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11-Jul	2.1	2.0	1.8	2.0	2.8	2.8	2.9	2.8	0.0	0.0	0.2	0.0	2.2	3.1	0.8	3.2	4.7	3.8	6.0	3.7
12-Jul	1.8	2.0	2.0	2.0	9.3	8.9	9.0	9.3	0.0	0.0	0.0	0.0	9.8	13.1	10.3	12.8	3.3	0.0	2.8	0.0
13-Jul	2.0	2.1	2.0	2.0	8.9	9.2	9.3	8.9	0.0	0.0	0.0	0.0	13.1	10.8	12.8	13.1	0.0	1.9	0.0	0.0
14-Jul	0.0	0.0	0.0	0.0	8.1	8.1	8.1	8.2	0.0	0.0	0.0	0.0	2.2	2.2	2.2	2.1	0.0	0.0	0.0	0.0
15-Jul	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16-Jul	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17-Jul	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
18-Jul	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
19-Jul	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
20-Jul	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21-Jul	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
22-Jul	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
23-Jul	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
24-Jul	2.0	2.0	2.0	2.0	3.0	3.0	2.8	3.0	0.0	0.0	0.0	0.0	3.3	3.3	3.6	3.3	1.1	1.1	0.9	1.1
25-Jul	2.1	2.0	2.0	2.0	10.8	10.8	10.8	10.8	0.0	0.0	0.0	0.0	5.8	11.0	8.3	11.0	5.2	0.0	2.8	0.0
26-Jul	0.0	0.0	0.0	0.0	6.2	6.2	6.1	6.3	0.0	0.0	0.0	0.0	4.8	5.2	5.3	5.1	0.4	0.0	0.0	0.0
27-Jul	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
28-Jul	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
29-Jul	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
30-Jul	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
31-Jul	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

For key to modes see Table A4.5

Note: Modes 1, 2, 3, 5 & 7 did not operate
Mode 4 operated for 4 hrs only (AHU 5 4/7/95)

Table A4.6 - Ionica mode of operation data (July) (hr)

	AHU1	AHU2	AHU4	AHU5	AHU1	AHU2	AHU4	AHU5	AHU1	AHU2	AHU4	AHU5	AHU1	AHU2	AHU4	AHU5	AHU1	AHU2	AHU4	AHU5
	Mode 0	Mode 0	Mode 0	Mode 0	Mode 6	Mode 6	Mode 6	Mode 6	Mode 8	Mode 8	Mode 8	Mode 8	Mode 9	Mode 9	Mode 9	Mode 9	Mode1	Mode10	Mode10	Mode10
01-Aug	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
02-Aug	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
03-Aug	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
04-Aug	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
05-Aug	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
06-Aug	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
07-Aug	1.5	0.0	1.8	1.8	2.9	0.0	2.8	2.8	0.0	0.0	0.0	0.0	0.0	4.6	0.0	0.0	0.2	0.0	0.0	0.0
08-Aug	2.0	2.0	2.0	1.8	11.0	2.8	10.9	11.2	0.0	0.0	0.0	0.0	11.0	19.2	11.1	11.1	0.0	0.0	0.0	0.0
09-Aug	2.0	2.0	2.0	2.1	9.0	9.3	8.9	8.8	1.8	1.8	1.8	1.8	11.3	11.0	11.3	11.3	0.0	0.0	0.0	0.0
10-Aug	2.3	2.1	2.0	2.0	9.1	8.9	8.9	8.9	2.5	2.5	2.5	2.5	8.1	8.6	8.7	8.7	0.2	0.0	0.0	0.0
11-Aug	0.0	0.0	0.0	0.0	8.2	6.2	8.0	8.3	0.0	0.0	0.0	0.0	0.5	2.5	0.8	0.5	15.3	15.3	15.3	15.3
12-Aug	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	24.0	24.0	24.0	24.0
13-Aug	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	24.0	24.0	24.0	24.0
14-Aug	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	24.0	24.0	24.0	24.0
15-Aug	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	24.0	24.0	24.0	24.0
16-Aug	2.0	2.0	2.1	2.1	2.8	2.9	2.8	2.8	0.0	0.0	0.0	0.0	2.0	1.8	1.8	2.0	17.3	17.3	17.3	17.2
17-Aug	0.0	0.0	0.0	0.0	6.3	6.1	6.2	6.3	0.0	0.0	0.0	0.0	1.7	1.8	1.8	1.7	16.1	16.1	16.1	16.1
18-Aug	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.8	9.8	9.8	9.8

For key to modes see Table A4.5

Note: Modes 1, 2, 3, 4, 5 & 7 did not operate

Table A4.7 - Ionica mode of operation date (August) (hrs)

Table A4.8 - Ionica data - correlation between different variables (July-Sept)

1 Weekday data

Variable 1	Variable 2	Correlation coefficient (r)
Zone occ max	OAT occ max	0.675
Zone occ min	OAT occ min	0.452
Zone occ ave	OAT occ ave	0.683
Zone occ swing	OAT occ swing	0.488
Zone occ max	Zone night cool ΔT	0.528

2 Weekend data

Variable 1	Variable 2	Correlation coefficient (r)
Zone occ max	OAT occ max	0.317
Zone occ min	OAT occ min	0.534
Zone occ ave	OAT occ ave	0.370
Zone occ swing	OAT occ swing	0.101
Zone occ max	Zone night cool ΔT	0.389

Key to table

Zone occ max = maximum zone air temperature during occupied period (min, ave, swing refer to minimum temperature, average temperature and temperature swing respectively).

OAT occ max = Maximum outside air temperature during occupied period.

Zone night cool ΔT = Drop in zone air temperature during night cooling.

IONICA- CORRELATION TESTS (WEEKDAY DATA JUL-SEPT)

Figure A4.6

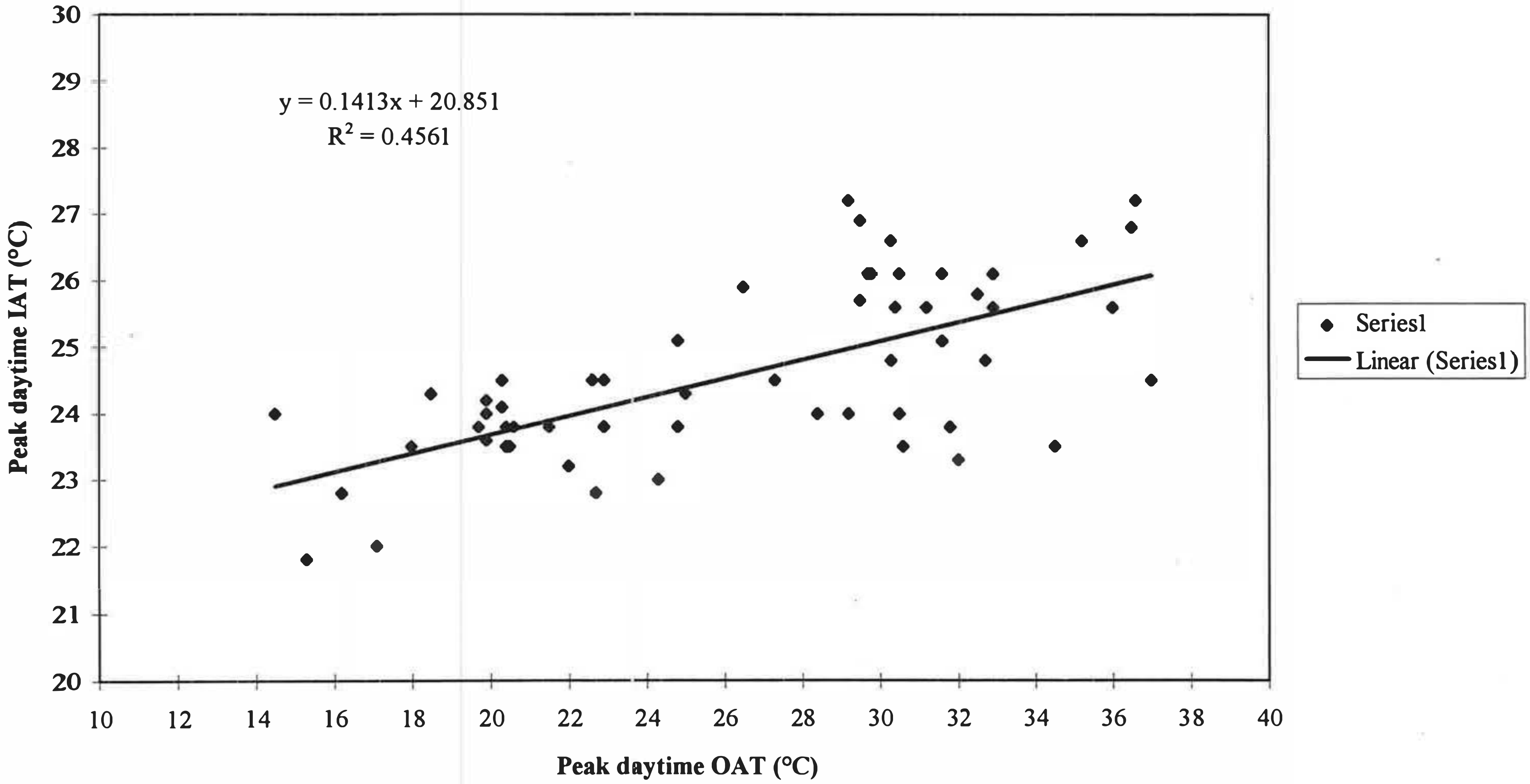
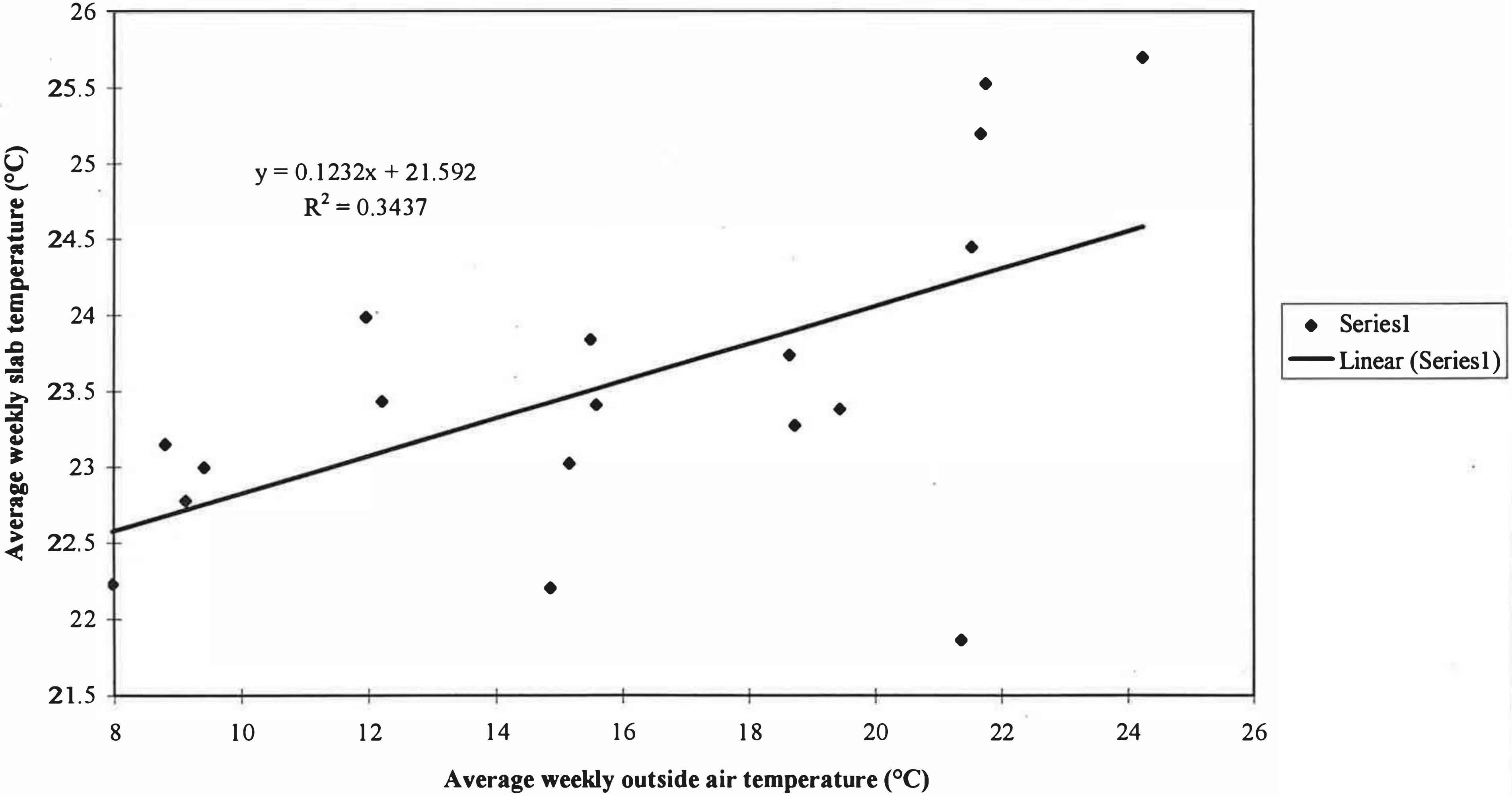


Figure A4.7

IONICA- RELATIONSHIP BETWEEN AVERAGE WEEKLY OUTSIDE AIR AND SLAB TEMPERATURES



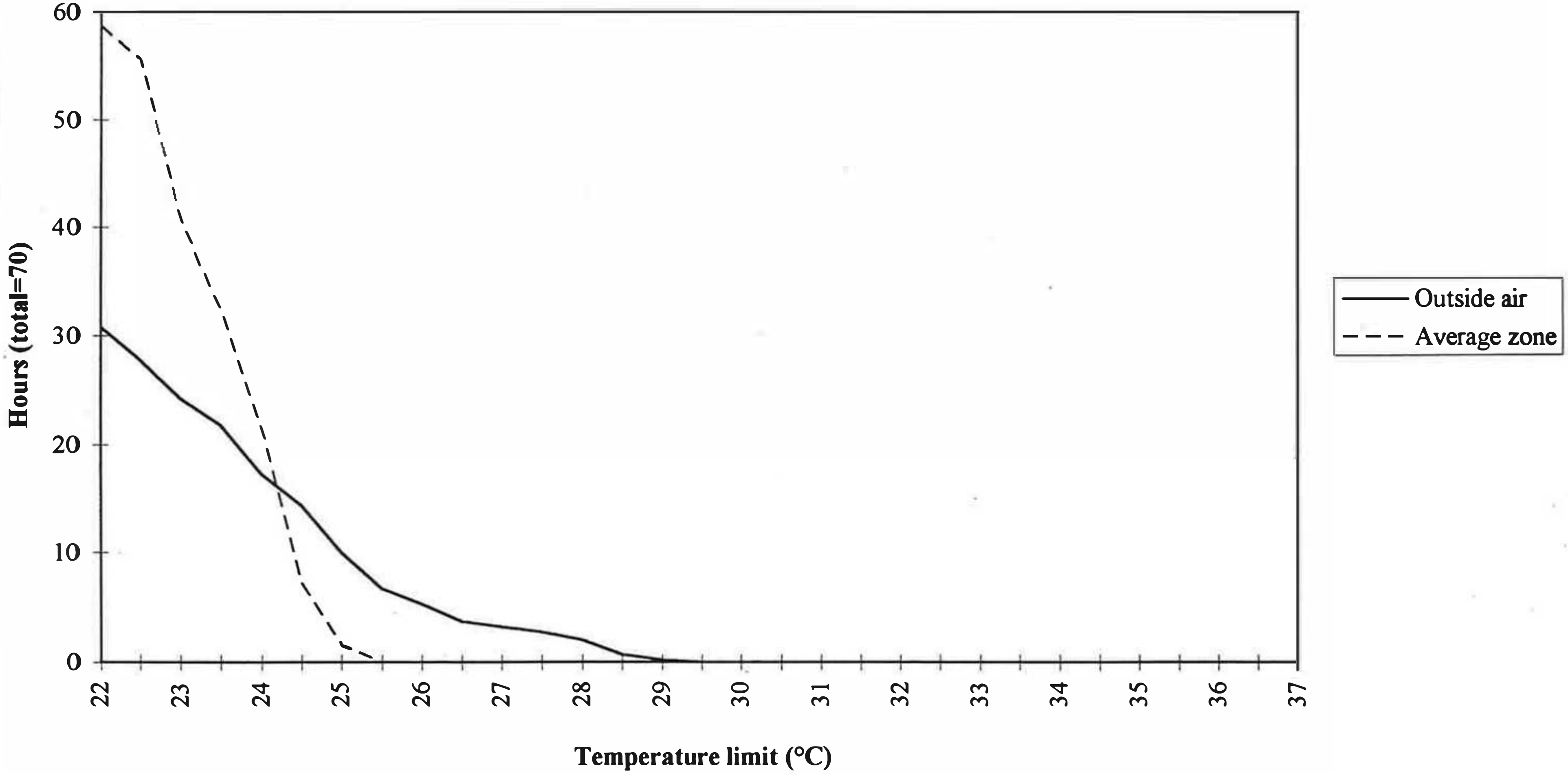
APPENDIX A5

RESULTS FROM THE POWERGEN BUILDING, COVENTRY

No. of pages: 19

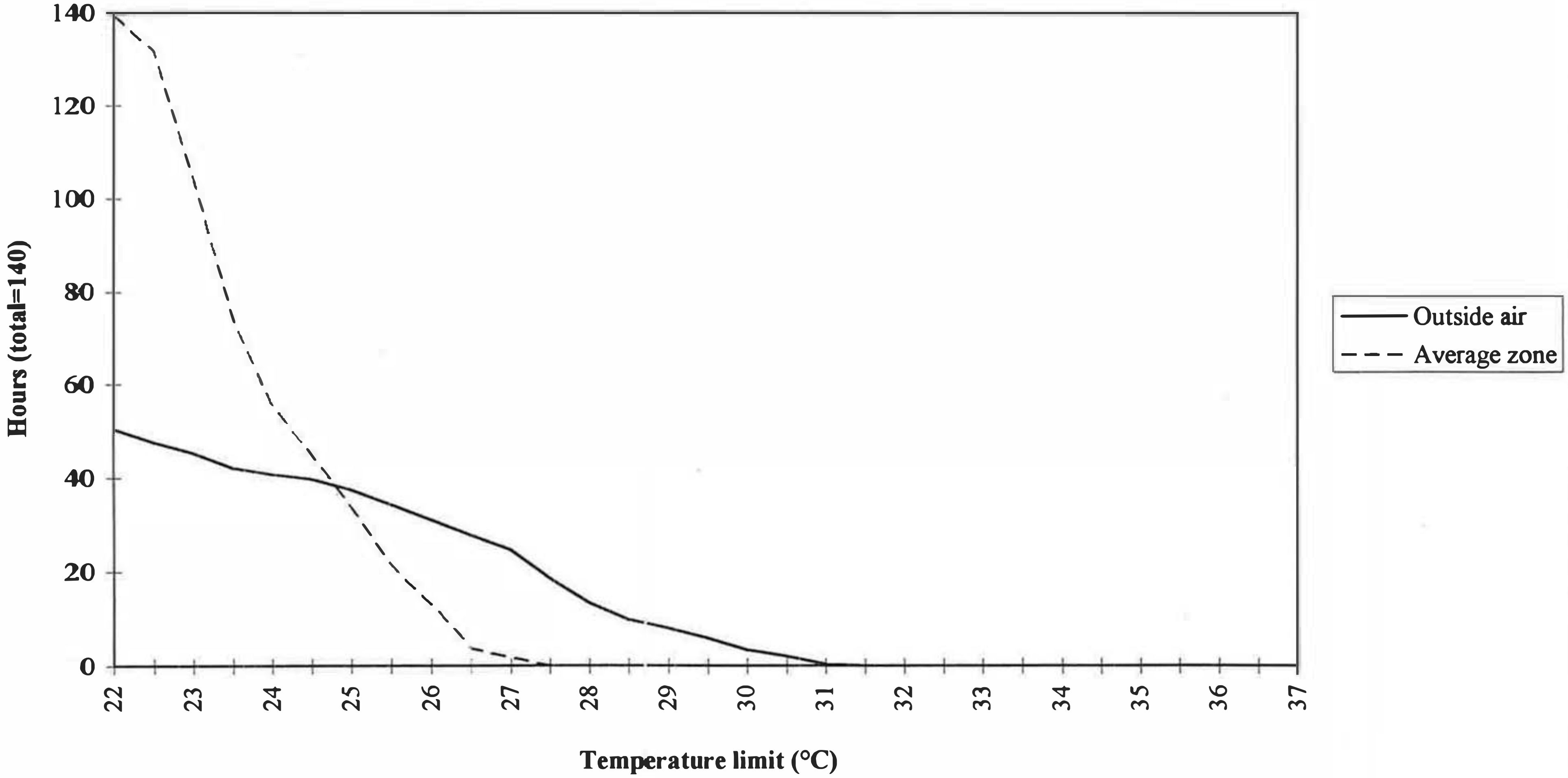
POWERGEN BUILDING- OCCUPIED HOURS ABOVE TEMPERATURE LIMITS- JULY (7/7-17/7)

Figure A5. 1



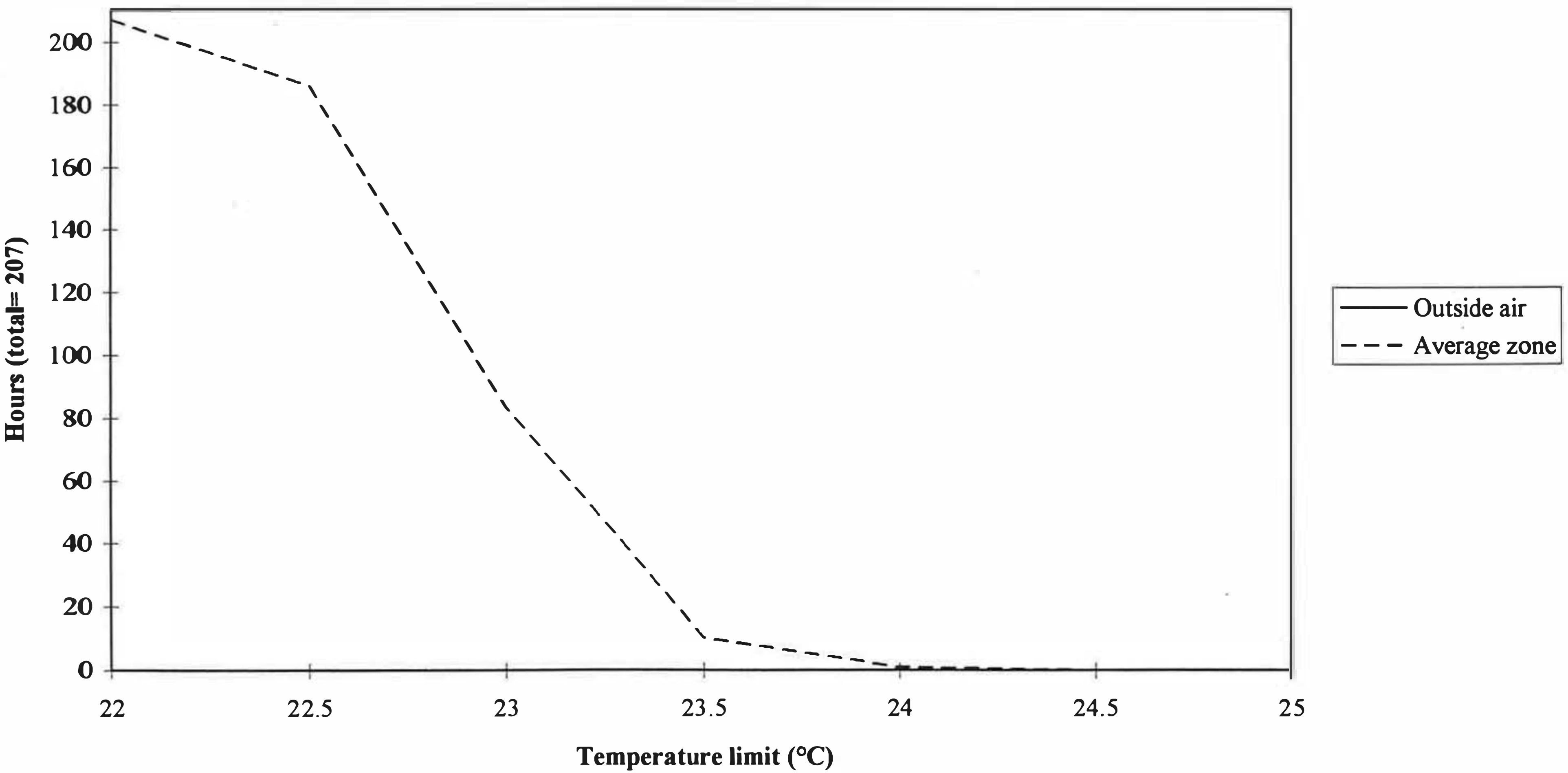
POWERGEN BUILDING- OCCUPIED HOURS ABOVE TEMPERATURE LIMITS- AUGUST (14/8-31/8)

Figure A5. 2



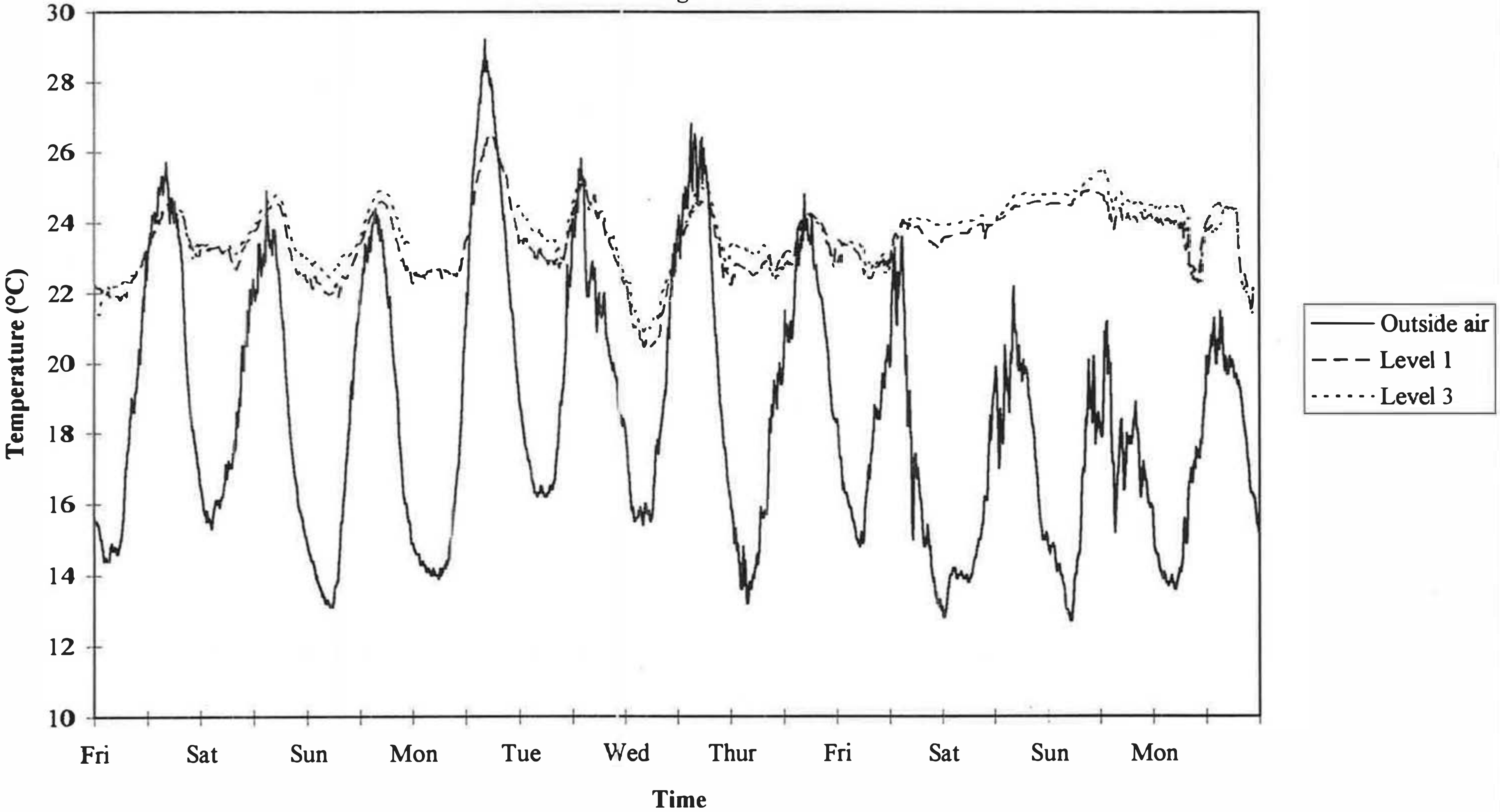
POWERGEN BUILDING- HOURS ABOVE TEMPERATURE LIMITS- SEPTEMBER (1/9-30/9)

Figure A5. 3



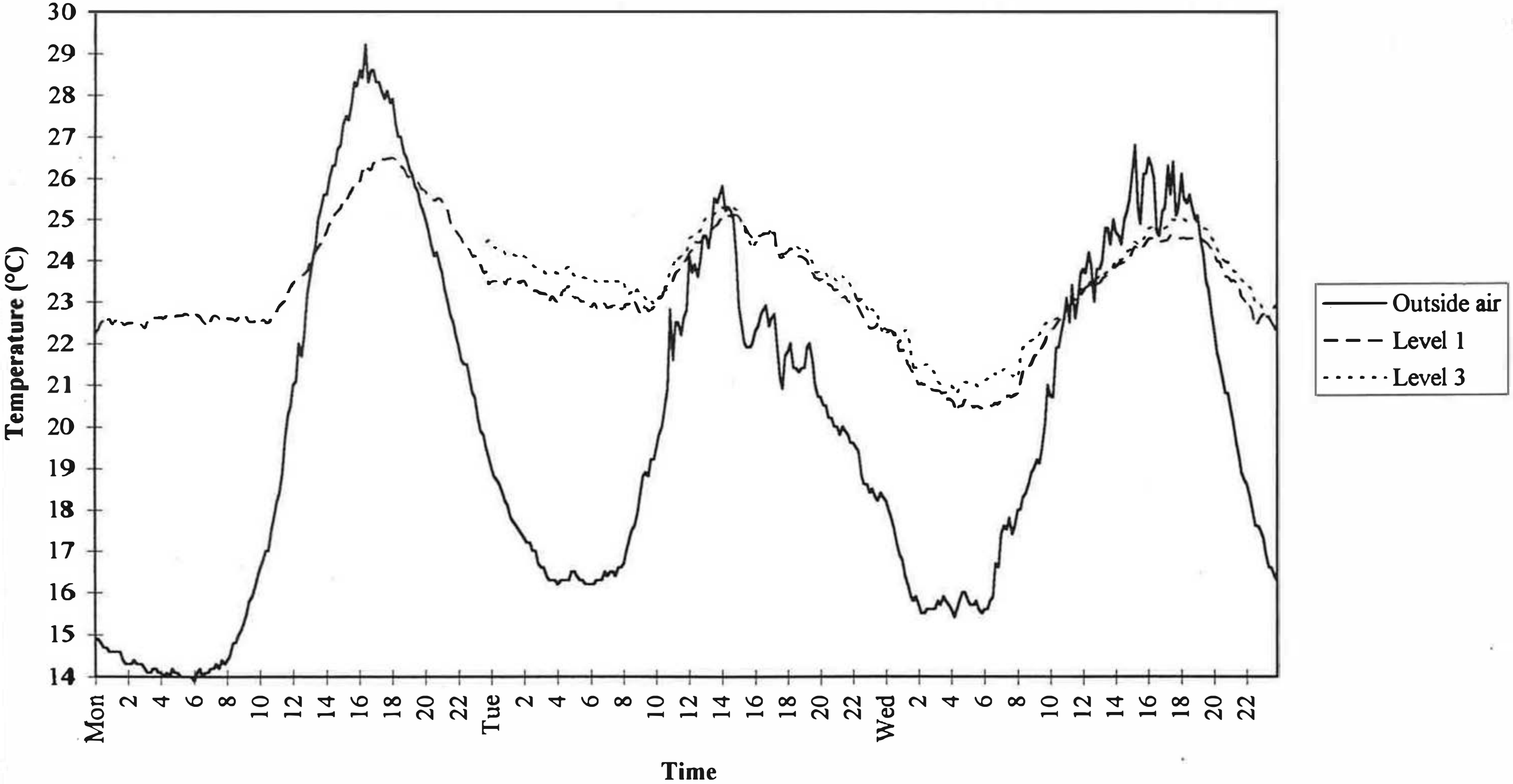
POWERGEN BUILDING EXAMPLE PERIOD (07/07/95-17/07/95)

Figure A5. 4



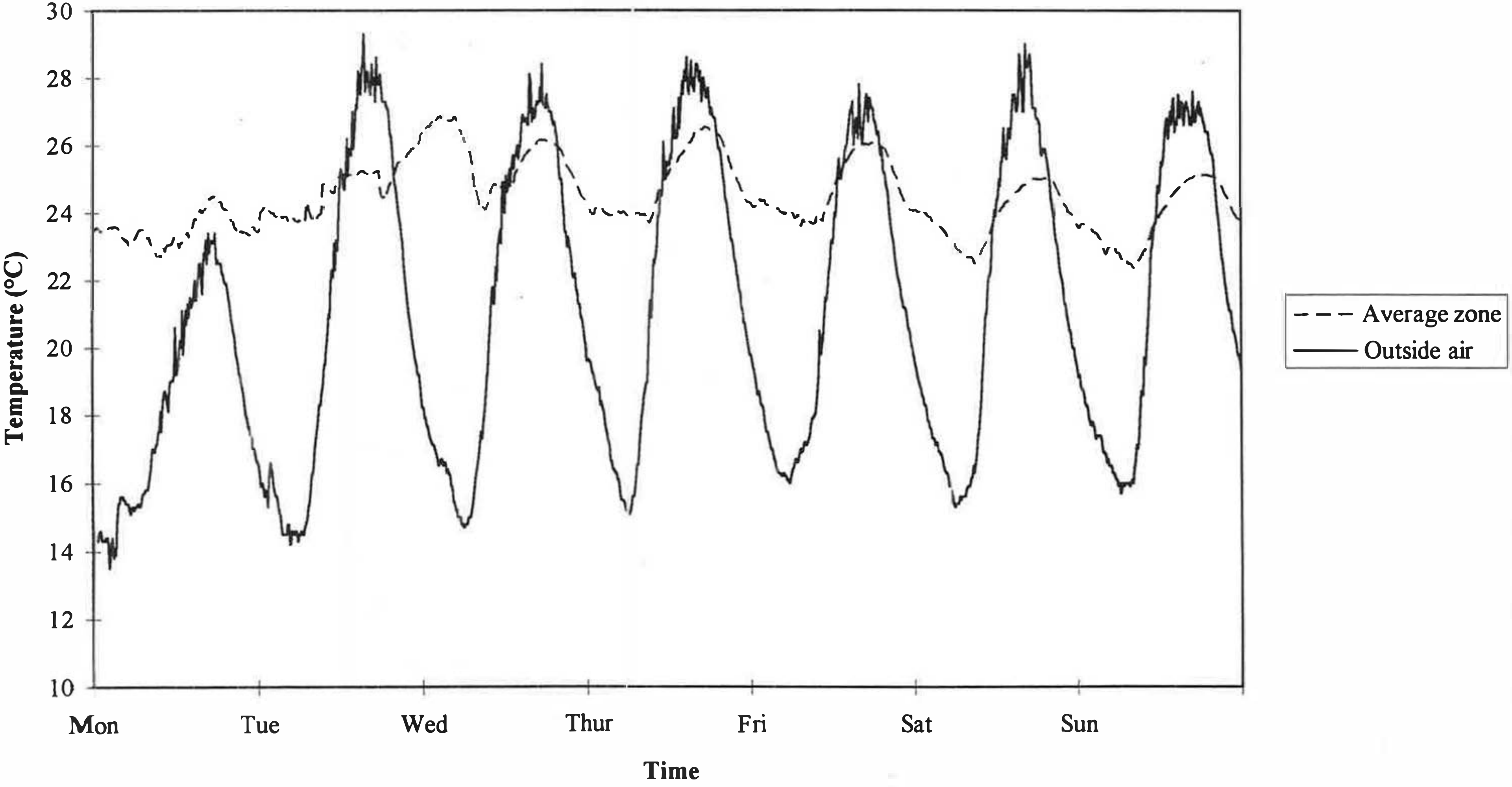
POWERGEN BUILDING- PEAK NIGHT COOLING (10/07/95-12/07/95)

Figure A5. 5



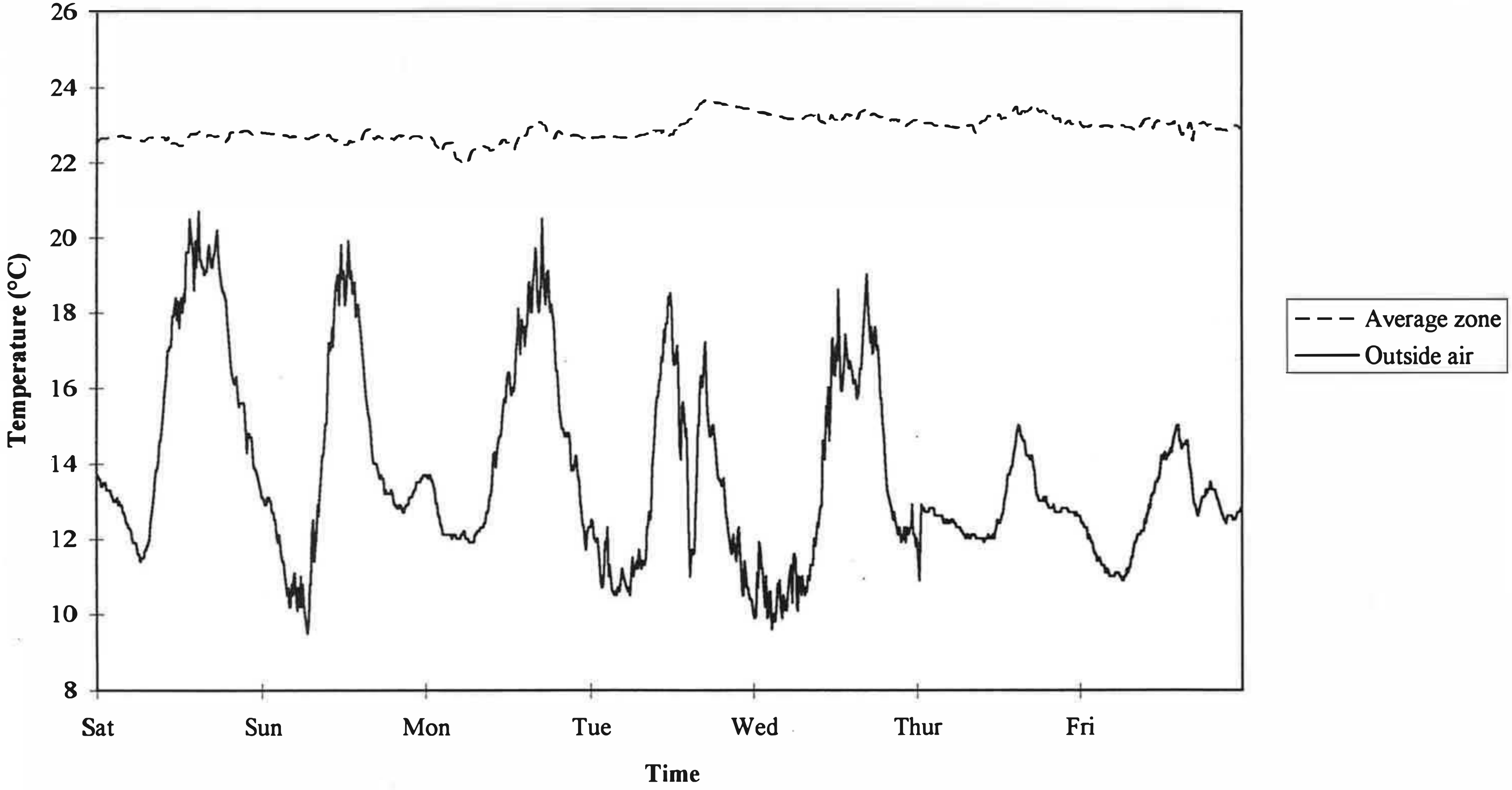
POWERGEN BUILDING- EXAMPLE AUGUST WEEK (14/8/95-20/8/95)

Figure A5. 6



POWERGEN BUILDING- EXAMPLE SEPTEMBER WEEK (9/9/95-15/9/95)

Figure A5. 7



		Zone	Zone	Zone	Zone	Occ hrs	Night cool	Night	Night	OAT	OAT	OAT	OAT
		Occ	Occ	Occ	Occ	above	temp drop	ave delta t	min delta t	Occ	Occ	Occ	Occ
Date	Day	max	min	ave	swing	25°C	"18-08"	zone-OAT	zone-OAT	max	min	ave	swing
07-Jul	Fri	24.5	22.2	23.5	2.2	0.0	-	-		25.7	18.0	22.7	7.7
08-Jul	Sat	24.7	22.9	23.9	1.8	0.0	1.4	5.3	-0.2	24.9	17.5	21.8	7.4
09-Jul	Sun	24.8	22.7	23.7	2.1	0.0	1.9	7.3	2.4	24.4	15.5	21.4	8.9
10-Jul	Mon	-	-	-	-	0.0		5.0	2.0	29.2	14.4	22.4	14.8
11-Jul	Tue	25.2	22.9	24.2	2.3	1.5		6.5	4.6	25.8	16.7	22.0	9.1
12-Jul	Wed	24.8	21.0	23.4	3.8	0.0	3.2	4.2	2.0	26.8	18.0	23.3	8.8
13-Jul	Thur	24.2	22.5	23.2	1.8	0.0	1.6	6.1	-1.4	24.8	15.7	20.8	9.1
14-Jul	Fri	24.1	22.6	23.4	1.5	0.0	1.6	5.0	0.0	23.6	15.0	19.9	8.6
15-Jul	Sat	24.6	23.8	24.2	0.9	0.0	0.0	9.6	6.6	22.2	14.8	18.3	7.4
16-Jul	Sun	25.2	24.1	24.8	1.1	4.2	-0.3	9.1	4.6	21.2	15.2	18.3	6.0
17-Jul	Mon	24.5	22.4	23.7	2.0	0.0	0.4	8.7	5.5	21.5	16.6	19.2	4.9
14-Aug	Mon	24.5	22.7	23.4	1.8	0.0	1.2	6.9	3.5	23.4	15.8	20.1	7.6
15-Aug	Tue	25.3	23.8	24.9	1.5	6.0	0.7	6.6	1.8	29.3	16.3	24.2	13.0
16-Aug	Wed	26.2	24.1	25.2	2.1	4.7	0.1	6.7	-3.2	28.4	16.6	24.0	11.8
17-Aug	Thur	26.6	23.7	25.3	2.9	6.7	2.2	4.6	-1.4	28.6	17.9	25.3	10.7
18-Aug	Fri	26.1	23.6	24.9	2.5	5.3	2.7	4.7	-0.7	27.8	17.1	23.4	10.7
19-Aug	Sat	25.0	22.5	23.9	2.6	0.8	3.4	4.5	-1.0	29.0	15.9	23.8	13.1
20-Aug	Sun	25.1	22.4	24.0	2.8	1.7	2.6	4.0	-1.8	27.6	16.0	24.0	11.6
21-Aug	Mon	26.4	23.1	25.0	3.3	5.3	2.1	4.1	-2.0	30.6	18.8	26.8	11.8
22-Aug	Tue	27.3	23.3	25.6	4.0	6.8	2.8	3.9	-3.2	31.1	20.4	27.7	10.7
23-Aug	Wed	24.1	23.1	23.7	1.0	0.0	3.6	3.6	-3.0	21.0	14.9	17.9	6.1
24-Aug	Thur	23.6	22.7	23.2	0.9	0.0	1.0	8.7	2.7	21.5	14.8	19.1	6.7
25-Aug	Fri	24.2	22.8	23.6	1.4	0.0	0.6	4.8	3.3	23.0	18.5	20.8	4.5
26-Aug	Sat	23.7	22.8	23.3	0.8	0.0	1.2	6.6	3.9	22.9	15.7	19.4	7.2
27-Aug	Sun	23.0	22.4	22.7	0.6	0.0	0.6	6.6	4.2	17.4	13.9	15.4	3.5
28-Aug	Mon	22.7	22.0	22.3	0.7	0.0	-0.1	10.3	6.7	17.6	10.9	15.2	6.7
29-Aug	Tue	23.2	22.6	22.9	0.6	0.0	-0.3	9.2	6.0	16.7	12.6	14.3	4.1
30-Aug	Wed	23.2	22.6	22.9	0.6	0.0	0.2	11.6	10.0	20.1	11.7	17.6	8.4
31-Aug	Thur	23.2	22.6	22.9	0.7	0.0	0.1	7.0	3.5	19.5	15.0	18.0	4.5

Key to tables A5.1 - A5.3

occ = occupied period (08:00 - 18:00)
OAT = outside air temperature
zone = zone temperature
max = maximum temperature
min = minimum temperature
swing = temperature swing
Night cool temp drop = zone temperature drop during night cool period
Night ave delta t (zone - OAT) = average temperature difference between zone temperature and outside temperature
Night min delta t (zone - OAT) = minimum temperature difference between zone temperature and outside temperature during night cool period.

Table A5.1 - PowerGen data (July - August)

		Zone Occ max	Zone Occ min	Zone Occ ave	Zone Occ swing	Occ hr above 25°C	Night cool temp drop "18-08"	Night ave delta t zone-OAT	Night min delta t zone-OAT	OAT Occ max	OAT Occ min	OAT Occ ave	OAT Occ swing
01-Sep	Fri	23.4	22.6	23.0	0.7	0.0	0.2	7.5	3.6	19.0	14.4	17.0	4.6
02-Sep	Sat	23.2	22.5	22.8	0.7	0.0	-0.2	6.6	4.6	17.6	12.7	15.1	4.9
03-Sep	Sun	23.3	22.4	22.9	1.0	0.0	0.2	11.6	7.4	18.4	11.0	15.6	7.4
04-Sep	Mon	24.1	23.2	23.7	0.9	0.0	0.1	11.0	7.0	19.4	12.5	16.4	6.9
05-Sep	Tue	23.1	22.7	22.9	0.4	0.0	1.1	11.2	7.2	17.4	11.2	14.3	6.2
06-Sep	Wed	23.1	22.6	22.9	0.5	0.0	0.2	10.6	10.0	19.7	12.7	16.9	7.0
07-Sep	Thur	23.4	22.7	23.0	0.7	0.0	-0.1	8.3	4.5	18.3	15.7	16.7	2.6
08-Sep	Fri	23.1	22.7	22.9	0.4	0.0	0.6	8.0	7.3	17.5	14.7	16.4	2.8
09-Sep	Sat	22.8	22.4	22.7	0.4	0.0	0.0	8.8	6.4	20.7	12.9	18.0	7.8
10-Sep	Sun	22.9	22.5	22.7	0.4	0.0	-0.1	9.5	3.9	19.9	12.6	16.4	7.3
11-Sep	Mon	23.1	22.3	22.7	0.8	0.0	0.2	9.8	9.0	20.5	12.3	16.4	8.2
12-Sep	Tue	23.6	22.7	23.1	1.0	0.0	0.0	10.0	4.5	18.5	11.0	15.1	7.5
13-Sep	Wed	23.4	23.0	23.2	0.4	0.0	0.4	12.0	8.6	19.0	10.9	15.7	8.1
14-Sep	Thur	23.5	22.8	23.2	0.8	0.0	0.3	10.3	6.1	15.0	11.9	13.2	3.1
15-Sep	Fri	23.2	22.6	23.0	0.6	0.0	0.5	11.0	10.2	15.0	11.9	13.5	3.1
16-Sep	Sat	23.0	22.3	22.8	0.7	0.0	0.2	10.1	9.5	16.5	12.8	14.4	3.7
17-Sep	Sun	22.9	22.2	22.6	0.7	0.0	0.1	9.1	8.2	19.7	14.6	17.5	5.1
18-Sep	Mon	23.5	22.4	23.0	1.0	0.0	0.1	7.8	4.7	17.8	13.9	16.0	3.9
19-Sep	Tue	22.9	22.4	22.7	0.4	0.0	0.5	10.4	7.0	16.8	11.0	14.4	5.8
20-Sep	Wed	23.5	22.2	22.9	1.3	0.0	0.0	11.6	7.0	19.1	9.9	16.1	9.2
21-Sep	Thur	23.3	22.4	22.9	0.8	0.0	-0.3	8.9	5.4	19.8	12.8	16.6	7.0
22-Sep	Fri	23.3	22.7	23.1	0.6	0.0	0.0	10.9	6.2	18.7	10.5	16.0	8.2
23-Sep	Sat	22.6	22.3	22.5	0.4	0.0	0.5	10.5	6.4	14.0	11.0	12.6	3.0
24-Sep	Sun	22.6	22.0	22.3	0.6	0.0	0.4	13.8	10.6	15.9	7.9	13.6	8.0
25-Sep	Mon	23.1	22.0	22.6	1.1	0.0	0.3	7.1	6.1	15.6	12.7	13.9	2.9
26-Sep	Tue	23.1	22.4	22.9	0.7	0.0	-0.3	10.7	8.6	13.7	9.5	12.2	4.2
27-Sep	Wed	23.2	22.4	22.8	0.8	0.0	0.4	15.5	12.3	13.7	6.9	10.6	6.8
28-Sep	Thur	22.9	22.4	22.6	0.6	0.0	0.7	15.4	12.9	16.3	6.9	13.1	9.4
29-Sep	Fri	23.4	22.2	22.8	1.2	0.0	0.6	12.8	10.2	17.0	6.4	13.1	10.6
30-Sep	Sat	23.1	22.5	22.8	0.6	0.0	0.8	9.6	7.9	17.7	14.2	16.0	3.5
01-Oct	Sun	23.9	23.0	23.4	0.9	0.0	0.1	10.3	8.3	17.7	14.2	16.0	3.5
02-Oct	Mon	24.0	22.9	23.6	1.1	0.0	0.9	12.9	9.7	17.8	9.8	15.0	8.0
03-Oct	Tue	24.2	23.0	23.8	1.2	0.0	0.5	10.1	7.8	18.4	12.6	16.1	5.8
04-Oct	Wed	23.8	22.5	23.2	1.4	0.0	0.6	8.3	7.0	18.1	15.4	16.5	2.7
05-Oct	Thur	24.2	23.1	23.8	1.2	0.0	0.5	12.6	8.5	16.5	9.8	14.4	6.7
06-Oct	Fri	23.5	22.4	23.2	1.2	0.0	1.4	11.2	8.7	14.6	13.2	14.1	1.4
07-Oct	Sat	23.7	23.4	23.5	0.2	0.0	0.0	8.7	7.9	17.8	14.6	16.4	3.2
08-Oct	Sun	24.3	23.3	23.8	1.0	0.0	0.3	8.8	7.0	23.6	14.0	20.3	9.6
09-Oct	Mon	24.4	23.0	23.9	1.4	0.0	0.4	8.4	4.0	20.8	14.3	18.8	6.5
10-Oct	Tue	23.4	22.9	23.2	0.5	0.0	0.2	9.7	6.1	18.6	12.4	16.7	6.2
11-Oct	Wed	23.8	22.8	23.3	1.0	0.0	0.1	11.2	8.9	18.2	12.3	15.3	5.9
12-Oct	Thur	23.7	23.0	23.3	0.7	0.0	-0.2	8.5	7.0	18.9	14.9	17.1	4.0
13-Oct	Fri	24.1	23.2	23.6	1.0	0.0	0.2	7.8	6.6	18.2	14.1	16.0	4.1
14-Oct	Sat	23.5	23.1	23.2	0.4	0.0	0.5	10.8	8.5	16.7	11.6	14.1	5.1
15-Oct	Sun	23.0	22.5	22.8	0.5	0.0	0.2	9.1	7.6	19.2	12.4	16.8	6.8
16-Oct	Mon	23.7	22.5	23.1	1.2	0.0	-0.1	11.0	7.4	17.9	11.9	15.2	6.0
17-Oct	Tue	23.2	22.7	23.0	0.5	0.0	-0.3	8.4	7.2	18.4	14.5	16.2	3.9
18-Oct	Wed	23.1	22.7	23.0	0.4	0.0	0.1	10.2	6.2	13.2	8.7	11.8	4.5
19-Oct	Thur	22.9	22.3	22.6	0.6	0.0	0.6	13.6	11.5	16.7	9.3	14.0	7.4
20-Oct	Fri	23.0	22.3	22.8	0.7	0.0	0.6	11.4	9.1	12.1	10.3	11.5	1.8
21-Oct	Sat	23.0	22.0	22.5	1.0	0.0	0.9	15.5	11.8	13.9	4.2	10.7	9.7
22-Oct	Sun	22.6	21.8	22.3	0.8	0.0	1.0	14.6	12.5	15.0	6.5	12.2	8.5
23-Oct	Mon	23.0	22.0	22.7	1.0	0.0	0.6	10.9	9.5	14.9	10.1	12.6	4.8
24-Oct	Tue	23.1	22.4	22.8	0.7	0.0	0.5	9.9	7.8	17.7	14.5	16.5	3.2
25-Oct	Wed	23.2	22.4	23.0	0.8	0.0	0.6	12.0	5.8	14.1	9.2	12.3	4.9
26-Oct	Thur	23.2	22.5	22.9	0.7	0.0	0.5	11.1	10.2	14.9	12.1	13.8	2.8
27-Oct	Fri	23.4	22.8	23.2	0.6	0.0	0.2	9.6	8.2	14.2	9.8	12.4	4.4
28-Oct	Sat	22.9	22.1	22.5	0.8	0.0	0.9	15.8	13.2	13.3	6.2	10.8	7.1
29-Oct	Sun	22.2	21.6	22.0	0.7	0.0	0.8	15.4	12.5	11.9	5.8	10.0	6.1
30-Oct	Mon	22.8	21.5	22.4	1.3	0.0	0.6	14.1	12.1	14.8	7.8	12.6	7.0
31-Oct	Tue	23.2	22.0	22.8	1.3	0.0	0.8	13.7	11.6	15.0	7.4	13.0	7.6

Table A5.2 - PowerGen data (September - October)

		Zone Occ max	Zone Occ min	Zone Occ ave	Zone Occ swing	Occ hr above 25°C	Night cool temp drop "18-08"	Night ave delta zone-OAT	Night in delta zone-OA	OAT Occ max	OAT Occ min	OAT Occ ave	OAT Occ swing
01-Nov	Wed	23.3	22.5	23.0	0.8	0.0	0.6	11.4	9.9	12.8	10.3	11.8	2.5
02-Nov	Thur	23.4	22.3	23.0	1.1	0.0	0.8	15.1	12.9	11.2	7.1	9.8	4.1
03-Nov	Fri	23.2	22.5	22.9	0.7	0.0	0.7	15.1	14.0	10.3	7.6	9.2	2.7
04-Nov	Sat	22.9	21.9	22.4	1.0	0.0	1.1	17.8	15.2	9.8	3.5	7.5	6.3
05-Nov	Sun	22.2	21.3	21.9	0.9	0.0	1.2	18.8	15.7	9.0	2.5	6.9	6.5
06-Nov	Mon	22.7	21.1	22.1	1.6	0.0	1.0	19.2	16.3	9.8	1.9	7.7	7.9
07-Nov	Tue	22.8	21.7	22.4	1.1	0.0	0.9	16.0	12.9	11.7	6.2	9.6	5.5
08-Nov	Wed	23.0	22.3	22.8	0.7	0.0	0.5	13.0	11.8	13.3	9.2	11.7	4.1
09-Nov	Thur	23.2	22.5	22.9	0.7	0.0	0.5	11.8	10.9	9.4	7.0	8.2	2.4
10-Nov	Fri	23.2	22.3	22.9	0.8	0.0	0.7	16.1	14.5	9.2	6.5	8.3	2.7
11-Nov	Sat	22.4	21.5	22.3	1.0	0.0	0.7	15.0	13.1	12.5	8.9	11.5	3.6
12-Nov	Sun	22.4	22.1	22.3	0.3	0.0	0.2	10.0	9.4	13.7	11.4	12.5	2.3
13-Nov	Mon	23.2	22.3	22.9	0.9	0.0	0.1	11.4	9.5	14.7	10.8	12.3	3.9
14-Nov	Tue	23.4	22.5	23.1	0.8	0.0	0.5	12.6	11.6	12.1	8.8	10.3	3.3
15-Nov	Wed	23.5	22.7	23.3	0.8	0.0	0.5	12.9	11.7	13.4	7.8	11.3	5.6

Table A5.3 - Powergen data (November)

Table A5.4 - PowerGen data - correlations between variables

Variable 1	Variable 2	Jul-Sep or Oct-Nov	Weekday or weekend	Correlation coefficient (r)
Zone occ max	OAT occ max	Jul-Sept	Weekday	0.905
Zone occ min	OAT occ min	Jul-Sept	Weekday	0.335
Zone occ ave	OAT occ ave	Jul-Sept	Weekday	0.854
Zone occ swing	OAT occ swing	Jul-Sept	Weekday	0.570
Zone occ max	Night cool temp drop	Jul-Sept	Weekday	0.636
Night cool temp drop	Ave night ΔT (zone-OAT)	Jul-Sept	Weekday	-0.640
Zone occ max	OAT occ max	Jul-Sept	Weekend	0.842
Zone occ min	OAT occ min	Jul-Sept	Weekend	0.474
Zone occ ave	OAT occ ave	Jul-Sept	Weekend	0.723
Zone occ swing	OAT occ swing	Jul-Sept	Weekend	0.784
Zone occ max	Night cool temp drop	Jul-Sept	Weekend	0.576
Night cool temp drop	Ave night ΔT (zone-OAT)	Jul-Sept	Weekend	-0.672
Zone occ max	OAT occ max	Oct-Nov	Weekday	0.640
Zone occ min	OAT occ min	Oct-Nov	Weekday	0.643
Zone occ ave	OAT occ ave	Oct-Nov	Weekday	0.608
Zone occ swing	OAT occ swing	Oct-Nov	Weekday	0.417
Zone occ max	Night cool temp drop	Oct-Nov	Weekday	-0.202
Night cool temp drop	Ave night ΔT (zone-OAT)	Oct-Nov	Weekday	0.619
Zone occ max	OAT occ max	Oct-Nov	Weekend	0.841
Zone occ min	OAT occ min	Oct-Nov	Weekend	0.850
Zone occ ave	OAT occ ave	Oct-Nov	Weekend	0.865
Zone occ swing	OAT occ swing	Oct-Nov	Weekend	0.552
Zone occ max	Night cool temp drop	Oct-Nov	Weekend	-0.625
Night cool temp drop	Ave night ΔT (zone-OAT)	Oct-Nov	Weekend	0.946

Key to tables A5.4 and A5.5

OAT	=	outside air temperature
occ	=	occupied period
max	=	maximum temperature
min	=	minimum temperature
ave	=	average temperature
swing	=	temperature swing
Night cool temp drop	=	zone air temperature drop during night cool period
Ave night ΔT (zone-OAT)	=	average temperature difference between zone and outside during night cool period

NW	=	North West
NE	=	North East
SW	=	South West
SE	=	South East
Level 1,2,3	=	building floor number

Variable 1	Variable 2	Correlation coefficient (r)	Variable 1	Variable 2	Correlation Coefficient (r)
NW level 1 occ max	NW level 2 occ max	0.962	NE level 1 occ max	NE level 2 occ max	0.988
NW level 1 occ max	NW level 3 occ max	0.957	NE level 1 occ max	NE level 3 occ max	0.909
NW level 2 occ max	NW level 3 occ max	0.847	NE level 2 occ max	NE level 3 occ max	0.919
NW level 1 occ max	OAT occ max	0.883	NE level 1 occ max	OAT occ max	0.925
NW level 2 occ max	OAT occ max	0.809	NE level 2 occ max	OAT occ max	0.932
NW level 3 occ max	OAT occ max	0.793	NE level 3 occ max	OAT occ max	0.788
NW level 1 night cool ΔT	NW level 2 night cool ΔT	0.705	NE level 1 night cool ΔT	NE level 2 night cool ΔT	0.928
NW level 1 night cool ΔT	NW level 3 night cool ΔT	-0.163	NE level 1 night cool ΔT	NE level 3 night cool ΔT	-0.100
NW level 2 night cool ΔT	NW level 3 night cool ΔT	0.767	NE level 2 night cool ΔT	NE level 3 night cool'ΔT	0.551
NW level 1 night cool Δt	Ave night OAT	0.755	NE level 1 night cool Δt	Ave night OAT	0.680
NW level 2 night cool ΔT	Ave night OAT	0.628	NE level 2 night cool ΔT	Ave night OAT	0.667
NW level 3 night cool ΔT	Ave night OAT	0.542	NE level 3 night cool ΔT	Ave night OAT	-0.100
NW level 1 occ max	NW level 1 night cool ΔT	0.654	NE level 1 occ max	NE level 1 night cool ΔT	0.693
NW level 2 occ max	NW level 2 night cool ΔT	0.561	NE level 2 occ max	NE level 2 night cool ΔT	0.621
NW level 3 occ max	NW level 3 night cool ΔT	-0.263	NE level 3 occ max	NE level 3 night cool ΔT	-0.298
SW level 1 occ max	SW level 2 occ max	0.971	SE level 1 occ max	SE level 2 occ max	0.973
SW level 1 occ max	SW level 3 occ max	0.939	SE level 1 occ max	SE level 3 occ max	0.930
SW level 2 occ max	SW level 3 occ max	0.917	SE level 2 occ max	SE level 3 occ max	0.949
SW level 1 occ max	OAT occ max	0.909	SE level 1 occ max	OAT occ max	0.896
SW level 2 occ max	OAT occ max	0.880	SE level 2 occ max	OAT occ max	0.894
SW level 3 occ max	OAT occ max	0.758	SE level 3 occ max	OAT occ max	0.854
SW level 1 night cool ΔT	SW level 2 night cool ΔT	0.588	SE level 1 night cool ΔT	SE level 2 night cool ΔT	0.615
SW level 1 night cool ΔT	SW level 3 night cool ΔT	-0.142	SE level 1 night cool ΔT	SE level 3 night cool ΔT	-0.171
SW level 2 night cool ΔT	SW level 3 night cool ΔT	0.901	SE level 2 night cool ΔT	SE level 3 night cool ΔT	0.851
SW level 1 night cool ΔT	Ave night OAT	0.760	SE level 1 night cool ΔT	Ave night OAT	0.680
SW level 2 night cool ΔT	Ave night OAT	0.407	SE level 2 night cool ΔT	Ave night OAT	0.542
SW level 3 night cool ΔT	Ave night OAT	-0.153	SE level 3 night cool ΔT	Ave night OAT	-0.117
SW level 1 occ max	SW level 1 night cool ΔT	0.747	SE level 1 occ max	SE level 1 night cool ΔT	0.644
SW level 2 occ max	SW level 2 night cool ΔT	0.240	SE level 2 occ max	SE level 2 night cool ΔT	0.504
SW level 3 occ max	SW level 3 night cool ΔT	-0.400	SE level 3 occ max	SE level 3 night cool ΔT	-0.344

Table A5. 5 PowerGen data - correlations between temperature on different levels (weekday data)

Variable 1	Variable 2	Correlation Coefficient (r)
NW level 1 night cool ΔT	NE level 1 night cool ΔT	0.953
NW level 1 night cool ΔT	SW level 1 night cool ΔT	0.968
NW level 1 night cool ΔT	SE level 1 night cool ΔT	0.922
NE level 1 night cool ΔT	SE level 1 night cool ΔT	0.921
NE level 1 night cool ΔT	SW level 1 night cool ΔT	0.974
SE level 1 night cool ΔT	SW level 1 night cool ΔT	0.932
NW level 3 night cool ΔT	NE level 3 night cool ΔT	0.996
NWlevel 3 night cool ΔT	SWlevel 3 night cool ΔT	0.993
NWlevel 3 night cool ΔT	SE level 3 night cool ΔT	0.994
NE level 3 night cool ΔT	SE level 3 night cool ΔT	0.995
NE level 3 night cool ΔT	SW level 3 night cool ΔT	0.992
SE level 3 night cool ΔT	SW level 3 night cool ΔT	0.996

Table 5.5 Cont.

Figure A5. 8

POWERGEN BUILDING- VARIATION OF PEAK DAYTIME NW ZONE TEMPERATURE WITH OUTSIDE TEMPERATURE

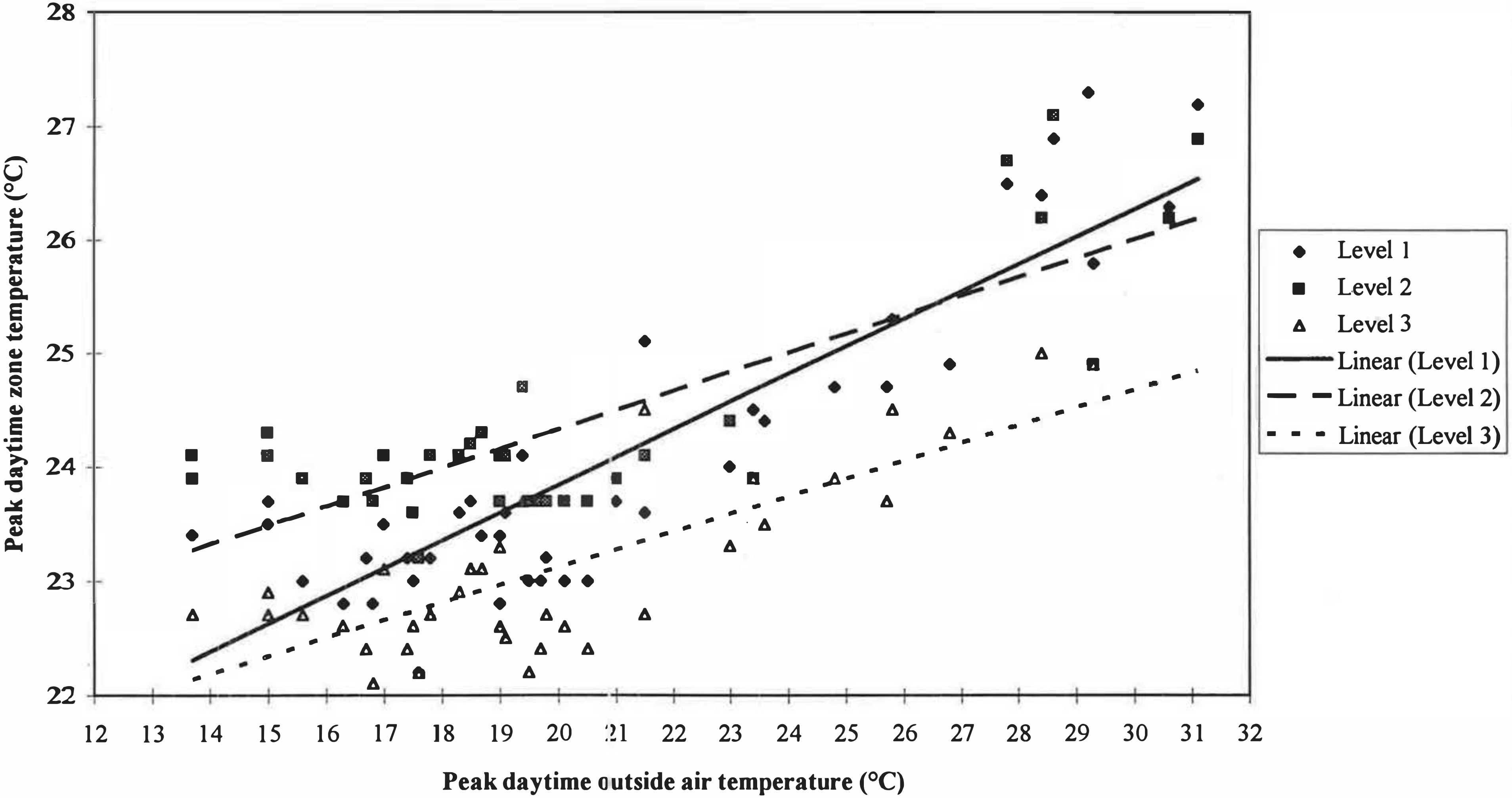


Figure A5. 9

POWERGEN BUILDING- VARIATION OF PEAK DAYTIME NE ZONE TEMPERATURE WITH OUTSIDE TEMPERATURE

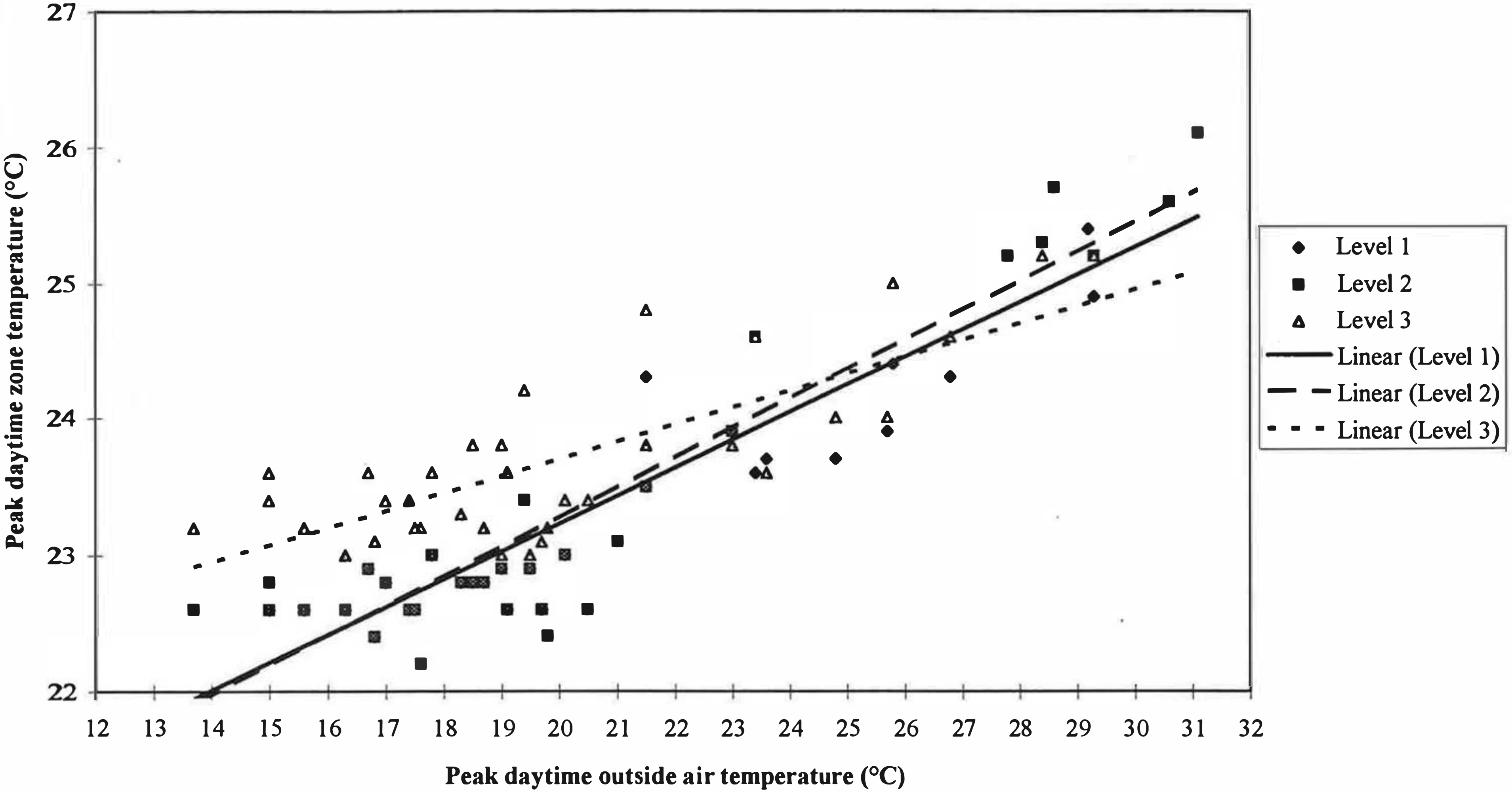


Figure A5. 10

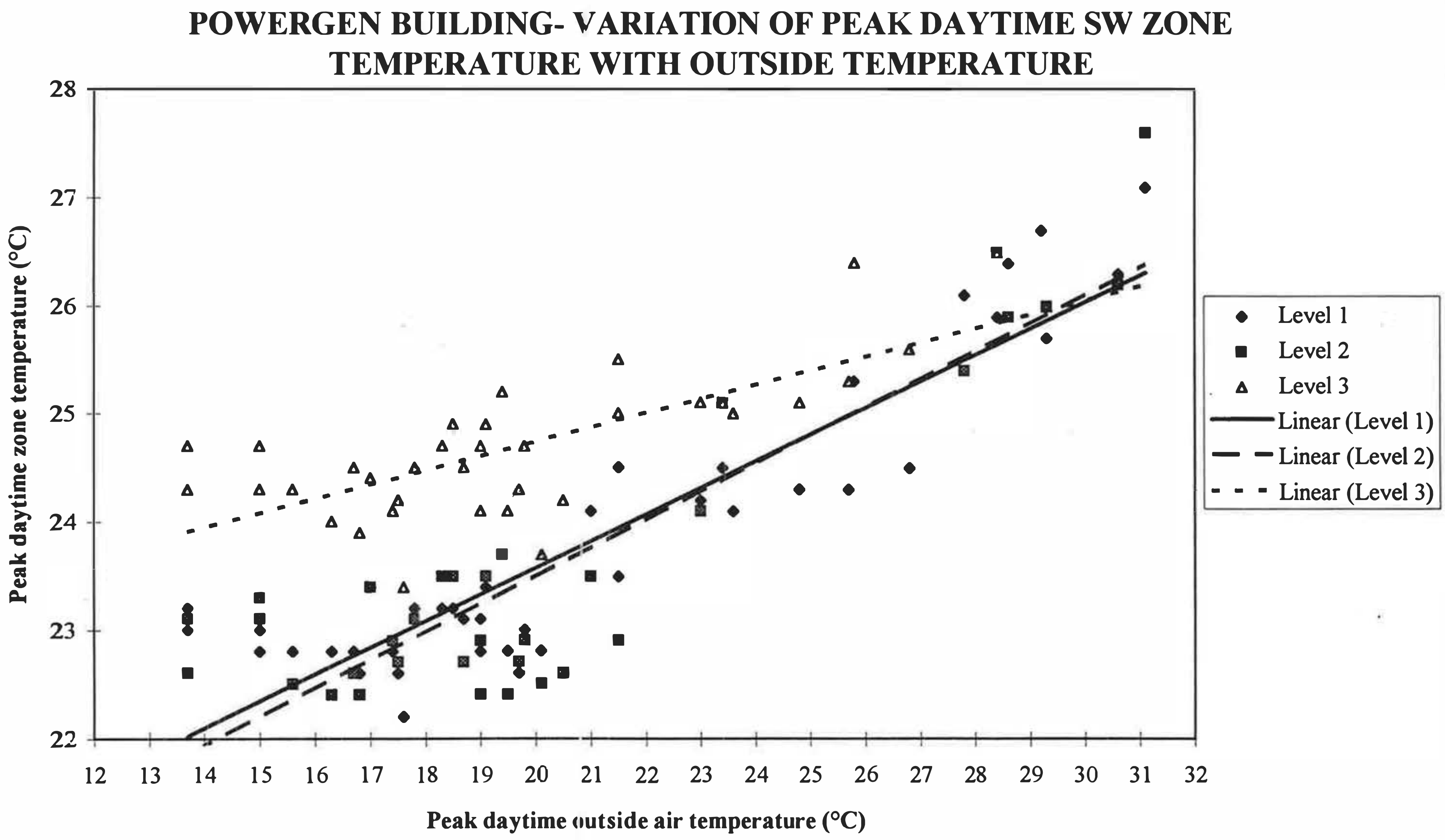
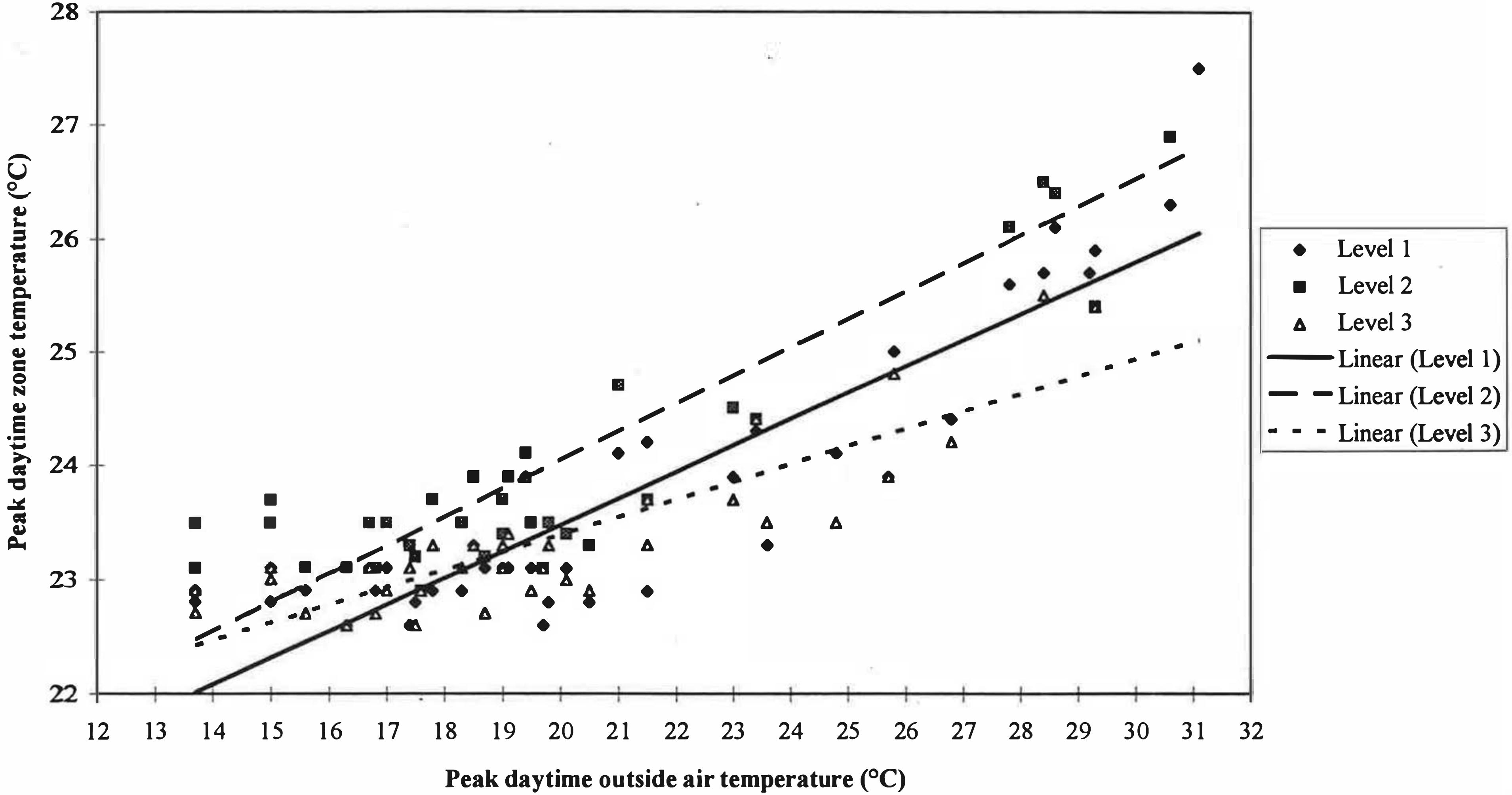

POWERGEN BUILDING- VARIATION OF PEAK DAYTIME SW ZONE TEMPERATURE WITH OUTSIDE TEMPERATURE
Peak daytime zone temperature (°C)
28
27
26
25
24
23
22
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
Peak daytime outside air temperature (°C)
Level 1
Level 2
Level 3
Linear (Level 1)
Linear (Level 2)
Linear (Level 3)

Figure A5. 11

POWERGEN BUILDING- VARIATION OF PEAK DAYTIME SE ZONE TEMPERATURE WITH OUTSIDE TEMPERATURE



POWERGEN BUILDING- CORRELATION TESTS (WEEKDAY DATA JULY-SEPT)

Figure A5. 12

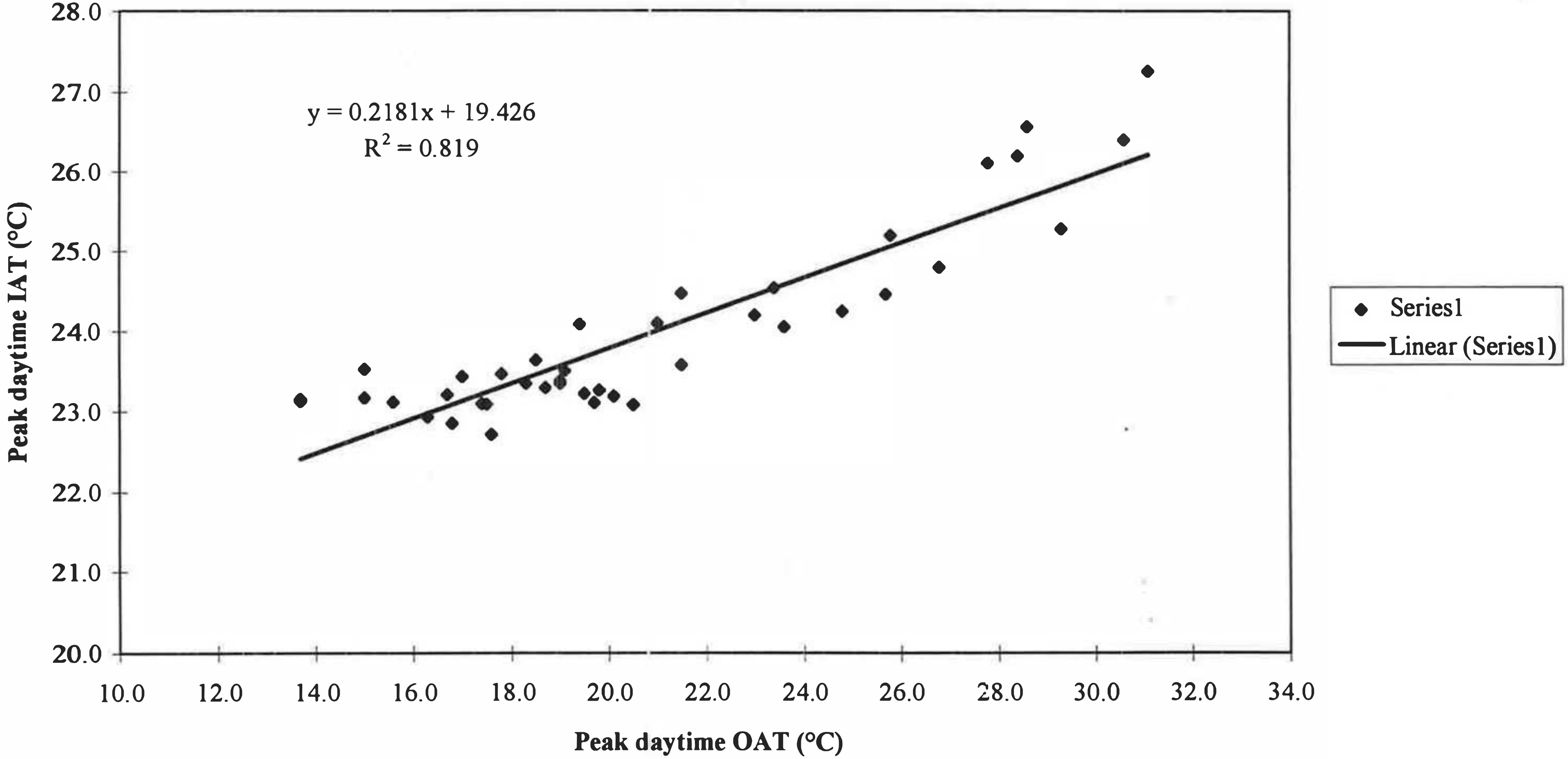


Table A5.6 - PowerGen regression analysis

1 Maximum zone temperature (weekday occupied period July-September)

	R^2	
NW grnd to NW other floors	0.945	T = 8.455 + 0.7621 Tg - 1.1462F
NE grnd to NE other floors	0.924	T = 0.600 + 0.9339 Tg + 0.4876F
SW grnd to SW other floors	0.923	T = -1.285 + 0.9373 Tg + 1.341F
SE grnd to SE other floors	0.924	T = 3.283 + 0.924 Tg - 0.4976F

2 Night cool temperature drop (weekday occupied period July-September)

	R^2		
NW grnd to NW other floors	0.417	ΔT	= 0.6354 + 0.661 ΔTg - 0.299F
NE grnd to NE other floors	0.727	ΔT	= 0.1014 + 0.792 ΔTg - 0.041F
SW grnd to SW other floors	0.192	ΔT	= 0.3822 + 0.529 ΔTg - 0.073F
SE grnd to SE other floors	0.297	ΔT	= 0.6412 + 0.410 ΔTg - 0210F

T = temperature on a particular floor other than ground
Tg = temperature on the ground floor
F = floor number
ΔT = temperature drop on a particular floor other than ground (night cooling period)
ΔTg = ground floor temperature drop (night cooling period)

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- environmental issues.

For further details contact Marketing Services at BSRIA

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