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Detailed Monitoring of the Canning Crescent Centre, London

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Building Research Establishment Ltd

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Work Package 2: Performance of naturally ventilated buildings

Detailed Monitoring Report
Canning Crescent Centre (GB2)

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1. Introduction

The Canning Crescent Centre was monitored as part of the European NatVent™ project to provide a case study of the performance of a naturally ventilated building located in an urban area. It was chosen for investigation because it incorporates a specially designed natural ventilation strategy as a result of its location on a polluted high street in London where external air and noise pollution levels are perceived to be high. Traditionally, for buildings located in such areas mechanical ventilation is recommended in the belief that it can provide a 'cleaner' and a more consistent quality of air. However, studies (Morris (1985) and Kukadia et al (1996)) have shown that there is little distinction between the two ventilation strategies in providing adequate indoor air quality, in terms of externally generated pollutants.

The objective of this study was to determine the performance of the ventilation strategy in providing adequate indoor air quality for metabolism (removal of carbon dioxide) and thermal comfort all year round. Minimisation of the ingress of external pollution (in particular from vehicular traffic) into the internal environment was also an important consideration.

The monitoring protocol developed by the NatVent™ Consortium was used as a basis for the measurements. The following parameters were measured: air change rates, temperature, relative humidity, air velocity, carbon dioxide, carbon monoxide, nitrogen oxides and sulphur dioxide. The airflow through the room inlet grille and the ingress of traffic noise into the building were also studied. This report gives details of the measurements carried out together with results, conclusions and any recommendations for improvement of the ventilation strategy and its operation.

2. Description of the Building

The Canning Crescent Centre (Figures 1(a) and 1(b)), is a purpose built L-shaped community day care centre completed in 1994 at a cost of £1.3 million. Located on a busy high street in Wood Green, an urban area of London, it is built on two storeys and has a gross floor area of 1350 m^2. The building is a high thermal mass construction comprising a steel frame with exposed brick walls and a concrete ground floor ceiling. It contains cellular office spaces all branching off from a central corridor. The occupancy within the offices is in general variable and of an intermittent nature.

The south west side of the building, on which the therapy and interview rooms are located, (Figure 2) faces the busy high street (Figure 1a) and pedestrian area where air pollution and noise levels are perceived to be high. The north east side of the building backs onto an enclosed garden courtyard, which also serves as the Centre's car park (Figure 1b).

Ventilation for the building is provided purely by natural means and the strategy is described later. Heating is provided by a natural gas heating system via thermostatically controlled water filled radiators.

3. Ventilation philosophy

The design of the building and its ventilation strategy was based on

- a relatively low budget
- the need to protect patient confidentiality by preventing pedestrians overhearing sensitive conversations from rooms situated on the busy high street and

- the need to prevent the intrusion of external noise and air pollution from the busy high street.

Due to the budget restrictions no provision had been made for mechanical ventilation or air-conditioning in the building. However, the natural ventilation strategy needed to be such as to provide maximum ventilation rates during the summer, especially at night, to cool down the thermal mass. In the winter, it needed to supply optimum ventilation rates required for occupants and their activities and to restrict heat losses and hence energy requirements, while at the same time ensuring adequate indoor air quality.

4. Ventilation Strategy

Taking the above into consideration, a natural ventilation strategy (Figure 3) was developed using diaphragm cross walls to provide a series of individual chimneys which allow air to be drawn through the building assisted by wind and/or buoyancy forces according to the prevailing weather conditions.

Ventilation air supply: Fresh air for the building comes exclusively from the rear courtyard side where air pollution and noise levels are believed to be low because they are less likely to be affected by the traffic on the busy high street. Air for rooms facing this rear courtyard is purely via trickle ventilators located in the window frames and openable windows (Figure **4**). Air for the offices on the high street side of the building is supplied through openings (Figure 5) in the external courtyard facing wall and is ducted through the footings of the building to low level wooden lattice supply grilles (air inlets) in each office (Figure 6). Window opening along the front of the building facing the high street is possible but discouraged.

Ventilation air extract: Each room is serviced, via a high-level wooden extract grille (Figure 4 and 6), by its own exhaust stack, the structure of which is shown in Figure 7. Adjustable airflow dampers in the stacks control the air change rate in each room. In general, the dampers are controlled centrally and are set to a fully open position in the summer to aid cooling and an almost closed position in the winter to provide reduced flow rates sufficient to maintain optimum indoor air quality while minimising energy loss. The central control switch is operated manually which in turn controls the dampers electrically.

A manual override switch is installed in each room to enable the damper for that room to be opened for a period of one hour whenever required. This increases the air change rate in that room to remove any excess heat. Aerofoils located above each stack opening are designed to introduce a ‘negative pressure region’, irrespective of wind direction above the stack to enhance the extraction of ‘stale’ air from the building.

4.1 Summer ventilation strategy

During the summer, cooling is achieved by utilising the thermal mass of the building and maintaining high rates of ventilation to cool the mass, especially at night. The dampers in each ventilation stack are set in the open position to maximise airflow in the stack and roof lights open up at night to provide cooling. It is important that for correct summer performance, the dampers in each ventilation stack are maintained in the open position to maximise airflow rate. Extract flow is further enhanced by the use of south and west facing double glazed panels, which form the topmost segment of the stacks. These were designed with the intention of absorbing solar energy to heat the out flowing air thus generating increased buoyancy (stack) pressure and air change rate to cool the building.

4.2 Winter ventilation strategy

During the winter, a natural gas heating system is used to provide heat via thermostatically controlled water filled radiators. The reduced need for ducting and other services, which would normally be required for mechanical ventilation, allow for more of the concrete and brickwork to be exposed thereby increasing the thermal capacity of the structure. It was expected that this would lead to lower energy requirements during the heating season by releasing the heat when required. Ventilation is maintained at a sufficient level to meet occupant needs by ensuring that the dampers are set in an almost closed position to provide background ventilation. Ventilation dampers can be opened by the occupants, to secure increased rates of air change for occupant comfort in individual rooms, if necessary.

4.3 Ventilation design methods

No evidence could be found as to the calculation methods or computer programs used for the design of the ventilation system. However, using simple mass balance calculations from buoyancy and wind driven flow suggests that the system was designed to enable the flow rates required to be delivered (see sections 5.3 and 6.3).

5. Measurements

The main objective of the present study was to determine the effectiveness of the natural ventilation strategy in both the winter and the summer. This was achieved by carrying out measurements of air change rates, temperatures, relative humidity and carbon dioxide in the winter and the summer. External and internal measurements of externally generated pollutants such as carbon monoxide and noise were also carried out in the winter. Local air velocities in one of the rooms (Office 3) were also measured.

Table 1 gives details of the parameters that were measured together with the instruments and methods used, measurement interval and averaging period over which the samples were recorded. Ventilation rates in the offices were measured by using active tracer gas techniques. The tracer gas sulphur hexafluoride was used and the constant concentration technique with a target concentration of 5 ppm applied. The location of the dosers and samplers for rooms 3 and 4 on the first floor is given in Figure 8. Rooms 1 and 2 are directly below rooms 3 and 4. The ventilation rates were analysed by a multi-point sampler and doser unit Bruel and Kjaer 1303. A detailed description of the constant concentration technique is given by Charlesworth (1987).

5.1 Winter measurements (March 1997)

Monitoring was carried out in four offices: two facing the busy high street and two facing the courtyard side (ground and first floor) at the south end of the building (Figure 8). Measurements of ventilation rates, air velocities, internal mean radiant temperature, external air temperature, relative humidity, carbon monoxide (CO) and carbon dioxide (CO_2) were carried out continuously over period of one week during March 1997. In addition, temperature and humidity measurements were carried out in the corridor and in the courtyard outside office 2.

External measurements of CO and CO_2 were also taken at a single point at a height of 4m immediately outside office 3 on the high street. For practical reasons, measurements of noise were carried out only in the two first floor offices, 3 and 4, and measurements of nitrogen oxides (NO_x) and sulphur dioxide (SO_2) in a seminar room in another part of the building.

Table 1. Summary of instruments and methods used to measure internal and external parameters

Parameter	Instrument used	Method	Averaging Period	Measurement interval
Ventilation rate	Bruel & Kjaer 1302 and 1303	Photo-acoustic	1 minute	Continuous
Air velocity	Solomat 2000	Hot wire anemometer	-	Continuous
Carbon dioxide	Bruel & Kjaer 1302 and 1303	Photo-acoustic	1 minute	30 minutes
Humidity	Bruel & Kjaer 1302 and 1303	Photo-acoustic	1 minute	30 minutes
Carbon monoxide	Bruel & Kjaer 1302 and 1303	Photo-acoustic	1 minute	30 minutes
Nitrogen dioxide	ThermoUnicam. 42c	Chemiluminescence	30 second	30 minutes
Nitrogen oxide	ThermoUnicam. 42c	Chemiluminescence	30 second	30 minutes
Sulphur dioxide	ThermoUnicam. 43c	Pulsed Fluorescence	30 second	30 minutes
Temperature	Thermistor	-	Spot	30 minutes
Noise	Cirrus meter	-	1 hour	1 hour

5.2 Summer measurements (July 1997)

During the summer, ventilation rates, internal mean radiant temperature, external air temperature, humidity and carbon dioxide were monitored in the four offices mentioned above, the corridor and at a point outside office 2 in the courtyard. The measurements were carried out over a period of one week in July 1997.

5.3 Air flow measurements through the wooden inlet grille.

The air flow characteristic of a wooden lattice inlet grille, taken from one of the offices, was determined by carrying out measurements, in the laboratory, of the air flow through the grille against the pressure drop across it. The objective of this was to enable one to allow evaluation of the airflow through the grille to determine whether or not it was sufficient.

5.4 User questionnaires

A user questionnaire that had been developed as part of the NatVent™ programme was distributed to occupants in the building. The purpose of this was to gain an idea of occupants' perceptions of how the building was performing throughout the year, the variation of occupancy in the rooms that were monitored and also the occupant window opening behaviour. Face to face interviews were also carried out.

6. Results

In general, ventilation rates, temperatures and relative humidity for office 3 (first floor, facing the high street) have been reported here. These results give a very good representation of the results obtained in all the locations where measurements were carried out. For the pollution measurements, the results obtained in all the four offices and externally to the building are reported.

6.1 Winter monitoring results

The objective of the winter monitoring was to determine the effectiveness of the ventilation strategy in providing adequate ventilation for the occupants while at the same time removing metabolic CO_2. Figure 9 shows the air change rates, temperatures, relative humidity and carbon dioxide results that were obtained for the winter period. Air change rates of about 1-2 air changes per hour were obtained. This is equivalent to ventilation rates in the offices of between 8–20 ls^{-1} per person and is in reasonable agreement with an average value of 10 ls^{-1} per person which is recommended in the UK.

Figure 9 also shows that the mean internal daily temperatures varied between 17 - 25°C and at night between 16-19°C. This is slightly higher than an average winter temperature internally of 18°C for which the offices in the building were designed. Relative humidity levels varied between about 40-60% in the offices monitored which is in agreement with general levels quoted for the UK.

From the results of the CO_2 and temperature measurements, it is apparent that the air change rates that were reached during the monitoring period were successful in removing metabolic CO_2 from the offices. CO_2 levels were kept below 1000 ppm and once the offices were left unoccupied at the end of the day, levels rapidly reduced to background levels of less than 400 ppm as expected. In general, the occupancy in each room was variable on each day and this is shown by the varying degree of CO_2 levels. Furthermore, temperatures in the offices were on average kept at values for which they were designed.

For practical reasons, air velocities were measured in office 3 only at a height of 1.1m ('seated head height'). Average values of about 0.1 ms^{-1} were obtained. This is in agreement with UK recommended values of between 0.1-0.25 ms^{-1}. It must be pointed out here that there were offices in other parts of the building where draughts from the stacks were being experienced. However, it was not possible to carry out measurements of air velocities, because of practical reasons in gaining access to these offices.

6.2 Summer monitoring results

The main objective of the summer measurements was to determine the effectiveness of the ventilation strategy in providing adequate thermal comfort and preventing overheating in the building. Figure 10 shows the results from the summer (July 1997) monitoring period. Internal temperatures varied between about 16°C during the night to 27.5°C during the day. These are higher than corresponding external temperatures and imply that adequate cooling was not being achieved.

From Figure 10 it can be seen that the summer air change rates varied on average around 2-3 air changes per hour. This is lower than design values (see section 6.3) and that necessary to achieve sufficient levels of cooling. Investigations revealed that control of the central damper was uncertain since it was not clearly marked as ‘open’ or ‘closed’ but as ‘0’ (for open) to 100% (for fully closed). Access to the main damper control room was restricted and it was not known what the real settings were. The suspicion remained that the damper had not been opened after the winter period. This decreased the opportunity for the building to be cooled effectively during the night as intended and, in turn, resulted in heat retention and relatively high temperatures. The short periods (1 hour) of high air change rates shown in Figure 10 indicate the times when the dampers in the office were opened manually by operating the override switch to reduce the high temperatures in the offices. Simultaneous study of the air change rate and temperature at these points shows that as the air change rate increased, the temperature began to decrease.

Air change rates were sufficient in removing metabolic CO_2 during office hours and keeping levels within a value of 1000 ppm. During unoccupied periods CO_2 levels decreased rapidly to values less than 400 ppm. Again, the occupancy in each room was variable on each day and this is shown by the varying degree of CO_2 levels.

Relative humidity levels varied between 40% to 67% over the monitoring period, which are in agreement with values quoted for the UK.

6.3 Results of air flow through grille

The results of the air flow measurements through the inlet grille gave a value for the discharge coefficient of 0.8. Using this value for subsequent calculations gave a theoretical value for the air change rate of about 8 ach. This is higher than that measured as part of the monitoring and does not take account of any pressure losses within the stack or any obstruction created by the dampers not operating correctly. This, together with the fact that the dampers had been left in the ‘closed’ position during the summer may be the reason for the low air change rates. Furthermore, there appeared to be no correlation between the size of the inlet grille used for each of the rooms in the building and the size of the room. For example, in some cases, there were very large rooms with very small inlet grilles and in other cases, very small rooms with large inlet grilles. This raised the doubt that the inlet grilles may not have been properly sized for these rooms, although the rooms that were monitored appeared to have adequately sized inlet grilles.

6.4 Indoor air quality

The final objective in the monitoring of the Canning Crescent Centre was to determine the effectiveness of the ventilation strategy in minimising the ingress of external pollutants while at the same time providing adequate ventilation to the occupants of the building. Measurements of CO, NO_x and SO_2 were carried out during the winter monitoring period (March 1997).

Carbon monoxide (CO)

Figures 11(a-e) show the internal and external (measured at one point on the roadside) concentrations of CO within the four offices monitored. As expected, all the offices show very similar contaminant levels because of the common air intake from the courtyard side. Low external CO levels measured over the weekend period indicate little vehicular activity in comparison with the working week. During certain periods of the working week, relatively high CO concentration peaks occurred externally reaching levels of about **12** ppm. Comparison of the contaminant levels measured inside the offices with external measurements taken at a single point on the roadside indicate that these high contaminant peaks were reduced considerably and did not occur inside any of the offices monitored. Even office 3, outside which the external measurements were carried out, does not show these peaks, indicating little pollutant infiltration through the fabric of the building.

Mean values of about 0.3 ppm inside the building were obtained. This are well within recommended air quality guidelines as given in Table 2.

Oxides of nitrogen (NO_x)

Due to practical constraints only internal measurements of nitrogen dioxide (NO_2) and nitric oxide (NO) could be made and it is not therefore possible to make any comparison with concurrent external concentrations. However, comparison of hourly concentration means of these pollutants with standard air quality guidelines (Table 2) shows that levels were low in the building. In general, NO_2 is a product of a variety of combustion processes including traffic. However, there were no other known sources of NO_2 in the area apart from the road traffic on the High Street. It can therefore be assumed that the low levels measured in the building indicate that air intake from the courtyard side away from the road traffic gave acceptable concentrations.

Table 2. Measured mean concentrations over the monitoring period inside the offices compared with recommended air quality guidelines.

Measured gas	Measured mean concentrations	Recommended air quality guidelines		
		Expert Panel on Air Quality Standards	World Health Organisation	European Community
CO (ppm)	0.3^1	10^1	10^1	-
CO_2 (ppm)	400	-	-	-
NO (ppb)	22^2	-	-	-
NO_2 (ppb)	43^2	150^2	80^1	105^1
SO_2 (ppb)	2^2	100^3	122^2	94^2

1 8-hour mean
2 1-hour mean
3 15-min mean

Sulphur dioxide (SO_2)

Internal levels of SO_2 (Table 2) were within recommended air quality guidelines. This is as expected, since in general, external trends of SO_2 concentrations in London show that background levels have decreased by almost 60% since 1970 and by 45% since 1980. This is largely attributable to the relocation of power stations away from city and urban areas and the growing use of natural gas and lower sulphur content fuel oils in combustion plant.

6.5 Noise Levels

Noise measurements gave average external noise levels of 75 dBA. It was found that, in general, average noise levels were lower in office 4 (courtyard side) at 40 dBA than in office 3 (roadside) at 50 dBA and higher during peak periods of traffic. These are in reasonable agreement with acceptable values for the UK of about 45-50 dBA for offices (BS8233, 1987).

6.6 Evaluation of occupant reaction

The opinions of the occupants of the building were obtained through questionnaire results and interviews. These revealed that during the winter, occupants frequently complained about cold draughts through the high-level extract grilles. There was also evidence that occupants sealed the grilles with plastic film and cardboard to reduce the draughts (Figure 12).

During the summer there were many complaints from the building occupants about excessive over heating especially in the offices facing the courtyard. There was also the feeling that, in some rooms, the system did not seem to respond quickly enough when occupants operated the manual over-ride switch in the room intended to increase the air change rate when required.

7. Discussion

An evaluation of the design calculations of the flow rates through the inlet grille indicated that, technically, the provision of both winter (metabolic) and summer (cooling) ventilation needs was possible. However, the control system was largely inadequate and operated incorrectly due to misunderstandings and lack of knowledge.

7.1 Areas of concern

Specific areas of concern include:

- ***Central stack damper control:*** This was intended to enable all air flow dampers throughout the building to be set to the 'open' position in the summer and 'closed' in the winter. Instead of being marked 'Summer' or 'open' and 'Winter' or 'closed' it was marked '0' (for fully open) and 100% (for fully closed). This misleading indicator resulted in the wrong setting being applied, during the summer. The winter setting was thought to have been changed as required to the summer setting. However, later investigations indicated that, in fact, it hadn't been changed to the correct setting, hence one reason for the low air change rates and subsequent overheating in the summer.

- ***Inadequate maintenance:*** There seemed to be a lack of response from some of the individual room over-ride controls. This may have been due to a lack of adequate maintenance of the dampers in the extract stacks so that they 'stuck' in the closed position and did not open up when the individual room controls were applied. They may also have been some dampers which were 'stuck' in the open position such that cold down draughts were being experienced. Easy access to the dampers for maintenance purposes proved to be difficult since climbing onto the roof of the building proved a safety hazard.

- ***Leaky air flow dampers**:* Either because the air exhaust dampers were leaky or inadvertently stuck' in the open position as mentioned above, there were cold draughts of outdoor air coming from the high level 'extract' grilles. This caused serious cold down draughts in the winter and resulted in the users covering these grilles with either plastic film or cardboard sheeting. In addition, electrical heaters were used as auxiliary heat sources. In effect, the airflow in the stacks was operating in reverse causing the cold down draughts.

- ***High pressure losses:*** Based on the air flow rates through the lattice wooden grille and an evaluation of the design calculations showed that the sizing of the system was probably adequate for provision of ventilation needs. However, measurements gave low air change rates. It Is possible that in addition to the reasons given above, the dampers in the stacks were giving high pressure losses resulting in the air change rates being reduced compared with the design values. It is possible that account had not been taken of all the pressure losses in the system when carrying out the design calculations. In addition to this it seemed that there was no correlation between the size of a room and the size of its inlet and extract grilles.

7.2 Suggested Improvements

It is suggested that the above problems can be overcome by:

- Removing the air flow dampers in each of the exhaust chimneys and replacing the inlet and outlet grilles in each room by conventional slide control grilles. This would help to reduce any pressure losses in the stacks, increase airflow rates and hence reduce summer overheating. It would also enable users to control their own environment according to their own needs.

- Should a damper be retained, the settings should be clearly marked 'open' and 'closed' or 'summer' and 'winter' to avoid confusion and so that the correct setting can be applied.

- Installation of external solar shading would help in reducing solar heat gains thereby helping to further reduce summer overheating.

- Reverse flow can be common in stack design systems if air in the stack corresponds to the outdoor rather than the indoor conditions (for example during a cold night or over a weekend). To overcome this problem a small low energy priming' fan should be considered (e.g. in place of the 'damper') to promote the correct flow direction of air. A simple control system could sense a reverse flow condition and operate the 'priming' fan until the correct operational condition has been achieved after which the system would be self driving. A non-return valve installed in the stacks would also be beneficial.

- Adequate training of the occupants to enable them to operate their building and various controls properly is essential in ensuring that the building operates efficiently.

In terms of ingress of external pollution into the building, some care had been taken in the architectural design to ensure that the air inlets were not located in the vicinity of sources of pollution. The air inlets were sited at the back of the building away from the busy high street. Although the garden courtyard had been converted into a car park by the users, measurements showed that the indoor air quality was not adversely affected. This may have been because the air inlets were sited at quite a high level on the external wall, well above the car exhaust level. Also, during the period of the monitoring, the car park was fully occupied during the working day. However, it is believed that no cars had been left running to have had any major adverse effect on the indoor air quality in the building. Despite this it must be noted that care must be taken to ensure that, in any design, air inlets are located well away from contaminant sources.

8. Conclusions

Finally the above measurements and an evaluation of the design calculations showed that the sizing of the system was probably adequate for the provision of both winter (air quality) and summer (cooling) ventilation needs. However, it appeared that not all pressure drops had been taken into account, which may have contributed to the low air change rates. It is important that they are taken account of when designing the ventilation system. Furthermore, the control system was largely inadequate and/or was operated incorrectly. This seemed to adversely affect the performance of the ventilation system. It is therefore important to design buildings with the end users in mind and that the users and maintenance managers for the building are fully informed of the operation modes of the building and also that maintenance on all aspects of a building is carried out on a regular basis.

9. Acknowledgements

The research team at BRE would like to express their gratitude to the owners and occupants of the Canning Crescent Centre, in particular N Morris, M Osbourne and M Strachan as well as I Logan and J Grace for assisting with the project. Thanks are also extended to Dr Martin Liddament for his advice and assistance during the course of this work.

10. Architect and Building Services

The Architects for the building were MacCormac, Jamieson, Prichard and the Building Services Engineers were Atelier One, both from the UK.

11. References

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Figure 1(a). View of the Canning Crescent Centre from the Busy High Street.

Figure 1(b). View of the Canning Crescent Centre from the Courtyard Side.

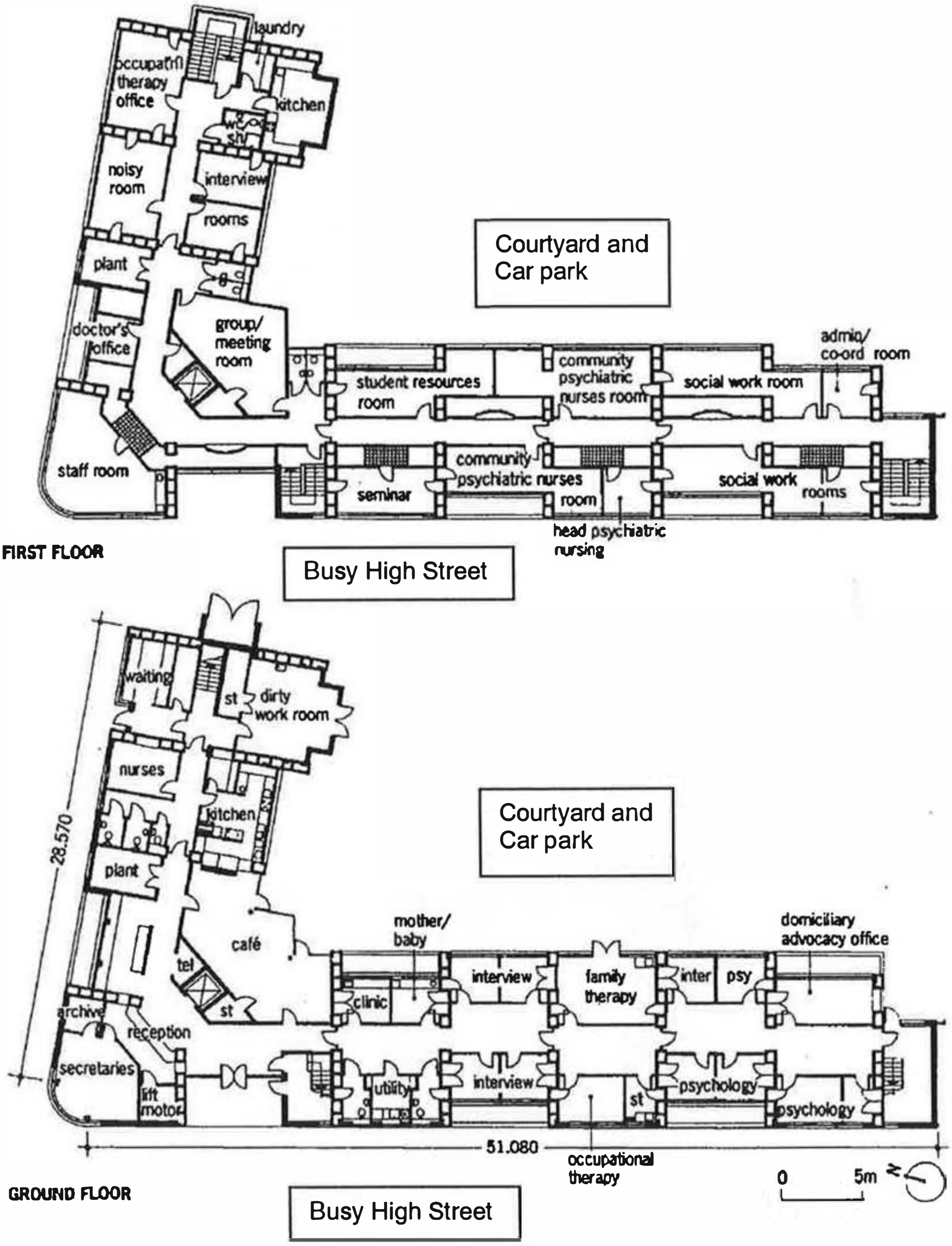

Figure 2. Plan view of the ground and first floors at the Canning Crescent Centre

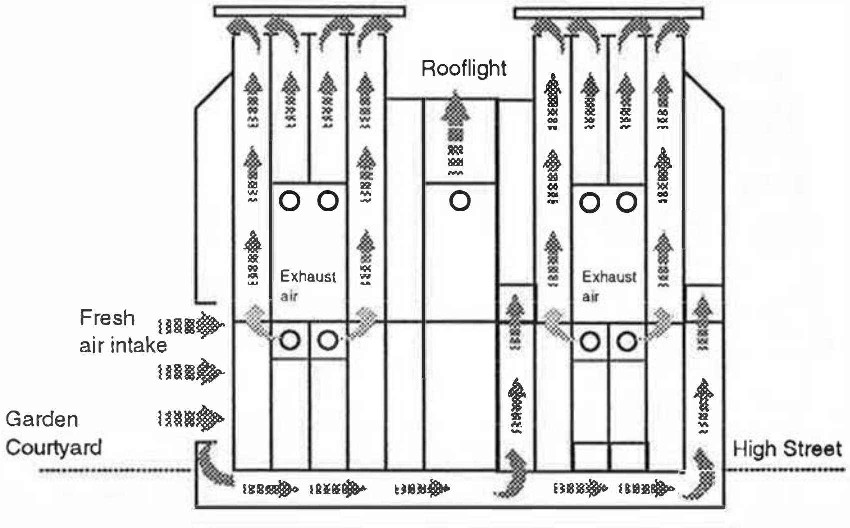

Figure 3. Natural Ventilation Strategy

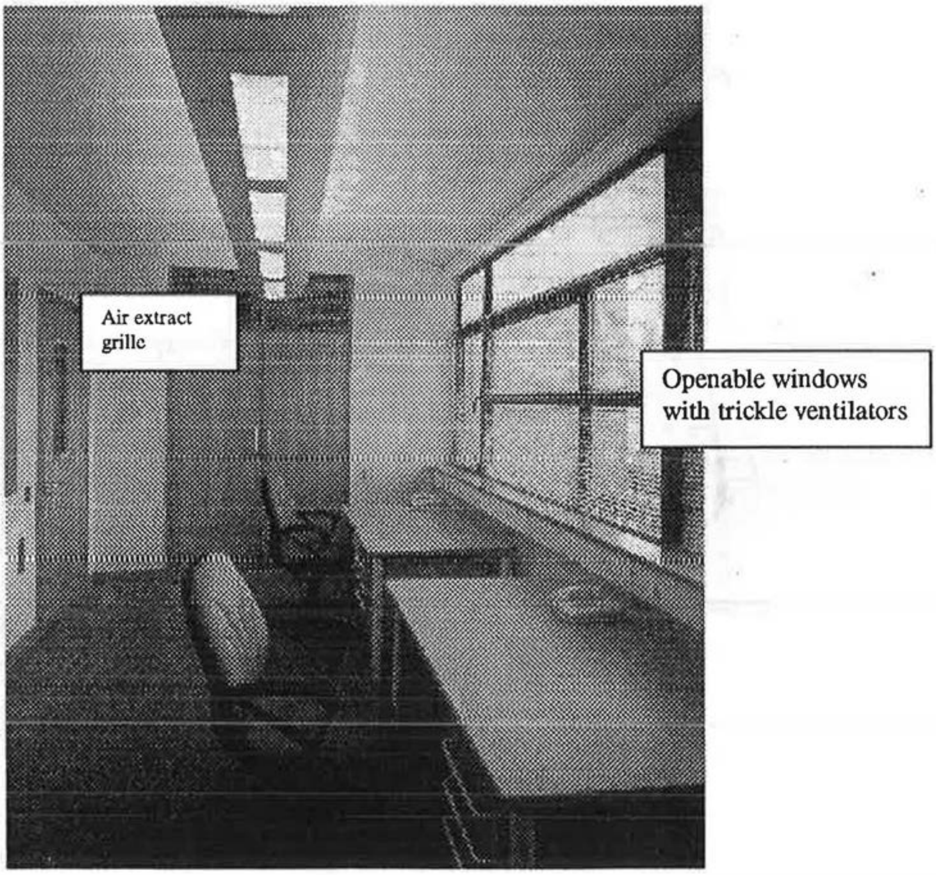

Figure 4. Courtyard facing office ventilated by openable windows and trickle ventilators

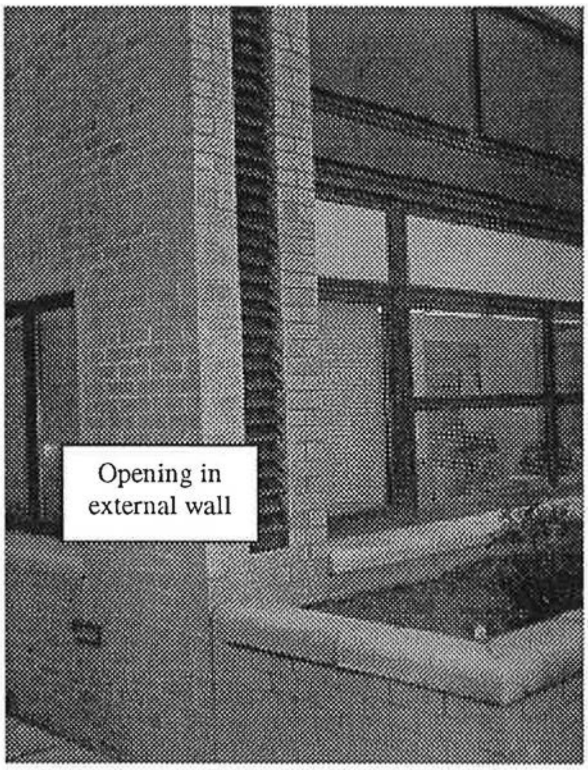

Figure 5. Air Inlet Openings on Walls Facing the Courtyard.

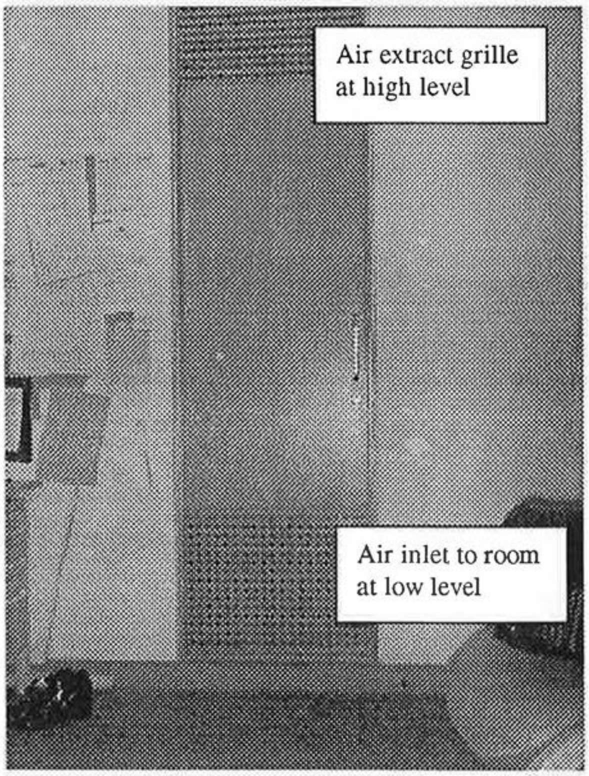

Figure 6. Wooden Air Supply and Exhaust Grilles.

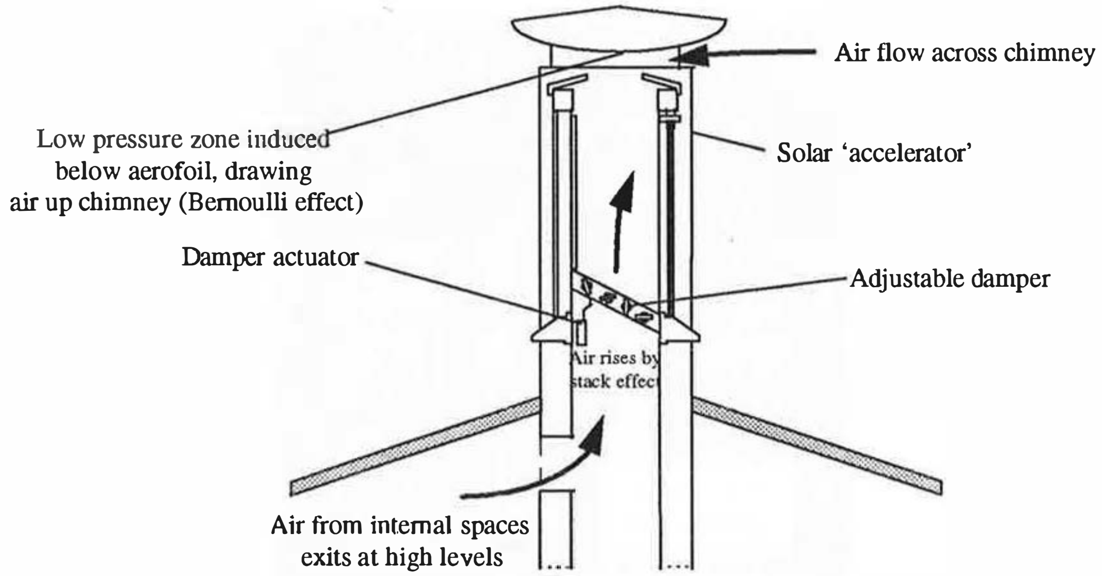

Figure 7. Structure of the Exhaust Stack

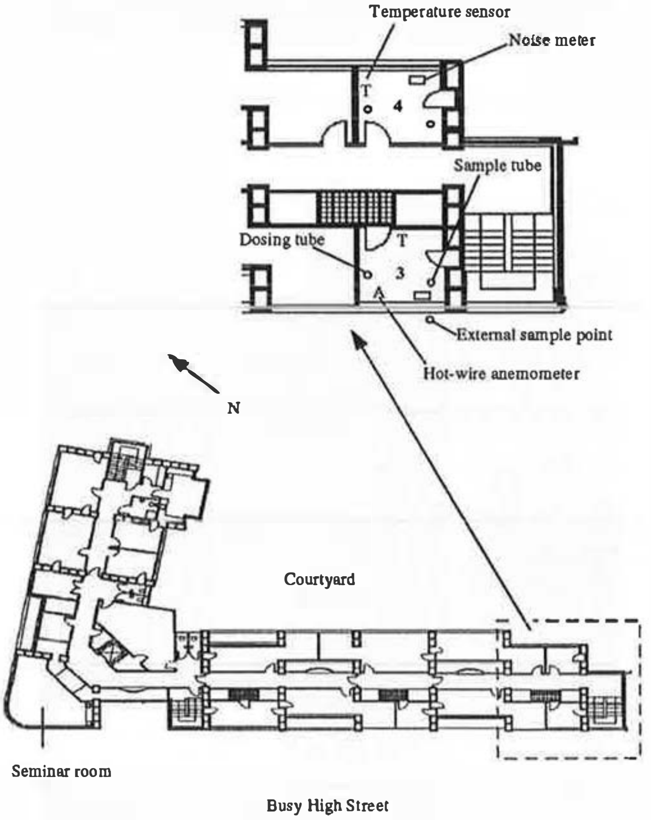

Figure 8. Location of sampling points in offices 3 and 4 on the first floor
(Offices 1 and 2 are directly below on the ground floor)

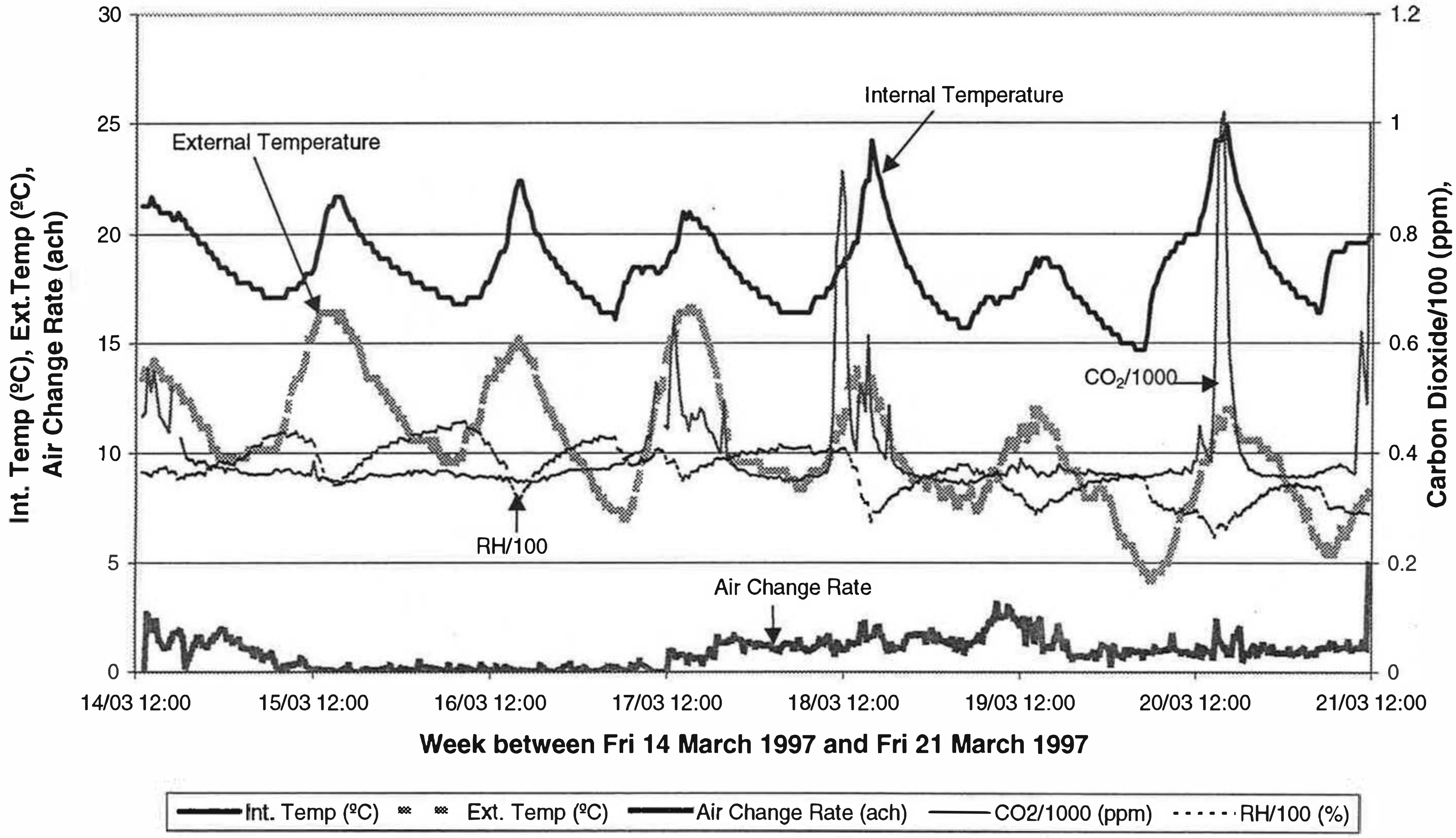

Figure 9. Winter Monitoring Results for the Canning Crescent Centre

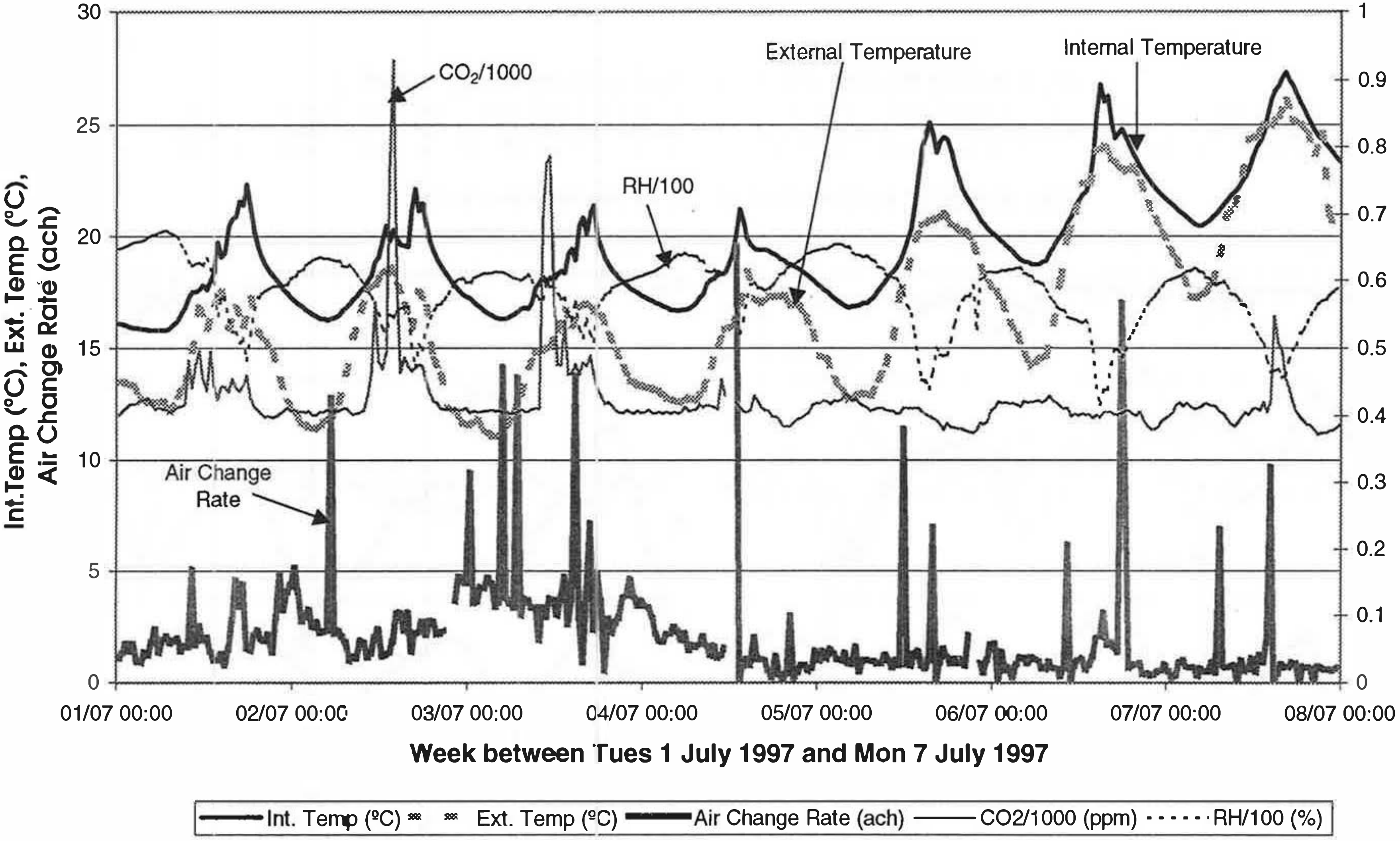

Figure 10. Summer Monitoring Results for the Canning Crescent Centre

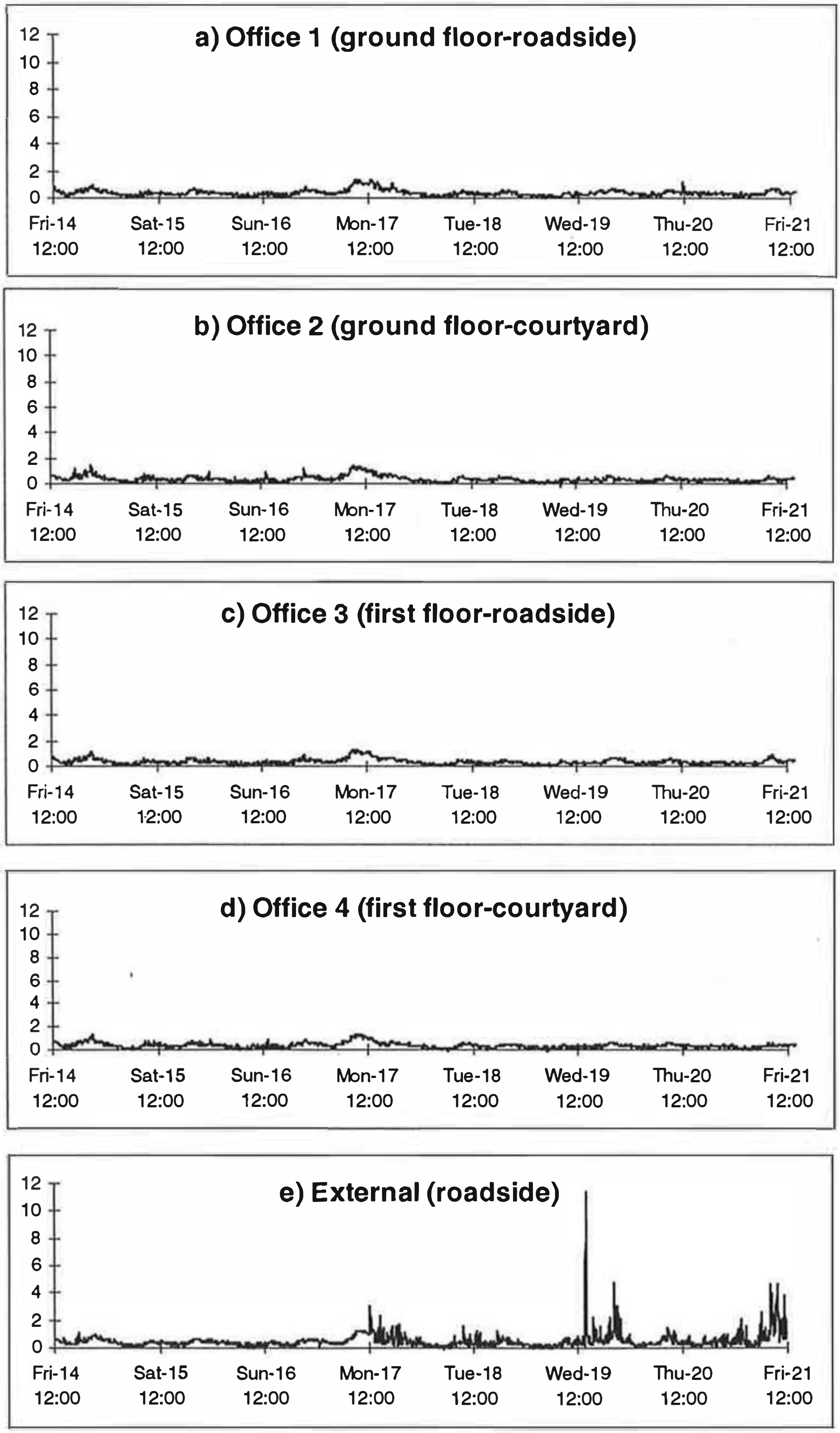

Figure 11(a-e). Carbon monoxide concentrations (ppm) vs Time of day (14-21 March 1997)

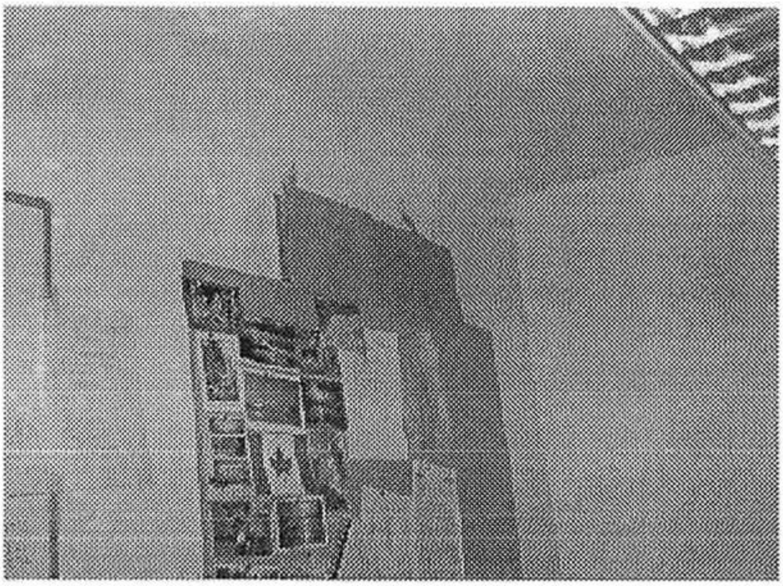

Figure 12. Extract grille at high level covered with card to prevent draughts