MONITORING AND EVALUATION REPORT

NELSON CITY COUNCIL LIBRARY
ENERGY EFFICIENT DESIGN

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for

Energy and Resources Division,
Ministry of Commerce

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1 DIRECTORY OF PARTIES INVOLVED

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2 EXECUTIVE SUMMARY

The Elma Turner Library opened on 28 February 1990. In the centre of Nelson, the design of the single-storey 1800 m^2 library, a converted car sales building, was helped by intensive daylight and thermal performance analysis. Although the building was to be naturally ventilated, the analysis suggested it would not overheat in summer.

The energy efficient features of the building include clerestory windows; external sunshading serving also to reflect daylight deep into the building; a central courtyard to let natural light and fresh air deep into the building; electrically operated high-level windows and manually operated wall-mounted low-level louvres for controlled and effective natural ventilation; electric ceiling fans to help air movement; higher levels of thermal insulation than would be normally used in a commercial building; and electronic controlled ceiling-mounted radiant heating panels.

From 1 April 1990 to 1 May 1991, the operation of the energy systems was monitored with temperature and electricity meter readings recorded by library staff each working day at 9 a.m. Detailed temperature and energy records were collected by computer link for the period March to May 1991. Photographs of daylight and sunlight penetration were taken once a month. Physical measurements of cloudy sky daylight conditions were made on a 2 m grid over the whole of the main floor area. A steady-state heating energy use and cool down temperature test were conducted on the weekend of 27 July 1990. Air change rate measurements were taken from 11-23 February 1991 using a passive sampling system.

Monitoring showed the decision to use natural ventilation combined with passive solar control devices was vindicated as the summer temperature measurements showed the internal daily maximum exceeded 23°C for less than 5% of the time. In winter, only one area did not maintain an inside-outside temperature-difference of 15°C, but remedial action is simple and low cost.

Within the normally expected limits, the thermal simulation and the actual energy use figures agree. The weekly, monthly and yearly figures demonstrate the accuracy (if not the precision) of such simulation programs: they predict trends well but absolute numbers less well. Where the mathematical model (perhaps the description of the building itself) is apparently less reliable is in predicting hour-by-hour temperature variations.

Measurements also confirmed that daylight provides the target light level for three-quarters of the working day across 25% of the public areas, and up to 60% of the public areas are daylit to the required level for 2 hours daily. While the lighting controls do not permit a simple response to exterior daylight, the actual 30 GJ energy use is a significant reduction compared to the expected 74 GJ.

The energy modelling work cost $19,000 with additional design and quantity surveying work of $5,000. This additional cost of $24,000 was recovered by the reduced net running and operating costs of $8,400, giving a payback of under 3 years.

Capital savings of $70,000 were made - nearly three times the additional cost of the energy design and support work. The savings include $50,000 in the form of air conditioning plant, and the reduction in load provided a further $20,000 capital saving as a new electricity sub-station was not required.

The total project (including fees, construction and fitout) cost approximately $1.5 million. The capital savings achieved by the investment in energy efficient design advice represent 5% of the total project cost.

3 INTRODUCTION

3.1 Elma Turner Library - A Brief History

The Nelson library has a long history. It started on board a ship coming out from England in about 1840. The few people who could read and owned books pooled them to give themselves some variety in their reading material. By 1842 the Nelson Institute had a building complete with library and reading room on Upper Trafalgar Street, with a second building erected on the Hardy Street corner site in 1860. Fire destroyed part of that building in 1906, but the rest remained in use as the Children's Library until 1989. The Nelson Institute Library and Museum was opened on the same site in 1912, continuing to offer a subscription library. The Nelson City Council took over the library in 1965. In 1972 the subscription system was dropped and the library joined the National Library Service. Over the next 19 years there was considerable debate over the library facilities with several sites being proposed and then dropped.[1]

Finally the central city site became available late in 1988, when a national car company merged its two Nelson sales yards. The huge barn of a building offered little street appeal, but was beside the Maitai River that skirts the central city and offered the council an opportunity to increase central city car parking. The river, once prone to flooding but now retained behind stopbanks, creates a very high water table on the site.

The single storey car sales building was in two parts - an older maintenance building, and the more modern display showroom and offices. Early in the design process, it was decided that the older building would be demolished, the oil sumps drained and filled, and replaced. The new "Elma Turner Library" (named after a long time advocate and worker for the new library) was opened on 28 February 1990. The final building is 1800 square metres in plan, approximately half new and half old, with a first floor consisting only of a staff cafeteria that has been retained and modernised. Figure 1 provides a floor plan of the final design.

[1] based on an article in the Nelson Evening Mail "Weekender" 25 February 1990

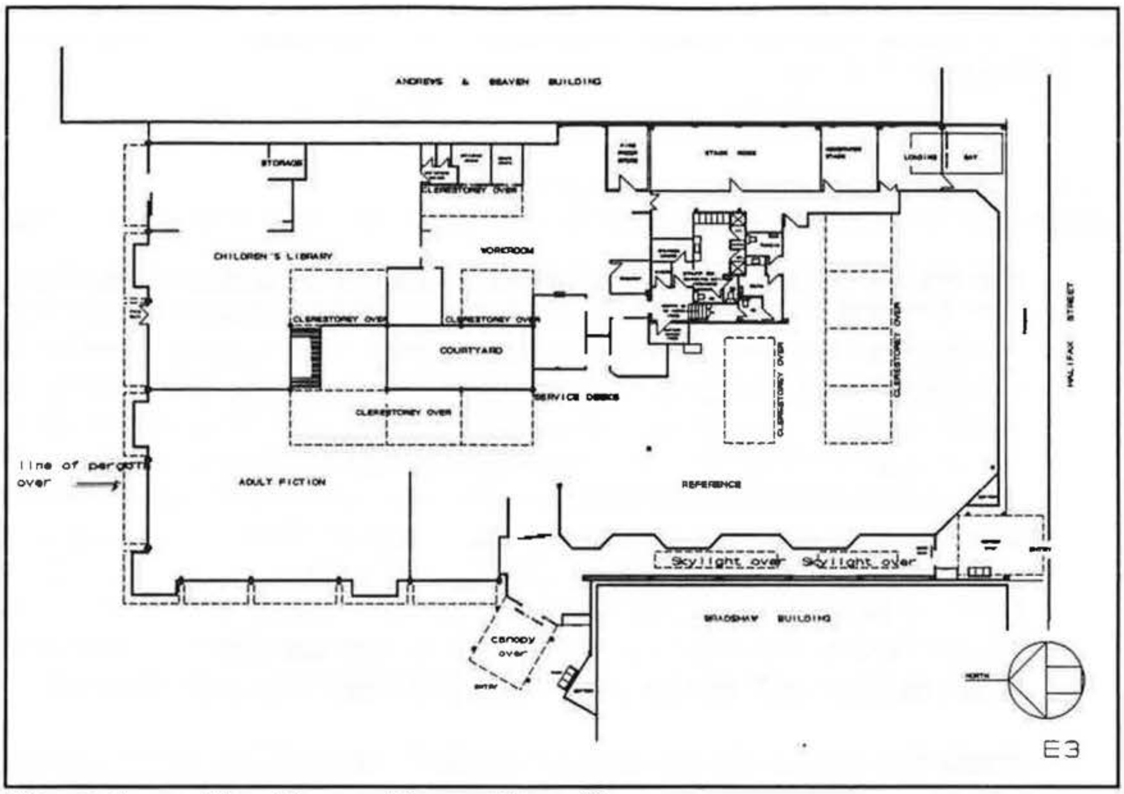

Figure 1 Elma Turner Library Floor Plan

The library holds approximately 105,000 volumes, requiring 3.8 km of shelving to meet present and future expansion plans. As well as lending books, the library offers facilities for the use of reference materials, study areas, children's library and play area plus the many backup services required to keep a library in operation. Of particular interest to librarians was the lack of a card based catalog - with the opening of the new building, the opportunity was taken to move fully onto an on-line computer system.

3.2 Design Requirements

The architects' (Upstream Design) design goals for the library were to reflect social aspects of the users with broad use of "pacific colours", fresh air and a high level of natural light.

The 40 page brief from the council was overwhelmingly concerned with the provision of space suitable for library activities involving books - mainly issues of storage. Requirements for the quality of the human environment - temperature and lighting were somewhat brief, but explicit:

Heating: The heating system should allow for a winter working temperature of 20°C with an outside minimum temperature of 5°C, for all public and staff areas. Three air changes per hour are recommended. Comfort conditions should be under automatic control, taking into account effects of heat input from windows, roof lighting etc. It is desired that a heat pump system be considered as one possibility. The system should avoid excessive heat to both the feet and the heads of occupants of the building.

Lighting: Electric lighting shall be designed to a standard of 400 Lux at working level of 750 mm above floor level, and shall be of a uniform intensity throughout public and staff areas. Daylighting shall be as uniform as possible throughout the building, avoiding the need for supplementary electric lighting under normal outside conditions. Methods of controlling daylight should be provided to control damage to book stock from direct sunlight.

In addition the electricity supply to the site was limited to a peak power demand of less than 160 kW, with a possibility of increasing to 200 kW by installing a new service main. Above this a large capital expenditure was required for the construction of a new substation.

3.3 Energy Efficient Features

In summary, energy efficient features used in the building included:

extensive use of clerestory windows to provide daylight throughout the building without night sky heat loss;

external shades for high summer sun that double as reflectors to enhance daylighting deep in the building;

central courtyard to let natural light and fresh air deep into the building, as well as providing an attractive focus for all users;

electrically operated high-level windows and manually operated wall-mounted low-level louvres for controlled and effective natural ventilation of a deep plan building;

electric ceiling fans to promote air movement and fresh air distribution throughout the entire building;

higher levels of thermal insulation than would be normal in a commercial building; and

ceiling-mounted radiant heating panels under optimiser control in the public areas and night-store heaters in offices.

3.4 Energy Consuming Equipment

The library is an 'all-electric' building. Appendix D provides details on the installed load as part of the description of the computer thermal modelling. This section provides a brief summary.

The building has approximately 6.7 kW of fluorescent lights installed, plus a number of ancillary and security lights. The majority of the light fittings are fluorescent triple tube fittings with low glare louvres, parabolic reflector and 36 W slim-line tubes.

Power using equipment (total of 3.7 kW) includes a photocopier; a computer based catalogue system with staff, issuing and public terminals; an electronic PABX system; and appliances in a small staff lunchroom.

Heating is provided by Panectric fibrous plaster radiant ceiling panels throughout the public areas. There are night-store heaters on an off-peak tariff located in staff offices. Total heating load is 151 kW.

3.5 Climate

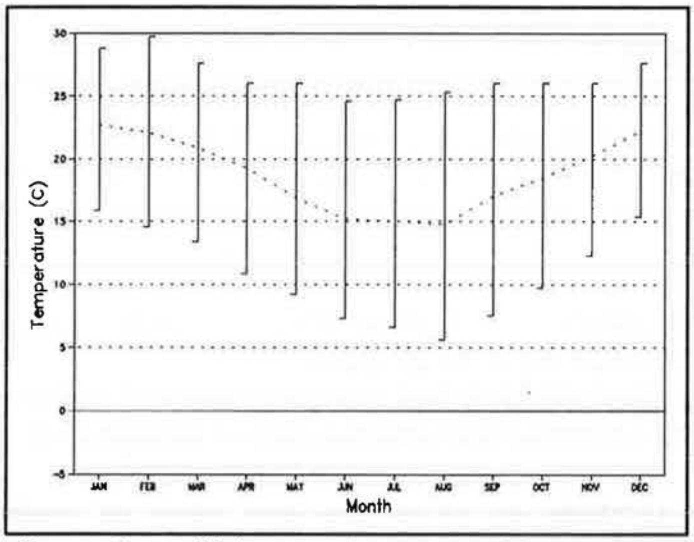

Figure 2 Nelson Average Temperature Range

Nelson (Latitude 41° 16' South, Longitude 173° 15' East) has a surprisingly benign climate as the region is spared many of the storms that characterise other areas near Cook Strait. Long term records place the region as one of the sunniest in New Zealand - with Nelson averaging 2418 hours of bright sunshine a year.

Nelson temperatures are not as mild as might be expected - summer temperatures over 30°C are not uncommon, with 36°C the highest reported. Winter temperatures can be cool, with -7°C the lowest reported. Figure 2 gives the minimum, mean and maximum temperatures by month for an "average" year.

Table I provides some climate comparison details for the actual 1990 year with the (hypothetical) average year used by the New Zealand Meteorological Service (NZMS) to characterise the Nelson climate, and with that used in the SUNCODE modelling. This last climate record was prepared in late 1989 as part of the development of weather files for 22 New Zealand sites (van der Werff, Donn & Amor 1990). Table I shows that the "Actual" year matches quite closely

	AVERAGE YEAR	SUNCODE YEAR	APRIL 90 - MARCH 91
Degree Days (Base = 15 C)	1153	1248	1147
Maximum Annual Temperature (C)	27.9	26.1	26.3
Mean Annual Temperature (C)	12.1	12.7	12.6
Minimum Annual Temperature (C)	-3.5	-2.1	-3.1
Sunshine hours (hr)	2400	-	2407
Maximum Wind Speed (ms^{-1})	10.4	18	10
Mean Wind Speed (ms^{-1})	3.1	3	3.8

Sources: 1990-1991 Actual: NZMS 301 monthly reports G13222
Average Year: NZMS 1978, NZMS 1983, de Lisle & Kerr 1965

Table I 1990 "Actual" Compared to "Average" Year Climate

the "Average", with only a higher mean wind speed standing out. From the Degree Day totals it could be expected that heating energy needs calculated by SUNCODE should be 9% higher. The Mean Temperatures in 1990/91 were warmer than normal (average) but the degree day total is normal suggesting a few extremely cold days pushing up the total heating needs but not affecting the average.

3.6 Monitoring Programme

The monitoring programme was designed to demonstrate the benefits and costs during operation of the low energy design philosophy adopted for the new Elma Turner Library in Nelson. Through monitoring of energy use, temperatures and occupant opinion the research was directed towards the following **GOALS:**

DEMONSTRATION: To demonstrate to designers and local government and businesses the benefits of thinking about energy consumption as part of the design process.

VERIFICATION: To verify that the calculated lighting, energy use and temperature parameters used during the design process provide a reliable indication of the as-built performance.

QUALITY CONTROL: To establish that the quality of the thermal and lighting environment in the new library is, for the users, similar to the quality predicted during the design process.

The monitoring covered the period 1 April 1990 to 1 May 1991, although daily temperature and energy use readings will continue to be made until the end of the 1991 heating season. Although the heating is under the control of an energy management controller, it was not possible to obtain modem access until March 1991. As a result, detailed temperature records are only available for part of the 1991 winter.

Temperatures (minimum, 9 am and maximum) and electricity meter readings (heating, light, power and night store heating) were recorded by library staff each working day for processing and analysis. Photographs have been taken once a month to provide a record of lighting levels and sun penetration.

A visit, in June 1990, of a senior class at the School of Architecture allowed detailed daylight measurements to be made, as well as conducting an "unoccupied co-heating test".

Infiltration measurements were taken from 11 February to 23 February 1991 using NAHB/AIMS (Song & Fan 1989) sampling system.

3.7 Description of Report

This report describes the passive solar design investigations (Section 4); the measured and calculated benefits of both are analysed for their economic benefits (Section 5), and the report ends with a brief conclusion (Section 6). The Appendices provide: plans of predicted and measured daylight and of the lighting layout and controls; analysis by the AIMS (Air Infiltration Measurement Service) measurement; detailed information and analysis of the unoccupied monitoring of the energy performance: a comparison of the performance predictions of the design SUNCODE thermal model with the actual building performance; and the documentation used during the investigation.

3.8 Acknowledgements

No project involving people in buildings ever proceeds totally smoothly. Here the assistance and general good spirit of all involved have helped achieve an excellent result. Particular thanks for Nelson assistance are due to:

The staff and management of the Nelson City Library, particularly **Ms Marian Gunn** and **Ms Helen Brownie**, for taking part with cheer and enjoyment even when the library was being wrapped in foil;

Mr Wayne Mackey and **Mr Simon Topp**, Nelson Citipower for expert advice, consumption details and assistance with monitoring;

Ms Rita Vitma, Mr Leigh Briars and Mr David Wallace of **Upstream Design** for recording the library on film and other assistance;

Considerable support has been given by numerous people in Wellington and elsewhere. In particular we would like to acknowledge the support of:

Mr Robert Amor for programming assistance and getting modems to talk to each other;

Students in **ARCH 332/432 Environmental Control** who wrapped the library in foil and undertook light measurements from 27th to 29th July 1990 (Kathryn Davies, Karl Frost, Roman Jacques, Cynthia Jamieson, Joanne Kelly, Chin Chong Lee, Richard Ormsby, Keith Small, Richard Zdrahal);

Mr Mark Bassett, BRANZ, provided advice and assistance with infiltration measurements;

Mr Kit Cuttle for participating in site visit and lighting advice;

Ms Kathryn Davies for managing the activities and undertaking analysis of the unoccupied monitoring;

Mr David Rutherford, Duroid Limited provided numerous rolls of Duroid Building Foil 252 for use in the Unoccupied Monitoring test;

Dr Ban-Huat Song, NAHB AIMS Laboratory for advice and analysis of infiltration, including a complete replacement set of receivers when the New Zealand customs agents stored the AIMS receivers and emitters together for a fortnight;

Mr Kevin McGill, NZMS for supply of climate data;

Ms Diane Taylor for data processing and report preparation;

Dr Alan Tucker, School of Engineering, University of Canterbury for advice;

Mr Ian van der Werff for his amazing SUNCODE skills;

Mr Gavin Woodward for participating in the site visit and photograph advice and processing;

and to those variously responsible for the project over the past two years:

Mr Robert Bishop, **Mr Stuart Bridgman**, **Mr Frank Pool**, and **Ms Alison Barrett**, Energy Management Group, Ministry of Commerce.

4 INVESTIGATIONS

This section describes the investigations undertaken into the design assumptions and the actual operation of the Elma Turner library.

4.1 NZMS Climate Data

The daily climatological record at 09:00 New Zealand Standard Time (NZST) (NZMS 301) was purchased from the New Zealand Meteorological Service for the months April 1990 to June 1991. The nearest climatological station is at Nelson Aerodrome (NZMS Site G13222), approximately 5 kilometres southwest of Nelson City on the east edge of the Waimea Valley facing Tasman Bay. Overall the climate should be similar for the aerodrome and the library site, with minor average temperature increases due to the urban location of the library.

The climate data was normally not available until one month after recording. It was electronically mailed from the NZMS to Victoria University. This e-mail transfer permitted greater resources to be put into analysis as there was no need to re-type or re-check data.

4.2 Library Technical Information

The library is open to the public from 10 am to 8 pm on Monday, Wednesday and Friday, 10 am to 6 pm Tuesday and Thursday, and from 10:00 am to 12 noon on Saturday - a total of 48 hours per week. However staff commence work from 8 am on weekdays and remain at least half an hour after closing on all days - giving a total of at least 61 occupied hours.

ZONE	LOCATION
1	Adult non-fiction (facing Halifax Street end)
2	Adult non-fiction (beneath clerestory)
3	Reference (behind desk)
4	Newspapers/entrance (on pillar)
5	Adult fiction
6	Young adults/children's library
7	Children's library/issue desk
8	Work room (wall beside courtyard)

Table II Temperature Sensor Locations

The library is divided into eight heating zones (7 public, 1 work room) for the **Paragon EC128** control, as listed in Table II. Although monitoring is effectively continuous, certain information is recorded on regular cycles. Temperatures are recorded every 15 minutes, and held for twenty-four hours. The controller analyses these to provide sensor highs and lows for the past week, history for one zone in one hour increments for the past 31 days and can also be analysed to provide heating and cooling degree days to a user specified base.

In addition, pulse output from a kilowatt hour meter is fed into the EC128 and is analysed to provide information on daily kilowatt hours, demand history (kilowatts) in five minute increments for the past twenty-four hours, demand history (kilowatts) in one hour increments for the past seven days and kilowatt highs for the past 31 days. Although in a special compact format, it took approximately two minutes for the 6912 bytes to be downloaded, and hence off-peak telephone rates were used. The PECOSOFT (Version 3.2, 1 March 1990) communications program was then used to extract temperatures for checking and analysis in a spreadsheet.

The library uses electricity as its sole energy source. Two tariffs are in use:
night store heating 3.9 c/kWh {$8/GJ}, and
power, light and heating standard tariff of 13.5 c/kWh {$37.5/GJ}
These costs exclude GST, and have no power (peak) charge.

4.3 Infiltration

Although many assumptions can be made about the provision of fresh air in naturally ventilated buildings, measurement of it has, in the past been very difficult and expensive. Computer based tracer gas systems are available in New Zealand, but have high set-up costs and require regular attention during the measurement period. Following discussions with BRANZ, it was decided to use a low cost, passive measurement system.

In 1982, Brookhaven National Laboratory developed a perfluorocarbon tracer (PFT) technology based on passive emitters and receivers (Dietz et alia 1983). In 1986 NAHB National Research Centre in Maryland, U.S.A, began offering an Air Infiltration Measurement Service (AIMS) primarily for monitoring airflows in homes (Song & Fan 1989). Although the various components of the system are expensive, in use the cost is low as all equipment is returned to NAHB after measurements are completed.

The equipment is simple to use and small - both parts are about the size of the small finger. The source emitter contains a PFT gas that is released into the air at a temperature dependent rate - in the range 1 to 4 x 10^{-8} litres per minute. The gas mixes readily and establishes a uniform environment within 5 to 8 hours. The receiver is a capillary adsorption tube containing a small quantity of activated 'ambersorb' to capture the PFT. At the conclusion of the test, the emitters and receivers are returned separately to the NAHB National Research Centre where the concentration of received gas is determined using a gas chromatograph. The reciprocal of the average concentration multiplied by the source emission rates provides the average air infiltration rate, which with the space volume allows the air exchange rate per hour to be calculated (Song & Fan 1989).

Thirty AIMS **Red** emitters were placed in small plastic dishes around the library on 7 February 1991. They were then mounted following NAHB/AIMS sampling instructions on individual push pins in locations well spaced around the library during the morning of 11 February 1991.

The twenty three AIM receivers were installed between 13:25 and 14:15 on 11 February 1991, and removed between 12:30 and 13:00 on 23 February

1991. The receivers were air mailed to the NAHB laboratory and the analysis certificate records the date of analysis as 19 March 1991.

DESCRIPTION	Floor Area m^2	Volume m^3	Average Temperature °C	Average Gas Concentration pl/l
Work Room	160	502	21	5.73
Children's Library	285	868	20	5.05
Adult Fiction	380	1,202		3.48
Non-fiction / Entrance	600	2,113	21	4.22
TOTAL	1,427	4,685	21	4.37
Overall Infiltration rate: 8,637.6 m^3/hr (Standard deviation: 1,221.5 m^3/hr)				
Overall Air exchange rate: 1.844 ach (Standard deviation: 0.277 ach)				

Table III Environmental Data & Average Tracer Gas Concentrations

Appendix B describes the locations with the receiver ID and the average concentration in pico-litres (10^{-12} litres) of gas per litre of air. As the library is a public space, the danger from friendly or malicious interest meant it was necessary to locate the receivers and emitters above head height - in most cases almost at ceiling height. However the operation of the ceiling fans during opening, and often during the unopen but occupied, hours ensured an even flow of air throughout the space. Table III provides a description of the locations, their floor area, room volumes (excluding ceiling space), the average temperature during the period of measurement, the average gas concentration and the overall infiltration and air exchange rates. The total volume was calculated from the plan floor area with the actual ceiling height for flat ceilings and average ceiling height for areas with clerestory windows. Although the ceilings are complex, the clerestories form only a small volume, and hence the overall error should be no more that a few percent.

Natural ventilation is caused by the interaction of the building envelope with weather-induced pressures. Equation 1 shows that the variables are the inside-to-outside temperature difference and the wind speed (Sherman & Grimsrud 1982). Assuming small changes in the temperature difference, infiltration will increase in direct proportion to the wind speed.

$$Q_o = L_o \sqrt{f_s^2\, \Delta T + f_w^2 v^2}$$

Equation 1

where: Q_o = *ventilation air infiltration*
L_o = *total leakage area*
ΔT = *inside / outside temperature difference*
v = *wind speed*
f_s = *building height (stack) parameter*
f_w = *wind parameter*

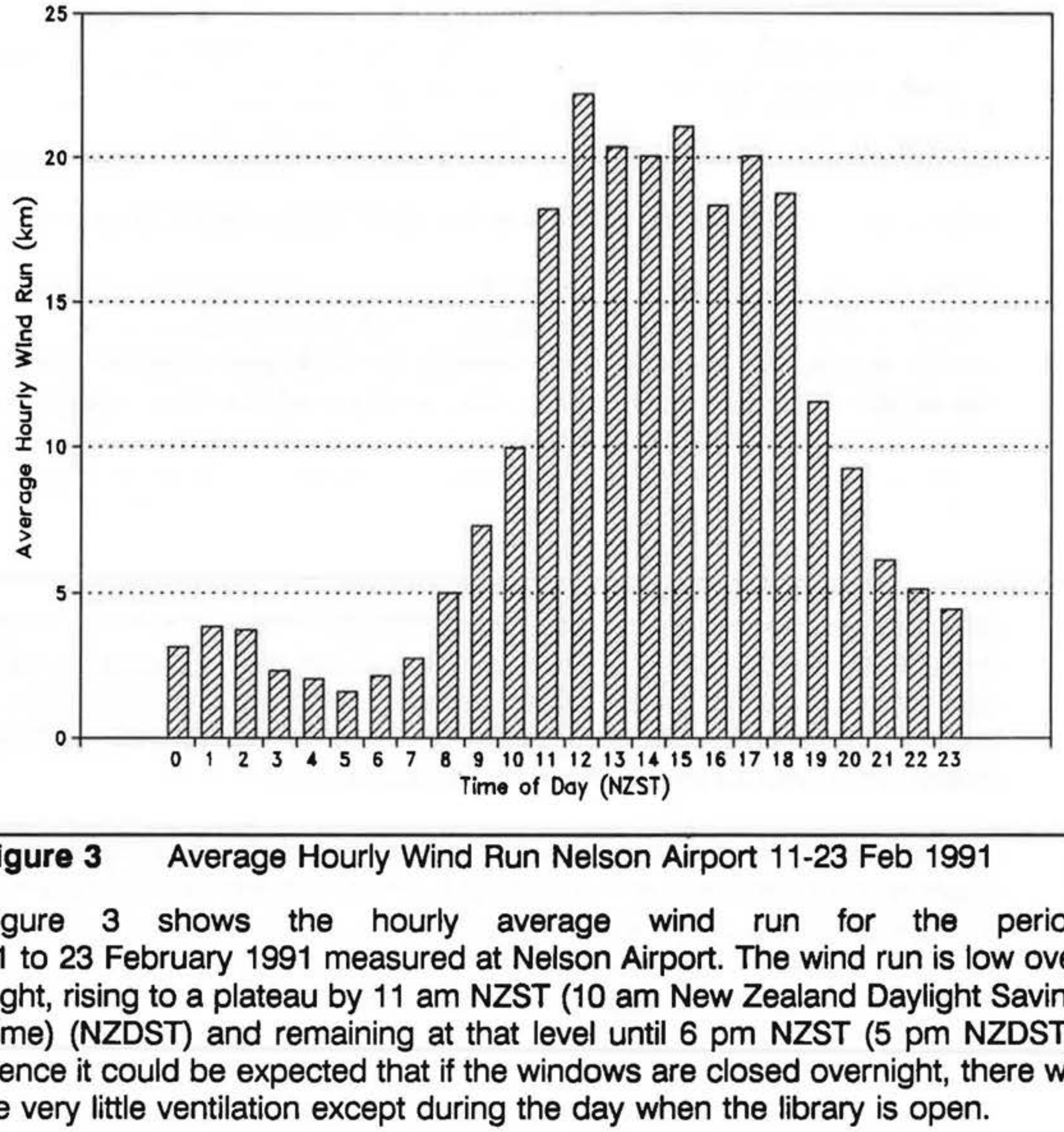

Figure 3 Average Hourly Wind Run Nelson Airport 11-23 Feb 1991

Figure 3 shows the hourly average wind run for the period 11 to 23 February 1991 measured at Nelson Airport. The wind run is low over night, rising to a plateau by 11 am NZST (10 am New Zealand Daylight Saving Time) (NZDST) and remaining at that level until 6 pm NZST (5 pm NZDST). Hence it could be expected that if the windows are closed overnight, there will be very little ventilation except during the day when the library is open.

The measured air exchange rate of 1.8 air changes per hour is an average over the 286 hours from 11 to 23 February. The library was open for 103 of these hours (36%). Assuming the infiltration is insignificant during hours when the library is closed, the average air exchange would be of the order of 5 air changes per hour during opening hours. This is consistent with the assumption of 5 air changes per hour used in the design SUNCODE modelling.

Library staff commented that conditions are very acceptable throughout the public spaces, but conditions in the Work Room do get extremely warm and uncomfortable that they suspect is due to a lack of fresh air. Although it is not possible to separate out areas due to the monitoring technique used, if the assumption is made that the rate of tracer emission equals the loss from the zone, calculations based on three emitters in the work room area (see Appendix B for concentration values) give 1.5 ach, which is below the overall average. Using the same assumptions as above, this implies that the infiltration and ventilation rate during the hours of occupancy is 4.5 ach. This quite reasonable rate suggests that some improvement in the distribution of fresh air would be of benefit to users of the Work Room. It may also be that the by-products of book repair and handling (glues, dust, solvents etc) are exacerbating the situation by adding to the "natural" pollution level in the room.

4.4 Unoccupied Monitoring

The model validation test is based on the SERI Class B testing, following the approach of Tucker (1987). The purpose of unoccupied monitoring is to enable a comparison of the actual thermal characteristics with that used in the initial computer modelling. The results are used to calculate the **heat loss coefficient, thermal decay time constant** and **thermal capacity.**

The steady state **heat loss coefficient** is a measure of the overall thermal resistance of the library - including the effects of windows, doors, junctions of floor/wall, wall/wall and wall/ceiling; and of infiltration. The overall quality of construction has a major effect on the actual values. The **thermal decay time constant** is a measure of the time taken for heat to travel from within to outside the building, and the **thermal capacity** is the amount of heat that is stored within the building fabric.

The library is a very large open space fitted with electric heating and ceiling fans, permitting energy consumption to be monitored and the air temperature to be maintained evenly throughout the main floor.

Unoccupied monitoring was carried out from 27 July to 31 July 1990. The steady state test ran from 7:00 pm 28 July to 8:00 am 29 July. The cooldown test was carried out from midnight 30 July to 7:00 am 31 July. Throughout the tests the weather remained fine with minimum wind.

	Heat loss coefficient (W/K)	Time constant (Hours)	Thermal capacity (kWh/K)
MEASURED	5460	19	102100
SUNCODE	3800		212400

Table IV SUNCODE Examination of Thermal Characteristics

Appendix C describes the unoccupied monitoring in detail, while Table IV summarises the results and compares them with the SUNCODE calculated characteristics.

The causes of the differences between the measured and calculated thermal characteristics are related to the calculation approach used with SUNCODE. This includes the modelling of one metre of the earth under the concrete floor as part of the building, to account for ground temperatures more precisely. The consequence was an unreal increase in the calculated total building thermal capacity, and therefore in its time constant as reported by the summary statistics output from SUNCODE.

SUNCODE also reported a total outside surface heat loss coefficient that differed from the measured figure. The reason was that the ventilated roof space was modelled as a separate unheated zone to more accurately reflect the physical situation. To SUNCODE, heat loss from inside to outside at roof level was therefore through the thin corrugated mild steel roofing above this zone, not from the heated zone, through the ceiling, then through 150 mm of fibreglass insulation, and finally through the unheated zone and then the steel roofing.

In manual calculations, where calculating heat losses between zones as well as to the outside is too time consuming to be practical, one normally approximates heat loss through unheated zones by a "standard" heat loss coefficient. Because the unoccupied monitoring test measures directly the heat loss from the heated zone through all intervening surfaces and zones to the outside, the results of this test are not directly comparable with the summary statistics produced by SUNCODE.

The intention of the SUNCODE modelling was to model realistically the building's overall energy consumption in relationship to the climate. As far as it is possible to make comparisons between the various SUNCODE summary parameters describing the thermal performance, the physical measurements confirm the original assumptions in the design model.

4.5 Monitored Results

Temperatures (9 am, minimum and maximum) and electricity consumption were recorded each day at approximately 9 am. This was carried out by a member of the library staff six days a week (Monday through Saturday), although some Sunday readings were also made. These records are available for the period 1 April 1990 to 31 July 1991. However, absences for library holidays and other meant that out of the 487 days, there are only 362 days of readings.

A number of approaches could have been taken to energy and temperature monitoring. Monthly, weekly or daily measurements could be made either manually or electronically. Measurements several times a day could only be made electronically. Baird et al (1984) show that for the type of analysis required daily measurements are needed.

A manual approach to daily temperature monitoring was chosen due to its low cost and simple nature. It was recognised that there would be some disbenefits. These were identified as:

i) the daily temperature and energy consumption data would only be available at the end of the month, meaning there would be constraints on feedback to help with control of the building;

ii) the small number of thermometers meant that there were limited zones being monitored; and

iii) poorer data security and quality could be expected due to the manual recording and data entry.

Given the monitoring budget constraints, manual recording was simplest and most secure based on our monitoring experience (Isaacs and Donn, 1987). Special attention was paid to error detection and correction before analysis could be undertaken.

In theory, information could be obtained electronically from the **Paragon EC128** controller, but during 1990 a suitable connection could not be made. In 1991, Citipower connected a modem to the controller, and after some initial difficulties a daily downloading commenced. To minimise toll costs, this was set up to take place automatically at 10:15 pm each night. These records are only available for the calendar period 31 March 1991 to 19 June 1991. Even in this period, controller and modem failures resulted in, only 62 days of data being available from a total of 79.

4.5.1 Manually Recorded Temperatures

At approximately 9 am each work morning, library staff recorded the present, the minimum and the maximum temperatures from a *REGENT* thermometer, as well as the three electric meter readings. Thermometer locations were:

1) in workroom (near to Paragon sensor 8)
2) behind the main issue desk at main door (near Paragon sensor 3)
3) behind the children's issue desk (Near Paragon sensor 7)

The thermometer manufacturer, Heiz Müller of Wertheim, Germany, claims an accuracy of ± 0.25°C, but measurements taken with nine other units from the same batch with an Assmanns Aspirated Hygrometer thermometer found the accuracy to be within a range of ±1.5°C, with the average reading +0.3°C high. Given the temperature readings were recorded only in whole digits, no allowance has been made for this.

The range of internal temperatures by month (from library staff recording) is shown in Figure 4, while Figure 5 gives the external range (NZMS) for the 1990/91 year. 1990 was a cool year, with minimum external temperatures close to or below zero from April through October. The internal daytime temperatures (9 am and maximum) remained within acceptable limits. The monthly average

9 am internal temperature was above 18 °C for the 1990 winter (May to October), and above 16 °C for the 1991 winter months (April to July 1991). The minimum internal temperature occurred when the library was unoccupied and unheated, and although it had an impact on the overall energy use of the building through the reduction in stored heat, it did not affect users as they were not present.

Internal temperature distributions for the Children's Desk are given in Figure 6, and the same analysis of NZMS external temperature data is given in Figure 7. The left hand curves are the minimum temperatures, the middle thicker line the 9 am temperature and the right hand curves are the maximum temperatures. The curves are calculated by counting the number of readings in 1°C intervals, calculating the percentage in each group, and summing. Thus below any given point, the curve represents the proportion of readings that were below the given temperature, and above, the proportion above that temperature. Winter is nominally defined for these graphs as the period during which the heating system was on - 1 May 1990 to 15 October 1990, and 10 April 1991 to 31 July 1991.

The greater the horizontal separation, the greater the temperature fluctuation - as can be seen for the external climate. Summer temperatures inside remained stable, while winter temperatures varied, particularly with the effect of overnight cooling (minimum temperature) and late afternoon sun (maximum temperature). In less than 10% of the days on which temperatures were taken was the 9 am temperature less than 14 °C.

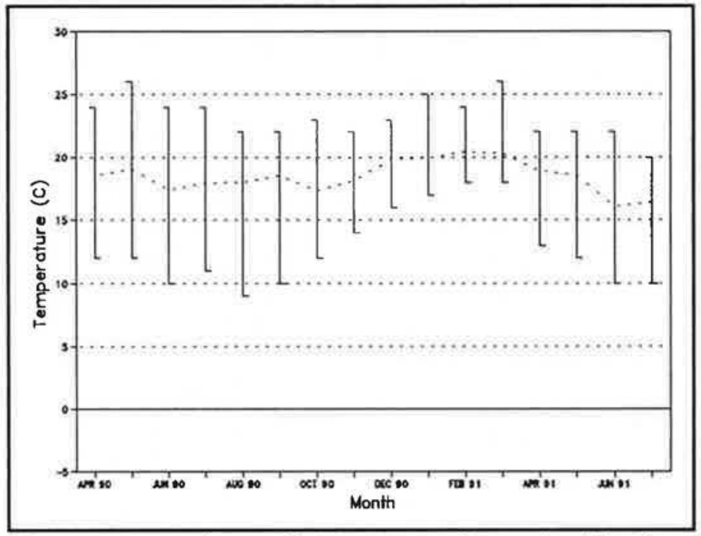

Figure 4 **Internal Temperature Range by Month**

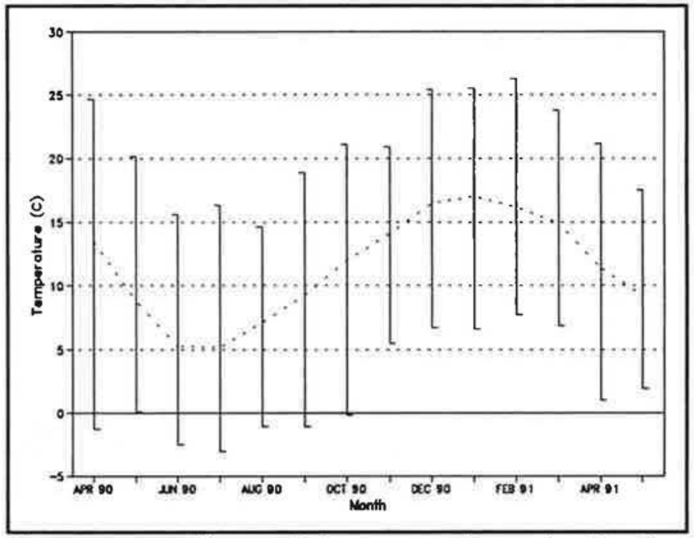

Figure 5 **External Temperature Range by Month**

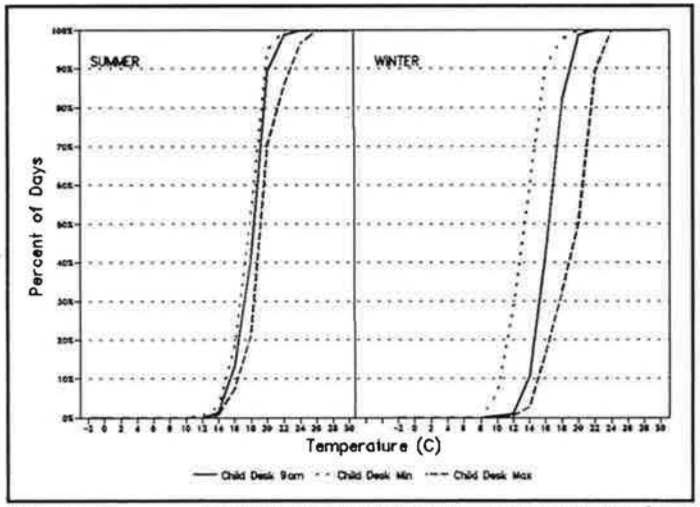

Figure 6 **Children's Desk Temperature Distribution**

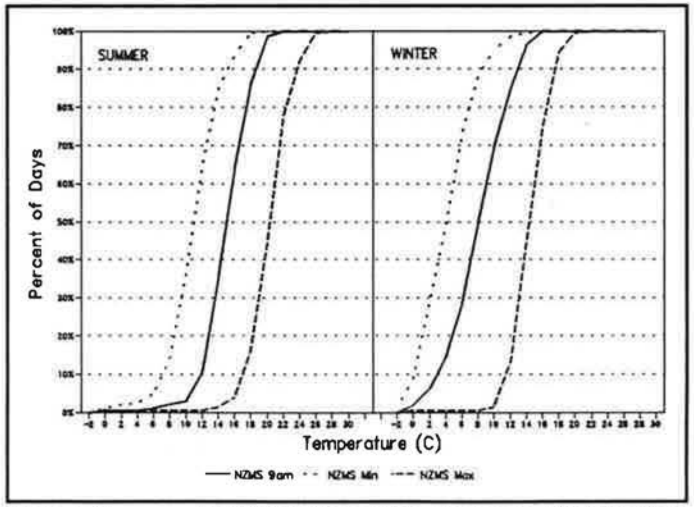

Figure 7 **NZMS External Temperature Distribution**

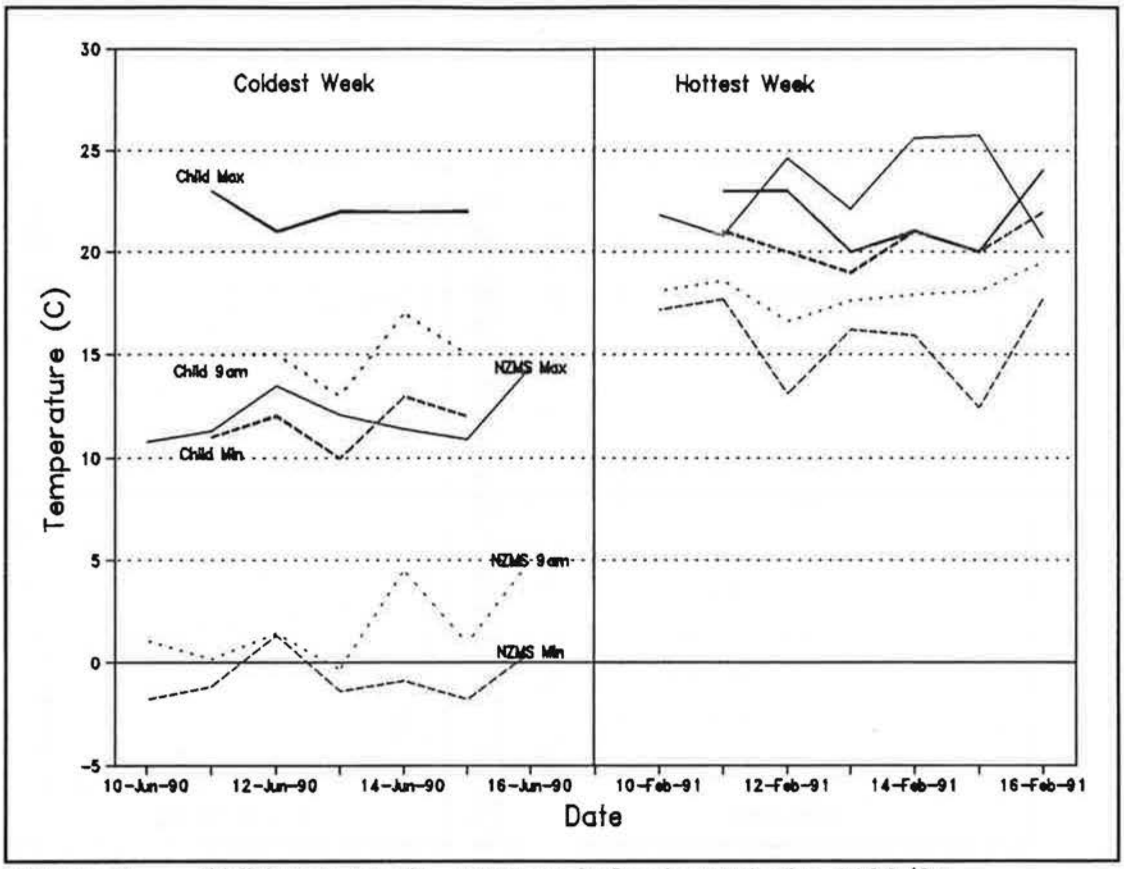

Figure 8 Children's Desk - Hottest & Coolest Weeks 1990/91

The Children's desk was considered by staff to be one of the coldest places in the library. Figure 8 gives temperature ranges for the hottest and coldest weeks (determined by the external temperatures) during the monitoring period. The daily minimum, maximum and 9 am readings are given for both the Children's Desk and the NZMS station. The coldest week was from 10 June 1990 to 16 June 1990, and it can be seen that minimum and 9 am external temperatures were close to 0°C. The 9 am internal temperature at the Children's desk was close to 15°C for the entire week. During this week the temperatures at the Front desk were consistently 1-3 degrees warmer. This confirms the staff impressions, and could be due to the high level clerestories directly above the Children's desk, as well as the open nature of that part of the library. To combat this discomfort, thought needs to be given to the following options: provision of an additional local heater behind the desk; adjustment of the controller either to bring heating on earlier or to have a higher temperature in this zone.

The hottest week was from 10 February 1991 to 16 February 1991. Unfortunately the thermometer readings during this period were not always at the high standard provided at other times during the year, and the 9 am and maximum temperatures are identical. Even so, the internal temperatures do not appear to have risen to unacceptable levels in any of the three thermometer locations.

4.5.2 Electronically Monitored Temperatures

As noted in Section 4.2, problems with connecting electronically to the **Paragon EC128** meant that it was not possible to obtain detailed information until the beginning of March 1991. Even after that date, minor problems meant that continuous information was not available.

In common with far too many control systems, the **Paragon EC128** documentation is neither user friendly nor complete. Considerable effort and preferably experience is required to determine what is happening, and then how to control it. Discussions with Citipower indicate that there was some initial difficulty in setting suitable temperature control levels.

In addition the sensors were not calibrated during commissioning, and as discussed in Appendix C, this resulted in some areas of the library being maintained at a warmer temperature than others. The use of conventional air air thermostats mounted on walls out of the direct influence of the radiant panels may have also caused some difficulties (NZ Fibrous Plaster Association 1980). Finally, suitable control temperatures were established by walking around the building and finding when staff were comfortable, and setting the reported temperature of the local sensor as the control temperature.

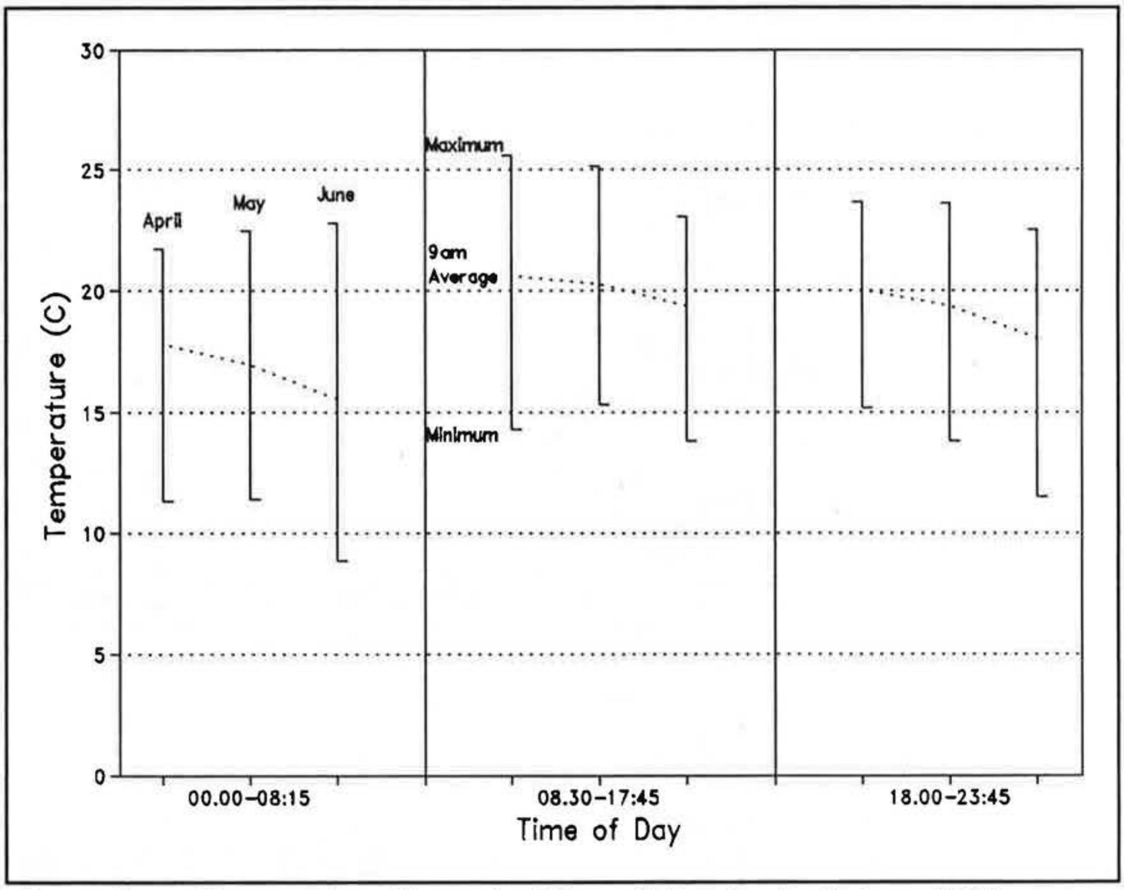

Figure 9 Temperature Range by Time of Day for April-June 1991

The sensor recordings provide information on the temperature range not only during occupation but also after hours. Figure 9 provides the maximum, average 9 am and minimum temperatures for working days (i.e. Monday through Saturday inclusive) for the time periods: midnight to 8:30 am; 8:45 am to 5:45 pm (day time working hours); and 6 pm to 11:45 pm for the months of April, May and June 1991. These temperatures have been extracted from the control records with corrections applied, but a maximum accuracy of no more than ± 1°C would be expected.

It can readily be seen that during the occupied hours (the central region of the graph) the temperatures are within the normally accepted comfort range for library activities (ASHRAE, 1989). Only in May 1991 during day time working hours did the minimum temperature drop below 15 C.

The 00:00 (midnight) to 8:15 am time period had a wider range with the minimum temperatures likely to be in the dead of the night and the maximum temperatures just before official opening hour. These results demonstrate that library temperatures are now under reasonable control.

4.5.3 Electricity

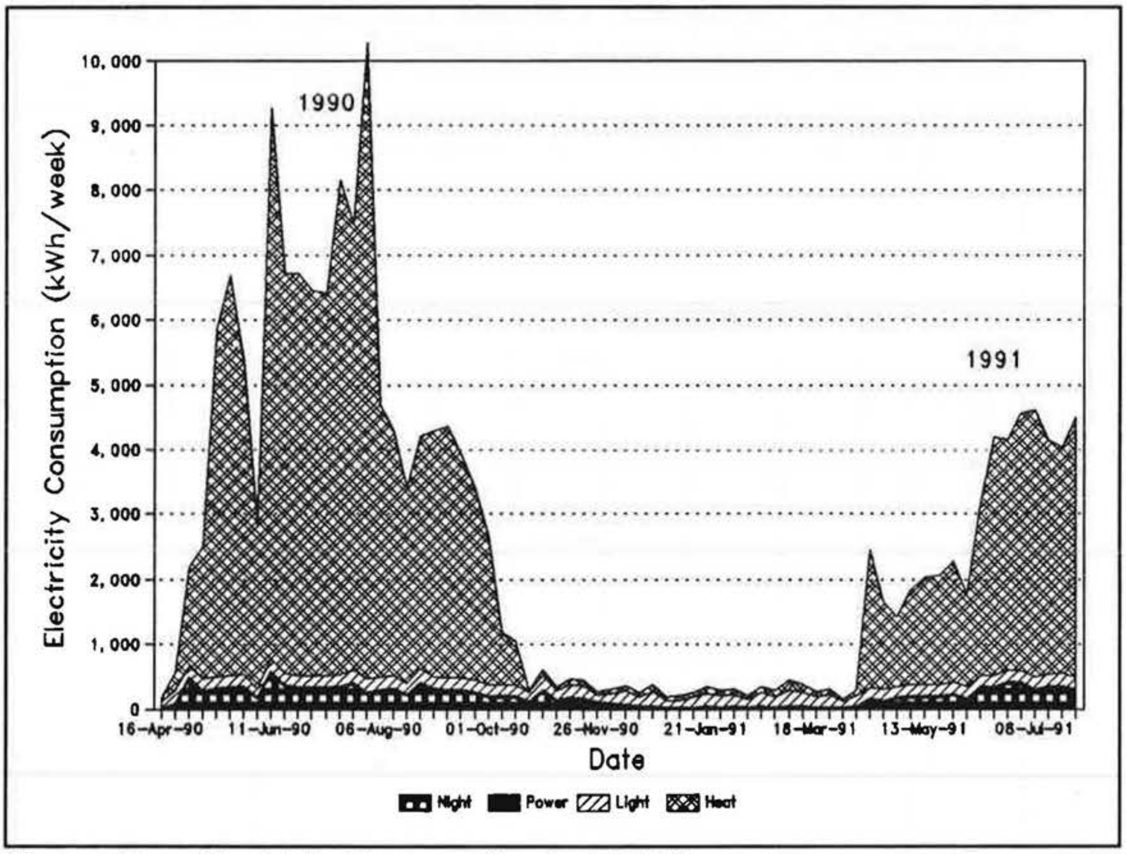

Figure 10 Electricity Consumption by End Use

Electricity is the only purchased energy source used in the library, and therefore energy use is relatively easy to monitor. Figure 10 provides an analysis of weekly electricity consumption by end use (night store heating 3.9 c/kWh {$8/GJ} plus GST, and power, light and heating standard tariff of 13.5 c/kWh {$37.5/GJ} plus GST). Converted to dollar terms, the 1990 peak week use was approximately $1,200, but in the 1991 winter to the end of July peak expenditure is only just above $500 maximum per week. This will be discussed in greater detail in the next section, where relationships between hours of operation, external climate and energy use are subjected to statistical analysis.

Figure 10 shows that the library's electricity use follows a common pattern in commercial buildings, with a few variations (for a discussion, see Baird & Pool, 1985). The trough in use around 4 June 1990 is partly due to the Queens Birthday weekend holiday, while the peak the following week is due to the meters not being read from 2 June 1990 to 5 June 1990, and all consumption over those 4 days appearing to fall in the following week. The peak in the week to 30 July 1990 is due to the unoccupied heating test.

The most interesting change appears to occur about the 20 August 1990, when the consumption not only drops, but remains at a lower level for the rest of the winter period. Discussions with Citipower indicate that this was about the time when the operation of the control system, was further investigated and Sunday operation was stopped. The consequences of this commissioning work were a significant reduction in electricity consumption. For comparison, taking no account of the external climate, the average daily consumption over the period 1 June to 31 July 1990 was 940 kWh/day, which dropped to 500 kWh/day for the period 1 August to 30 September 1990. In the following year, the period 1 June to 31 July 1991 had an average consumption of 528 kWh/day - a factor of 1.8 difference.

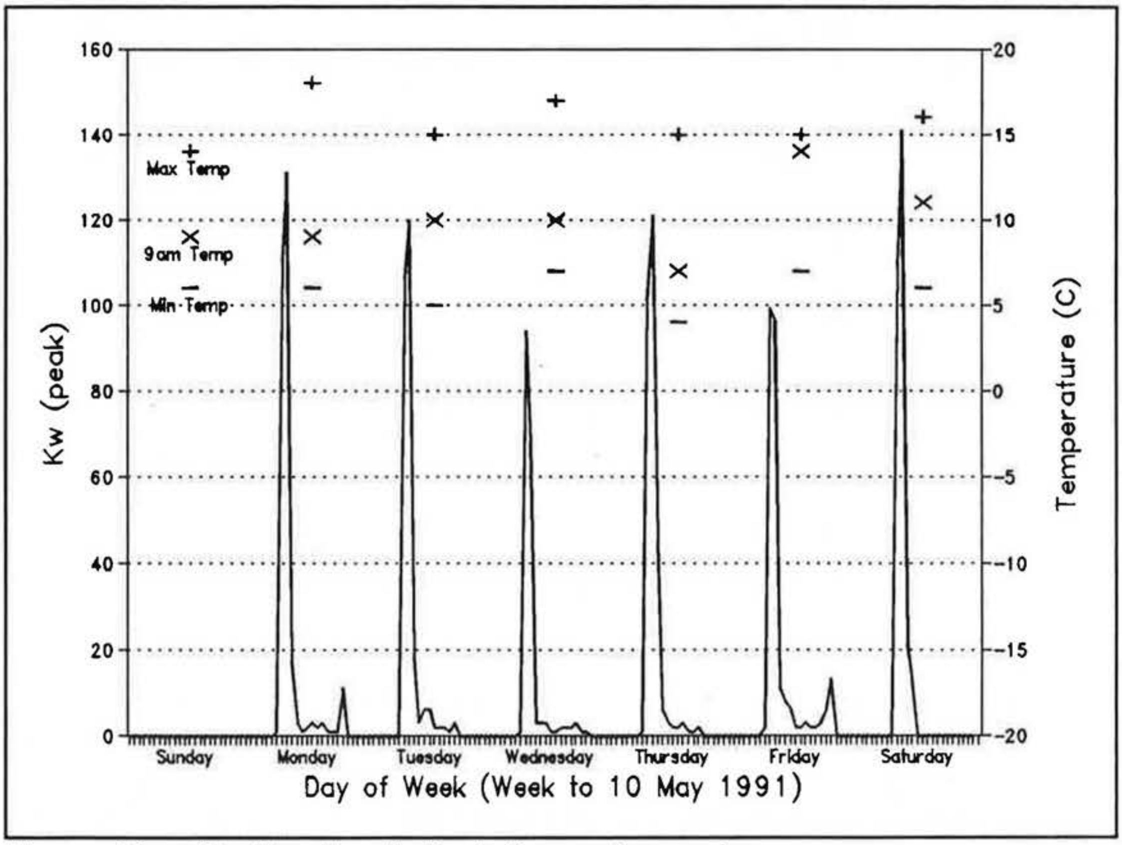

Figure 11 Heating Hourly Peak Power Demand

The library behaves as a thermally heavy building, as indicated by the stability of the summer temperatures. Figure 11 gives the peak power (by hour) extracted from the **Paragon EC128** daily report for 11 May 1991, and the NZMS reported 9 am, daily minimum and maximum temperatures, for a one week period from Saturday 4 May to Friday 10 May 1991. The heating is turned on at 7 am each working morning, but it can be seen that the highest daily peak and the area beneath the peak curve (i.e. energy consumed) are approximately the same for the first few hours of each day. Although these are hourly peak power demands, and it is unlikely that the full peak will be demanded for all of every hour, summation of the area under the curves shows that 90% of the daily energy use is from switch-on at 7:00 am to 8:59 am.

Referring back to Figure 8, Sunday 11 June 1990 shows a 9 am temperature of 15°C. This would appear to indicate that the heating system was operating on the Sunday. Discussions with Citipower indicate that this was indeed the case, and it was not until later in August that this operation error was detected and remedial action taken. As noted above, Figure 11 shows that operating the heating system even for a couple of hours on Sunday would lead to energy consumption nearly equivalent to operation for a full day - effectively increasing the weekly energy bill by one sixth or 17%. This would suggest that a major explanation for the difference between 1990 and 1991 heating season energy use is the lack of heating on Sundays in 1991.

	1990	1991	1990	1991
Actual Electricity Use May-July (kWh)				
HEAT	80,334	37,788	92.4%	86.3%
LIGHT	2,168	2,176	2.5%	5.0%
POWER	433	477	0.5%	1.1%
NIGHT	3,994	3,331	4.6%	7.6%
TOTAL	86,929	43,772	100.0%	100.0%
Actual Electricity Expenditure May-July ($)				
HEAT	$11,099	$5,099	95.6%	91.2%
LIGHT	$293	$294	2.5%	5.3%
POWER	$58	$64	0.5%	1.2%
NIGHT	$157	$131	1.4%	2.3%
TOTAL	$11,608	$5,588	100.0%	100.0%

Table V Winter Electricity Consumption and Expenditure

Figure 10 also shows the comparatively low electricity consumption for light and power during the heating season, although of course in summer months these are the total consumption. Table V provides an analysis by end use for electricity use during part of the winter heating periods of 1990 and 1991. The light energy use (0.6 GJ or 166 kWh per week) and the power (0.12 GJ or 34 kWh per week) remain almost constant throughout the year - a cost of about $27 per week. Night rate electricity (1 GJ or 300 kWh per week) used for heating staff offices is charged at a lower rate, giving a cost of approximately

$11 per week. The major winter heating cost is the main heating - averaging $775 per week during 1990, but only $365 during April to July 1991.

For comparison with other buildings of similar use, common practice is to calculate an index to normalise for size - most often the Area Energy Use Index (AUEI) (Baird et al. 1984). No AUEI has been calculated for this building as the 1990 heating season is clearly not representative, and at the time of writing full data was not available for the 1991 winter.

4.6 Energy Consumption Compared to Climate

The SAS® statistical analysis system was used to compare energy consumption (dependent variable) with the exterior climate reported by NZMS (wind run, solar radiation, degree days, 9 am dry bulb temperature), interior climate from daily readings (9 am, minimum and maximum temperatures) and the hours of operation.

The analysis looked to see if there was a statistically significant, linear relationship between the energy consumption and the independent variables of exterior climate, interior climate and operating hours. The strength of such a relationship is measured by the square of the correlation coefficient, the "R-squared" (R^2) value, where the closer to 1, the greater the proportion of the variation in the dependent variable is accounted for by the independent variables. A "partial R^2" attributed to a particular variable, is the fraction of the total variation due to that single variable. As these 'independent' variables are not totally independent, and as there may be some other relationship than a linear one, the results are most useful in establishing the strength of association between them and energy consumption. Proof of a causal relationship and prediction of a value for it were not sought.

4.6.1 Heating Electricity

Energy is used to create a comfortable internal environment, despite the external climate. At its simplest, it is expected that as weather grows cooler additional energy is required to maintain internal temperatures. However other climatic variables can also play an important role in determining energy use, as can the actual operation of the building.

Table VI presents the results from a linear regression analysis for the entire 1990 heating season (1 May to 15 October 1990, excluding the weekend of 27 to 30 July when unoccupied testing was carried out) and the portion of the 1991 heating season (10 April to 31 May 1991) for which full data was available. It shows the base daily consumption, which is modified by each variable with either a positive impact (the more of that variable then the more energy use) or negative impact (the more of that variable then the less energy use). The contribution made by each variable (R^2) is given as a percentage. Thus, for example, in 1991 the 9 am Children's Desk temperature had a positive impact and accounted for 50% of the variation in heating energy use for the library.

1991 (April-May)			1990 (May-October)		
Daily base consumption = 141 kWh			Daily base consumption = 308 kWh		
Impact	Variable	Contribution	Impact	Variable	Contribution
+	9 am Child Desk Temp	50%	+	Max Child Desk Temp	40%
-	Hours of opening	3%	-	Min Child Desk Temp	12%
-	Min Front Desk Temp	4%	-	Solar Radiation	3%
-	Daily Wind Run	3%	+	NZMS 9 am Temp	1%
+	Max Child Desk Temp	3%			

Table VI Factors affecting heating electricity use

Table VI raises some very interesting questions about the control of the heating system. Although external climate variables were included in the list for analysis, they were not selected by the analysis program as having a significant correlation with the heating energy use. In both years it is temperatures measured at the Children's Desk that account for the largest proportion of the variation in heating energy use.

Location	Heating Season	Contribution	Non-Heating Season	Contribution
Children's Desk Minimum	Outside Min Temp	47%	Outside Min Temp	61%
Front Desk Minimum	Outside Min Temp	39%	Outside Min Temp	54%
Workroom Minimum	Outside Max Temp	32%	Outside Max Temp	62%

Table VII Relationships Internal Minimum Temperatures & External Climate

The apparent importance of the Children's Desk temperatures in determining the heating energy use confirms the observation that this is a cold area of the library. To explore this issue further, more regression analyses were run. The most informative analyses compared the influence of the external climate on the minimum internal temperatures at the Children's Desk, the Front Desk, and in the Workroom. As can be seen in Table VII, the variation from day to day in the minimum internal temperature at the Children's Desk is largely explained by variations in the external minimum temperatures (earlier that morning) - 61% of the variation in the warm (non-heating) season and 47% of the variation in the cool (heating) season. The lower contribution of the external climate in the heating season is presumed to be due to the effect of the heating creating an artificial internal climate.

Table VII also shows that the Workroom minimum temperature is correlated to the external maximum temperature (on the previous day), rather than the external minimum for the two desks. A physical explanation includes the higher levels of thermal storage in the workroom area, and a slower rate of heat loss. This last assumption is confirmed by the comments of library staff that the Workroom is stuffy. In other words, there is less provision of fresh air, and hence less extract of hot, dirty air from the Workroom.

The conclusion reached from these regression analyses is that the variation in heating energy use in the library can at most be said to be 24% (50% of 47%) related to the external climate.

Examination of the **Paragon EC128** sensor list (Table II) shows that none of the sensors are monitoring external temperature. In addition, Figure 11 shows that the heating peak power and energy use largely occurs in the first three hours of operation and is not (apparently) related to the external temperature extremes. These observations, and the conclusions of the last paragraph, suggest that controls that made the energy use more responsive to the variations in external climate could reduce the energy use. Although sizeable energy, and money, savings were made between 1990 and 1991, there are still additional savings to be made through better control of the heating system by the inclusion of external temperature monitoring. This would involve the shifting of one of the sensors listed in Table II to an external position. Then the **PARAGON EC128** could be used as an optimiser rather than as a complicated timeclock as at present.

4.6.2 Lighting Electricity

The original design brief (see Section 3.2) established desired lighting levels ("400 lux at 750 mm above floor level"). The physical modelling investigated the use of daylight to meet these levels. Trials in the School of Architecture effulger (artificial sky) documented the 'daylight factor' for a physical model of the building. The 'daylight factor' is the ratio between the internal light levels and the external daylight level. In reality, the external light levels are not constant. Therefore, a specific 'daylight factor' cannot predict a specific internal lighting level. All that can be predicted is a probability of daylight exceeding certain values on average throughout the year.

The modelling suggested that daylight would provide more than 400 lux for an average of 2.2 hours of the working day throughout the year for 70% of the public areas of the library (>2% daylight factor). Daylight at this level provides more than 400 lux for an average of 6.7 hours of the 8 am-5 pm working day, for 25% of the public areas (>5% daylight factor). Had the budget allowed the placement of more skylights or clerestory windows then these daylight factors could have been exceeded.

Appendix A provides colour photocopies of the daylight factor plan taken from the design model, and actual measurements taken on 27 July 1990. It can be seen that the expected daylight levels were not achieved. The actual measurements show that 400 lux is exceeded for an average of 2.2 hours per day over 60% of the public areas of the library. Within the margin of error for measuring the areas, the daylight factors near the perimeter of the building are very similar in the model and in the actual building.

There are several complicating factors that made the lighting system work less effectively than originally expected, but for most of these the costs of modification are expected to be high. The main areas of difference, and possible actions (*identified in italics*) are:

1) the presence of dark coloured louvres, blinds and other reflecting surfaces near window openings and the use of windows smaller than originally modeled meant daylight levels inside do not reach the levels expected - *no change possible*;
2) the fluorescent lighting levels reach 600 lux on average without daylight assistance, thus the area under the lights (especially the emergency lights that are on continuously) can appear much brighter and more cheerful than the areas lit to the daylight target - *possibly switch tubes individually*;
3) the fluorescent luminaires (Phillips TBS 300) do not switch their tubes individually, so cannot be used to supplement daylight. For example if the daylight level is 402 lux then that is "sufficient", but if it is 350 lux then the lights are all on and the level is boosted to 950 lux - *Modifications possible, but rewiring is not expected to be cheap*;
4) the lighting circuits have been zoned to provide only 4 switches to control all the public area, and the zones while relating closely to expected daylight distribution do not form an intuitive operation for library staff - *Modifications are possible through running additional cables from the switch board to the lighting control panel and adding contactors to the switch board.*

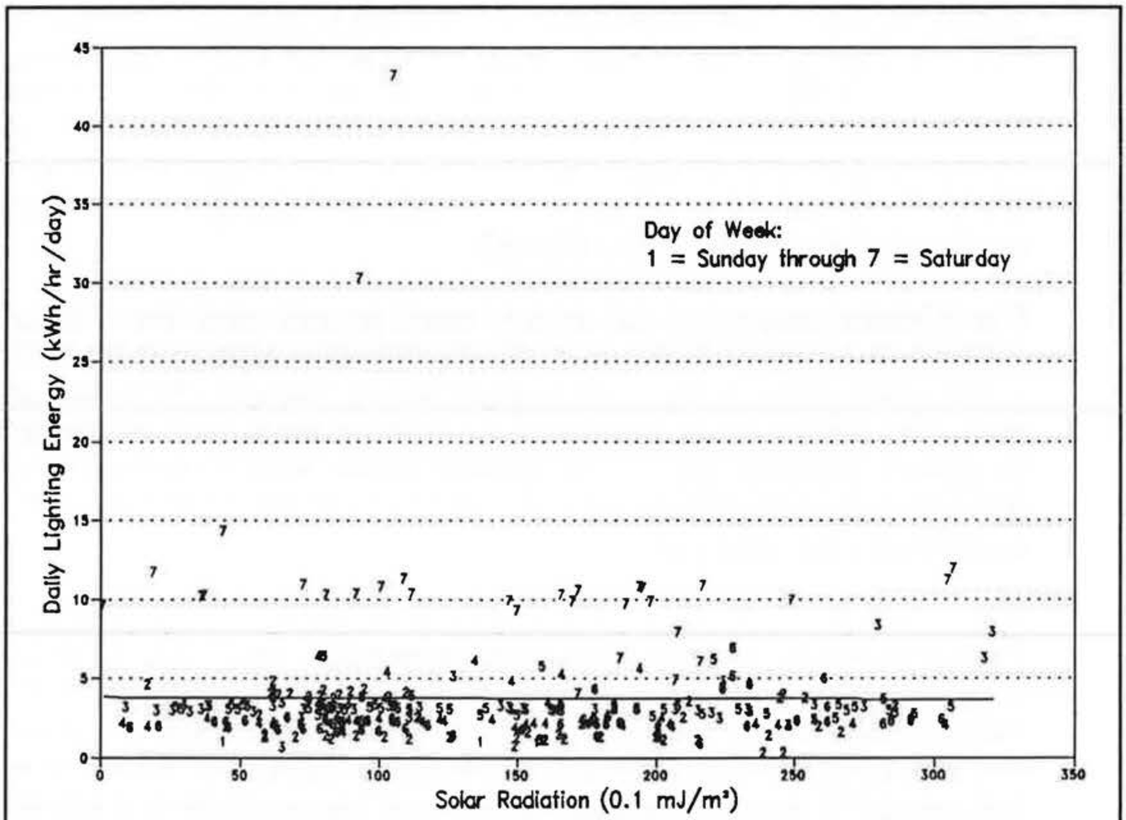

Figure 12 Lighting Energy and Solar Radiation

The effect of these differences can be seen in Figure 12, which shows that lighting energy use is not significantly affected by the availability of sunlight.

Each point represents the energy use per opening hour plotted against the solar radiation for the day the reading was taken. The regression line has an R^2 of 0.01%, i.e. virtually none of the variation in lighting energy use can be accounted for by solar radiation. A similar result is found when hours of sunshine are compared to lighting energy use. The numbers represent the days of the week, where 1 is Sunday through to 7 which is Saturday. In Figure 12 a number of the "7"s form a distinct group with consumption higher than the other days of the week. A check found these 22 Saturdays had about twice (10 kWh/hr compared to the normal 5 kWh/hr) the normal Saturday lighting electricity use. As it is unlikely that twice as many lights were turned on for some Saturdays, this would suggest that on some Saturdays the library is used for extra hours. To put this into perspective, on a normal Saturday 5 kWh/hr are used for three hours (13.5 c/kWh) for a cost of $2.03 while on the other Saturdays the cost would be $4.06. For all the 22 Saturdays the additional light electricity cost is $44.55, or 70% of the one day's heating electricity cost ($365 per week from Section 4.5.3).

Hence, although the lighting electricity use is above that expected, it is very small in comparison to the heating electricity use. Some savings are possible from the $1,125 annual lighting electricity cost, but effort should firstly be directed at the heating electricity use. If we compare the actual energy use of 30 GJ for lighting with the 74 GJ expected (see Appendix D.4) if the lights are on continuously when the library is open, then apparently there is already a significant reduction in lighting energy use due to daylighting.

5 SUNCODE COMPARISON

The use of computer thermal simulation packages in building design is now a relatively simple matter with improvements in computers as well as ease of use. However very little work is available comparing computer model results with actual performance. This project has allowed this to occur for the first time in New Zealand. The International Energy Agency Solar Heating and Cooling Agreement Task XI "Passive and Hybrid Solar Commercial Buildings" is presently completing a major study systematically comparing the results from computer simulations prior to construction with measurements in a number of buildings. New Zealand is no longer a member of this international co-operation and the detailed results are unlikely ever to be available through formal publishing channels.

Computer simulation models do not predict energy use. They offer an ideal world view - where the climate behaves as it is meant to, every component in the building is perfect and no human is allowed to deviate from the path of perfection. Extensive experience in investigations of building energy use (see for example Isaacs & Donn 1990) confirms that the most variable aspect of building energy use is the people, with other aspects following far behind.

This section therefore compares an "expected" energy use with the actual case. Differences of 50% are not unexpected, although gross differences tend to suggest, if corroborated by other information, that something is in error. Appendix D provides a detailed analysis of the differences between the design modelling assumptions and the actual energy use of the library over the period April 1990 to July 1991.

Figure 13 compares the actual energy use in 1990 and 1991 with that produced by the SUNCODE modelling program using the assumptions detailed in Appendix D. The very high energy use in 1990 shows clearly, with a noticeable fall between July and August 1990. The 1991 consumption is lower, but still higher than the SUNCODE model would have suggested.

Table VIII compares the SUNCODE monthly electricity end-use by type with the total 1990 and 1991 actual electricity use. The values given as "SUNCODE HEAT" are taken from Table XIV in Appendix D, and are the direct output of the computer simulation. However the computer model assumes the energy used in lighting and power contributes to heating - i.e. the electricity used for powering equipment (which ends up as heat) means less electricity needs to be used for heating. As the modeled light and power energy use is higher than the actual energy use, this extra heat energy has been added to give the data in the first column to give the "Adjusted Heat" for the months of April through October inclusive. Power and light monthly consumptions have been derived from actual readings for 1990 (July to December) and 1991 (January to August). Although monthly comparisons are possible, a full year of correct operation has yet to occur.

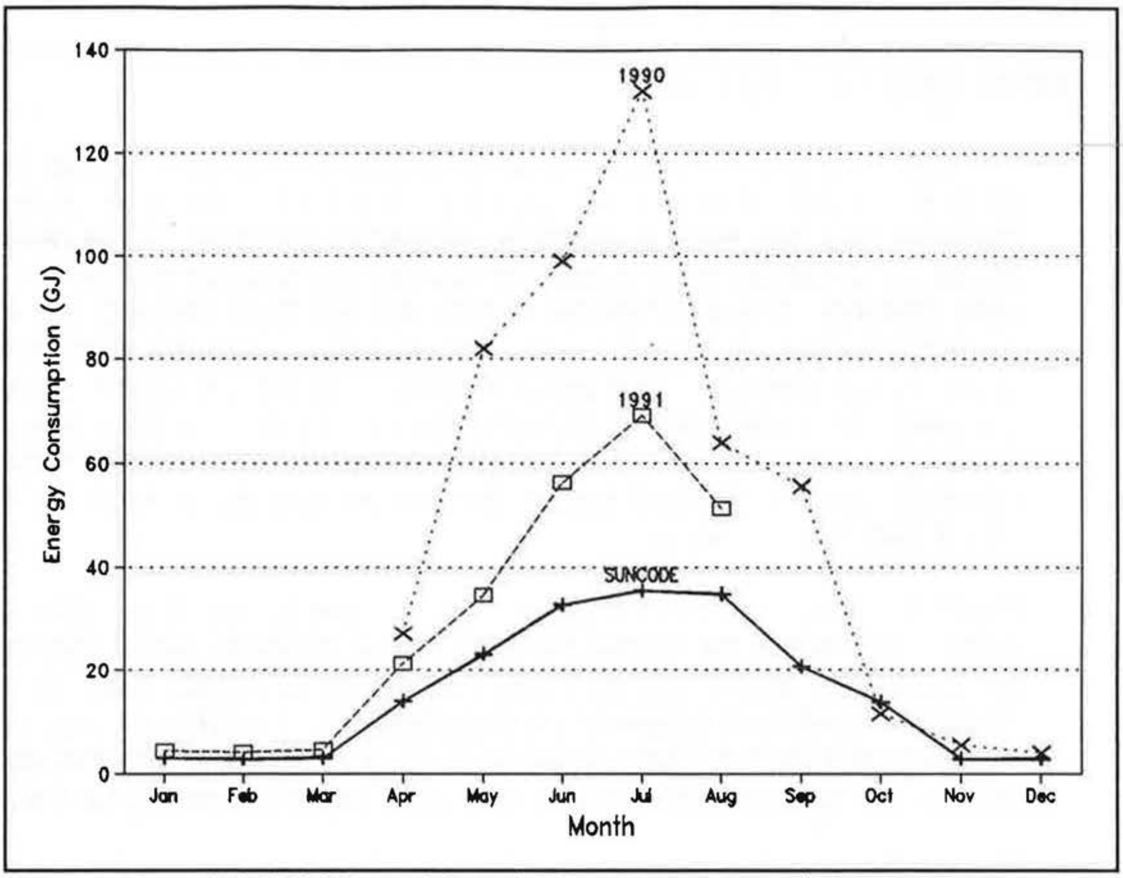

Figure 13 SUNCODE model and 1990 & 1991 Actual Energy Use

Energy GJ	SUNCODE HEAT	Adjusted Heat	ACTUAL Light	ACTUAL Power	Energy Use	Energy Use 1990	Energy Use 1991
Jan	0.0	0.0	2.5	0.5	3.0		4.3
Feb	0.0	0.0	2.3	0.5	2.8		4.1
Mar	0.0	0.0	2.6	0.5	3.1		4.5
Apr	2.4	10.9	2.3	0.5	13.7	27.2	21.4
May	11.6	20.5	2.7	0.5	23.7	82.1	34.5
Jun	21.3	30.7	2.4	0.5	33.6	99.1	56.3
Jul	23.9	36.0	2.8	0.6	39.4	132.0	69.2
Aug	23.2	33.0	2.8	0.6	36.4	64.0	51.4
Sep	9.1	18.0	2.4	0.5	20.9	55.7	
Oct	2.1	11.4	2.5	0.6	14.5	11.6	
Nov	0.0	0.0	2.4	0.5	2.9	5.5	
Dec	0.0	0.0	2.3	0.5	2.8	4.0	
TOTAL	93.6	160.5	30.0	6.3	196.8	481.2	245.7

Table VIII Validation of SUNCODE Model

The main difference between the modeled and actual energy use is in the heating energy use, where the actual 1991 consumption (January to August) of 245.7 GJ is about 60% more than the adjusted model of 155.7 GJ. This again suggests that there are still further energy savings possible.

6 CONCLUSIONS

The results of the monitoring have shown that even in New Zealand the coupling of energy modelling with design work can result in an energy efficient building. Even so, if the energy systems are not commissioned and operated correctly, an energy efficient building can easily turn into an energy wasteful building.

The result of this work, demonstrated by the monitoring reported here, has been to provide a comfortable, spacious building.

6.1 Conclusions

The various aspects of the design and operation of the building have been discussed in this report based on the measurements taken from April 1990 to July 1991. This section draws conclusions from these results.

6.1.1 Temperatures

The provision of detailed, performance oriented specifications permitted the designers to take an innovative approach to the design of this building. Although such specifications can still be used to force particular solutions, they were also tempered with an acceptance of trade-offs. In exchange for a small number of summer days with high internal temperatures, a naturally ventilated building was possible. The requirement that the heating system should allow for a winter working temperature of 20°C when there is an outside minimum temperature of 5°C has been achieved.

During the coldest week of the year (10 June 1990 to 16 June 1990), the temperature at the Children's desk averaged 15°C at 9 am when the outside temperature averaged 2°C. The target inside-outside temperature difference of 15°C has not quite been reached at this worst time of the day. For the rest of the library, and for the rest of the day at the Children's desk, the target difference is maintained. The Children's desk area could be brought up to a more acceptable temperature at 9 am if the heating system were more responsive to external temperatures and not operating merely as a time-clock, or if extra local heaters were installed in this area.

6.1.2 Natural Daylighting

The library receives a good supply of natural daylight throughout the floor area, as suggested by the modelling. Although the levels of illumination have not met the specification in all places, the main problem appears to have come from the strong effect of the large amount of vertical glazing which forms the exterior walls. This presents a strong light source that makes any comparison with the daylight provision to the internal spaces appear inadequate. This aspect of the energy design has not worked as well as would have been hoped, but the overall feeling is one of light and openness that was a design intention of the architect. The view out over the book-stacks from almost anywhere in the public areas of this deep plan building helps this "feeling".

6.1.3 Heating Energy

The building has achieved considerable savings in electricity use as well as in the reduced capital costs through not requiring either a new substation or air conditioning. Although the first year of operation had a high energy use, this is attributable to the fact that the heating control system was still in the process of commissioning. This initial period of high use does serve as an indication of how much energy might be used in a building if it is not operated correctly. The well operated building (1991) shows a 60% saving for heating energy used compared to 1990.

There is some doubt whether the temperature sensors used to control the ceiling heating panels are either correctly located or of a suitable type. As the library uses a radiant heating system, the sensors have to be positioned so that they are beneath the panels, and hence in the path of the radiant energy. The present placement of air temperature sensors high on the wall may lead to inefficient operation, as the air will be heated at a slower rate than the people at whom the heat is directed. This is possibly the cause of some of the complaints about some parts of the library occasionally being too hot. The actual locations of the sensors should be checked and compared to the manufacturers recommendations, and the positions changed if warranted.

Now that the heating control system has been commissioned, there are still opportunities for further savings through improved understanding of the operation of the library and use of the controller. In particular the poor relationship between internal temperatures, external temperatures and energy use suggests that the controllers' optimum start-stop feature would be of benefit. This feature monitors the external temperature against the required opening time internal temperature. The controller then compares this to the patterns of the previous days and adjusts the start time to be as late as possible. Conversely in the afternoon it arranges to 'stop' heating as early as possible based on the internal temperatures, the learnt cooldown relationships and the external temperatures.

6.1.4 Lighting Energy

Lighting electricity is higher than would have been expected from the day light modelling. However, the total energy use for lighting is less than half what would be expected if the lights were on all the time that the library was in use.

While lighting electricity use is small compared to heating, it is still a significant annual expenditure of $1,125 (plus supply charges and GST). This would suggest that although further savings may be possible in the lighting area, the measures should be viewed in relationship to the likely savings.

6.2 Investment Economics

The capital cost savings made in this building by using natural energy and natural ventilation are about $70,000 (all costs exclude GST). These more than paid for the energy efficient features and the additional design work required. The energy modelling work cost $19,000 while the additional design and quantity surveying work was estimated at $5,000.

Annual Cooling Cost with Heat Pump Systems: (present system: no cooling, alternative system: heat pump system with COP 1:3)		
53,000 kWh/yr @ $0.135 = $8,000/3	+$2,700	
Fan (1500 W)	+$500	
Maintenance	+$2,000	
Replacement (5 year life)	+$10,000	
Cooling Cost		+$15,200
LESS Heating Savings (present system: radiant panels, alternative system: heat pump system with COP 1:3)		
Present cost (heating only)	-$10,000	
Heat pump 1:3 running cost	+$3,200	
Heating Cost Savings		-$6,800
NET ANNUAL SAVINGS		**$8,400**

Table IX Calculation of Annual Cost Savings

The running cost savings system are estimated based on an alternate system with air conditioning provided by unit heat pumps for 5 zones. The approximate cost is estimated at $10,000 per zone, with a design life of 5 years. The cooling energy estimate of 53,000 kWh per year was provided by Citipower. Table IX shows that the major savings come from reduction of capital and maintenance costs, with the added cooling energy costs being matched by savings in heating energy due to the benefits of the heat pump.

6.3 Recommendations

This section provides recommendations for action for this building. Opportunities for other buildings are discussed in Section 7.

6.3.1 Lighting Energy

- Investigate the cost of providing greater zone control of public area lighting, to determine if a cost-effective solution is possible.

6.3.2 Heating Energy

There are still energy management opportunities for heating energy use:

- Maintain tight control over the operation of the controller including regular checking of the operating regime.
- Investigate the use of the 'optimum stop/start' feature of the controller by reducing the number of sensors used for internal zones by one and using that sensor input to monitor external temperatures.

7 REPLICATION

The range of energy options available in Nelson is limited - electricity, LPG or coal. The purpose of this final section is to draw conclusions that have wider significance for low energy buildings in other parts of New Zealand.

If the building had been built in a North Island city, a choice may have been to use Natural Gas as the heating fuel. The result of this would have been to highlight the higher cost lighting electricity relative to the heating energy. A comparison that does not consider any differences in capital cost, regular maintenance costs or supply charges is made in the following graphs.

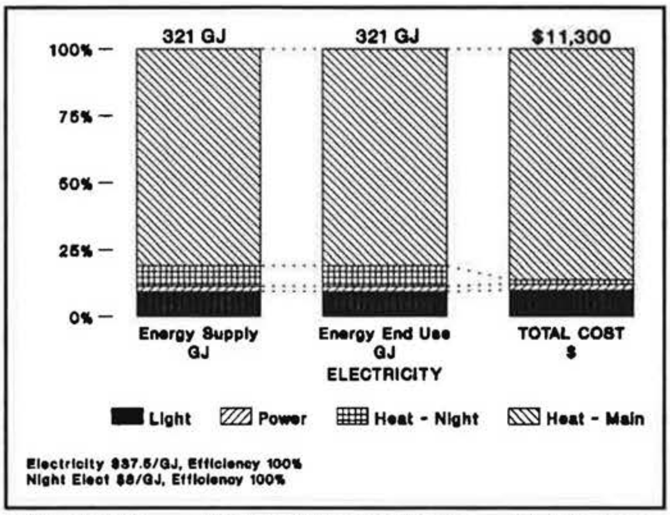

Figure 14 Energy Breakdown - All Electric

The total energy use in the Nelson library over the year once the initial commissioning work had been completed was 321 GJ. Figure 14 shows the components of the energy use, the cost of energy and the total expenditure. An energy use efficiency of 100% has been assumed for heating - whether by night store or radiant ceiling panels. This gives a total annual energy cost of $11,300.

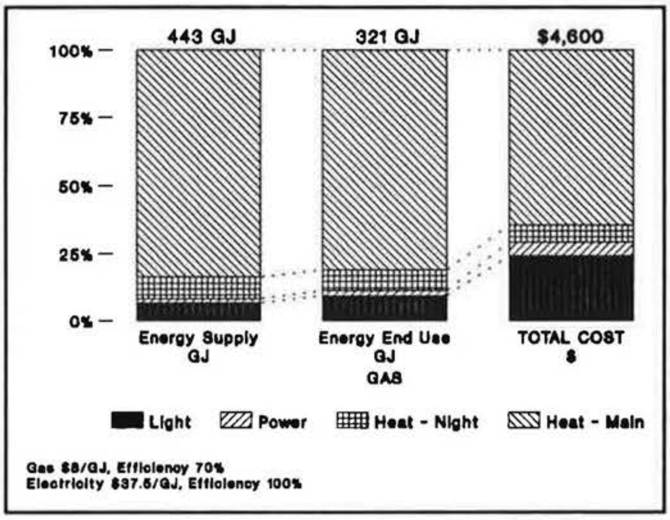

Figure 15 Energy Breakdown - Gas heating

Figure 15 takes the energy use shown in Figure 14, assumes heating efficiency of 70% for a flued gas heater (Energy Information Centre 1989) and calculates the annual total energy cost of $4,600 based on a gas price of $8/GJ.

It can thus be seen that in a building of this type in a North Island city with an alternative heating fuel, the energy use for lighting would be far more important as a proportion of the total expenditure.

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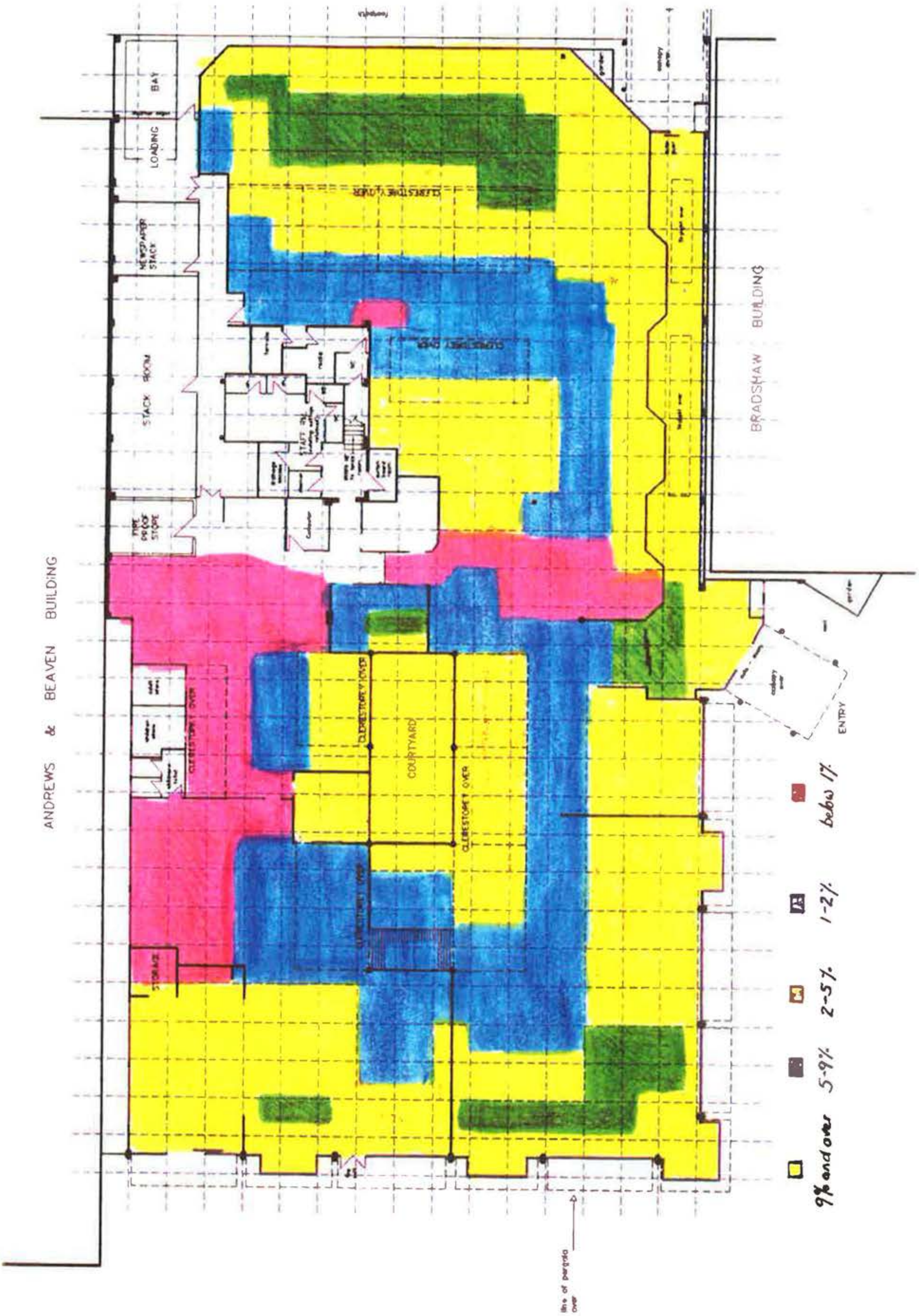
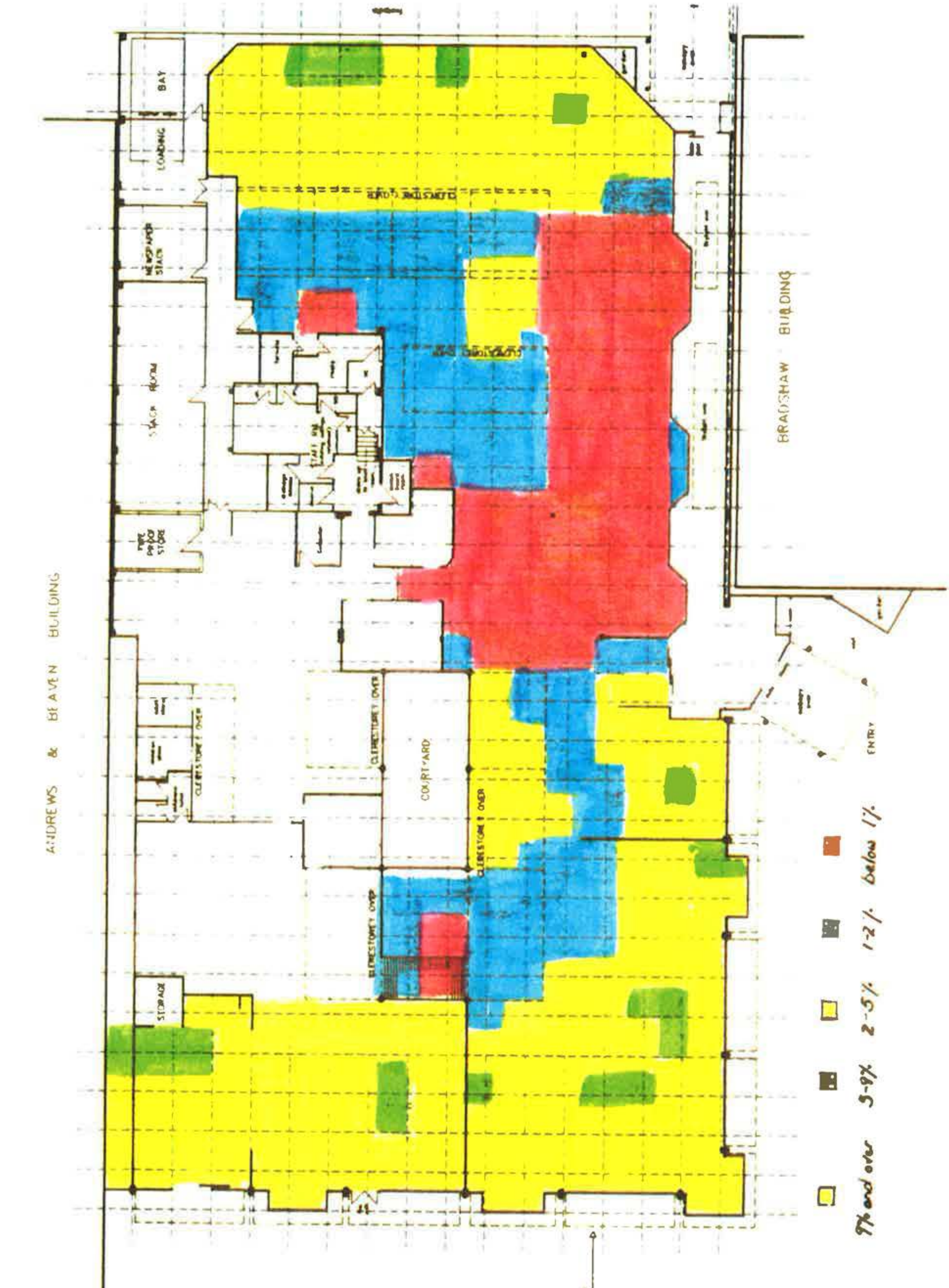
APPENDIX A : DAYLIGHT DIAGRAMS

The following pages provide colour photocopies of daylight factor plans derived from the physical model constructed during design, and actual measurements taken on 27 July 1991. A floor plan indicating the present lighting regime and the actual lighting circuits is also provided.

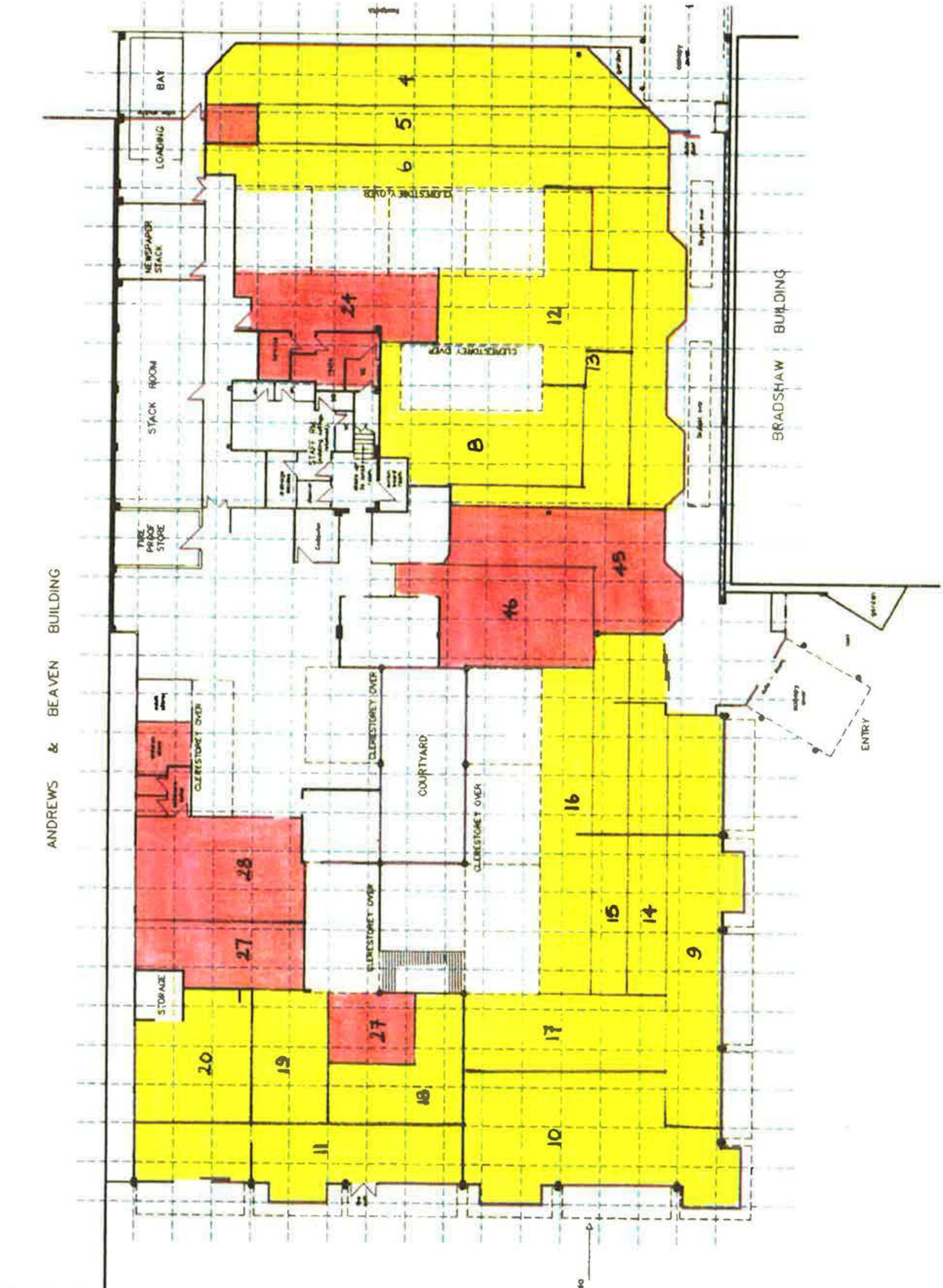
A.1 Design Model Daylight Factors



A.2 Actual Daylight Factors



A.3 Lighting Circuits



APPENDIX B : AIMS SENSOR LOCATIONS & RESULTS

Twenty three AIMS PFT Samplers where placed in the building from 11 February 1991 to 21 February 1991. The results provided by the NAHB National Research Centre (Project:NZ-Special, 8 March 1991) and the sensor locations are summarised below:

Detailed Location and results:

	ID#	Location (Volume)	PMCH Concentration pl/l
		Work Room (502 m^3)	
1	1640	On divider screen	5.323
2	2180	Internal wall above thermometer	7.207
3	889	Above divider (open top)	4.668
		Children's Library (868 m^3)	
4	2376	Above divider (open top) between adult & children's fiction	8.671
5	1995	On internal wall opposite sliding door to outside playground	4.781
6	1785	Far end of clestory cut away	4.665
7	1312	Internal wall to right of clock	3.541
8	1676	Internal wall above Children's Reference Books	3.609
		Adult Fiction (1202 m^3)	
9	1385	Far end of clestory cut away	4.755
10	1590	Held below ceiling tile above "Easy Readers"	3.663
11	890	Held below ceiling tile above "Large Print Books	3.422
12	2165	Held below ceiling tile above "P-T, U-Z Fiction"	3.090
13	213	Far end of clestory cut away	3.005
14	2310	Above open-top wall Newspapers & Fiction books	3.111
15	245	Beyond "display" unit at Service Desk	3.344
		Non-Fiction / Entrance (2113 m^3)	
16	1889	Above Chief Librarian's office door	3.851
17	1862	Internal wall behind Reference Desk	3.378
18	28	Below beam on column in front of Reference Desk	3.022
19	2280	Above window Non-fiction Reference, face Reference Desk	4.207
20	1223	Internal wall above heating thermostat	5.489
21	540	Held below ceiling tile above "800-819"	5.832
22	123	Held below ceiling tile above "630-635.9"	3.779
23	1419	Above glass fronted reference cabinets	4.191

Average Tracer Concentration 4.374 pl/l

TOTAL VOLUME 4685 m^3

Overall Infiltration rate: 8637.6 ± 1221.5 m^3/hr
Overall Air exchange rate: 1.844 ± 0.277 ach

AIMS Analysis was carried out by:
NAHB National Research Center
400 Prince Georges Boulevard, Upper Marlboro, MD 20772-8731, U.S.A.

APPENDIX C : UNOCCUPIED MONITORING

This appendix, prepared by Kathryn Davies, describes the unoccupied monitoring of the library, and provides a detailed summary of the results.

C.1 Procedure

Unoccupied monitoring requires the building to be sealed from outside influences such as solar radiation; and also from internal gains such as people and equipment in the building. Solar radiation was excluded from the building by covering all windows with reflective foil (Sisalation 252). All windows which might admit sun were covered during the day, and uncovered overnight so that normal heat loss occurs. On the final day of testing (31 July), the windows were not covered, but as the sky was overcast this should have had little impact.

Throughout testing, wind speeds remained lower than 3 ms^{-1}. Infiltration was thus normal (i.e. not forced by wind pressure), and so not a problem for the analysis.

Conditions within the library were not ideal, as people could not be excluded altogether from the building for the whole period of the test. The test was carried out over a weekend in an attempt to take measurements while the library was not open to the public. However, the building was open Saturday morning. The length of time the building was unoccupied was sufficient to provide a substantial amount of information on the thermal performance of the building.

The building was divided into eight zones, each of which had a temperature sensor connected to the **Paragon EC128** controller. At the time of the test the sensors had not been calibrated, and thermohygrographs were set up to double check the temperatures recorded. An additional thermohygrograph was set up in the courtyard to record the outside temperatures over the period. It had been arranged for the building to be heated to 21 °C and maintained at this temperature for several days. However, as the sensors were not calibrated there was some variation in temperature between the zones shown by the thermohygrograph records. To minimise the differences in temperatures throughout the building, the ceiling fans were kept on during the tests. The electricity use for these was recorded on a separate meter, and was insignificant compared to heating electricity use.

Temperatures were recorded every fifteen minutes by the **Paragon EC128**, and correction factors applied based on the difference between the sensors' reported temperatures and the thermohygrograph temperatures. Temperatures are only recorded to the full degree, and this results in small error. Electricity consumption was obtained by using **SUNX** Type PS-930M amplifier with an infra-red diode transmitter-receiver unit attached to the glass front of the electricity meters. The number of times the black mark on the meter disk passed the sensor was recorded every minute by a **TAUPO** datalogger (Solid

State Equipment Ltd), and the meter calibration (450 revolutions per 60 kWh) used to convert the count into electricity consumption.

C.2 Results

Steady state test

The purpose of the steady state test was to determine the heat loss coefficient (L) for the building, which is calculated from Equation 2.

$$L = \frac{\text{average power used}}{\text{average temperature difference}} \qquad \textbf{Equation 2}$$

The building is firstly heated to a constant temperature, and then the energy required to maintain this temperature recorded. Once the constant temperature is attained, it can be assumed that all building elements are at that temperature, and no energy is being used to increase heat storage within the building. At this point, all energy that is being supplied to the building is being lost to the outside at a rate controlled by the overall heat loss coefficient.
The library was heated to a constant 21 C, and then held at this temperature from 7:00 pm 28 July to 8:00 am 29 July. The measurements were made overnight to obtain constant outside temperatures, and to maximise the average temperature difference between inside and out.

Cooldown test

The cooldown test required the building to be maintained at 21 °C until a certain time, when all heating was switched off and the building allowed to cool. This test was carried out on 31 July, with the heaters switched off at midnight on 30 July. The rate of cooling was measured from midnight to 7:00 am. The thermal decay time constant (τ) is derived using Equation 3:

$$\tau = \frac{time}{\ln\,(\Delta t_i\,/\Delta t_e)} \qquad \textbf{Equation 3}$$

where: $time$ = *end time - start time (hours)*
Δt_i = *initial temperature difference inside - outside*
Δt_e = *end temperature difference inside - outside*

From these results, the building thermal capacity is given by Equation 4:

$$C = L\tau \qquad \textbf{Equation 4}$$

where: C = *thermal capacity*
L = *heat loss coefficient*
τ = *thermal decay time constant*

As there was some variation between temperatures in each zone, calculations were carried out for each zone independently, and for an average temperature over all the zones.

Test Results

The results of the measurements and calculations are set out in Table X, but they must be used with caution. Although temperatures could be measured for

	HEAT LOSS COEFFICIENT (W/K)	TIME CONSTANT (hrs)	THERMAL CAPACITY (kWh/K)
ZONE 1	5,385	22.2	119,492
ZONE 2	5,340	21.2	113,257
ZONE 3	5,396	16.5	88,813
ZONE 4	5,078	20.6	104,522
ZONE 5	6,105	13.6	83,281
ZONE 6	5,751	14.0	80,449
ZONE 7	5,731	17.9	102,424
ZONE 8	5,083	22.9	116,351
AVERAGE	5,464	18.6	102,116

Table X Unoccupied Monitoring Analysis

each zone, it was not possible to measure heat energy (i.e. power used) in each zone and the average power consumption for the whole building has been used. The differences in time constant for each zone in the table are therefore merely an by-product of the estimation procedure; the individual values have no meaning. It is expected that the result for the whole building is realistic.

C.3 Comparison with SUNCODE Assumptions

At first inspection, the thermal characteristics computed by SUNCODE in the original design modelling (N6BASE), and those calculated from the steady state and cooldown test results to differ markedly. However, the principal differences were due to the modelling approach which had been to most accurately represent the entire building with respect to energy use, rather than calculate the average building thermal characteristics.

SUNCODE calculates an average heat loss coefficient by area weighting the sum of all the thermal coefficients of the "external surfaces". The thermal capacity is computed from the thermal properties of the constituent materials in the building as described in the input file. From these results the time constant is derived, using the same formula as Equation 4.

With respect to the thermal capacity, in order to improve the realism of the heat loss calculation through the floor to ground, one metre of earth had been modelled as part of the floor of the building. By doing this, the ground temperatures for the area, measured at a depth of one metre, could be used. This resulted in more accurate modelling of the ground heat losses. However, in reporting the global heat capacity for the building this metre of earth had been included by SUNCODE as part of the thermal capacity of the building, considerably increasing the apparent overall thermal capacity.

The heat loss coefficient differed in the model for two reasons:
First, the courtyard was modelled as an internal zone with a transparent but high conductivity cover (U-value 99.9). This allowed the thermal performance of the building model to be close to that actually occurring, with the building

losing heat to a courtyard which, was exposed to outside air temperatures but, was not exposed to the extreme of sun and wind of a real outside surface. The aim was to 'fool' SUNCODE into modelling a more realistic situation. In this it was successful. However, as a factor in the summary thermal loss coefficient, this "glazed" top contributed almost 25% of the SUNCODE total heat loss.

The second reason for difference arose from a decision to model the ceiling heat loss more accurately with SUNCODE than is normally possible with manual calculations. The ceiling void was modelled as a separate zone. SUNCODE calculated the heat loss through the ceiling and insulation into this zone, then out from this zone through the steel roof. When interrogated about the heat loss through the 'outside' surfaces, SUNCODE returns the heat loss through the steel. In the test, the heat loss is measured from the heated internal spaces through the ceiling void. By calculating the heat loss of the building elements (as reported in the SUNCODE input file) and adding them together, a heat loss coefficient resulted that was much closer to the measured figure.

Heat loss calculations

	Heat loss coefficient (W/K)	Time constant (Hours)	Thermal capacity (kWh/K)
MEASURED	5460	19	102100
SUNCODE	3800		212400

Table XI SUNCODE Examination of Thermal Characteristics

Table XI compares the thermal characteristics of the building as found by the testing process and those based on the SUNCODE model after removing the effects of the courtyard and the one metre layer of earth, and combining the ceiling, void and roof.

Because of the way the SUNCODE program has been used, it was not expected that these figures would map precisely. However, it is encouraging to see that the measured results are of the same magnitude as those computed by SUNCODE, although the heat capacity of the model was too great.

As a final check, the base SUNCODE model (N6BASE) was rerun to simulate the tests that had been performed. Weather files for Nelson were created which followed the climate during the testing period. The results, and the external temperature conditions are illustrated in Figure 16.

Figure 16 shows the SUNCODE model predicted a much sharper response to the outside temperatures than measured. The small fluctuations in the graph of the test measurements are due to the testing equipment recording only in 1 degree increments. Following this run, the SUNCODE was adjusted to reflect the infiltration measurements.

In the base model, an infiltration (air leakage) rate of 1 air change per hour was used (assuming all windows closed) but this may have been too high based on

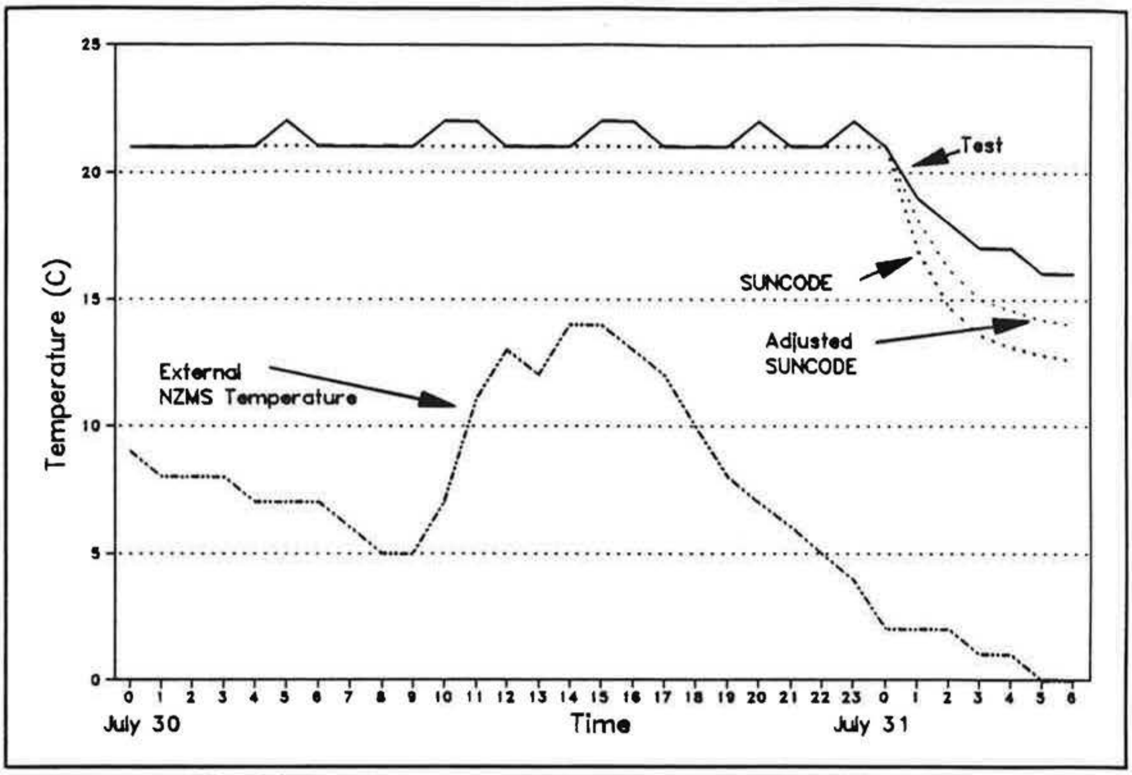


Figure 16 Cooldown test temperatures

the later infiltration measurements. The effect of reducing the infiltration from 1 ACH to 0.1 ACH is to increase the temperatures during the cool down period. However it does not bring the rate of temperature decay into line with that actually measured.

The rate of fall in the internal temperature is a combination of heat loss and heat gain from the building heat storage. A standard assumption is that there is a higher actual heat capacity than modelled. However it may be lower real heat loss, which would agree with the conclusions in the previous sections.

From this it can be inferred that the building envelope affords greater protection to the inside spaces than was initially assumed. The building is thus less responsive to external conditions, and the internal climate is far more stable than anticipated. This conclusion is consistent with the temperatures measured in February 1990, when the building remained cooler than predicted.

APPENDIX D : SUNCODE COMPARISON

This appendix, prepared by Ian van der Werff, describes the SUNCODE modelling undertaken to compare the actual energy use with an operating regime and climate more closely modelled on "actual" than was possible in the design work.

D.1 Summary

We are interested in comparing the results of the building that was modelled (N6BASE) with the actual running of the building, now that it is operational.

Various assumptions were made with N6BASE, that we find have not occurred in the actual building. In particular, we will be altering three broad assumptions that were made at the time of the modelling:

a) Adjust the infiltration and ventilation rates (IV);
b) Adjust the HVAC hours of operation, operating temperatures and heating capacities (HT);
c) Adjust the occupancy (internal gain) profiles (OC).

All simulations (with the exception of N6BASE) were run using the actual heating start and stop dates for 1990 (as we are using 1979 weather data, this is not strictly accurate, but a reasonable assumption)

Ten different simulations were undertaken, namely

N6BASE	Original simulation undertaken before construction.
N6MASTER	Original simulation with altered heating season.
N6IV	Master as base, with adjusted IV.
N6HT	Master as base, with adjusted HT.
N6OC	Master as base, with adjusted OC.
N6IVHT	Master as base, with adjusted IV and HT.
N6IVOC	Master as base, with adjusted IV and OC.
N6HTOC	Master as base, with adjusted HT and OC.
N6IVHTOC	Master as base, with adjusted IV, HT and OC.
N6AMBTEM	Non-simulation, producing only hourly weather data, so as to obtain degree day comparison with 1990.

D.2 Infiltration and Ventilation

The infiltration rate was initially assumed to be 1.0 ACH for all 24 hours every day, and the natural ventilation was assumed to have a capacity of 10 ACH which was available above that achieved by infiltration as required.

Since completion, the building has been measured to have an actual air change rate of 1.844 ACH. This assessment was made after measurements over 2 operational weeks, and incorporates both infiltration and ventilation.

Accordingly, we will remodel the building using an infiltration rate of 0.344 and a ventilation capacity of 1.5. These changes will apply to the public and administration zones only.

It should be noted that we do not know what the weather conditions were at the time of the actual measurements within the building, and accordingly the value of 1.844 may vary in practice, depending upon wind speed and other climatic conditions.

D.3 HVAC Profile

The heating profile was originally modelled as:

Heat to 20°C from April 1 to November 30
No heating in Summer
Heating times from 8 am to 6 pm
Heating capacity was 145 KW in public zone
Heating capacity was 30 KW in administration zone

The heating profile that appears to be used within the actual building is:

Heat to 18°C from April 23 to October 10 (public area)
Heat to 18°C from April 23 to October 10 (administration area)
No heating in Summer
Heating times from 7 am to 8 pm (Monday)
Heating times from 7:30 am to 6 pm (Tuesday and Thursday)
Heating times from 7:30 am to 8 pm (Wednesday and Friday)
Heating times from 8:30 am to 11:45 am (Saturday)

Heating capacity of the public zone heating panels is 131.5 KW. Given the high level of thermal insulation above the panels, about 10% of this heat would go up into the ceiling space, hence the heating capacity of the public zone is 118.4 KW.

Heating capacity of the administration zone heating panels is 19.75 KW. Assuming 10% of this heat goes up into the ceiling space, the heating capacity of the public zone is 17.8 KW.

The heating times that we have modelled are:

Heating times from 7 am to 7 pm (Monday-Friday)
Heating times from 9 am to 11 am (Saturday-Sunday)

The ventilation profile that was modelled was:

Start venting if the temperature rises above 26°C (in Winter)
Start venting if the temperature rises above 15°C (in Summer)

The venting profile actually in use is difficult to determine. The maximum temperature attained in each month in winter averages at 22°C in the public area and 21°C in the administration area. If venting was required, there was apparently sufficient capacity to keep the temperature below 22°C. The maximum temperature reached in the hot summer months (January - March) averaged 25°C in the public spaces and 24°C in the administration spaces.

Therefore, the ventilation profile that we will now model is:
Start venting if the temperature rises above 22°C (in Winter)
Have continuous venting (open windows day and night) during Summer

Assumptions that have been made with the actual building are:

- All the energy provided to heating panels enters either the public or administration zones as heat. The problem here is that we are unsure how much of this energy would actually go up through the ceiling insulation into the ventilated air space.
- The number of radiant panels were measured off the drawings as:

Public Area:	856 No. @ 125 W
	49 No. @ 500 W
Administration Area:	130 No. @ 125 W
	7 No. @ 500 W

- There is also constant heating from all the lights, but this is incorporated in the internal gain profile.
- The library closes at 6 pm two days and 8 pm three days of the week, so this has been averaged to 7 pm. The library is open on Saturdays from 9:30 am to 11:45 am. SUNCODE cannot model Saturday separate from Sunday, so the Saturday operation has been split over the two days.
- To achieve continuous summer venting, set the venting point at 10°C.

D.4 Internal Gain Profile

The assumptions made in the original modelling were:

- The library was open from 9 am to 6 pm every day.
- The lights were switched and controlled automatically to turn off if there was sufficient daylight.

The library is actually open to the public from 10 am - 6 pm Tuesday and Thursday, 10 am - 8 pm Monday, Wednesday and Friday, and 9:30 am - 11:45 am on Saturday. The staff arrive at 8 am during the week and 9 am on Saturday, and leave at closing time. Because of modelling restrictions, the Saturday timings must be split evenly with Sunday. The modelling schedule is:

<u>Weekdays:</u>

8 am	Staff arrive and turn on all lights throughout library, and all equipment in administration area.
10 am	Public are admitted, and remaining equipment is turned on.
7 pm	Library is closed down for the night. (There is a small amount of equipment that operates 24 hours.

Weekends:

9 am	Staff arrive and turn on all lights throughout library, and all equipment in administration area.
10 am	Public are admitted, and remaining equipment is turned on.
11 am	Library is closed down for the night. (There is a small amount of equipment that operates 24 hours.

The library has a large number of recessed ceiling light fittings. The public area lighting has a total rate of energy use of 5.4 KW. The administration area lights have a total rate of energy use of 1.26 KW. For this calculation, we will use the theoretical energy used by these lights based on the following hours of occupation: all these lights are on for 12 hours 3 days/week, 10 hours 2 days per week and 3 hours one day per week. Using 52 weeks/year, this implies that the lights are on for 3068 hours/year giving an energy use of lighting of 20432.9 KWh or 73.6 GJ

The miscellaneous electrical equipment modelled was:

photocopier, 1.2 KW, turned on during occupation.
computer terminals. 0.12 KW each, 11 in total, on during occupation.
computer, 1 KW, on 24 hours/day.
pabx, 0.1 KW, on 24 hours/day.
other, 0.2 KW, on during occupation.

This gives an energy use of 345.3 KWh/week; 17955 KWh/yr; or 65 GJ/year.

Zone	Season	Hour	Value	Hour	Value	Hour	Value	Hour	Value
public	week	1	0	9	6.3	11	14.5	20	0
public	weekend	1	0	10	6.3	11	14.5	12	0
admin	week	1	1.0	9	5.46	20	1.0		
admin	weekend	1	1.0	10	5.46	12	1.0		
lobby	week	1	0	9	0.5	20	0		
lobby	weekend	1	0	10	0.5	12	0		

Table XII As-built SUNCODE Modelling Assumptions

The SUNCODE modelling schedule showing power input to the building based on these calculations for hour ranges across the day is given in Table XII.

D.5 Summary of the results from each of the runs

RUN ID	TOTAL GJ	$ Saved	Worst Month GJ		Worst Month KW		Max Temp Public	Max Temp Work	Min Temp Public	Min Temp Work
Scheme 3 No insulation	222	BASE	50	JUL	172	AUG	29.2			
N6BASE	160	1860	35	JUL	157	AUG	27.7	27.8	5.3	6.0
N6MASTER	146	2280	35	JUL	157	AUG	27.7	27.8	5.3	6.0
N6IV	98	3720	24	JUL	135	AUG	30.5	31.0	6.6	7.6
N6HT	117	3150	28	AUG	134	AUG	27.7	27.8	5.4	6.2
N6OC	181	1230	44	JUL	152	AUG	26.9	26.4	5.3	6.0
N6IVHT	81	4230	20	JUL	120	AUG	30.7	31.0	6.7	7.8
N6IVOC	126	2880	31	JUL	130	AUG	30.0	29.2	6.6	7.6
N6HTOC	122	3000	30	JUL	135	AUG	27.0	26.4	5.3	6.0
N6IVHTOC	84	4140	21	JUL	122	AUG	30.0	29.2	6.5	7.5

Table XIII SUNCODE runs summary

The run N6IVHTOC is theoretically the building as it now is, but how does the predicted energy use compare with that actually achieved by the building.

The first thing to consider is that each figure for total energy used (GJ) shown in this table only represents the total heating energy use within the zones of the building. This is only 90% of the total energy used by the heating panels, as our model assumed that 10% of the provided heat would be lost to the ceiling space. We also need to add the amount of energy used each year for the lighting and other miscellaneous equipment.

Energy in GJ Run ID	Heat to Zones	Total Heat	Lighting	Misc	Total Energy Use
N6BASE	160	178			
N6MASTER	146	162			
N6IV	98	109			
N6HT	117	130			
N6OC	181	201	74	65	340
N6IVHT	81	90			
N6IVOC	126	140	74	65	279
N6HTOC	122	136	74	65	275
N6IVHTOC	84	93	74	65	**232**

Table XIV SUNCODE Calculated Total Energy Use

A summary of the results with the various components is given in Table XIV.

APPENDIX E : DOCUMENTATION

This Appendix summarises the materials held by the Energy Research Group, and the documentation used during the investigation.

E.1 Photographs and slides held

In addition to a number of "miscellaneous" transparencies taken during visits to the library, it was arranged for a member of the Upstream Design team (normally Rita Vitma) to make regular visits to the library to record the changes in lighting affects during the year, and day. Table XV gives the dates and times of day for the views listed in Table XVI.

Date	Time of Day		
12-Nov-90	10:10 AM		
16-Nov-90		1:20 PM	4:20 PM
18-Dec-90	10:00 AM	12:20 PM	4:45 PM
20-Feb-91	10:00 AM	12:30 PM	4:30 PM
20-Mar-91	10:30 AM	12:30 PM	5:00 PM
24-Apr-91	9:45 AM	12:20 PM	4:20 PM
29-May-91	10:10 AM		4:50 PM
26-Jun-91	10:10 AM	12:35 PM	4:45 PM

Table XV Dates and Times of Regular Transparencies

1	From north side of Children's library towards desk.
2	Children's library east side from beside Desk
3	From Young Adults at centre North.
4	Towards main desk below clerestory (near computers).
5	Towards Front Desk & Reference area from Reference.
6	From west windows in Adult fiction area to east wall.
7	View in workroom facing east to external wall.
8	View in workroom facing clerestory and children's store.
9	View of mural towards Halifax entrance.
10	From main entrance through covered walkway to Halifax St.

Table XVI Location of standard views

Aerial views of Nelson	Main entrance
Bay window and light shelf	Manual vents
Ceiling hangings	Min/max thermometer
Children's issue desk	Mural
Children's library	Nelson Library wrapped in foil
Children's library external windows	Outside landscaped area
Clerestory	**Paragon EC128** controller
Clerestory and vent	Pupil's drawings of library
Computers	Roof
Courtyard from inside	Roof space
Courtyard from outside	SUNCODE test model
Daylight factor - model	Section - East to West
Daylight factor - actual	Section - North to South
Energy monitors	Section of library - Exterior wall
External corner glazing	Stairs to lunchroom
Foundation stone	Sunshade
Front desk	Typical light fitting - Off
Inside Halifax entrance	Typical light fitting - On
Internal plant	Venetians
Light controls	Front desk from Children's library
Light shelf	Workroom
Light shelf controller	Workroom and central courtyard
Lunchroom	Workroom thermometer

Table XVII Other Transparencies Held

Table XVII lists the transparencies taken during various visits to the library by Nigel Isaacs, Michael Donn or Gavin Woodward of School of Architecture, Victoria University of Wellington.

E.2 Computer Datasets

SPREADSHEET	Description
COOLDOWN.WQ1	Cooldown test
ENERGY.WQ1	Energy use & graphs
MAXMINWK.WQ1	NZMS & library tabulated max & min temp readings
NELDATA.WQ1	Model used for monthly data entry
NELSLIDE.WQ1	Catalogue of slides
NZMSNEL.WQ1	NZMS 301 reports
PARAGON.WQ1	**Paragon EC128** downloaded readings
PARAVG.WQ1	Analysis of **Paragon EC128** readings
R116LGHT.WQ1	Light energy use analysis
R116MTH.WQ1	Library readings sorted in months. Degree Day calculation.
R116NELB.WQ1	Library daily readings - source for other files
R116NELX.WQ1	Graphs & analysis
R116NORM.WQ1	Daily readings normalised by opening hours
R116SAS.WQ1	Input for SAS regression analysis
R116UNOC.WQ1	Unoccupied monitoring
REGRNELX.WQ1	Regression results
STEADYST.WQ1	Steady state test
WIND.WQ1	NZMS 301 Monthly wind summaries
WORKOUT1,2.WQ1	**Paragon EC128** analysis

Table XVIII QUATTRO PRO 3.0 Spreadsheets

All energy, water use and climate data is held in QUATTRO PRO 3.0 spreadsheets. Where necessary, this been loaded into SAS® Version 6.04 datasets. The names of the files and datasets along with a brief description are given in Table XVIII. All datasets, and associated programs are held on the Energy Research Group NOVACAD Longshine 3200 computer.

E.3 Documentation

The following pages provide copies of the documentation used in the investigation to record daily temperatures and meter readings:

ELMA TURNER LIBRARY NELSON - TEMPERATURES AND ELECTRICITY USE

MONTH : . . . .

		TEMPERATURES									ELECTRICITY METERS			
		Front Desk Temperature			Work Room Temperature			Children's Desk Temperature			Heat	Light	Power	Night
DATE	**TIME**	**NOW**	**MIN**	**MAX**	**NOW**	**MIN**	**MAX**	**NOW**	**MIN**	**MAX**	**3298855**	**358454**	**358640**	**379617**
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ELMA TURNER LIBRARY NELSON - TEMPERATURES AND ELECTRICITY USE

MONTH : . . . .

		TEMPERATURES									ELECTRICITY METERS			
		Front Desk Temperature			Work Room Temperature			Children's Desk Temperature			Heat	Light	Power	Night
DATE	**TIME**	**NOW**	**MIN**	**MAX**	**NOW**	**MIN**	**MAX**	**NOW**	**MIN**	**MAX**	**3298855**	**358454**	**358640**	**379617**
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