Environmental Design and Performance of the Paraparaumu Public Library

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NE façade - Workrooms and archives above, café below

INTRODUCTION

Located some 50km north of Wellington, the 1750m² Paraparaumu Public Library was opened in November 2002. The building has since won a New Zealand Institute of Architects' Supreme Award (one of only five awarded in 2004) (NZIA, 2004).

Not only did the building win architectural praise, it also won a Silver Award in the Association of Consulting Engineers of New Zealand's 'Innovate NZ 2004' Awards of Excellence (ACENZ, 2004).

We report here on the thermal environmental design features of the building and the results of our occupant survey of library staff and users.

THE DESIGN PROCESS AND OUTCOME

The design brief for the building was to create a low energy building which provided best value over the life of the building. Major design intentions included keeping the main library space comfortably cool without the use of mechanical cooling, and the exploitation of natural daylighting.

In order to achieve this, an holistic 'whole building' design philosophy was adopted, an approach which involved all the design consultants from the earliest stages of the project. The result was the development of a building form, fabric, structure and supporting systems that integrate with and compliment one another. The architecture minimises the need for mechanical heating and cooling energy, and the exposed structure and ventilated concrete floor slab form integral components of the ventilation and environmental control systems.

Use of thermal analysis software and dynamic thermal computer modelling of the building and its mechanical and electrical services systems during the design process helped optimise solutions and enabled prediction of building performance. Modelling was carried out to determine optimum insulation levels and where strategic incorporation of thermal mass could best enhance the operation of thermal comfort systems and reduce energy usage. Modelling was also used for prediction of the performance of the passive design over a typical weather year, and for comparison of a proposed low energy design against a more conventional air conditioning solution.

The low energy design involved orientating the building on an approximately east-west axis to take advantage of available natural energies. In addition, the building envelope is well insulated and has extensive solar shading and overhangs to control solar heat gains to the thermally massive interior. The main library space has extensive south-facing double glazing, and the 100% fresh air supply is routed though a thermally massive, double-layer, floor slab before being supplied to the library via floor diffusers. The building is all-electric – the main library space uses a combination of tempered fresh air supply and ceiling mounted radiant heating, while the adjoining staff office areas have a more conventional system, consisting of a high performance variable refrigerant volume air conditioning system and mechanical ventilation.

The extra capital cost of the double glazing, increased insulation levels and the thermally massive double layer floor were offset by the savings made through the omission of traditional mechanical cooling systems. The computer simulations indicated that the low energy system (at around 25,500kWh) would use significantly less energy than a standard air conditioning system (at around 38,900kWh), saving around 13,400 kWh electrical use per year, or some 34 per cent. Hence, the building cost no more to construct than a more traditional solution and life cycle costing predictions indicated the low energy systems could potentially save some $280,000 over their economic lifetime.

The end result is a low energy passive design augmented by low energy mechanical and electrical engineering systems.

ENVIRONMENTAL CONTROL SYSTEMS

The building has two main elements. The major volume is the main library space containing book-stacks, reading areas, issue and information desks and the like, some 54 by 21 metres in plan and just over 5m internal height. This is linked to an adjoining two-storey block containing, on its (400m²) lower floor, a meeting/display area, entrance lobby, toilets, and a separate café; and on its (600m²) cantilevered upper floor, archives, NZ collection, a workroom, and offices. While the major south wall of the main library space is totally double glazed, the more limited east and west façade windows have single glazing. The ceiling has 150mm of fibreglass insulation over suspended gib board while the concrete floor has 50mm thick polystyrene edge insulation.

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The design concept for the building was that only minimal use of active measures should be employed to control the internal environment. The systems are therefore designed to operate only where conditions fall outside of what was considered to be acceptable parameters. The building itself has been designed with a high performance envelope and to allow user control of natural ventilation via the provision of opening doors onto deck areas. This feature also provides an indoor-outdoor flow to enhance the quality of the library experience for both staff and public. Providing an indoor-outdoor flow would have been out of the question for a conventionally air conditioned building.

The overall concept of the thermal environmental control system is shown in Figure.1

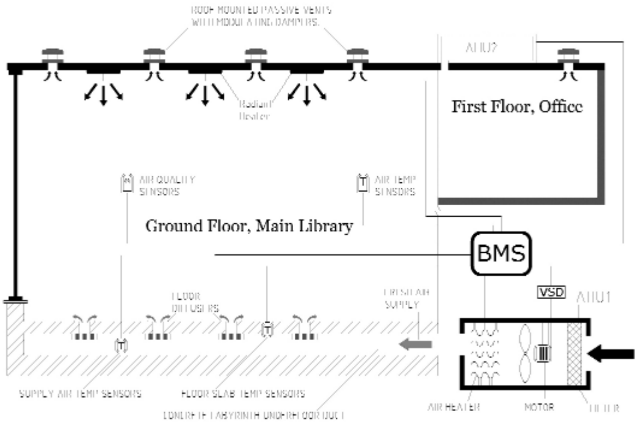

Figure 1: Environmental Control System - Overall Concept
Figure credit - Zhang Yanguang (David)

Main Library System

The system serving the main library is a combination of high level passive vents with modulating motorised damper control, low level tempered/passively cooled supply air provided by a 6m3/s maximum capacity variable volume air handling unit (AHU 1) installed within the basement plant room and 35 high level 2kW electric radiant heaters. The choice of direct electric radiant heating may at first seem at odds with the concept of a low energy building and it is accepted that a heat pump system (if used only to provide heating) would have further reduced the building's energy consumption. The case for their selection was as follows:

(a) The high performing thermal envelope resulted in a very low heat loss and therefore a very low heating energy demand (only limited cost savings available from more energy efficient systems). The higher cost and lower life expectancy of the heat pump option did not therefore stack up on a lifetime cost basis when compared to the direct electric alternative.

(b) The avoidance of refrigerants, lower manufacturing energy demand and reduced wastage (due to the longer life expectancy) associated with the electric heaters was considered a reasonable trade off in environmental terms.

(c) The height of the building is such that a warm air heating system would have required a very high air flow rate to avoid stratification and provide comfortable conditions. This prohibited the use of the ventilated floor slab as a means of distributing the heating systems air. It was also considered advantageous to divorce the heating system from the ventilated floor slab (to prevent the heat loss that would have occurred through the floor due to the higher supply air temperatures).

(d) The use of radiant heating was particularly compatible with the building's indoor-outdoor flow concept. The system warms the floor, objects, and people to provide comfortable conditions - rather than heating the air, which may well have been lost through open doors during intermediate seasons.

The air handling unit has variable volume control via modulation of the fan speed using an inverter variable speed drive and modulation of the electric heating coil output via a current valve. The fan speed is controlled via air quality and temperature sensors installed within the library to supply only the minimum amount of air necessary to maintain air quality or to control peak summertime temperatures.

Air is supplied to the library through low level supply grilles and exhausted though the high level passive vents to provide displacement ventilation (warm polluted air displaced by cooler fresh air).

The intent of the design is for the building to provide comfortable conditions with minimal energy input. In order to achieve this, the environmental control system operates as follows.

Daytime Cooling Operation

Cooling of the space is carried out by passing air though the ventilated concrete floor slab which has been cooled overnight to 18°C (refer night cooling control description below).

The speed of the fan and therefore the rate of cooling are controlled by averaging temperature sensors as follows.

Where the room temperature is below 22°C the fan does not run unless there is a requirement to provide increased ventilation to improve air quality as sensed by the air quality sensors.

When the room temperature reaches 22°C the fan starts and runs at minimum speed (17% of full speed). Between 22°C and 24°C the fan speed is modulated proportionally between 17% and 100% of full speed.

Night Cooling of the Floor Slab and Building

The hollow labyrinthine floor slab and interior of the building are pre-cooled overnight during warm summer periods to limit peak internal temperatures during the day. The control logic for the operation of this mode of control is as follows, using the nomenclature: Room temperature = TR; Slab temperature = TS; and Outdoor temperature = OAT.

Where TS>19°C and TR>20°C and OAT<(TS – 2°C) the passive vents open fully and the air handling unit supply fan operates at full speed. Where TS is less than 18°C the fans are switched off and the vents close. TS is the temperature sensed by averaging floor slab temperature sensors.

The operation of night cooling is controlled by a dedicated time schedule which only allows its operation at specific hours of the night during specific months of the year.

Fully glazed southerly façade of main library space

Daytime Heating Operation

During daytime operation of the building, the high level electric radiant heating elements are controlled in groups by local temperature sensors as follows:

TR = 20°C or lower, heaters enabled.
TR = 21°C or above, heaters disabled.

Daytime Ventilation Operation

Where there is no demand for cooling from the system but there is a demand for improved air quality as sensed by the air quality sensors the system operates as follows:

The high level dampers open 17% and the air handling unit fan operates at minimum speed (17%). Averaging supply air temperature sensors installed immediately below two of the linear floor grilles control the output of the air handling unit electric heating elements to provide a minimum supply air temperature as sensed at the grilles of 18°C (to prevent low level draught nuisance).

Conventionally Air Conditioned Areas

Due to the design brief requiring stricter temperature control for certain areas and the buildings design in these areas providing less opportunity for passive environmental control, the two-storey block is equipped with a more conventional type of system. An 800l/s air handling unit (AHU 2) with 18kW heating capacity supplies tempered fresh air to the offices, NZ collection and meeting/display areas, each of which have individually controlled high efficiency variable refrigerant volume air conditioning systems to provide space heating and cooling. A number of extract fans (for toilets, staff room, cleaners room, etc) complete the system.

PERFORMANCE ASSESSMENT - THE USERS' PERSPECTIVE

Methodology

We used the 'Workplace' version of a questionnaire developed by Building Use Studies. This questionnaire has evolved over several decades to a succinct two-page version for staff, and a one page version for 'transient' users of the building. *(Bordass and Leaman, 2004, BUS 2004a)*.

The two-page staff questionnaire seeks responses, on a 7-point scale, to a range of variables within the following fields: respondent's background; building overall; work area and requirements; thermal comfort and air quality; lighting; noise; overall comfort; productivity; health; and personal control. The simpler one-page questionnaire was employed to survey the library users. This covers the same basic parameters as the fuller two-page staff form, but could be filled in readily in less than five minutes (as opposed to the ten minutes or so required for the staff version).

Analysis of these responses yields a mean value (on the 7-point scale) for each variable. Each of these may be simply assessed in relation to the selected scale, or compared with the mean value from the BUS dataset benchmark together with the upper and lower 95% confidence intervals (which are based on the previous 50 buildings analysed).

As well as these individual ratings, two overall indices are also calculated from the staff responses: a Comfort Index, based on the overall comfort, lighting, noise, temperature, and air quality scores; and a Satisfaction Index based on the design, needs, health, and productivity scores. The average of these is termed the Summary Index for the building.
A Forgiveness Factor is also calculated. This is the ratio of the Overall Comfort score to the average of the individual overall air quality (summer and winter), temperature (summer and winter), noise, and lighting scores; with a factor >1 deemed more forgiving and <1 less forgiving.

In addition, the current analysis methodology yields an overall rating for the building – based on how it has scored in relation to the BUS dataset benchmarks and to the scale midpoints, over the following ten variables: comfort overall, temperature in winter, temperature in summer, lighting overall, noise overall, productivity, design, needs, health, and image – expressed both as a percentage and on a 7-point scale.

The method of calculating these overall indices and ratings is made completely transparent in the BUS analysis output documents, making them open to discussion and debate (BUS 2004b).

Staff were asked to fill in the standard two-page questionnaire, and users of the library were asked to fill in the shorter one-page version. Sample sizes were 11 permanent library staff (out of a possible 15), and 115 library users. An important point to make is the small number of staff. This may make results less significant so all data therefore should be interpreted with care and awareness of this small number of responses.

Quantitative Results of the Survey

In terms of the main study variables, the results of the survey are summarised in the Table 1. There, it can be seen that overall, Paraparaumu Library is rated on the BUS system as
- 'Very Good' - rating 7 on the 7-point scale
- and 95 percent on the 100-point scale.

In other words, this library is 'performing extremely well'. As noted above, this overall classification score is based on the building's relative performance on ten key variables by comparison with the BUS dataset values, and the mid-point of the corresponding 7-point scales.

The comfort and satisfaction indices provide a statistical snapshot of the occupants' perceptions of important subsets of the variables with a scale of +3 to -3, where +3 is 'best'.

Here, the Comfort Index works out at +1.13 which is significantly better than both the BUS Benchmark and the scale mid-point; while the Satisfaction Index is +1.50, which is in the top 5% of the dataset (i.e. 95th percentile); giving a Summary Index of +1.31. From these results, it can be seen that the building is performing slightly better for satisfaction compared to comfort.

The Forgiveness Factor is calculated to be 1.15 on a scale where <1 is less forgiving, and >1 is more forgiving. That is, the occupants' overall perception of comfort is likely to be relatively more tolerant of minor shortcomings in individual aspects such as winter and summer temperatures, air quality, lighting, and noise.

Overall, the library is performing well in terms of meeting the needs and criteria to provide comfort and satisfaction for the staff.

Looking in more detail at the individual factors listed in the table (while cautioning again that the number of respondents is relatively small), it can be seen that, almost without exception, staff perceptions are higher than the scale mid-point of 4 (in most cases) and the BUS Benchmark figures. The only exceptions to an otherwise outstanding set of scores being those for 'Ventilation in Summer', and 'Noise Overall', though even these are not significantly different from the benchmark figures.

Interestingly, the library users' perceptions (and there is no shortage of responses here) are even higher than those of the staff.

Particularly worthy of note are the scores for 'Health' - both groups average over the scale mid-point (4 in this case) and are significantly better (at 4.11 and 4.90 respectively) than the benchmark figure.

BUILDING *Unless otherwise stated, a higher value on the 7-point scale is better*	**LIBRARY STAFF**	**LIBRARY USERS**	**cf BUS BENCHMARK**	**cf SCALE MID-POINT**
Number of Respondents	11	115	-	-
Building Design	6.09	6.19	>	>
Needs	5.60	-	>	>
Space in the Building	5.64	-	>	>
Image	6.91	-	>	>
Cleaning	6.36	-	>	>
Furniture	6.09	-	>	>
Temperature in Winter	5.29	-	>	>
Temperature in Summer	4.25	-	>	>
Temperature Overall	4.77[1]	6.18	-	>
Ventilation in Winter	5.60	-	>	>
Ventilation in Summer	3.80	-	NSD (staff)	<
Air Quality Overall	4.70[1]	6.30	-	>
Noise Overall	4.20	5.30	NSD (staff)> (users)	>
Lighting Overall	5.00	5.77	>	>
Comfort Overall	5.40	5.82	>	>
Health	4.11	4.90	NSD (staff)> (users)	>
Control[2]	3.31	-	>	>
Productivity %	+5.56	+13.75	>	>
Forgiveness Factor[3]	1.15	-	>	>
Comfort Index[4]	+1.13	-	>	>
Satisfaction Index[4]	+1.50	-	>	>
Summary Index[4]	+1.31	-	>	>
1-7 Point Rating	7	-	-	-
% Rating	95	-	-	-
Classification	Very Good	-	-	-

Table 1 - Summary of results for main study variables

Note: blank spaces signify that no question was asked related to that variable

Key: [1] Average of summer and winter scores

[2] Average of all control scores

[3] <1 or >1 scale

[4] -3 to +3 scale

> significantly higher

< significantly lower

NSD - not significantly different

New Zealand collection area on first floor (conventionally air conditioned)

CONCLUSIONS

The staff results should be interpreted with care, as the very small numbers involved could make the results somewhat less robust and conclusive.

The Paraparaumu library is an excellent performing building overall.

In terms of overall comfort and satisfaction, this building performs extremely well. Perceived comfort is not as high as perceived satisfaction however. This is most probably due to noise and ventilation issues

While the design of the building is in the top 1 percentile of the BUS data set, ventilation/temperatures in summer and noise seem to be the main areas of concern.

This has implications for improvement in the acoustic nature of the building materials or design, or perhaps increased partitioning. The most predominant noise source was from children suggesting that the wide open-plan brief may not have been suited to this environment and demographic.

In terms of ventilation, the library was perceived as being slightly unsatisfactory - too dry and 'stuffy' - in summer conditions. Adjustment of the supply air distribution and temperature might be worth attempting for these circumstances.

While overall, lighting was perceived as performing well compared to the dataset, comments were made of some areas being too dark and of annoying glare from natural light. Vertical sunshades on the exterior and an increase in task lighting in specific areas could remedy this situation.

On the 7- point scale system, Paraparaumu Library is rated 7 (Very Good) which translates to a score of 95 out of 100.

This allows the conclusion to be made that overall this public library achieves comfort and satisfaction for all of its occupant's needs and expectations.

As a final comment, it is perhaps worth noting that the BUS dataset is not a random sample of buildings. It could be argued that the buildings that are prepared to have a post-occupancy survey done on them are likely to be somewhat better buildings initially. Thus, the dataset average or benchmark is likely to be higher or of a better standard than the average building. In relation to this case study, that only implies that the library is performing extremely well.

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Further Information

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