PASSIVE DESIGN IN THE PACIFIC ENVIRONMENT

NEIL H PURDIE BE MECH (HONS) MIPENZ

Connell Wagner Limited
Level 4, 139 Carlton Gore Road, P O Box 9762, Newmarket
Auckland
Telephone: +64 9 523 6433, Facsimile: +64 9 524 7815
Email: purdien@conwag.com

ABSTRACT

Connell Wagner modelled the performance of a new generic meetinghouse design for the Church of Jesus Christ of Latter Day Saints to be built in the Pacific region. The design was required to cater for any orientation and for a number of configurations based on the size of the congregation. Connell Wagner's brief was to optimise the passive design and predict the internal comfort conditions achievable in the tropical climate of the Pacific region. This was followed by capturing the thermal performance data of the prototype building for one full year at Faiaii in Savaii, Samoa. This was compared to an existing standard design of a meetinghouse at Faala in Savaii.

The results dispel a commonly held perception that natural ventilation is the primary mechanism for heat transfer in passive design. This applies to tropical maritime regions throughout the world as well as the Pacific and in subtropical temperate climates. These results are being applied to new meetinghouses, in New Zealand in conjunction with underfloor heating.

The report demonstrates the measured performance of the optimised passive design at Faiaii, designated the P230-17 meeting house, is performing better than our expectations with respect to internal temperature and humidity and significantly better than the old standard design .The internal temperatures at Faiaii rarely exceeds 31°C when occupied while maintaining humidity levels below 80%. In comparison the previous standard design, Faala an older standard design designated the Tropic 2000 showed significantly higher temperatures.

The design criteria for thermal comfort were based on The Church of Jesus Christ of Latter Day Saints internal standards and modified following the analysis of the data based on modelled performance (allowing for ceiling fans) with the boundaries defined by:

- Maximum 80% relative humidity (original 70% rh)
- Maximum 26°C (79°F) wet bulb temperature (original 25°C/77°F)
- Maximum 32°C (90°F) dry bulb temperature

The data collected correlates closely with the predicted temperatures from the ECOTECT model with better than expected humidity levels. The humidity inside is shown to be lower than the humidity level outside. This is a better result than expected.

The data demonstrates that performance of the building does not rely on external ventilation to dissipate heat but relies on heat storage in the shaded mass of the building. The key elements are:

- Insulated light coloured roof
- Good external shade to ensure the thermal mass remains cool
- Ceiling fans to transfer heat to the slab
- Obscure glazing which minimises glare/ solar radiation
- Louvres between classrooms

The modelling and data analysis clearly demonstrates that the passive design of meeting houses exceeds expectations.

KEY WORDS

Passive design; Pacific; ECOTECT

INTRODUCTION

The Church of Jesus Christ of Latter Day Saints commissioned Connell Wagner to model the passive performance of the largest standard meeting house configuration in the P series, family of buildings, comprising a 230 seat chapel, cultural hall and classroom block with 9 classrooms, offices and ancillary rooms.

Connell Wagner was asked to provide scientific analysis of passive tropical design on a prototype design in conjunction with Walker Architects Auckland. The optimum design for the meetinghouse was modelled using ECOTECT to analyse the building’s thermal performance in different latitudes, orientations and with different shade, insulation and material options.

The final design was arrived at, once limited returns were obtained from additional features. This design has now been successfully applied throughout the Pacific.

Key features of the successful design are:

- Light coloured insulated roof
- Eaves and high window sills
- Exposed concrete block walls
- Internal louvres between spaces
- Double skinned, ventilated gable end walls
- Ceiling fans spaced at 3.0 metre centres
- Slab on grade

Installing air conditioning into meeting houses in the Pacific is extremely expensive and energy costs are prohibitive, for this reason, LDS building projects do not receive air conditioning to selected countries and sites with external noise problems, Connell Wagner have air conditioned nine meeting houses with new air conditioning in American Samoa. These are done at high capital cost, operating cost and with substantial infrastructure problems obtaining adequate power supplies.

Faiaii is located on the south side of Savaii, Samoa. The gable ends face south and the classroom block is on the east side of the chapel and cultural hall. Ten data loggers were installed in two meeting houses (see figure 1), Faala and Faiaii and the data was analysed for the period of October 2nd to 17th 2004 through to November 2005.

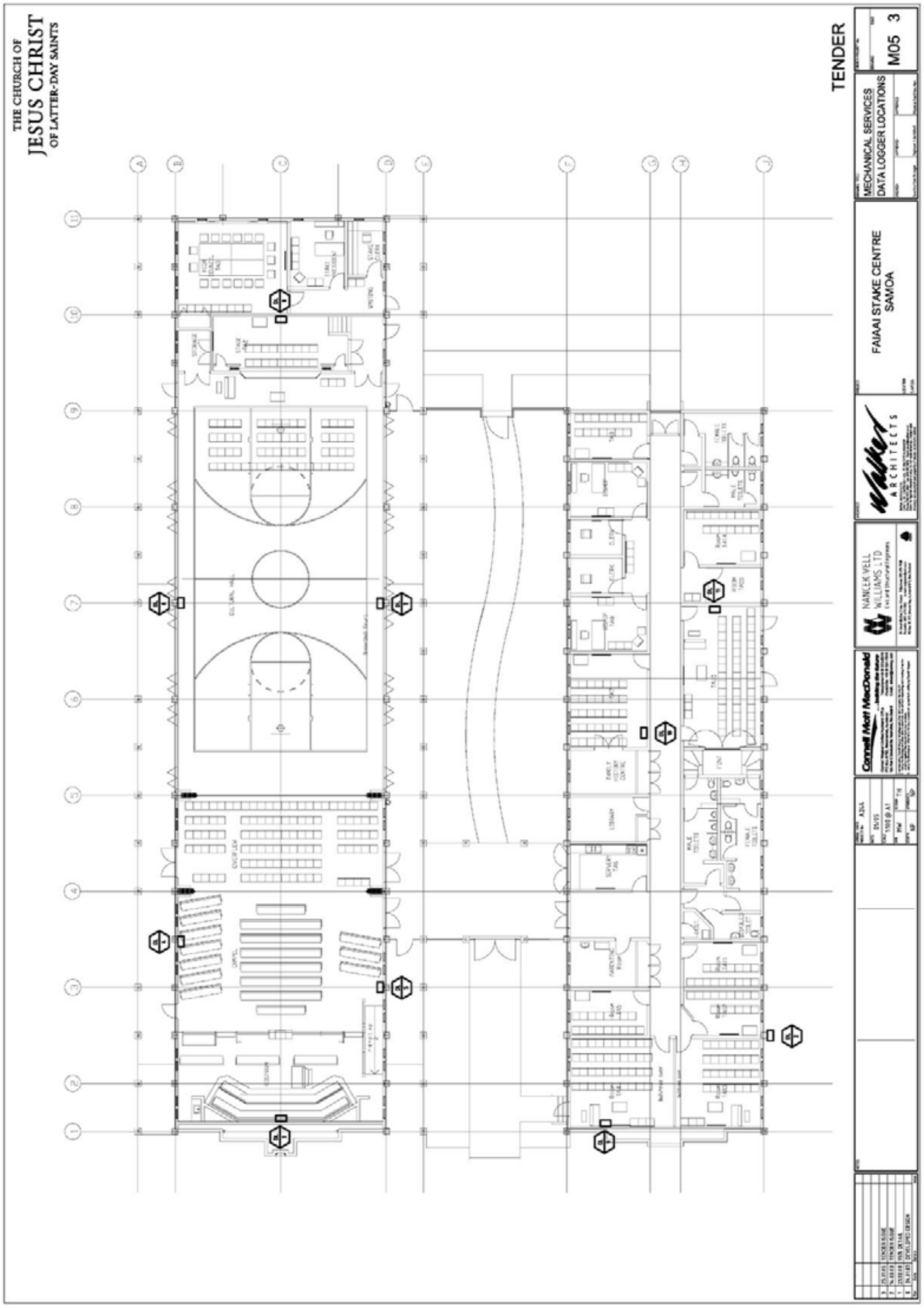

Figure 1. Floor plan of Faiaii Meeting House showing data logger locations

MODELLING OF PASSIVE COOLING WITHIN TROPICAL ENVIRONMENT

Modelling software

ECOTECT v.5.0 software is a comprehensive, and innovative building analysis programme, which is used to determine thermal equilibrium. It features a designer-friendly 3D modelling interface. Using detailed climatic analysis, the potential of solar radiation, building orientation, material properties and population densities can all be considered well before construction commences. Connell Wagner used weather data from Guam to model the typical tropical thermal performance.

ECOTECT modelling predicted that the optimised design would rarely experience temperatures exceeding 34°C during occupation. The analysis of the results has been summarised to evaluate the following information**:**

- Peak temperature in each area
- Space temperature relative to the outdoor temperature
- Minimum temperature relative to the outdoor temperature

Modelling of relative humidity was not studied, as we did not expect humidity levels to be controlled with the passive design.

Wind speeds in the tropics

The inter-tropical convergence zone (ITCZ) is the area near the equator characterised by very low wind speeds, (the doldrums). The satellite weather picture below (figure 2) demonstrates the doldrums as the blue area between the tropics of Cancer and Capricorn. Cyclones and storms create wind and afternoon sea breezes develop where there is sufficient landmass to create a thermal effect in late afternoon. Islands very close to the Tropic of Capricorn may experience the southeast trade wind (i.e. Tonga and Tahiti) while Hawaii is close to the Tropic of Cancer and experiences the northeast trade wind.

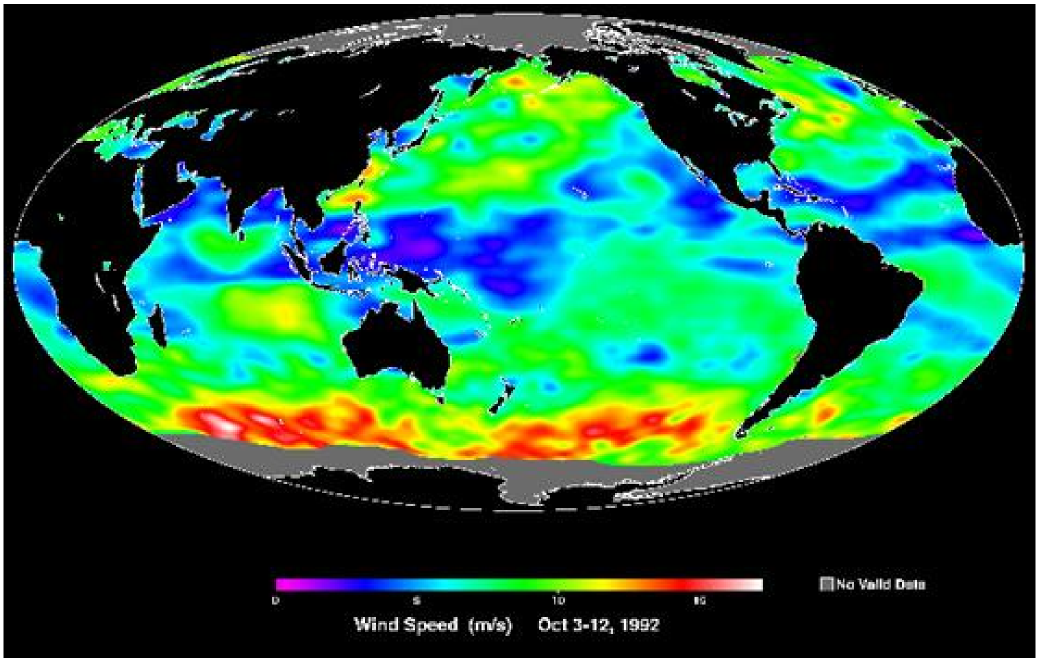

Image courtesy of the National Oceanic and Atmospheric Administration

Figure 2. Satellite image of Pacific Wind speeds

Pacific Tropical Maritime Climate

To understand the thermal performance it is necessary to understand the mechanisms that govern temperature and humidity in the tropics:

- The surface temperature of the Pacific Ocean largely determines the air temperature and humidity. The surface area of ocean is so large and has great thermal inertia that the water surface temperature of the tropics varies between approximately 22 °C and 28 °C and the dew point and wet bulb temperature are generally found to be within this range.
- The high humidity restricts the temperature range of the air. The wet bulb temperature generally follows the ocean surface temperature The Dry Bulb temperature can only drop as low as the water surface temperature (22 °C to 28 °C). The fact that the ocean temperature governs the wet bulb temperature also means that the Dry Bulb temperature does not often rise above 35 °C.
- The daily temperature range is a result of sensible heating of near saturated air. The air temperature heats and cools between day and night over a diurnal range of approximately 7°C with a maximum range of approximately 10°C. The temperature at night will not drop below the dew point unless it rains.

Thermal mass

The floor slab of the meetinghouse acts as a heat sink. To achieve the benefit of thermal storage we require a mechanism to allow the mass of the floor slab to reach an equilibrium temperature with the earth beneath the building (around 26°C). The floor slab must be protected from direct sunlight which would otherwise heat the slab and re-radiate heat. Ceiling fans transfer the heat from the occupants to the thermal mass, which then dissipates the heat into the cooler ground and into the night air during the unoccupied time.

Ceiling fans

Ceiling fans are critical for achieving comfort conditions, an air velocity of 2 - 3 m/s is required to provide enough air movement to promote evaporative cooling and heat transfer to the floor slab. Modelling and measurement of fan performance indicates that velocities of 2 to 3 m/s can be achieved. The primary mechanism for achieving comfort conditions is the evaporative cooling effect of air movement on the skin. The affect of this mechanism is measured as the effective temperature. Typically the perceived temperature is approximately 1°C to 2°C lower than the actual.

Considerable effort is required to optimise the coverage of ceiling fans, so that an even air distribution, even velocity and minimal noise levels are achieved.

LDS comfort cooling index

The LDS comfort-cooling index sets a desirable envelope below 25°C wet bulb, below 30°C dry bulb and below 80% relative humidity. These three limiting conditions were plotted on a psychrometric chart (Figure 3, Psychometric Chart for Comfort Cooling), to create a comfort-cooling envelope for the buildings. If the conditions in the buildings could be kept within this envelope the occupants would have physical comfort.

- Maximum dry bulb temperature for physical comfort (30 °C)
- Maximum wet bulb for physical comfort (25°C)
- Maximum relative humidity for physical comfort (80% relative humidity)

The target comfort-cooling envelope was extended to match and describe comfort levels experienced following the twelve-month monitoring period. The revised comfort envelope conditions are:

- Maximum 80% relative humidity (original 70% relative humidity)
- Maximum 26°C (79°F) wet bulb temperature (original 25°C/77°F)
- Maximum 32°C (90°F) dry bulb temperature

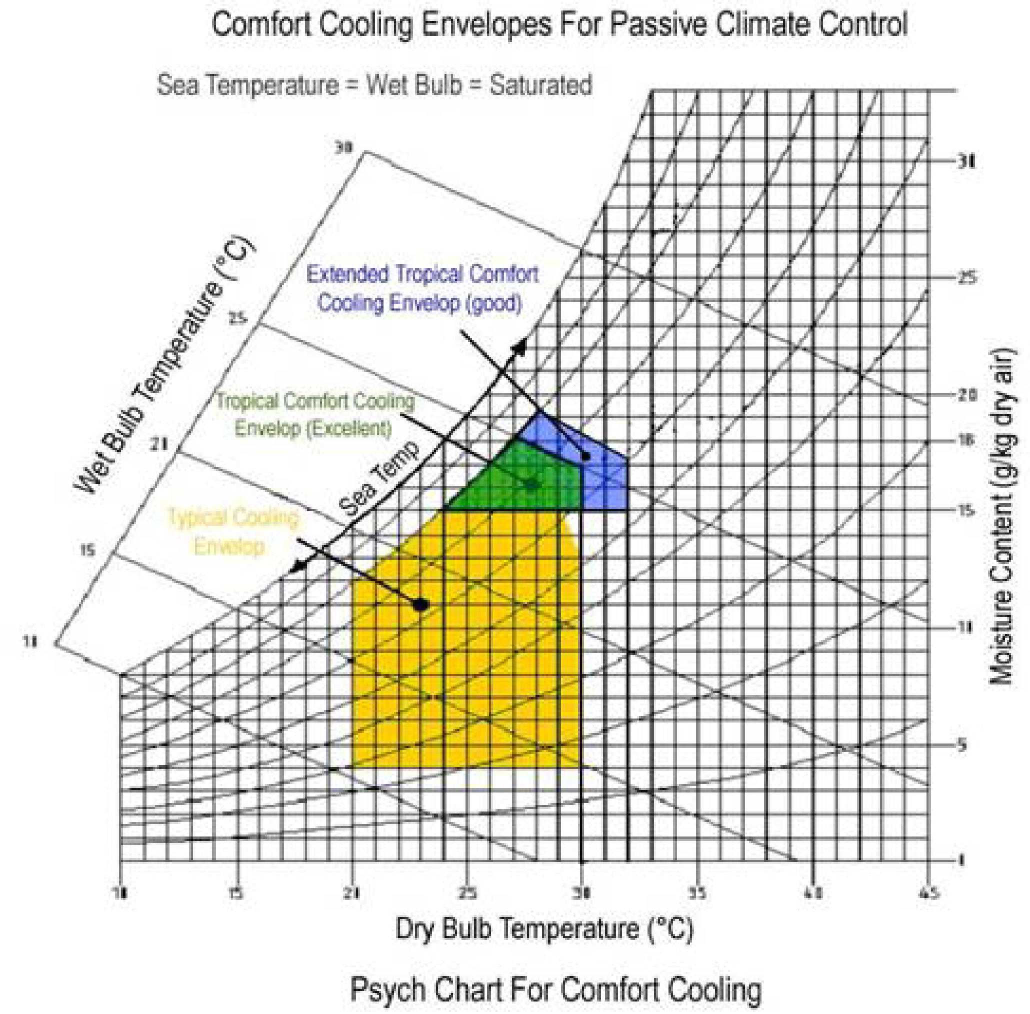

Figure 3. Extended Standard LDS Comfort Envelope
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COMPARISON OF ACTUAL AND PREDICTED TEMPERATURES

ECOTECT modelling clearly predicted internal temperatures would be below the outdoor temperature during occupied hours, as the heat was transferred to the thermal mass of the concrete floor slab.

The modelling shows that the 30°C dry bulb temperature is exceeded for 134 hours per year, and that the 25°C wet bulb is exceeded for 349 hours per year

The predicted temperature profile shows thermal storage

- Indoor temperature intersects outdoor temperature at about 8.30am
- Outdoor temperature dips below indoor temperature at about 6.30 pm to 7.00pm

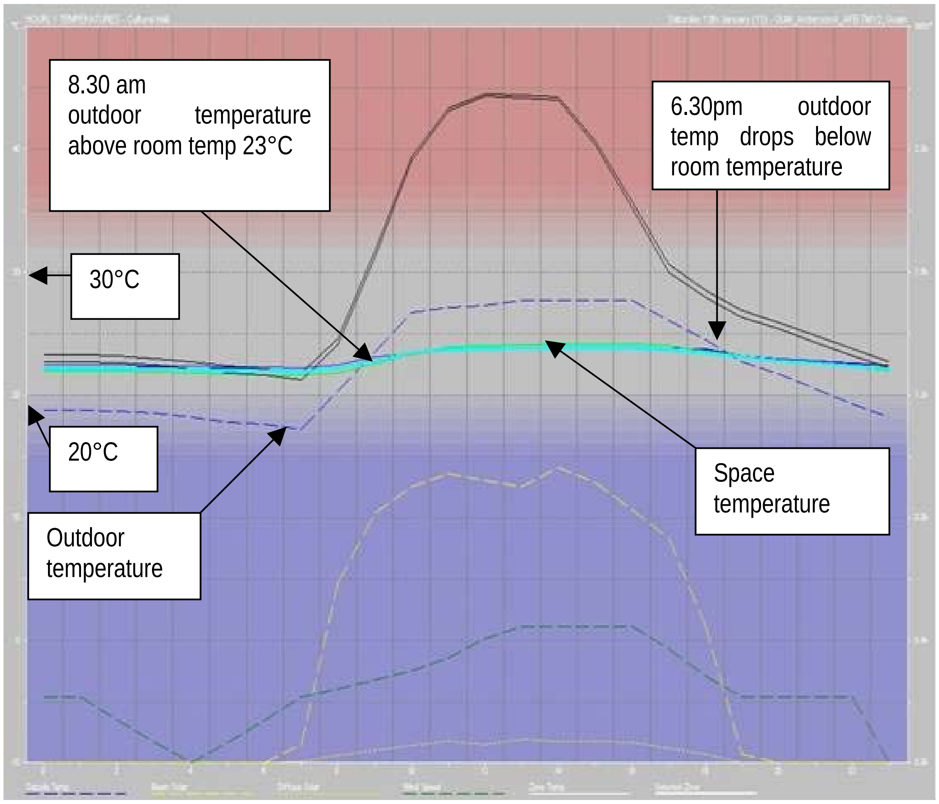
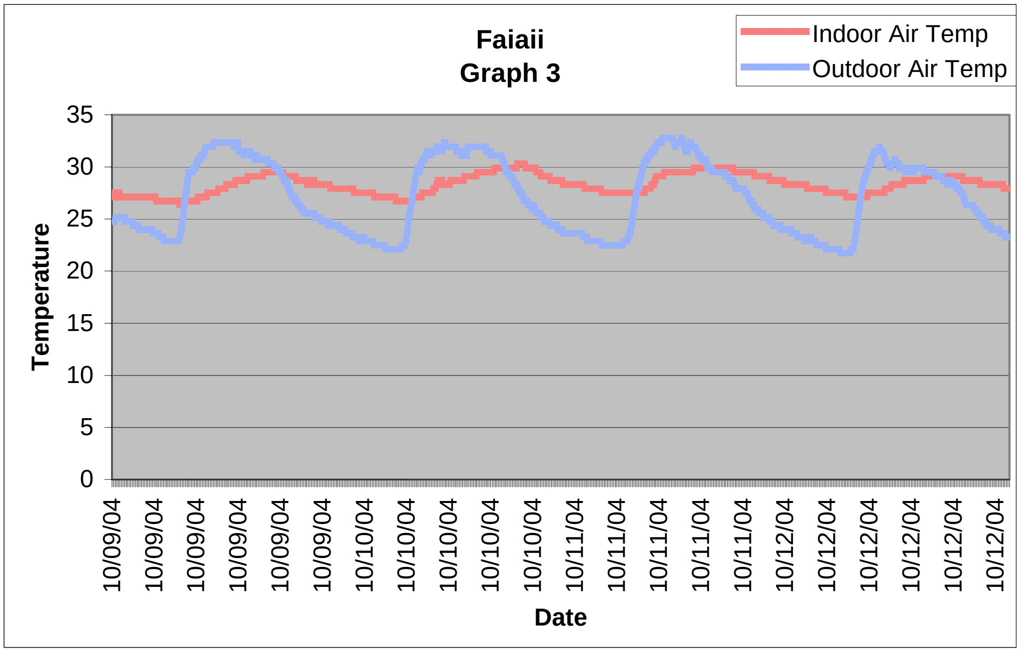


Figure 4. Typical Predicted Temperatures

Key

— Roof Temperature Profile
- - - Outdoor Temperature Profile
— Room Temperature Profile

Figure 5. Actual results, Faiaii Temperature Profile



Actual Measured Temperature Profile

The first data obtained confirmed that the thermal storage was effective; figure 5 shows the temperatures on the 9th October 2004 through to the 12th October 2004.

Key points to note are:

- The indoor air temperature is lower than the outdoor temperature during the day
- Indoor temperature intersects outdoor temperature around 26°C at about 8.00am
- Outdoor temperature dips below indoor temperature at about 6.30pm

ACTUAL PERFORMANCE

Data loggers were installed in three classrooms in each meetinghouse and in three locations in the chapel and in three locations of the cultural hall at Faala and Faiaii. Each meetinghouse also had an external data logger measuring the outdoor temperature and humidity. Data was recorded at 10minute intervals, 24 hours a day for one year. The data presented shows the performance of the worst performing classroom (data logger 9), chapel rostrum (data logger 3), cultural hall data logger 8 and a typical classroom, (data logger 10)

Temperature

The outdoor temperatures ranged between 25°C and 34 °C.

The results demonstrate that the inside temperature does not exceed the outdoor temperature during the day for the occupied classrooms. The equilibrium temperature of the floor slab drops the peak inside temperature during the day and releases the heat during the night.

The temperatures generally showed that both the classrooms and the chapel block temperatures fluctuated between 25 °C and 30 °C with only occasional incidents of temperatures rising above 30°C. The temperatures stay below the 32 °C when the outdoor temperature is within the predicted range.

Humidity

All of the data plotted on the psychometric charts demonstrated excellent performance with respect to temperature. Significantly, the data demonstrated that the humidity inside the building was lower than outside. Cooling air should raise the relative humidity unless dehumidification occurs (air conditioning), and the moisture exhaled by the occupants should raise the humidity.

The relief society classroom (data logger 9) has the highest humidity levels but performs well in respect of maximum temperature. The extended comfort envelope allows temperatures of 29°C to 31 °C with humidity above 65% but below 80%.

Further scientific work needs to be carried out to determine the mechanism that absorbs moisture within the building, we consider that the materials, painted concrete block and timber, are absorbing and releasing water.

Louvre Performance

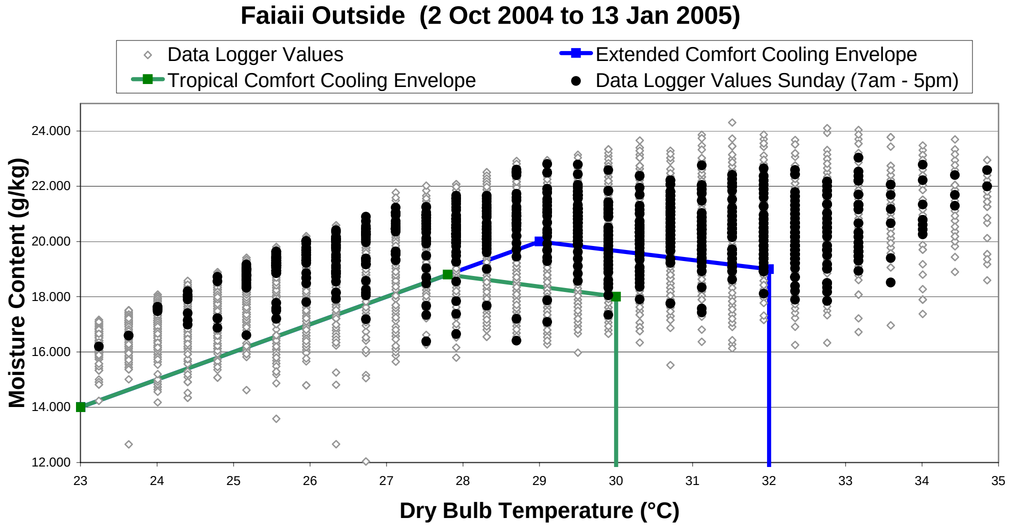
The analysis included trials with the external louvres closed to minimise the external ventilation effects. It was found that the classrooms and the chapel performed well under either scenario with better performance with the louvres closed. The classrooms appear to reach equilibrium, between internal spaces between shaded and sunny sides of the building.

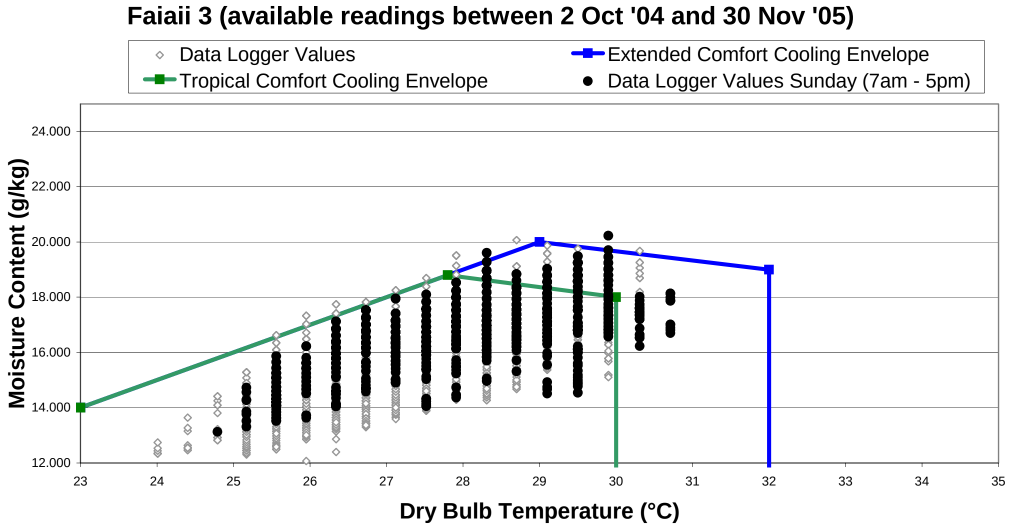
Data Logger results

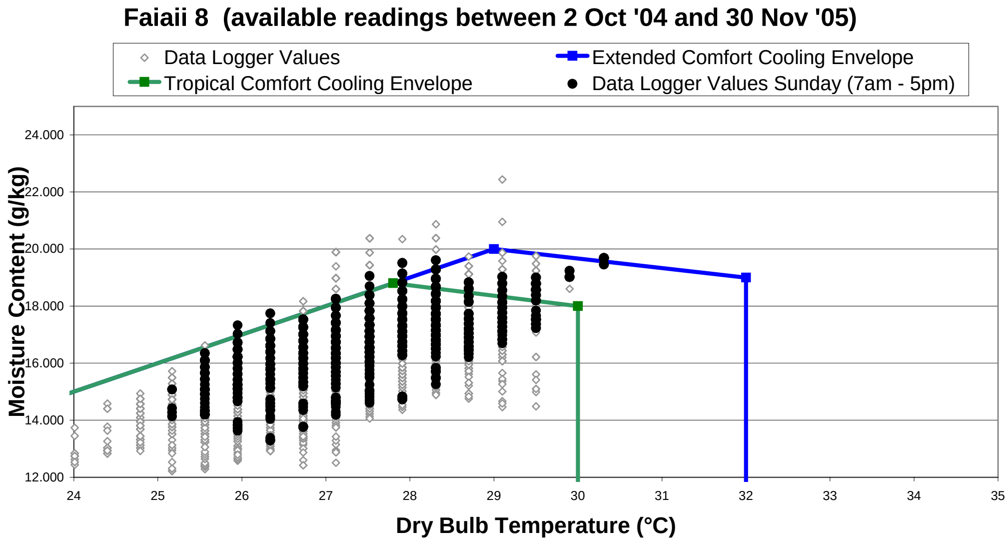
The following graphs (figure 6) display both the tropical and extended comfort cooling envelopes with the data logger values for each building location plotted. The data logger values are divided into unoccupied and occupied building times, shown as white and black dots respectively. The comfort envelope is shown as the green boundary line and the blue boundary line for the extended, standard LDS comfort envelope.

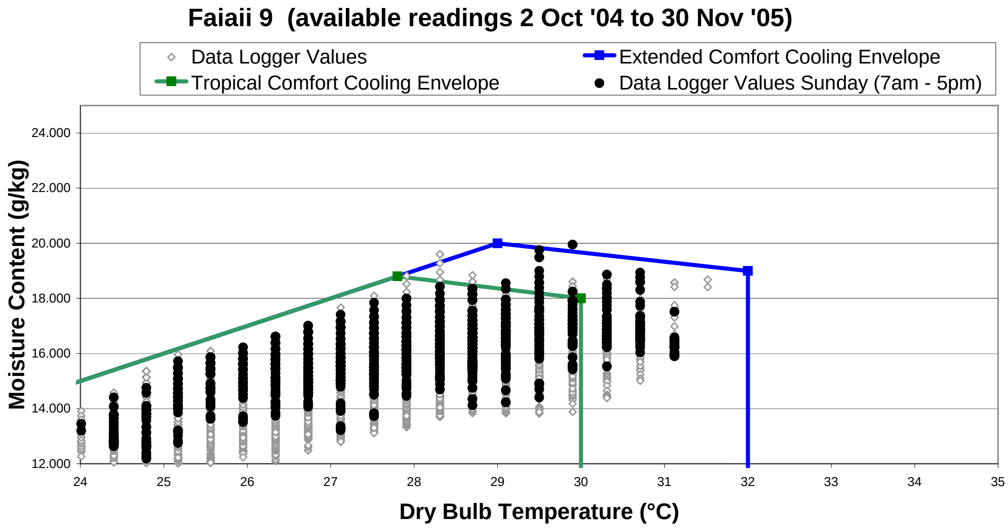
The results are shown for Faiaii as they show that the occupied temperatures

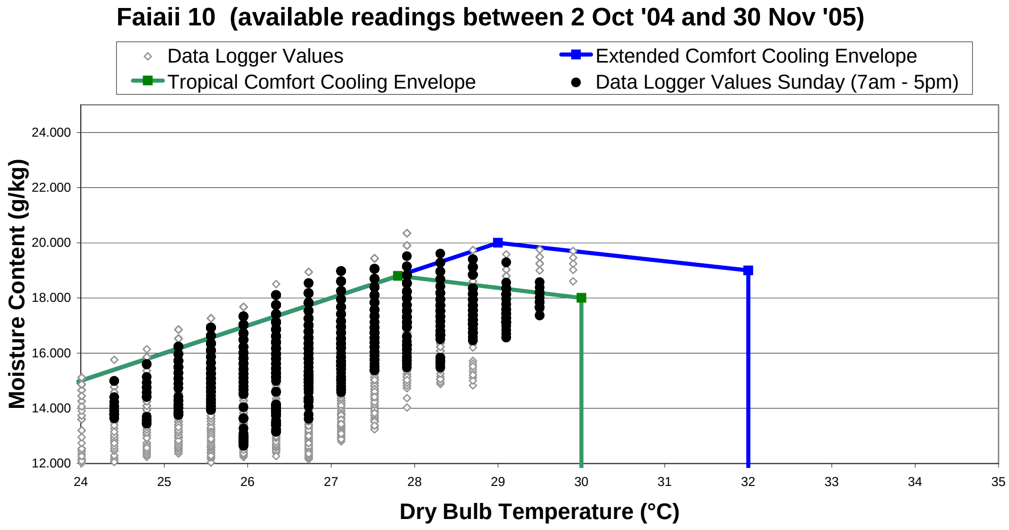
Figure 6. Graphs of readings from Faiaii, Samoa






Faiaii 8 (available readings between 2 Oct '04 and 30 Nov '05)
Data Logger Values
Tropical Comfort Cooling Envelope
Extended Comfort Cooling Envelope
Data Logger Values Sunday (7am - 5pm)
Moisture Content (g/kg)
24.000
22.000
20.000
18.000
16.000
14.000
12.000
24
25
26
27
28
29
30
31
32
33
34
35
Dry Bulb Temperature (°C)


Faiaii 9 (available readings 2 Oct '04 to 30 Nov '05)
Data Logger Values
Tropical Comfort Cooling Envelope
Extended Comfort Cooling Envelope
Data Logger Values Sunday (7am - 5pm)
Moisture Content (g/kg)
24.000
22.000
20.000
18.000
16.000
14.000
12.000
24
25
26
27
28
29
30
31
32
33
34
35
Dry Bulb Temperature (°C)


Faiaii 10 (available readings between 2 Oct '04 and 30 Nov '05)
Data Logger Values
Tropical Comfort Cooling Envelope
Extended Comfort Cooling Envelope
Data Logger Values Sunday (7am - 5pm)
Moisture Content (g/kg)
24.000
22.000
20.000
18.000
16.000
14.000
12.000
24
25
26
27
28
29
30
31
32
33
34
35
Dry Bulb Temperature (°C)

CONCLUSION

The modelling and data gathering demonstrates that passive design in the Pacific is practical and that the mechanism is heat transfer to the floor slab using ceiling fans. The classrooms and chapel are heavily populated but still achieve good thermal conditions due to the heat sink created by the floor slab.

Temperature and humidity levels during occupied periods are consistently lower than outside, which is a result that exceeded expectations. The humidity levels were expected to be higher than measured due to the external specific humidity, which we consider is due to the hygroscopic effect of the concrete walls and floor material.

ACKNOWLEDGEMENTS

The following sources have been used to carry out the research:

LDS Church (The Church of Jesus Christ of Latter Day Saints) "Standard Design Guidelines for the Construction of Meeting Houses 2004"

LDS Church (The Church of Jesus Christ of Latter Day Saints) "P Series Meeting House generic design guidelines 2004"

ECOTECT Version 5 software, SquareOne*research*Ltd,53EmpressTerrace,Central Promenade, Douglas, IM2 4EE, Isle of Man, British Isles