Active Solar Space Heating for a Cool Temperate Climate

A Case Study

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ABSTRACT

Active solar space heating is a well understood but little practiced technology developed primarily in Europe and North America before the oil price slump in the mid 1980s. This paper describes a recent application of this technology to the visitor centre of a national park just outside Canberra, Australia. The system designed uses commercially available water heating technology in an integrated architectural context which includes some aspects of passive solar and hybrid design to supplement the active system in a building which is only occupied during office hours but on a seven day week basis.

This paper describes the system, its design process, computer simulation, optimisation and construction in the field.

1. INTRODUCTION

The Tidbinbilla Visitors Centre is located in the Tidbinbilla valley, some 20km outside Canberra, in the Australian Capital Territory, latitude 35°S, altitude approximately 700m.

Canberra's climate is cool temperate, with very high solar availability and 2186 Heating Degree Days for an 18°C base temperature.

Energy Partners was engaged as specialist energy consultants as part of the design team, working with the Architects, TT Architecture, and services consultants, Northrop Engineers.

During the preliminary design development phase, it was decided to make the building a demonstration project which would showcase best practice for building and building services design. As such it was to incorporate an active solar system for space heating as well as domestic hot water.

The active solar system was partially funded by the Australian Greenhouse Office's Renewable Energy Commercialisation Programme (RECP) funding scheme (AGO, 1999).

The heating, cooling and ventilation systems that were proposed included the following features:

- heating by ducted in-ceiling fan coil units
- hot water heating by means of roof mounted solar water heater panels
- hot water storage capacity to be designed to allow for heating the building through 1 cloudy day as well as morning warm up and preheating of domestic hot water.
- summer cooling and ventilation by means of 4 ducted evaporative coolers.
- Pre-heating of outdoor air by means of a solar wall and glazed sunspace / foyer.

2. SYSTEM MEASUREMENT

Measurements of temperature and irradiance were taken at various positions throughout the system Datataker™ loggers locations of probes and their respective logger channels (indoor/outdoor) are outlined in Table 1.

Table 1

Measurement	Logger/Channel
Shop Temperature	???
Office Temperature	???
Incident Radiation	???
Gloabal Radiation	???
Storage Outlet Temperature	OUT/2TT
Heating Fluid Flow Temperature	OUT/3TT
Solar Return Temperature	OUT/4TT
Heating Water – After Bypass	OUT/6TT
Heating Water – Before Bypass	OUT/7TT
Mid-Tank Temperature	OUT/8TT
Solar Flow Temperature	OUT/10TT

Probe locations for the “OUTDOOR” logger are depicted in Figure 1:

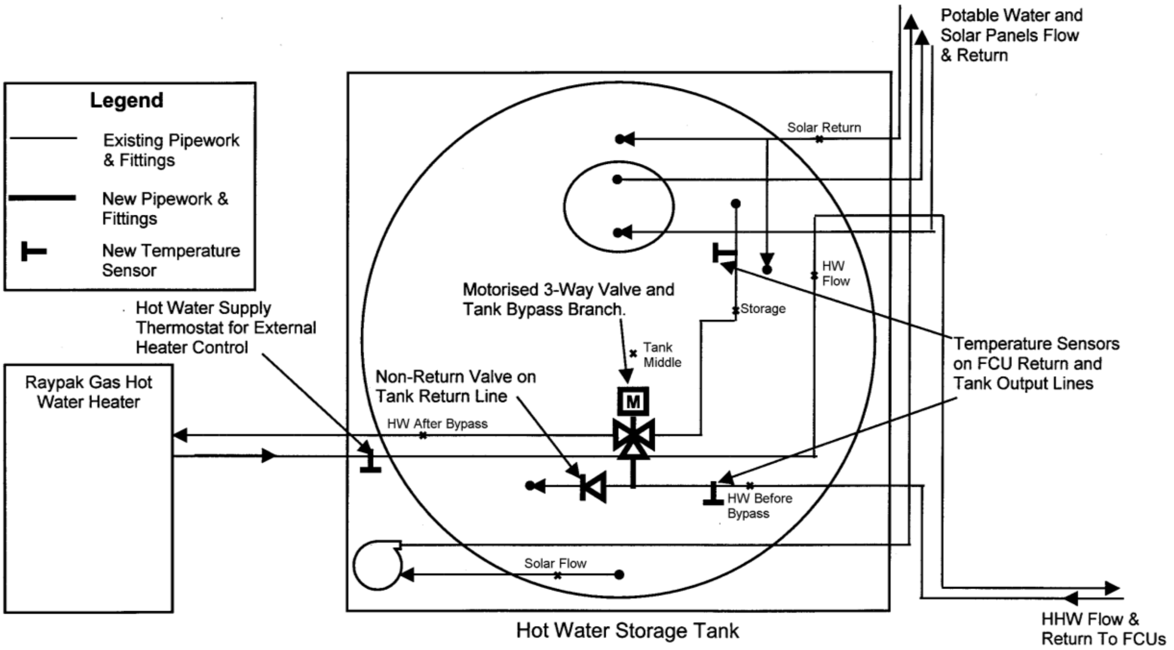

Figure 1: Probe Locations

The design brief for the building and water heating system required that the active solar heating system achieve a solar contribution of 70%, meaning that 70% of the required heating energy, including domestic hot water (DHW), is provided by the sun.

To determine that this requirement was achieved, involved the following process:

- establish the load patterns and annual heating energy demand of the building as documented and described;
- adopt a likely annual load pattern for the hot water demand for the kitchen and ablution facilities;
- establish the annual performance of the nominated solar space and water heating system to meet those loads in combination;
- where the predicted solar contribution is found to be less than 70%, carry out further parametric simulations in order to confirm how best to lift the solar contribution to that minimum acceptable level, bearing in mind the capital and running cost implications of the available options.

This work was undertaken using the computer building energy simulation programme DOE2.1E to establish the building loads and patterns, and the solar water heating simulation programme Sunbear to establish the solar contribution of the proposed solar space and water heating system design available to meet those loads.

2.1. Modelling Assumptions

The modelling assumed the following parameter values, which were set initially in collaboration with the client, Environment ACT, TT Architecture and the mechanical design engineers, Northrops:

- the building heating system and domestic hot water system use the one energy storage tank, although the potable water is isolated in a 300L tank within the main storage tank;
- the performance of the solar collectors (complete with a single glass cover) was set in accordance with data given in a UNSW report provided by the manufacturers, Solahart;
- the modelling assumed a heat exchanger between the solar collectors and the storage tank. The installed system does not have a heat exchanger, as it uses a drain-back system which circulates the stored water through the solar panels only when the panels are above a set temperature;
- the domestic hot water (DHW) operates with a supply water temperature of 55^{o}C and has an average daily usage of 300L/day;
- the heating coils in the fan coil units are sized to meat the peak heating load utilising 50°C supply water;
- the heat loss from the storage tank is not greater than 0.6W/m^2K (equivalent to 200mm polyurethane foam on a 6,000L tank);
- the heat loss rate from the auxiliary DHW tank is less than 4W/K;
- the heat loss from pipework is 0.25W/K (20m of 25mm piping with 25mm mineral wool insulation).
- the solar collectors comprise 28m^2 of panels in 2 banks of 7 x 2m^2 selective surface steel flooded panels with single low iron glazing couple in parallel. (Solahart 2000)
- the solar collectors are inclined at 60^{o} to the horizontal, facing due north, in accordance with earlier optimisation work by Energy Partners, receiving an average daily irradiation of 15MJ/m^2 in June (Lee et al,1995);
- hot water is circulated to the collectors by a single speed pump controlled by a mini-panel mounted between the 2 banks of collectors.
- the hot water heating system includes a supplementary gas fired hot water heater, with a minimum capacity of 100MJ/hour and 70% efficiency, to meet any DHW and HHW shortfalls from the storage and solar heating system.
- the outside air load can be reduced from the design maximum of 1,000L/s during times of medium and low occupancy to achieve an effective average outside air intake of 600L/s over the heating season, even allowing for the temperature effects of the diurnal cycle (ie, adjusting for the extra load from air intake on cold mornings versus warmer afternoons);
- the fresh air is drawn through the solar north wall for the retail and coffee shop and drawn through the north-east facing foyer for the Gallery;
- the kitchen exhaust hood is a balanced hood (design exhaust rate 1000L/s, outside air make-up 800L/s, 200L/s from interior); and
- the Visitors Centre operates from 9:00am to 5:00pm each day and was estimated to have a daily and seasonal variation similar to that shown in Figure 1;

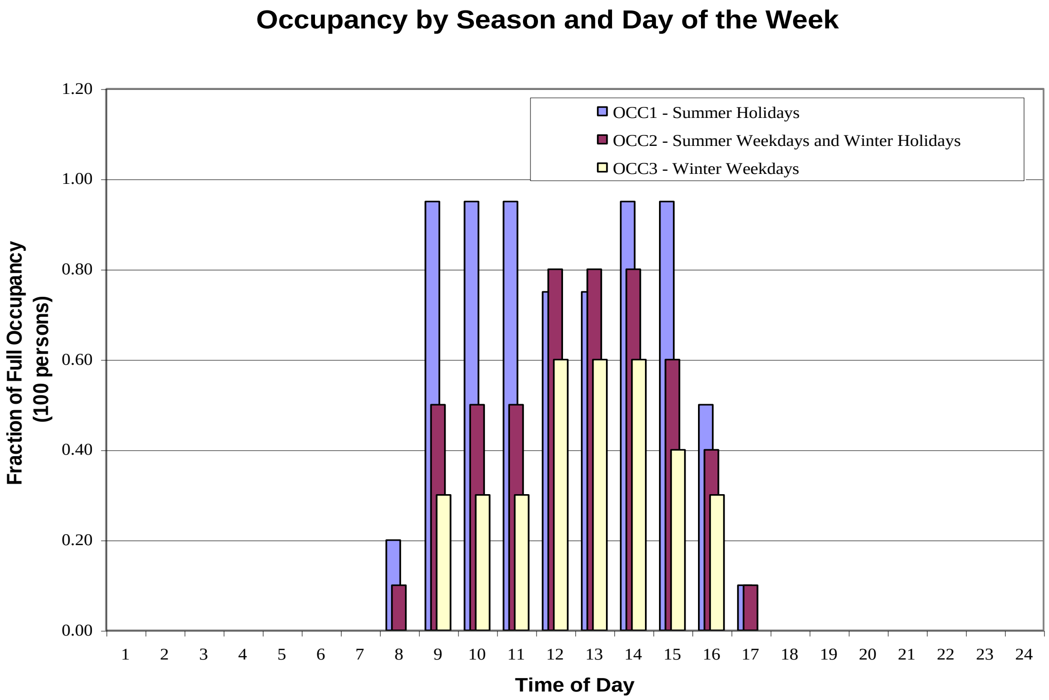

Figure 2: Visitors Centre Occupancy Estimate (source: client)

2.2. Theory

Energy flows in each timestep (Δt):

$$\text{Solar in} = \dot{q}_c \Delta T_c \Delta t$$

Where $\dot{q}_c$ =collector fluid flowrate; and

ΔT_c = temperature difference across collectors.

$$\text{Heating out} = \dot{q}_s \Delta T_s \Delta t$$

Where $\dot{q}_s$ =secondary (heating) fluid flowrate; and

ΔT_s = temperature difference across fan coil units (heating circuit).

Tank losses were calculated from an estimation of tank temperature, measured at the centre of the tank (OUT/8TT), and a theoretical value $(UA)_{tank}$ = 0.00135 kJ/s.°K.

$$\text{Initial Tank Energy} = mc_p T(initial)$$

Tank energy is calculated from an energy balance of the storage, with initial conditions taken from the original temperature estimation (as above). Storage temperature is predicted from this calculation, and used as an error checking mechanism against the mid-tank temperature measurement.

2.3. Modelling Outcomes

Design parameters were varied to determine the performance of the collector system. As a basis for sizing the collector/storage tank system it was assumed that the outside air flow rate could be varied in accordance with the occupants in the space and that the average outside air rate was 60% of the maximum rate, ie., 600L/s.

With this outside air ventilation rate, the occupancy profile shown in Figure 2, above and the building design details were entered in DOE2.1E to calculate the average daily and monthly heating loads.

2.3.1. Roof Reflectivity

A series of simulations were conducted to evaluate the significance of roof finish immediately in front of the collector panels, with the recommended choice being pale colourbond steel, or zincalume.

For these comparisons, the minimum storage tank size was initially set at one day's "average" building heating and one day's domestic hot water heating requirement, or 230MJ (170MJ building + 60MJ DHW).

Table 2 shows the calculated solar contribution to the combined heating and domestic hot water heating for the building for different roof reflectivities and outside air flow rates.

As would be expected, the outside air rate has a substantial impact on the solar contribution, whereas the roof reflectivity has only a minor impact.

Table 2: Effect of Outside Air & Roof Reflectivity (diffuse)

Outside Air Rate	Roof Reflectivity	Tank Capacity	Solar Contribution
600L/s (60%)	0.4	230MJ	75.5%
	0.65		77.1%
1,000L/s (100%)	0.4	230MJ	55.9%
	0.65		57.3%

2.3.2. Tank Size

The tank and pump are house in a purpose built enclosure adjacent to the south side of the building.

Increasing the tank size has a marginal effect on the solar contribution although it does effect the ability of the system to accommodate heating loads for following days.

If the roof reflectivity is fixed at 0.4 and the outside air rate maintained at the average of 600L/s, for a 20K temperature rise, the solar contribution varies with increased storage as follows.

Table 3: Effect of Tank Size

Tank Capacity, MJ	Solar contribution
183	76.0%
230	75.5%
278	74.9%
325	74.3%
373	73.7%
420	73.0%
468	72.5%

Given the requirement to use heat energy collected the previous day to warm up the building each morning and the conventional philosophy that the domestic hot water heater should be sized for one and one-half days use, this gives a revised minimum size for the storage tank of not less than 475 MJ:

Table 4

Building heating	170 MJ
Next day's building heating	170 MJ
DHW	60 MJ
Half day's DHW	30 MJ
Standing losses	45 MJ
Total	475 MJ

For a nominal water temperature rise of 20K, this is equivalent to a tank size of approximately 5,700Litres.

With this size tank and twelve collectors, we can estimate from Table 4 and Table 3 that the solar contribution would be in the order of 70%.

Therefore it was concluded that the storage tank should have a capacity of not less than 6,000L and the system controls must include outside air controls such that the time and temperature weighted average intake did not exceed 60%.

The solar contribution was further improved by the inclusion of a warm-up cycle on the fan coil unit heaters, whereby the outside air intakes can be closed first thing in the morning during the heating season until the building warms up.

3. EMBODIED ENERGY

In keeping with the project philosophy of providing a low energy building using Ecologically Sustainable Development techniques, as well as creating a building in harmony with its surrounds, the preferred building material was mud-brick, using the local soil.
The total embodied energy of the building was estimated during the design phase, both for the mud-brick / adobe construction which was used, and with standard brick veneer construction for comparison.
As can be seen in below, the selected Adobe construction was found to give a 15.2% energy saving over the standard brick veneer construction, which confirmed it as the preferred building material.

Table 5: Embodied Energy Audit Results

	Adobe	Brick Veneer
Building Element	Energy Content (GJ)	Energy Content (GJ)
Substructure	643.9	643.9
Columns	67.4	67.4
Roof	989.5	989.5
External Walls	569.0	1,448.8
Windows	57.4	57.4
External Doors	146.4	146.4
Internal Walls	68.8	68.8
Internal Screens & Borrowed Lights	108.8	108.8
Internal Doors	218.3	218.3
Wall Finishes	221.2	221.2
Floor Finishes	97.3	97.3
Ceiling Finishes	246.3	246.3
Fitments	343.5	343.5
Solar Collectors Etc.	170.0	170.0
HVAC & DHW	550.0	550.0
Kitchen Equipment	450.0	450.0
General Electrical Services	589.5	589.5
Comms Cables And Security	86.0	86.0
Water & Gas Reticulation	145.0	145.0
Sanitary Fixtures	23.2	23.2
Total Building Structure	**5,791.4**	**6,671.2**
Percent Increase Over Adobe		15.2%
Gross Bldg Area (m^2)	530	530
Embodied Energy / m^2 (GJ/m^2)	10.93	12.59

4. CONSTRUCTION AND OPERATION

The centre was constructed under a standard commercial construction contract, whereby the entire building including the services was documented together and tendered together by selected builders and the building services contractors were engaged as sub-contractors by the builder.
The building comprises 2 large semi-circular spaces, with the curved walls constructed of double skin

mud-bricks with 50mm extruded styrene insulation, and the remaining walls constructed of a mixture of aluminium framed glazed panels and colourbond steel cladding.

The services design was substantially simplified during construction, in an effort to reduce the total construction costs. From the perspective of building energy conservation, the following items were omitted from the final installation:

- Digital controls. Hence the system is not readily interrogated and adjusted and system logging by the controller is not possible.
- Variable outside air ventilation controls were omitted. The building design was re-evaluated such that it was recognized that natural ventilation could meet the ventilation code requirements. Hence the fixed outside air was reduced to only 150L/s, which negates the issue of heating large volumes of outside air.

4.1. System Features

In addition to the design requirements identified during the simulation phase, the system incorporates several important features that are essential to its successful operation:

- Fan coil units are fitted with 2 row heating coils to absorb sufficient energy from the 50°C nominal heating water.
- The hot water system incorporates an adjustable 2 stage compensation control for the heating hot water set-point.
    - On the 1st stage, the gas hot water booster heater is set to 50°C, so that the heating is generally satisfied by the hot water provided at approximately 60°C by the solar panels and the gas heater is rarely required.
    - The 2nd stage of heating is invoked if the outside temperature is below 2°C or the indoor temperature is below 15°C. In this case, the gas heater set-point is reset to 75 °C, to boost the amount of heat available to the fan coil units.
    - The 2nd stage heating also closes the normally open outside air damper on Fan Coil Unit 3, which serves an internal gallery space.
- As shown in Figure 3 below, a bypass valve at the hot water storage tank opens to bypass the storage tank if the return water from the fan coil units is hotter than the tank water.
  This protects against the situation that the solar panels are not working, such as early morning, and the tank can cool the water instead of heating it. In these situations, the system reverts to a simple gas-fired hot water heating system. The bypass is controlled by temperature sensors on the pipes inside the storage tank enclosure. The bypass remains open until the return water is at least 3 °C colder than the tank.
- A summer night-time "dry-run" control for each of the 4 evaporative coolers runs the supply fans with the water supply shut off, in order to flush the building with cooler and drier night air during summer.
    - During the months of December, January & February, if the indoor temperature is above 18 degrees and more than 2°C above the outdoor temperature, then the evaporative cooler supply fans operate from midnight to 5am with the water shut off.

Figure 3: Hot Water Pipework Configuration