PREDICTION OF HOT WATER USAGE IN A SOLAR HEATED COMMUNITY BATHING CENTRE IN NEPAL

R.J. Fuller and D. Schwede
School of Architecture and Building
Deakin University, Geelong, Victoria 3217, Australia
rjfull@deakin.edu.au

A. Malla and A. Zahnd
Department of Mechanical Engineering
Kathmandu University, Nepal and RIDS-Nepal
azahnd@wlink.com.np

ABSTRACT

A natural thermosyphon solar water heating system (SWHS) has been constructed at a high altitude research station in a remote northwestern region of Nepal. This SWHS is the prototype for a larger community bathing system proposed for a nearby village. This paper describes the community bathing centre and presents the results of a validated TRNSYS model that has been used to predict its performance and to test various operational strategies. Predictions from the model indicate that the design target of 550 showers can be provided each week if these showers are limited to 10 litres at 35°C and the centre is operated between 9am and 3pm.

1. INTRODUCTION

Nepal is a landlocked country and lies between 26°-30° N latitude and 80°-88° E longitude. The terrain ranges in altitude from 70 metres in the South to 8848 metres in the North. Approximately 80-85% of Nepal's 28.5 million people live in rural and inaccessible areas. Conditions vary across the country and some areas are particularly disadvantaged. One of these regions is the province of Humla, which lies in the far northwest of Nepal. Compared to industrialised countries, the health statistics for Nepal are alarming. Infant mortality is high, ranging from 86 to 53 per 1000 live births for the poorest and richest 20% respectively. Malaria, tuberculosis and HIV/AIDS are all targets for on-going national and international health programmes. Less publicised, however, is that the skin condition, scabies, ranks first among Nepal's five most common illnesses. In the remote mountain communities, this condition is particularly prevalent among children. The problem is a direct outcome of the extremely poor hygiene conditions, which many of the high altitude communities in Nepal have to endure. Often people in these regions are totally unaware that inadequate basic personal hygiene, particularly periodic washing and cleaning, is a major contributor to their poor state of health. Furthermore the harsh and cold climate, combined with the extensive deforestation, prevents them from heating water for showering or washing their clothes. As a result, it is not uncommon for these people not to bathe for months at a time, with some of them rarely bathing at all. In direct response to this situation, a community bathing centre is to be built by a local NGO in a remote village of Humla. The bathing centre should have a significant impact on hygiene conditions and hence on the health of the local population. This paper describes part of the research undertaken to ensure the successful design and operation of the solar water heating system at the bathing centre.

2. DESCRIPTION OF BATHING CENTRE

The bathing centre is to be constructed in the village of Dhadhaphaya, which is approximately three hours walk from Simikot, the main town in Humla, and has a population of approximately 1100 people. The idea of the bathing centre was extensively discussed with the villagers, who agreed to provide all materials such as stone, wooden beams, mud and sand, which are available locally. The community also agreed to carry out all the necessary excavation work where the bathing centre is to be built. Figure 1 shows a schematic layout of the bathing centre. The solar hot water system for the bathing centre will be a thermosyphon system, developed at Kathmandu University. Such a system will avoid the additional expense and maintenance incurred if forced circulation was used. The system to be built will be a larger version of one that was installed in November 2005 at the High Altitude Research Station (HARS) in Simikot. The system is owned and operated by RIDS-Nepal, which is a local NGO that has been implementing a holistic community-based development programme in the Humla Province since 2001. The community bathing centre is part of that programme. Figure 2 shows the HARS system, which comprises four 1.5 m^2 solar collectors and a 300 litre tank. The collectors are made from aluminum sheet with galvanised iron 27 mm internal diameter (ID) headers and 16 mm ID risers. Each panel has nine risers, which are a 'push fit' into the absorber panel. Reflective and insulating covers are placed over the absorbers at night to prevent freezing. The storage tank for the system is made of stainless steel and insulated with 100 mm of polyurethane foam.

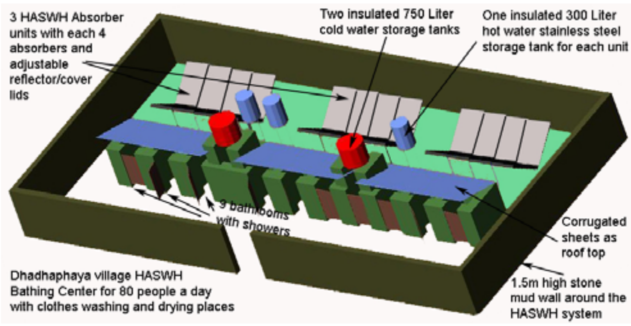

Fig. 1: Schematic layout of Dhadhaphaya bathing centre

Fig. 2: HARS system with reflective insulating covers

3. TRNSYS MODEL

The simulation software, TRNSYS (Version 16.0) was used to predict the daily performance of the community bathing centre system. The sub-routine, Type 45, within this programme allows the user to describe a thermosyphon collector-storage system. An option in this subroutine is for the internal calculation of internal pressure drop and flow, rather than as user-supplied data. Since no data existed for this collector, this option was used in these simulations. The user must supply various system parameters; the key system parameters are listed in Table 1.

TABLE 1: KEY SYSTEM PARAMETERS

PARAMETER	VALUE
Collector area (m^2)	6.0
$F_R\tau\alpha$	0.53
F_RU_L ($kJh^{-1}m^{-2}$ °C^{-1})	19
Collector slope (°)	40
Riser internal diameter (m)	0.016
Header internal diameter (m)	0.027
Vertical. distance between collector outlet and inlet (m)	1.14
Vertical distance between tank outlet & collector inlet (m)	1.55
Diameter of collector inlet pipe (m)	0.027
Length of collector inlet pipe (m)	7.65
Number of right angle bends in inlet pipe	4
Loss coefficient of collector inlet pipe + insulation (kJh^{-1} m^{-2} °C)	1.073
Diameter of collector outlet piping (m)	0.03
Length of collector outlet piping (m)	1.58
Number of right angle bends in outlet pipe	3
Loss coefficient of collector outlet pipe + insulation (kJh^{-1} m^{-2} °C)	1.07
Tank volume (m^3)	0.3
Tank height (m)	1.2
Height of collector return to tank above bottom of tank (m)	0.875
Effective thermal conductivity of fluid and walls (kJh^{-1} m^{-2} °C)	1.5
Overall UA value for tank (kJh^{-1} °C)	5.76
Ratio of top insulation to side insulation thickness	1.0

Key parameters were determined by calculation and assumptions. The collector efficiency factor (F′) and the collector heat loss factor (U_L) were calculated to be 0.73 and 27.4 $kJh^{-1}m^{-2}$ °C^{-1} respectively. The flow factor (F′′) was assumed to be 0.93 (Whillier and Saluja, 1965). Solar transmittance (τ) and absorptance (α) were assumed to be 0.82 and 0.95 respectively.

Using these parameters, the model was validated against data collected from the HARS thermosyphon system in 2006. The staff and local residents of Simikot both currently use the hot water produced by the HARS system for showering and washing clothes. The hot water is made freely available between the hours of 6am and 9am. At all other times, the shower door is normally locked, and neither staff nor residents can access the hot water that is produced on that day. On Saturdays, however, the shower is not locked and hot water can be used at any time. A sixteen day period in November 2006 was randomly selected and used to validate the model. Water temperatures at four positions in the tank were measured at 10-minute intervals and recorded on a data logger. The actual 'load' or hot water drawn from the system was calculated by estimating the amount of cold water that must have been introduced into the system to achieve the decline in water temperature at each hour of use. Water temperatures changes due to tank losses were ignored because these are very small compared to those caused by the introduction of cold water. Figure 3 compares the average measured tank temperature for the sixteen days with the model's predictions for the same period.

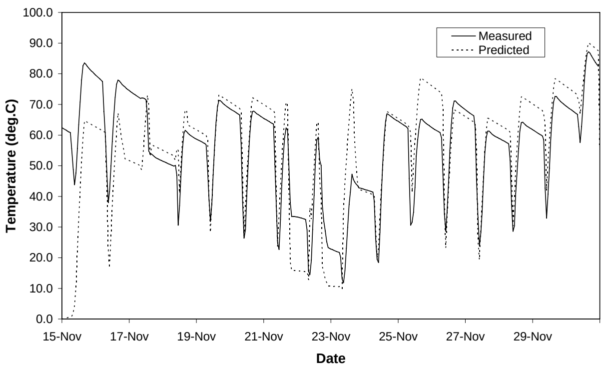

Fig 3: Measured and predicted average tank temperatures

One of the deficiencies of the Type 45 subroutine is the inability to set the initial storage temperature and this accounts for the discrepancy between measured and predicted temperatures over the first two days of the period. The model is also prone to instability and 'range check' errors. This occurred inexplicably sometimes when small changes in the value of parameters were made. As a result, a higher value of F_RU_L (23 $kJh^{-1}m^{-2}\,°C^{-1}$) was used in the simulations than that calculated. However, given the instability of the subroutine, the uncertainties in the hot water load and the assumptions made, agreement between the measured and predicted average tank temperatures was considered to be good enough over the two week period to give confidence that year long predictions of performance could be made.

4. CHECKING DESIGN AIM

The size of the SWHS for the bathing centre is based on the aim of providing 10 litres of 50°C water to 1100 people every two weeks (Zahnd and Malla, 2006). Water at 45°C is the limit that can be tolerated for any appreciable time by the human hand. If a temperature of 35°C is used for a 'design-temperature' shower, it is possible to establish the amount of hot water used from a tank at any particular temperature to provide 10 litres at 35°C. It is then also possible to readily calculate the number of these 10 litre showers that may be taken from a 300 litre tank at any temperature at or above 35°C. At that particular temperature, 30 showers are available and no cold water is added. As the tank temperature increases more showers are available because the higher temperature water is now mixed with some cold water, assumed to be at 15°C. It was also assumed, however, that the maximum number of these showers that could be taken in any one hour was ten, based on the allowance of six minutes per shower for undressing, washing, drying and getting dressed again.

These limitations (temperature and time) were initially used to predict the number of 'design-temperature' showers that could be taken between 6am and 9am, because it is the cultural preference to wash early in the morning. A climatic data file (solar radiation and ambient temperature) for one year, constructed using averaged data collected from the HARS site between May 2004 and May 2006, was used in the simulations. The model predicted that the HARS system would allow 3458 'design-temperature' showers to be taken annually. Since the bathing centre system will be three times the size of the HARS system, 10373 early-morning showers would be available. The design target is to provide 550 showers for the local people in the village per week or 28,600 annually. The predictions indicate therefore that only 36% of this target will be reached using this operating strategy, and therefore that an alternative operating strategy is required.

5. ALTERNATIVE OPERATING STRATEGIES

Initially there will be no time-of-day restrictions on the use of the bathing centre because of the current cultural preference. However, the aim is gradually to introduce a bathing centre operating regime, which will maximise the potential of the SWHS. Ultimately, it is believed that by spreading the hot water demand across the day, say from 9am to 3pm, this will reduce storage tank heat losses overnight. However, some hot water will remain in the tank to allow showering to take place at 9am. This means that the bathing centre will be open for approximately six hours per day. As an interim step, however, an operating regime of 7.30am to noon will be introduced, but only once the bathing centre is being used regularly by a significant number of villagers. The annual performance of the SHWS with these two alternative operating strategies was therefore predicted with the model. The performance indicator used, as before, is the number of 10 litre 'design-temperature' showers. The model predicted that with the interim operating strategy (7.30am-noon) the bathing centre would annually be able to supply 18468 'design-temperature' showers i.e. 65% of the target. The ultimate operating strategy (9am-3pm) would be able to supply 31934 showers i.e. 614 per week, and therefore exceed the design target by approximately 10%.

6. DISCUSSION

The previous parts of the paper have discussed the validation and use of a simulation model to understand the behaviour of a thermosyphon hot water system. This work is useful because it can guide the designer towards system and operational improvements. The research, however, assumes an ideal world where user behaviour is entirely rational and predictable. Several social and cultural factors make the operation of the proposed bathing centre extremely challenging and need to be continuously considered particularly in operational decisions. The section below discusses some of these considerations.

- Low flow shower heads will be used to maximize water efficiency. However, experience at HARS has shown that many local people do not like the water pattern created by a shower head and prefer to wash under a constant stream of water. Some users even remove the shower rose from its fitting! It is recognised that such cultural behaviour will only change slowly.

- Experience with the HARS system shows that people often bring clothes to wash at the same time as showering. This means that more water is used than would be the case if water use was restricted only to personal washing. Preventing users from washing clothes in the shower cubicle will be a challenging task. To help prevent such a problem, a cold water clothes washing and drying area will be provided adjacent to the showering facilities.

- Controlling the individual allocation of hot water will be probably be the most challenging task and would be so in any culture. One of the components of the holistic development programme of RIDS-Nepal is non-formal education, which includes a section on how to shower and even wash babies. This work will complement specific instructions on the use of the bathing centre.

- One of the main aims of the modelling is to better understand the behaviour of the hot water system and hence try to minimise user disappointment. The community will have invested time and money in the bathing centre and expectations will be high. Experience at HARS indicates that many local people have little or no understanding of the relationship between solar radiation and the availability of hot water. Regulating opening times to when hot water is available will be crucial to the successful introduction of the community bathing centre.

7. CONCLUSIONS

Hygiene conditions in remote parts of Nepal are poor and this has a high impact on the health of villagers. Scabies ranks first amongst common diseases in rural Nepal and this disease is directly linked to poor hygiene. A Nepali-based NGO is building a community bathing centre in the village of Dhadaphaya in the northwest province of Humla to provide a washing facility for its 1100 residents. The prototype of the village system is a 300 litre 6 m^2 thermosyphon solar water heating system operating at the NGO’s high altitude research station. Based on operational data from that system, the performance of the larger system for the community bathing centre has been predicted.

It was found that in order to meet the design aim of 550 showers per week, the cultural pattern of people’s early morning bathing time has to be slowly altered. If a 9am-3pm operating strategy is adopted, then over 600 showers can be provided each week, exceeding the design target by over 10%. While this result is encouraging, it is acknowledged that changing cultural and traditional habits i.e. the so-called non-technical factors or ‘software issues’ will pose additional challenges on the successful operation of the facility.

8. ACKNOWLEDGMENTS

The work described in this paper would not have been possible without the considerable support of many of the RIDS-Nepal HARS staff, particularly with provision of performance and climatic data. Thanks are also given to The ISIS Foundation, RIDS-Nepal's Humla project implementation partner and main donor of the HCD projects currently running.

9. REFERENCES

(1) RIDS-Nepal <www.rids-nepal.org>
(2) TRNSYS (V.16.0). Solar Energy Laboratory, University of Wisconsin, USA
(3) A. Whillier and G. Saluja, “The thermal performance of solar water heaters”, *Solar Energy, 9, 1, 21-26, 1965.*
(4) A. Zahnd and A. Malla, “High altitude solar water heater community bathing center for a remote and impoverished Himalayan village”, *Proc. Solar’06, Australian and New Zealand Solar Energy Society Annual Conference*, 13th-15th Sept. Canberra. Australia.