High Altitude Solar Water Heater Community Bathing Center Renewable Energy utilised for a Remote and Impoverished Himalayan Village in Humla Nepal

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Abstract

This paper aims to highlight the importance and need for High Altitude Solar Water Heaters (HASWH) for poor, remote communities in order to improve their hygiene conditions. It draws attention to the utilisation of the abundant, locally available solar energy resource, as a sustainable source of energy for the poorest of the poor in the remote Himalayan communities. It emphasises that improved personal hygiene, through appropriate applied renewable energy technologies, is an important and integral part of people's appropriate and sustainable holistic development. In addition it is an effective preventative medical treatment for people in such communities.

This paper discusses the results of the first two years of service of the 1st generation HASWH, including, its shortcomings and need for improvements. It discusses the details of the 2nd generation HASWH which has provided, since November 2005, encouraging and satisfactory results, and is now a part of an installed and holistic community development project in the village of Dhadhaphaya in Humla. It includes the data collected under defined climate conditions, presented through diagrams and graphs; the first practical experiences obtained by the project implementing High Altitude Research Station (HARS) staff and the local community; and the lessons learned and possible further improvements and developments of this technology.

KEYWORDS: Renewable Energy Resource, High Altitude Solar Water Heater, Bathing Center, Holistic Community Development, Hygiene, Sustainability, Appropriate Technology, Local Technology

1. INTRODUCTION

Nepal is a landlocked country, with India to the south, east and west and the People's Republic of China to the north. It lies between 26° to 30° N la titude and 80° to 88° E longitude, with an altitudi nal range from 60m in the south to 8,848m in the north. Broadly, Nepal lies within the subtropical monsoon climatic system, and has five different types of climates (sub-tropical monsoon, warm temperate, cool temperate, alpine and tundra) due to its immense topographical variation. With ~80%-85% of Nepal's 28 million people living in rural and difficult to access areas, it is no surprise that there are significant differences between regions in Nepal's development stage. So e.g. the average national life expectancy in Nepal is 60.1 years for men and 59.5 years for women[1], while it is between 36–50 years[2] in Humla, with the women on an average 2 years lower than men. The national literacy rate is given as 45.2%, (62.7% for men and 27.6% for women[3]), while it is only 20.9% for men and 4.8% for women in the remote and impoverished mountain district of Humla, in the north-west of Nepal, with just 0.88 years of schooling[4] on average. The GDP/capita (Gross Domestic Product) is 1,100-1,370 US$[5], with a strong bias towards the urban, wealthier part, of the society. The HDI (Human Development Index) is 0.499 for Nepal, but just about half that (0.244) in the Humla district[6].

About 85%-88% of the rural population has still no access to any electricity energy services. They also belong to the 2.4 billion of the world's people who rely solely on fuel wood (often supplemented by crop residues and animal manure, subject to the prevailing local customs, caste, altitude and geographical zone) as their primary energy source, to provide their necessary daily energy services for cooking, heating, lighting and hot water. There is a direct link and relationship between available energy services and poverty[7] [8], which becomes more significant the more remote communities are located[9]. These are reasons why around 40% of Nepal's people are still living below the poverty line[10].

Nepal is poor in fossil fuel resources, but blessed with two major renewable energy resources, water and sunshine. More than 6,000 rivers, with a total estimated run off into the Ganges basin in the north of India of 225 billion m^3 per year[11], provide an economically feasible hydro power potential of 42,130 MW[12]. Nepal lies also along the ideal 30° northern latitude, often called the "solar belt"[13 14]. That results in about 300 sunny days a year[15], with an average daily utilisable solar irradiation of 4.8–6.0[16] kWh/m^2. Thus the application of renewable energy resources has an enormous potential to make a difference to millions of poor Nepali families' lives, and therefore strong emphasis has to be given to the development of appropriate Renewable Energy Technologies (RETs)[17] and related projects.

Among Nepal's five most common illnesses, scabies ranks first. In the remote and difficult to access mountain communities, scabies, especially among children, is very common. This is a direct outcome of the extremely poor hygienic conditions which many of the high altitude communities in Nepal suffer. Often people in these regions are totally unaware that part of their poor living conditions is due to insufficient basic personal hygiene through lack of periodical washing and cleaning. Further, the harsh and cold climate, combined with the enormous prevailing deforestation, prevents them from heating water for showering or washing their clothes. Thus it is not uncommon that these people have no bath for months at a time with some of them rarely bathing at all.

Since 2001 the Kathmandu University (KU) has been involved, initially through student projects, in the research and development of a Nepalese Solar Water Heater (SWH). This is designed to address the urgent need for warm water for personal hygiene and utilises the abundant solar energy available at high altitudes. Special emphasis has been given since 2002 to the needs of the poor and remote high altitude communities' for improved personal hygiene. Therefore KU's Mechanical Engineering research group focused on a High Altitude SWH (HASWH), which is able to perform throughout the year under the harsh high altitude climatic conditions. That means it has to be able to generate and store hot water under extreme conditions such as ambient temperatures, as low as –20℃. It also needs to be able to withstand snow storms, hail, high UV radiation and high altitude intensive solar radiation >1200W/m^2, with a guaranteed life cycle expectancy of 15–20 years. The first small scale HASWH design and prototype was manufactured and installed in the HARS (High Altitude Research Station) in Simikot Humla, at 3,000 m altitude in early 2004. Periodical monitoring and usage revealed its strengths and weaknesses, which provided the basis for the 2nd generation HASWH design. One of the important issues for improvement in the 2nd model was the unsatisfactory hot water storage tank insulation which led to very significant losses over cold winter nights. This, and other factors were addressed through a number of Kathmandu University based, research projects. The design changes have been successfully incorporated into the 2nd generation HASWH, which was installed in the HARS in Simikot in November 2005. It has been subjected to detailed monitoring and has, provided valuable information and experience for the first HASWH Community Bathing Center in the Dhadhaphaya village, with 1,067 people, in the Humla district. The construction of this Center commenced in June 2006 and it is expected to be opened in October-November 2006.

2. UTILISING OF THE AVAILABLE RENEWABLE ENERGY RESOURCES

Scabies, worms and amoebic dysentery (diarrhea) are among the five most common illnesses in Nepal. These diseases are directly linked with, and often the major cause of, the poor health of the people living in remote mountainous areas. The hardship of the high altitude mountain regions, with their long and cold winter season, does not support periodical washing or bathing. Very rarely is sufficient care given to personal hygiene, as for most of the year the cold river water temperature is between 4℃-12° C, with the warmest being during the short summer from June–August, measured as 12℃-16℃. Thus people have to heat wat er on their open fireplaces, or on their cooking stoves for bathing and washing their cloths. That puts increased strain on the already scarce and difficult to get firewood, as the women and teenage girls already spend up to 42 hours per week on firewood collection[18], increasing their already enormous daily fire wood consumption of 20–40kg/day. Hence people rarely wash themselves during the 6 winter months. Thus, the incentive to utilise the locally available

Figure 2-1 >95% of all the children under 5 suffer from worms, permanent dysentery and malnourishment.

solar energy resource to provide basic energy services such as electricity through photovoltaic systems, cooking through solar cookers, and hot water generation through solar water heaters (SWHs)[19]. Solar energy provides the best option for a more decent and dignified livelihood and it is a viable[20], and appropriate solution to meet an urgent need of the high altitude mountainous regions of Nepal. Because neither the electricity grid nor roads will make it into these remote areas for decades to come. Solar energy provides alternative options to the century-old local traditions and pattern of using firewood to meet the daily energy service demands. Further, the lucrative tourist business in many major trekking areas, provides a good reason to exploit the local solar energy resource through SWHs, for increased hygiene and comfort. Ultimately, improved hygienic conditions provide a basic prerequisite for healthy growth and sustainable development of these communities.

2.1. Solar Water Heater (SWH) in Nepal

A solar energy conversion technology widely used and installed in the urban areas of Nepal is the solar water heater (SWH). The thermo-siphon SWH technology was transferred from Switzerland to Nepal in the early 70s and has now around 220 local, Kathmandu based, SWH manufacturers. Most of the locally manufactured SWHs are of the same old technology, size and quality. The main focus of the SWH market in Nepal has been on economic growth and competitiveness rather than the development of appropriate new products. The most widely available, locally made SWH system consists of a 2 x 2m^2 absorber with galvanized steel pipes and steel absorber fins, painted with a simple black, non-reflective blackboard paint. A SWH unit typically has a 150 liter storage tank with 50mm glass wool insulation, to provide minimal insulation. The overall efficiency [energy gained in the hot water (MJ)/incoming solar irradiation (MJ)] is rather low, around 22%-25%[21]. It is believed that approximately 80,000 SWH units are operational in urban areas all over Nepal.

Figure 2-2 SWH without pipe insulation, insufficient absorber insulation, and poor absorber blackboard paint.

Figure 2-3 SWHs are poorly manufactured, with cheap materials and thus high unnecessary heat losses occur.

The Nepal-made SWHs have single layered ordinary window glass with high, approximately 0.1%, Fe_2O_3 (iron-oxide) content, allowing only 80%-82% of the solar radiation to be transmitted[22]. The glass wool insulation is insufficient during the cold winter months (with 0℃-5℃ night time temperatures in Kathmandu), and they are often very loosely packed due to the high price competitiveness. Further, the lack of any quality control or standards for manufacturers to adhere to, does not allow the customers to make a sound judgment from among the available SWH products on the market. In this context it is not surprising that the challenge of developing a new SWH for the poor, high altitude communities, for far more difficult climatic conditions, has not been previously taken up by any manufacturer or institution.

2.2. High Altitude Solar Water Heater (HASWH)

Since 2001 the Kathmandu University (KU) Mechanical Engineering Department (ME), under the main author's supervision, has been engaged in an applied research project to develop an improved SWH model for wider domestic use. The research project's main focus is on a locally manufactured, thermo-siphon HASWH system, providing its services under freezing conditions to high altitude mountain communities.

2.3. Points of Reference and Prototype Testing of the 1st Generation HASWH

Technology is designed and developed to be applied within a defined society and environment. That means that each technology, in order to be appropriate and more sustainable, has to be contextualised accordingly. Thus, in order to provide the required hot water services, the environmental, the cultural and social conditions of the HASWH end users, have to be known and defined. They set the peripheral conditions for the design and manufacturing, so that the services can be provided appropriately. Therefore the following criteria have been defined for a HASWH design, based on a survey regarding the needs of the user community within their environment.

- Due to the high altitude Himalayan mountain climate, considerably increased ambient temperature differences have to be taken into consideration (-20℃ to +30℃).
- Thicker and different insulation materials have to be used (e.g. polyurethane foam instead of glass wool).
- The HASWH system's main focus groups are whole communities rather than single families (due to the cost, culture and development stage of the remote mountain communities).
- Freeze protection must be in place for the absorbers and piping system as a thermo-siphon system is considered (active systems with a secondary loop and a glycol-water mixture with a pump would not be appropriate, as electricity would need to be generated through a solar PV system, which increases the cost and maintenance needs substantially).
- As much as possible only locally available materials will be used to increase sustainability, strengthening of the local economy and providing new skills and entrepreneurship.

With the above criteria in mind the first small size, Nepali made, thermo-siphon system prototype HASWH was designed, manufactured, installed and put under field test in the HARS (High Altitude Research Station) in Simikot, Humla, at an altitude of 3,000 m in early 2004. A copper fin absorber, with selective coating, imported from India, with a total absorber surface of 1m^2 was chosen for this initial trial. The insulated storage hot water tank was designed as an integrated part of the HASWH, with a capacity of 50 liters (see Figure 2-4). For all insulations, the local available glass wool, 65mm thick for the hot water tank and 50mm for the absorber box, was chosen. In order to protect the absorber raiser and header pipes during the 5-6 months freezing cold, high altitude winter nights, as well as to increase the interception of the available solar radiation on the absorber during the day, a highly reflective, Styrofoam insulated aluminum lid cover, was added to the system. Beside the insulated reflector lid, which can be manually adjusted according to the seasonal position of the sun and closed before sunset, manual drain down system through valves[23] are installed (one at the bottom of the absorber and one before the hot water storage tank), for additional protection against the extreme ambient temperatures conditions during the month of January (below -15℃).

A further challenge was to construct the HASWH in such a way that it is compact and thus easier to transport into the remote areas, as many remote mountain communities can be reached only by air plane and then carried by porters for hours or days. The installation and maintenance need to be easy with simple to follow installation procedures.

In order to understand and analyse the performance of the HASWH prototype, it is regularly monitored through the following nine different parameters which have been recorded with a dataTaker logger DT605, since the 1st May 2004:

- Global solar radiation on the plane of the absorber at 30° south inclined
- Cold inlet and hot outlet water temperatures (hot water storage tank temperature)
- Four absorber temperatures at different raiser heights
- Ambient temperature
- Water storage tank insulation temperature at 50% insulation depth (to measure the heat loss)

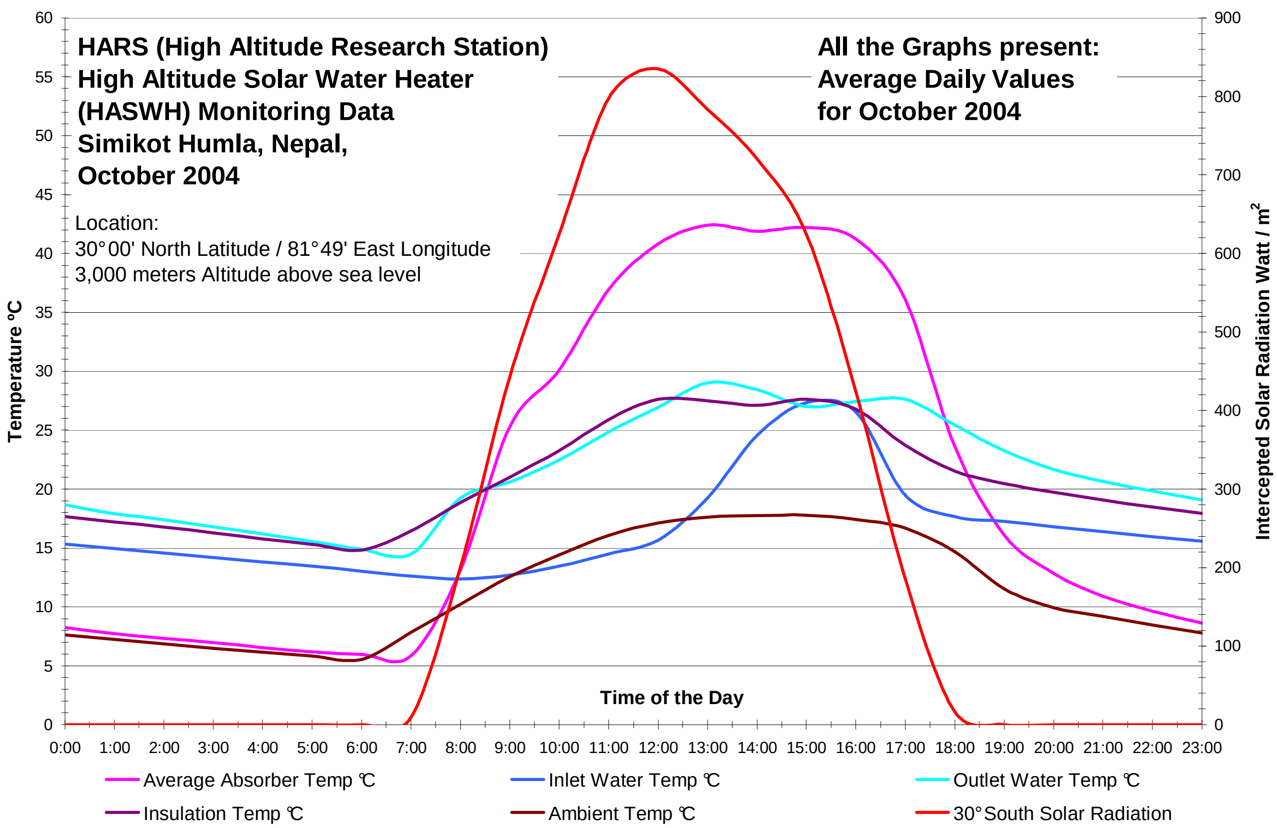
The following photographs[24] show the 1st HASWH installed and under field test at the HARS in Simikot, Humla.

Figure 2-4 The storage tank is integrated to limit pipe heat losses. The insulated, reflecting aluminum lid acts as a night time cover and day time reflector.

Figure 2-5 Selective coating, copper fin absorber with 4 thermocouples at different heights to record the temperature profile. The normal window glass cover limits the incoming solar radiation to 80%-82%.

Figure 2-6 Manual water drainage is possible, in addition to the insulated reflector lid. The absorber body is insulated with 50mm glass wool, while the hot water storage tank is insulated with 65mm.

The following graph shows the average daily performance of the 1st HASWH during October 2004



Graph 1 First HASWH Average Daily Performance at 3,000 m Altitude in Humla, Nepal in October 2004

During the month of October the average day time hot water temperature attained is around 30℃, compared to the cold water intake temperature of around 15℃. The first HASWH prototype's average system efficiency is only 15%-20%. There is a direct correlation between the incident irradiation and the absorber temperature with prolonged absorption and retention of the absorbed solar heat. The selective coating of the copper absorber supports that due to its high absorption and low re-radiation (emissivity, or high retention of heat) properties. The minimal night time temperature difference

between the absorber and the ambient temperature, despite using the insulated cover lid, shows that the lid is not as efficient as initially intended.
The outlet water temperature (representative of the hot water storage tank temperature) and the 50% insulation depth (~32.5 mm) temperature lines have a similar daily pattern, indicating that the 65mm glass wool insulation is not sufficient for high altitude SWHs, and thus increased heat loss occurs. This will be even more, the higher the ΔT between outlet hot water and ambient temperature.

There are a few interesting points to be mentioned:

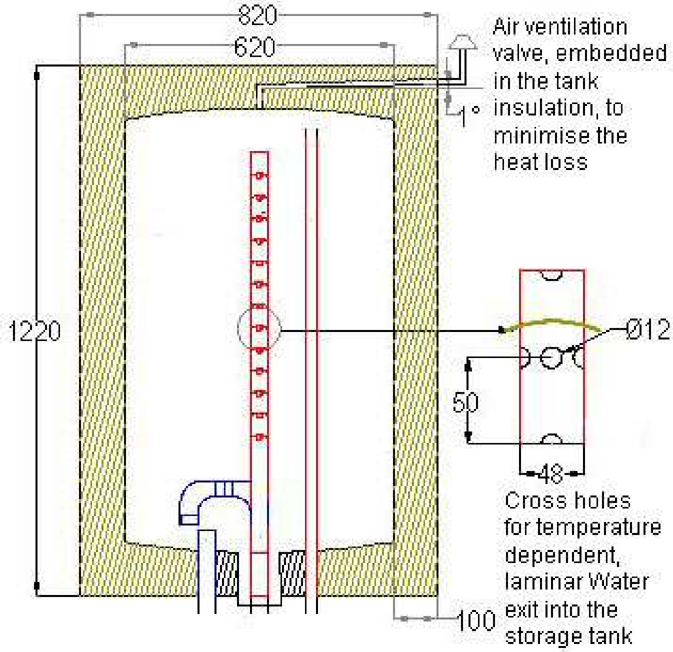
- The HASWH absorber reacts quickly to the first sunshine in the morning (7:00AM) with an increased absorber and outlet water temperature. That indicates that its thermal mass is rather low, and that its insulation is not sufficient, and it will quickly lose any energy gained.
- The average intercepted solar radiation from 15:30-16:30PM is ~400W/m^2, indicative of the minimum solar radiation needed to overcome the HASWH's internal heat losses (to keep it in its equilibrium state), as the warm water outlet temperature during that time remains constant.
- From 17:00-20:00PM, and even more from 0:00-06:00AM the ambient temperature, the tank insulation and storage tank temperature fall at a similar steep rate, indicating the inadequate insulation properties of the loosely packed 65mm glass wool insulation.

Based on these data and experience major improvements for the next, 2nd generation HASWH prototype have been identified as:

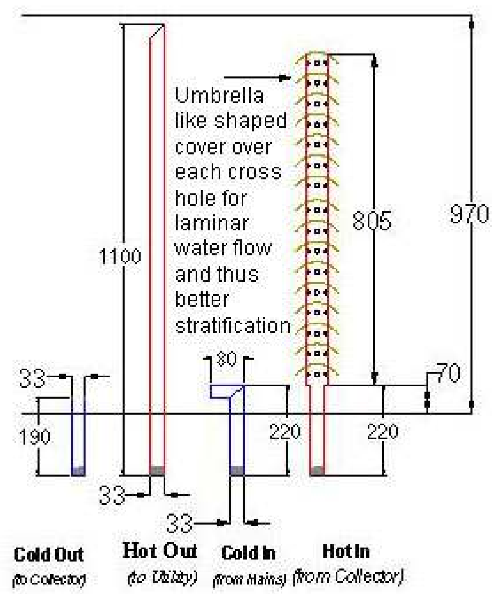
- Minimising the heat loss in the hot water storage tank and absorber through better insulation.
- Use a vertical hot water storage tank with 300 liter volume for better stratification.
- Improve cover lid insulation and shape, extending the cover over the absorber's sides
- Improved seasonal adjustment of the reflecting lid to utilise the incident solar radiation fully.
- Increase absorber surface to 1.5m^2 and combine 4 absorbers as one HASWH system unit.

2.4. 2nd Generation HASWH, Prototype Testing and First Results

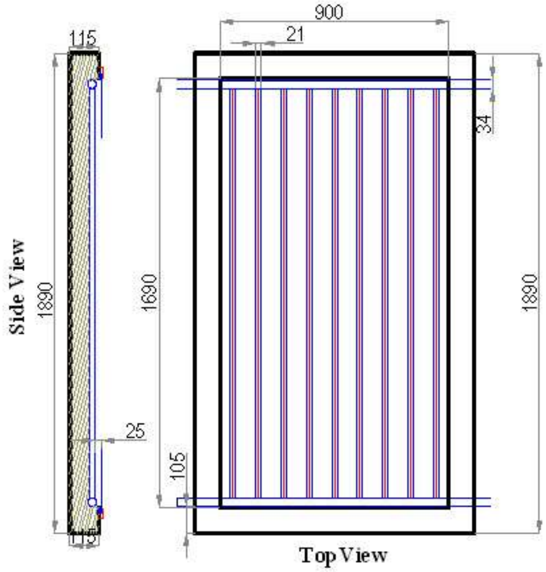
Based on the first two years experience with the 1st HASWH prototype and a clear project in view, the first, community owned high altitude solar water heater bathing center for the village of Dhadhaphaya (1,067 people), enough motivation and momentum was present for the re-designing and manufacturing of the 2nd generation HASWH. The following design drawings show some central parts of the new 2nd generation HASWH, which was manufactured during September–October 2005.



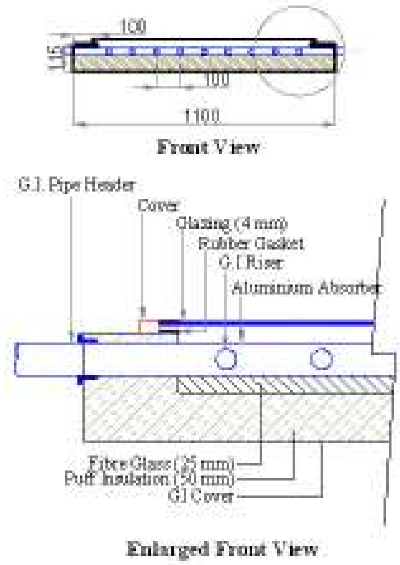
Drawing 2-1 New 300 liter stainless steel hot water storage tank with 100mm polyurethane foam insulation



Drawing 2-2 Hot and cold water pipes inside the storage tank. Cross holes and cover minimise turbulences, thus improving tank stratification.



Drawing 2-3 Dimension of the new absorber, with its nine ½' GI raisers, aluminum fins, and 1" headers. Insulation with polyurethane foam



Drawing 2-4 Close-up of the new absorber structure with GI-pipe raisers, aluminum fins and the improved box insulation materials.

The first of a total of three units (each with four absorbers @ 1.5m^2 and one 300 liter hot water storage tank) for the high altitude village SWH bathing center project, was installed in November 2005 in Simikot Humla (see Figure 2-7 and 2-8) and is at the moment of writing undergoing its first year field test. Once approved, it will be finally installed as part of a participatory holistic community development project in the village of Dhadhaphaya in Humla, from October 2006 onwards.

Figure 2-7 The 2nd Generation Thermo-Siphon HASWH, with opened, adjustable cover lid reflectors. A 40° south angle pyranometer, records the received solar irradiation on the absorber. The absorbers and insulated pipes can be shut off from the storage tank and emptied through hand valves as part of the freezing protection.

Figure 2-8 The HASWH in closed, freezing night position. Absorber boxes and hot water storage tank are insulated with 50mm and 100mm polyurethane foam respectively. Four thermocouples on one absorber and four in the hot water tank, each at different heights, record the different water temperatures. All data is recorded with a dataTaker DT605.

Figures 2.9 to 2.14 show some of the changes integrated in the 2nd generation HASWH, based on the 2 years experience of the 1st generation HASWH. They are the results of an applied research project with intensive, two years data monitoring and recording. These data needed to be evaluated and properly interpreted in order to identify the actual reasons of certain shortcomings of the 1st HASWH. The right balance of knowledge of the context the HASWH will have to perform for an appropriate life cycle of 15-20 years, as well as appropriate engineering design, in order to manufacture the HASWH with mostly locally available materials, infrastructure and skills are crucial for sustainability. Some of the changes and improvements made for the 2nd generation of HASWH, and presented in the following pictures, are the outcome of this process. They are distinct and necessary features to enable the HASWH to perform more reliably in regard to meeting the defined needs.

Figure 2-9 The 300 liter, stainless steel hot water storage tank is insulated with 100mm polyurethane foam. The air ventilation valve exits at the top on the side, in order to minimise heat losses. Four thermocouples at different heights in the hot water tank measure the attained stratification.

Figure 2-10 Nine ½" GI-pipe raisers with aluminum fins are used as absorber, rather than copper, for sustainability reasons, as copper can not yet properly be welded in Nepal. Four thermocouples at different heights measure the temperature profile on the absorber. The top and sides are overlapped with galvanised sheets while at the bottom the rain can run off freely.

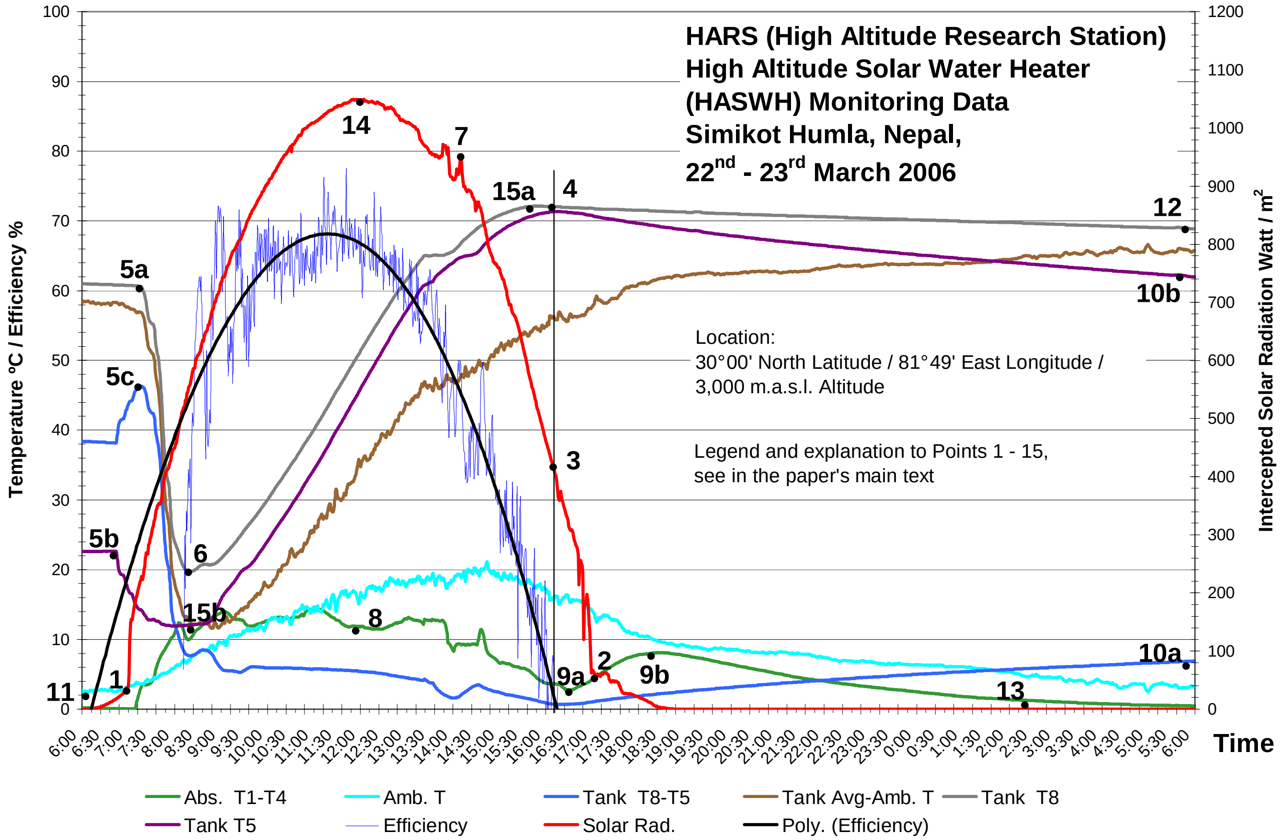
Figure 2-11 A 50mm Styrofoam insulated aluminum lid covers the absorber all around tide, including 50mm overlapping, in order to minimise the absorber heat losses during the freezing nights. The lid's corners are reinforced to increase its stiffness. The lid acts during the day as a reflector with its high gloss, stainless steel sheet on the inside.

Figure 2-12 The drain and the hot water storage tank inlet closing valves at the top of the absorber unit. They isolate the storage tank from the absorber unit as part of the freeze protection during the cold, 5-6 freezing winter month, nights.

Figure 2-13 Valves at the bottom of the absorber unit. Once the hot water storage tank inlet valve is closed and the top drain valve is opened, the bottom valve is opened and the absorber water circuit is emptied. In this way only air remains inside the absorber pipes.

Figure 2-14 In order to maximise the winter hot water generation, the absorbers are at 40° South installed at a latitude of 30° North.

The following graph shows the average daily performance of the 2nd HASWH during March 2006



Graph 2 Second HASWH Average Daily Performance at 3,000 m Altitude in Humla, Nepal in March 2006

Legend and explanation to the 2nd Generation HASWH graph from the 22nd – 23rd March 2006:

- **1:** Sunrise at 07:15AM. Before that 100% diffuse light only.
- **2:** Sunset at 17:15PM. After that 100% diffuse light only.
- **3:** A minimum global solar radiation of 420W/m^2 is needed to keep the HASWH system in equilibrium (heat gain – heat loss = 0). At this point the HASWH system efficiency is zero.
- **4:** No heat gain into the hot water under these conditions (hot water temperature, solar radiation, heat loss, ambient temperature). Zero system efficiency.
- **5a / 5b / 5c:** A ΔT of ~40-45℃ between 5a (hottest water) and 5b (co ldest water) inside the storage tank could be maintained throughout the night with an average tank water temperature – average ambient temperature of ~65℃. Good strati fication inside the tank. 5c increased initially as hot water was dispatched from the tank and cold water (~10℃) flows into the bottom of the tank. After 5c the hot water tank is almost emptied and re-filled with cold water.
- **6:** Hot water dispatch stopped, with minimal ΔT (~8℃) and stratification. Tank is full of fresh, cold water, with an average temperature of ~16℃.
- **7:** Sudden sharp increase of the beam solar radiation. Possibly caused by the passing by of cumulus humilis clouds. Just as the sun reappears these white sharp edged clouds, can give sudden solar radiation raise due to the strong reflection at the white cloud's edges.
- **8:** From about 08:15AM to 15:00PM, T1-T4 (hottest – coldest absorber temperature, see Figure 2-10) is between 10℃-14℃. A good ΔT to "drive" the received heat energy into the water flowing inside the nine absorber raisers.
- **9a / 9b: 9a:** Shortly after the minimal intercepted solar radiation (equilibrium point), the insulated absorber lid was closed, and the freezing protection valves (see Figures 2-12 and 2-13) closed and opened respectively, to drain the absorber. Thus only air remains in the absorber, and thus the ΔT over the absorber increases again slightly till 9b, before the hot air slowly starts to cool as well. Thus the absorber is protected throughout the night from freezing.
- **10a / 10b:** 10a: The hot water storage tank temperature ΔT:T8 (hottest) – T5 (coldest) shows increased stratification since the cover lids were closed, as no heat gaining solar radiation, nor

hot water is dispatched and no cold water enters the tank. The water inside the storage tank remains "calm" and thus can stratify clearly according to the different temperature dependent water densities. 10b (coldest tank temperature T5) shows a steeper drop compared to T8, as over time the cold water descends to the bottom of the tank due to its greater density.

- **11:** Praxis proves the theory, as the coldest ambient temperature is normally between 06:00AM and 06:30AM, just before sunrise[25].
- **12:** The average hot water storage tank heat loss has been measured (over many days) to be 0.3℃-0.4℃ per hour at an average tank inside – am bient temperature ΔT of 60℃-70℃.
- **13:** The air inside the emptied, and with the freezing protection lid covered, absorber cools down to a more and more equal absorber temperature, just above the ambient temperature in the early morning, thus T1-T4 goes to zero.
- **14:** The total global solar radiation on the plane of the absorbers over the course of the day amounts to: 45.258kWh/day. (Total measured solar radiation received at 40° South inclination is 7.569 kWh/m^2 per day. With a total absorber surface of 5.979 m^2 (one unit with 4 absorbers, each 1.495m^2) the total intercepted global daily solar radiation amounts to: 5.979 m^2 x 7.569kWh/m^2 = 45.258kWh/day).
- **15a / 15b:** The total HASWH system efficiency is calculated according to the total gained energy in the water, divided by the total energy received by the total absorber unit:

$$\eta_{\ HASWH\ System} = \frac{V_{Water} \times \rho_{Water} \times \Delta T_{av.water\ end - av.water\ beginning} \times C_P}{I_G \times 3.6 \times A_{Total\ Absorber\ Surface}} \times 100 = 45.32\%$$

with: V_{Water} = 0.315m^3 (total water volume of: hot water storage tank and absorber unit circuit)

ρ_{Water} = 1,000kg/m^3 (density of water)

$\Delta T_{av.water\ end - av.water\ beginning}$ = 56℃ (Average hot water tank temperature in the evening – average hot water tank temperature in the morning)

I_G = 7.569kWh/m^2 (total intercepted global solar radiation over the day)

$A_{Total\ Absorber\ Surface}$ = 5.979m^2

C_P = 4.186×10^{-3} MJ/kg℃

Discussion:

Based on the identified major improvements needed (see section 2.3.), good performance was achieved during the first six months test period of the 2nd generation HASWH, installed at the same place in the HARS in Simikot, Humla.

The heat loss reduction due to the improved hot water tank insulation with polyurethane foam, has in particular been remarkable (see point 12 in above graph explanation compared with the heat loss recorded in graph 1, even at a much lower temperature level).

Also the vertical, stainless steel, hot water storage tank maintained distinct stratification levels inside the tank. >40℃ between the top and the bottom wate r inside the tank have been achieved and maintained (with temperature difference between the top and bottom measured of up to 70℃).

The highly reflective, glossy stainless steel, insulated cover lid showed improved performance. The heat loss from the absorber cover glass is less, as the insulated lid also covers 50mm of the top and the two sides of the absorber (see Figure 2-11 and 2-14). The seasonal adjustment is simple and quick to teach and learn, and a single person can open, close or adjust the cover/reflector lid easily.

The absorber size of 1.5m^2 has turned out to be at the upper limit in regard to the ability to transport each absorber by aircraft, and afterwards by porters over the mountains, to the final installation place. The concept of 4 absorbers joined together on site to form one unit of just under 6m^2 total absorber size, seems to be an appropriate system size for community bathing centers. According to the population, hot water demand and affordability, several units can be put together and thus great flexibility for proper sizing of a defined context is possible.

2.5. HASWH Community Bathing Center

The high altitude community bathing center for the Dhadhaphaya village in Humla, will allow up to 1,100 people to take a hot shower once every two weeks, addressing the pressing need to improve their hygiene conditions. The capacity of the HASWH bathing center was laid out for up to 80 people a day, with each person using ~10 liters of 50℃ hot water, which can be mixed with cold water at their convenience. As shown in the following, an average daily 5.2 hours of full sunshine, or 5.2 PSH (Peak Sun Hours) with ~1,000W/m^2 solar radiation, are needed to generate the daily hot water energy.

$$\frac{N_{people} \times V_{Water} \times \rho_{Water} \times \Delta T_{Water} \times C_P}{3.6 \times \eta_{HASWH\ System} \times A_{Total\ Absorber\ Surface}} = PSH$$

with: V_{Water} = 0.01m^3 (10 liters of 50℃ hot water per person per bath/shower)

ρ_{Water} = 1,000kg/m^3 (density of water)

ΔT_{Water} = 40℃ (with an assumed minimum water inlet temperature of 10℃)

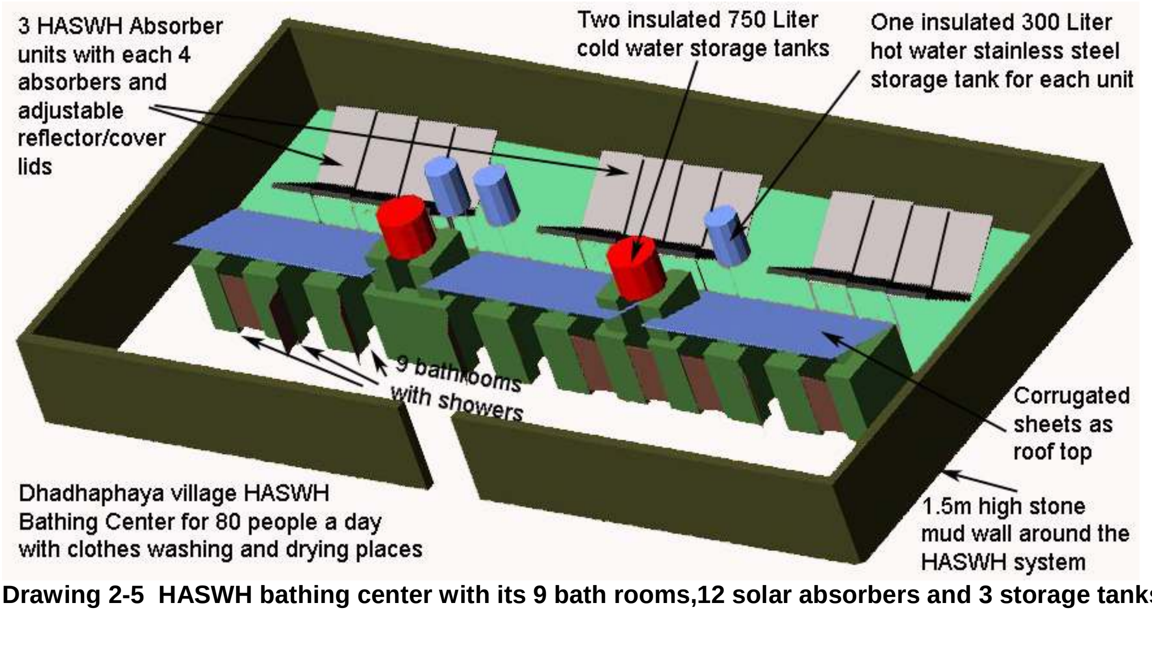
$A_{Total\ Absorber\ Surface}$ = 18m^2 (for 3 units with each 4 absorbers, each with 1.495m^2 exposed surface area)

C_P = 4.186×10^{-3} MJ/kg℃

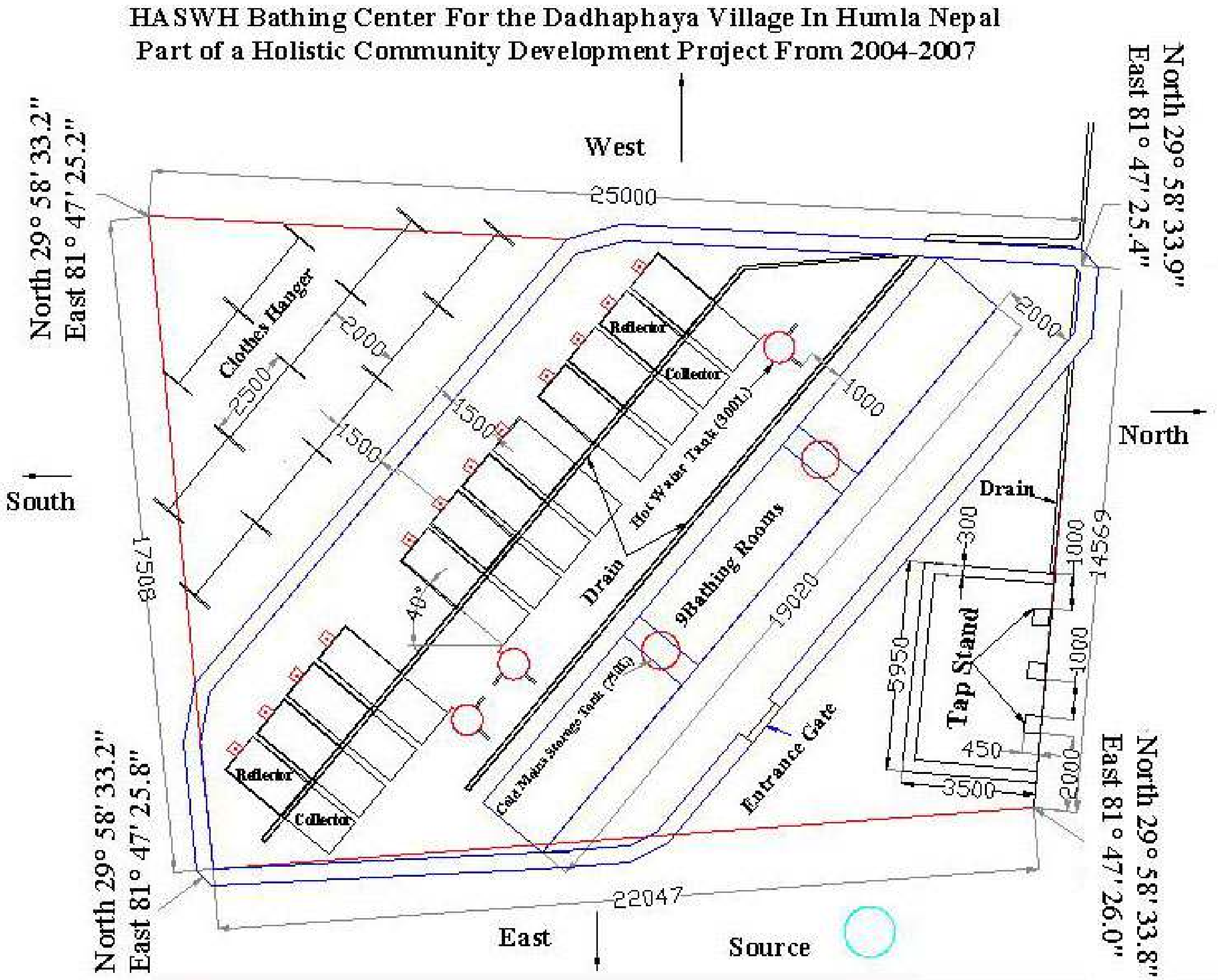
$\eta_{HASWH\ System}$ = 40% (assumed average)

thus $$PSH = \frac{80_{people} \times 0.01m^3{}_{hot\ water}\ 1{,}000kg \times 40°C \times 4.186 \times 10^{-3}}{m^3 \times 3.6 \times 0.4 \times 18m^2} = 5.2\,PSH$$

5.2 PSH per day are compared with the average daily solar radiation for Nepal of 4.8-6.0kWh/m^2 per day (see Introduction) a good middle value. The HASWH bathing center was discussed with the local people and they have enthusiastically agreed to provide all the locally available materials such as stone, wooden beams, mud and sand, besides all the necessary digging work where the bathing center is being built. They paid for half of the land, which is now registered under the name of the newly established “village bathing center committee”. The committee is in charge of the use and maintenance of the bathing center infrastructure. A caretaker was appointed by the committee for the daily operation, maintenance and protection of the bathing center, for which he/she earns a small monthly salary. For that, each family contributes 10 NRp (approx. 0.2 $AUS) a month for the hot water services received. Drawing 2-5 shows a 3-D layout of the main HASWH bathing center, while Drawing 2-6 shows a plain view including the cloth washing and drying facilities adjacent to the bathing center.



Drawing 2-5 HASWH bathing center with its 9 bath rooms,12 solar absorbers and 3 storage tanks



Drawing 2-6 HASWH Bathing Center Layout for 1,100 people in Dhadhaphaya Village for bathing, clothes washing and drying. In this way the pressing need, to increase people's personal hygiene, is addressed with the sun's locally available renewable energy. It is expected that through increased hygiene other aspects of life, such as the ability to work as a result of better health, interest to be educated and participate in their development, will improve remarkably. Thus, the HASWH bathing center promises important synergetic benefits alongside the implemented smokeless stove, electric light inside the homes, clean drinking water and other projects, which are all part of the holistic community development project in Dhadhaphaya village.

3. THE HASWH BATHING CENTER AS AN INTEGRATED PART OF AN HOLISTIC COMMUNITY DEVELOPMENT PROJECT

The main author's last 10 years of intensive involvement in community based development projects has shown, that in order to utilise the synergetic effect of individual rural development projects, a holistic community development (HCD) project approach can bring more long-term impact and sustainability for the end user community than the sum of individual projects. Thus the HASWH community bathing center has not been intended to be an individual project, but as one of several, fully integrated in a HCD project.

Based on the Dhadhaphaya village's request for a HCD project, meetings between the village elders and the project staff of the RIDS-ISIS[26], Humla project took place. A detailed HCD project plan was developed, including the following projects.

- A basic rural village PV electrification scheme for 3 white LED (WLED) lights per household

- A smokeless metal cooking and heating stove for each household, designed to cook the local available food according to the community's traditional eating habits
- A pit latrine for each household
- A village drinking water scheme with tap stands in the village
- Five greenhouses to grow vegetables for up to 10 months per year (from previously 3 months)
- Five non-formal education classes for mothers and out-of-school children (mostly girls)
- A HASWH village bathing centre for all of the 1,067 people from Dhadhaphaya village

These projects, designed and implemented alongside each other recognise that the people's needs are multi faceted and holistic. Thus in order to maximize the long-term impacts and synergetic benefits, these projects have to be seen together as an HCD[27] project (see Figures 3-1 to 3-6).

Figure 3-1 Light (WLED lamps) inside the home

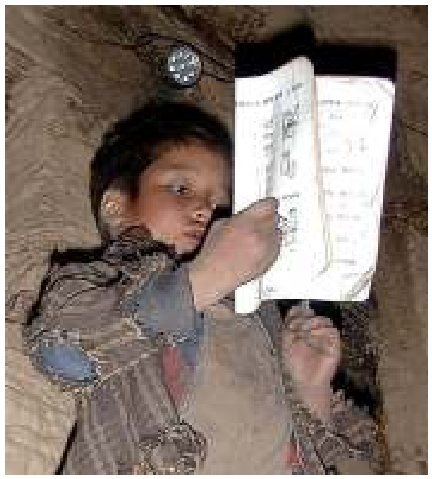


Figure 3-2 Light brings education, hygiene and improved social life

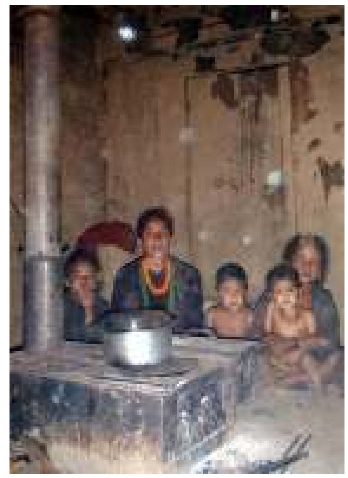


Figure 3-3 Smokeless stove provides clean indoor air

Figure 3-4 Pit latrine for a clean, hygienic environment

Figure 3-5 Clean drinking water for better health

Figure 3-6 Greenhouse for more nutritious food the whole year

4. LESSONS LEARNED

The two years of field experience with the 1st generation HASWH formed the basis for the design and manufacturing of the 2nd generation HASWH, which has now been under real field testing since November 2005. Valuable lessons learned, through recorded data and interviews with users, have been evaluated, technically interpreted and realised in the new HASWH design and manufacturing as discussed. Already new potential improvements have been identified for the 3rd generation HASWH, if a community requests a HCD project, and a dedicated donor partner can be found. Some of these parameters are increased overlapping of the covering galvanized steel sheet for the hot water storage tank and absorbers, increased aligned and stronger hinges for the cover lid, thicker valve insulation (with extended valve handles), smaller diameter for the absorber pipe connections, a 450 liter hot water storage tank per HASWH unit of 4 absorbers, low Fe_2O_3 glass cover (thus far unavailable in Nepal and India) and increased manufacturing quality and quality control.

5. CONCLUSIONS

Technology is never developed in a vacuum but always within a defined culture and environment, and thus has to be contextualised to fit the prevailing context in regard to demands and needs identified by the end users. Skill and experience are needed to bring these various parameters of technology, life and context together under the same denominator. It makes technology tangible, and no longer is the highest efficiency or cheapest cost per energy unit the ultimate goal, but appropriateness and sustainability within a defined environmental context and culture. With both being dynamic factors of life, technology can never remain at a certain status quo. Rather, the task of contextualising technology is an ongoing one. It includes professional engineering, field data monitoring of the actual performance, environmental impact and cultural changes.

Periodical interviews and periodical impact survey questionnaires for the end users' feedback are an important part of a project. These bring to light the more anthropological factors, or "software issues" of a project. They reveal the natural and project implementation related changes perceived and experienced by the users. They are key parameters to make a project more successful and sustainable in the long-term.

Thus it becomes clear that an HCD project approach is necessary to be relevant and respectful towards the partnering community's identity and culture. An HCD project is a dynamic process of different disciplines, of which engineering is just one. It pays due respect to the fact that there are crucial social, and technical parameters, within a defined cultural, geographical and climatic context. Also a longer time scale[28], compared to more traditional development projects which often have initially defined and limited (1-2 years) time frames. Further, they often distinctively dichotomise between project implementer and project end user/receiver. These matters though are often at the center of a project's "software issues", and thus need to be considered, as culture and people's ability to adjust to changes and take ownership of projects takes often place at a much slower pace than technological changes.

With this framework in mind the HASWH research, prototype and implementation project has been launched initially, so that it is able to become, over time, part of the local community's life and culture, in accordance with their ability to accommodate and integrate changes with own initiative and ownership. In this way the HASWH will provide its benefits beyond the mere project level, as it is an imbedded and integrated part of a community initiated, implemented and owned HCD project.

6. ACKNOWLEDGMENTS

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