SOLARCHILL - A SOLAR PV REFRIGERATOR WITHOUT BATTERY

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ABSTRACT: A solar powered refrigerator (SolarChill) has been developed in an international project involving Greenpeace International, GTZ, UNICEF, UNEP, WHO, industrial partners and Danish Technological Institute. The refrigerator is able to operate directly on solar PV panels, without battery or additional electronics, and is therefore suitable for locations where little maintenance and reliable operation is mandatory. The main objective of the SolarChill Project is to help deliver vaccines and refrigeration to the rural poor. To achieve this objective, the SolarChill Project developed — and plans to make freely available a versatile refrigeration technology that is environmentally sound, technologically reliable, and affordable. SolarChill does not use any fluorocarbons in its cooling system or in the insulation.
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1 INTRODUCTION

A developing project funded by the Danish Energy Agency and conducted by the Danish Technological Institute started in 1999 in co-operation with Danfoss Compressors, Vestfrost and other Danish companies. The aim was to develop a photovoltaic powered vaccine cooler without battery back-up. Instead energy storage of ice should keep the temperature stable during nights and periods without sunshine.

In parallel to that discussions were held at various times (starting in 1998-99) between UNEP, WHO, Greenpeace and GTZ with the objective to promote environmentally sound refrigerators. The idea to bring all these interested parties together arose at a refrigeration summit in Chicago in November 2000, which then led to a common meeting at GTZ headquarters in 2001. This resulted in an international project with the aim to develop, test, and use environmental sound, affordable and reliable photovoltaic powered vaccine cooler.

The Solar Chill project is a unique partnership among key international agencies, research and industry bodies. The Project Partners and their main respective roles are:

- Greenpeace International provides project coordination and fundraising.
- GTZ Proklima provides technology advice and assessment and fund raising.
- United Nations Children's Fund provides need analysis and technology advice and assessment.
- United Nations Environment Programme provides overall technology assessment and policy advice.
- World Health Organization provides equipment specifications and technology advice and assessment.
- Program for Appropriate Technology in Health provides technology advice and conducts field test.
- Industry partners: Vestfrost, Vibocold, Danfoss, Gaia Solar provide hardware.
- Danish Technological Institute coordinates the technology development.

The unique feature of SolarChill is that energy is stored in ice instead of in batteries. An ice compartment keeps the cabinet at desired temperatures during the night. SolarChill is made from mass produced standard components, which results in a favourable cost compared with other vaccine solar refrigerators.

The SolarChill has undergone intensive laboratory tests in Denmark, proving that it fulfils the objectives set for the project. In addition, a field test programme in three different developing countries is ongoing with the aim to gather practical experience from health clinics.

For domestic and small business applications, another type of solar refrigerator is under development. This is an upright type, suitable for cool storage of food and beverages in areas where grid power is non-existent or unstable. The market potential for this type is thus present in industrialised countries as well as in countries under development.

The paper describes the product development, possible SolarChill applications and experience with the two types of solar refrigerators, as well as results from the laboratory and field test.

2 THE BASIC TECHNOLOGY

The main task has been to develop a new cooler, which fulfil the current WHO requirements for vaccine coolers with battery back up, as no standard exist for the battery less type. According to these guidelines the design temperature interval is 0 ºC to + 8 ºC. The vaccine must also be kept cool for four days without power, and this is the sizing criteria for the ice storage in the cooler. Computer simulation was done based on the most efficient mass-produced freezer cabinets on the market. Those cabinets have 100 mm polyurethane insulation and are of the chest type.

The reason for choosing energy storage in ice was to avoid a lead battery for energy storage. Lead batteries tend to deteriorate, especially in hot climates, or they are misused for other purposes. This makes it necessary to install a new battery after a couple of years, and has in practice been an obstacle for the use of solar powered refrigerators. In addition to that some pollution of lead might be expected from the used batteries.

In many places kerosene or gas powered absorption refrigerated coolers are widely used in areas with poor or no grid electricity. Absorption coolers are used for both vaccine storage and for household applications and obviously needs regular supply of fuel. Furthermore, they are difficult to adjust, which does often result in destructive freezing of the medicine.

So far, two generations of SolarChill prototypes have been build and tested in climate chamber at the DTI and an advanced control were build with the purpose to control the temperature in the cooler and the speed of the DC-compressor in order to exploit maximum power from the solar panels.

2.1 Specific energy of ice storage

If electrochemical energy storage is replaced by a thermal one, an obvious question will be how the energy density for the two compares.

A simple calculation shows the interesting result, that the cooling capacity in the ice storage is at similar level as in a lead battery based on both volume and weight.

One supplier of lead battery informs, that a 50 Ah, 12 Volts battery has the weight of 13,6 kg. The dimensions are 0.24*0.175*0.175 meters. The energy content of 50 Ah can be calculated as a specific energy content of 0.159 MJ/kg or 294 MJ/m3.

The cooling system will have a COP-value (coefficient of performance) of about 1.3 (Danfoss BD35F, CECOMAF-data for –15 ºC, 2000 RPM). This will result in a specific cooling capacity of 0.206 MJ/kg or 382 MJ/m3. For the ice storage: the specific cooling capacity is identical to the melting heat of ice, which is 0.333 MJ/kg or 333 MJ/m3.

Figure 1 Cabinet with ice storage to the right

The conclusion is, that the specific cooling capacity of ice is 62% higher compared to lead battery on basis of weight and 13% smaller compared with lead battery based on volume. In reality, the ice storage outperforms the lead-acid battery, because the allowed daily cycling is less than the nominal 50 Ah, which corresponds to 100% depth of discharge.

2.2 Compressor and control

The first prototypes were equipped with a standard Danfoss BD35F direct current compressor and an external electronic control. A big electrical capacitor (60 mF) was used in order to overcome the start torque.

During 2003 a quite new compressor BD35K became available. The new compressor is using R600a (isobutane), which does not contribute to the greenhouse effect. A new integrated electronic control was also available. This control has been developed to ensure that photovoltaic solar panels can be connected directly to the compressor without an external control and/or capacitor.

The compressor is able to do a smooth start at low speed and is equipped with an adaptive energy optimiser (AEO-control). By using this control, the compressor will slowly speed up from minimum to maximum speed (from 2000 to 3500 RPM). If the panels cannot deliver sufficient power, the compressor will stop and after a short while it will try to start again. If the start fails, the compressor will try to start again after another one minute.

Once the power from the solar panels is sufficient, the compressor will start at low speed and slowly speed up again. The controller accepts a voltage between 10 and 45 Volts. The voltage from solar panels can vary, so this new feature is very useful for solar powered refrigerators and freezers. On a 12 V module, the compressor needs a current of about 4,5 A to start, and it can run continuously at 2 A.

The temperature is controlled by an electric heater that will prevent freezing of the vaccine, as the compressor is running whenever the PV panels can deliver sufficient power. An internal fan circulates air from the ice storage to the vaccine compartment when power is available.

Table 1: Comparison of refrigerator technologies

	Normal solar refrigerator	**SolarChill**
Energy storage	Battery	Icepacks
BOS components	Cables, charge regulator, blocking diode	Cable (with plugs)

With the current design, the project team believe to have found a very simple and reliable solution for solar cooling in remote areas.

3 TEST RESULTS

In a project like this, with a lot of trial and error experiments, it is important to check up the effects of every modification made. The Refrigeration and Solar Energy sections at DTI have conducted those tests.

3.1 Laboratory test results

The vaccine cooler has been tested in climate chamber at DTI. The holdover time for the vaccine cooler was measured to be about four days at 32 ºC ambient temperature. For the upright version, the hold-over time is one day less due to the geometry and smaller ice volume.

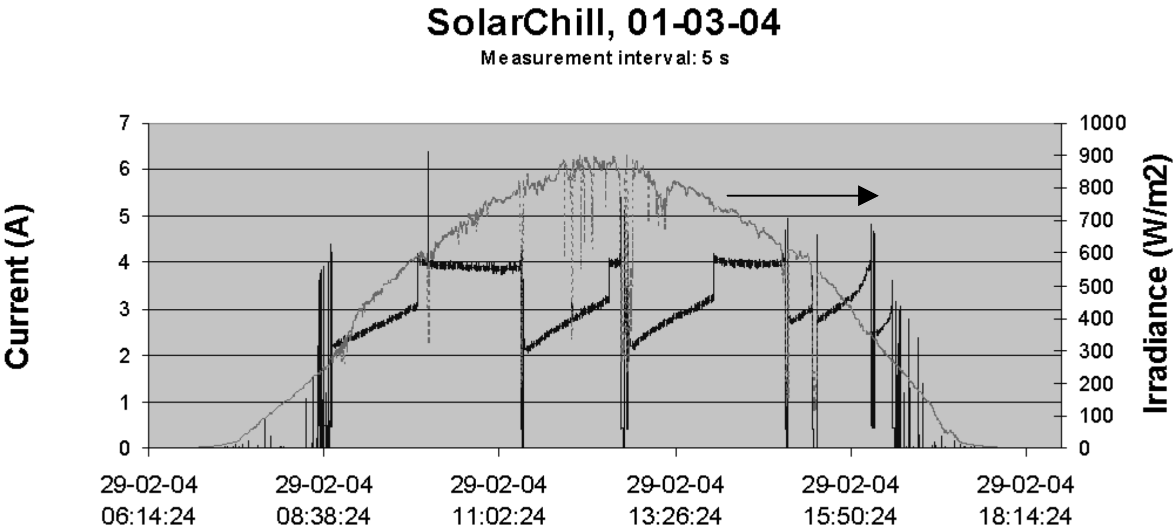

Figure 2 Current consumption on a sunny day

The typical daily mode of operation has been the following, as seen on figure 2: After sunrise, the short circuit current of the panel increases, and the compressor will try to start. However, it takes about an hour with start attempts, before continuous operation can begin.

If the sky is clear, the compressor control will adjust to maximum speed and keep it there until the panel current dictates a reduction in RPM. If the insolation is suddenly reduced (in case of clouds) the compressor is "knocked out" and must restart. It is seen that the speed, and current consumption, is gradually ramped up after each restart.

By end of the day, the compressor will stop when the current falls below 2 A, in our case corresponding to an insolation of about 200 W/m^2.

The tests have been used to determine the necessary PV panel size for the selected locations. As the critical parameter is the minimum current for start of the compressor, it was decided to use a panel with a short circuit current of 2.5 times the start current. In this way it is ensured that the compressor will also start at most overcast days, but the economical optimum may be found at a smaller panel size. Experience will show this.

3.2 Field trial

In January-February 2004 9 coolers were shipped from Unicef in Copenhagen (3 to Senegal, 3 to Indonesia and 3 to Cuba) and they have all reached their final destinations recently. One additional cooler has been installed at DTI for field test, which began in February 2004. Each unit has been packed with 3x60 W solar PV panels and has data loggers integrated for evaluation of the operating conditions.

For the unit installed at DTI there are now sufficient data to conclude that the operation under real solar conditions ensures an inside temperature within the desired range (at an ambient temperature of 20°C). There have been sunny and less sunny periods, but from the

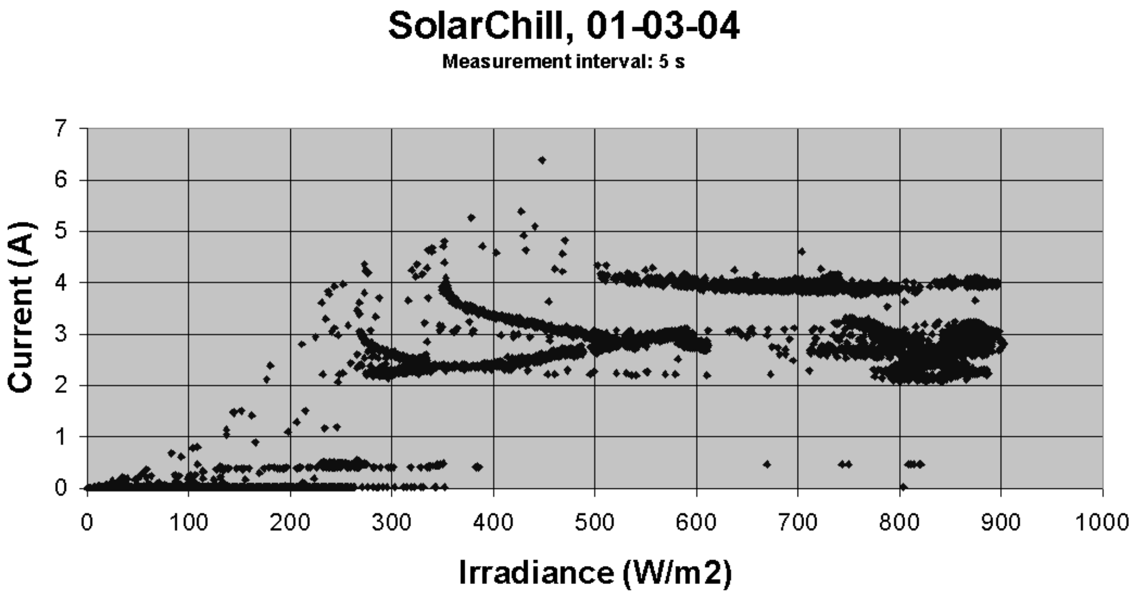

Figure 3 Points of operation during a sunny day. The points below 2A represent current consumption of fan.

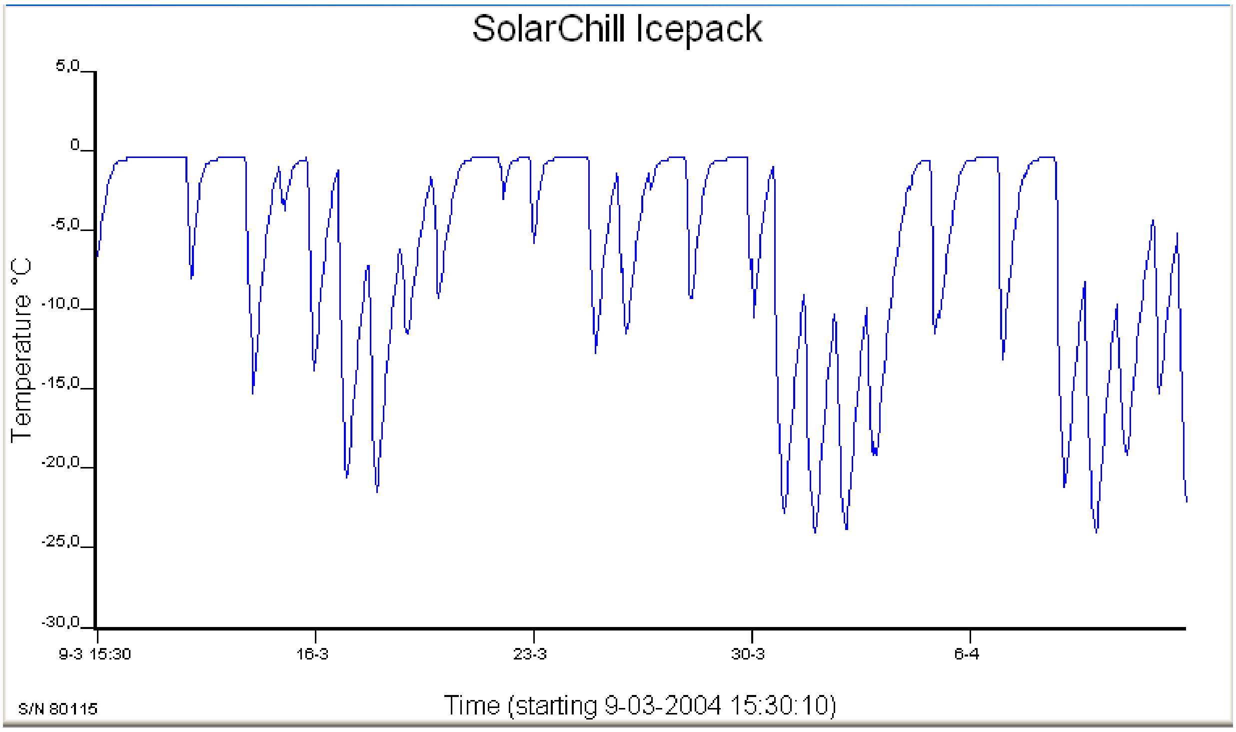

Figure 4 Temperature cycling of ice storage over several days

data it was found that the temperature becomes rather stable after a period of storage freeze-in. On figure 4 the temperature of the icepack storage is depicted as a function of time, and it is seen how there are periods where the storage does not thaw during night. The very deep temperatures are critical, because the vaccine could freeze and thus be damaged, but the insulation between the two chambers should prevent that this happens.

4. FURTHER DEVELOPMENT

Until now the project has focused on development of a reliable chest type vaccine refrigerator that is now almost ready for the market. Even after an expected WHO approval, there is still basis for optimisation, such as:

- Minimisation of the module area for specific climatic regions.
- Optimisation of the control strategy in order to minimise the needed PV-power.
- Further simplification and cost reduction of the construction.

The upright type has recently been tested and shows promising results with hold a over time of 3-4 days. The project group will now refine the product and conduct field tests on this type as well.

5. CONCLUSIONS AND PERSPECTIVES

The SolarChill has been developed in a fruitful co-operation between leading appliance manufacturers and international organizations, setting the desired properties of the product. It has been proven that it is fully possible to run a solar refrigerator without battery or start capacitor, both elements that would decrease the reliability.

Combined with a cheap and simple design, this opens up for a more general acceptance and dissemination of solar refrigeration, not only in the health sector, but also for commercial or domestic use.

Some obvious future applications for this product could be milk chilling, vending booths for food and beverages, recreational purposes or as a grid independent household refrigerator.

The authors sincerely wish to thank the sponsors and project partners for their very constructive assistance and participation in this project.

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