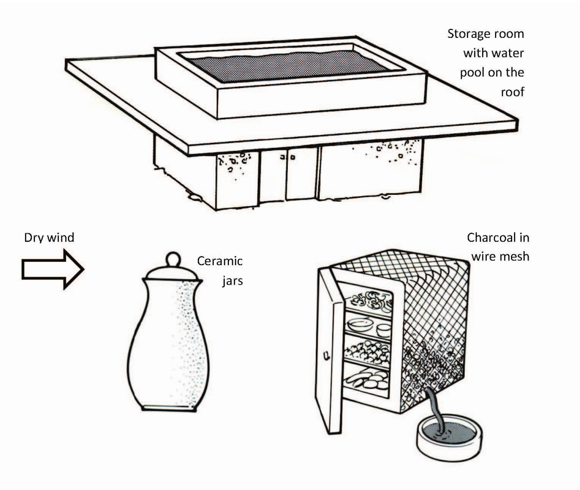
PRACTICAL ACTION
Technology challenging poverty

REFRIGERATION FOR DEVELOPING COUNTRIES

Introduction

Refrigeration plays an important role in developing countries, primarily for the preservation of food, medicine, and for air conditioning. Examples of these applications are:

- *In agriculture and dairies:*
  Removal of field heat immediately after harvesting of crops, storage of fruit, flowers, vegetables, milk, meat, and cooling during transport.
- *In retail trades:*
  sale of fresh foods, fish and cold drinks.
- *Buildings, computer installations:*
  air conditioning and temperature regulation.
- *Domestic:*
  food and drink storage.
- *Health clinics:*
  storage of blood, vaccines and medicine.



Choice of technology

Cooling can be provided in different ways. The method adopted in industrialized countries depends heavily on grid electricity, supplied continuously and reliably to every part of the country. In contrast, refrigeration is required in developing countries to stimulate agriculture and commerce, in vast areas without a reliable electricity supply. Alternative methods are therefore necessary. A number of approaches can be considered. Three kinds of cooling technology are contrasted in Figure 1 a-c, these are:

- Passive / evaporative
- Sorption heat driven
- Mechanical compression

The third method, mechanical compression, is usually dependent on a reliable and continuous supply of grid or diesel generated electricity.

The other two methods are therefore more suitable in non-industrialized areas. They require further development on the basis of requests from users in rural locations.

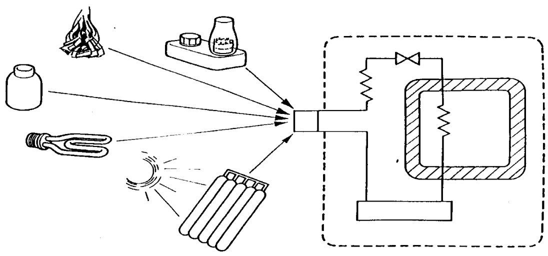


Figure 1b: Sorption refrigerator

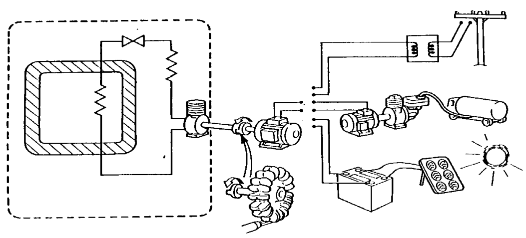


Figure 1c: Compression refrigerator

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Several approaches, which can be considered, are:

- Production of ice using electricity in regional centres; transport of this ice to agricultural areas; packing of produce to be cooled with ice in insulated containers. Electricity is either grid or diesel generated. Refrigerators, which are electrically driven, use mechanical compression technology.
- In some cases refrigerators can be driven directly by mechanical shaft power, for instance where water turbines can be readily installed.
- Production of ice using heat driven coolers ('HDCs') on a local level at agricultural production points. Packing of produce with ice for transport. The heat sources for HDCs are varied; it can be from wood, charcoal or agro-waste burnt in open stoves, from fossil fuel in conventional burners, or it can be from thermal solar collectors. HDCs use sorption technology.
- Provision of cold storage chambers using either passive, sorption, or mechanical compression technology. If passive cooling is used, temperatures less than 10°C can rarely be achieved.
- Provision of cold storage at the point of use using mechanical compression coolers drawing electricity from photovoltaic cells. This is referred to as photovoltaic cooling technology.

The most suitable method of cooling chosen will depend upon various factors; the application, the degree of reliability required, the supply of power, the level of skill needed to operate and maintain, training facilities, and available finance. The different technologies should be considered with these factors in mind. As with any technology, sufficient training is especially important; it must be planned as an integral part of an implementation programme and remains a constant concern during the years following installation. This will increase reliability of the system and reduce life cycle costs dramatically.

Temperatures and ventilation

Different applications have different requirements for temperature control and ventilation. Figure 2 shows the temperatures needed for the storage of butter, meat, fresh fish and milk. Very often storage of vegetables is complicated by the need for careful ventilation to remove unwanted gases, and to avoid humidity conditions, which would spoil the produce. Relative humidity requirements vary depending on the moisture content of the produce. A simple method of increasing humidity is to sprinkle water on the floor. In vaccine and blood storage very careful temperature control is required.

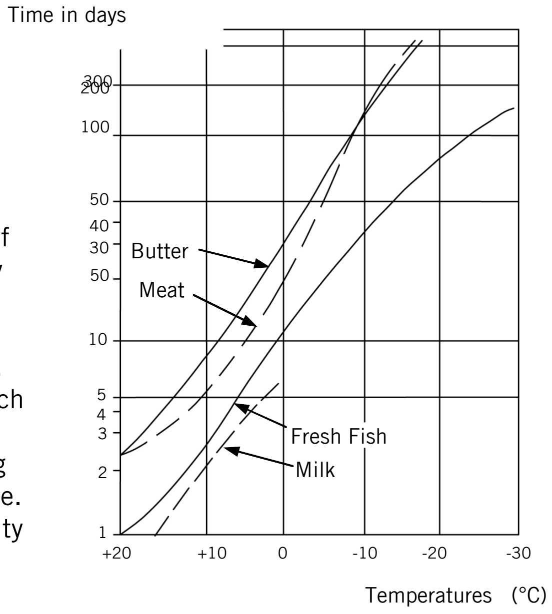


Figure 2: Temperatures for safe storage

Passive / evaporative

In applications where temperatures between 10-25°C are needed, passive methods can be used, see *Evaporative Cooling* Practical Action Technical Brief. These include traditional methods such as the use of porous jars or wet sack coverings, where the evaporative heat of the liquid, usually water, is drawn into the atmosphere. This method is effective where the atmosphere is naturally dry. Domestic storage devices have been designed along these lines, particularly with the use of charcoal beds, drip-fed with water.

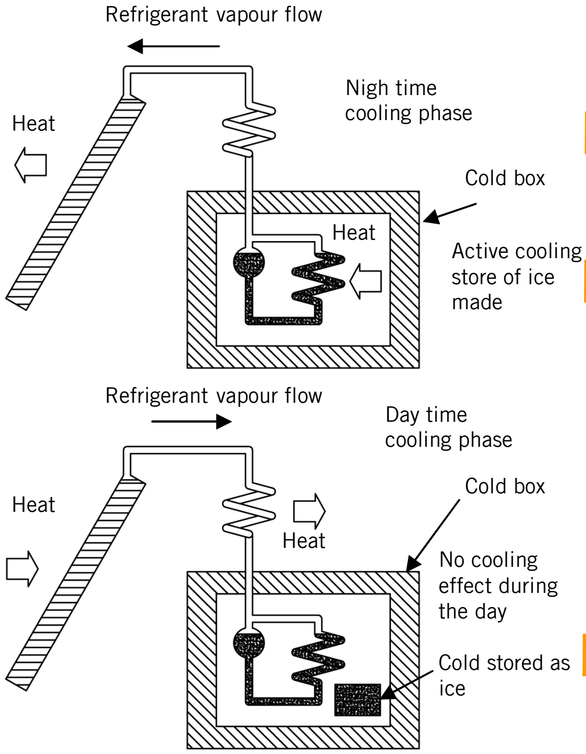
Nocturnal cooling in areas where clear night skies are common, can be effective. In air-conditioning applications, the use of shade has been developed effectively in traditional architecture, together with evaporative cooling by fountains and roof ponds.

Wherever possible passive methods should be used both in agriculture and architecture, since they can be sustained locally and are economic. Only when cooling below 10°C is needed, is it justifiable to look at active cooling technology, requiring complex machinery, and technical maintenance programmes.

Sorption Heat driven coolers (HDCs)

The principle of sorption refrigeration is shown in Figure 3 which illustrates the simplest type of sorption cooler and which has an intermittent cycle consisting of two phases. Continuous cycles are also possible - the Electrolux uses a continuous cycle. The general term sorption covers both liquid absorption and solid adsorption variants of this technology. Sorption units have some very important advantages. They can be designed to contain no moving parts, so that skilled maintenance personnel and replacements of components are less likely to be needed. Secondly, they are simple to manufacture; local manufacture increases local knowledge of the technology, which improves operation, maintenance and faultfinding. Thirdly, they are readily adaptable to locally available fuels, including biomass and solar energy. Finally, the refrigeration circuit does not use CFCs, which damage the environment. Sorption units are referred to as HDCs (heat-driven coolers).

Refrigeration phase: Because of low temperature in the bed and low pressure, the refrigerant evaporates in the cold box, drawing in heat, freezing water and cooling the storage space. Refrigerant vapour releases heat while it recombines with the sorbent which can either be a solid eg charcoal, calcium chloride, or a liquid eg water.



Heat phase: At high bed temperature and systems pressure, the refrigerant is driven out of the sorbent and collects in the cold box as a liquid.

Figure 3: Sorption cooler.
Illustration: Neil Noble / Practical Action.

Conventional gas and kerosene-driven sorption units

The heat source in conventional sorption refrigerators is usually gas or kerosene flame. Units powered from gas bottles are used on caravans or boats. A domestic unit, often used in remote locations in developing countries is the kerosene-driven Electrolux. It has been calculated that the cost of purchasing and running one of these units is around £1000 for 10 years use. The refrigeration circuits of these devices operate reliably for many years.
Maintenance of the burner assembly is required and a constant supply of wicks, burners and lamp glasses are essential. Lastly, the fuel tank must be replenished with kerosene of suitable quality. These units involve the use of hydrogen as a working fluid and cannot be designed as efficient icemakers, although they have some ice-making capacity.

Novel sorption units

Novel sorption units are under development for greater efficiency in ice making and cold storage. They do not involve hydrogen as a working fluid. A great deal of emphasis is being placed on design for reliable operation in remote environments where technical maintenance services are not available. Emphasis is also placed, in some cases, on design for local manufacture. Costs and performance figures are not easily available since these units are still on trial.

technical brief

Solar-powered sorption units
The heat source for sorption units of the kind shown in Figure 3 can be the sun. In a simple version the heating phase ends at sunset, and the refrigeration phase occurs during the night. If the sun fails to shine for a few days, the ice made on previous days acts as a store of cold, keeping the cold box at a low temperature while it gradually melts. It is expected that a unit producing 100 kg of ice per day can be produced for £4,000 (including the cost of highly efficient solar thermal panels), giving an ice cost of £0.03 per kg.

A project that Practical Action is working on in collaboration with SCORE at the University of Nottingham is a thermoacoustic device that uses thermal energy from a stove or solar energy that generates acoustic waves that then produce electricity.

http://peswiki.com/index.php/Directory:Acoustic_Generator:SCORE:Stove_for_Cooking,_Refrigeration_and_Electricity

More information is available from Paul Riley, Score Project Director, on +44 (0) 0115 951 5600, +44 (0)7973 426 379 paul.riley@nottingham.ac.uk or Internal Communications Manager Tara de Cozar in the University's Communications Office on +44 (0)115 8468545, tara.decozar@nottingham.ac.uk
http://www.score.uk.com/

Mechanical Compression
Grid electricity
Where a reliable electricity supply exists, the most economic option is to install a standard compressor driven unit. Conventional refrigerators of this kind are sold commercially. As an example, a unit making about 100 kg of flaked ice, for fisheries use, each day in tropical conditions will cost £7000, not including the cost of storage containers for the ice, or delivery. The power consumption would be in the order of 4 kW continuously. There will be extra costs in the form of replacement parts, maintenance and ancillary equipment.

Water turbine driven coolers
Costs can be reduced if shaft power is used directly to drive the compressor, for example from a water turbine. An auxiliary electricity supply is useful to provide control and protection functions, and for instance to drive ventilation fans. It is nevertheless feasible to design wholly mechanical cold storage and ice-making systems.

Diesel generating sets
The cost of operating a generator in rural areas is dependent on local conditions and must be assessed in the light of local experience. Quite often the cost can be very much higher than expected because of the need for maintenance personnel and the difficulties encountered in obtaining fuel and spare parts. If the generated electricity is not available continuously then the refrigerator should be designed as an ice-maker, allowing cold to be stored in the form of ice. Experience has shown that systems involving the storage of electricity in batteries have very high costs and are unreliable.

Solar photovoltaic systems
Solar energy is an intermittent power source, usually available for 12 hours every day. The intensity of insolation is very variable. It can be converted by photovoltaic cells into electricity, which is then stored in batteries, so that a continuous smooth electrical supply can be provided to power a mechanical compression refrigerator. Also see *Solar Photovoltaic Refrigeration of Vaccines* Practical Action Technical Brief.

The advantage of using solar power is that it is a source that can be relied upon, never to fail for more than a few days. This reliability is very important in some cases, such as vaccine storage, where loss of temperature control can spoil the vaccines completely. The battery is designed to continue to provide electricity at night and on days when no sunshine is available. In this application, the high cost of photovoltaic cells, batteries and control equipment is justified. The size of the photovoltaic array and the battery capacity must be carefully calculated to provide an economic system.

Solar refrigeration units of this kind, especially designed for vaccine preservation, are commercially available. A system providing 60-80 watts of cooling is typically priced in the range of £3000-5500. Replacement parts will tend to cost £500-1000 in the course of four years of operation. Most of this cost will be in the replacement of batteries which are designed to have a four year life but can fail in a shorter period if maintained poorly. Replacement costs are considerably reduced if skilled, technical maintenance personnel are available.

Combined heating/drying/cooling system

Because a refrigerator releases heat it can be used to raise temperatures in agricultural processes like crop or spice drying. The cooling effect can be used to dehumidify the air passing over the crop and the heating effect can be used to warm the air. In this, very high efficiencies can be obtained (for instance up to 7 times as much useful energy produced as required to drive the device). Such efficiencies are commonly met in timber drying plants using these principles. Practical Action is developing low cost methods of utilizing this effect, with respect to drives from small hydro turbines or from steam or diesel engines.
A second example is the use of heat from a refrigerator (also known as a heat pump, exactly the same machine) to help sterilize milk, while the same refrigerator cools the milk to preserve it.

Choosing the system

In order to decide which refrigeration system to adopt for a particular purpose, it is necessary to consider the ongoing inputs required by each system. Table 1 lists the various systems and the inputs required for each. The choice of system is based on the foreknowledge that all the necessary inputs will continue to be available in the locality of the fridge. The mistake is often made of installing a unit with a relatively low purchase cost which later ceases to function through lack of necessary inputs.

	COMMENT	ENERGY SOURCE	PERSONNEL	SPARE PARTS	10 YEAR TOTAL COST
MECHANICAL COMPRESSION					
Grid	Electricity available for other purposes, e.g. lighting, flaking of ice.	Grid electricity. Cost of connecting/ transforming can be high.	Maintenance: skilled personnel.	Source of parts may be distant. Supply may be uncertain.	Purchase cost, electricity, personnel, replacement parts.
Diesel	Electricity available for other purposes, e.g. lighting, flaking of ice.	Diesel generator	Maintenance: skilled personnel permanently on-site.	Source of parts may be distant. Supply may be uncertain.	Purchase cost, diesel, replacement parts.
Solar photovoltaic	Expensive. Electricity available for lighting, communications, temperature control.	Irradiation of 10-20 MJ/day/m^2. Long cloudy periods problematic.	Skilled personnel permanently available.	Battery life 2-4 years. Control electronics can fail.	£3500-6500 for 60-80 W cooling, includes replacement costs.
SORPTION (HDCs)					
Conventional	Well known in the field.	Gas/kerosene quality must be adequate.	Burner parts, wick adjustment, etc.	Replacement of burner parts routine.	£1000-2000 for 60-100 W cooling and small maintenance cost.

Novel (biomass driven)	Local manufacture possible. Under development, relatively low cost.	Any locally available heat source suitable, eg charcoal, coal, agro wastes, cow dung fossil fuels.	Maintenance of open burner, brine tank, cooling water. Local skills sufficient.	Locally available spare parts.	Purchase cost projected at £2000 for 100 kg ice/day. Fuel cost £50-100 per year.
Solar	Very new on market. Performance not yet evaluated. Low night temperatures can be advantageous in some cases. Presence of cooling water advantageous. Provincial manufacture possible.	Solar irradiation 10-120 MJ/day/m². Long periods of cloud problematic.	Local skills sufficient, few moving parts.	Solar panels may require import of spare parts.	Current purchase cost £1500-2500 for 10 kg ice/day. Projected cost £4000 for 100kg ice/day (including solar panel).

Table 1: Choosing a system.

Further information

Factsheets & handbooks

- *Evaporative Cooling* Practical Action Technical Brief http://practicalaction.org/evaporative-cooling-1
- *Evaporative Cooler - The Ceramic Refrigerator* Engineering drawings of the Sudan Zeer pot-in-a-pot evaporative cooler. http://practicalaction.org/evaporative-cooling-the-ceramic-refrigerator-1
- *Solar Photovoltaic Refrigeration of Vaccines* Practical Action Technical Brief http://practicalaction.org/solar-photovoltaic-refrigeration-of-vaccines-1
- *Cold Storage of Fruit and Vegetables* Practical Action Technical Brief http://practicalaction.org/cold-storage-of-fruit-and-vegetables-1
- *Solar Energy and Rural Health Care: Fact Sheet N132*: https://apps.who.int/inf-fs/en/fact132.html WHO
- *Solar Energy for Cooling and Refrigeration* http://www2.warwick.ac.uk/fac/sci/eng/staff/dbm/es368/solarcool.pdf DTU
- ASHRAE Handbooks:
  1997, *Fundamentals*
  1998, *Refrigeration*
  1999, *HVAC Applications*
  2000, *HVAC Systems and Equipment*
  American Society of Heating, Refrigeration & Air Conditioning Engineers (ASHRAE)
  1791 Tullie Circle
  North East Atlanta
  GA 30329, USA
  Tel: +1 (404) 636 8400
  Fax: +1 (404) 321 5478
  Website: www.ashrae.org
- R J Dossat, 1997, *Principles of Refrigeration*. Prentice Hall, 4th edition.
- Ray Tomkins, 1985, *Prospects for Solar Refrigeration*,
  Ray Tomkins Management School
  Imperial College, 53 Princes Gate
  Exhibition Road, London, SW7 2PG,
  United Kingdom
  Tel: +44 (0)20 7594 9137
  Fax: +44 (0)20 7823 7685
  Website: www.ms.ic.ac.uk
- US AID – Powering Health
  http://www.poweringhealth.org/topics/refrigeration/index.shtml

Useful contacts

Light up the World
University of Calgary, Mechanical Engineering
1111 22nd Ave NW
Calgary
Alberta
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Canada
Tel: +1 (403)284-2596
E-mail: lutw@lutw.org
Website: http://www.lutw.org/

Centre for Renewable Energy
Ga-2/717, Bag Bazar
Kathmandu, Nepal
P.O. Box 589
(Near Hotel Ganapati, Bag Bazar)
Tel: +977 1 248852/351052
E-mail: cre@ccsl.com.np
Website: http://www.crenepal.org.np/
Promoting WLEDs in Nepal.

Grameen Shakti
Grameen Bank Bhaban
Mirpur-2, Dhaka-1216
Bangladesh
Tel: +8802 9004081, 9004314
Fax: +8802 8035345
E-mail: g_shakti@grameen.net
g_shakti@grameen.com
Website: http://www.gshakti.org/
Solar home systems for Bangladesh.

Winrock International India
7, Poorvi Marg, Vasant Vihar
New Delhi 110 057
India
Tel: +91 11 614 2965
Fax: +91 11 614 6005
E-mail: winrock@vsnl.com
Website: www.winrockindia.org
Winrock developed a solar lantern for India.

Lights for Leaning
69 High Street, Cricklade, Wiltshire, SN6 6DA
United Kingdom
Tel: +44 (0)1793 750844
E-mail: info@lightsforlearning.org
Website: www.lightsforlearning.org
LED lighting systems for educational projects in Africa.

SolarAid
Bunhill Fields Meeting House
Quaker Court, Banner Street
London
EC1Y 8QQ
United kingdom
Tel: +44 (0)20 7490 3321
Fax: +44 (0)20 7490 3321
E-mail: info@solar-aid.org
Website: http://solar-aid.org/
Developed a solar LED lantern kit to fit kerosene lamps. This project is focused on Malawi.

The Solar Electric Light Fund (SELF)
1775 K Street, NW Suite 595
Washington, DC 20006
USA
Tel: 202-234-7265
Fax: 202-328-9512
E-mail: solarlight@self.org
Website: http://www.self.org/
The Solar Electric Light Fund, Inc. (SELF) is a non-profit charitable organisation. SELF seeks to help communities and governments in the acquisition, financing and installation of decentralised household solar electric systems in the developing world.

Lighting Africa
IFC, CBA building, 4th Floor, Upper Hill, Mara / Ragati Road
P.O. Box 30577-00100
Nairobi, Kenya
Tel: +254 20 275 92 00
Website: http://www.lightingafrica.org/
Lighting Africa, a joint IFC and World Bank program, is helping develop commercial off-grid lighting markets in Sub-Saharan Africa as part of the World Bank Group's wider efforts to improve access to energy.

Organisations

Institute of Food Research,
Norwich Research Park, Colney,
Norwich, NR4 7UA
United Kingdom
Tel: +44 (0)1603 255 000
Fax: +44 (0)1603 507 723
E-mail: ifr.library@bbsrc.ac.uk
Website: http://www.ifr.ac.uk/

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School of Engineering
University of Warwick
Coventry
CV4 7AL
United Kingdom
Tel: +44 (0)24 765 23137
Fax: +44 (0)24 76 418922
Website:
http://www.eng.warwick.ac.uk/~esrec/energy/

EPI (Expanded Programme on Immunisation),
World Health Organisation,
Attn Director EPI,
Avenue Appia 20, 1211 Geneva 27,
Switzerland
Tel: +41 (0)22 791 4517
Fax: +41 (0)22 791 4193
Website: www.who.int

International Institute of Refrigeration,
177 Boulevard Malesherbes,
75017 Paris,
France
Tel: +33 (0)1 4227 3235
Fax: +33 (0)1 4763 1798
Website: www.iifiir.org/

Institute of Refrigeration
Kelvin House, 76 Mill Lane
Carshalton, Surrey, SM5 2JR,
United Kingdom
Tel: +44 (0)20 8647 7033
Fax: +44 (0)20 8773 0165
Website: www.ior.org.uk

Manufacturers

Note: This is a selective list of suppliers and does not imply endorsement by Practical Action.

Ice making machines

Total Refrigeration Ltd.,
Unit 2A East Tame Business Park
Rexcine Way
Talbot Road
Hyde
Cheshire
SK14 4GX
United Kingdom
Tel: 0845 127 2527
Fax: +44 (0)161 366 7374
E-mail: total@totalrefrigeration.co.uk
Website: www.totalrefrigeration.co.uk
Icemakers, cabinets, chillers & freezer cold rooms.

Ziegra Ice Machines (UK) Ltd.,
Unit 2, Phoenix Court, Hammond Avenue
Stockport, Cheshire, SK4 1PQ
United Kingdom
Tel: +44 (0)161 429 0525
Fax: +44 (0)161 480 7927
E-mail: ice@ziegra.co.uk
Website: www.ziegra.co.uk
Ice machines and ice storage systems.

Sibir International AB
S-105 45 Stockholm
Torggatan 8
S-171 54 Solna
Sweden
Tel: +46 (8) 501 025 08
Fax: +46 (8) 501 025 99
Email: info@sibir.com
Website: www.sibir.com
Domestic kerosene refrigerators, domestic gas refrigerators, medical kerosene refrigerators, medical gas refrigerators.

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