Appropriate Technology & its Applications

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Appropriate Technology

The Universal Nut Sheller in use in Uganda, an example of appropriate technology

Appropriate technology (AT) is technology that is designed with special consideration to the environmental, ethical, cultural, social, political, and economical aspects of the community it is intended for. With these goals in mind, AT proponents claim their methods require fewer resources, are easier to maintain, and have less of an impact on the environment compared to techniques from mainstream technology, which they contend is wasteful and environmentally polluting.

The term is usually used to describe simple technologies proponents consider suitable for use in developing nations or less developed rural areas of industrialized nations. This form of "appropriate technology" usually prefers labor-intensive solutions over capital-intensive ones, although labor-saving devices are also used where this does not mean high capital or maintenance cost. In practice, appropriate technology is often something described as using the simplest level of technology that can effectively achieve the intended purpose in a particular location. In industrialized nations, the term *appropriate* *technology* takes a different meaning, often referring to engineering that takes special consideration of its social and environmental ramifications.

Background and definition

Sustainable portable classroom design proposal

The term *appropriate technology* came into some prominence during the 1973 energy crisis and the environmental movement of the 1970s. The term is typically used in two arenas: utilizing the most effective technology to address the needs of developing areas, and using socially and environmentally acceptable technologies in industrialized nations.

Appropriate technology founders

In the modern world appropriate technology is supposed to commence from Mahatma Gandhi who advocated small, local, mostly village-based technology to help India's villages become self reliant and thus aid in the freedom struggle against British and wealthy Indians. Gandhi's philosophies on technology were contrary to the belief that technological development was inherently synonymous with progress. He believed the powers of technology should be produced and used artfully and the benefits should be close to the individual and widely produced and distributed in a decentralised fashion. Gandhi claimed that his favorite technologies were the sewing machine, because it was invented out of love, and the bicycle, because it kept one's feet close to the ground. He felt that the paradigm of technology should not be one that disenfranchises people and be used in the pursuit of violence, rather, it should be used in a way that empowers people broadly. Integrated with the movement for self-rule, which was based on local economies, Gandhi championed the spinning wheel, or *charka*, employed in the khadi movement in the 1920s, which produced cloth locally in an act of civil disobedience of the imperial system, causing the British monopoly on textiles to collapse. However, in the movement for *Swaraj*, or home rule, Gandhi believed in a total revolution of production, saying that "It is not about getting rid of the tiger and keeping the tiger's nature". Having said "it is better for a machine to be idle than a man to be idle", Gandhi rejected the factory model of industrialisation, which valued production over the worker. He raised money to offer a reward for someone to invent a spinning wheel that could employ people in the same way, while producing more thread.

E. F. Schumacher who was very strongly influenced by Gandhi's philosophy took his village development further and coined "intermediate technology" in early 1970s. It is Schumacher through his book Small is Beautiful and later by creating the Intermediate Technology Development Group that really started the appropriate technology movement.

Appropriate technology practitioners

Some of the well known practitioners of the appropriate technology-sector include: M K Ghosh, B.V. Doshi, Buckminster Fuller, William Moyer (1933–2002), Amory Lovins, Sanoussi Diakité, Victor Papanek, Johan Van Lengen and Arne Næss (1912–2009)

Appropriate technology in developing areas

The term has often been applied to the situations of developing nations or underdeveloped rural areas of industrialized nations. The use of appropriate technology in these areas seeks to fill in the gaps left by conventional development which typically focuses on capital-intensive, urban development.

Appropriate technologies are not necessarily "low" technology, and can utilize recent research, for example cloth filters which were inspired by research into the way cholera is carried in water. A type of high-efficiency, white LED lights is used by the Light Up the World Foundation in remote areas of Nepal to replace more traditional forms of lighting that cause health problems associated with kerosene lamps or wood fires.

Intermediate technology

Coined by E. F. Schumacher, the term **intermediate technology** is similar to appropriate technology. It refers specifically to tools and technology that are significantly more effective and expensive than traditional methods, but still an order of magnitude (one tenth) cheaper than developed world technology. Proponents argue that such items can be easily purchased and used by poor people, and according to proponents can lead to greater productivity while minimizing social dislocation. Much intermediate technology can also be built and serviced using locally available materials and knowledge. This intermediate technology is conducive to decentralization, compatible with the laws of ecology, gentle in its use of scarce resources, and designed to serve the human person instead of making him the servant of machines.

Appropriate hard and soft technologies

According to Dr. Maurice Albertson and Faulkner, appropriate hard technology is “engineering techniques, physical structures, and machinery that meet a need defined by a community, and utilize the material at hand or readily available. It can be built, operated and maintained by the local people with very limited outside assistance (e.g., technical, material, or financial). it is usually related to an economic goal.” Some have explored the use of classroom projects for university-level physics students to research, develop and test appropriate hard technology.

Albertson and Faulkner consider Appropriate soft technology as technology that deals with “the social structures, human interactive processes, and motivation techniques. It is the structure and process for social participation and action by individuals and groups in analyzing situations, making choices and engaging in choice-implementing behaviors that bring about change.”

Appropriate technology in developed countries

The term *appropriate technology* is also used in developed nations to describe the use of technology and engineering that results in less negative impacts on the environment and society. E. F. Schumacher asserts that such technology, described in the book *Small is Beautiful* tends to promote values such as health, beauty and permanence, in that order.

Often the type of appropriate technology that is used in developed countries is "Appropriate and Sustainable Technology" (AST); or appropriate technology that, besides being functional and relatively cheap (though often more expensive than true AT), is also very durable and lasts a long time.

Parallel to this theory, British architect interested in human settlements and development, John F. C. Turner (co-author and editor of the book Freedom To Build and author of the book Housing By People), has said that truly appropriate technology is technology that ordinary people can use for their own benefit and the benefit of their community, that doesn't make them dependent on systems over which they have no control. This definition focuses on the idea that technology typically creates dependencies and thus to truly be appropriate, technology should enhance the local or regional capacity to meet local needs, rather than creating or amplifying dependencies on systems beyond local control.

Determining a sustainable approach

Features such as low cost, low usage of fossil fuels and use of locally available resources can give some advantages in terms of sustainability. For that reason, these technologies are sometimes used and promoted by advocates of sustainability and alternative technology.

Besides using natural, locally available resources (e.g. wood or adobe), waste materials imported from cities using conventional (and inefficient) waste management may be gathered and re-used to build a sustainable living environment. Use of these cities' waste material allows the gathering of a huge amount of building material at a low cost. When obtained, the materials may be recycled over and over in the own city/community, using the cradle to cradle method. Locations where waste can be found include landfills, junkyards, on water surfaces and anywhere around towns or near highways. Organic waste that can be reused to fertilise plants can be found in sewages. Also, town districts and other places (e.g. cemeteries) that are subject of undergoing renovation or removal can be used for gathering materials as stone, concrete, or potassium.

The waste materials include

- recyclable plastics such as PE, PP, PVC, PS, SB; PSE, ABS PMMA, PTFE, PA, PC, PUR, EP, UP and PET. ISF has made two documents on how respectively discarded plastics and aluminum can be salvaged and reused in developing countries.
- ferrous waste materials (e.g. cans, ...)
- sewage sludge (for use as a fertiliser)

The waste materials can be gathered by waste pickers, or – if possible – with more sophisticated machines such as materials recovery facilities (MRFs),and solid waste processing facilities. The latter may allow better separation of the different metals, plastics, ... resulting in a higher – and more efficient- yield. Also, waste pickers -besides usually not being equipped to disassemble the materials - risk being exposed to various poisonings.

Sewage sludge is collected not by hand, but through a sludge processing plant that automatically heats the matter and conveys it into fertiliser pellets (hereby removing possible contamination by chemical detergents, ...) This approach eliminates seawater pollution by conveying the water directly to the sea without treatment (a practice which is still common in developing countries, despite environmental regulation). Sludge plants are useful in areas that have already set up a sewage system, but not in areas without such a system, as composting toilets are more efficient and do not require sewage pipes (which break over time).

After collection, the obtained materials often need to be melted and recast in forges and/or may require bending, cutting, folding, ... in a workshop. Plastics are a special case that are too melted in a workshop, using small, purpose-built hand-operated melting containers. Metalworking tools that can be used to cut or fold the metal are the OpenLathe and Multimachine. Also, some CNC metalworking tools can be appropriate.

In some cases, melting and recasting is not required, as some parts can be simply cut and used as is in different devices. An example is the passive solar collector built from old refrigerator tubing.

City construction

In order to increase the efficiency of a great number of city services (efficient water provisioning, efficient electricity provisioning, easy traffic flow, water drainage, decreased spread of disease with epidemics, ...), the city itself must first be built correctly. Having the city designed using a grid plan brings the benefits all in a single go. As in the developing world, a lot of cities are hugely expanding and new ones are being built. Looking into the cities design in advance is a must for every developing nation.

Building construction

- Adobe (including the variation called Super Adobe),
- Rammed earth,
- Compressed earth block,
- Dutch brick,
- Animal products,
- Cob
- and/or other green building materials could be considered appropriate earth building technology for much of the developing world, as they make use of materials which are widely available locally and are thus relatively inexpensive.

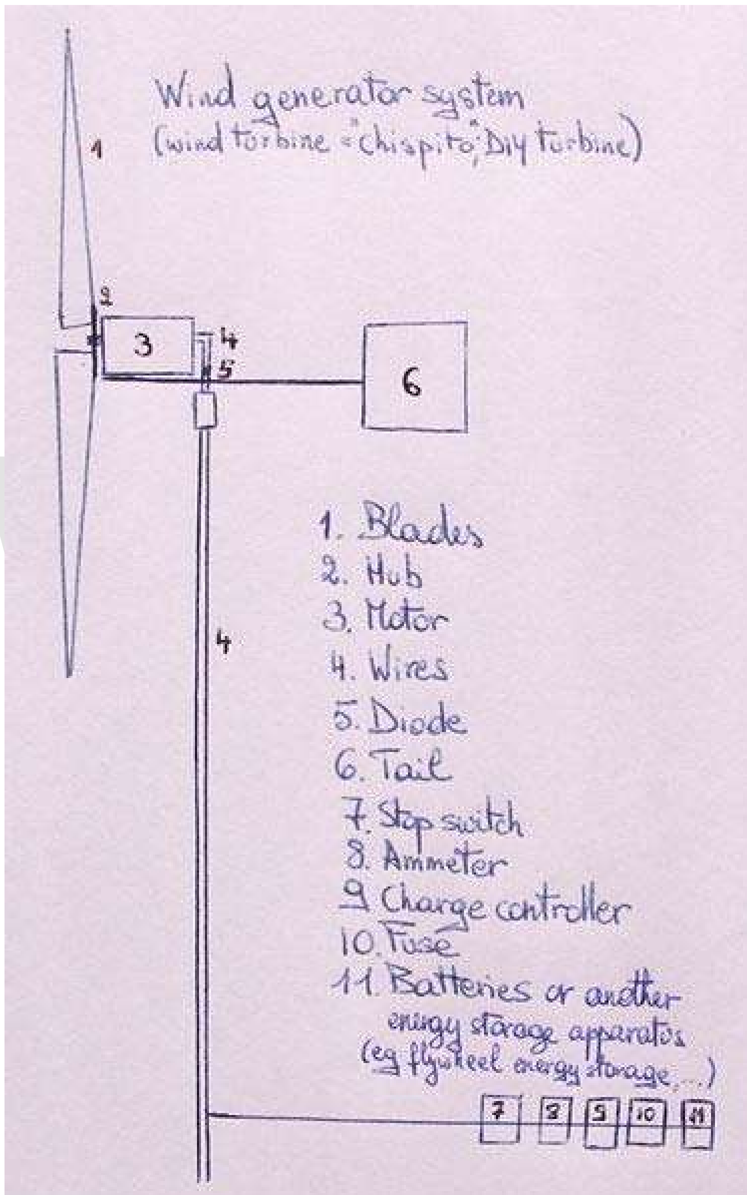
The local context must be considered as, for example, mudbrick may not be durable in a high rainfall area (although a large roof overhang and cement stabilisation can be used to correct for this), and, if the materials are not readily available, the method may be inappropriate. Other forms of natural building may be considered appropriate technology, though in many cases the emphasis is on sustainability and self-sufficiency rather than affordability or suitability. As such, many buildings are also built to function as autonomous buildings (e.g. earthships, ...). One example of an organisation that applies appropriate earthbuilding techniques would be Builders Without Borders.

The building structure must also be considered. Cost-effectiveness is an important issue in projects based around appropriate technology, and one of the most efficient designs herein is the public housing approach. This approach lets everyone have their own sleeping/recreation space, yet incorporate communal spaces e.g. mess halls, Latrines, public showers, ...

In addition, to decrease costs of operation (heating, cooling, ...) techniques as Earth sheltering, Trombe walls, ... are often incorporated.

Organizations as Architecture for Humanity also follows principles consistent with appropriate technology, aiming to serve the needs of poor and disaster-affected people.

Energy



Small-scale (DIY) generation system

The term soft energy technology was coined by Amory Lovins to describe "appropriate" renewable energy. "Appropriate" energy technologies are especially suitable for isolated and/or small scale energy needs. However, high capital cost must be taken into account.

Electricity can be provided from:

- PV solar panels (which are expensive initially, but simple), and (large) Concentrating solar power plants. PV solar panels made from Low-cost photovoltaic cells or PV-cells which have first been concentrated by a Luminescent solar concentrator-panel are also a good option. Especially companies as Solfocus make appropriate technology CSP plants which can be made from waste plastics polluting the surroundings (see above). In certain cases, a dish stirling setup could be appropriate (by using low-cost Stirling engines as the Thermomechanical generator); primarily as they have greater efficiency, reducing the size required for the plant. However, repair of these more efficient CSP setups is more difficult than with regular CLFR, solar power towers or parabolic troughs.
- Solar thermal collector
- wind power (home do-it yourself turbines and larger-scale)
- micro hydro, and pico hydro
- human-powered handwheel generators
- other zero emission generation methods

Some intermediate technologies (causing still some degree of pollution) include:

- Biobutanol,
- biodiesel,
- and straight vegetable oil can be appropriate, direct biofuels in areas where vegetable oil is readily available and cheaper than fossil fuels.
- Anaerobic digestion power plants
- Biogas is another potential source of energy, particularly where there is an abundant supply of waste organic matter. A generator (running on biofuels) can be run more efficiently if combined with batteries and an inverter; this adds significantly to capital cost but reduces running cost, and can potentially make this a much cheaper option than the solar, wind and micro-hydro options.
- Feces (e.g. cow dung, human, etc.) can also be used. For example DEKA's Project Slingshot stirling electricity generator works this energy source to make electricity.
- Biochar is another similar energy source which can be obtained through charring of certain types of organic material (e.g. hazelnut shells, bamboo, chicken manure, ...) in a pyrolysis unit. A similar energy source is terra preta nova.

Finally, urine can also be used as a basis to generate hydrogen (which is an energy carrier). Using urine, hydrogen production is 332% more energy efficient than using water.

Electricity distribution could be improved so to make use of a more structured electricity line arrangement and universal AC power plugs and sockets (e.g. the CEE 7/7 plug). In addition, a universal system of electricity provisioning (e.g. universal voltage, frequency, ampère; e.g. 230 V with 50 Hz), as well as perhaps a better mains power system (e.g.

through the use of special systems as perfected single wire earth returns; e.g. Tunisia's MALT-system, which features low costs and easy placement)

Electricity storage (which is required for autonomous energy systems) can be provided through appropriate technology solutions as deep-cycle and car-batteries (intermediate technology), long duration flywheels, electrochemical capacitors, compressed air energy storage (CAES), liquid nitrogen and pumped hydro. Thanks to Daniel Nocera, low-cost hydrogen storage is now also possible as a mid to short-term storage solution. Many solutions for the developing world are sold as a single package, containing a (micro) electricity generation power plant and energy storage. Such packages are called remote-area power supply

Water supply and treatment

Hand-operated, reciprocating, positive displacement, water pump in Košice-Tahanovce, Slovakia (walking beam pump).

As of 2006, waterborne diseases are estimated to cause 1.8 million deaths each year while about 1.1 billion people lack proper drinking water.

Water generally needs treatment before use, depending on the source and the intended use (with high standards required for drinking water). The quality of water from household connections and community water points in low-income countries is not reliably safe for direct human consumption. Water extracted directly from surface waters and open hand-dug shallow wells nearly always requires treatment.

Appropriate technology options in water treatment include both community-scale and household-scale point-of-use (POU) designs.

The most reliable way to kill microbial pathogenic agents is to heat water to a rolling boil. Other techniques, such as varying forms of filtration, chemical disinfection, and exposure to ultraviolet radiation (including solar UV) have been demonstrated in an array of randomized control trials to significantly reduce levels of waterborne disease among users in low-income countries.

Over the past decade, an increasing number of field-based studies have been undertaken to determine the success of POU measures in reducing waterborne disease. The ability of POU options to reduce disease is a function of both their ability to remove microbial pathogens if properly applied and such social factors as ease of use and cultural appropriateness. Technologies may generate more (or less) health benefit than their lab-based microbial removal performance would suggest.

The current priority of the proponents of POU treatment is to reach large numbers of low-income households on a sustainable basis. Few POU measures have reached significant scale thus far, but efforts to promote and commercially distribute these products to the world's poor have only been under way for a few years.

On the other hand, small-scale water treatment is reaching increasing fractions of the population in low-income countries, particularly in South and Southeast Asia, in the form of water treatment kiosks (also known as water refill stations or packaged water producers). While quality control and quality assurance in such locations may be variable, sophisticated technology (such as multi-stage particle filtration, UV irradiation, ozonation, and membrane filtration) is applied with increasing frequency. Such microenterprises are able to vend water at extremely low prices, with increasing government regulation. Initial assessments of vended water quality are encouraging.

Whether applied at the household or community level, some examples of specific treatment processes include:

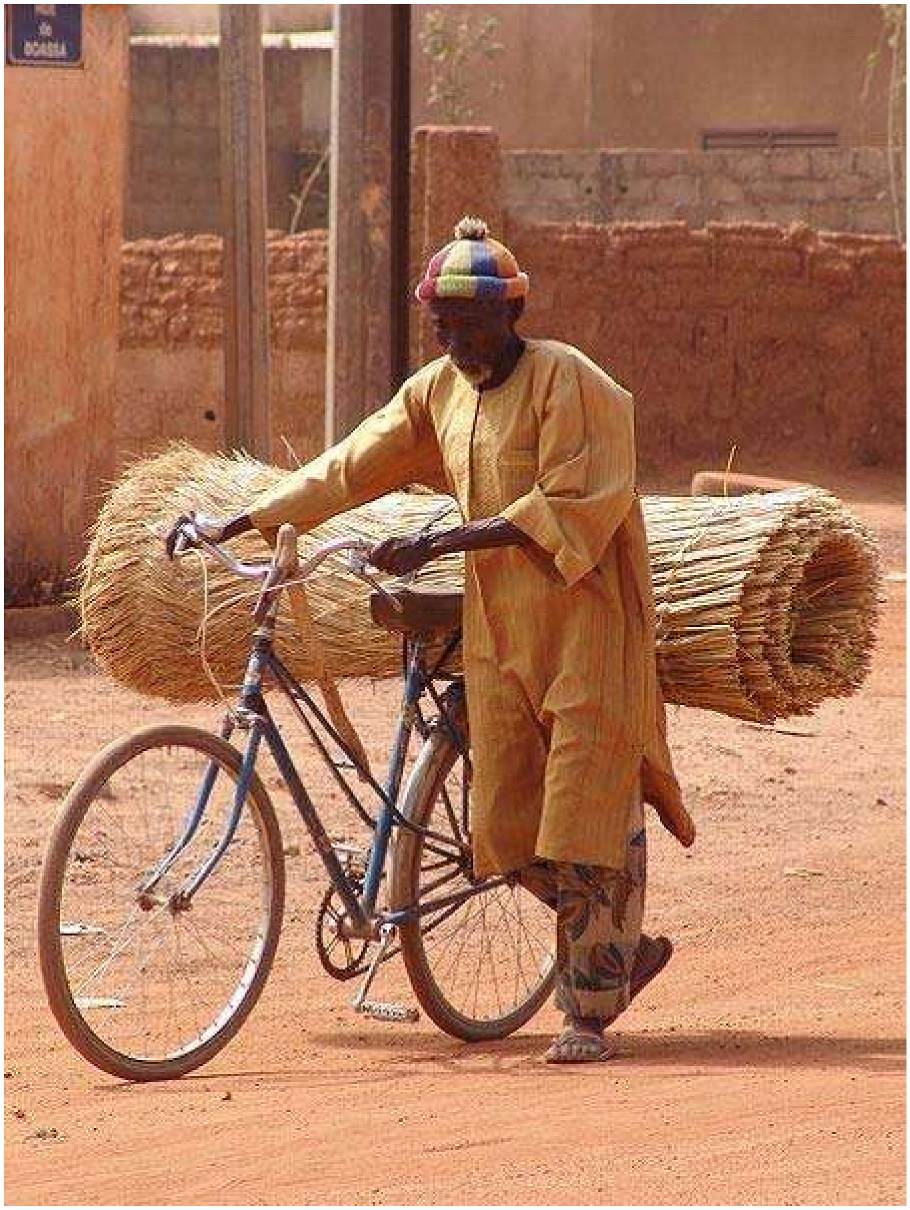
- Porous ceramic filtration, using either clay or diatomaceous earth, and oriented as either cylinder, pot, or disk, with gravity-fed or siphon-driven delivery systems. Silver is frequently added to provide antimicrobial enhancement
- Intermittently operated slow-sand filtration, also known as biosand filtration

- Chlorine disinfection, employing calcium hypochlorite powder, sodium hypochlorite solution, or sodium dichloroisocyanurate (NaDCC) tablets
- Chemical flocculation, using either commercially produced iron or aluminum salts or the crushed seeds of certain plants, such as Moringa oleifera
- Mixed flocculation/disinfection using commercially produced powdered mixtures
- Irradiation with ultraviolet light, whether using electric-powered lamps or direct solar exposure
- membrane filtration, employing ultrafiltration or reverse osmosis filter elements preceded by pretreatment

Some appropriate technology water supply measures include:

- Deep wells with submersible pumps in areas where the groundwater (aquifers) are located at depths >10 m.
- Shallow wells with lined walls and covers.
- rainwater harvesting systems with an appropriate method of storage, especially in areas with significant dry seasons.
- Fog collection, which is suitable for areas which experience fog even when there is little rain.
- Air well, a structure or device designed to promote the condensation of atmospheric moisture.
- Handpumps and treadle pumps are however only an option in areas is located at a relatively shallow depth (e.g. 10 m). For deeper aquifers (>10 m), submersible pumps placed inside a well) need to be used. Treadle pumps for household irrigation are now being distributed on a widespread basis in developing countries. The principle of Village Level Operation and Maintenance is important with handpumps, but may be difficult in application.
- Condensation bags and condensation pits can be an appropriate technology to get water, yet yields are low and are (for the amount of water obtained), labour intensive. Still, it may be a good (very cheap) solution for certain desperate communities.
- The hippo water roller allows more water to be carried, with less effort and could thus be a good alternative for ethnic communities who do not wish to give up water gathering from remote locations, assuming low topographic relief.
- The roundabout playpump, developed and used in southern Africa, harnesses the energy of children at play to pump water.

Transportation

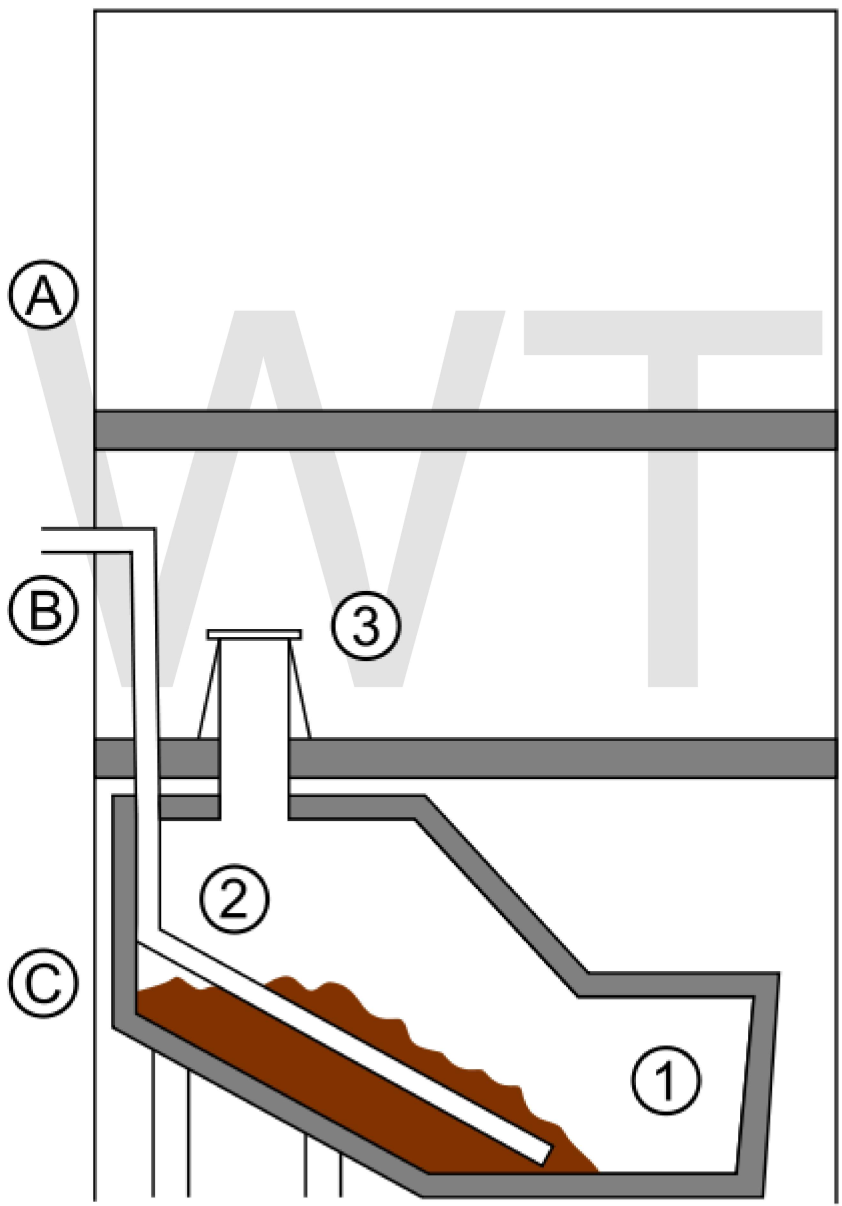


A man uses a bicycle to cargo goods in Ouagadougou, Burkina Faso (2007)

Human powered-vehicles include the bicycle, which provides general-purpose, human-powered transportation at a lower cost of ownership than motorized vehicles, with many gains over simply walking, and the whirlwind wheelchair, which provides mobility for disabled people who cannot afford the expensive wheelchairs used in developed countries. Animal powered vehicles/transport may also be another appropriate technology. Certain zero-emissions vehicles may be considered appropriate transportation technology, including compressed air cars, liquid nitrogen and hydrogen-powered vehicles. Also, vehicles with internal combustion engines may be converted to hydrogen or oxyhydrogen combustion.

Bicycles can also be applied to commercial transport of goods to and from remote areas. An example of this is Karaba, a free-trade coffee co-op in Rwanda, which uses 400 modified bicycles to carry hundreds of pounds of coffee beans for processing. Other projects for developing countries include the redesign of cycle rickshaws to convert them to electric power.. However recent reports suggest that these rickshaws are not plying on the roads.

Sanitation



A clivus Multrum composting toilet
A. Second floor, B. First floor, C. Ground floor, 1. Humus compartment, 2. Ventilation pipe, 3. Water closet.

As of 2006, waterborne diseases are estimated to cause 1.8 million deaths each year, marking the importance of proper sanitation systems. It is clear that the developing world is heavily lacking in proper public sanitation and that solutions as sewerages (or alternatively small-scale treatment systems) need to be provided.

Ecological sanitation can be viewed as a three-step process dealing with human excreta: (1) Containment, (2) Sanitization, (3) Recycling. The objective is to protect human health and the environment while limiting the use of water in sanitation systems for hand (and anal) washing only and recycling nutrients to help reduce the need for synthetic fertilizers in agriculture.

Small scale systems include:

- Composting toilets are the most environmental form of excrement disposal systems. In addition, the toilets design allows the nutrients to be reused (e.g. for fertilising food crops). Also, DIY composting toilets can be build at a very low cost.
- BiPu is a portable system suitable for disaster management, while other forms of latrine provide safe means of disposing of human waste at a low cost. The Orangi Pilot Project was designed based on an urban slum's sanitation crisis. Kamal Kar has documented the latrines developed by Bangladeshi villagers once they became aware of the health problems with open defecation.
- Treatment ponds and constructed wetlands can help to purify sewage and greywater. They consist mostly of plants (e.g. reed, ...) and therefore require only little power, and are hugely self-sufficient.
- Certain other options as Slow sand filters, UV filters, ... may also be employed

Lighting

LED Lamp with GU10 twist lock fitting, intended to replace halogen reflector lamps.

- White LEDs and a source of renewable energy (such as solar cells) are used by the Light Up the World Foundation to provide lighting to poor people in remote areas, and provide significant benefits compared to the kerosene lamps which they replace. Certain other companies as Powerplus also have LED-flashlights with imbedded solar cells.
- Organic LEDs made by roll-to-roll production are another source of cheap light that will be commercially available at low cost by 2015.
- Compact fluorescent lamps (as well as regular fluorescent lamps and LED-lightbulbs) can also be used as appropriate technology. Although they are less environmentally friendly then LED-lights, they are cheaper and still feature relative high efficiency (compared to incandescent lamps).
- The Safe bottle lamp is a safer kerosene lamp designed in Sri Lanka. Lamps as these allow relative long, mobile, lighting. The safety comes from a secure screw-

on metal lid, and two flat sides which prevent it from rolling if knocked over. An alternative to fuel or oil-based lanterns is the Uday lantern, developed by Philips as part of its Lighting Africa project (sponsored by the World Bank Group).
- The Faraday flashlight is a LED flashlight which operates on a capacitor. Recharging can be done by manual winching or by shaking, hereby avoiding the need of any supplementary electrical system.
- HID-lamps finally can be used for lighting operations where regular LED-lighting or other lamps will not suffice. Examples are car headlights. Due to their high efficiency, they are quite environmental, yet costly, and they still require polluting materials in their production process.

Food production

Food production has often been included in autonomous building/community projects to provide security. Skilled, intensive gardening can support an adult from as little as 15 square meters of land. Some proven intensive, low-effort food-production systems include urban gardening (indoors and outdoors). Indoor cultivation may be set-up using hydroponics with Grow lights, while outdoor cultivation may be done using permaculture, forest gardening, no-till farming, Do Nothing Farming, etc. In order to better control the irrigation outdoors, special irrigation systems may be created as well (although this increases costs, and may again open the door to cultivating non-indigenous plants; something which is best avoided). One such system for the developing world is discussed here.

Crop production tools are best kept simple (reduces operating difficulty, cost, replacement difficulties and pollution, when compared to motorized equipment). Tools can include scythes, animal-pulled plows (although no-till farming should be preferred), dibbers, wheeled augers (for planting large trees), kirpis, hoes, ...

Greenhouses are also sometimes included. Sometimes they are also fitted with irrigation systems, and/or heat sink-systems which can respectively irrigate the plants or help to store energy from the sun and redistribute it at night (when the greenhouse starts to cool down).

Food preparation

According to proponents, Appropriate Technologies can greatly reduce the labor required to prepare food, compared to traditional methods, while being much simpler and cheaper than the processing used in Western countries. This reflects E.F. Schumacher's concept of "intermediate technology," i.e. technology which is significantly more effective and expensive than traditional methods, but still an order of magnitude (10 times) cheaper than developed world technology. Key examples are:

- the Malian peanut sheller
- the fonio husking machine
- the screenless hammer mill

- the ISF corn mill
- the ISF rice huller
- all other types of electrical or hand-operated kitchen equipment (grinders, cutters, ...) Special multifunctional kitchen robots that are able to perform several functions (e.g. grinding, cutting, and even vacuum cleaning and polishing) are able to reduce costs even more. Examples of these devices were e.g. the (now discontinued) Piccolo household appliance from Hammelmann Werke (previously based in Bad Kissingen.) It was equipped with a flexible axis, allowing a variety of aids to be screwed on.

Cooking

In Ghana, Zouzugu villagers use solar cookers for preparing their meals

- Solar cookers are appropriate to some settings, depending on climate and cooking style. They are emission-less and very low-cost. Hybrid variants also exist that incorporate a second heating source such as electrical heating or wood-based.
- Hot plates are 100% electrical, fairly low cost (around 20€) and are mobile. They do however require an electrical system to be present in the area of operation.
- Rocket stoves and certain other woodstoves (e.g. Philips Woodstove) improve fuel efficiency, and reduce harmful indoor air pollution. The stoves however still make use of wood. However, briquette makers can now turn organic waste into fuel, saving money and/or collection time, and preserving forests.

Refrigeration

- Solar, special Einstein refrigerators and thermal mass refrigerators reduce the amount of electricity required. Also, solar and special Einstein refrigerators do not use haloalkanes (which play a key role in ozone depletion), but use heat pumps or mirrors instead. Solar refrigerators have been built for developing nations by Sopology.

- The pot-in-pot refrigerator is an African invention which keeps things cool without electricity. It provides a way to keep food and produce fresh for much longer than would otherwise be possible. This can be a great benefit to the families who use the device. For example, it is claimed that girls who had to regularly sell fresh produce in the market can now go to school instead, as there is less urgency to sell the produce before it loses freshness.

Ventilation and air conditioning

Chunche, naturally ventilated sheds for drying raisins in Xinjiang

- Natural ventilation can be created by providing vents in the upper level of a building to allow warm air to rise by convection and escape to the outside, while cooler air is drawn in through vents at the lower level.
- Electrical powered fans (e.g. ceiling fans) allow efficient cooling, at a far lower electricity consumption as airconditioning systems.
- A solar chimney often referred to as *thermal chimney* improves this natural ventilation by using convection of air heated by passive solar energy. To further maximize the cooling effect, the incoming air may be led through underground ducts before it is allowed to enter the building.

- A windcatcher (*Badgir*; بادگیر) is a traditional Persian architectural device used for many centuries to create natural ventilation in buildings. It is not known who first invented the windcatcher, but it still can be seen in many countries today. Windcatchers come in various designs, such as the uni-directional, bi-directional, and multi-directional.
- A passive down-draft cooltower may be used in a hot, arid climate to provide a sustainable way to provide air conditioning. Water is allowed to evaporate at the top of a tower, either by using evaporative cooling pads or by spraying water. Evaporation cools the incoming air, causing a downdraft of cool air that will bring down the temperature inside the building.

Health care

According to the Global Health Council, rather than the use of professionally schooled doctors, the training of villagers to remedy most maladies in towns in the developing world is most appropriate. Trained villagers are able to eliminate 80% of the health problems. Small (low-cost) hospitals - based on the model of the Jamkhed hospital – can remedy another 15%, while only 5% will need to go to a larger (more expensive) hospital.

- Before being able to determine the cause of the disease or malady, accurate diagnosis is required. This may be done manually (through observation, inquiries) and by specialised tools.
- Herbalist medicines (e.g. tinctures, tisanes, decoctions, ...) are appropriate medicines, as they can be freely made at home and are almost as effective as their chemical counterparts. A previous program that made use of herbal medicine was the Barefoot doctor program.
- A phase-change incubator, developed in the late 1990s, is a low cost way for health workers to incubate microbial samples.
- Birth control is also seen as an appropriate technology, especially now, because of increasing population numbers (overpopulating certain areas), increasing food prices and poverty. It has been proposed to a certain degree by PATH (program for appropriate technology in health).
- Jaipur leg was developed by Dr. P. K. Sethi and Masterji Ram Chander in 1968 as an inexpensive prosthetic leg for victims of landmine explosions.
- Natural cleaning products can be used for personal hygiene and cleaning of clothing and eating utensils; in order to decrease illnesses/maladies (as they eliminate a great amount of pathogens).

Note that many Appropriate Technologies benefit public health, in particular by providing sanitation and safe drinking water. Refrigeration may also provide a health benefit. (These are discussed in the following paragraphs.) This was too found at the Comprehensive Rural Health Project and the Women Health Volunteers projects in countries as Iran, Iraq and Nepal.

Information and communication technology

Netbooks as the Eee PC allow low cost information sharing and communication

- The OLPC XO, Simputer, Eee PC, and other low cost computers are computers aimed at developing countries. Besides the low price, other characteristics include resistance to dust, reliability and use of the target language.
- Eldis OnDisc and The Appropriate Technology Library are projects that use CDs and DVDs to give access to development information in areas without reliable and affordable internet access.
- The Wind-up radio and the computer and communication system planned by the Jhai Foundation are independent from power supply.
- There is also GrameenPhone, which fused mobile telephony with Grameen Bank's microfinance program to give Bangladeshi villagers access to communication.
- Mobile telephony is appropriate technology for many developing countries, as it greatly reduces the infrastructure required to achieve widespread coverage. However, mobile phone network may not always be available (it depends on the location) and may not always provide both voice and data services.
- Loband, a website developed by Aptivate, strips all the photographic and other bandwidth-intensive content from webpages and renders them as simple text, while otherwise allowing one to browse them normally. The site greatly increasing the speed of browsing, and is appropriate for use on low bandwidth connections as generally available in much of the developing world.
- An increasing number of activists provide free or very inexpensive web and email services using cooperative computer networks that run wireless ad hoc networks. Network service is provided by a cooperative of neighbors, each operating a router as a household appliance. These minimize wired infrastructure, and its costs and vulnerabilities. Private Internet protocol networks set up in this way can operate without the use of a commercial provider.
- Rural electrical grids can be wired with "optical phase cable", in which one or more of the steel armor wires are replaced with steel tubes containing fiber optics.
- Satellite Internet access can provide high speed connectivity to remote locations, however these are significantly more expensive than wire-based or terrestrial wireless systems. Wimax and forms of packet radio can also be used. Depending on the speed and latency of these networks they may be capable of relaying VoIP

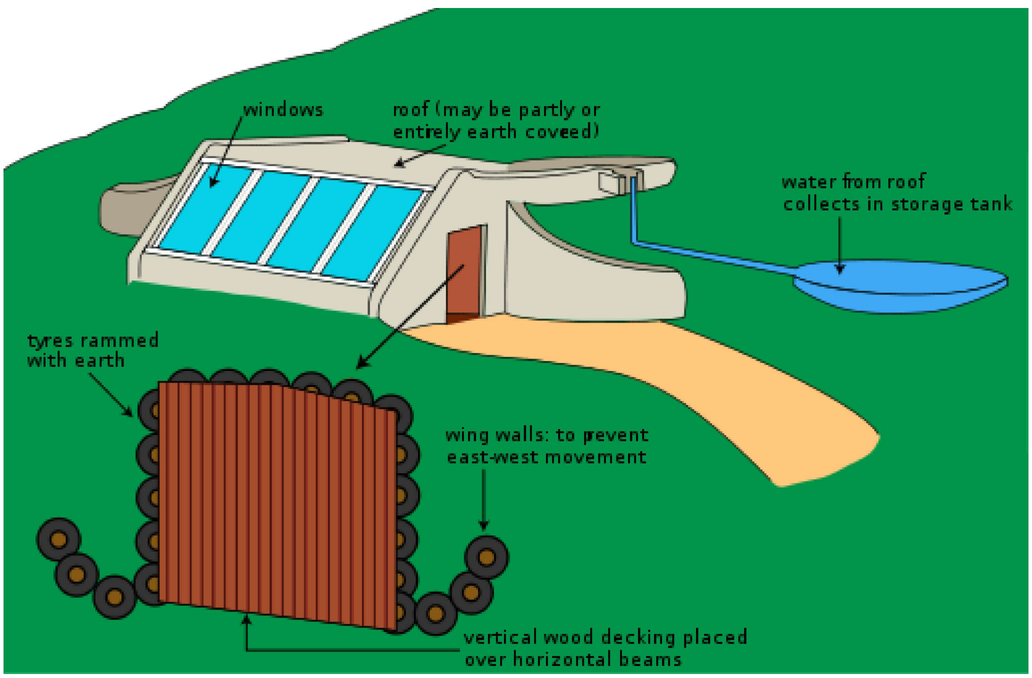
traffic, negating the need for separate telephony services. Finally, the Internet Radio Linking Project provides potential for blending older (cheap) local radio broadcasting with the increased range of the internet.
- satellite-based telephone systems can also be used, as either fixed installations or portable handsets and can be integrated into a PABX or local IP-based network.

Money lending and finance

Through financial systems envisioned especially for the poor/developed world, many companies have been able to get started with only limited capital. Often banks lend the money to people wishing to start a business (such as with microfinance). In other systems, people for a Rotating Savings and Credit Association or ROSCA to purchase costly material together (such as Tontines and Susu accounts). Organisations, communities, cities or individuals can provide loans to other communities/cities (such as with the approach followed by Kiva.org, MicroPlace and LETS). Finally, in certain communities (usually isolated communities such as small islands or oases) everything of value is shared. This is called gift economy.

Chapter 2

Earthship



The design used with most earthships. A large series of windows characterise the earthsheltered building and the use of tires

A somewhat customised earthship build at Rio Arriba County, New Mexico, USA and shot from the side

An **Earthship** is a type of passive solar home made of natural and recycled materials. Designed and marketed by Earthship Biotecture of Taos, New Mexico, the homes are primarily constructed to work autonomously and are generally made of earth-filled tires, using thermal mass construction to naturally regulate indoor temperature. They also usually have their own special natural ventilation system. Earthships are generally Off-the-grid homes, minimizing their reliance on public utilities and fossil fuels.

The original Earthships' designs were at first very experimental, but with practice and evolution the houses began looking attractive.

Earthships are built to utilize the available local resources, especially energy from the Sun. For example, windows on sun-facing walls admit lighting and heating, and the buildings are often horseshoe-shaped to maximize natural light and solar-gain during winter months. The thick, dense inner walls provide thermal mass that naturally regulates the interior temperature during both cold and hot outside temperatures.

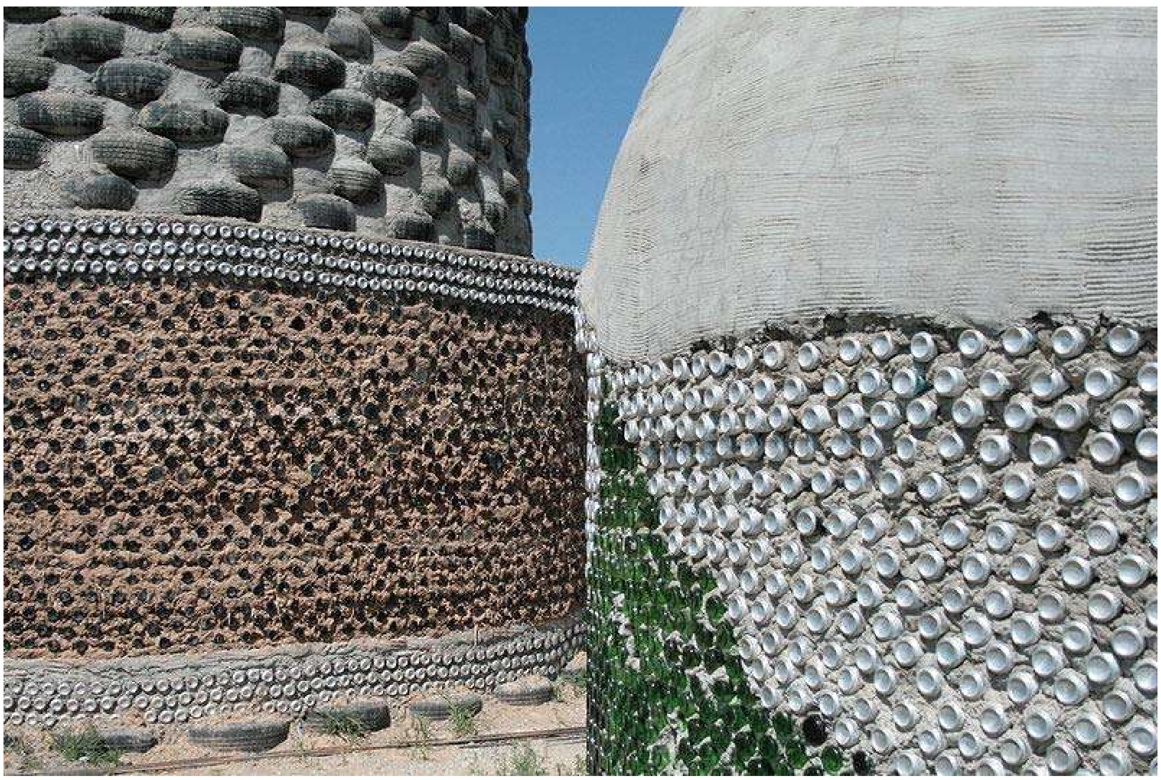
Internal, non-load-bearing walls are often made of a honeycomb of recycled cans joined by concrete and are referred to as tin can walls. These walls are usually thickly plastered with stucco.

The roof of an Earthship is heavily insulated - often with earth or adobe - for added energy efficiency.

History

The Earthship, as it exists today, began to take shape in the 1970s. Mike Reynolds, founder of Earthship Biotecture, a company that specializes in designing and building Earthships, wanted to create a home that would do three things; first, it would be sustainable, using material indigenous to the entire planet as well as recycled materials wherever possible. Second, the homes would rely on natural energy sources and be independent from the "grid", therefore being less susceptible to natural disasters and free from the electrical and water lines that Reynolds considered unsightly and wasteful. Finally, it would be economically feasible for the average person with no specialized construction skills to be able to create.

Eventually, Reynolds' vision took the form of the common U-shaped earth-filled tire homes seen today. As a concept, the Earthship was not limited to tires - any dense material with a potential for thermal mass, such as concrete, adobe, or stone could theoretically be used to create an Earthship. However, the earth-rammed tire version of the Earthship is now the most common design, and is usually the only structure referred to as "Earthship".



Earthships are made of Earth-rammed tires, bottles and cans

Unlike other materials, rammed-earth tires are more accessible to the average person. Scrap tires are ubiquitous around the world and easy to come by; there are an estimated 2 billion tires throughout the United States. As of 1996, as many as 253 million scrap tires were being generated each year in the United States, with 70% being reclaimed by the scrap tire market (leaving perhaps 75 million scrap tires available for reuse as whole tires). In addition to the availability of scrap tires, the method by which they are converted into usable "bricks", the ramming of the earth, is simple and affordable.

The earth-rammed tires of an Earthship are usually assembled by teams of two people working together as part of a larger construction team. One member of the two person team shovels dirt, which usually comes from the building site, placing it into the tire one scoop at a time. The second member, who stands on the tire, uses a sledge hammer to pack the dirt in. The second person moves in a circle around the tire to keep the dirt even and avoid warping the tire. These rammed earth tires in an Earthship are made in place because, when properly made, they weigh as much as 300 pounds and can be very difficult to relocate.

Additional benefits of the rammed earth tire are its great load-bearing capacity and its resistance to fire.

A fully rammed tire, which is about 2 feet 8 inches wide, is massive enough to surpass conventional requirements for structural load distribution to the earth. Because the tire is full of soil, it does not burn when exposed to fire. In 1996 after a fire swept through many conventional homes in New Mexico, an Earthship discovered in the aftermath was relatively unharmed. Only the south-facing wall and the roof had burned away, compared to the total destruction of the conventional homes.

Currently, Earthships are in use in almost every state in the United States, as well as many countries in Europe. The use of insulation on the outside of tire walls, which was not common in early designs, is improving the viability of Earthships in every climate without compromising their durability. In the year 2000, Mike Reynolds, in partnership with Daren Howarth, launched Earthship Biotecture Europe, an organization that aims to explore and evolve the concept of the Earthship within a European context. Two more directors were appointed to Earthship Biotecture Europe in July 2006 - Kevan Trott and Kirsten Jacobsen.

Europe

Brighton Earthship, UK

In 2004, the very first Earthship in the UK was opened at Kinghorn Loch in Fife, Scotland. It was built by volunteers of the SCI charity. In 2005, the first earthship in England was established in Stanmer Park, Brighton with the Low Carbon Trust.

Earthship biotecture has now finalized plans for a planning application to build on a valuable development site overlooking the Brighton Marina in the UK. The application follows the successful six-month feasibility study funded by the UK Environment Agency and the Energy Savings Trust. The application calls for sixteen one, two, and three-bedroom earthship homes on this site. The homes are all designed according to basic earthship principles developed in the United States. 15,000 tires will be recycled to construct these homes (the UK burns approximately 40 million tires each year). The plans include the enhancement of habitats on the site for lizards that already live there, which is the reasoning behind entitling the project "The Lizard". This will be the first development of its kind in Europe, and successful development in Brighton may help to pave the way for similar projects around the UK and other places.

The first official Earthship home in Europe with official planning commission approval was built in a small French village called Ger. The home, which is owned by Kevan and Gillian Trott, was built in April 2007 by Kevan, Mike Reynolds and an Earthship Crew from Taos. The design was modified for a European climate and is seen as the first of many for the European arena. It is currently used as a holiday home for eco-tourists.

Africa

The first earthship was built by Angel and Yvonne Kamp from 1996 to 1998. They rammed a total of 1,500 tires for the walls. The earthship, near Hermanus, is located in a 60 hectare private nature reserve which is part of a 500000ha area enclosed in a game fence and borders the Walker Bay Nature Reserve.

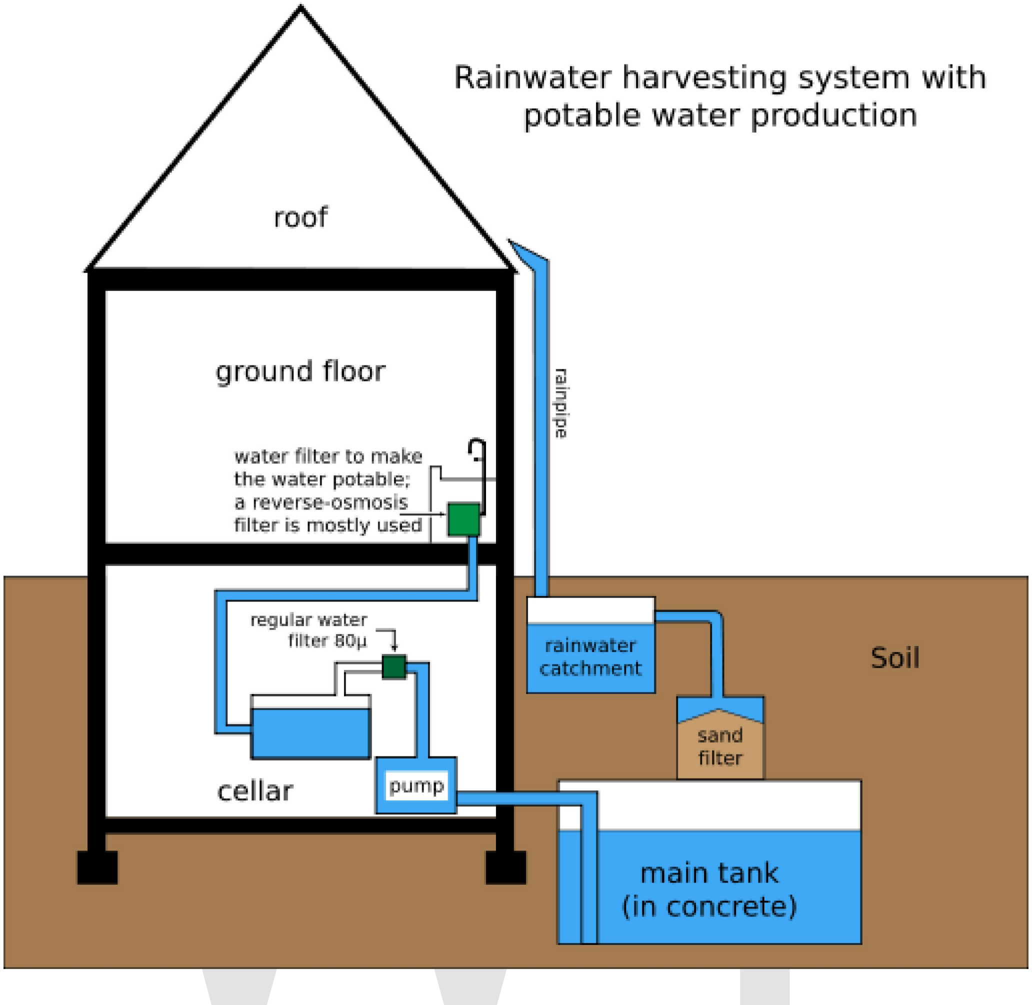
Two new projects are also in early development in Africa, an information and training centre in Orania, South Africa and a residential house in Swaziland.

Systems

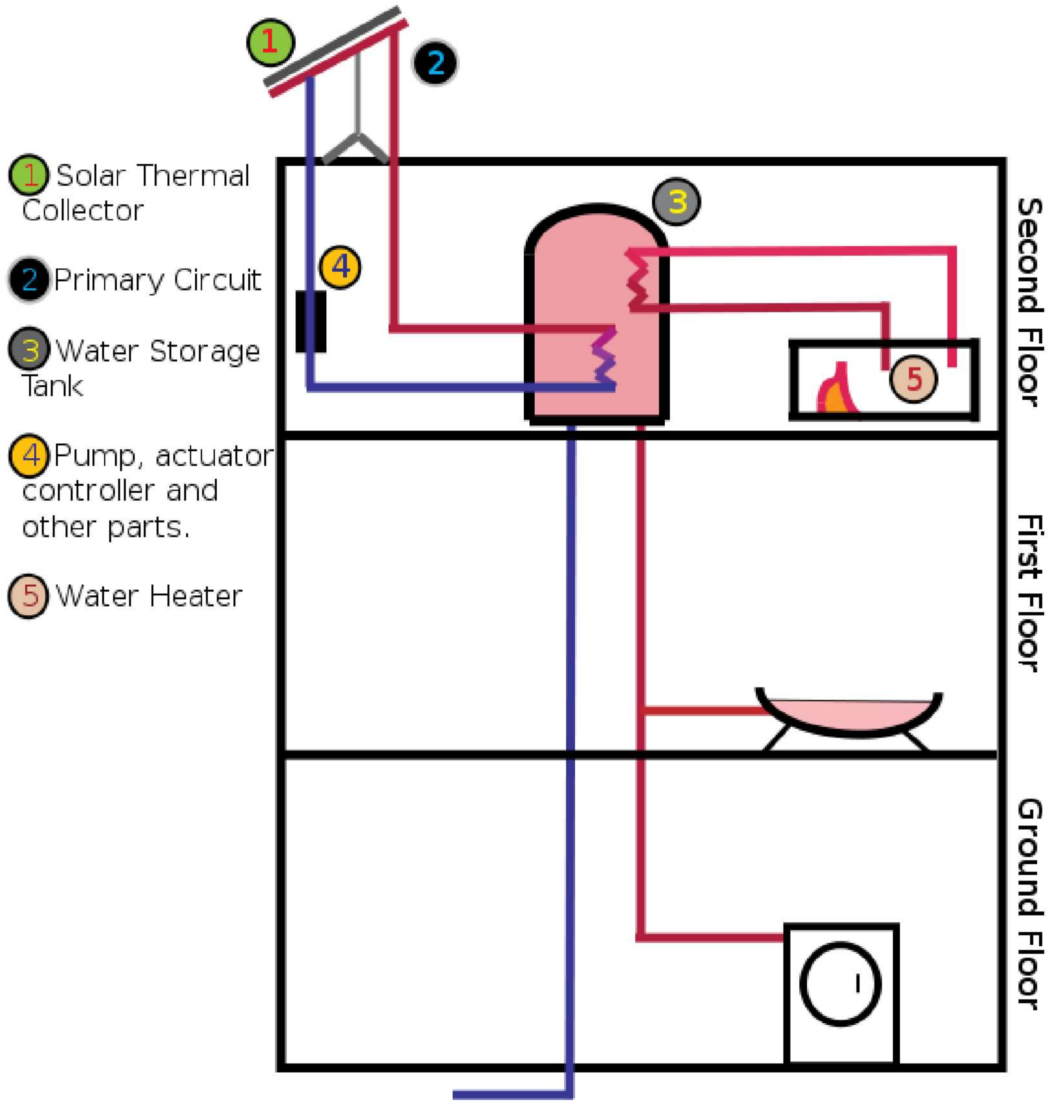
The Earthship was designed as a structure that would exist in harmony with its environment and be freed from the constraints of modern shelters which rely on centralized utilities. It is important that the Earthship create its own utilities as well as use readily available and sustainable materials. In order to be entirely self-sufficient the Earthship needs to be able to handle the three systems of water, electricity, and climate. While these systems are not exclusive to Earthships, a properly designed Earthship must have these systems.

Water

A botanical cell for greywater treatment featuring interior banana trees



A domestic rainwater harvesting system



Schematic of an active solar heating system

Collection

Earthships are designed to catch and use water from the local environment without bringing in water from a centralized source. Water used in an Earthship is harvested from rain, snow and condensation. As water collects on the roof it is channeled through a silt-catching device and into a cistern. The cisterns are positioned so they gravity-feed a WOM (water organization module), that filters out bacteria and contaminants, and makes it suitable for drinking. The WOM consists of filters and a DC-pump that are screwed into a panel. Water is then pushed into a conventional pressure tank to create common household water pressure. Water collected in this fashion is used for any household activity except flushing toilets the conventional way. Rather, the water used for flushing toilets has been used at least once already: frequently it is filtered waste-water from sinks and showers, and described as "Greywater".

Greywater

Greywater, water that has been used and is unsuitable for drinking, is used within the Earthship for a multitude of purposes once it is reclaimed. First, before the greywater can be reused, it is channeled through a grease and particle filter/digester and into a 30”-60" deep rubber-lined botanical cell, a miniature living machine, within the Earthship. This filter with imbedded plants can potentially also be used to produce food (by using a fruit tree, ...). Oxygenation, filtration, transpiration, and bacteria-encounter all take place within the cell and help to cleanse the water (Reynolds 2000). Within the botanical cell, filtration is achieved by passing the water through a mixture of gravel and plant roots. Because of the nature of plants, oxygen is added to the water as it filters, while nitrogen is removed. Water taken up through the plants and transpired at their tops helps to humidify the air. In the cell, bacteria will naturally grow and help to cleanse the water.

Water from the low end of the botanical cell is then directed through a peat-moss filter and collected in a reservoir or well. This reclaimed water is then passed once more through a greywater board and used to flush conventional toilets.

Often, any greywater that is made at earthships is not polluted enough to justify treatment (its "pollution" being usually just soap, which is often not environmentally damaging). At earthships, the use of plants placed at outlets of fixtures is then practiced to regain the water and the nutrients lost (from the soaps, etc.).. Usually, a single plant is placed directly in front of the pipe, but mini drain-fields are also sometimes used. The pipe is made large enough (5,08 cm) so that the formation of underground gas (from the greywater) is avoided. This is done with kitchen and bathroom sinks, and even showers, washing machines, and dishwashing machines. The plants are usually placed indoors with the sinks and outdoors with the washing/dishwashing machines and shower (to avoid indoor "floods"). Also, with the latter, larger drain-fields are used instead of a mere plant being placed before an outlet.

Black water

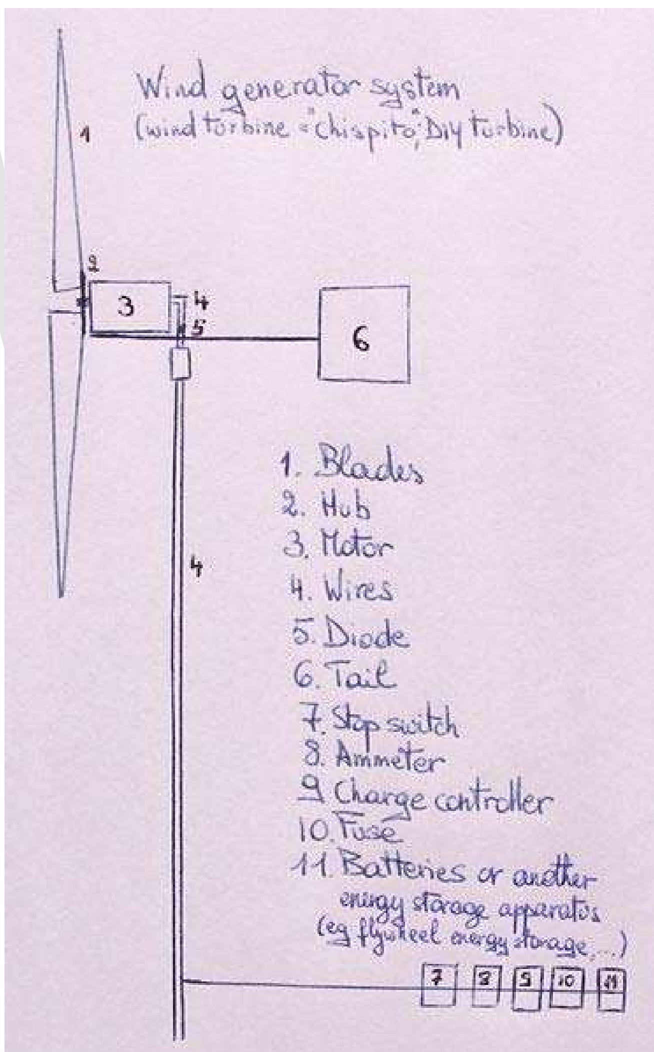
Black water, water that has been used in a toilet, was usually not created within many of the earliest earthships as the use of conventional toilets was discouraged. Instead, in the early days composting toilets were advocated, which use no water at all. However, with the new greywater treatment system design (used in Nautilus, Helios, ...) created by Michael Reynolds, flush toilets have now found a place in the earthship and the general water system has been redesigned according to the new "6-step process".

Now, when the newly included flush-toilets are used, blackwater is not reused within the Earthship. Instead, blackwater is sent to a solar-enhanced septic tank with leach-field and planter cells (the whole being often referred to as the “incubator”). The solar-enhanced septic tank is a regular septic tank which is heated by the sun and glazed with an equator-facing window. The incubator stores the sun's heat in its concrete mass, and is insulated, to help the anaerobic process. Water from the incubator is channeled out to an exterior leach field and then to landscaping "planter cells" (spaces surrounded by concrete in which plants have been put). The cells are similar to the botanical cell used in greywater treatment and are usually placed just before and under the windows of the earthship.

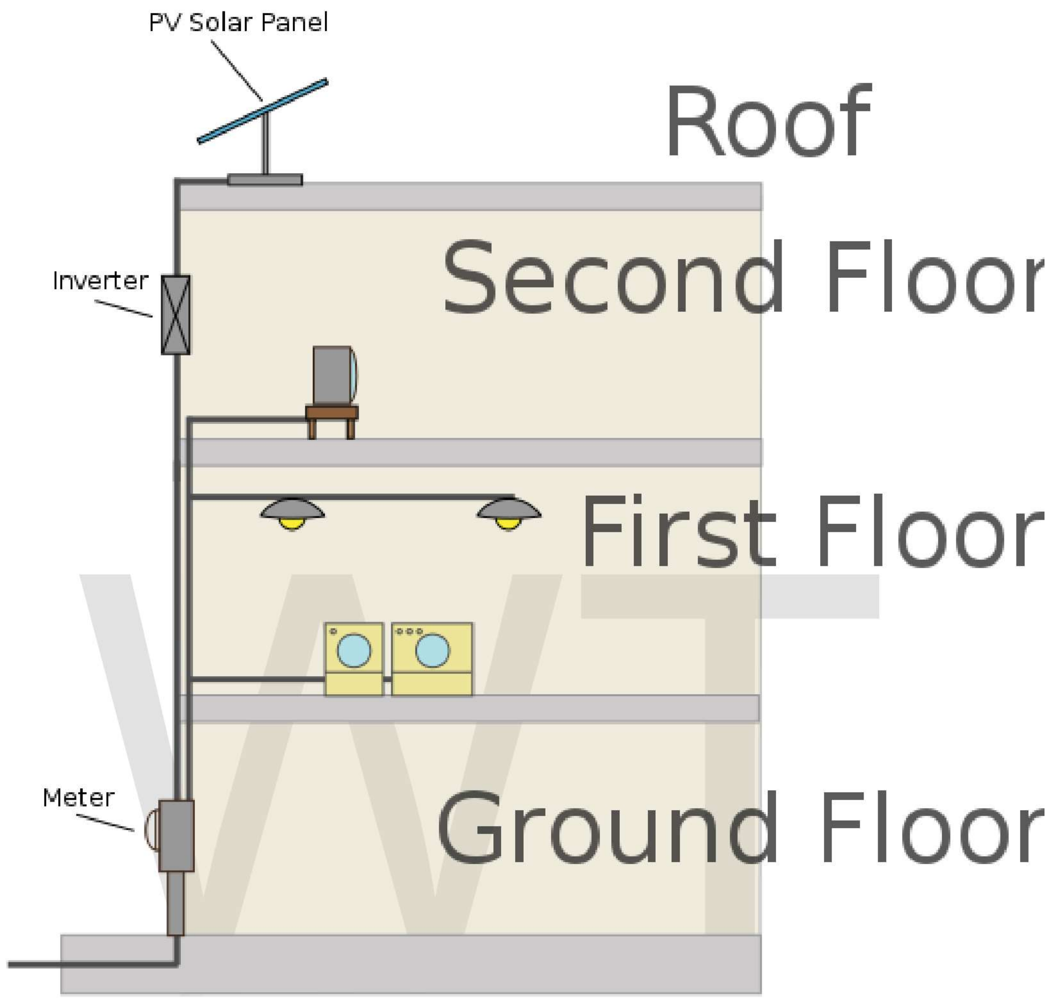
In cases where it is not possible to use flush-toilets operating on water, dry solar toilets are now advocated, instead of *regular* composting toilets. If this is the case, obviously no black water is formed and the use of an incubator is thus (usually) not necessary. Instead, regular "planters" (plants used for sucking up water/nutrients) are then used. When using regular planters as well, no chemical soaps or detergents can be used.

The space where the WOM (water organization module), graywater pump panel, pressure tank, (first set of) batteries, and POM (power organising module) are stored is in a small room referred to as the "systems package".

Electricity



Parts of DIY Wind turbine



A PV-solar system

Earthships are designed to collect and store their own energy from a variety of sources. The majority of electrical energy is harvested from the sun and wind. Photovoltaic panels and windturbines located on or near the Earthship generate DC energy that is then stored in several types of deep-cycle batteries. The space in which the batteries are kept is usually a special, purpose-built room placed on the roof. Additional energy, if required, can be obtained from gasoline-powered generators or by integrating with the city grid.

In an Earthship, a Power Organizing Module is used to take stored energy from batteries and invert it for AC use. The Power Organizing Module is a prefabricated system provided by Earthship Biotecture that is simply attached to a wall on the interior of the Earthship and wired in a conventional manner. It includes the necessary equipment such as circuit breakers and converters. The energy run through the Power Organizing Module can be used to run any house-hold appliance including washing machines, computers, kitchen appliances, print machines, vacuums, etc. Generally, none of the electrical energy in an Earthship is used for heating or cooling.

Climate

The interior climate of an Earthship is stabilized and made comfortable by taking advantage of many phenomena. Mainly, the Earthship tries to take advantage of the properties of thermal mass and passive solar heating and cooling. Examples are large front windows with integrated shades, trombe walls and other technologies such as skylights or Track Rack solar trackers (dualling as an energy generation device and passive solar source.

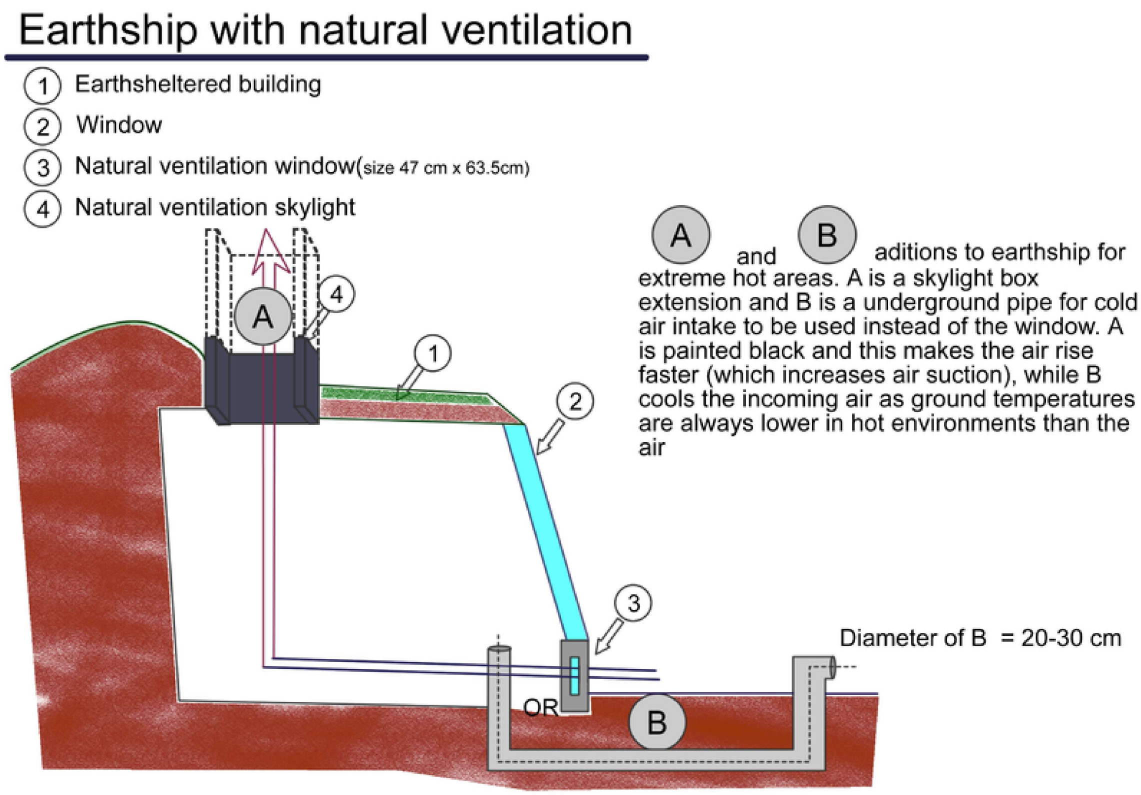
The load-bearing walls of an Earthship, which are made from steel-belted tires rammed with earth, serve two purposes. First, they hold up the roof, and second, they provide a dense thermal mass that will soak up heat during the day and radiate heat during the night, keeping the interior climate relatively comfortable all day.

In addition to high thermal mass, some Earthships may be earth-sheltered. The benefits of earth-sheltering are twofold because it adds to the thermal mass and, if the Earthship is buried deep enough, allows the structure to take advantage of the Earth's stable temperature.

The Earthship is designed in such a way that the sun provides heating, ventilation, and lighting. To take advantage of the sun, an Earthship is positioned so that its principal wall, which is nonstructural and made mostly of glass sheets, faces directly towards the equator. This positioning allows for optimum solar exposure.

To allow the sun to heat the mass of the Earthship, the solar-orientated wall is angled so that it is perpendicular to light from the winter sun. This allows for maximum exposure in the winter, when heat is wanted, and lesser exposure in the summer, when heat is to be avoided. Some Earthships, especially those built in colder climates, use insulated shading on the solar-orientated wall to reduce heat loss during the night (Reynolds 2000).

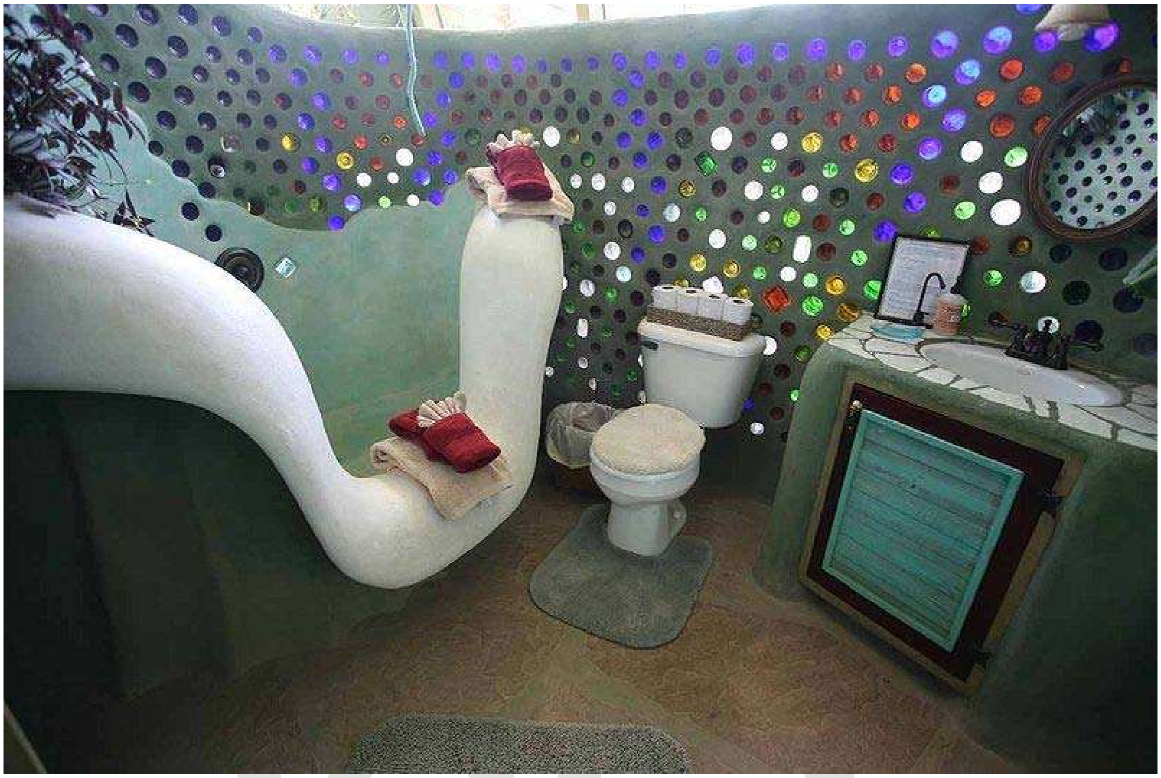
Natural ventilation



The ventilation system of an earthship

The earthships usually use their own natural ventilation system. It consists of cold(er) air coming in from a front ("hopper") window, especially made for this purpose and flowing out through (one of) the skylights that are placed on the earthship. As hot air rises, the system maintains itself and keeps sucking in (and out), air.

Heating problems



Bottle walls are used in earthships such as this earthship bathroom, located in Phoenix Earthship, Taos, NM, USA

Earthships rely on a balance between the solar heat gain and the ability of the tire walls and subsoil to transport and store heat. The design intends to require little if any auxiliary heat. Some earthships have suffered from over-heating and some from over-cooling.

Some earthships appear to have serious problems with heat loss. In these cases heat appears to be leaking into the ground constantly during the heating season and being lost. This situation may have arisen from the mistaken belief that ground-coupled structures (building in thermal contact with the ground) do not require insulation. The situation may also be due to large climatic differences between the sunny, arid, and warm Southwest (of the USA) where earthships were first built and the cloudier, cooler, and wetter climates where some are now being built. Malcolm Wells, an architect and authority on earth-sheltered design, recommends R-value 10 insulation between deep soils and heated spaces. Wells's insulation recommendations increase as the depth of the soil decreases.

In very limited and specific situations, uncommon during the heating season, thermal mass can marginally increase the apparent R-value of a building assembly such as a wall. Generally speaking thermal mass and R-value are distinct thermodynamic properties and should not be equated. Thermal performance problems apparently seen in some earthship designs may have occurred because of thermal mass being erroneously equated to R-value. The R-value of soil is about 1 per foot.

Potential advantages

- Having an earth-bermed home with windows facing the sun is a good idea in any climate where heating is required.
- Collecting rainwater that falls on the roof reduces the runoff impact of the building and may reduce water and even sewer service fees.
- Having a combination of photovoltaic cells and wind generation is a prudent way to provide electricity in many situations.
- Using curved modules as horizontal arches to resist earth loads is a sound structural design.
- On-site processing of runoff water, grey water, and black water using plant beds reduces the environmental impact of the building.
- Rubber tires make a wind- and puncture- resistant wall. They may be safe from outgassing when plastered semi-airtight.
- Rubber tires are usually free and it may be possible to be paid to take them. It also is beneficial to keep them out of landfills or prevent them from being illegally burnt.
- Potential to eliminate utility bills.
- The structure is highly moldable to different aesthetic tastes.

Potential disadvantages

- The sloped glazing may be hard to keep watertight and in warm climates allows excessive solar gain in summer. In colder climates, the glazing itself, which has far poorer insulating properties than any other component, will obviously be the major conduit of heat loss in winter. New designs call for vertical windows with an overhang.
- Uninsulated ground-coupled thermal mass presents a large potential for heat loss, especially in climates with a heating season. This varies to a degree with soil type and moisture content.
- Rubber-tire walls tend to lack structural stiffness and may require perpendicular stiffening ribs.
- Most solar photovoltaic systems suffer from poor efficiency and some wind systems only generate in periods of high wind velocity.
- The novel design may diminish resale value or make buyers more difficult to find.
- The intimate ground contact inherent in this approach may increase hazards due to soil gases including Radon, and those due to water intrusion.
- Packing or ramming dirt into the inside of tires is a very labor-intensive process.
- Many Earthship builders are drawn to this system by its apparently low environmental impact. However, this is only valid if the design is highly thermally efficient. Earthship designs may require substantial thermal analysis and redesign to be adapted to non-Southwest USA climate.

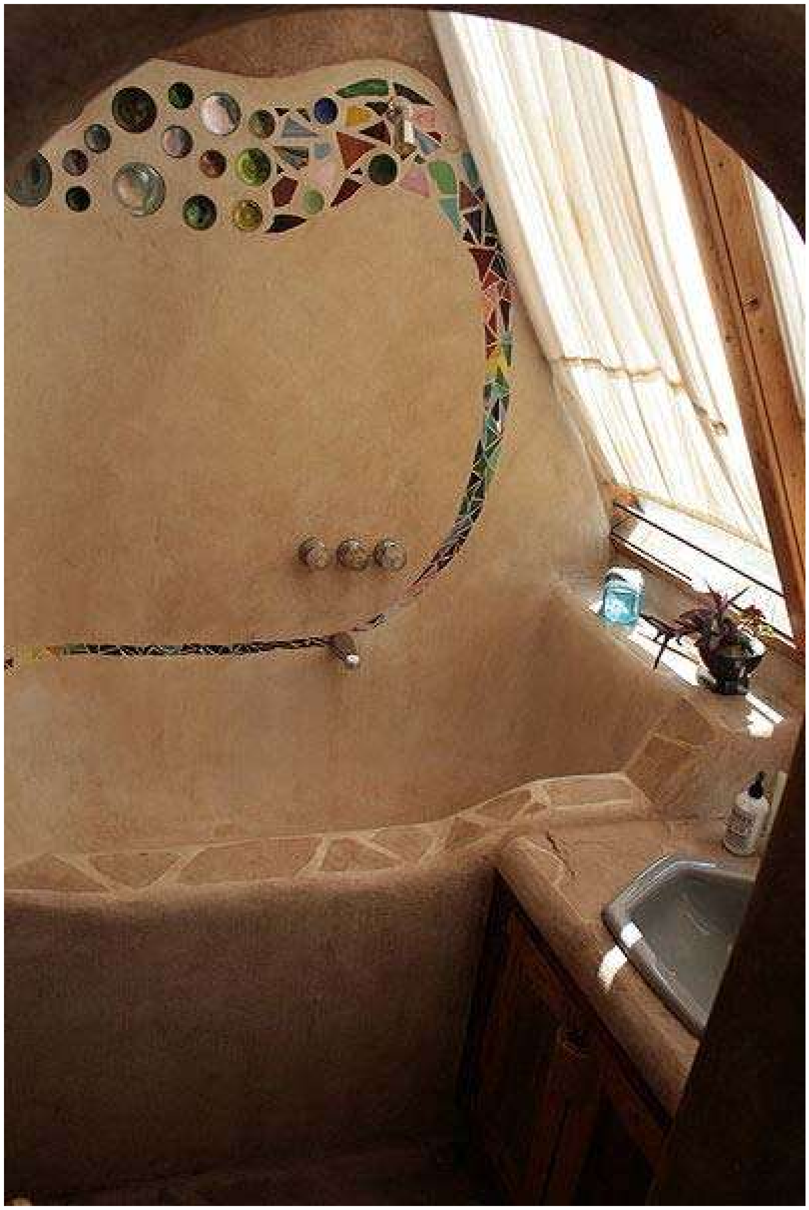
- Earthships built with concrete, sand bags, or adobe and with better solar and heat control perform better.
- Earthships are usually built in areas of extremely low population density, so unless they are entirely self-sufficient, a significant amount of fossil fuels could have to be expended in their construction because of the transportation of materials and workers. They can be built anywhere, however, and this can mitigate certain issues dealing with fossil fuels and transportation.

Images of Earthships

An unfinished Earthship

An unfinished Earthship

An unfinished Earthship



An Earthship bathroom

Chapter 3

Adobe and Rammed Earth

Adobe

Renewal of the surface coating of an adobe wall in Chamisal, New Mexico

Adobe is a natural building material made from sand, clay, water, and some kind of fibrous or organic material (sticks, straw, and/or manure), which is shaped into bricks using frames and dried in the sun. It is similar to cob and mudbrick. Adobe structures are extremely durable and account for some of the oldest existing buildings in the world. In hot climates, compared to wooden buildings, adobe buildings offer significant advantages due to their greater thermal mass, but they are known to be particularly susceptible to earthquake damage.

Buildings made of sun-dried earth are common in the West Asia, North Africa, West Africa, South America, southwestern North America, and Spain (usually in the Mudéjar style). Adobe had been in use by indigenous peoples of the Americas in the Southwestern United States, Mesoamerica, and the Andean region of South America for several thousand years, although often substantial amounts of stone are used in the walls of Pueblo buildings. (Also, the Pueblo people built their adobe structures with handfuls or basketfuls of adobe, until the Spanish introduced them to the making of bricks.) Adobe brickmaking was used in Spain already in the Late Bronze Age and Iron Age, from the eighth century B.C. on. Its wide use can be attributed to its simplicity of design and make, and the cheapness thereby in creating it.

A distinction is sometimes made between the smaller *adobes*, which are about the size of ordinary baked bricks, and the larger *adobines*, some of which may be one to two yards (2 m) long.

Detail of adobe kilns in Arizona

Etymology

Church at San Pedro de Atacama, Chile.

The word *adobe* has come to us over some 4000 years with little change in either pronunciation or meaning: the word can be traced from the Middle Egyptian (c. 2000 BC) word *dj-b-t* "mud [*i.e.*, sun-dried] brick." As Middle Egyptian evolved into Late Egyptian, Demotic, and finally Coptic (c. 600 BC), *dj-b-t* became *tobe* "[mud] brick." This evolved into Arabic *al-tub* (الطّوب *al* "the" + *tub* "brick") "[mud] brick," which was assimilated into Old Spanish as *adobe* [aˈ dobe], still with the meaning "mud brick." English borrowed the word from Spanish in the early 18th century.

Adobe style in Santa Fe, New Mexico

In more modern English usage, the term "adobe" has come to include a style of architecture that is popular in the desert climates of North America, especially in New Mexico. (Compare with stucco).

Composition

An adobe brick is a composite material made of clay mixed with water and an organic material such as straw or dung. The soil composition typically contains clay and sand. Straw is useful in binding the brick together and allowing the brick to dry evenly. Dung offers the same advantage and is also added to repel insects. The mixture is roughly half sand (50%), one-third clay (35%), and one-sixth straw (15%).

Adobe bricks

Adobe bricks near a construction site in Milyanfan, Kyrgyzstan

Bricks are made in an open frame, 25 cm (10 in) by 36 cm (14 in) being a reasonable size, but any convenient size is acceptable. The mixture is molded by the frame, and then the frame is removed quickly. After drying a few hours, the bricks are turned on edge to finish drying. Slow drying in shade reduces cracking.

The same mixture to make bricks, without the straw, is used for mortar and often for plaster on interior and exterior walls. Some ancient cultures used lime-based cement for the plaster to protect against rain damage.

The brick's thickness is preferred partially due to its thermal capabilities, and partially due to the stability of a thicker brick versus a more standard size brick. Depending on the form that the mixture is pressed into, adobe can encompass nearly any shape or size, provided drying time is even and the mixture includes reinforcement for larger bricks. Reinforcement can include manure, straw, cement, rebar or wooden posts. Experience has shown that straw, cement, or manure added to a standard adobe mixture can all produce a stronger, more crack-resistant brick. A general testing is done on the soil content first. To do so, a sample of the soil is mixed into a clear container with some water, creating an almost completely saturated liquid. After the jar is sealed the container is shaken vigorously for at least one minute. It is then allowed to sit on a flat surface for a day or so until the soil has settled into layers or remains in suspension. Heavier particles settle out first so gravel will be on the bottom, sand above, silt above that and very fine clay and organic matter will stay in suspension for days. After the water has cleared percentages of the various particles can be determined. Fifty to 60 percent sand and 35 to 40 percent clay will yield strong bricks. The New Mexico US Extension Service recommends a mix of not more than 1/3 clay, not less than 1/2 sand, and never more than 1/3 silt. The largest structure ever made from adobe (bricks) was the Bam Citadel, which suffered serious damage (up to 80%) by an earthquake on December 26, 2003. Other large adobe structures are the Huaca del Sol in Peru, with 100 million signed bricks, the ciudellas of Chan Chan and Tambo Colorado, both in Peru.

Thermal properties

An adobe wall can serve as a significant heat reservoir due to the thermal properties inherent in the massive walls typical in adobe construction. In desert and other climates typified by hot days and cool nights, the high thermal mass of adobe levels out the heat transfer through the wall to the living space. The massive walls require a large and relatively long input of heat from the sun (radiation) and from the surrounding air (convection) before they warm through to the interior and begin to transfer heat to the living space. After the sun sets and the temperature drops, the warm wall will then continue to transfer heat to the interior for several hours due to the time lag effect. Thus a well-planned adobe wall of the appropriate thickness is very effective at controlling inside temperature through the wide daily fluctuations typical of desert climates, a factor which has contributed to its longevity as a building material. In addition, the exterior of an adobe wall can be covered with glass to increase heat collection. In a passive solar home, this is called a Trombe wall.

Adobe wall construction

The citadel of Bam or Arg-é Bam in Kerman province of Iran: The world's largest adobe structure, dating to at least 500 BC.

When building an adobe structure, the ground should be compressed because the weight of adobe bricks is significantly greater than a frame house and may cause cracking in the wall. The footing is dug and compressed once again. Footing depth depends on the region and its ground frost level. The footing and stem wall are commonly 24" and 14", much larger than a frame house because of the weight of the walls. Adobe bricks are laid by course. Each course is laid the whole length of the wall, overlapping at the corners on a layer of adobe mortar. Adobe walls usually never rise above 2 stories because they're load bearing and have low structural strength. When placing window and door openings, a lintel is placed on top of the opening to support the bricks above. Within the last courses of brick, bond beams are laid across the top of the bricks to provide a horizontal bearing plate for the roof to distribute the weight more evenly along the wall. To protect the interior and exterior adobe wall, finishes can be applied, such as mud plaster, whitewash or stucco. These finishes protect the adobe wall from water damage, but need to be reapplied periodically, or the walls can be finished with other nontraditional plasters providing longer protection.

Adobe roof

The traditional adobe roof has been generally constructed using a mixture of soil/clay, water, sand, and other available organic materials. The mixture was then formed and pressed into wood forms producing rows of dried earth bricks that would then be laid across a support structure of wood and plastered into place with more adobe. For a deeper understanding of adobe, one might examine a cob building. Cob, a close cousin to adobe, contains proportioned amounts of soil, clay, water, manure, and straw. This is blended, but not formed like adobe. Cob is spread and piled around a frame and allowed to air dry for several months before habitation. Adobe, then, can be described as dried bricks of cob, stacked and mortared together with more adobe mixture to create a thick wall and/or roof.

Roof materials

Depending on the materials available, a roof can be assembled using lengths of wood or metal to create a frame work to begin layering adobe bricks. Depending on the thickness of the adobe bricks, the frame work has been performed using a steel framing and a layering of a metal fencing or wiring over the framework to allow an even load as masses of adobe are spread across the metal fencing like cob and allowed to air dry accordingly. This method was demonstrated with an adobe blend heavily impregnated with cement to allow even drying and prevent major cracking.

Traditional adobe roof

More traditional adobe roofs were often flatter than the familiar steeped roof as the native climate yielded more sun and heat than mass amounts of snow or rain that would find use in precipitous roofs. Cement may be introduced to prevent moisture from penetrating the composite of mud and organic matter. Vigas are beams across the roof that support the roof.

Raising a traditional adobe roof

To raise a flattened adobe roof, beams of wood or metal should be assembled and span the extent of the building. The ends of the beams should then be fixed to the tops of the walls using the builder's preferred choice of attachments. Taking into account the material the beams and walls are made from, choosing the attachments may prove difficult. In combination to the bricks and adobe mortar that are laid across the beams creates an even load-bearing pressure that can last for many years depending on attrition.

Once the beams are laid across the building, it is then time to begin the placing of adobe bricks to create the roof. An adobe roof is often laid with bricks slightly larger in width to ensure a larger expanse is covered when placing the bricks onto the beams. This wider shape also provides the future homeowner with thermal protection enough to stabilize an even temperature through out the year. Following each individual brick should be a layer of adobe mortar, recommended to be at least an inch thick to make certain there is ample strength between the brick's edges and also to provide a relative moisture barrier during the seasons where the arid climate does produce rain.

Attributes

Adobe roofs can be inherently fire-proof, an attribute well received when the fireplace is kept lit during the cold nights, depending on the materials used. This feature leads the homeowner and builders to begin thinking about the installation of a chimney, a feat regarded as a necessity in any adobe building. The construction of the chimney can also greatly influence the construction of the roof supports, creating an extra need for care in choosing the right materials. An adobe chimney can be made from simple adobe bricks and stacked in similar fashion as the surrounding walls. Basically outline the location and perimeter of the hearth, minding the safety elements common to a fireplace, and begin to stack and mortar the walls with pre-made adobe bricks, cut to size.

Around the world

Still in production today, Romania's Danube Delta

Mixing mud and straw in brick frames

Community effort

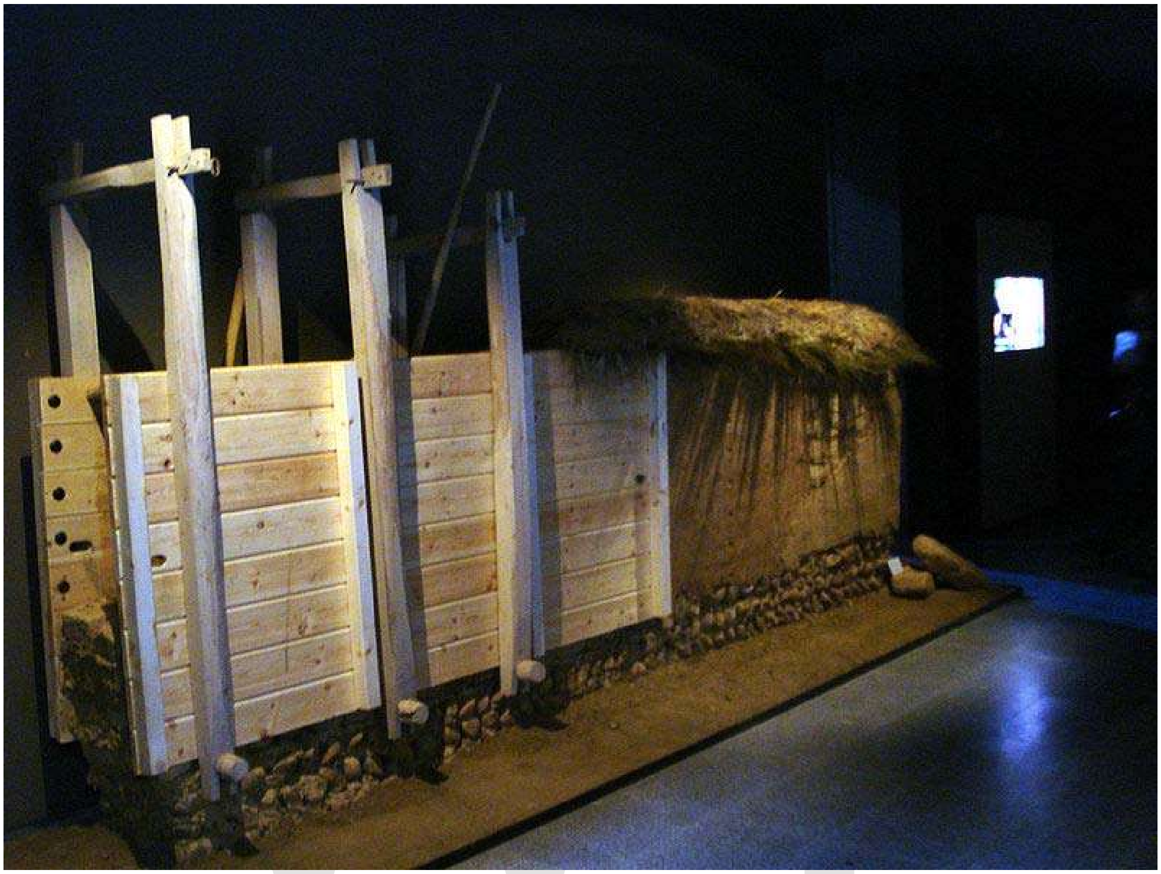
Frame removed and drying

Rammed earth

The ruins of a Han Dynasty (202 BC - 220 AD) Chinese watchtower made of rammed earth at Dunhuang, Gansu province, the eastern end of the Silk Road

Rammed earth, also known as **taipa** (Portuguese), **tapial** (Spanish), ***pisé de terre*** or simply **pisé** (French), is a technique used in the building of walls using the raw materials of earth, chalk, lime and gravel. It is an ancient building method that has seen a revival in recent years as people seek more sustainable building materials and natural building methods. Rammed earth walls are simple to construct, incombustible, thermally massive, very strong and hardwearing. Conversely they can be labour-intensive to construct without machinery (powered rammers), and if improperly protected or maintained they are susceptible to water damage. Traditionally, rammed earth buildings are found on every continent except Antarctica. From temperate and wet regions of north Europe to semi dry deserts, mountain areas and the tropics. The availability of useful soil and building design for the local climatic conditions are the factors which favour its use.

Overview of use



Model showing construction of rammed earth wall on foundation

Building a rammed earth wall involves a process of compressing a damp mixture of earth that has suitable proportions of sand, gravel and clay (sometimes with an added stabilizer) into an externally supported frame, creating a solid wall of earth. Historically, stabilizers such as lime or animal blood were used to stabilize the material, whilst modern rammed earth construction uses lime, cement or asphalt emulsions. Some modern builders also add coloured oxides or other items such as bottles or pieces of timber to add variety to the structure.

A temporary frame (formwork) is first built, usually out of wood or plywood, to act as a mold for desired shape and dimensions of each wall section. The frames must be sturdy and well braced, and the two opposing wall faces clamped together, to prevent bulging or deformation from the high compression forces involved. Damp material is poured in to a depth of between 100 to 250 mm (4 to 10 in), and compressed to around 50% of its original height. The compression of material is done iteratively in batches, to gradually build up the wall to the required height dictated by the top of the frame. Compression was historically done by hand with a long ramming pole, and was very labor-intensive.

Modern construction can be more efficient by employing pneumatically powered tampers.

Once the wall is complete, it is strong enough that the frames can be immediately removed. This is necessary if a surface texture (e.g. by wire brushing) is desired, since walls become too hard to work after about an hour. The walls are best constructed in warm weather so that they can dry and harden. Walls take some time to dry out completely, and may take up to two years to completely cure. Compression strength increases with increased curing time, and exposed walls should be sealed to prevent water damage.

In modern variations of the method, rammed earth walls are constructed on top of conventional footings or a reinforced concrete slab base.

Features and benefits

Taipa fortifications at Paderne Castle in the Algarve, Portugal

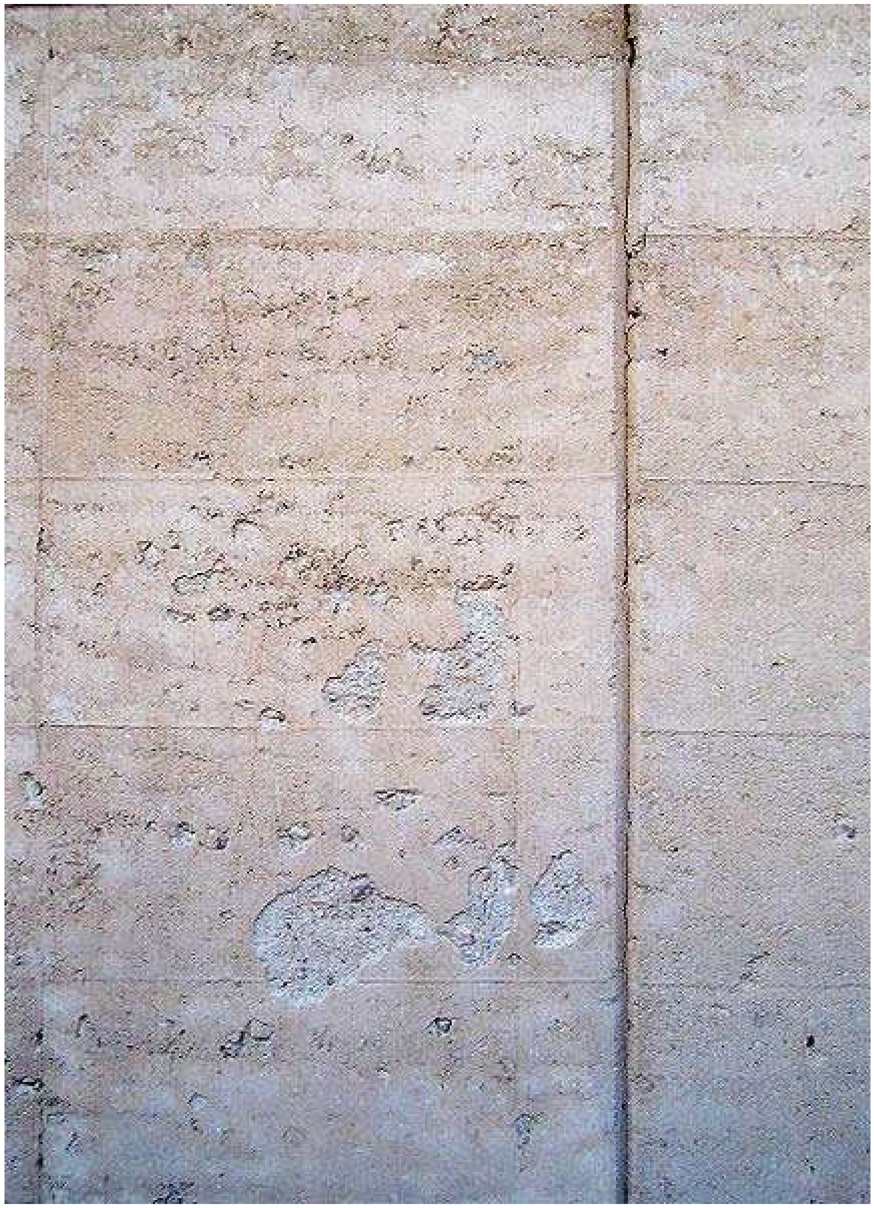
The compression strength of rammed earth can be up to 4.3 MPa (620 psi). This is less than the value of a similar thickness of concrete, but more than strong enough for use in domestic buildings. Indeed, properly built rammed earth can withstand loads for thousands of years, as many still-standing ancient rammed earth structures around the world attest. Rammed earth using re-bar, wood or bamboo reinforcement can prevent failure caused by earthquakes or heavy storms. Mixing cement with the soil mixture can also increase the structure's load bearing capacity but can only be used in clay-poor mixtures. The USDA observed that rammed earth structures last indefinitely and could be built for no more than two-thirds the cost of standard frame houses.

Rammed earth has been used around the world in a wide range of climatic conditions, from wet northern Europe to dry regions in Africa.

Soil is a widely available, low cost and sustainable resource, and harvesting it for use in construction has minimal environmental impact. This makes rammed earth construction highly affordable and viable for low-income builders. Unskilled labor (often friends and family) are able to provide most of the necessary labor, and today more than 30 percent of the world's population uses earth as a building material.

While the cost of material is low, constructing rammed earth without mechanical tools can be a very time consuming project; however with a mechanical tamper and prefabricated formwork it can take as little as two to three days to construct the walls for a 200 to 220 m^2 (2,200 to 2,400 sq ft) house.

One of the significant benefits of rammed earth is its excellent thermal mass; like brick or concrete construction, it can absorb heat during the day and release it at night. This can even out daily temperature variations and reduce the need for air conditioning and heating. However rammed earth, also like brick and concrete, often requires insulation in colder climates. It must also be protected from heavy rain and insulated with vapor barriers.



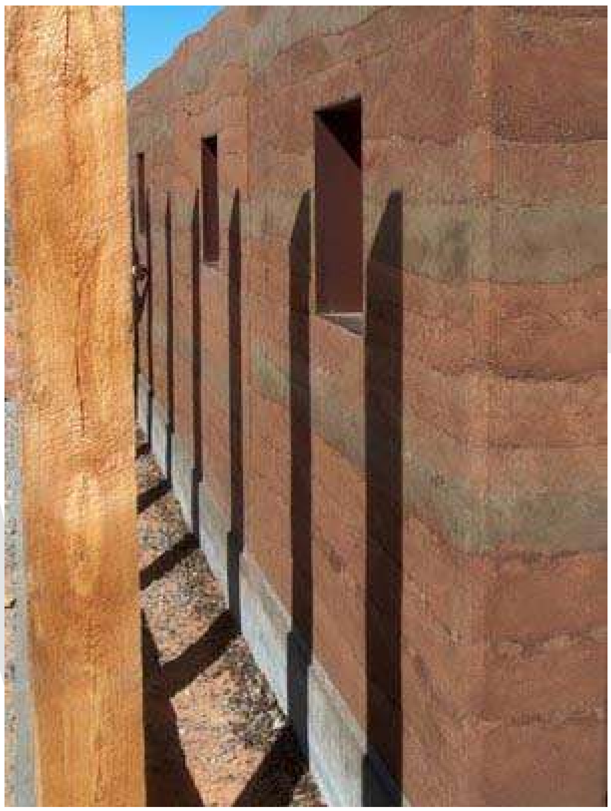
Rammed earth wall surface detail. Apart from the patches of damage, the surface shows regular horizontal lines from the wooden form work used in constructing the wall and subtler horizontal strata from the successive compacted layers of earth used to build the wall.

Untouched, the walls have the color and texture of natural earth. Blemishes can also be patched up using the soil mixture as a plaster and sanded smooth. Care needs to be taken to avoid moisture-impermeable finishes such as cement render, as these will impair the ability of the wall to desorb moisture, leading in turn to a loss of compressive strength.

The thickness and density of rammed earth walls, typically 300 to 350 millimetres (12 to 14 in) thick, lends itself naturally to soundproofing. Rammed earth walls are also termite-resistant, non-toxic, inherently fireproof and ultimately biodegradable.

Nails or screws can be driven easily into well-cured walls, and they can be effectively patched with the same material used to build them.

Environmental aspects and sustainability



Rammed earth trombe wall built by the Design Build Bluff Organization

Because rammed earth structures use locally available materials, they typically have low embodied energy and generate very little waste. The soils used are typically subsoils low in clay, between 5% and 15% typically with the topsoil retained for agricultural use. Ideally, the soil removed in order to prepare the building foundation can be used, further reducing cost and energy used for transportation.

Rammed earth buildings reduce the need for lumber because the formwork used is removable and can be continually reused.

A Taipa section of the Great Wall of China

Rammed earth can effectively control humidity where unclad walls containing clay are exposed to an internal space. Humidity is held between 40% and 60% which is the ideal humidity range for asthma sufferers and the storage of susceptible items, such as books.

When cement is used in the earth mixture, sustainable benefits such as low embodied energy and humidity control will not be realized. Manufacture of the cement itself adds to the global carbon dioxide burden at a rate of 1.25 tonnes per tonne of cement produced. Partial substitution of cement with alternatives such as ground granulated blast furnace slag has not been shown to be effective and brings other sustainability questions with it.

Rammed earth can contribute to the overall energy-efficiency of buildings. The density, thickness and thermal conductivity of rammed earth makes it a particularly suitable material for passive solar heating. Warmth takes almost 12 hours to work its way through a 350-millimetre (14 in) thick wall.

The material mass and clay content of rammed earth allows the building to "breathe" more than concrete structures, avoiding condensation issues without significant heat loss.

Rammed earth housing has been shown to resolve problems with homelessness caused by otherwise high building costs, as well as to help address the ecological dilemma of deforestation and toxic building materials associated with conventional construction methods.

History

One of many pictures available of buildings of the Borough House Plantation, built in the 1820s, in Stateburg, South Carolina.

Rammed earth walls form part of the entrance building for the Eden Project in Cornwall, England.

Evidence of the early use of rammed earth has been seen in Neolithic archaeological sites of the Yangshao culture and the Longshan culture in China along the Yellow River dating back to 5000 BCE. By 2000 BCE, the use of rammed earth architectural techniques was commonly used for walls and foundations in China.

In the 1800s in the United States, rammed earth was popularized by a book *Rural Economy* by S. W. Johnson. It was used to construct Borough House Plantation and Church of the Holy Cross in South Carolina, which are two National Historic Landmarks of the United States:

Constructed in 1821, the Borough House Plantation complex contains the oldest and largest collection of 'high style' pise de terre (rammed earth) buildings in the United States. Six of the 27 dependencies and portions of the main house were constructed using this ancient technique, which was introduced to this country in 1806 through the book *Rural Economy*, by S.W. Johnson.

An outstanding example of rammed earth construction in Canada is St. Thomas Anglican Church (Shanty Bay, Ontario) built between 1838 and 1841.

Church of the Holy Cross (Episcopal) Stateburg or Holy Cross Episcopal Church in Stateburg, South Carolina, built of rammed earth in 1850–1852

The 1920s through the 1940s was an active research period for rammed earth construction in the US. South Dakota State College carried out extensive research and built almost 100 weathering walls of rammed earth. Over a period of thirty years the college researched the use of paints and plasters in relation to colloids in soil. In 1945 Clemson Agricultural College of South Carolina published their results on rammed earth research in a pamphlet called "Rammed Earth Building Construction." In 1936 on a homestead near Gardendale, Alabama, the United States Department of Agriculture constructed an experimental community of rammed earth buildings with architect Thomas Hibben. The houses were built inexpensively and sold to the public, along with land sufficient for a garden and small livestock plots. The project was a success and provided valuable homes to low-income families.

The U.S. Agency for International Development is working with undeveloped countries to improve the building science around rammed earth houses. They also financed the writing of the "Handbook of Rammed Earth" by Texas A&M University and the Texas Transportation Institute. The handbook was never available for purchase by the public until the Rammed Earth Institute International gained permission to reprint it.

Interest in rammed earth fell after World War II when the costs of modern building materials dropped. Rammed earth became viewed as substandard, and often meets opposition with many contractors, engineers, and tradesmen who are unfamiliar with earth construction techniques.

Chapter 4

Compressed Earth Block and Cob (Material)

Compressed earth block

Compressed Earth Block often referred to simply as **CEB**, is a type of manufactured construction material formed in a mechanical press that forms an appropriate mix of dirt, non-expansive clay, and an aggregate into a compressed block. Creating CEBs differs from rammed earth in that the latter uses a larger formwork into which earth is poured and tamped down, creating larger forms such as a whole wall or more at one time. CEB blocks are installed onto the wall by hand and a slurry made of a soupy version of the same dirt/clay mix, sans aggregate, is spread or brushed very thinly between the blocks for bonding. There is no use of mortar in the traditional sense.

The advance of CEB into the construction industry has been driven by manufacturers of the mechanical presses, a small group of eco-friendly contractors and by cultural acceptance of the medium in areas where it is seen as superior to adobe. In the United States, most general contractors building with CEB are in the Southwestern states: New Mexico, Colorado, Arizona, California, and to a lesser extent in Texas. However, manufacturers of the mechanical presses enjoy their heaviest sales overseas. Mexico and Third World countries have been attractive markets for the presses for years.

The advantages of CEB are in the wait time for material, the elimination of shipping cost, the low moisture content, and the uniformity of the block thereby minimizing, if not eliminating the use of mortar and decreasing both the labor and materials costs.

- CEB can be pressed from humid earth. Because it is not wet, the drying time is much shorter. Some soil conditions permit the blocks to go straight from the press onto the wall. A single mechanical press can produce from 800 to over 5,000 blocks per day, enough to build a 1,200 square feet (110 m^2) house in one day. The Liberator, a high performance, open source CEB press, can produce from 8,000 to over 17,000 blocks per day.

- Shipping cost: Suitable soils are often available at or near the construction site. Adobe and CEB are of similar weight, but distance from a source supply gives

CEB an advantage. Also, CEB can be made available in places where adobe manufacturing operations are non-existent.

- Uniformity: CEB can be manufactured to a predictable size and has true flat sides and 90-degree angle edges. This makes design and costing easier. This also provides the contractor the option of making the exteriors look like conventional stucco houses.

CEB had very limited use prior to the 1980s. It was known in the 1950s in South America, where the Cinva Ram was developed by Raul Ramirez in the Inter-American Housing Center (CINVA) in Bogota, Colombia. The Cinva Ram is a lever-action, manual press that makes one block at a time.

U.S. manufacturers produce much larger machines that run with diesel or gasoline engines and hydraulic presses that receive the soil/aggregate mixture through a hopper. This is fed into a chamber to create a block that is then ejected onto a conveyor.

During the 1980s, soil-pressing technology became widespread. France, England, Germany and Switzerland began to write standards. The Peace Corps, USAID, Habitat for Humanity and other programs began to implement it into housing projects.

Construction method is simple. Less skilled labor is required; wall construction can be done with unskilled labor encouraging self-sufficiency and community involvement. If the blocks are stabilized with cement and/or fly ash, they can be used as bricks and assembled using standard masonry techniques of brick-laying.

Soil mix conditions: The soil mix is 15-40 percent non-expansive clay, 25-40 percent silt powder, and sharp sand to small gravel content of 40-70 percent. The more modern machines do not require aggregate (rock) to make a strong soil block for most applications. Soil moisture content ranges from 4 to 12 percent by weight. Clay with a plasticity index (PI) of up to 25 or 30 would be acceptable for most applications. The PI of the mixed soil (clay, silt and sand/gravel combined) should not exceed 12 to 15; that is the difference between the Upper and Lower Atterberg limits, as determined by laboratory testing.

Other advantages:

- Non-toxic: materials are completely natural and do not out-gas toxic chemicals
- Sound resistant: an important feature in high-density neighborhoods, residential areas adjacent to industrial zones
- Fire resistant: earthen walls do not burn
- Insect resistant: the walls are solid and very dense, discouraging insects
- Mold resistant: there is no cellulose material - such as in wood, Oriented Strand Board or drywall - that can host mold

Completed walls require either a reinforced bond beam or a ring beam on top or between floors (8')and if the blocks are unstabilized, a plaster finish, usually stucco wire/stucco cement and or lime plaster. Stabilized blocks create a brick wall that if properly stabilized can be left exposed with no outer plaster finish.

Foundations: Standards for foundations are similar to those for brick walls. A CEB wall is heavy. Footings must be at last 10 inches thick, with a minimum width that is 33 percent greater than the wall width. If a stem wall is used, it shall extend to an elevation not less than eight inches (203 mm) above the exterior finish grade. Rubble-filled foundation trench designs with a reinforced concrete grade beam above are allowed to support CEB construction.

CEB's strongest market in the USA is probably New Mexico, which has incorporated the method into its Earthbuilding Code family. The first CEB Code Development meeting in New Mexico took place Dec. 12, 2001. The persons present at that meeting are considered today the leading experts in the field. They include:

- Fermin Aragon, general bureau chief of the Construction Industries Division for Santa Fe, New Mexico
- Joe M. Tibbets, publisher of Adobe Builder Trade Publications, Bosque, New Mexico
- Larry Elkins, Adobe International Inc., Milan, New Mexico
- Jim Hallock, Earth Block Inc., Pagosa Springs, Colo.
- Lawrence Jetter, A.E.C.T., San Antonio, Texas
- Jim Hands, P.E., Red Mountain Engineering, Santa Fe, New Mexico
- Todd Swanson, Bio-Hab Inc., Hesperus, Colo.
- Joaquim Karcher, architect, Taos, New Mexico

Code work was completed June 10, 2002 and melded into New Mexico's new section, R1100 Earthen Building Materials.

The CEB code is different from the adobe code in numerous respects. For instance, the CEB code allows slip mortars and permits blocks ejected from a press to go directly to the wall.

CEB Strength: Using the ASTM D1633-00 stabilization standard, a pressed and cured block must be submerged in water for four hours. It is then pulled from the water and immediately subjected to a compression test. The blocks must score at least a 300 pound-force per square inch (p.s.i) (2 MPa) minimum. This is a higher standard than for adobe, which must score an *average* of at least 300 p.s.i. (2 MPa)

It must be emphasized that the compressive strength minimums for code compliance are nothing like the true strength of CEB blocks. New Mexico only sought to assure that CEB would be at least as strong as adobe.

CEB can have a compressive strength as high as 2,000 pounds per square inch (13.7×10^6 Pa). Blocks with compressive strengths of 1,200 (8.27×10^6 Pa) to 1,400 p.s.i. (9.65×10^6 Pa) are common.

Thermal advantages: Also, due to the enormous mass **-** these are monolithic walls **-** CEB has excellent thermal performance, reducing heating and cooling costs.

Thermal testing: From May 31 to June 3, 2004, the Biology Dept. of Southwest Texas Junior College, Del Rio, Texas, conducted tests for thermal change on three structures: concrete block, adobe and compressed earth block.

Results indicate the interior temperature of the adobe and CEB modules were significantly lower than for concrete blocks.

With a maximum ambient temperature of 107 °F (42 °C), the interior temperatures were:

Concrete Module: 111 °F (44 °C) (four degrees Fahrenheit above ambient)
Adobe Module: 95 °F (35 °C)
CEB Module: 91 °F (33 °C)

The CEB module was consistently cooler inside than the adobe by approximately 3 degrees.

Cob

Constructing a wall out of **cob**

Cob or **cobb** is a building material consisting of clay, sand, straw, water, and earth, similar to adobe. Cob is fireproof, resistant to seismic activity, and inexpensive. It can be used to create artistic, sculptural forms and has been revived in recent years by the natural building and sustainability movements.

History and usage

Cob building is usually a highly cooperative activity, as seen here at the University of Washington's construction of a cob oven

Cob is an ancient building material, that may have been used for construction since prehistoric times. Cobwork (*tabya*) was used in the Maghreb and al-Andalus in the 11th and 12th centuries and was described in detail by Ibn Khaldun in the 14th century. Cobwork later spread to other parts of Europe from the 12th century onwards.

Cob structures can be found in a variety of climates across the globe; In the UK it is most strongly associated with counties of Devon and Cornwall in the West Country; the Vale of Glamorgan and Gower Peninsula in Wales; Donegal Bay in Ulster and Munster, South-West Ireland; and Finisterre in Brittany where many homes have survived over 500 years and are still inhabited. Many old cob buildings can be found in Africa, the Middle East, Wales, Devon, Ireland, Cornwall, Brittany and some parts of the eastern United States. A number of cob cottages survive from mid-19th century New Zealand. Traditionally, English cob was made by mixing the clay-based subsoil with straw and water using oxen to trample it. The earthen mixture was then ladled onto a stone foundation in courses and trodden onto the wall by workers in a process known as *cobbing*. The construction would progress according to the time required for the prior course to dry. After drying, the walls would be trimmed and the next course built, with lintels for later openings such as doors and windows being placed as the wall takes shape. The walls of a cob house were generally about 24 inches thick, and windows were correspondingly deep-set, giving the homes a characteristic internal appearance. The thick walls provided excellent thermal mass which was easy to keep warm in winter and cool in summer. Walls with a high thermal mass value act as a thermal buffer inside the home. The material has a long life span even in rainy climates, provided a tall foundation and large roof overhang are present.

Modern cob buildings

An example of a modern, Pacific Northwest-style cob home. The exterior cob wall has had plaster applied to it for an attractive, uniform appearance.

One of the more desirable attributes of cob is the ability for creating completely unique, handmade architecture; including aesthetic designs of an artistic nature.

When Kevin McCabe built a two-storey, four bedroom cob house in England in 1994, it was reputedly the first cob residence built in the country in 70 years. His methods remained very traditional; the only innovations he added were using a tractor to mix the cob itself, and adding sand or shillet (a gravel of crushed shale) to reduce the shrinkage.

From 2002 to 2004, sustainability enthusiast Rob Hopkins initiated the building of a cob house for his family, the first new one in Ireland in about one hundred years. It was undertaken as a community project, but destroyed by an unknown arsonist shortly before completion. This house, located at The Hollies Centre for Practical Sustainability in County Cork, is being rebuilt (2010). There are also a number of other modern cob houses completed and more planned including an public education centre.

In 2000/2001, a modern, four-bedroom cob house in, UK, designed by Associated Architects sold for £745,000. Cobtun House was built in 2001 and won the Royal Institute of British Architects' Sustainable Building of the Year award in 2005. The total construction cost was £300,000, but the metre-thick cob outer wall cost only £20,000.

In the Pacific Northwest of the US there has been a resurgence of cob building both as an alternative building practice and one desired for its form, function and cost effectiveness. There are more than ten cob houses in the Southern Gulf Islands of British Columbia built by Pat Hennebery, Tracy Calvert, Elke Cole and the Cobworks workshops.

In 2007, Ann and Gord Baird began constructing a two-storey cob house in Victoria, British Columbia for an estimated $210,000 CDN. The 2,150 sq. ft. home includes heated floors, solar panels and a southern exposure for passive solar heating.

The building process known as "Oregon Cob" is one which was refined by Welsh architect Ianto Evans and researcher Linda Smiley in the 1980s. Oregon Cob integrates the variation of wall layup technique which uses loaves of mud mixed with sand and straw with a rounded architectural stylism.

Chapter 5

Solar Thermal Collector

Solar Thermal Collector Dish

A **solar thermal collector** is a solar collector designed to collect heat by absorbing sunlight. The term is applied to solar hot water panels, but may also be used to denote more complex installations such as solar parabolic, solar trough and solar towers or simpler installations such as solar air heat. The more complex collectors are generally used in solar power plants where solar heat is used to generate electricity by heating water to produce steam which drives a turbine connected to an electrical generator. The simpler collectors are typically used for supplemental space heating in residential and commercial buildings. A collector is a device for converting the energy in solar radiation into a more usable or storable form. The energy in sunlight is in the form of electromagnetic radiation from the infrared (long) to the ultraviolet (short) wavelengths. The solar energy striking the Earth's surface depends on weather conditions, as well as location and orientation of the surface, but overall, it averages about 1,000 watts per square meter under clear skies with the surface directly perpendicular to the sun's rays.

Types of solar collectors for heat

Solar collectors fall into two general categories: non-concentrating and concentrating. In the non-concentrating type, the collector area (i.e. the area that intercepts the solar radiation) is the same as the absorber area (i.e., the area absorbing the radiation). In these types the whole solar panel absorbs the light.

Flat plate and evacuated tube solar collectors are used to collect heat for space heating or domestic hot water.

Flat plate collectors

Flat plate thermal system for water heating deployed on a flat roof.

Flat plate collectors, developed by Hottel and Whillier in the 1950s, are the most common type. They consist of (1) a dark flat-plate absorber of solar energy, (2) a transparent cover that allows solar energy to pass through but reduces heat losses, (3) a heat-transport fluid (air, antifreeze or water) to remove heat from the absorber, and (4) a heat insulating backing. The absorber consists of a thin absorber sheet (of thermally stable polymers, aluminum, steel or copper, to which a matt black or selective coating is applied) often backed by a grid or coil of fluid tubing placed in an insulated casing with a glass or polycarbonate cover. In water heat panels, fluid is usually circulated through tubing to transfer heat from the absorber to an insulated water tank. This may be achieved directly or through a heat exchanger. Most air heat fabricates and some water heat manufacturers have a completely flooded absorber consisting of two sheets of metal which the fluid passes between. Because the heat exchange area is greater they may be marginally more efficient than traditional absorbers.

There are a number of absorber piping configurations:

- harp - traditional design with bottom pipe risers and top collection pipe, used in low pressure thermosyphon and pumped systems
- serpentine - one continuous S that maximises temperature but not total energy yield in variable flow systems, used in compact solar domestic hot water only systems (no space heating role)
- completely flooded absorber consisting of two sheets of metal stamped to produce a circulation zone. Because the heat exchange area is greater they may be marginally more efficient than traditional absorbers.

As an alternative to metal collectors, new polymer flat plate collectors are now being produced in Europe. These may be wholly polymer, or they may include metal plates in front of freeze-tolerant water channels made of silicone rubber. Polymers, being flexible and therefore freeze-tolerant, are able to contain plain water instead of antifreeze, so that they may be plumbed directly into existing water tanks instead of needing to use heat exchangers which lower efficiency. By dispensing with a heat exchanger in these flat plate panels, temperatures need not be quite so high for the circulation system to be switched on, so such direct circulation panels, whether polymer or otherwise, can be more efficient, particularly at low light levels.

Some early selectively coated polymer collectors suffered from overheating when insulated, as stagnation temperatures can exceed the melting point of the polymer. For example, the melting point of polypropylene is 160°C, while the stagnation temperature of insulated thermal collectors can exceed 180°C if control strategies are not used. For this reason polypropylene is not often used in glazed selectively coated solar collectors. Increasingly polymers such as high temperate silicones (which melt at over 250C) are being used. Some non polypropylene polymer based glazed solar collectors are matt black coated rather than selectively coated to reduce the stagnation temperature to 150C or less.

In areas where freezing is a possibility, freeze-tolerance (the capability to freeze repeatedly without cracking) can be delivered by the use of flexible polymers. Silicone rubber pipes have been used for this purpose in UK since 1999. Conventional metal collectors are vulnerable to damage from freezing, so if they are water filled they must be carefully plumbed so they completely drain down using gravity before freezing is expected, so that they do not crack. Many metal collectors are installed as part of a sealed heat exchanger system. Rather than having the potable water flow directly through the collectors, a mixture of water and antifreeze such as propylene glycol (which is used in the food industry) is used as a heat exchange fluid to protect against freeze damage down to a locally determined risk temperature that depends on the proportion of propylene glycol in the mixture. The use of glycol lowers the water's heat carrying capacity marginally, while the addition of an extra heat exchanger may lower system performance at low light levels.

A pool or unglazed collector is a simple form of flat-plate collector without a transparent cover. Typically polypropylene or EPDM rubber or silicone rubber is used as an absorber. Used for pool heating it can work quite well when the desired output temperature is near the ambient temperature (that is, when it is warm outside). As the ambient temperature gets cooler, these collectors become less effective.

Most flat plate collectors have a life expectancy of over 25 years.

Evacuated tube collectors

Evacuated tube collector

Most (if not all) vacuum tube collectors use heat pipes for their core instead of passing liquid directly through them. Evacuated heat pipe tubes (EHPT's) are composed of multiple evacuated glass tubes each containing an absorber plate fused to a heat pipe. The heat from the hot end of the heat pipes is transferred to the transfer fluid (water or an antifreeze mix—typically propylene glycol) of a domestic hot water or hydronic space heating system in a heat exchanger called a "manifold". The manifold is wrapped in insulation and covered by a sheet metal or plastic case to protect it from the elements.

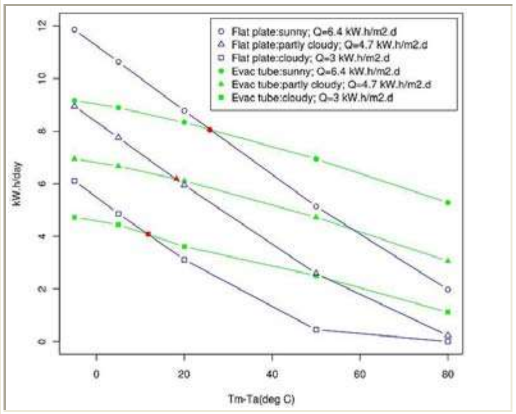
The vacuum that surrounds the outside of the tube greatly reduces convection and conduction heat loss to the outside, therefore achieving greater efficiency than flat-plate collectors, especially in colder conditions. This advantage is largely lost in warmer climates, except in those cases where very hot water is desirable, for example commercial process water. The high temperatures that can occur may require special system design to avoid or mitigate overheating conditions.

Some evacuated tubes (glass-metal) are made with one layer of glass that fuses to the heat pipe at the upper end and encloses the heat pipe and absorber in the vacuum. Others (glass-glass) are made with a double layer of glass fused together at one or both ends with a vacuum between the layers (like a vacuum bottle or flask) with the absorber and heat pipe contained at normal atmospheric pressure. Glass-glass tubes have a highly reliable vacuum seal but the two layers of glass reduce the light that reaches the absorber and there is some possibility that moisture will enter the non-evacuated area of the tube and cause absorber corrosion. Glass-metal tubes allow more light to reach the absorber and protect the absorber and heat pipe (contained in the vacuum) from corrosion even if they are made from dissimilar materials.

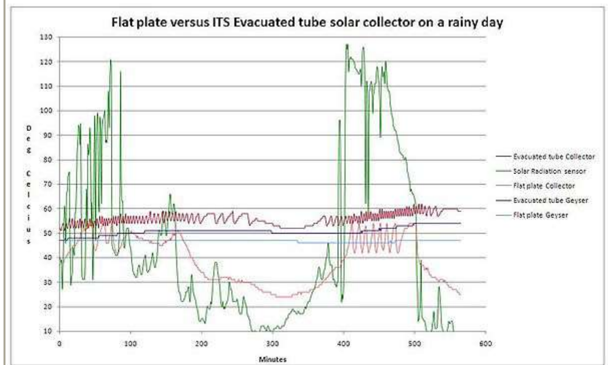
The gaps between the tubes may allow for snow to fall through the collector, minimizing the loss of production in some snowy conditions, though the lack of radiated heat from the tubes can also prevent effective shedding of accumulated snow.

Comparisons of flat plate and evacuated tube collectors

A long standing argument exists between protagonists of these two technologies. Some of this can be related to the physical structure of evacuated tube collectors which have a discontinuous absorbance area. An array of evacuated tubes on a roof has 1) open space between collector tubes and 2) (vacuum-filled) space occupied between the two concentric glass tubes of each collector tube. Consequently, a square meter of roof area covered with evacuated tubes (collector gross area) is larger than the area comprising the actual absorbers (absorber plate area). If evacuated tubes are compared with flat-plate collectors on the basis of area of roof occupied, a different conclusion might be reached than if the areas of absorber were compared. In addition, the way that the ISO 9806 standard specifies the way in which the efficiency of solar thermal collectors should be measured is ambiguous, since these could be measured either in terms of gross area or in terms of absorber area. Unfortunately, power output is not given for thermal collectors as it is for PV panels. This makes it difficult for purchasers and engineers to make informed decisions.



A comparison of the energy output (kW.h/day) of a flat plate collector (blue lines; ThermoDynamics S42-P; absorber 2.8 m^2) and an evacuated tube collector (green lines; SunMaxx 20EVT; absorber 3.1 m^2. Data obtained from SRCC certification documents on the Internet. Tm-Ta = temperature difference between water in the collector and the ambient temperature. Q = insolation during the measurements. Firstly, as (Tm-Ta) increases the flat plate collector loses efficiency more rapidly than the evac tube collector. This means the flat plate collector is less efficient in producing water higher than 25 degrees C above ambient (i.e. to the right of the red marks on the graph). Secondly, even though the output of both collectors drop off strongly under cloudy conditions (low insolation), the evac tube collector yields significantly more energy under cloudiness than the flat plate collector. Although many factors obstruct the extrapolation from two collectors to two different technologies, above, the basic relationships between their efficiencies remain valid.



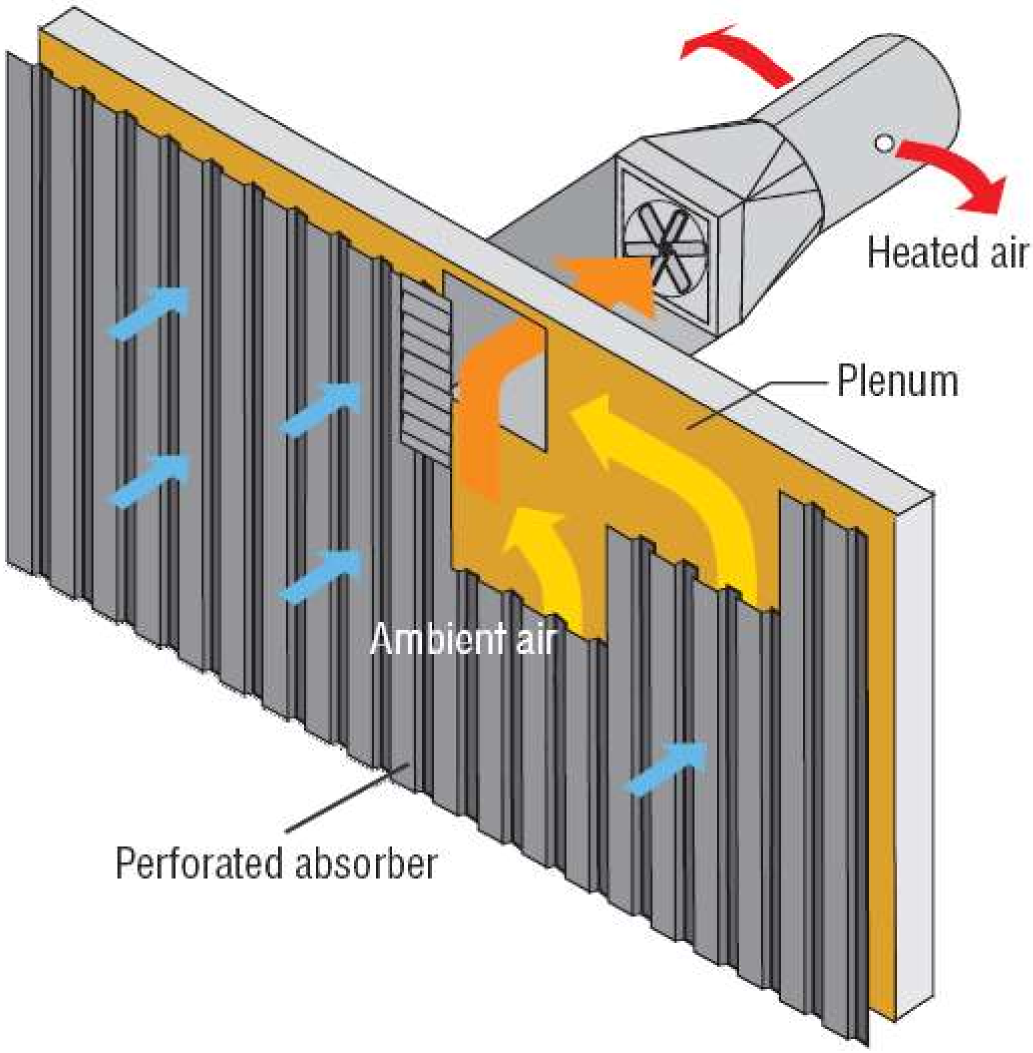
A field trial illustrating the differences discussed in the figure on the left. A flat plate collector and a similar-sized evacuated tube collector were installed adjacently on a roof, each with a pump, controller and storage tank. Several variables were logged during a day with intermittent rain and cloud. Green line = solar irradiation. The top maroon line indicates the temperature of the evac tube collector for which cycling of the pump is much slower and even stopping for some 30 minutes during the cool parts of the day (irradiation low), indicating a slow rate of heat collection. The temperature of the flat plate collector fell significantly during the day (bottom purple line), but started cycling again later in the day when irradiation increased. The temperature in the water storage tank of the evac tube system (dark blue graph) increased by 8 degrees C during the day while that of the flat plate system (light blue graph) only remained constant. Courtesy ITS-solar.

Flat-plate collectors usually lose more heat to the environment than evacuated tubes and this loss increases with temperature difference. So they are usually inappropriate choice of solar collector for high temperature commercial applications such as process steam production. Evacuated tube collectors have a lower absorber plate area to gross area ratio (typically 60-80% of gross area) compared to flat plates. (In early designs the absorber area only occupied about 50% of the collector panel. However this has changed as the technology has advanced to maximize the absorption area.) Based on absorber plate area, most evacuated tube systems are more efficient per square meter than equivalent flat plate systems. This makes them suitable where roof space is limiting, for example where the number of occupants of a building is higher than the number of square metres of **suitable and available** roof space. In general, per installed square metre, evacuated tubes deliver marginally more energy when the ambient temperature is low (e.g. during winter) or when the sky is overcast for long periods. However even in areas without much sunshine and solar heat, some low cost flat plate collectors can be more cost efficient than an evacuated tube collectors. Although several European companies manufacture evacuated tube collectors, the evacuated tube market is dominated by manufacturers in the East. Several Chinese companies have long favorable track records of 15–30 years. There is no unambiguous evidence that the two collector technologies (flat-plate and evacuated tube) differ in long term reliability. However, the evacuated tube technology is younger and (especially for newer variants with sealed heat pipes) still need to prove equivalent lifetimes of equipment when compared to flat plates. The modularity of evacuated tubes can be advantages in terms of extendability and maintenance, for example if the vacuum in one particular tube diminishes.

For a given absorber area, evacuated tubes can therefore maintain their efficiency over a wide range of ambient temperatures and heating requirements. In most climates, flat-plate collectors will generally be a more cost-effective solution than evacuated tubes. When employed in arrays, when considered instead on a per square metre basis, the efficient but costly evacuated tube collectors can have a net benefit in winter and also give real advantage in the summer months. They are well suited to cold ambient temperatures and work well in situations of consistently low sunshine, providing heat more consistently than flat plate collectors per square metre. On the other hand, heating of water by a medium to low amount (i.e. Tm-Ta) is much more efficiently performed by flat plate collectors. Domestic hot water frequently falls into this medium category. Glazed or unglazed flat collectors are the preferred devices for heating swimming pool water. Unglazed collectors may be suitable in tropical or subtropical environments if domestic hot water needs to be heated by less than 20°C. A contour map can show which type is more effective (both thermal efficiency and energy/cost) for any geographic region.

Besides efficiency, there are other differences. EHPT's work as a thermal one-way valve due to their heat pipes. This also gives them an inherent maximum operating temperature which may be considered a safety feature. They have less aerodynamic drag, which may allow them to be laid onto the roof without being tied down. They can collect thermal radiation from the bottom in addition to the top. Tubes can be replaced individually without shutting down the entire system. There is no condensation or corrosion within the tubes. There is the question of vacuum leakage over their lifetime. Flat panels have been around much longer, and are less expensive. They may be easier to clean. Other properties, such as appearance and ease of installation are more subjective.

Air



Unglazed, "transpired" air collector

Solar Air Heat collectors heat air directly, almost always for space heating. They are also used for pre-heating make-up air in commercial and industrial HVAC systems. They fall into two categories: Glazed and Unglazed.

Glazed systems have a transparent top sheet as well as insulated side and back panels to minimize heat loss to ambient air. The absorber plates in modern panels can have an absorptivity of more than 93%. Air typically passes along the front or back of the absorber plate while scrubbing heat directly from it. Heated air can then be distributed directly for applications such as space heating and drying or may be stored for later use.

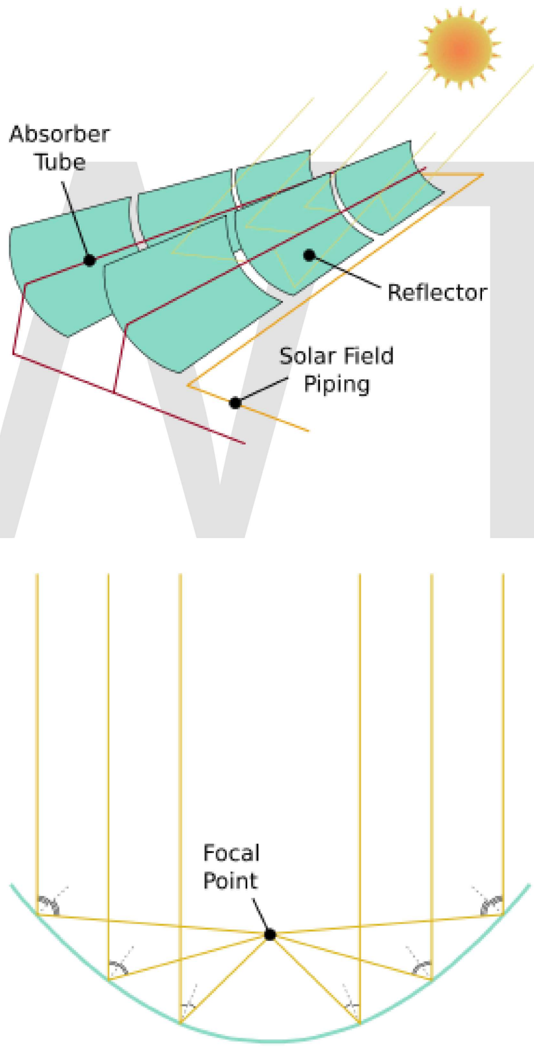
Unglazed systems, or transpired air systems, consist of an absorber plate which air passes across or through as it scrubs heat from the absorber. These systems are typically used for pre-heating make-up air in commercial buildings.

These technologies are among the most efficient, dependable, and economical solar technologies available. Payback for glazed solar air heating panels can be less than 9–15 years depending on the fuel being replaced.

Types of solar collectors for electricity generation

Parabolic troughs, dishes and towers described in this section are used almost exclusively in solar power generating stations or for research purposes. The conversion efficiency of a solar collector is expressed as eta0 or η0.

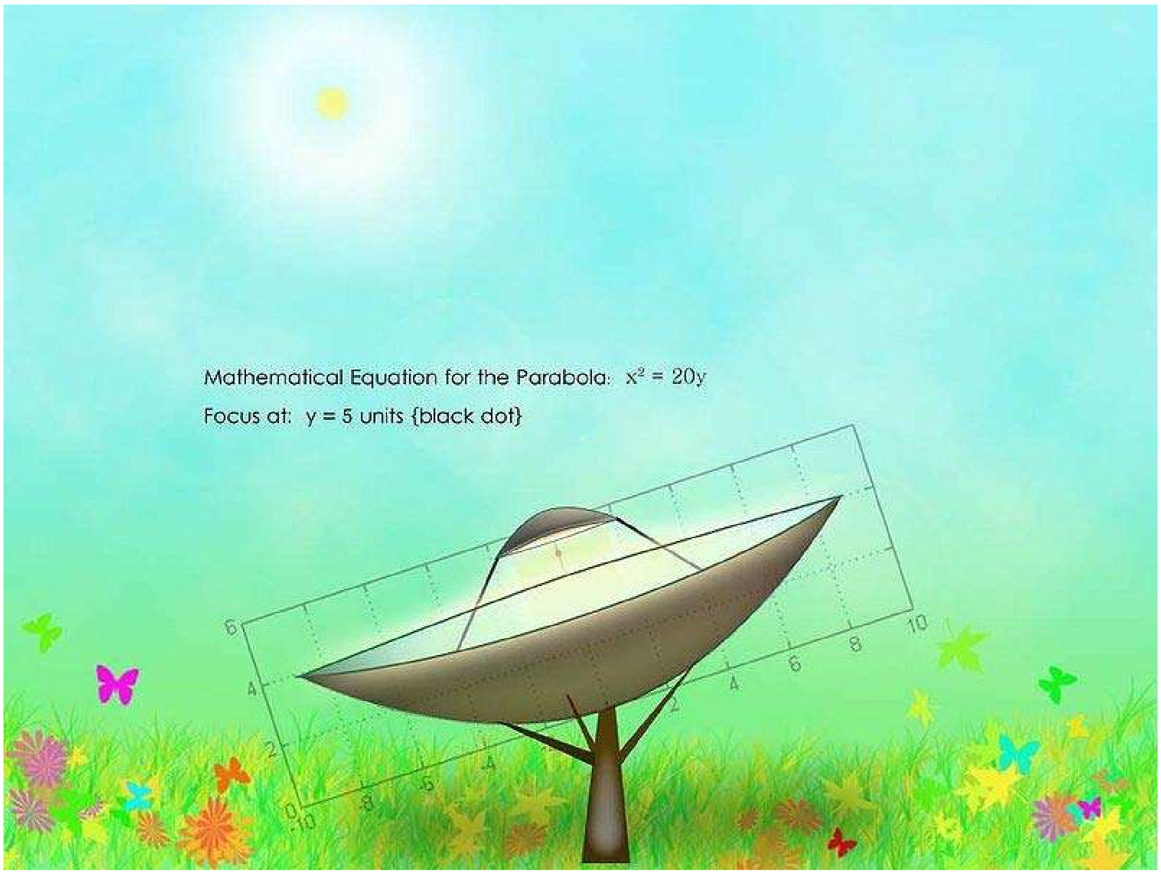
Parabolic trough



Parabolic trough

This type of collector is generally used in solar power plants. A trough-shaped parabolic reflector is used to concentrate sunlight on an insulated tube (Dewar tube) or heat pipe, placed at the focal point, containing coolant which transfers heat from the collectors to the boilers in the power station.

Parabolic dish



Solar Parabolic dish

It is the most powerful type of collector which concentrates sunlight at a single, focal point, via one or more parabolic dishes—arranged in a similar fashion to a reflecting telescope focuses starlight, or a dish antenna focuses radio waves. This geometry may be used in solar furnaces and solar power plants.

There are two key phenomena to understand in order to comprehend the design of a parabolic dish. One is that the shape of a parabola is defined such that incoming rays which are parallel to the dish's axis will be reflected toward the focus, no matter where on the dish they arrive. The second key is that the light rays from the sun arriving at the Earth's surface are almost completely parallel. So if dish can be aligned with its axis pointing at the sun, almost all of the incoming radiation will be reflected towards the focal point of the dish—most losses are due to imperfections in the parabolic shape and imperfect reflection.

Losses due to atmosphere between the dish and its focal point are minimal, as the dish is generally designed specifically to be small enough that this factor is insignificant on a clear, sunny day. Compare this though with some other designs, and you will see that this could be an important factor, and if the local weather is hazy, or foggy, it may reduce the efficiency of a parabolic dish significantly.

In some power plant designs, a stirling engine coupled to a dynamo, is placed at the focus of the dish, which absorbs the heat of the incident solar radiation, and converts it into electricity.

Power tower

Power Tower

A power tower is a large tower surrounded by tracking mirrors called heliostats. These mirrors align themselves and focus sunlight on the receiver at the top of tower, collected heat is transferred to a power station below.

Advantages

- Very high temperatures reached. High temperatures are suitable for electricity generation using conventional methods like steam turbine or some direct high temperature chemical reaction.

- Good efficiency. By concentrating sunlight current systems can get better efficiency than simple solar cells.
- A larger area can be covered by using relatively inexpensive mirrors rather than using expensive solar cells.
- Concentrated light can be redirected to a suitable location via optical fiber cable. For example illuminating buildings.
- Heat storage for power production during cloudy and overnight conditions can be accomplished, often by underground tank storage of heated fluids. Molten salts have been used to good effect.

Disadvantages

- Concentrating systems require sun tracking to maintain Sunlight focus at the collector.
- Inability to provide power in diffused light conditions. Solar Cells are able to provide some output even if the sky becomes a little bit cloudy, but power output from concentrating systems drop drastically in cloudy conditions as diffused light cannot be concentrated passively.

Chapter 6

Appropriate Technology Applications in Cooking

Solar cooker

In Ghana, Zouzugu villagers like this woman prevent dracunculiasis and other waterborne diseases by pasteurizing water in a CooKit solar cooker.

A **solar oven** or **solar cooker** is a device which uses sunlight as its energy source. Because they use no fuel and they cost nothing to run, humanitarian organizations are promoting their use worldwide to help slow deforestation and desertification, caused by using wood as fuel for cooking. Solar Cookers are a form of outdoor cooking and are often used in situations where minimal fuel consumption is important, or the danger of accidental fires is high.

Types

Sun Oven experiments

Sun Oven

There are a variety of types of solar cookers: over 65 major designs and hundreds of variations of them. The basic principles of all solar cookers are:

- Concentrating sunlight: Some device, usually a mirror or some type of reflective metal, is used to concentrate light and heat from the sun into a small cooking area, making the energy more concentrated and therefore more potent.
- Converting light to heat: Any black on the inside of a solar cooker, as well as certain materials for pots, will improve the effectiveness of turning light into heat. A black pan will absorb almost all of the sun's light and turn it into heat, substantially improving the effectiveness of the cooker. Also, the better a pan conducts heat, the faster the oven will work.

- Trapping heat: Isolating the air inside the cooker from the air outside the cooker makes an important difference. Using a clear solid, like a plastic bag or a glass cover, will allow light to enter, but once the light is absorbed and converted to heat, a plastic bag or glass cover will trap the heat inside. This makes it possible to reach similar temperatures on cold and windy days as on hot days.
- Plastic Sheet: Uses plastic sheets to assure that liquids do not seep through into the oven. Also to prevent staining of the underlying sheet in the oven.

The top can usually be removed to allow dark pots containing food to be placed inside. One or more reflectors of shiny metal or foil-lined material may be positioned to bounce extra light into the interior of the oven chamber. Cooking containers and the inside bottom of the cooker should be dark-colored or black. Inside walls should be reflective to reduce radiative heat loss and bounce the light towards the pots and the dark bottom, which is in contact with the pots.

Box cookers

Global Sun Oven

Insulator for the solar box cooker has to be able to withstand temperatures up to 150°C (300 °F) without melting or off-gassing. Crumpled newspapers, wool, rags, dry grass, sheets of cardboard, etc. can be used to insulate the walls of the cooker, but since most of the heat escapes through the top glass or plastic, very little insulation in the walls is necessary. The transparent top is either glass, which is durable but hard to work with, or an oven cooking bag, which is lighter, cheaper, and easier to work with, but less durable. If dark pots and/or bottom trays cannot be located, these can be darkened either with flat-black spray paint (one that is non-toxic when warmed), black tempera paint, or soot from a fire.

The solar box cooker typically reaches a temperature of 150 °C (300 °F). This is not as hot as a standard oven, but still hot enough to cook food over a somewhat longer period of time. Food containing a lot of moisture cannot get much hotter than 100 °C (212 °F) in any case, so it is not always necessary to cook at the high temperatures indicated in standard cookbooks. Because the food does not reach too high a temperature, it can be safely left in the cooker all day without burning. It is best to start cooking before noon, though. Depending on the latitude and weather, food can be cooked either early or later in the day. The cooker can be used to warm food and drinks and can also be used to pasteurize water or milk. If you use an indoor stove for your actual cooking, you can save significant fuel by using the solar cooker to preheat the water to be used for cooking grains, soups, etc., to nearly boiling.

Solar box cookers can be made of locally available materials or be manufactured in a factory for sale. They range from small cardboard devices, suitable for cooking a single meal when the sun is shining, to wood and glass boxes built into the sunny side of a house. Although invented by Horace de Saussure, a Swiss naturalist, as early as 1767, solar box cookers have only gained popularity since the 1970s. These surprisingly simple and useful appliances are seen in growing numbers in almost every country of the world.

Panel cookers

Panel solar cookers are very inexpensive solar cookers that use shiny panels to direct sunlight to a cooking pot that is enclosed in a clear plastic bag. A common model is the CooKit. Developed in 1994 by Solar Cookers International, it is often produced locally by pasting a reflective material, such as aluminum foil, onto a cut and folded backing, usually corrugated cardboard. It is lightweight and folds for storage. When completely unfolded, it measures about three feet by four feet (1 m by 1.3 m). Using materials purchased in bulk, the typical cost is about US$5. However, CooKits can also be made entirely from reclaimed materials, including used cardboard boxes and foil from the inside of cigarette boxes.

The CooKit is considered a low-to-moderate temperature solar cooker, easily reaching temperatures high enough to pasteurize water or cook grains such as rice. On a sunny day, one CooKit can collect enough solar energy to cook rice, meat or vegetables to feed a family with up to three or four children. Larger families use two or more cookers.

The HotPot cooking vessel consists of a dark pot suspended inside a clear pot with a lid

To use a panel cooker, it is folded into a bowl shape. Food is placed in a dark-colored pot, covered with a tightly fitted lid. The pot is placed in a clear plastic bag and tied, clipped, or folded shut. The panel cooker is placed in direct sunlight until the food is cooked, which usually requires several hours for a full family-sized meal. For faster cooking, the pot can be raised on sticks or wires to allow the heated air to circulate underneath it.

High-temperature plastic bags (oven roasting bags) can be re-used for more than a month, but any plastic bag will work, if measures (such as sticks or wires) are taken to keep the bag from touching the hot cooking pot and melting to it. The purpose of the plastic bag is to trap heated air next to the pot; it may not be needed on very bright, windless days.

A recent development is the HotPot developed by US NGO Solar Household Energy, Inc. The cooking vessel in this cooker is a large clear pot with a clear lid into which a dark pot is suspended. This design has the advantage of very even heating since the sun is able to shine onto the sides and the bottom of the pot during cooking. An added advantage is that the clear lid allows the food to be observed while it is cooking without removing the lid. The HotPot provides an alternative to using plastic bags in a panel cooker.

Solar tea kettle, Norbulingka, Tibet

Solar kettles

Solar kettles are solar thermal devices that can heat water to boiling point through the reliance on solar energy alone. Some of them use evacuated solar glass tube technology to capture, accumulate and store solar energy needed to power the kettle. Besides heating liquids, since the stagnating temperature of solar vacuum glass tubes is a high 220 °C (425 °F), solar kettles can also deliver dry heat and function as ovens and autoclaves. Moreover, since solar vacuum glass tubes work on accumulated rather than concentrated solar thermal energy, solar kettles only need diffused sunlight to work and needs no sun tracking at all. If solar kettles use solar vacuum tubes technologies, the vacuum insulating properties will keep previously heated water hot throughout the night e.g. the SK-TF.

Parabolic Solar Cooker

Cookers with parabolic reflectors

Scheffler cooker. The reflector has an area of 16 m², and produces 3 kW of heat.

Although these types of solar cookers can cook as well as a conventional oven, they are difficult to construct. Parabolic cookers reach high temperatures and cook quickly, but require frequent adjustment and supervision for safe operation. Several hundred thousand exist, mainly in China. They are especially useful for large-scale institutional cooking.

Parabolic reflectors that have their centres of mass coincident with their focal points are useful. They can be easily turned, to follow the sun's motions in the sky, rotating about an axis that passes through the focus. The cooking pot therefore stays stationary. If the paraboloid is axially symmetrical and is made of material of uniform thickness, this condition occurs if the depth of the paraboloid is 1.8478 times its focal length.

Using two parabolic troughs to simulate a paraboloid

It is possible to use two parabolic troughs, curved in perpendicular directions, to bring sunlight to a point focus as does a paraboloidal reflector. The incoming light strikes one of the troughs, which sends it toward a line focus. The second trough intercepts the converging light and focuses it to a point. A diagram that shows the principle is at:

Compared with a single paraboloid, using two partial troughs has important advantages. The troughs are "single curves", which can be made by bending a sheet of metal without any need for cutting, crumpling, or stretching. Also, the light that reaches the target - the cooking pot - is directed approximately downward, which reduces the danger of damage to the eyes of anyone nearby. On the other hand, there are disadvantages. More mirror material is needed, increasing the cost, and the light is reflected by two surfaces instead of one, which inevitably increases the amount that is lost.

Experimental arrangements of this kind have been made, and have worked well. The two troughs have been held in a fixed orientation relative to each other by being both fixed to a wooden frame, The whole assembly of frame and troughs has to be moved to track the sun as it moves in the sky.

However, this idea does not yet seem to have been tried in a practical cooker.

Cookers with spherical reflectors

The Solar Bowl is a unique concentrating technology used by the Solar Kitchen in Auroville, India. Unlike nearly all concentrating technologies that use tracking reflector systems, the solar bowl uses a stationary spherical reflector. This reflector focuses light along a line perpendicular to the sphere's surface and a computer control system moves the receiver to intersect this line. Steam is produced in the solar bowl's receiver at temperatures reaching 150 °C and then used for process heat in the kitchen where 2,000 meals are prepared daily.

Hybrid cookers

A hybrid solar oven is a solar box cooker equipped with a conventional electrical heating element for cloudy days or nighttime cooking. Hybrid solar ovens are therefore more independent. However, they lack the cost advantages of some other types of solar cookers, and so they have not caught on as much in third world countries where electricity or fuel sources simply do not exist.

A hybrid solar grill consists of an adjustable parabolic reflector suspended in a tripod with a movable grill surface. These outperform solar box cookers in temperature range and cooking times. When solar energy is not available, the design uses any conventional fuel as a heat source, including gas, electricity, or wood.

Using a solar cooker

Solar oven in use

The different kinds of solar cookers have somewhat different methods for use, but most follow the same basic principles.

Food is prepared as it would be for an oven or stove top. Because food cooks faster when it is in smaller pieces, solar cookers usually cut the food into smaller pieces than they might otherwise. For example, potatoes are usually cut into bite-sized pieces rather than being roasted whole. For very simple cooking, such as melting butter or cheese, a lid may not be needed and the food may be placed on an uncovered tray or in a bowl. If several foods are to be cooked separately, then they are placed in different containers.

The container of food is placed inside the solar cooker, perhaps elevated on a brick, rocks, metal trivet, or other heat sink, and the solar cooker is placed in direct sunlight. If the solar cooker is entirely in direct sunlight, then the shadow of the solar cooker will not overlap with the shadow of any nearby object. Foods that cook quickly may be added to the solar cooker later. Rice for a mid-day meal might be started early in the morning, with vegetables, cheese, or meat added to the solar cooker in the middle of the morning. Depending on the size of the solar cooker and the number and quantity of cooked foods, a family may use one or more solar cookers.

The solar cooker is turned towards the sun and left until the food is cooked. Unlike cooking on a stove or over a fire, which may require more than an hour of constant supervision, food in a solar cooker is generally not stirred or turned over, both because it is unnecessary and because opening the solar cooker allows the trapped heat to escape and thereby slows the cooking process. If wanted, the solar cooker may be checked every one to two hours, to turn the cooker to face the sun more precisely and to ensure that shadows from nearby buildings or plants have not blocked the sunlight. If the food will be left untended for many hours during the day, then the solar cooker is often turned to face the point where the sun will be when it is higher in the sky, instead of towards its current position.

The cooking time depends primarily on the equipment being used, the amount of sunlight at the time, and the quantity of food that needs to be cooked. Air temperature, wind, and latitude also affect performance. Food cooks faster in the two hours before and after the local solar noon than it does in either the early morning or the late afternoon. Larger quantities of food, and food in larger pieces, take longer to cook. As a result, only general figures can be given for cooking time. For a small solar panel cooker, it might be possible to melt butter in 15 minutes, to bake cookies in 2 hours, and to cook rice for four people in 4 hours. However, depending on the local conditions and the solar cooker type, these projects could take half as long, or twice as long.

It is difficult to burn food in a solar cooker. Food that has been cooked even an hour longer than necessary is usually indistinguishable from minimally cooked food. The exception to this rule is some green vegetables, which quickly change from a perfectly cooked bright green to olive drab, while still retaining the desirable texture.

For most foods, such as rice, the typical person would be unable to tell how it was cooked from looking at the final product. There are some differences, however: Bread and cakes brown on their tops instead of on bottom. Compared to cooking over a fire, the food does not have a smoky flavor.

Advantages

Solar ovens can be used to prepare anything that can be made in a conventional oven or stove — from baked bread to steamed vegetables to roasted meat. Since solar ovens are placed outside, they do not contribute unwanted heat inside houses. Nearly three-quarters of US households prepare at least one hot meal per day; one-third prepare two or more. Many of these meals could be made in a less fuel-intensive way using a solar oven, although people living in apartments or townhomes have little or no outside space to use a solar coooker.

The indoor concentration of health-damaging pollutants from a typical wood-fired cooking stove creates carbon monoxide and other noxious fumes at anywhere between seven and 500 times over the allowable limits.

Disadvantages

Solar cookers provide hot food during or shortly after the hottest part of the day, when people are less inclined to eat a hot meal. However, a thick pan that conducts heat slowly (such as Cast Iron) will lose heat at a slower rate, and that, combined with the insulation of the oven or an insulated basket, can be used to keep food warm well into the evening.

Solar cookers take longer time to cook food compared to an oven. Using a solar oven therefore requires that food preparation be started several hours before the meal. However, it requires less hands-on time cooking, so this is often considered a reasonable trade-off.

Solar cookers are less usable in cloudy or rainy weather, so some fuel-based backup heat source must still be available to cook food at these times.

Some solar cooker designs are affected by strong winds, which cool the food and can disturb the reflector.

Solar cooking projects

Students perform an experiment, using a solar cooker built out of an umbrella.

Bakeries in Lesotho

Michael Hönes of Germany has established solar cooking in Lesotho, enabling small groups of women to build up community bakeries using solar ovens.

Darfur refugee camps

Cardboard, aluminum foil, and plastic bags for well over 10,000 solar cookers have been donated to the Iridimi refugee camp and Touloum refugee camps in Chad by the combined efforts of the Jewish World Watch, the Dutch foundation KoZon, and Solar Cookers International. The refugees construct the cookers themselves, using the donated supplies and locally purchased Arabic gum, and use them for midday and evening meals. The goal of this project was to reduce the Darfuri women's need to leave the relative safety of the camp to gather firewood, which exposed them to a high risk of being beaten, raped, kidnapped, or murdered. It has also significantly reduced the amount of time women spend tending open fires each day, with the results that they are healthier and they have more time to grow vegetables for their families and make handicrafts for export. By

2007, the Jewish World Watch had trained 4,500 women, and had provided 10,000 solar cookers to refugees. The project has also reduced the number of foraging trips by as much as 70 percent, thus reducing the number of attacks.

Indian solar cooker village

Bysanivaripalle, a silk-producing village that is 125 km (80 mi) northwest of Tirupati in the Indian state of in Andhra Pradesh, is the first of its kind: an entire village that uses only solar cooking. Intersol, an Austrian non-governmental organisation, sponsored the provision of powerful "Sk-14" parabolic solar cookers in 2004.

Gaza

Some Gazans have started to make solar cookers in order to cook their meals, due to a lack of cooking fuels. The cooker is made from cement bricks, mud mixed with straw and two sheets of glass. About 40 to 45 Palestinian households are said to have started using these solar cookers.

2.Hot plate

A **hot plate** is a portable self-contained tabletop small appliance that features one, two or more gas burners or electric heating elements. A hot plate can be used as a stand alone appliance, but is often used as a substitute for one of the burners from an oven range or the cook top of a stove. Hot plates are often used in food preparation, generally in locations where a full kitchen stove would not be convenient or practical. Because a hot plate is easily moved from one location to another, care must always be used to ensure that there is sufficient clearance between the appliance location and combustible materials. In addition, a hot plate should not be located in a place where the heat control of the appliance would be accessible to children and others unfamiliar with its operation.

In scientific research

This laboratory hot plate with magnetic stirrer is used for preparing chemicals used in scientific research.

In laboratory settings, hot plates are generally used to heat glassware or its contents. Some hotplates also contain a magnetic stirrer, allowing the heated liquid to be stirred automatically.

Advantages

This type of cooking equipment is typically powered by electricity, however, gas fired hot plates were not uncommon in the 19th and 20th century and are still available in various markets around the world. Hot plates can be environmentally responsible, if the heat generated from them comes from renewable resources. In addition, the low cost of hot plates (usually little more than €20 for a 1,000W plate) allows them to be used in the developing world or by those who are frugal or have a limited budget. As such, hot plates can be considered an appropriate technology.

3. Rocket stove

Rocket stove with oven

A **rocket stove/Rocket mass heater** is a type of stove combining the air-intake with the fuel-feed slot in an opening terminated by the combustion chamber, further leading to a chimney and heat exchanger. A rocket stove is signified by ease of construction and simplicity of building materials while accepting small-diameter fuel such as twigs or small branches, yielding high combustion efficiency and directing the resultant heat onto a small area.

Overview

A small manufactured rocket cooking stove

A rocket stove achieves efficient combustion of the fuel at a high temperature by ensuring that there is a good air draft into the fire, controlled use of fuel, complete combustion of volatiles, and efficient use of the resultant heat. It has been used for cooking purposes in many third-world locales (notably Rwandan refugee camps) as well as for space and water heating.

A rocket stove's main components are:

- Fuel magazine: Into which the unburned fuel is placed and from where it feeds into the combustion chamber
- Combustion chamber: At the end of the fuel magazine where the wood is burned
- Chimney: A vertical chimney above the combustion chamber to provide the updraft needed to maintain the fire
- Heat exchanger: To transfer the heat to where it is needed, ie the cooking pot.

The fuel magazine can be horizontal where additional fuel will be added manually or vertically for automatic feeding of fuel. As the fuel burns within the combustion chamber convection draws new air into the combustion chamber from below ensuring that any smoke from smoldering wood near to the fire is also drawn into the fire and up the chimney. The chimney should be insulated to maximize the temperature and improve combustion. From the chimney the heat passed into a suitable heat exchanger to ensure the efficient use of the generated heat.

For cooking purposes the design keeps the cooking vessel in contact with the fire over the largest possible surface area by use of a pot skirt to create a narrow channel which forces hot air and gas to flow along the bottom and sides of the cooking vessel. Optionally baffles guide hot air and flame up the sides of the pot. For space heating purposes the heat is transferred to a heat store which can in some cases be part of the structure of the house itself. The exhaust gasses then pass out of the building via the chimney.

The design of stove means that it can operate on about half as much fuel as a traditional open fire and can use smaller diameter wood. They are insulated and raised from the floor which reduces the danger of children burning themselves. Some more recent designs use are self feeding using gravity to add fuel to the fire as required.

History

Dr. Larry Winiarski, now Technical Director of Aprovecho, began developing the Rocket Stove in 1980 and invented the principles of the Rocket stove in 1982. TWP and AHDESA were winners at the Ashden Awards for Sustainable Energy in 2005 in the 'Health and Welfare' category for their work in Honduras with the 'Justa Stove' which is based on principles of the rocket stove. Aprovecho were winners of the Special Africa Award at the Ashden Awards in 2006 for their work with rocket stoves for institutional cooking in Lesotho, Malawi, Uganda, Mozambique, Tanzania and Zambia.

Types of stove

attached to a heat exchanger to heat water

Cooking stove

The rocket stove was originally developed for cooking purposes where a relatively small amount of heat is required on a continuous basis which is applied to the bottom and sometimes also the sides of the cooking pot. Stoves can be constructed from brick, old tin cans, steel or be purchased.

Rocket Stoves are found more commonly in the third world countries where wood fuel sources are more scarce but it has been introduced in the United States in the recent years. Some of them are small for portability with insulation inside a double-walled design with a chamber for partial biomass gasification and additional mixing to increase BTUs and provide a cleaner, more complete burn. The advantage of these rocket stoves is the very little fuel they need, such as wood and dry weeds, to be able to cook a whole meal with it, keeping the air more clean with less hydrocarbons.

Space heater

For space heating the aim is normally to use the rocket stove to heat a mass of material which will hold the heat and slowly release it. The chimney is sometimes developed as a horizontal heat exchanger to distribute heat around a building before the exhaust gasses are released outside.

Water heater

Rocket stoves can be used to heat water via a heat exchanger which transfers heat to a body of water in a nearby container.

Chapter 7

Solar Water Disinfection and Ultrafiltration

Solar water disinfection

SODIS application in Indonesia

Solar water disinfection, also known as **SODIS** is a method of disinfecting water using only sunlight and plastic PET bottles. SODIS is a free and effective method for decentralized water treatment, usually applied at the household level and is recommended by the World Health Organization as a viable method for household water treatment and safe storage. SODIS is already applied in numerous developing countries. Educational pamphlets on the method are available in many languages.

Principle

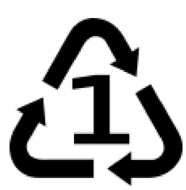
Exposure to sunlight has been shown to deactivate diarrhea-causing organisms in polluted drinking water. Three effects of solar radiation are believed to contribute to the inactivation of pathogenic organisms:

- UV-A interferes directly with the metabolism and destroys cell structures of bacteria.
- UV-A (wavelength 320-400 nm) reacts with oxygen dissolved in the water and produces highly reactive forms of oxygen (oxygen free radicals and hydrogen peroxides), that are believed to also damage pathogens.
- Cumulative solar energy (including the infrared radiation component) heats the water. If the water temperatures rises above 50°C, the disinfection process is three times faster.

At a water temperature of about 30°C (86°F), a threshold solar radiation intensity of at least 500 W/m^2 (all spectral light) is required for about 5 hours for SODIS to be efficient. This dose contains energy of 555 Wh/m^2 in the range of UV-A and violet light, 350 nm-450 nm, corresponding to about 6 hours of mid-latitude (European) midday summer sunshine.

At water temperatures higher than 45°C (113°F), synergistic effects of UV radiation and temperature further enhance the disinfection efficiency.

Process for household application



PET recycling mark

- Colourless, transparent PET water or pop bottles (2 litre or smaller size) with few surface scratches are chosen for use. The labels are removed and the bottles are washed before the first use.
- Water from contaminated sources are filled into the bottles. To improve oxygen saturation, bottles can be filled three quarters, shaken for 20 seconds (with the cap on), then filled completely and recapped. Very cloudy water with a turbidity higher than 30 NTU must be filtered prior to exposure to the sunlight.
- Filled bottles are then exposed to the sun. Bottles will heat faster and to higher temperatures if they are placed on a sloped sun-facing corrugated metal roof as compared to thatched roofs.
- The treated water can be consumed directly from the bottle or poured into clean drinking cups. The risk of re-contamination is minimized if the water is stored in the bottles. Refilling and storage in other containers increases the risk of contamination.

Suggested Treatment Schedule

Weather Conditions	**Minimum Treatment Duration**
sunny	6 hours
50% cloudy	6 hours
50-100% cloudy	2 days
continuous rainfall	unsatisfactory performance, use rainwater harvesting

Applications

SODIS is an effective method for treating water where fuel or cookers are unavailable or prohibitively expensive. Even where fuel is available, SODIS is a more economical and environmentally friendly option. The application of SODIS is limited if enough bottles are not available, or if the water is highly turbid.In fact, if the water is highly turbid, SODIS can not be used alone, additional filtering is then necessary.

In theory, the method could be used in disaster relief or refugee camps. However, supplying bottles may be more difficult than providing equivalent disinfecting tablets containing chlorine, bromine, or iodine. Additionally, in some circumstances, it may be difficult to guarantee that the water will be left in the sun for the necessary time.

Other methods for household water treatment and safe storage exist, e.g. chlorination, different filtration procedures or flocculation/disinfection. The selection of the adequate method should be based on the criteria of effectiveness, the co-occurrence of other types of pollution (turbidity, chemical pollutants), treatment costs, labor input and convenience, and the user’s preference.

Cautions

If the water bottles are not left in the sun for the proper length of time, the water may not be safe to drink and could cause illness. If the sunlight is less strong, due to overcast weather or a less sunny climate, a longer exposure time in the sun is necessary.

The following issues should also be considered:

- **Bottle material:** Some glass or PVC materials may prevent ultraviolet light from reaching the water. Commercially available bottles made of PET are recommended. The handling is much more convenient in the case of PET bottles. Polycarbonate blocks all UVA and UVB rays, and therefore should not be used.

- **Aging of plastic bottles:** SODIS efficiency depends on the physical condition of the plastic bottles, with scratches and other signs of wear reducing the efficiency of SODIS. Heavily scratched or old, blind bottles should be replaced.

- **Shape of containers:** the intensity of the UV radiation decreases rapidly with increasing water depth. At a water depth of 10 cm (4 inches) and moderate turbidity of 26 NTU, UV-A radiation is reduced to 50%. PET soft drink bottles are often easily available and thus most practical for the SODIS application.

- **Oxygen**: Sunlight produces highly reactive forms of oxygen (oxygen free radicals and hydrogen peroxides) in the water. These reactive molecules contribute in the destruction process of the microorganisms. Under normal conditions (rivers, creeks, wells, ponds, tap) water contains sufficient oxygen (more than 3 mg Oxygen per litre) and does not have to be aerated before the application of SODIS.

- **Leaching of bottle material:** There has been some concern over the question whether plastic drinking containers can release chemicals or toxic components into water, a process possibly accelerated by heat. The Swiss Federal Laboratories for Materials Testing and Research have examined the diffusion of adipates and phthalates (DEHA and DEHP) from new and reused PET-bottles in the water during solar exposure. The levels of concentrations found in the water after a solar exposure of 17 hours in 60°C water were far below WHO guidelines for drinking water and in the same magnitude as the concentrations of phthalate and adipate generally found in high quality tap water.
  Concerns about the general use of PET-bottles were also expressed after a report published by researchers from the University of Heidelberg on antimony being released from PET-bottles for soft drinks and mineral water stored over several months in supermarkets. However, the antimony concentrations found in the bottles are orders of magnitude below WHO and national guidelines for antimony concentrations in drinking water. Furthermore, SODIS water is not stored over such extended periods in the bottles.

- **Regrowth of bacteria**: Once removed from sunlight, remaining bacteria may again reproduce in the dark. A 2010 study showed that adding just 10 parts per million of hydrogen peroxide were effective in preventing the regrowth of wild Salmonella.

Health impact, diarrhea reduction

Only forty-six percent of people in Africa have safe drinking water.

It has been shown that the SODIS method (and other methods of household water treatment) can very effectively remove pathogenic contamination from the water. However, infectious diseases are also transmitted through other pathways, i.e. due to a general lack of sanitation and hygiene. Studies on the reduction of diarrhea among SODIS users show reduction values of 30-80%.

Research and development

The effectiveness of the SODIS was first discovered by Professor Aftim Acra at the American University of Beirut in the early 1980s. Substantial follow-up research was conducted by the research groups of Martin Wegelin at the Swiss Federal Institute of Aquatic Science and Technology (Eawag) and Dr Kevin McGuigan at the Royal College of Surgeons in Ireland. Clinical control trials were pioneered by Professor Ronan Conroy of the RCSI team in collaboration with Michael Elmore-Meegan.

Currently, a joint research project on SODIS is implemented by the following institutions:

- Royal College of Surgeons in Ireland (RCSI), Ireland (coordination)
- University of Ulster (UU), United Kingdom
- CSIR Environmentek, South Africa, Eawag, Switzerland
- The Institute of Water and Sanitation Development (IWSD), Zimbabwe
- Plataforma Solar de Almería (CIEMAT-PSA), Spain
- University of Leicester (UL), United Kingdom
- The International Commission for the Relief of Suffering & Starvation (ICROSS), Kenya
- University of Santiago de Compostela (USC), Spain
- Swiss Federal Institute of Aquatic Science and Technology (Eawag), Switzerland

The project has embarked on a multi-country study including study areas in Zimbabwe, South Africa and Kenya.

Other developments include the development of a continuous flow disinfection unit and solar disinfection with titanium dioxide film over glass cylinders which prevents the bacterial regrowth of coliforms after SODIS. Research has shown that a number of low-cost additives are capable of accelerating SODIS and that additives might make SODIS more rapid and effective in both sunny and cloudy weather, developments that could help make the technology more effective and acceptable to users. Another study showed that natural coagulants (seeds of five natural legumes (peas, beans and lentils) – *Vigna unguiculata*, *Phaseolus mungo*, *Glycine max*, *Pisum sativum*, and *Arachis hypogaea* – were evaluated for the removal of turbidity), were as effective as commercial alum and even superior for clarification because the optimum dosage was low.

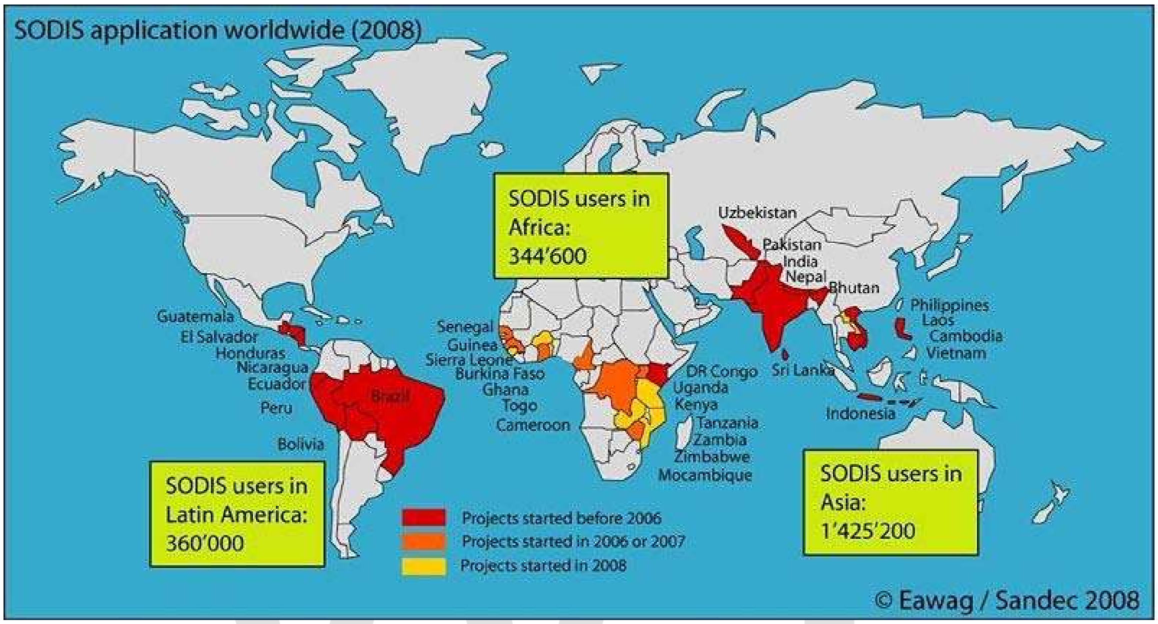
Issues to consider

The following are some of the issues discussed in the literature:

- Applicability is mostly in communities that have significant incidence or risk of water-borne diseases.
- Local education in the use of SODIS is important to avoid confusion between PET and other bottle materials.
- Applying SODIS without proper assessment (or with false assessment) of existing hygienic practices & diarrhea incidence may not address other routes of infection. Community trainers need to themselves be trained first.
- When the water is highly turbid, SODIS can not be used alone, additional filtering is then necessary.

- Although safe and effective, the SODIS system is not as convenient as turning a tap, so it is unlikely to be widely adopted in developed countries with more expensive water treatment infrastructure.

Worldwide application



Worldwide application of SODIS in projects coordinated by Eawag

The Swiss Federal Institute of Aquatic Science and Technology (Eawag), through the Department of Water and Sanitation in Developing Countries (Sandec), coordinates SODIS promotion projects in 33 countries including Bhutan, Bolivia, Burkina Faso, Cambodia, Cameroon, DR Congo, Ecuador, El Salvador, Ethiopia, Ghana, Guatemala, Guinea, Honduras, India, Indonesia, Kenya, Laos, Malawi, Mozambique, Nepal, Nicaragua, Pakistan, Perú, Philippines, Senegal, Sierra Leone, Sri Lanka, Togo, Uganda, Uzbekistan, Vietnam, Zambia, and Zimbabwe. Contact addresses and case studies of the projects coordinated by the Swiss Federal Institute of Aquatic Science and Technology (Eawag) are available at sodis.ch.

SODIS projects are funded by, among others, the SOLAQUA Foundation (), several Lions Clubs, Rotary Clubs, Migros, and the Michel Comte Water Foundation.

SODIS has also been applied in several communities in Brazil, one of them being Prainha do Canto Verde north of Fortaleza. There, the villagers have been purifying their water with the SODIS method. It is quite successful, especially since the temperature during the day can go beyond 40°C (100°F) and there is a limited amount of shade.

Ultrafiltration

Ultrafiltration (**UF**) is a variety of membrane filtration in which hydrostatic pressure forces a liquid against a semipermeable membrane. Suspended solids and solutes of high molecular weight are retained, while water and low molecular weight solutes pass through the membrane. This separation process is used in industry and research for purifying and concentrating macromolecular (10^3 - 10^6 Da) solutions, especially protein solutions. Ultrafiltration is not fundamentally different from microfiltration, nanofiltration or gas separation, except in terms of the size of the molecules it retains. Ultrafiltration is applied in cross-flow or dead-end mode and separation in ultrafiltration undergoes concentration polarization.

The Process

Ultrafiltration systems eliminate the need for clarifiers and multimedia filters for waste streams to meet critical discharge criteria or to be further processed by wastewater recovery systems for water recovery. Efficient ultrafiltration systems utilize membranes which can be submerged, back-flushable, air scoured, spiral wound UF/MF membrane that offers superior performance for the clarification of wastewater and process water.

Membrane Geometries

Spiral wound module:
Consists of large consecutive layers of membrane and support material rolled up around a tube. Maximizes surface area.
Less expensive, however, more sensitive to pollution.
Tubular membrane:
The feed solution flows through the membrane core and the permeate is collected in the tubular housing.
Generally used for viscous or bad quality fluids.
System is not very compact and has a high cost per m2 installed
Hollow fiber membrane:
The modules contain several small (0.6 to 2 mm diameter) tubes or fibers.
The feed solution flows through the open cores of the fibers and the permeate is collected in the cartridge area surrounding the fibers.
The filtration can be carried out either “inside-out” or “outside-in”

Ultrafiltration Module Configurations

Pressurized system or pressure-vessel configuration:
TMP (transmembrane pressure) is generated in the feed by a pump, while the permeate stays at atmospheric pressure.
Pressure-vessels are generally standardized, allowing the design of membrane systems to proceed independently of the characteristics of specific membrane elements.

Immersed system:
Membranes are suspended in basins containing the feed and open to the atmosphere. Pressure on the influent side is limited to the pressure provided by the feed column. TMP is generated by a pump that develops suction on the permeate side.
Ultrafiltration, like other filtration methods can be run as a continuous or batch process