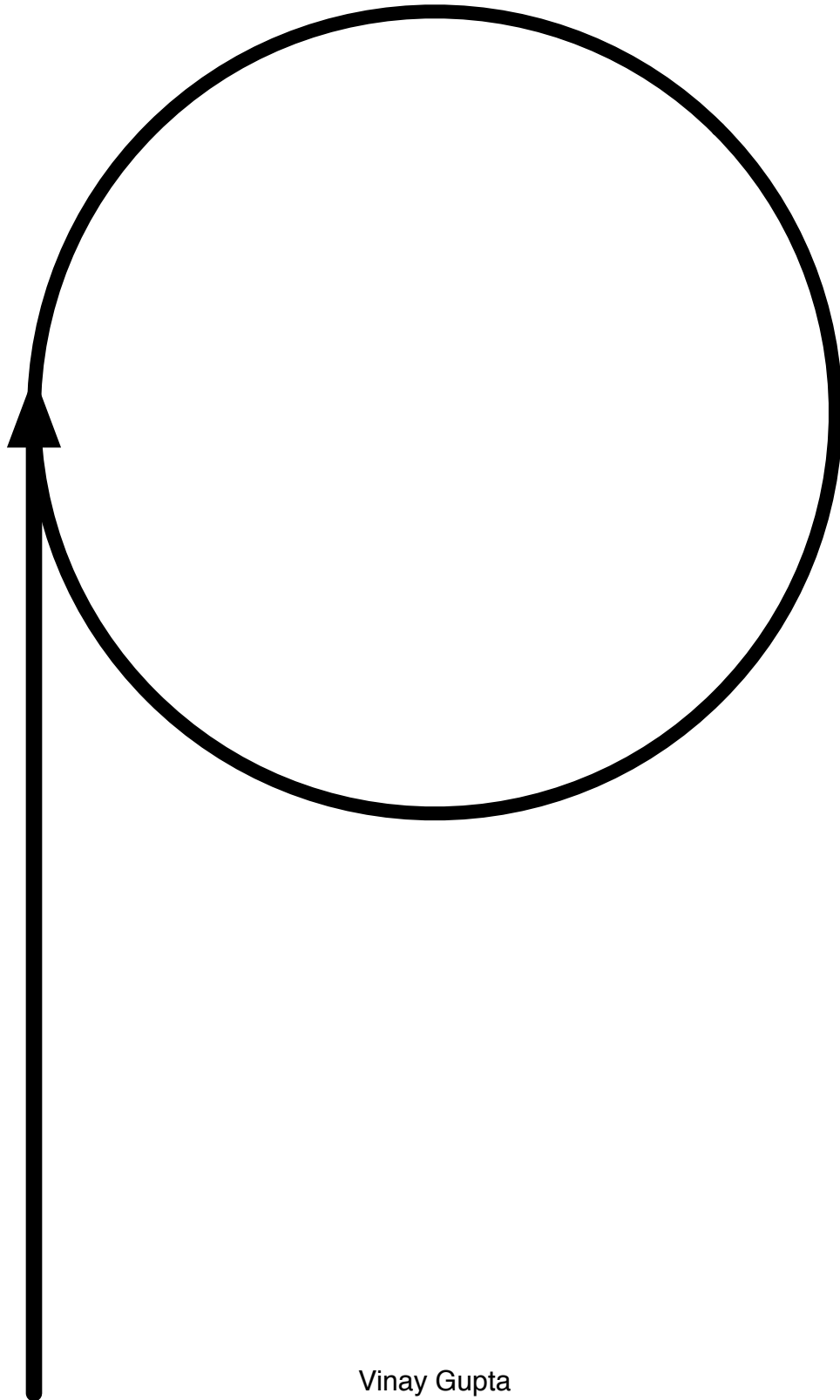


The Physical Aspects of Distributed Infrastructure Design for the Developing World



Vinay Gupta
hexayurt@gmail.com

1. Axiomatic Framework

The primary function of a building is to maintain the body temperature of the people inside at a safe and comfortable level.

Building utilities extend the comfort range and range of activities the inhabitants can perform, like reading at night.

Effectively using the energy gradients given to us by nature can require additional energy in different forms (electricity) or additional functions (insulation.)

Outside of Victorian England (plentiful water, generally cold) infrastructure can look radically different.

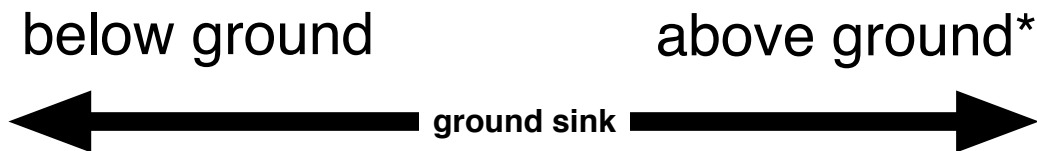
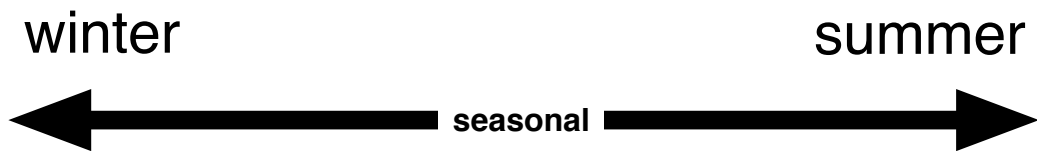
One model: "could a 17th century American with Solar Panels have lived this way?"

Remember, too, this is intended as an upgrade for farmers who intend to stay on their land, and perhaps some slum dwellers.

What is the minimum-cost alternative to the systems presented below?

A **ton** of prototyping and computer modeling of climates and machineries is going to be required to prove this out.

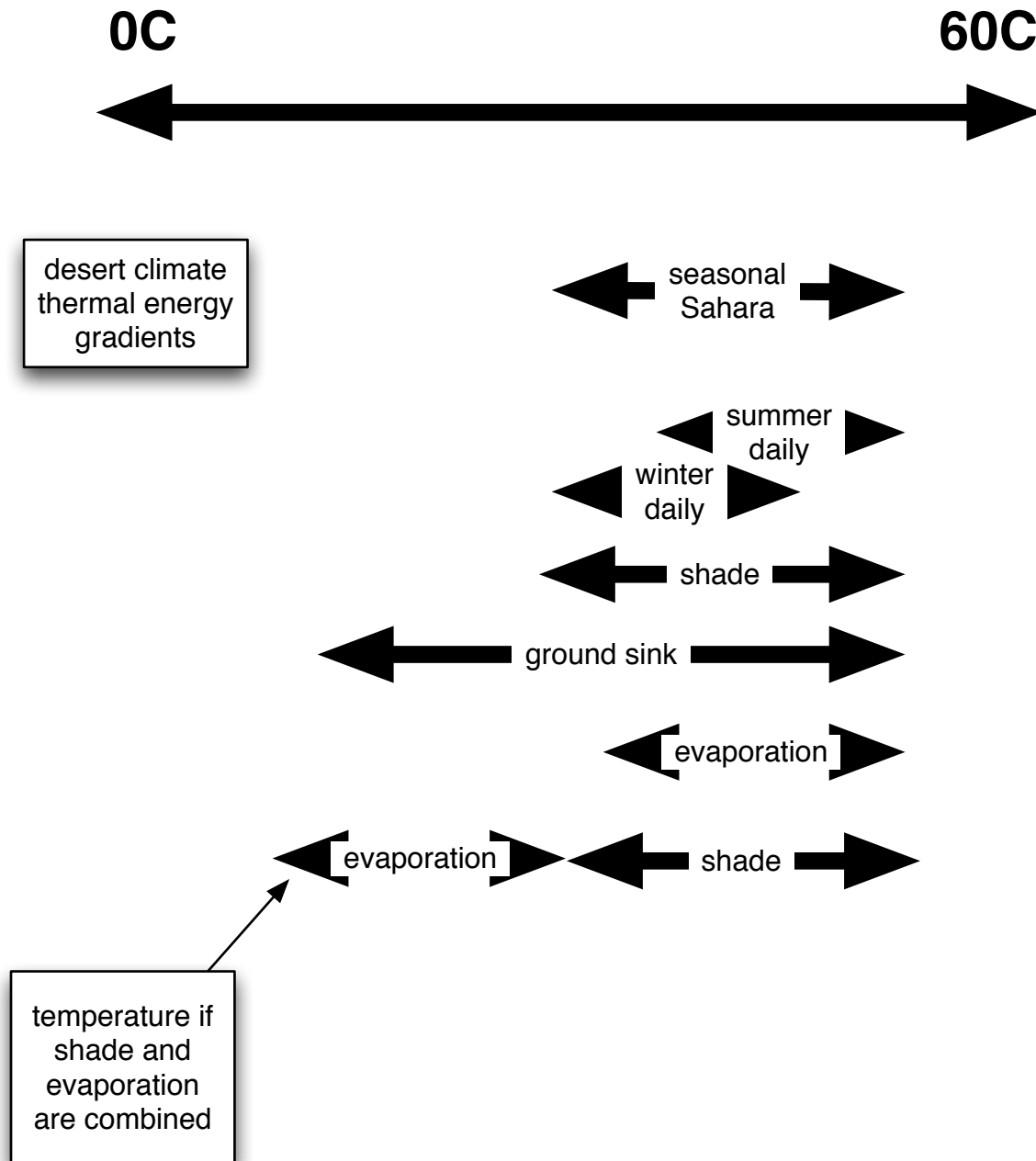
A. Thermal Energy Gradients



* except in very cold places, where these should be reversed

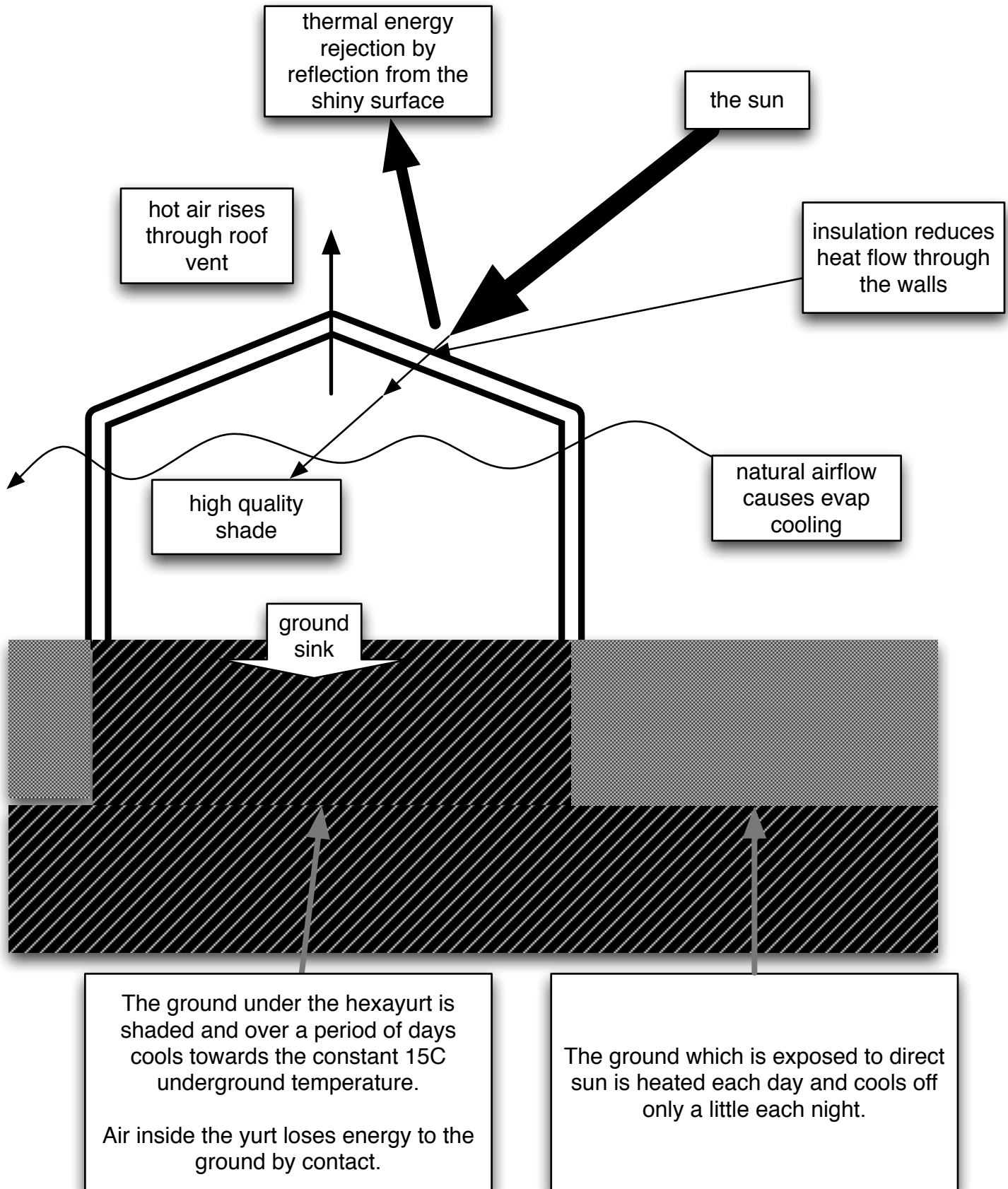


Scaled Thermal Energy Gradients



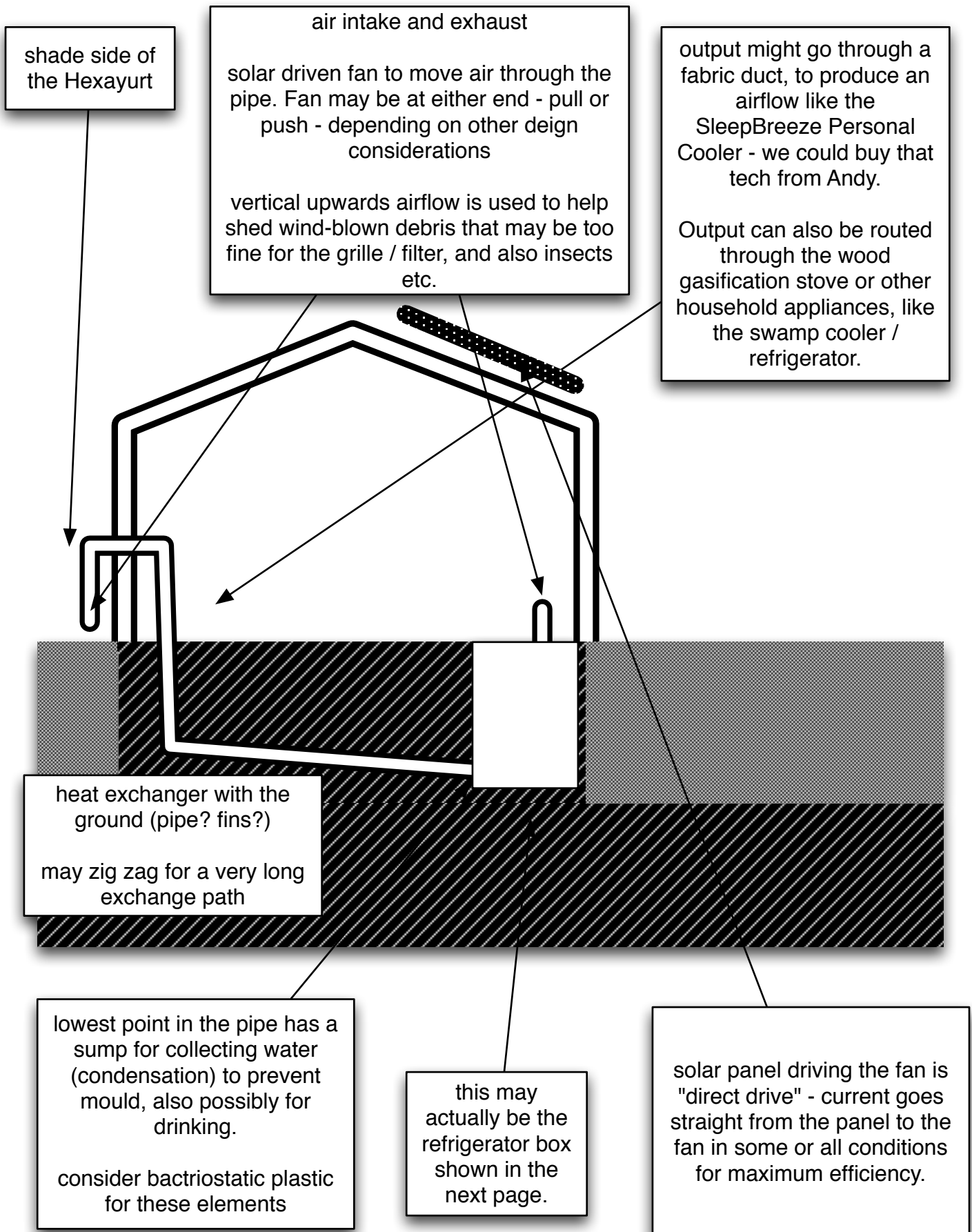
Without massive energy inputs, the only thermal performance control we have over buildings is these five natural gradients.

Explaining The Hexayurt - hot, dry climates

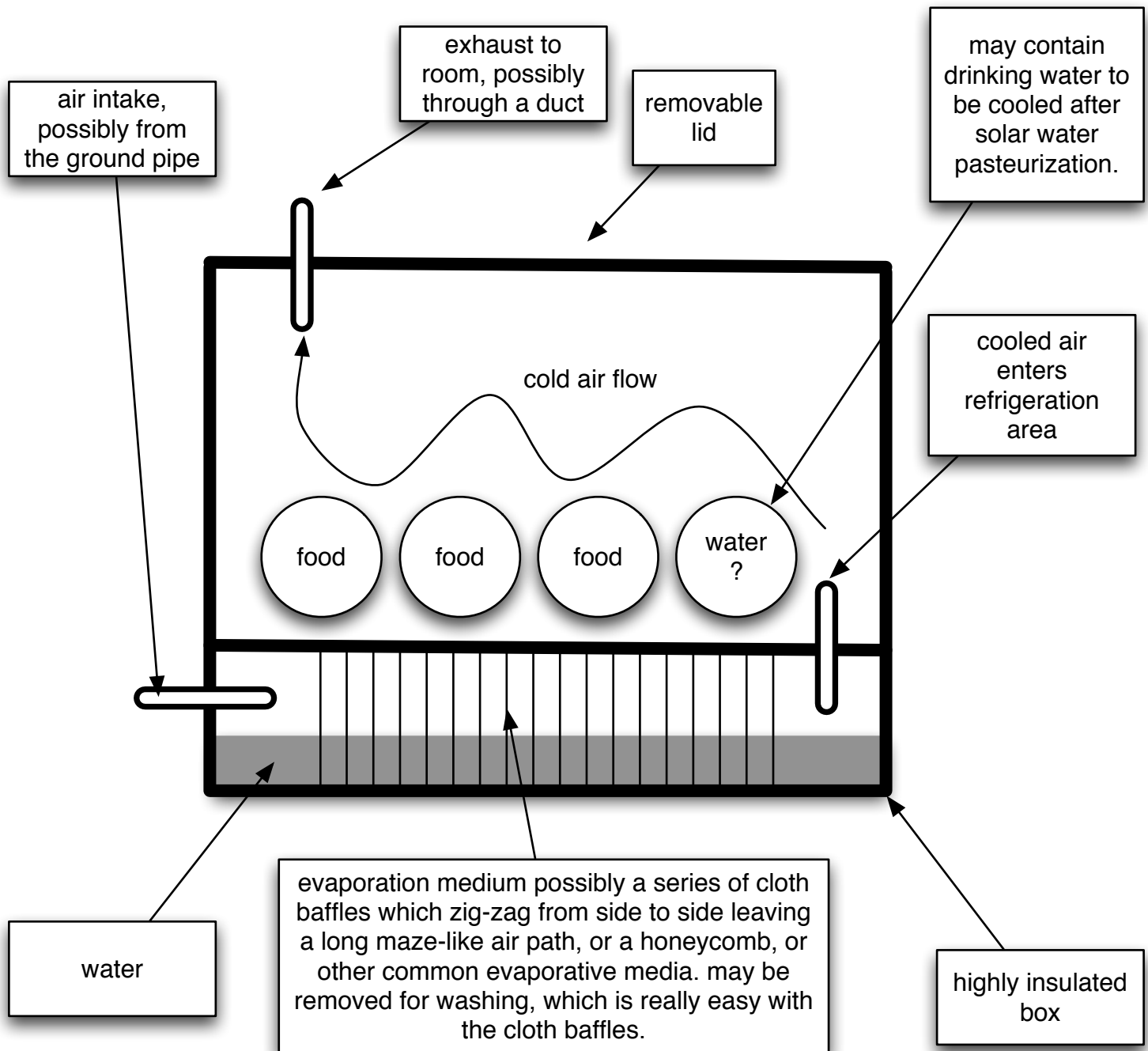


**Result - 10C cooler inside than outside
on dry bulb tests**

Enhancing the ground sink



Integrated refrigerator and evaporative cooler aka cold side utilities box



interior of the box may contain various shelves and similar typical refrigerator paraphernalia.

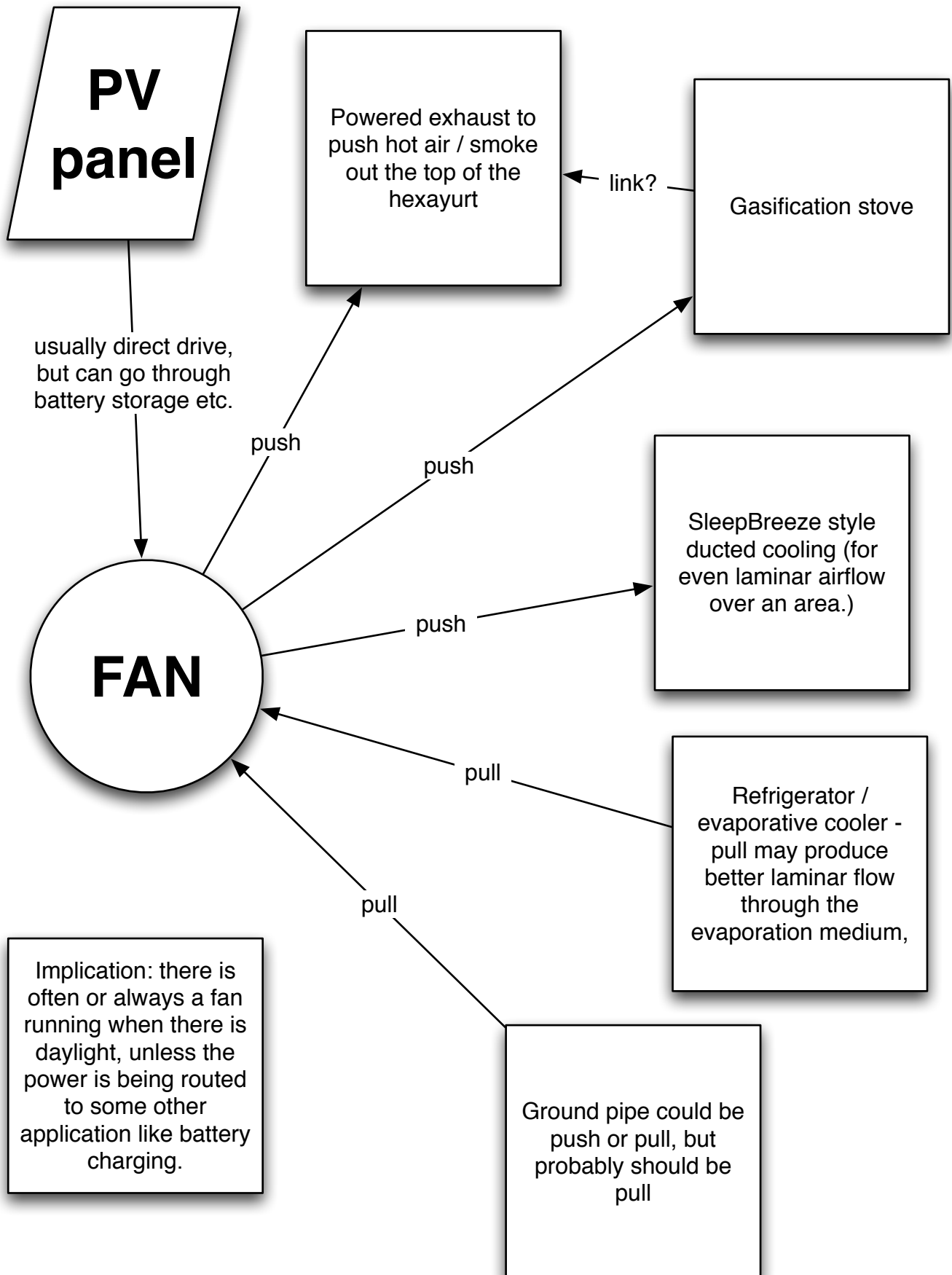
airflow through the food may be enhanced by additional spacers, grilles and similar apparatus

nozzles for pouring in additional cooling water are not shown

device may be buried in the ground so that the water reservoir of the refrigerator / cooler is actually the lowest point in the ground pipe. the cooler should come last in the flow so that air is already cooled by the time it hits the fridge box.

bacteriostatic plastics may apply throughout. additional sterilization measures may be used such as UV light, silver ions in the water, or other approaches common in the field.

Fan backbone



Lighting - optical considerations

eye science

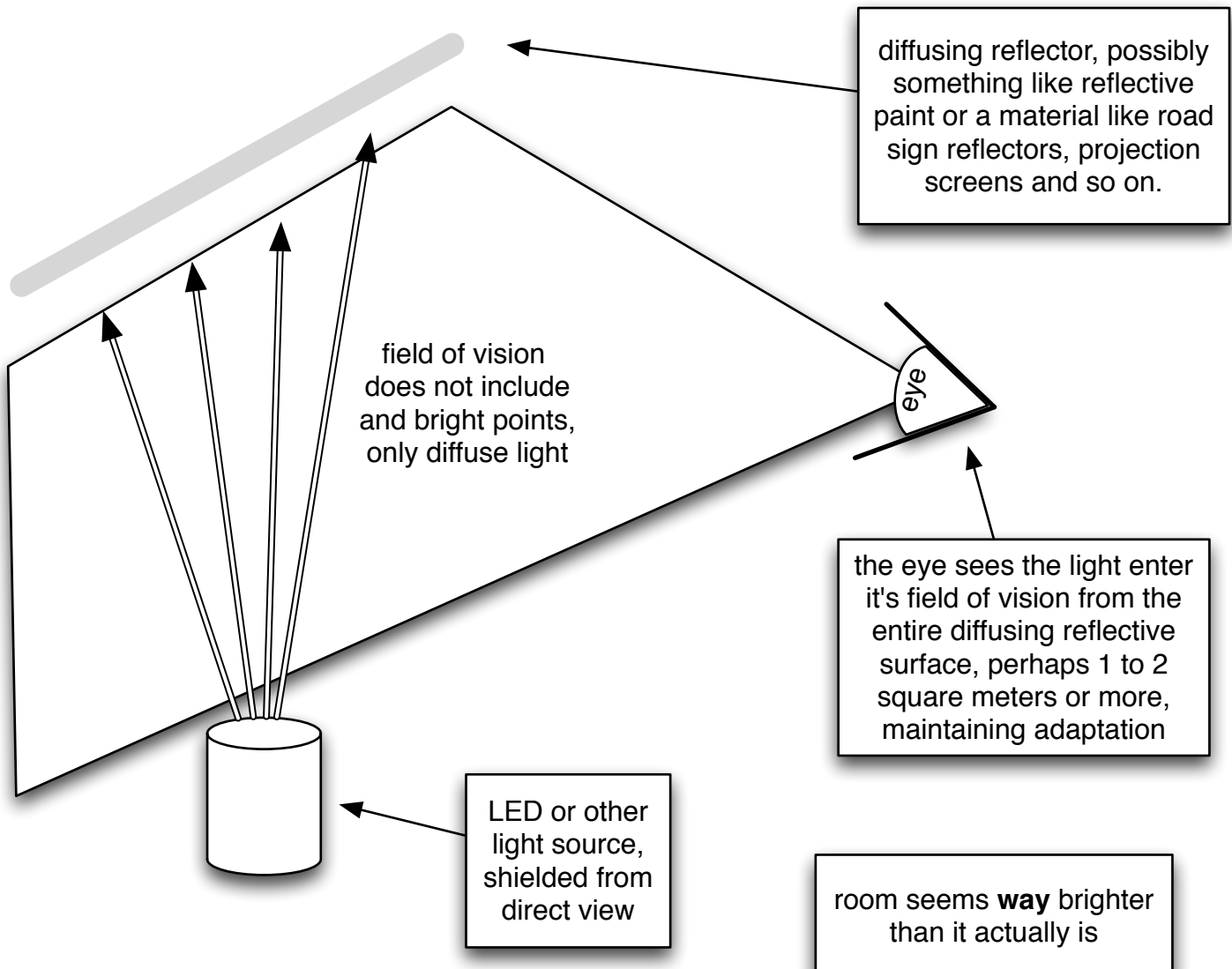
human eye is sensitive over something like six orders of magnitude variation in lighting conditions

brightest object in your field of vision drives how much your pupil dilates / contracts and how sensitive your vision is to light

therefore the gap between the brightest and dimmest object in the room should be minimized, to preserve eye sensitivity and make the room feel brighter

lighting designs

key concept: spread the light emitting area out as much as possible, while not losing efficiency.

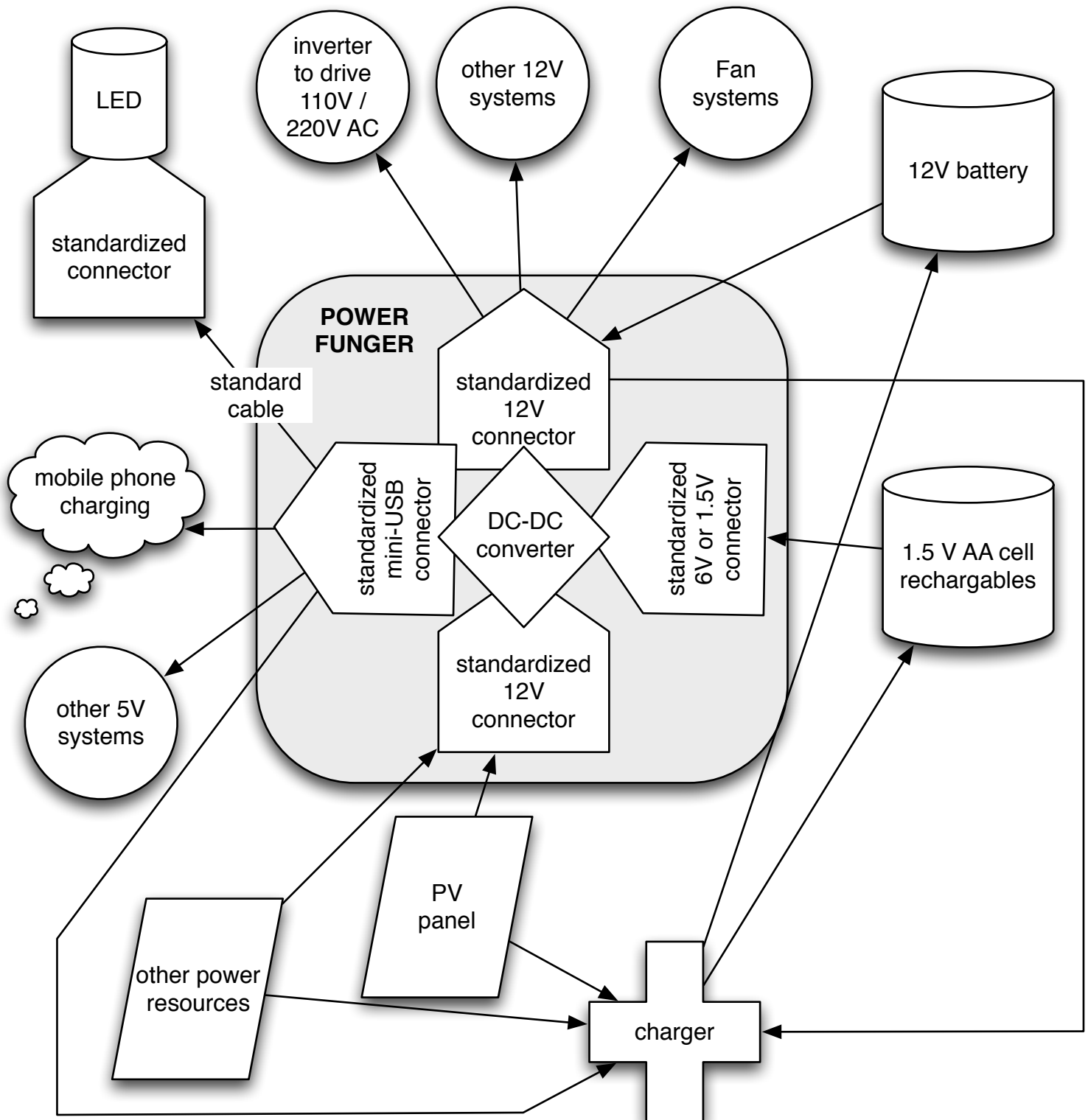


Electrical Considerations

CFLs and CCFLs (cold-cathode fluorescents) are brighter watt-for-watt than many LEDs.

however, intelligent light distribution removes the need for very bright sources - the optical elements compensate

therefore, a small-but-efficient lightsource, such as a CREE LED, is enough for each room



Power Fungus?

The "Power Fungus" is a small box which contains DC/DC converters aka voltage regulators

It likely produces power in two formats: 12V and USB (5V).

Other voltages - 9V and 3V, 6V and 24V may be produced by more complex fungers.

The Fungus (technical term) adds *fungibility* to power resources, driving whatever you need with whatever you have.

Think of it as a power hub - you plug it into your devices, then you plug it into power, and it works.

Batteries with a fungus don't gradually dim your lights as they die - power output is constant.

Furthermore, the fungus protects batteries from undercharge - **critical to long lifespan!**

Think of it as a power hub - you plug it into your devices, then you plug it into power, and it works.

The fungus provides constant high quality of service from questionable inputs.

Charger/s?

High tech charge controllers are no joke - hard to do cheaply

but without them, fast charge can rapidly erode battery capacity

options: only slow charge, which generally implies a solar panel or similar per house

or fast charge with associated circuitry at a centralized location where the cost is amortized

one other worthwhile option is getting serious about cooling batteries during charging

perhaps using a heat pipe or other large heat sink in the ground or in water to cool batteries during charging

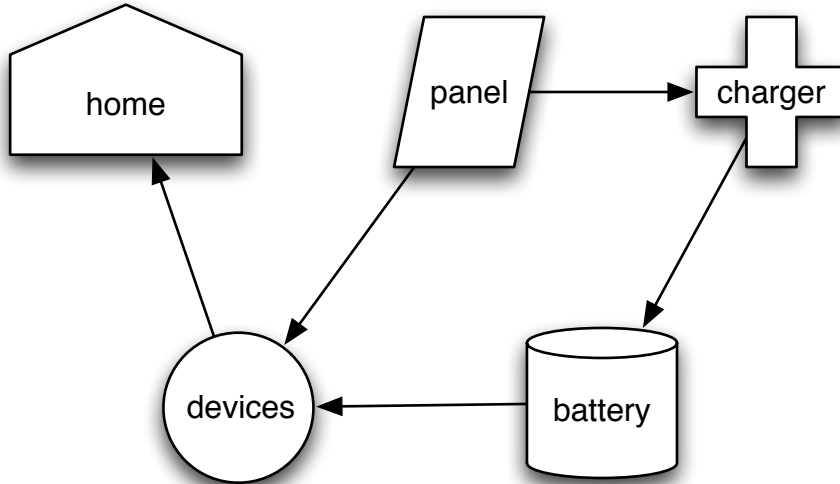
perhaps households slow-charge 1.5V batteries routinely and operate a different scheme for 12V units

a power fungus breaks the 1:1 link between batteries and devices, permitting asynchronous device upgrades

you add new batteries, or new devices, but you don't have to upgrade either one when you change the other

Household and Village Electrical Services Architectures

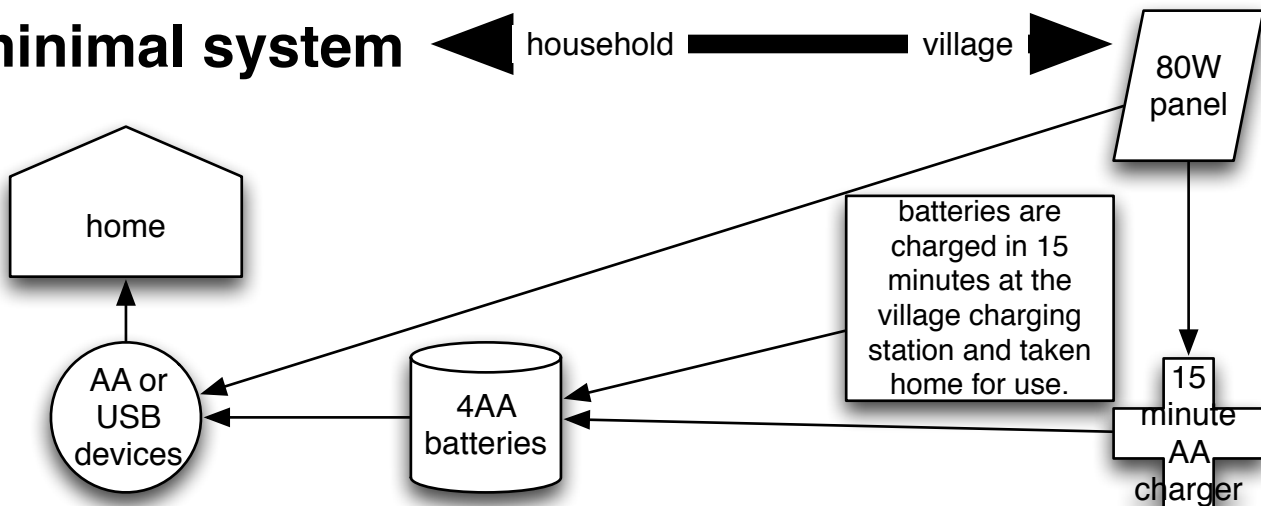
abstract system



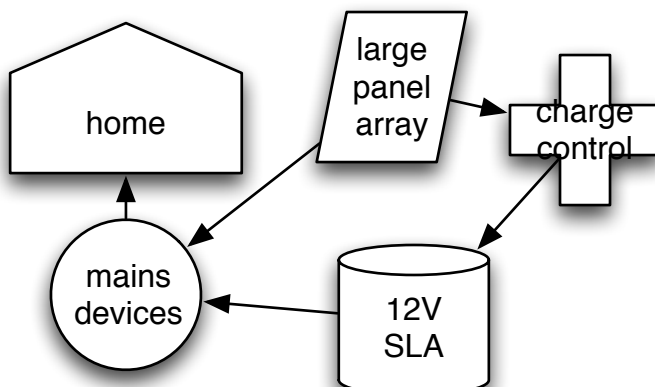
Question: in a real system,
which elements are shared,
which are configured how?

This is a multi-variate problem.

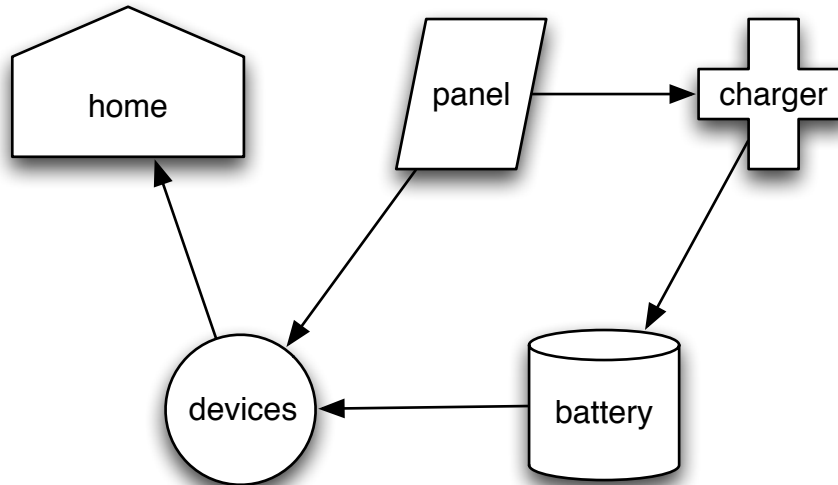
minimal system



wealthy off-the-grid system



Whole Systems Optimization of Small Electrical Resources



Each of these abstract systems has multiple instantiations - panels, small wind big wind, different batteries.

The power funder helps bridge the gap between devices and the power resources, but does not solve the supply problem

what's needed is a whole systems model of power draw per appliance and relative device performance

the idea is to have a spreadsheet or application that multiplies out all factors

including day length, seasonal light and wind variability, power demand across the day and so on

to rapidly and effectively model these micropower installations (up to, say, 50AH of storage.)

this is a simple "infrastructure design aid" and represents a class of software which is not currently available

at least at the modeling level of a single household in a village, and it can be extended to water and sewage too

one input is technological acceleration, so one can define at what point it is economic to do X, Y or Z

extensions to this system can also optimize land use for calories or other factors

including input from precision agriculture systems and historical cultivation records

to produce an integrated "six ways to die" modeling package - including epidemiology and local healthcare

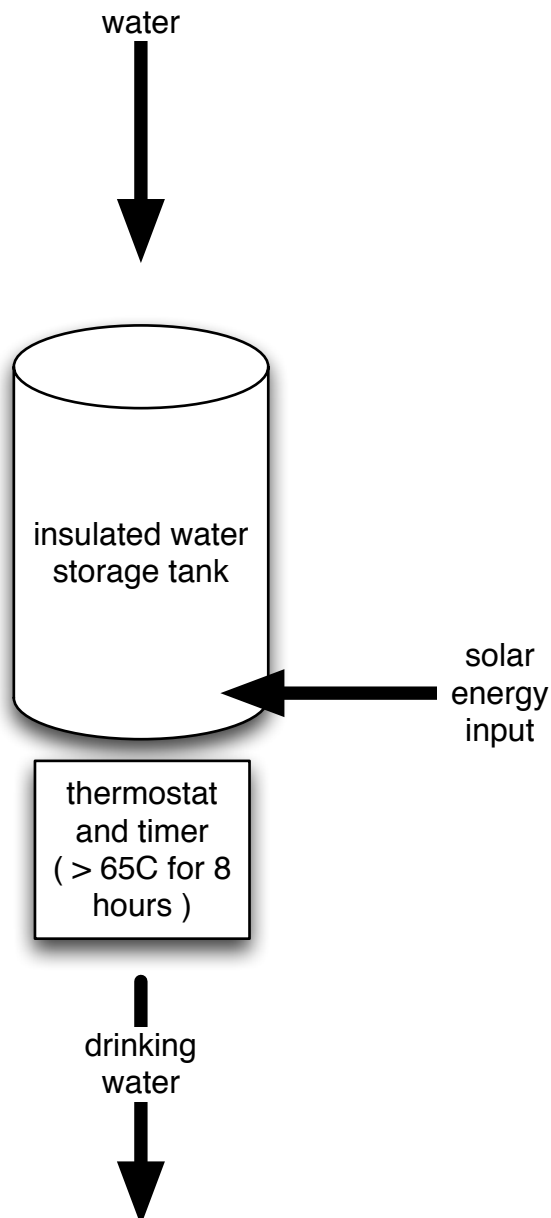
Solar Water Pasteurization

water purification science

65C for 8 hours kills more or less all pathogens because they are evolved to survive in the wild or inside of the human body

solar water pasteurization operates by using solar cookers to heat the water to the safe point and hold it there all day

but they require skill to operate and have very serious problems in (for example) flood conditions



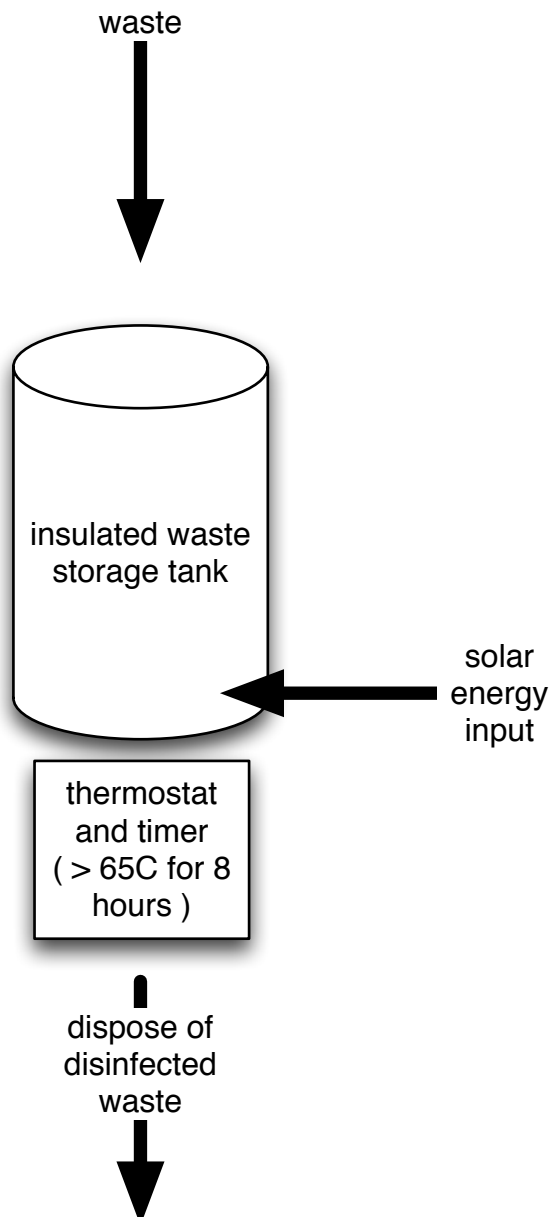
The Solar Toilet?

sewage science

65C for 8 hours kills more or less all pathogens because they are evolved to survive in the wild or inside of the human body

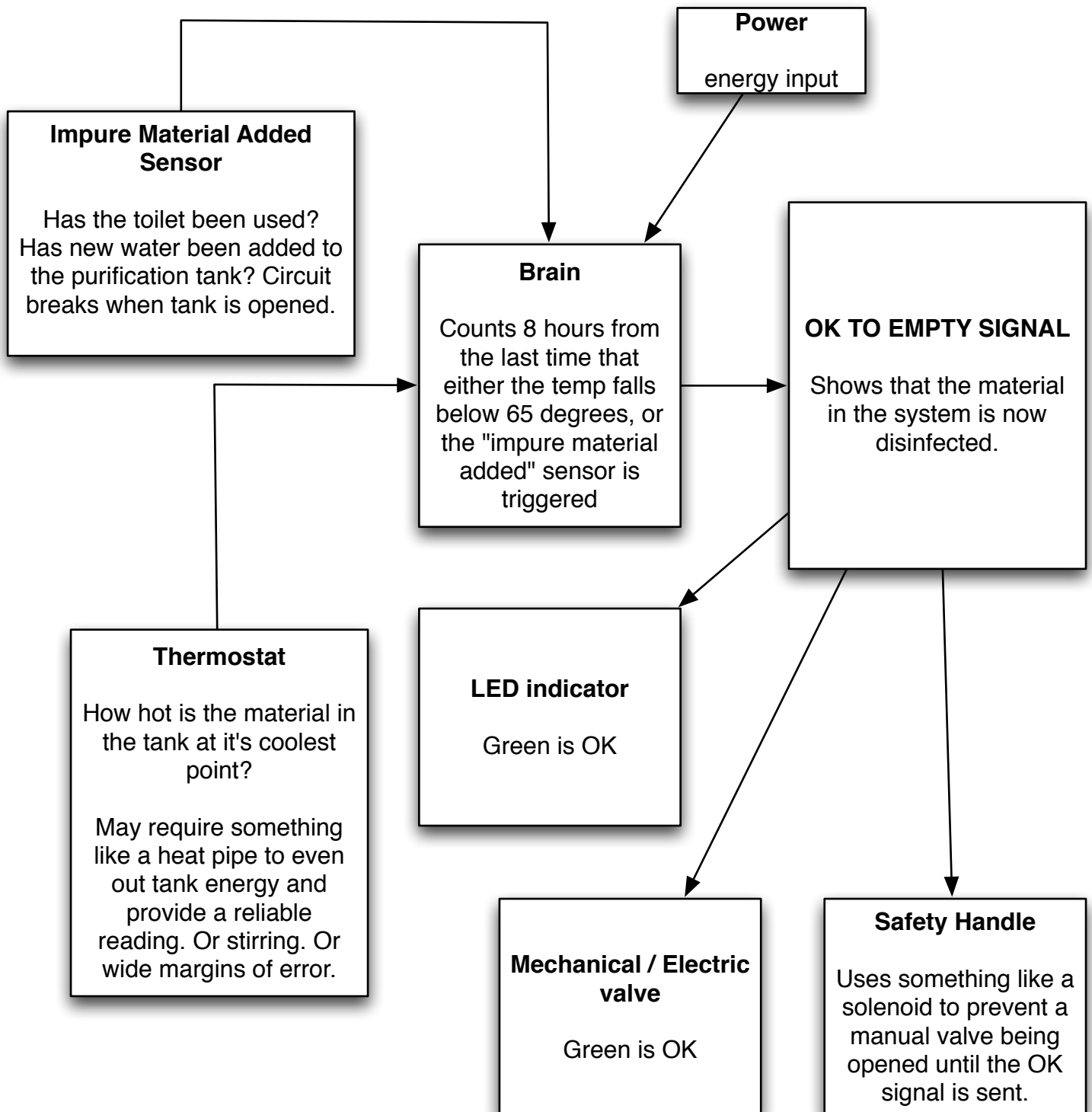
thermophilic composting toilets use the bacteria already in human waste to produce the heat necessary to disinfect the pile

but they require skill to operate and have very serious problems in (for example) flood conditions

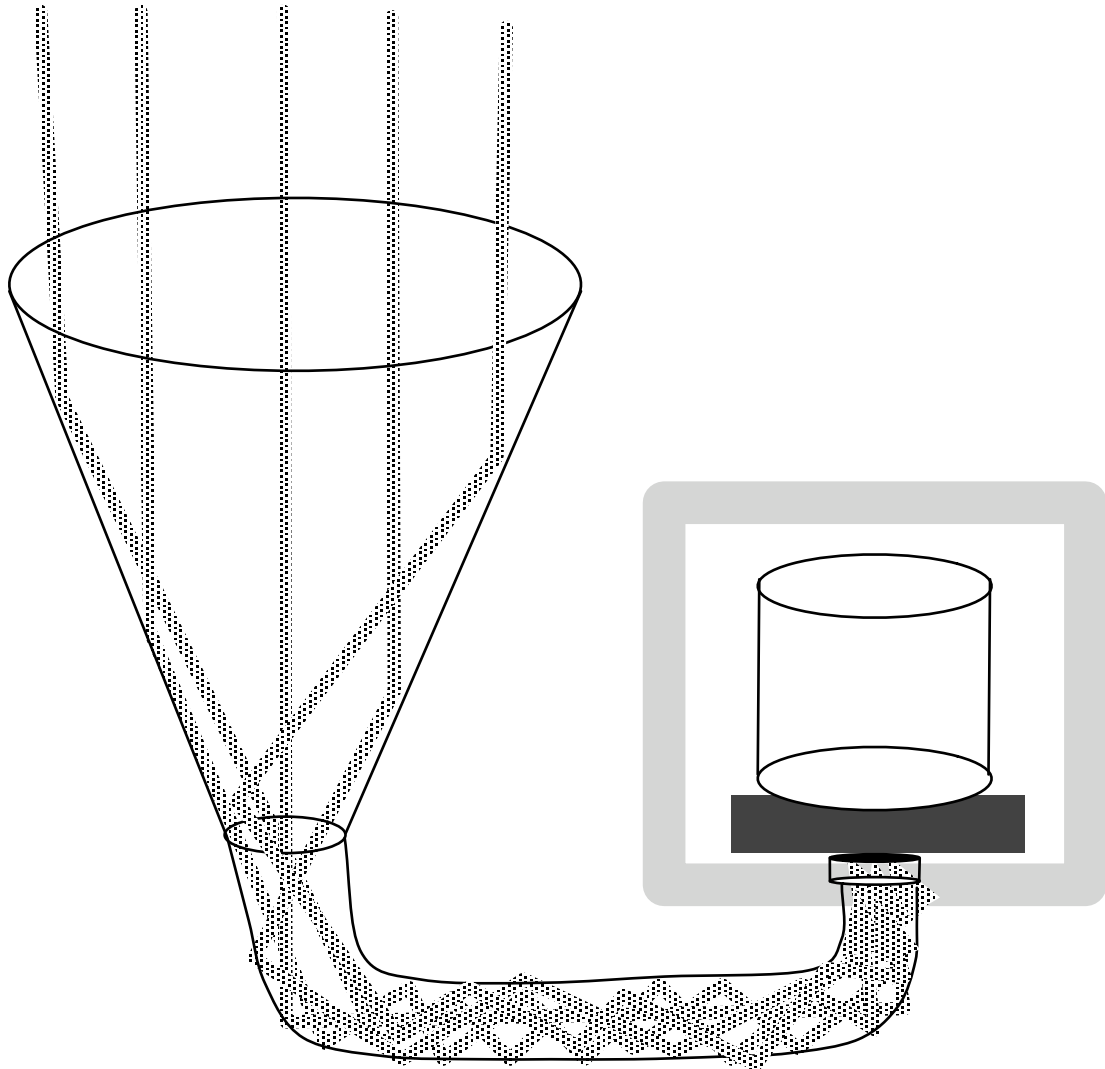


same fundamental mechanism: destroy pathogens with heat and time, using insulated containers to maximize the efficiency of the process

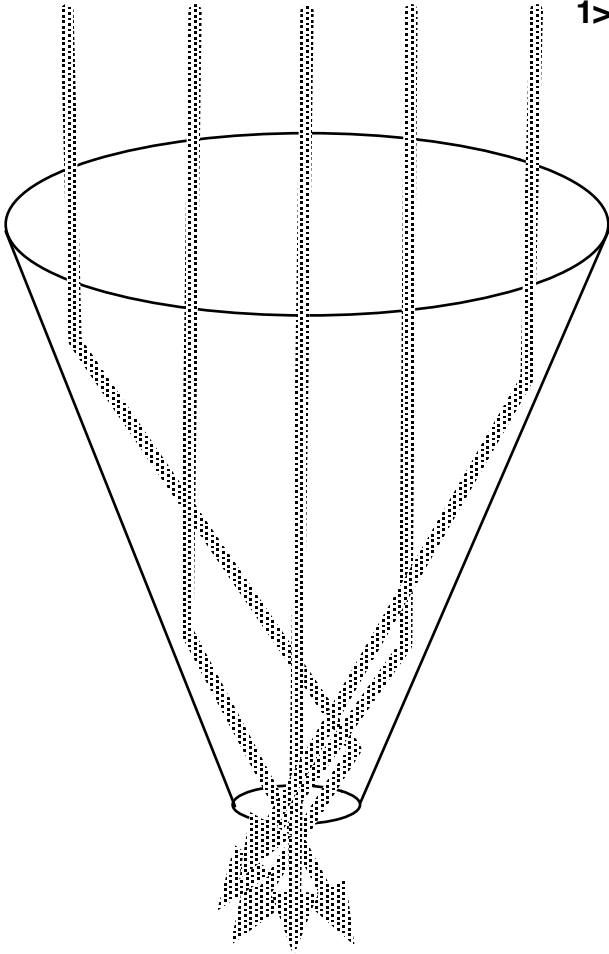
The Digital Solar Valve



Next generation building-integrated solar cooker



1> The Solar Funnel

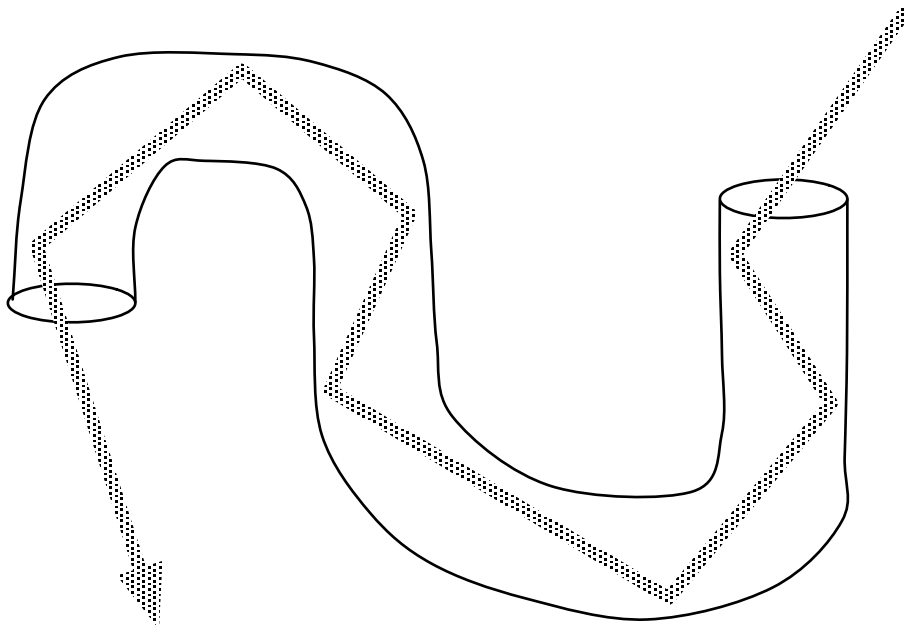


Invented by a professor of astrophysics at Brigham Young.

Better than a parabolic solar cooker because there's no point in space above the cooker than can put your eye out because of the burning-glass property. Even the business end of the solar funnel doesn't align the beams at a single point (they pass through a general area) so it's unlikely to present significant eye risks.

Conventionally, the solar funnel has food placed at the base of the funnel in the same kind of black metal pot as is used in conventional solar cooking. This is an inefficient approach.

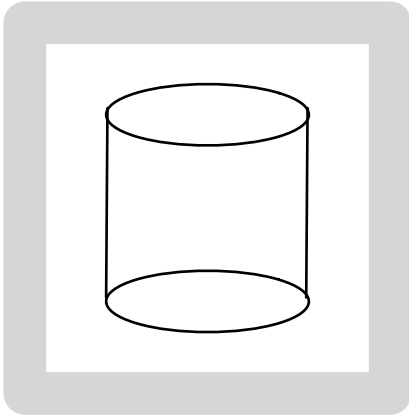
2> The Solar Tube



Used in natural lighting applications, it's basically a flexible duct with a reflective interior.

No rocket science at all.

3> The Haybox



A simple insulated box put around a hot pot of food to keep it cooking. Also called a retained heat cooker. Very commonly paired with solar cookers because it makes up for the "food got cold when the sun went down" problem.

4> Solar Energy Diode

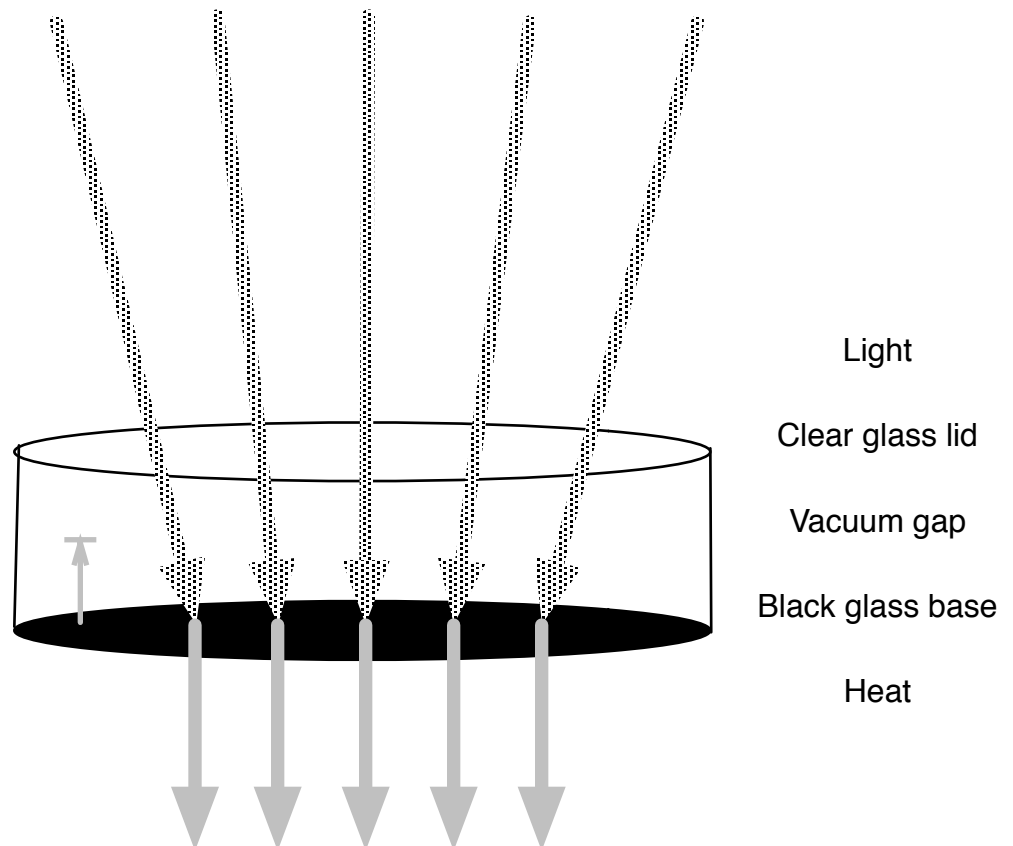
Inspired by the solar kettle, which itself seems to be a repurposing of a common Australian design for a solar collector. The idea is that sunlight passes through a vacuum gap before being converted into heat, thereby preventing heat loss by conduction or convection, trapping the solar energy where you want it.

Incoming solar energy

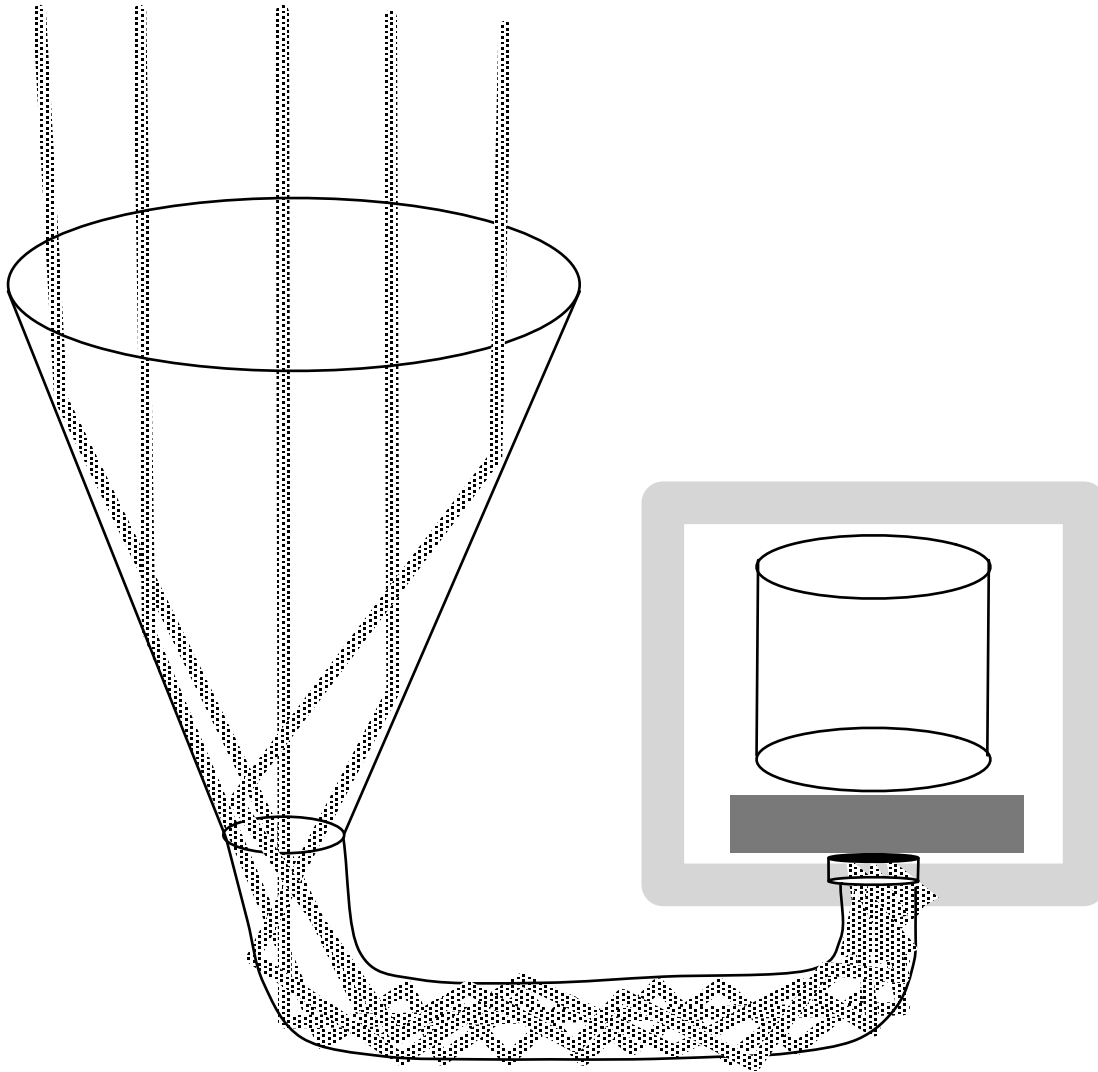
Light is converted to heat when it hits the black glass base.

The heat cannot effectively escape by convection or conduction because of the vacuum gap.

The heat can then be used for whatever purpose the system is designed for.



5> Whole System



Probable performance breakthroughs.

A> Light-to-heat conversion is done **inside** the insulated shell of the haybox.

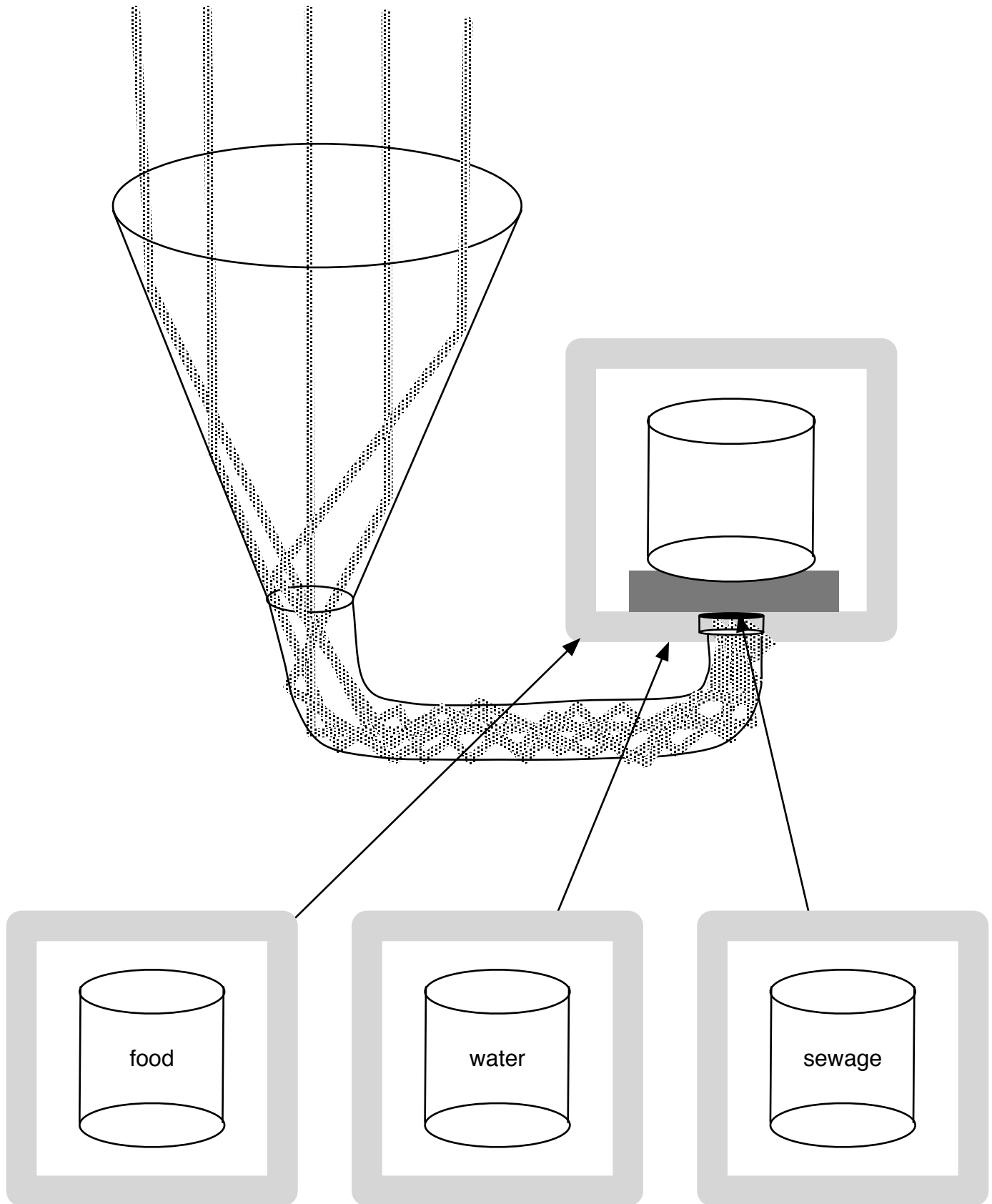
B> The solar energy diode prevents loss of heat through the hole which the light enters through.

C> The orange block - the thermal transfer medium - can be something which is designed to get very hot and stay hot 24/7, giving ready access to heat even at night. In a cold-start situation, the block could be removed to cook food fast, then replaced to heat up all day.

D> Solar funnels accept the sun over a wide arc, and the flexible neck of the solar tube allows the funnel to be adjusted as needed.

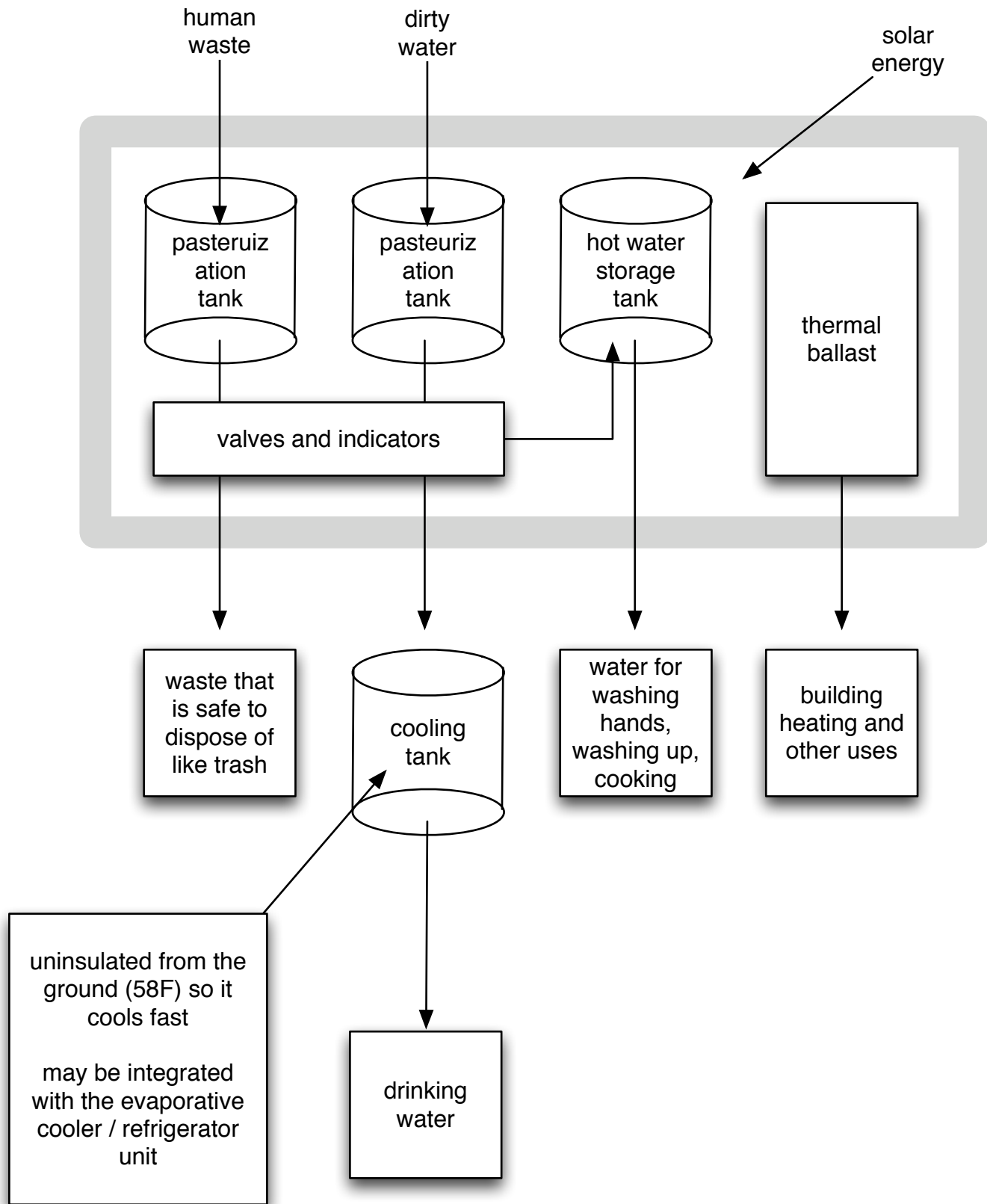
E> System is suitable for integrating into a building, giving an insulated "oven" which things are placed in. Ideally, in hot climates, the oven would be outside the insulated shell of the building, but would still be perceived as being part of it.

Solar Energy Capture and Application

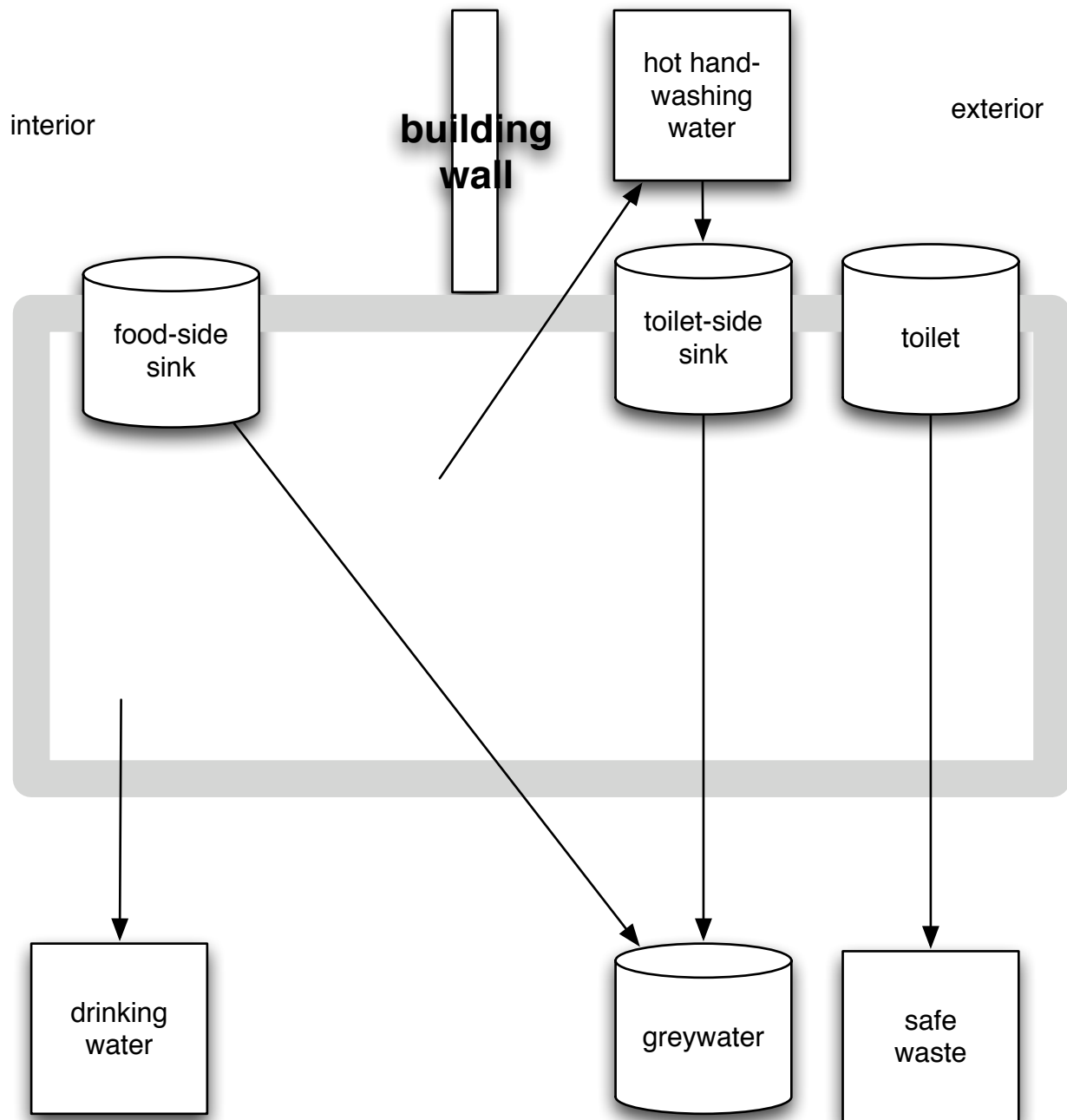


The same basic mechanism recurs: hold things at temperature until the harmful bacteria are gone.

Building-integrated solar energy management (the hot box)



Hot-side utilities box

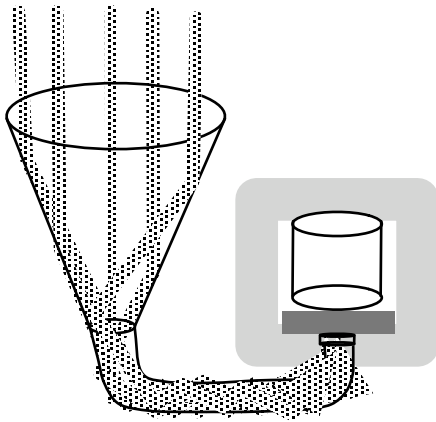


one option is to build a single insulated box into the wall of the building which contains thermal ballast, tanks for various kinds of flows, and the digital solar valving system which indicates when various substances are safe to move around the system.

Thermal energy can be released into the building for heating purposes, but the stored heat works on things like pasteurization and so on when it is not being used for heating.

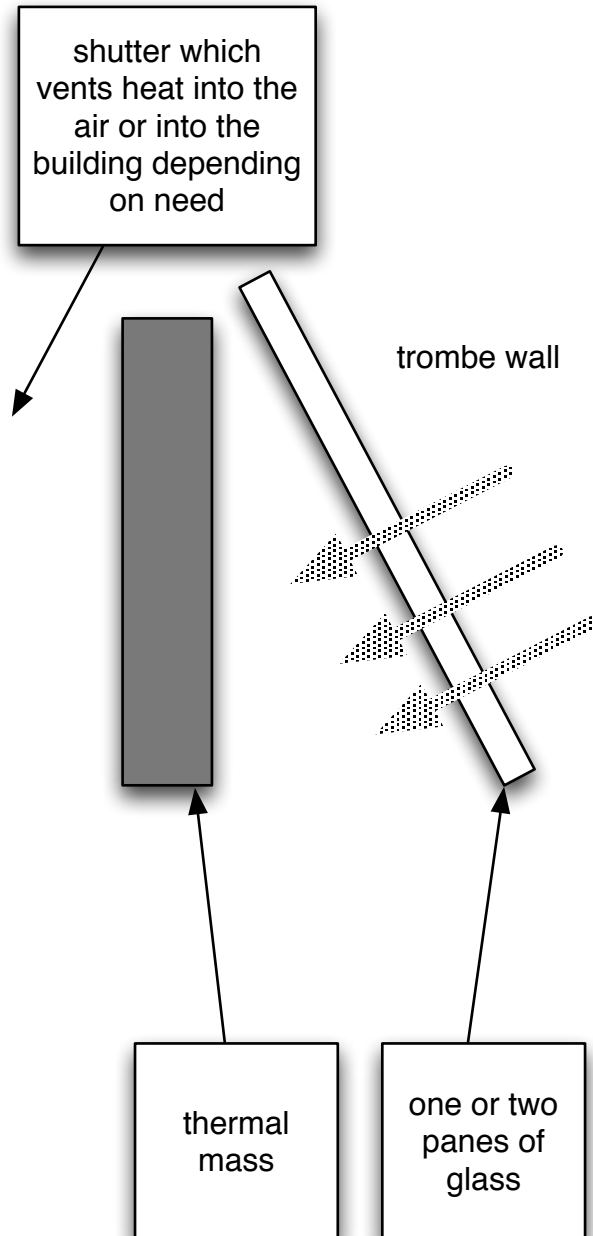
This is more of an issue for climates with extreme day/night temperature fluctuations.

Soft and Hard Solar Energy Capture



hard energy capture

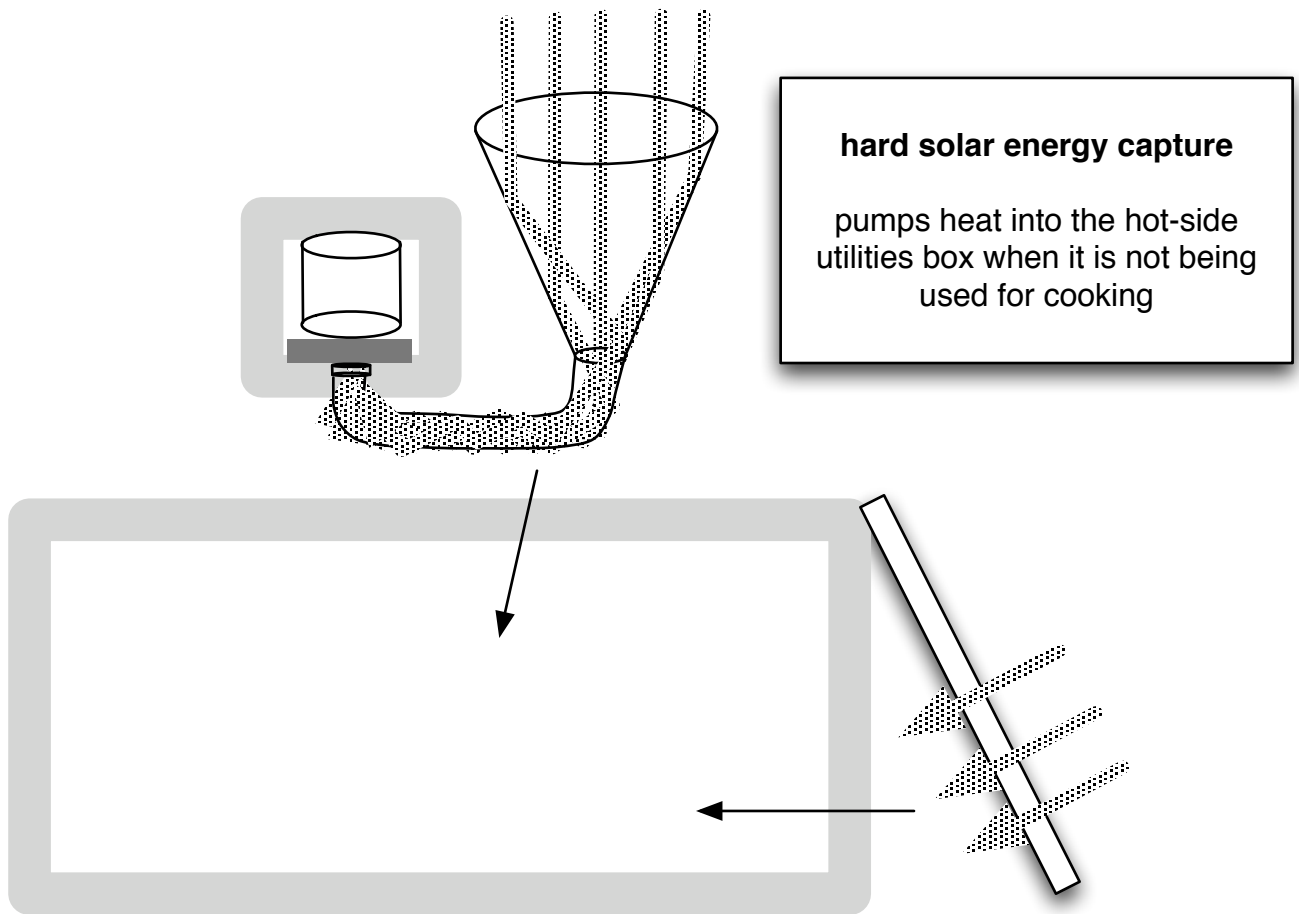
lots of concentration
high temperatures
typical of solar cookers, solar
thermal energy generation and so
on.



soft energy capture

very little concentration
medium to low temperatures
typical of passive solar
architecture, greenhouses,
trombe walls and so on.

Building-integrated hard and soft solar capture



hard solar energy capture

pumps heat into the hot-side utilities box when it is not being used for cooking

soft solar energy capture

pumps heat into the hot-side utilities box all the time, because serious concentration is not needed.

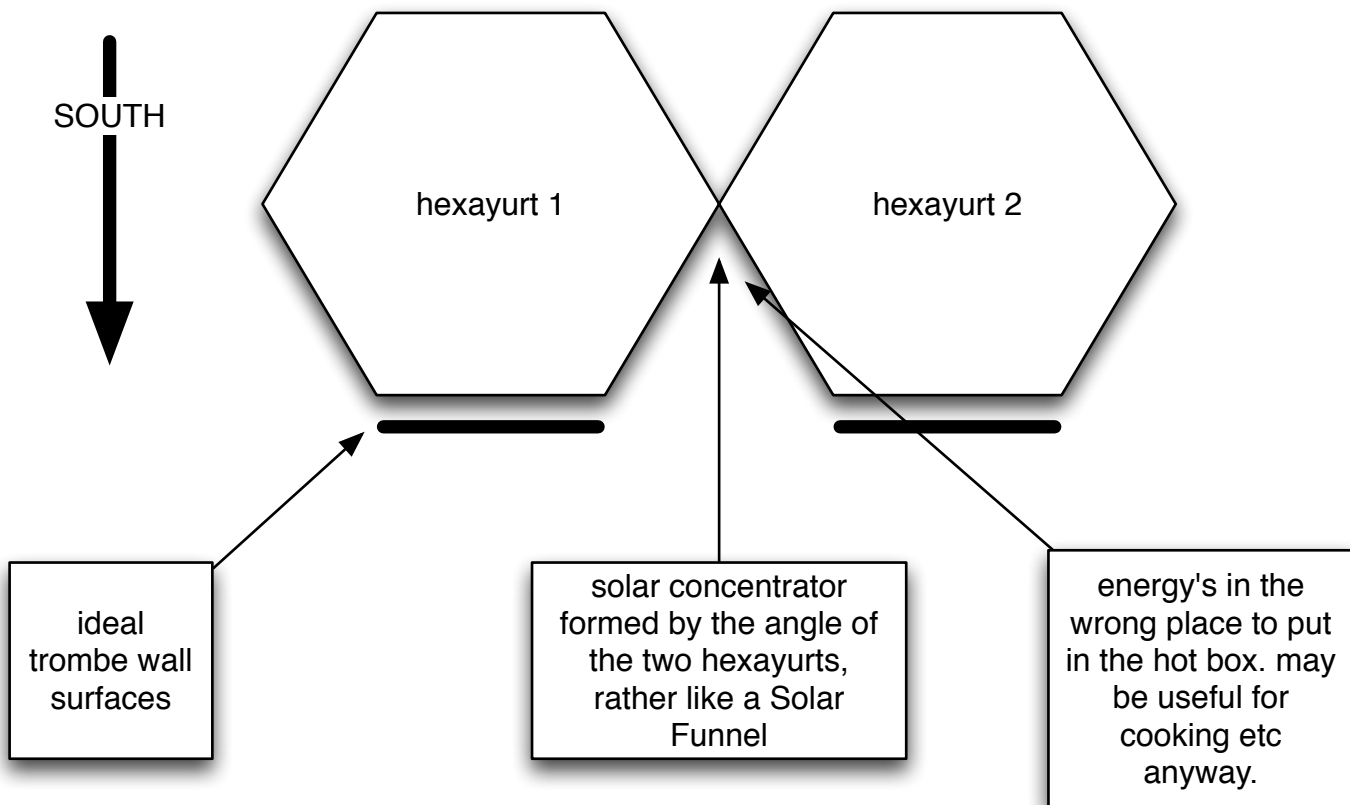
open questions

how much energy do you need to purify each day's water and sewage?

cooking is a separate process which requires focussed heat **now** in many cases.

the solar energy diode based cooker then diverts it's energy from the store to the food at hand.

Energy-pickup points



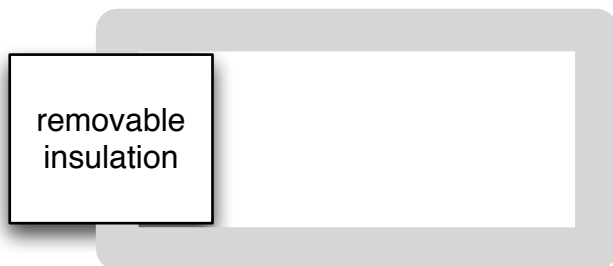
four climatic variations

where it is hot both day and night (see the Thermal Energy Gradients section) the "hot box" may be outside of the building.

in areas where it is hot in the day and cold at night, the hot box can have an opening into the house and perhaps operates by removing insulation from one side.

in areas where it tends to be chilly all the time the wood stove exhaust pipe may be fed through a (very cheap / crude) heat exchanger into the hot box

in areas where there is a strong summer/winter swing, some functions of the hot box may simply not work in winter, requiring alternate strategies..

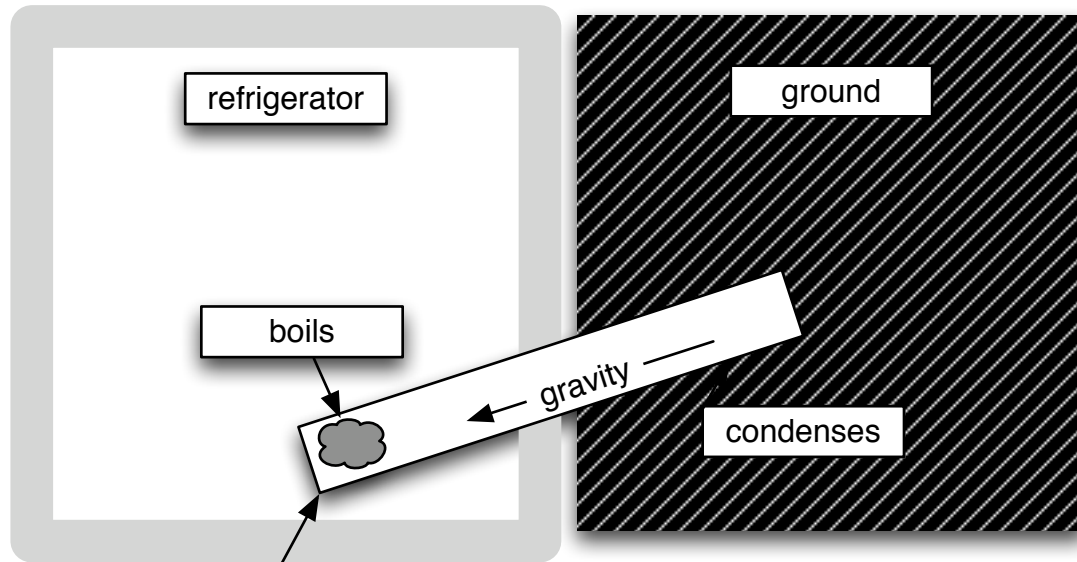


low hanging fruit!!

climate and thermal modeling tells us where this basic approach will work, and how much it fails by in other climates. if we have coverage of 25% of the globe, we have a viable solution for a lot of people.

but this is not going to work in Britain.

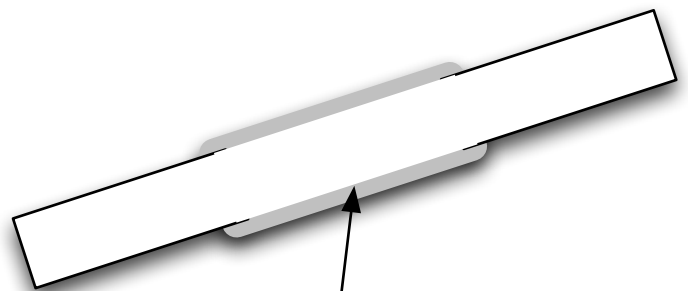
Ground sink with heat pipes



heat pipe

The working fluid boils at 58F. If the refrigerator gets above this temperature, the working fluid becomes a gas, and the vapor condenses at the top end of the tube against the 58F ground heat. This pumps heat out of the refrigerator into the ground.

On the other hand, if the working fluid is not boiling, the thermal transfer down the tube is limited to the ability of the tube to conduct heat, which may be quite limited if the center section of the tube is made of an insulating material.

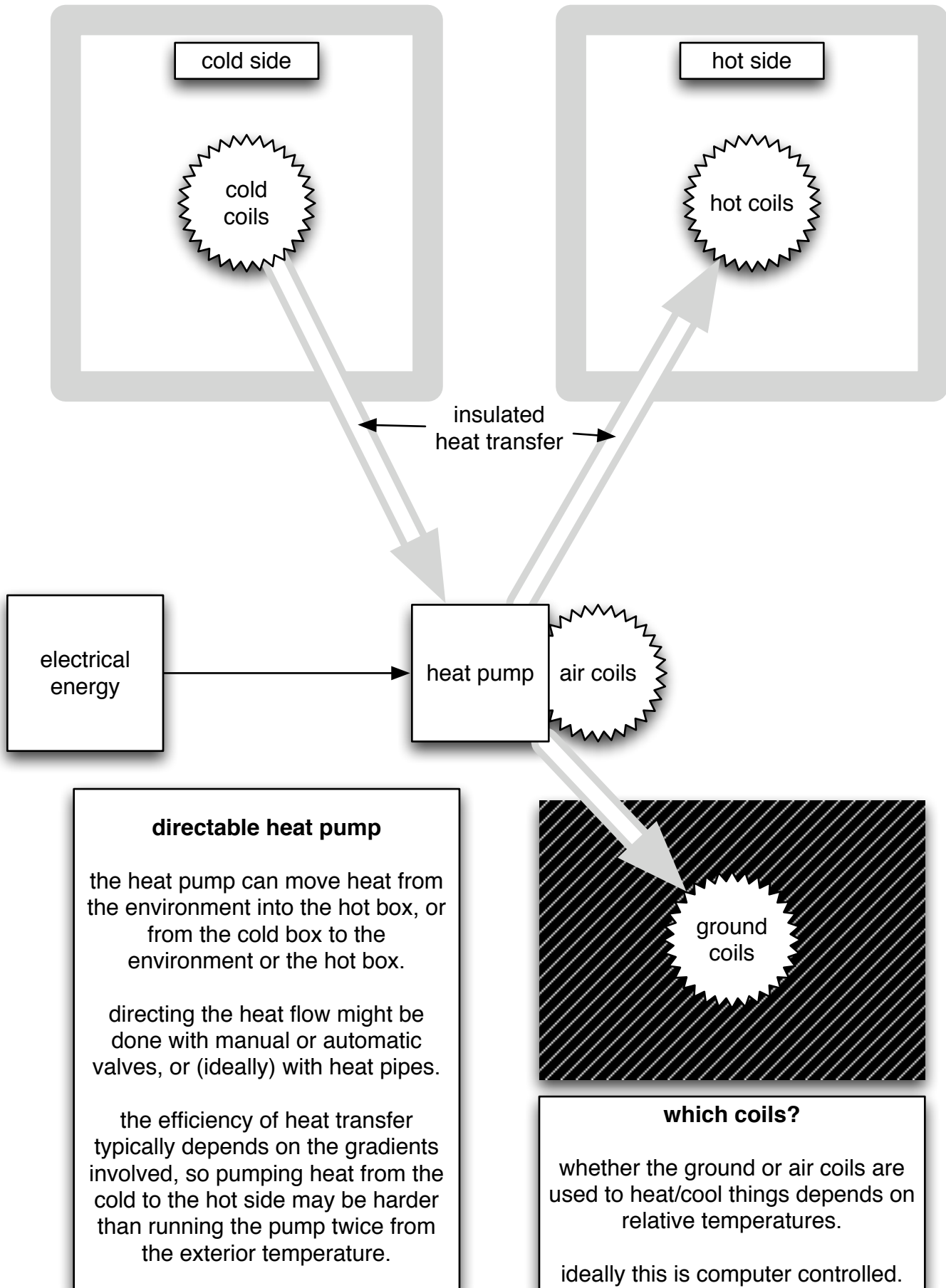


insulated heat pipe

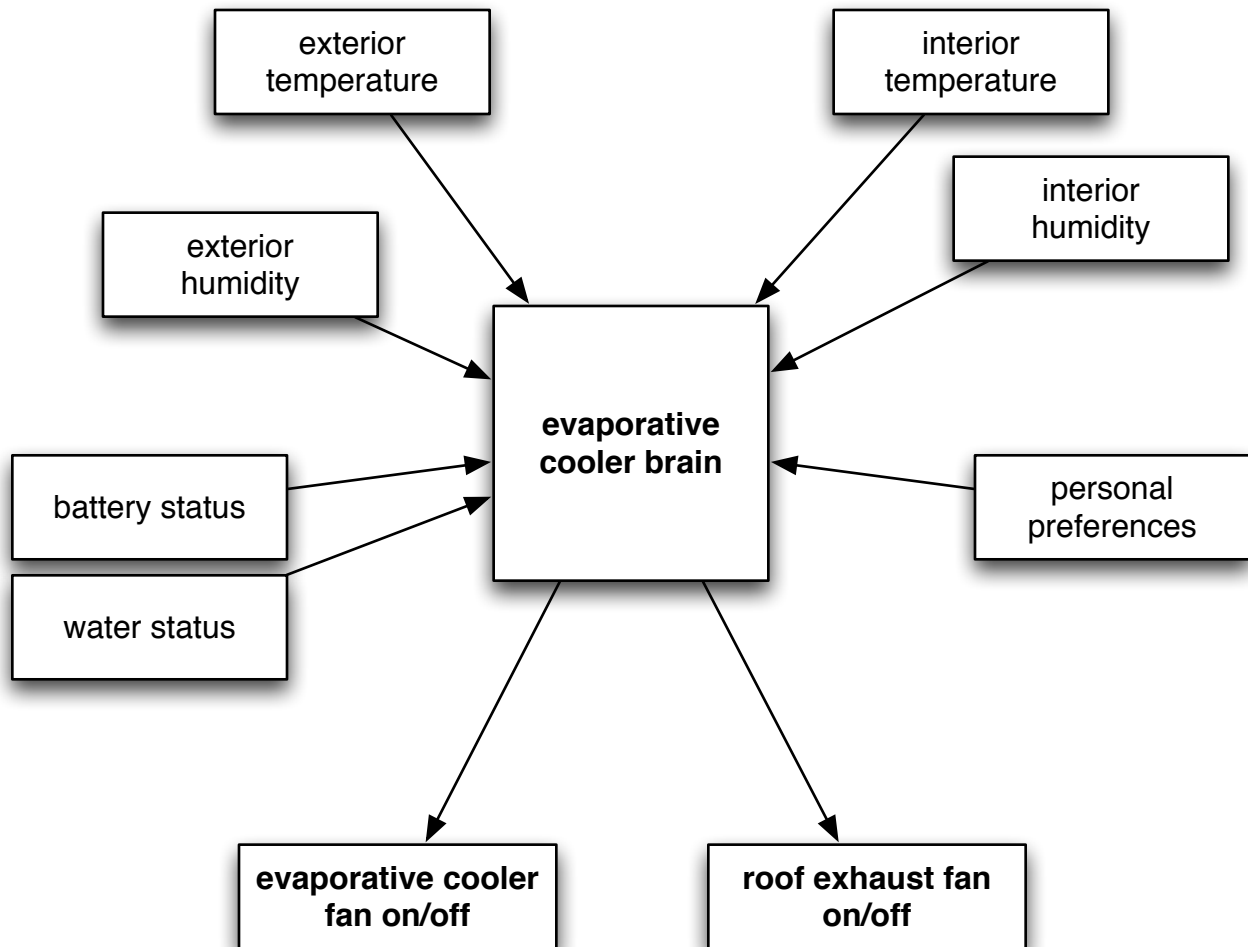
The center section of the heat pipe is made from an insulating material, minimizing conduction down the length of the pipe.

The only efficient thermal energy transfer down the pipe is when the fluid boils at the bottom, rises to the top, condenses, and falls again. If the lower end is colder than the upper end, thermal transfer down the length of the pipe will be limited to conduction through the insulated pipe section.

Power-assisted thermal management



Thermal Brains



how to manage energy effectively?

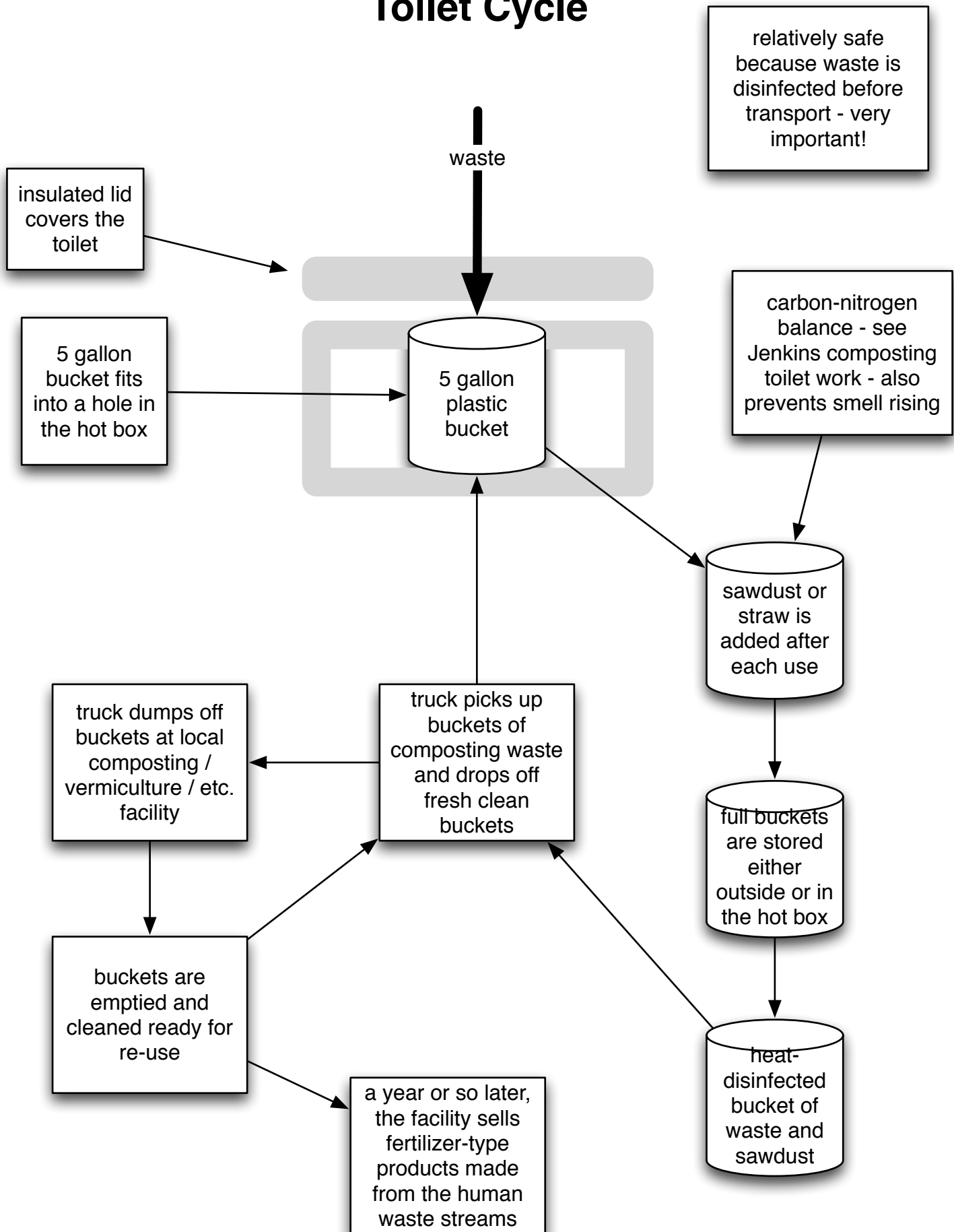
Inside the device a simple program or even hardware network decides for what conditions of humidity and temperature to run the two fans in the building. When it is hot and humid inside, but dry outside, the building will be more comfortable if the humid air is pulled out by the exhaust fan, and then the evaporative cooler run into the dry interior environment, for example.

managing the other thermal components

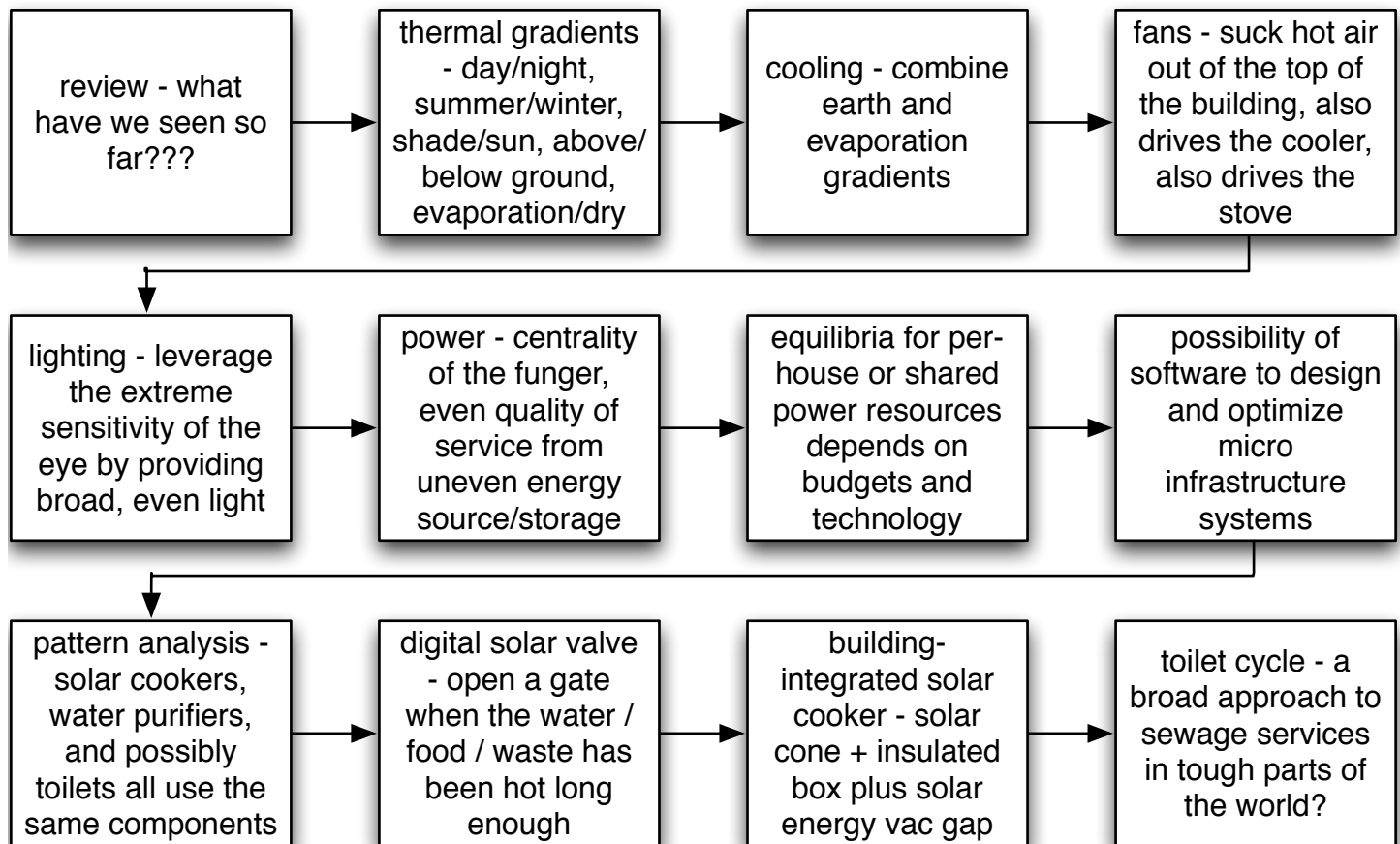
Battery charging, electrical power management, water purification through water pasteurization and so on all have processes which may benefit from having a brain in the loop. Some processes will be best served by indicators which request or suggest actions to humans, but others may be best served with electronic actuators (like the fans in this example.)

Chips are cheap. Energy costs.

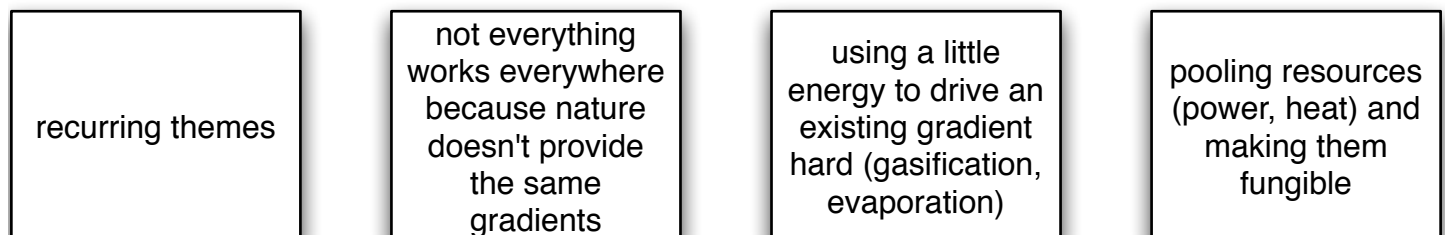
Toilet Cycle



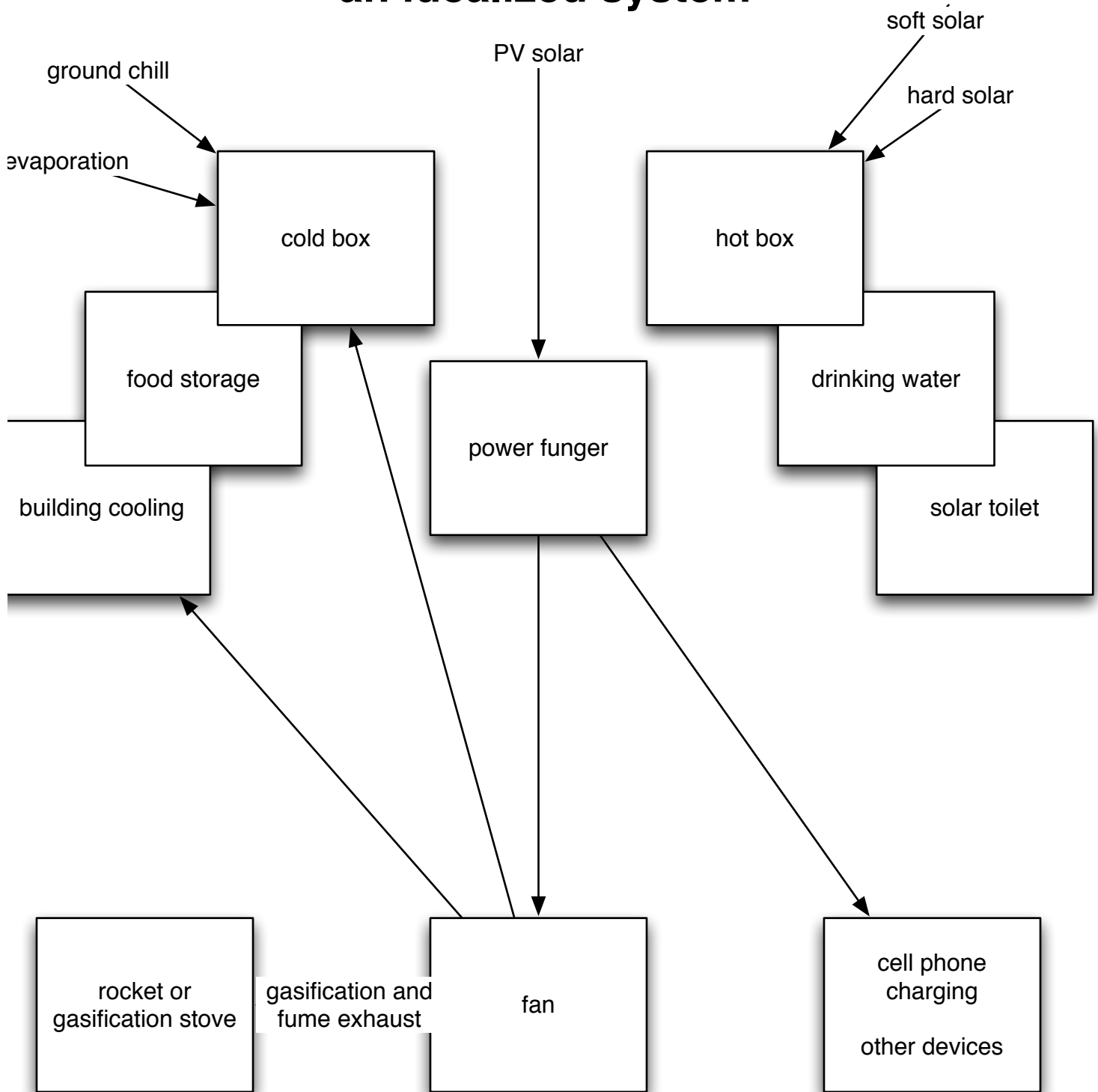
Review



**if even half of
this works, it's a
pretty serious
set of products**



an idealized system



**cost per household in mass production,
in areas with the right geography?**

\$200 per household?

much work remains
even to assess
feasibility!!!

