Introduction

Cellular sites consume 25KWh worth of power of which about 50% is consumed by HVAC chilling systems. This means the equipment inside the cell site are dissipating about 12.5KWh worth of energy some of which is radiated away via the antenna while the remainder is shed as heat inside the building.

This amount of heat is sufficient to rapidly raise the temperature inside the building high enough to cook electronic equipment so air conditioning systems are used to keep the equipment cool. There are two problems with the air conditioning approach the first is that they consume large amounts of power some cell companies are spending over 380 million per year for this power. The second issue is that when main power fails the standby power system must supply sufficient power to operate both the equipment and the HVAC equipment which requires storing more fuel on site accepting shorter run times.

This paper explains how the XDOBS patent pending night radiant chilling system can be used to cool these sites. The night radiant system provides maximum chilling at night so and the cold energy is stored in insulated water tanks and used to provide chilling energy during the day. Recent innovations have allowed enhancement of cell site HVAC systems to exchange outside in lieu of running the HVAC compressors. These low powered fans can save up to 70% of the energy used for cooling however they only work when the outside air is 80F or below. Depending on the climate and season that can leave from 1 to 16 hours where additional chilling is needed. This additional chilling can be provided by the night radiant chilling system with the HVAC compressor providing final backup. In some climates and seasons the night radiant system can deliver 100% of the needed chilling energy at a lower total energy cost.

This system can extend the life of the standby power during power outages by storing 5 days worth of chilling energy which can be used in lieu of the HVAC compressors. In general every hour the HVAC system does not need to turn on allows the cell site one additional hour of runtime.

The design goal is to eliminate 95% of the air conditioning power during times when the system is operating on emergency power and 90% of power used for air conditioning on a day to day basis.

Financial impact

There are two returns from implementation of this system. The first is savings from day to day reduction of power consumption which is recouped over time. The second is a reduction in the power requirements needed for standby systems which reduces capital costs for generators, stored fuel and batteries.

The Nextel and Sprint cell system which is spending $380 million in power for the total cell site estimates that $190 million is used for air conditioning. By reducing the cooling related energy consumption by 90% it will save a$171 million per year. Over a 15 year life this would save $2.6 billion.

Since power costs are likely to continue increasing during the 15 year life the actual savings could be as high as $7 billion depending on the assumptions the rate of increase in electricity costs.

Financial summary

Annual power cost	$380,000,000	enter
HVAC cost ratio	50%	enter
Power Cost HVAC chilling	$190,000,000	calc
% saving of power	90%	enter
annual power savings	$171,000,000	calc
System life in years	15	enter
Savings during system life	$2,565,000,000	calc
Number of cell sites	26,000	site overvie
Amortized per site	$98,654	calc

Environmental Summary

Avg HVAC KWh per day	300	site overvie
% savings from night radiant and Fan	90%	enter
Avg KWh savings per day	270	calc
Avg KWh savings per year per Site	98550	calc
Annual		
Anual KWh savings per all sites	2,562,300,000	calc
Greenhouse gas pounds per KW avg	0.9	enter
Greenhouse reductions pounds	2,306,070,000	calc
Greenhouse reduction in Tons	1,153,035	calc
Likely indirect greenhouse gas tax per p	0.05	enter
Greenhouse gas tax saved per year	$115,303,500	calc
Greenhouse gas tax saved lifetime	$1,729,552,500	calc

Combined Savings Lifetime

Power cost savings Lifetime	$2,565,000,000 calc
Greenhouse gas tax saving lifetime	$1,729,552,500 calc
Total combined savings	$4,294,552,500 calc
Amortized per site	$165,175.10 calc

Capital savings

Cellular companies are obligated to keep cell site infrastructure operational during emergencies especially when wire line infrastructure has failed. Supplying adequate electricity to keep these sites on line during power outages is expensive. ½ of the power consumed is used by air conditioning. By reducing the energy consumed for cooling the same amount of battery storage can nearly double operating time.

The traditional mechanism for supplying power is either battery or for longer run times local generators. Both of these strategies must be sized to provide sufficient power to operate both the cell site equipment and the related HVAC systems.

The reduction in power consumption allows a reduction in battery requirements or by retaining similar battery capability the longer run time may eliminate the need for local generators, fuel, tanks and associated maintenance.

Race to failure

In a site which has 48 hours of battery backup capacity which is averaging 13KWh for air conditioning it will consume 624KWh worth of electricity for air conditioning over the 48 hour period.

The innovative forced air exchange system driven by DC fans is capable of running on 4 amps @ 50V which burns 200 watts so over 48 hours it will burn 9.5 KWh. The typical HVAC system will burn 10 amps at 220V (2200 Watts) or 105.6 KWh. The fan based system shows a 90% reduction in power consumption.

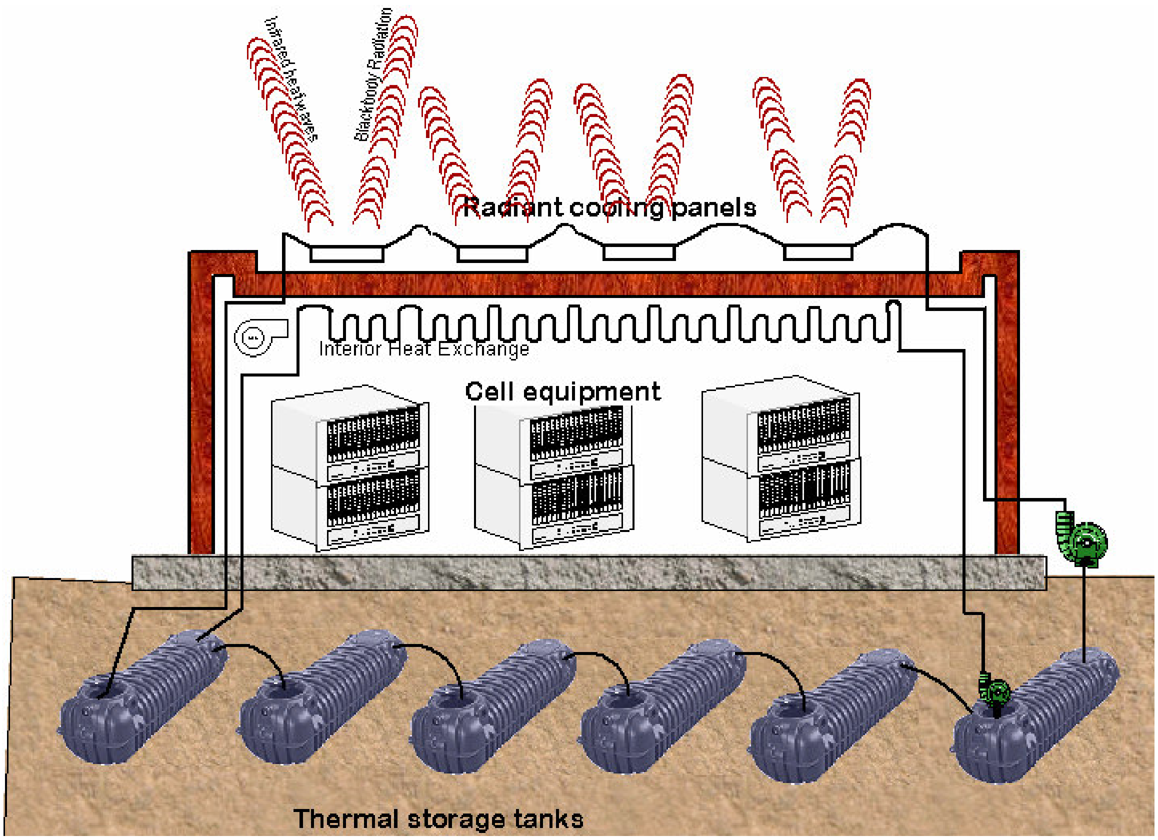
The external air exchange system breaks is not effective when outdoor temperatures exceed tolerances. During these times the HVAC compressor would normally activate which is undesirable due to it's high power consumption. The stored cold system avoids the need to activate the HVAC compressor during this critical time. If during the 48 hour emergency period the night radiant system saved 5 hours per day of compressor activation it would reduce total power consumption by 125 KWh which is enough to allow operation of the Radio portion of the site for an additional 10 hours.

By decreasing air conditioning power demands by 90% while retaining the same battery capacity we extend the site run life from 48 hours to approximately 91.2 hours.

Another important aspect is that it may allow a site that would otherwise have required a on site generators to survive the needed amount of time while using a battery bank.

System Overview

Basic system diagram



Note for simplicity the distribution manifold which allows water to be individually routed from any tank through the night radiant panels or the interior cooling loops is not shown. This intelligent routing is a critical aspect of the overall design which is what allows it to achieve the average of 400 watts per sq meter.

Several smaller tanks are used to allow heat during the day to be concentrated which provides better thermal performance for shedding it at night. A micro controller and sophisticated sensing techniques combined with proprietary software seek to find the optimal heat shedding for given ambient conditions. It is also used to detect freeze risks and adjust fluid flow or in extreme conditions drain the fluid loops.

The drawing only shows cooling panels on top of the cell site roof which may be adequate in some locations especially during cooler seasons. In areas with more harsh summer heat such as Lancaster California where daytime temperatures exceed 105F and the night radiant system would need to provide 16 hours per day of cooling more square foot of cooling panel will be needed.

Math and physics

This approach depends on an objects ability to shed heat through radiative processes. Heat shed from objects in the range of 110F down to 32F are considered long wave infrared. Warmer objects emit shorter infrared waves and the warmer the object that more energy it can shed per area of exposed surface.
All objects above absolute zero shed heat in this fashion however in most instances heat gained from other objects and from convection (moving air) re-heat the object so that it reaches a temperature within a few degrees of ambient.

Specialized shapes and materials allow our panels to shed much more heat radiative than they absorb from the surrounding air and objects. Tests conducted in Utah during the summer and fall of 2006 regularly achieved 10F chilling and quite often achieved 15F chilling. In rare circumstances 20F chilling was achieved. These tests where conducted over a period of several months and in a wide range of weather conditions using a wide variety of materials and shapes which allowed XDOBS to derive a shape the provided the best average performance under the test conditions.

Several DOE funded studies have shown the efficiency of this type of cooling approach although most of them resulted in a maximum average cooling of approximately 100 to 120 watts per square meter. Theory indicates the maximum radiation shed of up to 400 watts per square meter is possible provide no heat is absorbed by surrounding objects and there is little or no convective warming and the air is relatively dry representing a low dew point and low absorption and reemission by the humid air.

Our approach utilizes specialized approaches that allow us to deliver more than 120 watts per square meter however even with these approaches it is infeasible to reach 400 watts per square meter without additional tactics. In short when the cooling fluid is used each tank is isolated to allow it to heat to 90F prior to switching to the next tank. At night when the temperature drops into the range of 70F in most areas the first 20F is shed using convective processes which can deliver much more cooling per square meter. The convective cooling is enabled by a sub set of the panels that are specially designed to provide high thermal conductivity and high Emissivity the warm cooling fluid warms the surface of these specialized panels which create a natural chimney resulting in rapid shedding of heat at a rate that can be 10 to 20 times that possible with purely radiative processes. Once these specialized panels reach ambient the airflow is stopped which allows them to cool below ambient. Due to their high thermal conductivity they this sub set of panels is less effective at reaching lower temperatures below ambient so a specialized computer controlled solenoid is used to route the water from the warmest tanks through these panels.

Once a given tank has been cooled to ambient it's fluid is routed through the night radiant panels for cooling further below ambient. If the night temperature continues dropping faster than the radiant processes can cool the fluid the specialized micro controller will continue to switch between tanks always finding the one that can benefit the most from convective cooling.

Even the standard night radiant panels benefit from convective cooling whenever the cooling fluid is warmer than ambient. They are specially shaped so that when the cooling fluid is below ambient they trap a stagnant layer of cold air which acts as an insulator however whenever their surface is above ambient they exchange heat to the closest air which has not choice to rise and be replaced by new cooler ambient air. These panels have a higher R factor than the specific convective panel which is what allows them to obtain lower net temperatures but they can still conductively transfer heat to the surface for convective exchange.

Experiments in Utah during the summer and fall of 2006 showed that it is possible to archive 6F to 12F cooling as early as 10F 2:00 pm provided that the radiator is shielded from direct solar exposure with a slight northern tilt. In contest the northern tilt slightly degreases chilling capacity at night.

Math for average sites

Each average cell site that contains both CDMA and IDEN technology will burn about 25KW average of which about 50% is allocated to cooling. This means that each sites radio and related equipment is dissipating about 12.5KW continuous or 300 KWh of heat energy per day. In most areas well over 50% of this can be shed using simple air exchange which leaves about 150KWh per day that the night radiant system needs to shed.

The average cell site building is 200 square foot (20 sq meters) while the average site has is licensed for 900 square foot 93 square meters. In many parts of the country the night temperatures average in the in 60's and using our night radiant system new can achieve temperatures outputs in the range 12 to 15F below ambient which means we can produce temperatures in the range of 45 to 50F.

Night radiant chilling can provide a maximum of 400 watts per square meter of heat shedding capacity which means that over a dark period that averages from 8:00 pm to 7:00 am or 11 hours the system can shed 4,400Wh per square meter. This equates to 89.7KWh which can be shed from the 200 square foot roof per night or 367.8 KWh shed from the complete 900 sq foot site per night.

The amount of heat shed per square meter is higher than planned for the water condensation version of the night radiant system. This is facilitated by allowing individual thermal storage tanks to reach a full 90F maximizing the difference between ambient and radiator increases the rate at which heat can be shed.

Needed or in some conditions would be sufficient to provide 100% of the cooling energy needed for the site even without air exchange.

Using a high density heat exchange fluid the maximum safe temperature for operations of the equipment will be when the fluid reaches 90F. In an area where the night radiant system cools as far as 58F this provides a temperature differential of 38F. Single gallon water can absorb 95Wh of energy in the process of rising from 58F to 90F. In other words a 10,000 gallons reservoir of water could absorb 952,100 who of heat energy which is over 6 days of stored cooling. In reality some heat is shed every night even in adverse conditions even during worst case conditions the stored energy should suffice for 20 or more days.

As shown below the Lancaster location would need a minimum of 250 square foot ideally 700 square foot of cooling surface area. The average cell site lease size is 900 square foot and if the entire site lease area is covered with convective panels even in Lancaster during the worst month the system would product 1.8 times the estimated needed cooling which is 30% above recommended 50% margin. In the more moderate San Jose location during May the 220 square foot system would produce 89% of the cooling energy needed while the 900 square foot site could produce 380% of the minimum needed.

Sample Site San Jose, CA May

Sample San Jose CA - May 15 2006	Rooftop only	Covering Leased Land	
June Chosen for worst case conditions			
Local Cell site			
Cell site square foot	220	900	summary
Cell site size sq meters	20.4	83.6	calc
Total site power consumption KW	25		calc
Less HVAC consumption	12.5		calc
Heat disipation KWh per hour	12.5		calc
Sq foot of radiant system needed to meet needs	245.10		
Local Enviornment			
Hours cool enough for air exchange	16		enter
Hours of cooling needed from stored cold	8		enter
Max temperature for air exchange	80		enter
Average daytime temp	85		enter
Average nightime temp	65		enter
target chill by degree F	14		enter
target chill to F	51		calc
Heat Disipation requirements			
Max temperature F for air exchange	80		calc
KWh needed per day from night radiant system	100		calc
Heat Storage requirements			
Max allowed equipment temperature	90		
Degrees difference	39		
KWh stored per gallon at temp differential	0.09521		calc
Margin of storage	120%		enter
Gallons storage needed	1261		calc
Cubic foot of storage tank needed	21		calc
Tank height in foot	8		enter
Square foot of tank space	2.625		calc
Size of square foot on each side	1.8		calc
Days of storage to allow for bad weather	5		enter
Sq foot Tank size needed for extra storage	14		calc
Radiant pannel calculations			
Maximum radiation watts per square meter	400	400	enter
Meters of available roof surface	20.4	83.6	calc
Hours of effective operation per day	11	11	calc
Max Wh shed in available space per day	89760	367840	calc
Max KWh shed in available space per day	89.76	367.84	calc
Watts per sq foot per day	408	409	calc
Ratio of cooling provided vesus needed	0.8976	3.6784	calc

Sample Site Lancaster, CA July

Sample Lancaster CA - July 15 2006	Rooftop only	Covering Leased Land	
June Chosen for worst case conditions			
Local Cell site			
Cell site square foot	220	900	summary
Cell site size sq meters	20.4	83.6	calc
Total site power consumption KW	25		calc
Less HVAC consumption	12.5		calc
Worst case Heat disipation KWh per hour	12.5		calc
Sq foot of radiant system needed	730		
Local Enviornment			
Hours cool enough for air exchange	8		enter
Hours of cooling needed from stored cold	16		enter
Max temperature for air exchange	80		enter
Average daytime temp	102		enter
Average nightime temp	72		enter
target chill by degree F	14		enter
target chill to F	58		calc
Heat Disipation requirements			
Max temperature F for air exchange	80		calc
KWh needed per day from night radiant system	200		calc
Heat Storage requirements			
Max allowed equipment temperature	90		
Degrees difference	32		
KWh stored per gallon at temp differential	0.07812102		calc
Margin of storage	120%		enter
Gallons storage needed	3073		calc
Cubic foot of storage tank needed	411		calc
Tank height in foot	8		enter
Square foot of tank space	51.375		calc
Size of square foot on each side	7.4		calc
Days of storage to allow for bad weather	5		enter
Sq foot Tank size needed for extra storage	257		calc
Radiant pannel calculations			
Maximum radiation watts per square meter	400	400	enter
Meters of available roof surface	20.4	83.6	calc
Hours of effective operation per day	11	11	calc
Max Wh shed in available roof space per day	89760	367840	calc
Max KWh shed in available roof space per day	89.76	367.84	calc
Watts per sq foot per day	408	409	calc
Ratio of cooling provided vesus needed	0.4488	1.8392	calc

Phase Change to Ice

Assuming a 12 to 14F target drop below ambient the system whenever the ambient nighttime temperature is below 46F the stored water will begin to form ice crystals. It takes quite a bit of energy to freeze water which allows a larger amount of heat storage so an ideal condition freezes the stored water to a thick slush. If requires 73 Watt hours to cool a gallon of water 30F and another 351 watt hours or 10 times as much to freeze the same gallon of water once it has reached 32F. That amount of heat energy is released during the thawing process which means that at the phase change to we have 10 times the energy storage density we did with simple chilled water.

The problem with the phase change to ice is that the night radiant system maxes out at a temperature drop of 20F with 10F being a more typical this means that during the time when the system is capable of reaching the freezing point is also the same part of the year when the DC fan based air exchange could provide all the needed cooling without assistance from the stored cold.

When designing to tolerate freezing conditions the system must utilize a secondary heat exchanger mechanism where the primary chilling fluid is a freeze proof antifreeze which exchanges it's cold energy into the tanks using a secondary heat exchanger. This extra complexity does not yield much benefit since the higher density cold is present only when the system doesn't need it.

Resistance to freeze damage

The amount of water in the storage tanks and their buried insulated condition makes freezing extremely unlikely. If there is any risk of this the stored cold systems is simply used for more hours per day in lieu of the external fan which absorbs more heat from the shelter and is sufficient to prevent freezing. It also reduces the amount of external air drawn through the external filters which extends their life. The water in the tanks could freeze to a thick slush without causing any damage however if it was allowed to freeze solid it could crack the tanks.

There is some risk of fluid freezing in the main radiant condensers especially during winter in northern latitudes. The least expensive way to avoid this is to continually circulate the water from the storage tanks through the chilling tubes. The warmth drawn from the storage thanks and the momentum of the fluid is sufficient to prevent freezing in the radiant chillers provided sufficient fluid momentum is maintained in the pipes.

In areas with very cold temperatures an additional solenoid valve can be sued to directly circulate the fluid coming out of the interior room through the nigh chillers. There is also an option to drain all fluid out of the chillers and into the storage tanks during times of extreme cold.

Design features for Cell site system

Use two sets of tanks one which is used for day to day cooling and a second which is used for emergency cooling. The system is setup so that any cooling developed by the night radiant system is directed first to emergency storage until it has reached the maximum cold level viable for current ambient conditions. Then the cold energy is routed to the system for day to day chilling. The time when this does not hold true is during the early evening when the water heated during the day is substantially above ambient it's heat can be radiated away most efficiently so the rule is that the water which is above ambient always chilled to ambient first.

To maximize radiation efficiency each tank is drawn from for chilling purposes individually. When that tank has reached 95% of the maximum allowed temperature the next tanks is used. In this way the warm tanks can be chilled to ambient faster with a higher degree of efficiency than a larger set of tanks at a lower average temperate.

The theory is that for a given site there is a high probability of night air being sufficiently cold to provide all chilling needed for the site during any emergency period. That means we do not need to use any chilling from the night radiating system for nighttime cooling and can route it entirely to storage. This can dramatically extend the life of the chilling energy

Cold transfer to cell site

Transferring cold energy from storage to the cell building can be done in a number of ways. The most simple strategy uses a series of thermal exchange tubes suspended ran in network below the ceiling in the cell site. These tubes have the cold fluid pumped through them and chill the air closest to them which falls downward to the radio cabinets crating a natural convective cycle. The heat exchange from the tubes can be increased by pumping moderate volume of air past them with a fan as shown in the drawing. There are also commercial radiant cooling panels which use a similar approach. A favorite option is to clip the tubes to light gauge aluminum panels which absorb the heat from the room and transfer it to the tubes while chilling the air.

An alternative strategy is to plumb the cooling tubes directly into the cabinets of the cellular equipment. By running the coils along the outside or if there is room the interior of each cabinet the metal case becomes cool and transfers part of the cold to the room and part to the air inside the cabinet.

The final option and one that is possibly the easiest to retrofit into existing sites is to use a fluid to air heat exchanger. These heat exchangers are quite often called tube in shell exchangers allow the cold energy from the fluid to be transferred to the air. The same fans used for external air flow can be re-routed using a computer controlled baffle to blow air through this heat exchanger. It has the advantage of containing any condensation in the exchanger so it also acts as a viable dehumidifier.

Thermal storage tanks

There are two main options for storage tanks. The first are pre-fabricate, pre-stressed cement tanks commonly used for septic systems. The second is a wide variety of tanks made from variety plastics. Cement tanks can also be fabricated on site but will require customized mix hydraulic cement and is ideally pre-stressed. If the stored water may be used in the future for human consumption then cement tanks should be lined with fiberglass or plastic.

Cement tanks may be preferred because they are better suited to support the weight of the actual cell building when installed under the building. . Taller tanks will provide maximum storage based on consuming the 100% of the footprint for the site.

To preserve the stored cold energy 4 inches of polyurethane, poly styrene or equivalent water proof insulation will be added to the sides, top and bottom of the tanks.

The total storage is ideally divided into a series of individual tanks each of which has its own insulation. A computerized system chooses which tanks are providing chilling energy for the shelter and which ones are receiving chilling energy from the roof. The compartmentalized tank structure allows the system to maximize the temperature one tank before using the next one by maximizing that temperature it also maximizes radiant heat exchange which increases the BTU per sq meter of shed heat.

Environmental Impact

This system does not require any toxic chemicals, Freon or other environmentally unfriendly gases.

Using an average of 270KWh saved per day each cell site will save 98,550KWh per year which is 2.56 billion KWh across all 26,000 sites.

In the USA the EPA estimates that electricity consumption generates an average of 1.2 pounds of greenhouse gas such as carbon dioxide per KWh consumed in the California a state with high levels of hydro electric power the average emissions are 0.867 pounds per KWh. Using a conservative average emission of 0.9 pounds per KW the savings deployment would save 2.3 billion pounds or 1.15 million tons.

Law makers are currently considering laws that will charge industrial consumers by the pound for greenhouse emissions both direct and indirect. The estimates range from $0.01 up to $0.30 per pound of emissions. Most experts expect the eventual tax to be in the range of $0.05 per pound and if this becomes the emissions reduction will save an additional $115.3 million per year.

Environmental Summary

Avg HVAC KWh per day	300	site overvie
% savings from night radiant and Fan	90%	enter
Avg KWh savings per day	270	calc
Avg KWh savings per year per Site	98550	calc
Annual		
Anual KWh savings per all sites	2,562,300,000	calc
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Greenhouse reduction in Tons	1,153,035	calc
Likely indirect greenhouse gas tax per p	0.05	enter
Greenhouse gas tax saved per year	$115,303,500	calc
Greenhouse gas tax saved lifetime	$1,729,552,500	calc

Reference

- One BTU is sufficient to raise one pound of water by 1 degree F http://bbq.about.com/od/gasgrills/g/gbtu.htm
- One BTU is equal to 1 BTU = 0.29307107 watt hours – Google conversion
- Water weight 8.33 pounds per gallon http://ga.water.usgs.gov/edu/waterproperties.html
- It takes 8.33 * 1 BTU = 8.33 BTU to raise 1 gallon by 1 degree F.
- 8. 8.33 BTU = 2.44128201 watt hours - goggle conversion
- Assuming a 30F change in water temperature 1 gallon of water can absorb = 2.44128201 watt hours * 30 = 73.2 Watt hours worth of heat energy.
- 1 (cubic foot) = 7.48051945 US gallons – Google conversion
- Los angels June weather history http://www.wunderground.com/history/airport/KCQT/2006/6/15/DailyHistory.html?req_city=NA&req_state=NA&req_statename=NA
- Lancaster California July weather history http://www.wunderground.com/history/airport/KWJF/2006/7/15/DailyHistory.html?req_city=NA&req_state=NA&req_statename=NA
- On site generation – provides diesel consumption per KW at various efficiencies. - http://amarillo.tamu.edu/programs/irrigtce/publications/On%20Site%20Electric%20Generation.pdf
- It requires 144BTU to freeze one pound of water. Since one gallon weight 8.33 pounds it takes 1,199.5 BTU to freeze one gallon of water. Converted to Watt hours it takes 351.54 watt hours to freeze one gallon of water. http://irc.nrc-cnrc.gc.ca/pubs/cbd/cbd026_e.html

Storage tanks

- FRALO Plastech prides itself in the ability to continually foster innovative ideas in blow-mold plastic technology that ultimately results in the absolute best products for our customers and the environment. http://www.fralo.net/?source=SSI_Gaw and http://www.fralo.net/products_cisterns.asp

- **Septic & Sewage Tanks** As consumers and industries become increasingly accountable to meet ecological requirements for underground collection and storage of products and materials, Xerxes Corporation continues to be in the forefront with innovative solutions. Xerxes fiberglass-reinforced plastic (FRP) tanks offer a superior option - http://www.accutanks.com/?gclid=CM_2yqaRlokCFRNlYQod-guiNw
- **Septic (Waste) Tanks** See list below. We carry a complete line of below ground septic tanks up to 2500 gallons - 1500 gallon version cost $1299 – Fresh water $1500 gallon version $1380 - http://www.plastic-mart.com/class.php?cat=5 http://www.plastic-mart.com/?gclid=CLKf8dWQlokCFQxjYAodQjnkPA
- **National Tank outlet 2,500 gallon underground tank $2,266 - http://www.ntotank.com/25gabegrwata.html** http://www.ntotank.com/ **1500 gallon below ground septic tank $1,050**
- Build 6,500 gallon underground storage tank for $1,500 but 1981 $ - http://www.backwoodshome.com/articles2/ainsworth101.html
- Ampro tanks - http://www.tanksystems.com/

Thermal exchange tubing

- Radiant Heating and Cooling Panels – could be used to transfer cold energy into the cell system. http://www.twapanels.ca/

Black body radiant cooling

- Wikpedia explanation of blackbody radiation – http://en.wikipedia.org/wiki/Blackbody_radiation
- Black body radiation and heat exchange by answers.com. A person radiates about 95 watts - http://www.answers.com/topic/black-body
- Impact of Surface Characteristics on Radiant Panel Output P. Calvin Lindstrom Daniel E. Fisher, Ph.D. Curtis O. Pedersen, Ph.D. Student Member ASHRAE Member ASHRAE Fellow ASHRAE http://www.hvac.okstate.edu/pdfs/ASHRAE%20PDFs/Lindstrom_Fisher_Pedersen_98.pdf
- BLACK BODY RADIATION - MAX PLANCK http://www.launc.tased.edu.au/online/sciences/physics/blackbody1.html
- Radiative Cooling in Hot Humid Climates Aubrey Jaffer February 2006 http://swiss.csail.mit.edu/~jaffer/cool/cool.pdf
- Electromagnetic Spectrum and Principles of black Body Radiation http://www.geog.unt.edu/mcgregor/Electromagnetic%20Spectrum.and%20bands.pdf
- TITLE: Diurnal Heat Transfer Through Concrete – Includes good set of formula for calculating radiant heat loss. - http://www-sldnt.slac.stanford.edu/nlc/notes/Bowden_Eng/NLC_Menote-14-98rev0.pdf
- Passive cooling techniques – includes both convection and radiant – shows radiant cooling capability of 30 Btu per foot per hour. This converts to 198,000 Btu per 11

hour night with 600 sq foot. This equates to 58,028 watt hours per night. Our calculations show better than this due to more effective emissive characteristics, reduced amounts of undesirable convective warming and using convective cooling where it can help when the coolant temperatures are above ambient. http://www.azsolarcenter.com/technology/pas-3.html

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