Using the Night radiant system for cooling in areas where it is too dry for them to produce water.

Imagine staying cool and comfortable with an electric bill that is 1/10th your current bill.

Portions Patent Pending

XDOBS.COM 800-657-8745

Air conditioning for space cooling (HVAC) represents one of the largest and fastest growing consumers of electricity. It is also one of the largest indirect causes of greenhouse gas emissions.

Most renewable sources including Photo voltaic solar panels are not economical for use in large scale cooling applications however night radiant cooling can deliver the cooling needed at less than 10% the cost of PV and even more important can easily scale up for large scale use.

A recent proposal filed with the State of California showed renewable cooling has the ability to reduce California greenhouse emissions by 4.2 billion pounds per year with only a 10% market adoption. Imagine what a 80% adoption would do.

Night radiant cooling can provide these incredible savings while reducing peak loads which can save or defer billions of dollars worth of grid and generating upgrades especially in states already experiencing peak load related brownouts and grid failures.

We are currently installing customer funded test sites throughout the United States. Distributors and manufactures who fund these sites are being granted most favorable terms for exclusive relationships. Contact 800-658-8745 if you your organization is interested in hosting such a test or desires to negotiate for manufacturing rights in your region.

See also our related technologies http://a2wh.com and http://eedrt.com

Thanks, Joe Ellsworth
CTO of XDOBS.COM LLC

Background

This concept was originally developed on behalf of the R&D group inside one of a major cell company who is looking for options to reduce their $380 million per year electric bill while also extending the emergency run life when sites are forced to resort to backup power. Based on the calculations we ran it will save this cellular company about $2.6 billion in power costs over 15 years with an addition $1.4 billion in greenhouse emissions tax over a 15 year life while reducing greenhouse emissions by 2.3 billion pounds per year. In most areas it would sufficient chilling energy to completely replace 12.5KW of cooling being consumed by the average cell site. It is even feasible toe store enough thermal energy in chilled water underneath the 200 square foot cell building to carry the thermal load for 5 days. The Cell site is a unique beast because they have a lot of heat in the range of 300KWh per day being dissipated in room that is only 11'X20' in size. The cellular equipment can tolerate temperatures up to 140F which allows us to design a 90F cutoff for the cooling fluid which gives us a very high effective energy density from the radiant panels. The reduction in cooling related power consumption will also extend the run life of a site that currently has 48 hours of battery backup so that site can run for about 91 hours on the same batteries.

The same strategy can work for comfort cooling and while it will not deliver the same energy density for comfort cooling it does not need as much cooling due to the lower thermal loads. There are ways to combine this strategy with parabolic trough system absorption chillers to improve total performance year round.

Introduction

In Amman Jordan numbers during the on July 15, 2005 there was a high temperature of with 30.4 (86.72F) and a low of 22.2 (71.96F). Using a baseline of 12F cooling from the panels they chill the storage fluid to approximately 15.5C (60F). There are two main uses of the stored cold the first is direct thermal exchange the other is using high efficiency Geoexchange heat pumps. Direct thermal exchange is cheaper to operate providing greater total energy savings while the Geoexchange pumps allow stored fluid to utilize for of the total stored cold energy can allow the system to operate in climates that have extremely hot nights like Phoenix AZ.

When used for cooling the panels are modified to allow water to circulate through the radiant panels at night. The heat is dumped in the same way as the water system but the chilled water is circulated into a number of buried and insulated tanks. The tanks ultimately reach the panel temperature and represent thermal storage. In an ideal system the water from the tanks is circulated through radiant cooling panels mounted in the ceiling.

During the early part of the night when the temperature drops rapidly convection comes into play since the circulating water is warmer than ambient air. The convective assist allows the panels to shed more heat per sq meter than they can when used in pure radiant mode. It is quite conceivable to see the panels shed 90 to 140 watts per sq meter when used in pure radiant mode which can increase by 200% to 400% when using convective assist. There is a trade off in maximizing the thermal assist from convection versus maximizing radiant driven chilling.

Storage based calculation

Based on our calculations 1 Liter of water raised 1 Degree C contains 1.16 watt hours of stored thermal energy. If we take a 5,000 Liter tank (5 cubic meters) and chill it from 30.4C to 15.3 C it will contain 86,644Kwh worth of thermal energy. In reality we can not let the water reach the full 30.4C or it would be too warm for human comfort when used for direct thermal exchange. We can only allow it to warm to 24C which brings it's thermal storage down to 37,147Wh.

During an 11 hour night the panels would be able to shed in the range of 2750 Watt hours worth of heat per sq meter assuming 250 watt hours per square meter. To deliver

37,147Wh worth of cooling energy during a 11 hour night would require an average of 250 watt hours per sq meter it would require 13 square meters which we would double to provide a margin of safety 26 square meters (280 sq foot).

Square foot based calculation

The roof of a Moderate sized home of 140 square meters (1500 square foot) could deliver in the range of 385,000Wh of cooling which we will reduced by 40% for safety margin to 231,000Wh (231KWh). This would be enough to 33,000 liters by 6C (10.8F) and with the safety margin applied is only planning for 150 watts per square meter.

A minimum of 5 days worth of storage is recommended which would make the recommended storage for the 140 square meter structure 165,000 liters.

Thermal capacity of storage tank	
Tanks Size in Liters	5000
Tank size in cubic meters	
Tank size in cubic foot	
Beginning temp in C	30
ending temp in C	20
Delta between temperatures C	10
stored Wh thermal energy	58,043
Energy available on a given Roof	
Roof size in sq meters	140
Effective Watts heat shed per sq meter	250
Watts per entire roof	35,000
Length of radiant period (night) hours	11
Wh shed per entire roof per night	385,000
Safety margin reduction	40%
Adjusted Wh shed per entire roof per night	231,000
Safety adjusted watts per sq meter shed	150
Thermal storage requriements for given roof	
Target cooling degrees in C	6
Target cooling degrees F	10.8
Wh to cool 1 liter to target	6.96512
Liters of fluid cooled to target per night	33,165
Liters converted to cubic meters	33.2
Height of tank in meters	2.0
Length of sides for 2 meter high tank	4.1

Cooling energy versus energy needed

Residential cooling

Several reports show that average homes in AZ and Florida ranging from 1200 to 1500 square foot consume from 31Kwh to 55Kwh per day in air conditioning. Using the 31KWh for 1500 square foot home provides a very conservative base. 31KWh per day at EER 10 converts to 310,000BTU that must be removed from the house. 310,000BTU equates to 90,852 Watt hours or 90.8KWh

Another way to derive total BTU heat load per day is the industry average of 502 square foot per Ton of air conditioning indicates a 3 ton air conditioner. If the 3 ton air conditioner is ran for 8 hours per day it will displace a total of 288,000 BTU per day. At EER 10 it costs 1.2KW per ton of air conditioning per hour which indicates a total power consumption of (1.2 * 3 * 8) = 28Kwh per day. The difference is assumptions is represented in more than 8 hours per day and lower EER ratings for some of the test houses in Florida and Arizona

As mentioned above the 140 square meter home will be able to shed 231KWh on a clear night while the same average home air conditioner is only having 90.8KWh worth of heat energy removed per day which gives the system a error margin of 254% the surplus cooling is even higher when used the 502 sq foot per ton rule is used.

Commercial building cooling

Commercial buildings tend to have higher internal heat loads and taller walls which increase heat gain from the sides. The industry average for commercial office space runs from 2.5 to 3.5 tons per 1000 square foot. Even at the higher number of 3.5 tons per 1000 square foot the numbers still work out for single floor buildings.

A 1,000 square foot (93 sq meters) of night radiant panel at an estimate of 150 watts per square meter and an 11 hour night will remove 153,450 watt hours (523,593 BTU) of energy per night. An average office building operating for 9 hours per day with 3.5 tons running continuously the HVAC system will move 378,000 BTU (110780 Wh)out of the building which gives the night radiant system 1.38 times the mandatory capacity. The additional 0.38 will be stored in thermal tanks to carry the system for days when weather conditions prevent adequate chilling.

The tank requirements to store 378,000 BTU of energy using a 8C (14.4F) heat differential is 11,928 liters (3151 gallons). This would be increased to about 10,000 gallons to provide 3 days of thermal storage.

Super warehouse cooling

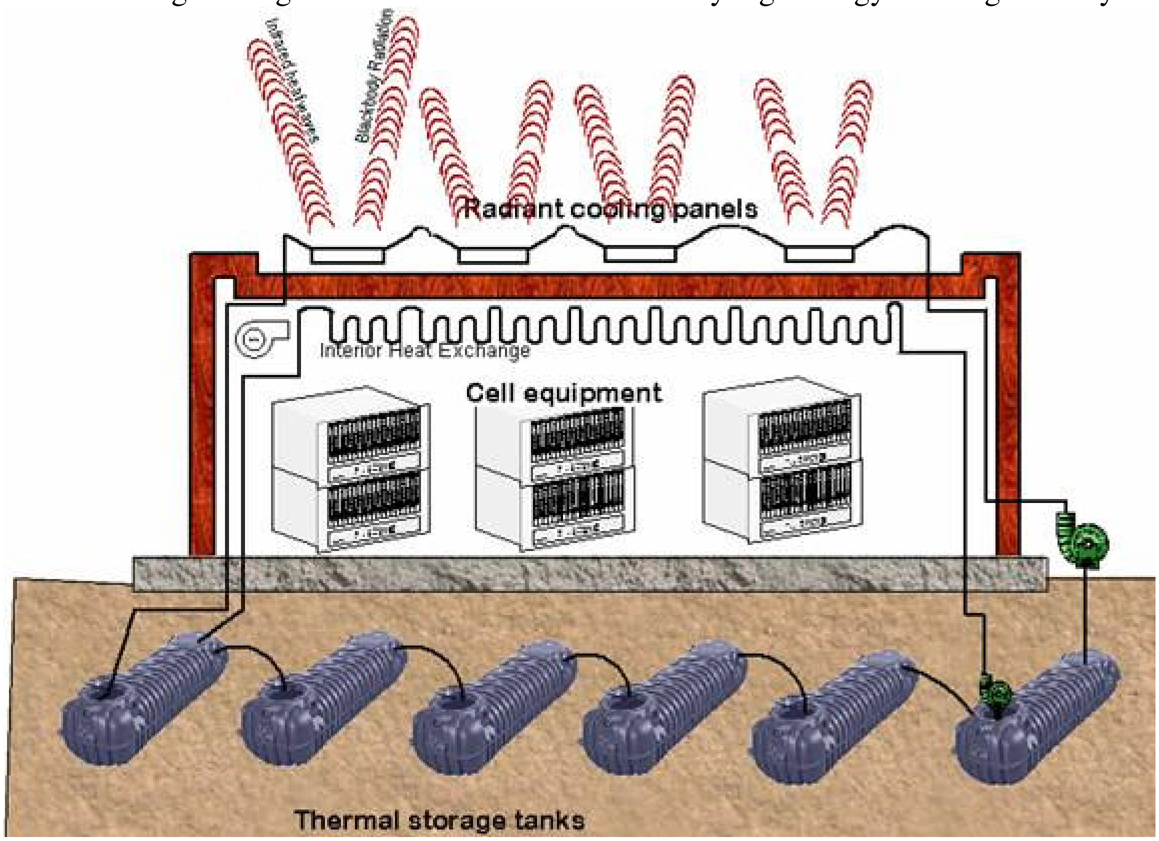
Wal-Mart super centers average 186,000 square foot and in southern states typically mount 450 tons of air conditioning. Estimating that these stores keep these air conditioners active 13 hours per day average they are moving

Wallmart Super center analysis	
Wallmart size sq foot	186,000
size in sq meter	17,280
Ton of air conditioning	450
hours active	13
BTU displaced per day	70,200,000
Watt hours moved per day	20,573,589
Night radiant estimated watts per sq	165
Avg hours of cooling per night	11
Watt hours chilling per night	31,363,200
Margin of excess chilling	1.52
Depth of storage tank in meters	2
Cooling degrees in C	8
cooling degrees in F	14.4
Liters of water required for storage	3,377,171
Gallons of water required for 1 day	892154.1994
Cubic meters of water	3377.171034
Size of tank meters per side	41.1
Size of tank as % of store size	0.238%
Assumed EER of Wallmart air condit	14
BTU per hour	5400000
Watts consumed per hour	385,714
KWh consumed per day	5,014
Estimated energy savings percent	93%
KWh energy saved per day	4,663

As shown in this spreadsheet the Wal-Mart super center could produce 1.5 times the amount of cooling they are currently using from their 450 ton of roof mounted air conditioners. This example was based on a southern Texas Wall-mart marts which have a high heat load compared to stores in cooler states like Utah, Colorado, Washington and Oregon

Illustration of Radiant panels cooling cell sites.

Cell sites are unique because we can allow them to heat the cooling fluid up to 90F before loosing cooling effectiveness. This allows a very high energy exchange density.



Note: Intelligent system that uses thermal energy one tank at a time is not show for sake of simplicity.

The physics why it works

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. The power of heat exchange by convection is generally much more powerful than the amount of heat exchanged radiantly however it is possible to minimize convective warming by careful selection of shapes and materials.

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 that 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. XDOBS has developed a proprietary strategy that overcomes much of the convective losses associated with the design of the units the DOE funded for study which allows the XDOBS units to deliver below ambient cooling in a broader range of conditions. Theory indicates the maximum radiant heat transfer of up to 400 watts per square meter is possible when no heat is absorbed by surrounding objects and there is little or no convective warming and the air is relatively dry. XDOBS design optimizes to create these conditions although ambient humidity can not be controlled.

XDOBS approaches use a class of thermal plastics which have very high long wave infrared transmission characteristics, high infrared Emissivity which is coupled with relatively high R value insulating characteristics. This allows infrared energy to be transferred out of the chilling panels while minimizing the transfer of heat gained at the surface via convection through to the interior surface. In addition the high Emissivity tends to shed any surface heat gained rapidly. In low wind conditions the surface temperature can actually be 2 to 5F below the interior temperatures however in moderate to brisk winds the interior surface will be substantially below ambient while the exterior surface will be either at or only a couple degrees below ambient.

Our design utilizes specialized approaches that allow us to deliver more than 120 watts per square meter however even with these approaches it is unlikely to reach 400 watts per square meter without additional tactics. One of the tactics used by this solution is the heat absorbed by the storage fluid during the day exchanged during the early night to using a convective assist. The convective exchange continues to occur as long as the fluid temperature is above ambient. Once storage fluid reaches ambient the system reverts to radiant only mode which forces it to operate at the lower rate of shedding heat. When operating in convective assist mode it is possible to increase watts shed per square meters by several times. A special manifold and micro controller valves allows the storage to be segmented which allows thermal differentials to be maximized in individual sub tanks which allows us to maximize the convective exchange.

Even though standard night radiant panels benefit from convective cooling whenever the cooling fluid is warmer than ambient. They are specially shaped to trap a stagnant layer of cold air which as an insulators whenever the cooling fluid is below ambient. Whenever the cooling fluid is above ambient it causes surface warming in the radiant panel which warms the local air which has no choice to rise and be replaced by new cooler ambient air. In larger systems a subset of the panels is specifically optimized with to maximize convective transfer even though for those panels it decreases the performance slightly when operating in radiant mode at near max cooling.

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.

Using for Load balancing

Most buildings will include standard HVAC compressors for use in times when the night radiant system is not delivering sufficient cooling energy. These HVAC systems can be used in the earlier part of the days reserving the stored cold energy for the hottest part of the days. This strategy effectively removes the electrical load from the equipped buildings during the peak demand period.

In most areas sufficient stored cold can be developed to remove over 90% of the electricity demands for all cooling periods but it is reasonable to size the system to provide 90+% of the cooling for 4/5 of the cooling season knowing that it may be necessary to use some traditional HVAC energy during the hottest 1/5th.

Combined with Parabolic concentrators absorption chillers

Parabolic concentrators and absorption chillers or compression chillers as is used by http:://eedrt.com could be considered competitive with the night radiant chilling. We consider it more complementary where the strengths of each can bolster the other.

The night radiant system is likely to be cheaper per BTU shed due to the simple fixed panel design versus the tracking parabolic collectors which by definition must be stronger, more mechanically complex and require more electronics. The Night radiant chillers are limited to a lowest possible temperature to which they can chill the thermal storage fluid in a given climate. The parabolic troughs + chillers may cost more per BTU but they can reach lower temperatures. That means an ideal marriage is to use the night radiant chillers and ground loops to shed as many BTU as possible and then use the absorption or compression chillers to maximize the stored cold.

The chillers would be used in two modes each in conjunction with the stored cold.

We could use the night radiant system obtain the maximum chill temperature possible during the night and then have the parabolic troughs driven chillers take over further chill the fluid during hours from 8:00 to 10:00 when most buildings are running on the thermal momentum from the night. Depending on the size of the system this should be

able to push temperature in the storage tanks down several more degrees and extend the effective life of thermal storage.
When the building becomes warm enough to require cooling chillers switch over to chilling fluid from the cold storage system prior to entering the building. The fluid entering the chillers is coming from the thermal storage system at a much lower temperature that it would normally be returning from the building which means the chillers can deliver the needed cooling while moving fewer total BTU. The lower entrance temperature means the chiller can chill a larger volume with the same energy input.

During the day whenever the parabolic driven chillers are capable of delivering more cooling energy than needed by the building the excess is used to continue chilling the stored cold reservoirs.

As night approaches and the energy from the parabolic troughs tapers off the absorption chiller would be bypassed and fluid used directly. A subset of the stored cold during the day would have been reserved in a isolated tank which was kept ad the morning cold levels which will allow it in conjunction with the cooler night temperatures to provide adequate cooling in a direct thermal exchange mode.

In extremely warm areas like Phoenix during the early evening a Geoexchange heat pump would be ideal to take over the job of the chiller when the fluid temp is below ambient but too warm for direct thermal exchange and the parabolic troughs are not receiving significant solar energy. Some solar powered absorption chillers also have the option to augment their heat source with natural gas or hydrogen which would allow their use to be extended into the night in lieu of the Geoexchange pump.

The radiant cooling panels can start providing chilling energy during the late afternoon provided they are fully shaded and protected from indirect radiant gain from the south and west sun. This shade can extend the system operation by as much as 3 to 5 hours per day. The daytime operation can be increased by adding a slight tilt towards the northern sky.

One of the effective mechanisms for providing the shade is using parabolic solar thermal collectors which capture a majority of the direct solar radiation from the south and west and in doing so provide shade for the night radiant collectors.

Winter heating in moderate climates

The systems cooling surface area can be specifically colored to encourage heat gain during sunny days. This can easily yield temperatures above 100F which can be stored in the same thermal storage tanks. The warmed fluid can be circulated through the same radiant panels or ideally a radiant floor to deliver direct warming.

There will be convective losses which limits the efficiency of these panels when used for heating especially in cold weather however these can be offset by adding 2 mill solarex cover to the top of the wind guard. The solarex allows over 90% of the solar heat energy to enter and is very effective in capturing it to minimize convective losses. In the summer there is less solar heat available due to solar tilt but it is reasonable to expect 250 watts per square meter for at least 5 hours per day on sunny days.

For a 140 sq meter roof this equates to 35,000 watts per hour or 175,000 watts per day. These collectors are not optimized for heating so they will only capture the thermal energy at about 20% to 30% efficiency and at 20% this equates 35,000 watt hours of captured heat energy. 35,000 Wh converts to 119,424 Btu.

> Note: The total energy available during winter months changes by region. Locations near the equator tend to have longer days and greater amounts of solar energy available.

In moderate climates and well insulated buildings this will provide all the heating energy needed. In harsh northern climates it can offset a portion of the heating load during the day.

Freeze prevention must be practiced in areas where it is a risk. See the secondary heat exchanger below.

Limitations on viable areas of use

The night radiant system is capable of achieving 10F to 14F worth of chilling below local ambient conditions. In exceptional conditions it can reach 20F below ambient. Assuming that our target for the stored cold fluid is 65F and asserting that we can reach 14F worth of chilling below ambient that means the nighttime temperatures must reach (65 + 14) = 79F for the system to work in a direct radiant cooling mode. Ideally lower night temperatures are ideal.

This would seem to imply that it would not work in the hottest summer months in Phoenix, Arizona however this is not entirely accurate. The peak temperatures on July-15 2006 was 111F which by 11:00pm had dropped to 95F and a low of 93F at 6:00 am. Using the 14F average our thermal storage fluid would have reached 81F. 81F is still above the human comfort level however a Geoexchange heat pump could use water at this temperature to provide cooling to 75F and as the day progresses it would expend 80% less energy than is needed for an air exchange system to deliver equivalent cooling.

Combined with Geoexchange Heat pump

Using a Geoexchange heat pump with strategy can allow the nigh chiller system to work in even more efficiently by shedding a portion of the accumulated heat into the ground before it is returned to the storage tanks.

During the bulk of all days the Geoexchange heat pump is dumping heat from the structure into stored cold in the fluid reservoir. This is in contrast to a normal HVAC system which is dumping heat into the warm ambient air.

The Geoexchange pump is only working to shed heat from the building into the stored cold reservoir which is at anywhere from 50F t to ambient whereas the heat being shed into the air is working against ambient. The net effect is the Geoexchange heat pump is doing much less work to exchange the heat until the fluid reaches ambient. Most HVAC air conditioners shed their concentrated heat from the building into the air at temperatures from 120 to 150F. In this mode this fluid can be routed directly through the night radiant collectors which will dump shed a portion of the heat even during the day.

Rather than shedding heat into 90F air it is shedding it into 50F to 80F fluid which means it does not need to expend as much energy in the thermal transfer which dramatically lowers the total air conditioning costs. In addition the Geoexchange pump can continue shedding energy even as the thermal reservoir reaches 110F which allows the radiant panels to kick in and shed heat energy even during the day.

The night radiant system presents options for extreme energy efficiency that simply do not exist with a pure Geoexchange solution. In effect when the water is cold enough to deliver sufficient cooling directly to the radiant cooling panels then the night radiant system can use a low powered circulation pump. Only when the fluid has warmed enough that it is no longer delivering sufficient cooling to the radiant cooling panels does the heat pump need to activate and even then it will be shedding heat into water that starts at 75F rather than the air which may be a 90F or above. This means that on most days of most seasons the geothermal heat exchange pump will never activate and even when it does it will be expending less energy perhaps 70% less energy an equivalent air exchange pump due to the lower ground input temperature. The net savings should be over 95% reduction in total energy consumption.

Combined with Geoexchange ground or vertical well loop

A Geoexchange ground loop can be used with to good advantage in conjunction with the night radiant systems. In effect the ground loop can be used chill the thermal fluid to the coldest temperature the ground can provide and then the Night radiant collectors take over and provide the maximum chilling they can provide. Together they deliver more fluid chilled to a lower temperature than either could alone.

As the cooling fluid is routed through the structure being cooled it picks up heat which is normally returned directly to the storage tanks which warms the entire thermal mass over time. By routing the warmed fluid through the ground loop prior to returning to the tank a portion of the energy can be dumped which allows the cooling energy in storage to last longer.

In addition when a Geoexchange pump operates it can generate fluid temperatures over 120F. By circulating this fluid through the ground loop prior to returning to the tank a majority of this heat can be shed. For example if the ground loop can lower the fluid temp 120F to 75F it will prevent 109Wh and only 58Wh is returned to the storage tank assuming the fluid started at 51F. If the entire mass of 1000 tank is circulated 1 time during the day this represents a reduction of 109KWh that does not need to be shed through the night radiant collectors the following night. In addition the lower amount of energy returning will keep the fluid colder for longer which saves on electrical energy consumed by the Geoexchange heat pump.

Geoexchange heat pumps like all others are rated by the BTU they can shift per hour however a little understood fact is that the same pump when operating with colder input fluid does not have to move as many BTU which allows it to deliver more fluid chilled to the target temperature or to deliver the same amount of fluid with less energy. In the worst case conditions the stored fluid will never rise above the temperature of the ground loop which means that even when all stored cold has been exhausted the system will still be operating in a mode that saves 30% to 50% of the energy consumed by the most efficient air source heat pumps.

Since the ground loop will quite often deliver fluid similar to the average summer night temperatures the night radiant collectors will seldom receive fluid that is above ambient to chill which means they will be working predominantly in radiant only mode which allows certain optimizations that maximize energy shed in that fashion.

During extremely hot spells when then the stored cold is expected to be exhausted the Geoexchange pump can be used earlier during the day feeding directly from fluid coming out of the ground loop preserving stored cold for latter in the day when peak loads hit which generally occurs between Noon and 3:00PM. The stored cold kicks in during these peak hours and can either be used in direct thermal exchange mode which eliminated the need to run the Geoexchange heat pump at all or even if the Geoexchange heat pump is used the water being fed into will be 10F to 20F below the ground loop temperatures which means it is consuming less electricity to deliver the necessary cold.

Contrasted with Geoexchange and ground loop only systems

In some of the colder locations around the world A Geoexchange pump with a ground loop may deliver all of the needed cooling energy. This is particularly true of parts of the Northeast USA and parts of Canada where the ground temperature is sufficiently cold to drive a direct chilling even without the use of the Geoexchange heat pump.

.However world wide averages only show a 30% savings when using a Geoexchange ground loop system when compared to the best air exchange systems. Even the best available systems rarely save more the 50% as was published by the USA federal government in a memo encouraging federal agencies to use the Geoexchange systems.

Our goal is a 90% reduction in power usage which is 300% that provided by the average Geoexchange ground loop system.

In areas with higher average ground temperatures the ground loop will not deliver fluid that is adequately cold to gain the maximum benefit from the Geoexchange pump which will need to work harder to shed heat from the building into the ground loop. In many areas installing a sufficient amount of ground loop can be difficult or impossible whereas the storage tanks mentioned require much less space and can be used even in small yards.

Compared to Insulation and better windows

The least expensive way to increase the performance of just about any HVAC system is to increase ceiling insulation followed by ensuring windows and doors are leak free.

These can be combined with increased wall insulation and high efficiency windows.
Of all the investments those which decrease air leaks around windows and doors provide the highest payback.

The general advice is to plan for adding upgrading attic insulation to at least R30 and wall insulation to R19 either prior to concurrent with installing the night radiant system. With this said it is relatively complex to calculate the relative payback from these systems and depending on the area if may actually be more efficiency to stop at R13 in the ceiling and add more radiant panels.

More insulation and high efficiency windows will generally reduce the rate which heat from the exterior moves to the interior and as such it will allow the stored energy in the thermal storage tanks to last longer.

In contrast the night radiant panels also provide a shaded air gap over the ceiling area. When the surface of the roof is directly exposed to the sun it can easily increase that temperature to over 180F with temperatures over 220F being relatively common. Even with great insulation a portion of this heat will leak through into the structure.

The night radiant panels blocks a majority of the sun from ever reaching the roof structure and the air gap between the panels and the roof surface makes an effective convective system for moving the away from the roof surface using convection. As a result the roofing surface under then radiant panels remains very close to the ambient air temperature which can be over 100F cooler than a roof directly receiving this solar energy. This dramatic reduction in surface temperature decreases the amount of thermal energy available to leak through the insulation. This effect combined with the night chilling effects of the radiant panels can make them more cost effective than adding additional insulation once the reasonable minimums are already installed.

One of the key laws of thermo dynamics indicates that the higher the temperature differential between the interior surface and the roof surface the more heat will leak through any insulation. By reducing the temperature differential between the surface of the roof and interior of the building we dramatically reduce the amount of thermal energy leaking in through the roofing insulation.

Properly installed photovoltaic solar panels can provide similar benefits however compared on a square foot basis the night radiant panels actually deliver more usable energy at a much lower cost per square foot. Reflective roof coatings can also provide some of the same benefits however in the best case conditions more energy will still make it to the reflective roof and the reflective roofs do not provide the air gap system which minimizes energy transference. In addition several studies have shown that reflective coatings loose their effectiveness quite rapidly as dust accumulates so while they can start at reflecting over 80% of the incoming heat energy they rapidly degrade which the night radiant panels do not do.

Freeze and Freeze resistance

For systems in areas where they provide cooling energy year round freezing is of limited risk. It actually requires removing 73Wh of energy do chill one gallon of water by 30F. It requires removing 351 additional watt hours (5 times as much) to freeze the same water. For a system designed for to reduce water temperatures by 14F with a 3 day thermal storage capacity would require operation in below freezing conditions for at least 15 days before freezing became a risk and that is only if none of the store cold is used for cooling purposes.

Freezing of the water in the night radiant chillers and associate pipes is a larger risk. This risk can be minimized by operating the circulation pumps which circulates warmer water from the tanks through the collectors and never stays still long enough to freeze.

In areas where extended periods of cold will occur there are two primary options.

- The first option uses a computer controlled valve which allows all water to drain out of the chilling panels and pipes into the storage tanks.
- The second option uses antifreeze in the main chilling loop and a heat exchanger in the tanks which transfers the cold energy from the loop into the storage tanks. This option allows the chillers to remain flooded but not at risk of freezing. It has the benefit of allowing the system to operate until the water in the tanks has frozen to a thick slush. The amount of antifreeze is relatively low compared to the volume of water and there are environmentally friendly antifreeze solutions readily available. The disadvantage is substantial additional cost in the form of heat exchangers needed in each tank.

- The Third option is to use a salt or anti freeze solution in the thermal storage tanks which is circulated through the night radiant chillers. This can be used to allow the fluid to be chilled below the freezing point.

The most efficient use of the extra freezing energy is the secondary heat exchanger which safely allows a fraction of the water in the storage tanks to be frozen however for most space cooling applications the seasons when sufficient cold energy is available to cause freezing are also the seasons when the additional energy is unlikely to be needed. For this reason the primary suggestion is use a computer actuated solenoid to drain the flooded collectors during freezing conditions.

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

Energy calculations

- At EER 12 it will cost 1KW to deliver 1 Ton of air conditioning - this is calculated as 12/EER - Converting KWh to Tons - http://www.engineeringtoolbox.com/cop-eer-d_409.html
- 1 Refrigeration Ton = 12,000 Btu per hour. EER is calculated at (BTU moved per hour) / Watts consumed. Example 10,000BTU Moved in one hour at cost of 1000

watts give EER of (10,000 / 1,000) = EER 10. http://www.engineeringtoolbox.com/cooling-loads-d_665.html

- COPD = Watts of heat moved per Watt consumed. EG: 4 watts moved for 1 Watt consumed = COPD of 4. http://www.engineeringtoolbox.com/cooling-heating-efficiency-d_410.html
- Heat load from moving water is calculated in BTU moved per hour which is equal to = 500 * (Flow rate in gallons per min) * (temperature difference in F). Example 10 gallons per minute that is 20F colder hot side heat exchanger will move 500 * 10 * 20 = 100,000BTU per hour. A Ton of cooling is 12,00BTU per hour so 100,000BTU per hour = 8.3 Ton. At EER 10 this is equivalent to burning 10,000 watts.
- http://www.engineeringtoolbox.com/cooling-loads-d_665.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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Background

- Climate information on Jordan http://www.memr.gov.jo/GENERAL%20INFORMATION%20AND%20ENERGY%20SITUATION%20IN%20JORDAN.htm

Air conditioning sizing

- Bigger is Not Better: Sizing Air Conditioners Properly. Discusses various approaches which yield proper air conditioner sizing. Industry average is 502 square foot per ton. http://www.public.iastate.edu/~lhodges/house.htm
- Study showing costs and relative savings of various home upgrades as compared against each other - http://www.engineering.sdsu.edu/~kwalsh/walsh_files/Cost-Benefit%20Analysis%20Walsh%20Bashford%20Anand.pdf
  Very good white paper on cost and payback analysis for power reduction and efficiency improvement for air conditioning. This article show that during the hottest

day of the year in phoenix the average 1000 to 1500 square foot house will draw from 2KWH in the cool part of the day up to 3.5KW during the hot part of the day. Averaged out and summed for the day shows this type of house consuming 60KWh per day -
http://www.homeenergy.org/archive/hem.dis.anl.gov/eehem/94/940311.html
http://www.homeenergy.org/archive/hem.dis.anl.gov/eehem/94/940509.html

- Reflective roof and impact on utility bills. Homes with no insulation total electricity consumption decease by 40% homes with moderate insulation saw utility decreased by 20%. Homes with good attic insulation and efficient air conditioners saved 11% – Average Florida homes use 4,400Kwh for air conditioning per cooling season.- A well insulated home was using 38.8KWh per day with tight ducts http://www.public.iastate.edu/~lhodges/house.htm
- http://www.mwi.gov.jo/home/Tuesday/bassam_sunna.pdf - Geothermal energy in Jordan
- http://www.ju.edu.jo/confernces/gcreader/abstracts.htm - Global conference for renewable energy for the desert.
- http://cevre.cu.edu.tr/annex14/general-staterep-final.pdf - Cooling in all climates with thermal storage
- http://www.ezsim.com/hrpaper1.htm - Formula for calculating heat gains in structures based on average monthly temperatures.
- Cooling calculator - http://www.cooloff.org/cgi-bin/ac99cap.cgi
- Heat calculation software - http://www.hvaccalc.com/main.asp
- Space heating and cooling estimates - http://www.nyseg.com/nysegweb/webcontent.nsf/Lookup/NYSEG%20Home%20Energy%20Use/$file/Home%20Energy%20Use%20Broc.pdf
- Electricity consumption averages - http://www.pse.com/solutions/pdfs/1236_RES_EnergyCostGuide.pdf
- Introduction for hydronic heating http://www.slantfin.com/he2/
- http://www.pge.com/docs/pdfs/res/rebates/central_air/TechSheetEER.pdf - Air conditioning efficiency calculations and impact on costs. Both EER and SER are important, EER 10.52 system at 33,000BTU draws 3,420 watts.

Geoexchange / Geothermal

- Central Air-conditioner Intelligent Power Efficiency System Selecting and Installing a Geothermal Heat Pump System
- http://www.alibaba.com/catalog/11562573/Central_Air_conditioner_Intelligent_Power_Efficiency_System.html
- Heating and Cooling Efficiency of Geothermal Heat Pumps - http://www.eere.energy.gov/consumer/your_home/space_heating_cooling/index.cfm/mytopic=12670
- Incentives for Geoexchange systems - http://www.geoexchange.org/incentives/incentives.htm
- USA Federal government recommendations for ground source heat exchange systems - A 25,000 square foot facility in Washington DC will consume 45,000KWh for cooling with standard 10EER air conditioner or 31,200Kwh with the agency

recommended 14EER ground loop or 22,200Kwh with the best available ground loop - http://www1.eere.energy.gov/femp/pdfs/groundsource_heatpumps.pdf

- Geo exchange system over view Claims that mm BTU from geo exchange costs $5.86 while the same from nautral gas costs $7.14 http://www.soundgt.com/economics.htm
- Geo exchange heat pump organization - http://www.geoexchange.org/press/contractors.htm
- 44% of all energy usage in homes if for space conditioning - http://www.gainesville.com/apps/pbcs.dll/section?category=NEWS&template=wiki&text=Energy_conservation

