BJS-BM08

Pool House Energy Analysis & Modeling

A Major Qualifying Project
submitted to Brian J. Savilonis
of the
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in partial fulfillment of the requirements for the
Degree of Bachelor of Science
by

Brendan McMasters
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Abstract

Greenwood Memorial Bath House is one of the state's leading training facilities for swimmers, but a lack of funding and a deterioration of the building have caused the bathhouse to become highly energy inefficient. This project used data logging thermometers and infrared temperature readers as well as fluid modeling software to suggest energy saving methods that could be implemented in order to save money heating the bathhouse and pool. A multiphase project is proposed using solar energy, insulating measures, and energy recovery devices to save money on heating fuel and to decrease the use of fossil fuels and electricity.

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Introduction

The Greenwood Memorial Bath house, built in 1914, is the oldest active municipal pool in New England. This pool is currently the training location for the Lady Wildcats who held 15 consecutive state championships between the years of 1994-2008. Even though the bathhouse has produced Olympic medalists, the physical state of the pool is currently in need of work. The building is being heated using steam heat from oil-fired boilers, however most of the heat being produced is being lost through faulty physical building properties as well as the buildings age. The bathhouse has presently looked into ideas for the future involving renewable solar energy, but unfortunately being a city building there is little to no funding for the renovations. The goal of this project was to be able to determine cost effective methods and renovations that can be used to help cut back on the heating costs. These costs were then organized into phases to be able to give an idea of how the system as a whole will maintains a good level of energy efficiency. They are also setup in such a way that if the funding does not exist to continue through all phases, the building will still be saving money and the payback periods will still stand.

Background

Building Description

Greenwood Memorial Swimming Pool House contains a volume of $4248M^3$, $231m^2$ of floor space along with a pool surface area of $225m^2$ and a pool volume of $675m^3$. The building was constructed in 1915 and consists mainly of concrete and other un-insulated building materials. All heat for the building can be broken down into two separate systems: the space heating and pool heating. The space heating system consists of a single steam boiler, running on #2 oil, that provides heat to 4 Beacon-Morris steam unit heaters. The pool heating system consists of one oil-fueled boiler that keeps the pool at a constant 84°F.

Walkthrough

A walkthrough of the site was conducted before the project began in order to decide on the appropriate model layouts and check for any visible flaws with the building. This divided the building into a six different areas, which were, the upper pool area, lower pool area, basement, outside, entryway, and second floor office.

Lower Pool Area

The main areas of heat loss for this section of the building are the lower windows. These eighteen windows are primarily made from block glass. The glass block, or glass brick was developed in the early 1900’s as a cheap way to maximize sunlight indoors and also to decrease heat loss [3].

Figure 1-Lower Windows

These blocks are assembled much like bricks and consist of a 3” of solid glass thickness. In this building they are assembled in two layers to create a window.

The downstairs windows are drafty due to leaky edges and worn out seals. This rate can be estimated at around 1.81 CFM per foot of crack [4]. Since these windows have a 10 ft perimeter, the infiltration rate is estimated at 326 CFM for all of the windows.

A second contributing factor to the energy balance for the building is the 4 Beacon-Morris HB-60S steam heaters.

Figure 2-Steam Box Heaters

These heaters are able to each provide 54,000 BTU per hour at full capacity as seen in the specification sheet in appendix B.

Other heat fluxes seen in this area have to do primarily with the pool water itself. The water is losing heat to the surrounding area by conduction, evaporation, and radiation. Other than the heat from the Beacon-Morris steam heaters, this is the only other major contributing heat addition to the pool area.

Upper Pool Area

The upper pool area was the second area analyzed and also in the walkthrough. Main areas of heat transfer include the roof, second floor windows, skylights, and vents.

The second floor widows in this area are double paned windows with a ½ inch air space as seen in figure 3.

Figure 3-Upper Windows

A main concern for these windows is that most of them are damaged or broken through the outer pane. The infiltration rate is assumed to be 1.81 CFM per foot of perimeter, same as the lower windows

A second area of heat loss is through the skylights and roof. The roof is constructed of wood and surrounds a very large surface area of skylight.

Figure 4-Skylights

As seen in figure 4, most of the skylights have cracks and leaking seals. There are unused steam heated pipes in front of the windows. It was observed that water was condensing and dripping from the roof and support structures. This was mainly because there is currently no dehumidification system in the building.

Also observed in this area are the roof vents, which have old seals and are allowing air to leak though them. Some of these vents are also malfunctioning and are unable to close, leading to more air infiltration.

Basement

The third area observed in the building was the basement, which contains both boilers for the steam heaters and the pool, as well as the water treatment system(see figure 5).

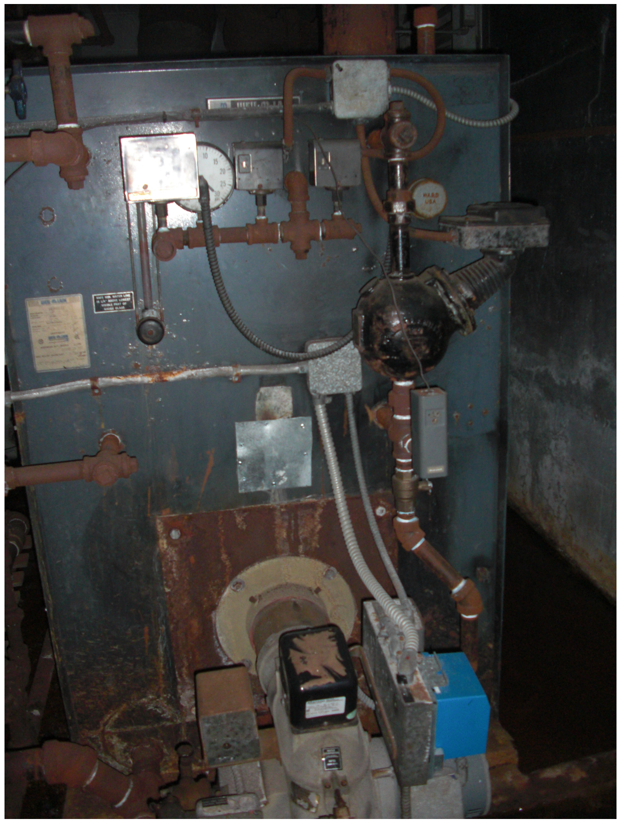


Figure 5-Main Boiler

The main area of concern for the basement is that the piping for all heating systems has had the insulation removed. This is causing heat loss to the air in the basement through convection and radiation.

This area also contains a room directly underneath the pool. The pool is completely surrounded by 6 inches of concrete, which is un-insulated allowing heat loss to the basement through convection.

Entryway and Second Floor Office

The 4th and 5th areas observed were the entry way and second floor offices. These areas are provided steam heat from the main steam heater in the basement.

As seen in figure 6, steam radiators mainly provide the heat. It was also observed that there are leaks in the roof, which cause heat loss through infiltration.

Figure 6-Entrance Way Radiators

Outside

Property outside the building was observed in order to take measurements for possible solar panels or pipe runs for energy recovery. It was observed to have an area of 1000 square meters for solar panels and a distance of approximately 200 meters between the Memorial Pool House and neighboring ice skating rink. This 200 meter distance is used for heat loss calculations through underground pipe in a potential energy recovery system.

Heat Transfer

In order to analyze and understand the goals and results of this project it is crucial to have a good understanding of the three modes of heat transfer, conduction, convection, and radiation. All three of these are used to calculate the total heat flux of the system.

Conduction

Conduction is the most basic form of heat transfer with transfer occurring between 2 surfaces in contact. This concept depends on 4 variables, temperature difference, surface area, conductive coefficient, and material thickness [2]. These variables all come together in Fourier's law that states that Q, or flux, is:

$$-kA\frac{dT}{dx} = -kA\frac{(T_B - T_A)}{L} = kA\frac{(T_B - T_A)}{L} = Q$$

In this one-dimensional equation if T_A is equal to T_B then there will be no heat transfer between the two materials. Also if the thickness of the material is too high there will be negligible heat transfer.

Convection

Convection is the second mode of transfer and can be broken down into 2 categories, free convection and forced convection. The main focus of this project is free convection because there is no external flow indoors to act on the surfaces. Free convection is defined as fluid next to a solid boundary causing circulation because of the density difference resulting from the temperature variation throughout a region of the fluid [5]. This type of heat transfer is mainly governed by the equation:

$$\frac{q}{A} = h\Delta T$$

This equation is also referred to as "Newton's Law of Cooling" [5]. In the equation heat flux is determined by multiplying the change in temperature by the area 'A' and the convection coefficient 'h'.

Since there is heat being added to a fluid through convection, this mode of heat transfer can cause turbulence in the air. This turbulence increases mixing of the air in velocity of the air and accelerates heat loss due to convection.

Radiation

Radiation is the third and final mode of heat transfer, which unlike conduction and convection is the only mode of heat transfer that can occur without direct contact of a fluid or surface. Radiation, like convection and conduction is governed by an equation for heat flux:

$$Q = A\varepsilon\sigma T^4$$

Emissivity is the ratio of energy radiated by a material compared to that of a black body at the same temperature. The Boltzmann constant relates energy at the particle level to the temperature at the bulk level of a material [6].

Data Collectors

There are a variety of data collection devices that are used to be able to help calculate the energy efficiency of a building. The main types of data being collected for energy efficiency and heat transfer are ambient temperatures, surface temperatures, and humidity.

Temperature Loggers

The temperature logger being used for data collection is the 3M TL series temperature logger. This logger has a wide range of functionality as well as decent raw data storage size and other options. The accuracy of the device is +/- .5°C and the resolution is .1°C. An example of this device can be seen in figure 7.

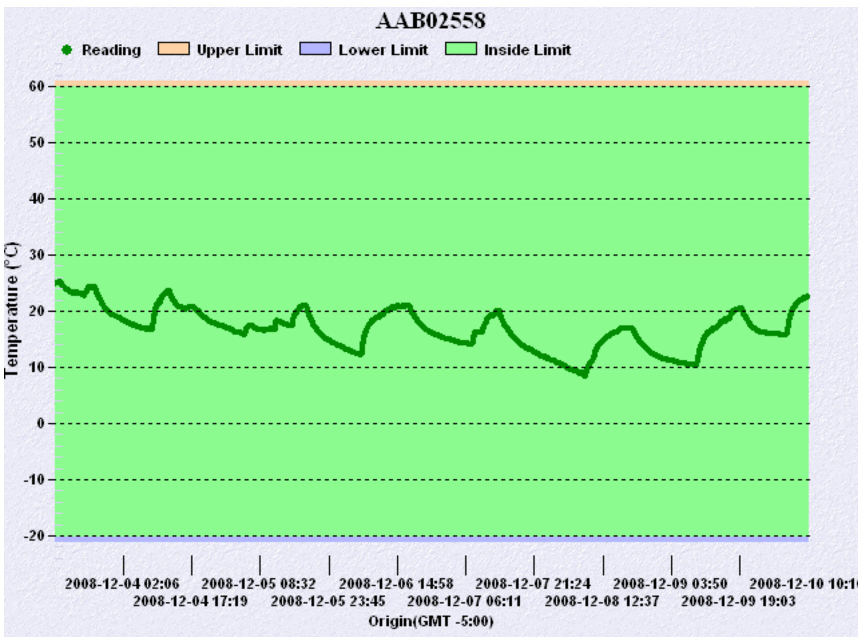
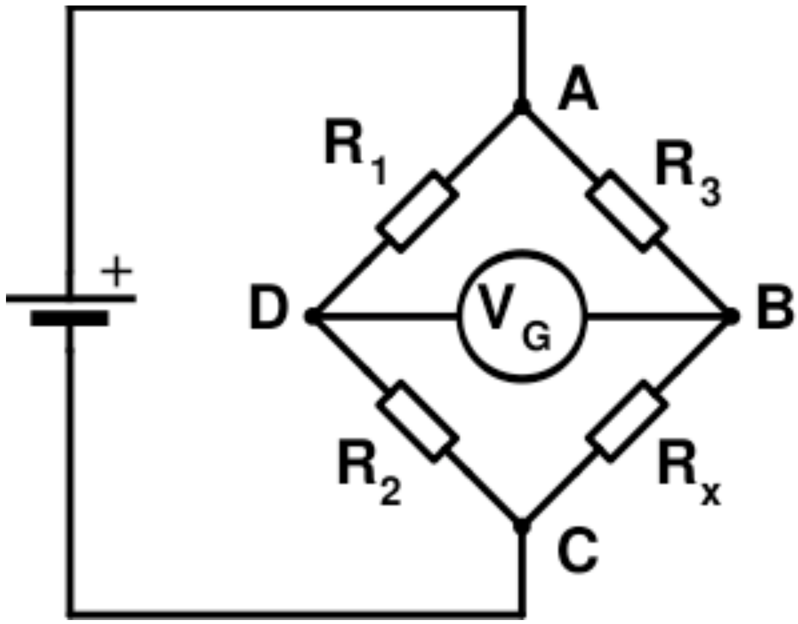


Figure 7-Temperature Logger Sample

This logger uses a Wheatstone bridge, which uses a series of resistors to compare voltage changes.



[11]

Figure 8-Wheatstone Bridge

As seen in figure 8, resistors 1 and 3 are at a set value, and resistor 2 is set for calibration by the factory. This means that once the battery reaches low power it needs to be replaced and the device recalibrated. Once calibrated, the change in voltage is proportional to the change in temperature.

Some of the features of this device are its ability to set tolerance ranges and also its ability to give average and peak temperatures. This device also allows for exporting data graphs to Excel for further analysis.

IR Temp Reader

For surface temperatures or temperatures that are too hot to safely measure without injury, an infrared temperature reader can be used. The chosen IR temperature reader for this situation is the IRTN002Ci. This device is fairly accurate with a +/- 2°C range of error and a .1°C resolution. The range of this thermometer is

-33°C to 220°C, which falls in the range of measurement for this project. All specifications for this IR thermometer can be seen in appendix D.

This device measures temperature through the concentration of infrared light being released from a surface. The accuracy of the device also depends on the emissivity of the surface being measured. Once the amount of infrared light is read it is converted to a voltage in a way similar to that of the temperature logger's Wheatstone bridge.

Humidity Sensor

The humidity sensor used was the Compuflow 8585, which has a range of 0-95% relative humidity. The accuracy and resolution are 3% and .1% respectively. This works similar to the temperature sensor, except gives a digital read out on the unit itself. Also, this unit allows for data logging so the average relative humidity of the room could be taken

FLUENT

FLUENT is a CFD software package that is used for modeling of flow, heat transfer, acoustics, and many other fluid principles and properties. This software uses both static and dynamic meshes in order to simulate real world situations[7]. For this project FLUENT will be used to model heat transfer and fluid flow caused by the 3 modes of heat transfer. A user inputs a series of boundary conditions, material properties, and accuracy specifications for the solution. This software package works with the modeling program Gambit, which allows for the importing of IGS files to create meshes for analysis. Once iterations are run in FLUENT, the user is allowed to display graphical results for many aspects of the interior of the model, such as turbulence, temperature, and humidity. The way that iterations work, is to check residuals, which are statistical errors that can be reduced through repetition of calculations.

Methodology

In order to determine the most appropriate and effective energy saving solutions for the Greenwood Memorial Swimming pool, there were a series of objectives that needed to be met. First, it was necessary to identify the current monthly and annual costs of the swimming pool in terms of oil and electricity. Second, we identified current energy saving techniques and technologies being implemented at the pool. The third objective was to gather actual temperatures and humidity data for multiple sections of the pool house over an extended period of time. This chapter outlines the methods that were used to achieve these objectives and the project goal.

Ambient Temperature Readings

All of the ambient temperature data was taken using the 3M TL20 to log the data. The smallest time increment that is allowed by the devices software is one minute. the range for the loggers was set to the maximum range of -20°C to 60°C. so no data would outside the range of the device.

All of the TL20 data loggers had to be synchronized and calibrated. In order to achieve this, the times were set and the loggers' cycles started at the same time. allowed data to be compared from different points in the structure.

Once this setup was complete, the loggers were put in place (installed?). There were 4 sensors: one was placed in the 1st floor of the pool area, the second was in the boiler and pump room, the third was placed outside, and the fourth was placed in the crawl space under the pool.

These loggers were left in place for 7 days in order to take approximately 10,000 readings. Once the 7th day was reached all of the logger cycles were ended at the same time. The data from the loggers was then downloaded to a computer and markers were put at the beginning and end of operation hours for each day in order to be able to find peak energy use. The data software was used to be able to display minimum, maximum, and average temperatures.

Surface Temperature Readings

All of the surface temperature readings were taken with the IRTN002Ci infrared thermometers. The surfaces that were needed were the pipe temperatures for steam supply to the pool heating system, pool temperature, and window temperatures. The window temperatures were used to check against the CFD models of the building.

In order to take these temperatures, the device was checked against a known surface temperature in the building. Then the pool surface temperature was taken. This was done over a period of 3 hours, every 20 minutes and the average of all temperatures was calculated. The time was also recorded for the temperatures in order to be able to compare against other collected data.

Next, the window surface temperatures were taken using the same infrared thermometer. Every window on the 1st and 2nd floor of the pool area had the temperature taken 10 times at different points on the window and then averaged. Then an average temperature for the 1st floor windows and then the second floor windows were calculated. This is because all of the 1st floor windows are similar and the second floor windows are similar.

The final measurement that was taken with the infrared thermometer was the temperature of the steam pipes in the basement. Temperatures were taken every 5 feet of the steam pipe so that heat loss could be calculated. These temperatures were each taken 10 times and averaged while the boiler was running at full load.

Humidity Data

The humidity data for the building was also collected. This was done by using a Compuflow 8585 humidity logger. The humidity was taken at 10 points in the poolroom, both on the 1st and 2nd floor. These humidity ranges were each taken 10 times and an average was taken for the entire room. This data was later used for mass balance equations in order to calculate evaporative heat loss.

Fuel Data

The fuel data was collected from information that the pool house already has on record. In order to calculate the efficiency and heat loss for the building, the total gallons of fuel used was acquired from the oil bills. This number was then used to calculate efficiency of the boiler and also how much fuel could be saved after using energy conservation measures. Also, these numbers will also be used to determine payback periods.

Data

This section includes the results of all of the measurement; temperature loggers, an infrared thermometer, and a digital humidity reader. These results will be used for the analysis section and further for the recommendations to the Greenwood Memorial Bath House.

Temperature Loggers

The results for the temperature loggers were each taken over the course of one week in order to obtain an average ambient temperature for that area of the building. All Loggers were calibrated and started at the same time in order to insure accuracy for dependent zones.

The first area was the main pool area, in which the temperature logger was placed in a location 7 ft off of the ground in order to obtain data. The results for the 7-day cycle ending on 12/10/2008 are shown in figure 9.

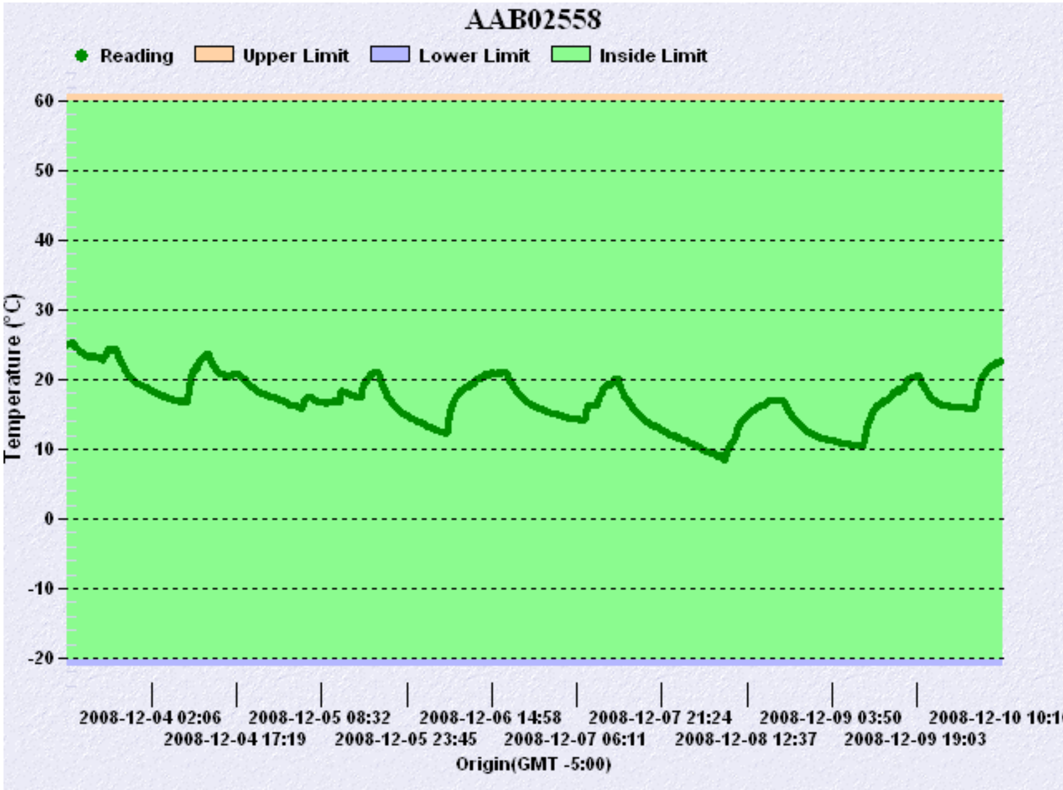


Figure 9-Pool Area Temperature Log

As seen in the figure, each lower peak represents the time that the heat was turned on every day, and the upper peaks represent which time the heat was turned off. This gave approximately 8 hours of operation of the building per day. The average ambient temperature during this time was 19.9° C.

The second area was the basement area, in which the temperature logger was placed in a location 7 ft off of the ground, in the main basement near the boiler room in order to obtain data. The results for the 7-day cycle ending on 11/18/2008 are shown in figure 10.

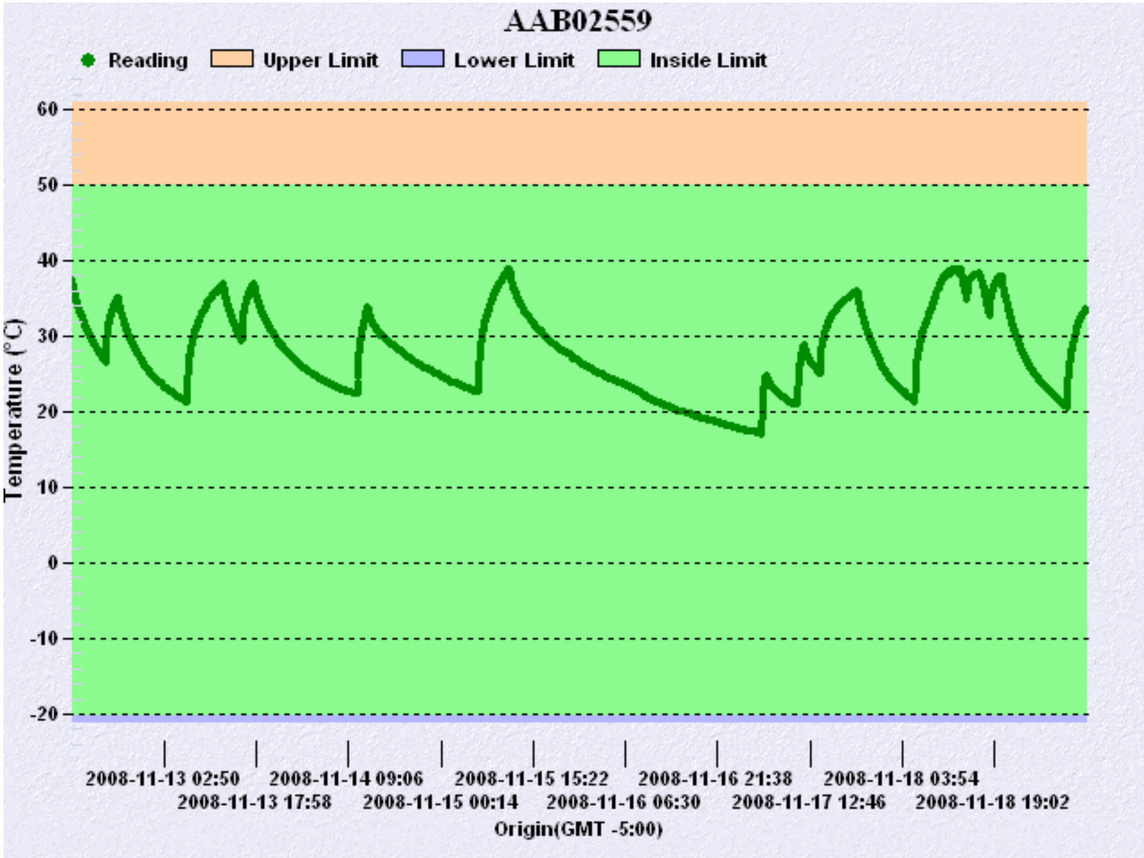


Figure 10-Basement Temperature Log

As seen in the figure, the hours of operation still average out to around 8 hours per day. This cycle is also continuing all 7 days except for one day during the weekend of 11/16. The average ambient temperature during this time was 27.6°C.

The third area that the ambient temperature was observed was the crawl space underneath the pool foundation. The logger was placed 4 feet off the ground in the middle of the space. This series of temperatures was taken over the 7-day cycle ending on 12/10/2008 and can be seen in figure 11.

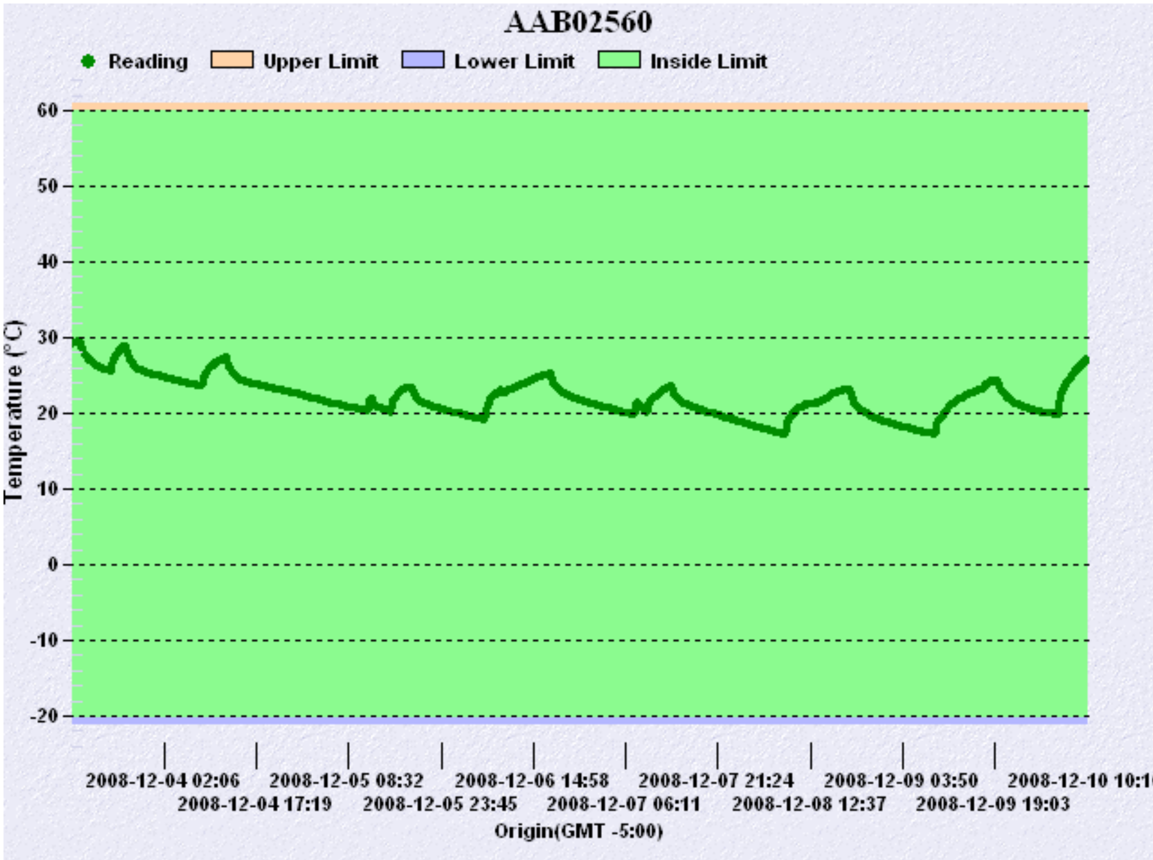


Figure 11-Pool Foundation Temperature Log

The cycle is consistent with the other results and the ambient temperature for this area was 22.0°C.

The fourth and final area being taken into consideration is the outside temperature. The logger was placed outside, underneath an overhang so it would not be affected by sunlight or rain. This series of temperatures was taken over the

7-day cycle ending on 12/10/2008 and can be seen in figure 12.

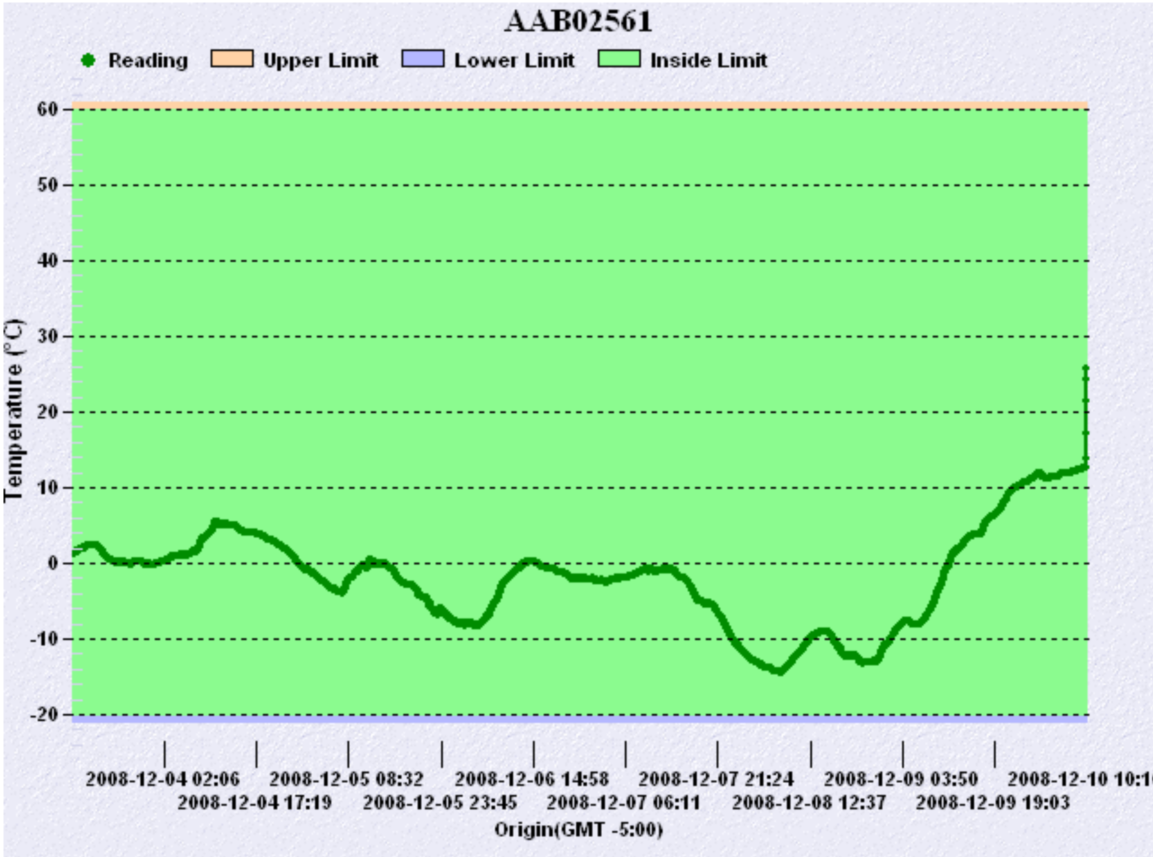


Figure 12-Outside Temperature Log

This only tells the outside temperatures in order to help calculate heat loss. The spike on the end of the graph was because when all logger cycles were terminated, the logger was brought inside for the last minute. The average outside temperature after throwing out the rejected data was 4.7°C

Infrared Thermometer

The results for the infrared thermometer were taken 10 times at each location and then averaged in order to give a surface temperature. This was done during the week of 12/10/2008.

The first set of data was for the windows in the upper and lower pool area. It was found that the average surface temperature was 10.1°C. The second set of data was the surface temperature for the steam heat pipes, located in the basement, for the pool. The surface temperature for the steam pipes was found to be 110°C when the pool was running, which as stated before was approximately 8 hours out of the day.

Digital Humidity Reader

The humidity readings were taken at the same time as the temperatures, on 12/10/2008. Like the infrared thermometer, these readings were taken 10 times and the average was used. The average relative humidity was 87.2% and the wet bulb and dew point were 58.0°F and 56.5°F respectively.

Results & Analysis

Within this section, both the final results from the data analysis and the energy conservation measures will be covered. The results mainly consist of the heat fluxes at all set boundary lines and the energy conservation measures shows mathematically what each strategy will provide. Also, to give an idea of savings, the total gallons per year of #2 oil used is 18125, which is estimated at a cost of $63,618 per year.

Pool Losses

There are 4 main losses between the pool and the surrounding area. These losses consist of conduction through pool walls, free convection, evaporative heat loss, and radiation.

Conduction

The conduction at the pool wall is due to the change in temperature between the pool water temperature and the surrounding air. This is calculated using the equation:

$$Q = KA(\Delta T / \Delta X)$$

Q is the total heat loss in watts through the wall. This depends on K, the conduction coefficient, A, the wall surface area, ΔT, the change in temperature, and ΔX, the wall thickness. The values are as follow:

K (conduction coefficient of concrete) = 0.42 w/m K

ΔT(difference in temperature across the wall)=6.05°K

A (area)=349m^2

X=thickness=0.15m

With these values the total heat loss due to conduction is calculated to be 5800W. This is a very small loss for the large surface area of the entire pool, so energy savings based on this value can be neglected.

Convection

Convection from the pool surface is similar to conduction in terms of the temperature change, but it also depends on turbulence and vortices created by convection. In order to solve for the convective heat loss, one must first calculate the convective heat transfer coefficient. This can be done by calculating the ratio of convection to conduction, better known as the Nusselt number. In order to calculate this, one must first calculate the Rayleigh number. This is done by using the equation:

$$Ra_L = Gr_L \Pr = \frac{g\beta}{\upsilon\alpha}(T_S - T_\infty)L^3$$

The variables are as follows:

g (gravitational acceleration)=9.8 m/s^2

ß (thermal expansion coefficient)=1/T=1/292=.00342

υ (kinematic viscosity)=15.11x$10^{-6}m^2/s$

α (thermal diffusivity)=k/(ρ *cp) = 2.12x$10^{-5}m^2/s$

L (length)=Area/Perimeter=3.31m

Δ T (difference in temperature across surface)=9.1 K

This gives a Rayleigh number of $1.06E^{10}$, which is a dimensionless number relating flow in certain buoyancy ranges. Now, to take this number and calculate the Nusselt number using the following equation:

$$\overline{Nu_L} = 0.15 Ra_L^{1/3} \quad 10^7 \leq Ra_L \leq 10^{11}$$

This number comes out to be 330.16330 and can be used with a known conductive heat transfer coefficient of .0257 $wm^{-2}K^{-1}$ and the equation:

$$Nu_L = \frac{hL}{k_f} = \frac{\text{Convective heat transfer}}{\text{Conductive heat transfer}}$$

in order to calculate a convective heat transfer coefficient of 2.56$wm^{-2}K^{-1}$. This is used, like the conduction equations, to be able to find total heat transfer at a surface for convection. The equation is:

$$Q = HA\Delta T$$

H (convection coefficient)=2.56$wm^{-2}K^{-1}$

A (area) =225m^2

ΔT (difference in temperature across surface)=9.1°K

This gives a total convective heat loss of 5200W, which is similar to the heat lost from conduction, but over a smaller, more easily accessible area.

Evaporation

Evaporation is like conduction, but instead of using a heat transfer coefficient the equations uses mass transfer and humidity. The equation for evaporation as taken from the US EPA is as follows:

$$E = \frac{(0.284)u^{0.78} M^{.667} AP}{RT}$$ [9]

E (Evaporation Rate) lb/min

U (Wind Speed Above Pool)= 0.09 m/s

M (Molecular Weight of Water)= 18.01 g/mol

A (Pool Surface Area)= 2421 ft^2

P (Vapor Pressure of Pool Liquid)=22.19 mmHg

T (Pool Temperature)=297°K

R (Universal Gas Law Constant)=82.05 atm cm^3 $gmol^{-1}$ K^{-1}

This gives an evaporation rate of 0.66 lb/min or 18 kg/hr. This can be used with the heat needed for phase change in evaporation to get the total watt loss. This value is 57KW.

Radiation

The heat loss due to radiation is from the surface of the pool to the surrounding area and depends on the following Boltzmann equation:

$$Q = A\varepsilon\sigma T^4$$

A (area)=225m^2

ε (emissivity)=0.90

σ (Boltzmann's Constant)=5.76x10^{-8} W/m^2K^{-4}

T (Temperature Difference)=9°K

This gives a total heat loss due to radiation from the pools surface of 12000W.

Window Losses

Heat lost from the windows in the building can be broken down into 3 separate areas. These areas are 1st floor windows, 2nd floor windows, and skylights. The heat losses from all of these are due to both conduction and air infiltration except for the skylights which is just infiltration.

1st Floor Windows

The first source of heat loss from the first floor windows is through conduction. The equation being used takes into account the R-value, which is thermal resistivity and is as follows:

$$Q = AU\Delta T$$

The variables are the following:

A (area)=6 ft^2 = .55m^2

U (overall heat transfer coefficient)=1/Rsi=1/(2*.176)=2.84 w/m^2K

ΔT (difference in temperature across window)=15.2°K

This gives a total heat loss due to conduction of 22.3W per window. Since there are 18 windows there is a total loss of 402W.

2nd Floor windows

The equation for the conductive heat loss from the windows is the same as for the 1st floor windows but the new variable values are:

A (area)=6 ft^2 = .55m^2

U (overall heat transfer coefficient)=1/Rsi=1/(2.5*.176)=2.27

ΔT (difference in temperature across window)=8.8°K

This gives a total heat loss due to conduction of 10.9 per window. Since there are 16 windows there is a total loss of 175.7w.

Infiltration

Air infiltration in the building can be calculated by an air infiltration rate. The infiltration rate was estimated to be 1.85 CFM per linear foot of crack [8]. This makes the total leakage per week for the lower and upper windows 31228 CFM. The value for the skylights is much higher due to the higher area and lack of some windows and the value is 56000 CFM.

Basement Pipe Losses

The heat loss from basement pipes is based on 2 values, the first is the convection from the pipe and the second is the radiation lost from the pipe. The convective value is estimated at 300 W/m and the run of the pipe is approximately 12.5 meters from boiler to pool. This gives a total loss of 3750 W for a steady state loss from the pipe.

The value of heat loss due to radiation can be calculated using the Boltzmann equation, which is:

$$Q = A\varepsilon\sigma T^4$$

A (area)=3.49m^2

ε (emissivity of rusting steel pipe)=0.70

σ (Boltzmann's Constant)=5.76x10^{-8}W/m^{2}K^{-4}

T (Temperature Difference)=83°K

This gives a heat loss due to radiation of 1900W.

Dehumidification

The cost associated with a dehumidification system for the building is in KWH. It is necessary at some point to install such a system due to the high rate of relative humidity, which is around 90%. The estimates are as follows

Area=231m^2 = 2486 ft^2

ASHRAE CFM recommendation= .5 CFM per square ft

Pool Dehumidifier power @ 60F/80%RH =27 KWH

CFM per unit = 550 CFM

CFM Needed = 1243 CFM

Units Required=2

KWH=54KWH

Operating hours = 8

Total = 432 KW per day

ECM 1-Pool Cover

A first energy saving step that can and has already been taken is to install a heavy-duty pool cover. This will stop most of the evaporative heat loss and also heat loss due to radiation. So the total savings from the installation of the pool cover is 30KW. Since the pool cover was already purchased, the initial price is set at the cost, which was $4000.

ECM 2- Basement Pipe Insulation

The second energy conservation measure that can be taken into consideration is the installation of ½ inch basement pipe insulation. This would eliminate most of the radiation losses from the pipe and would change other heat losses to 49 W/m. This would in turn change the value of total heat loss from the pipes to 615W. The new heat loss value gives a total savings of 6.9KW. The total cost of the project is estimated to be around $300 to insulate the pipes.

ECM 3- Window Replacement

Replacing the upper and lower windows of the pool house is the third energy conservation measure. By replacing the windows the thermal resistivity properties change to a new r-value of 3. The air infiltration rate also decreases from the 1.8 CFM per linear foot of crack to 0.07 CFM. This will give a total savings of 14.9K. In order to replace the windows, the total cost including labor is approximately $9095.

ECM 4- Skylight Replacement

The skylight replacement is very similar to the window replacement, with the exception of the higher area for air infiltration. The material properties will also change immediately because the windows are almost non-existent and will be replaced with energy star rated skylights. The new R-value will be around the same as the lower and upper windows in the building. The infiltration rate will also be lowered to .07 CFM per linear foot of crack. Both of these savings combined will be

26 KW of heat loss savings. The initial cost for the skylights and installation is approximately $16,500.

ECM 5-Drop Ceiling

Installing a drop ceiling of approximately ½ inch fiberglass insulation construction is the 5th conservation measure. After taking the report with FLUENT as seen in figures 13 and 14.

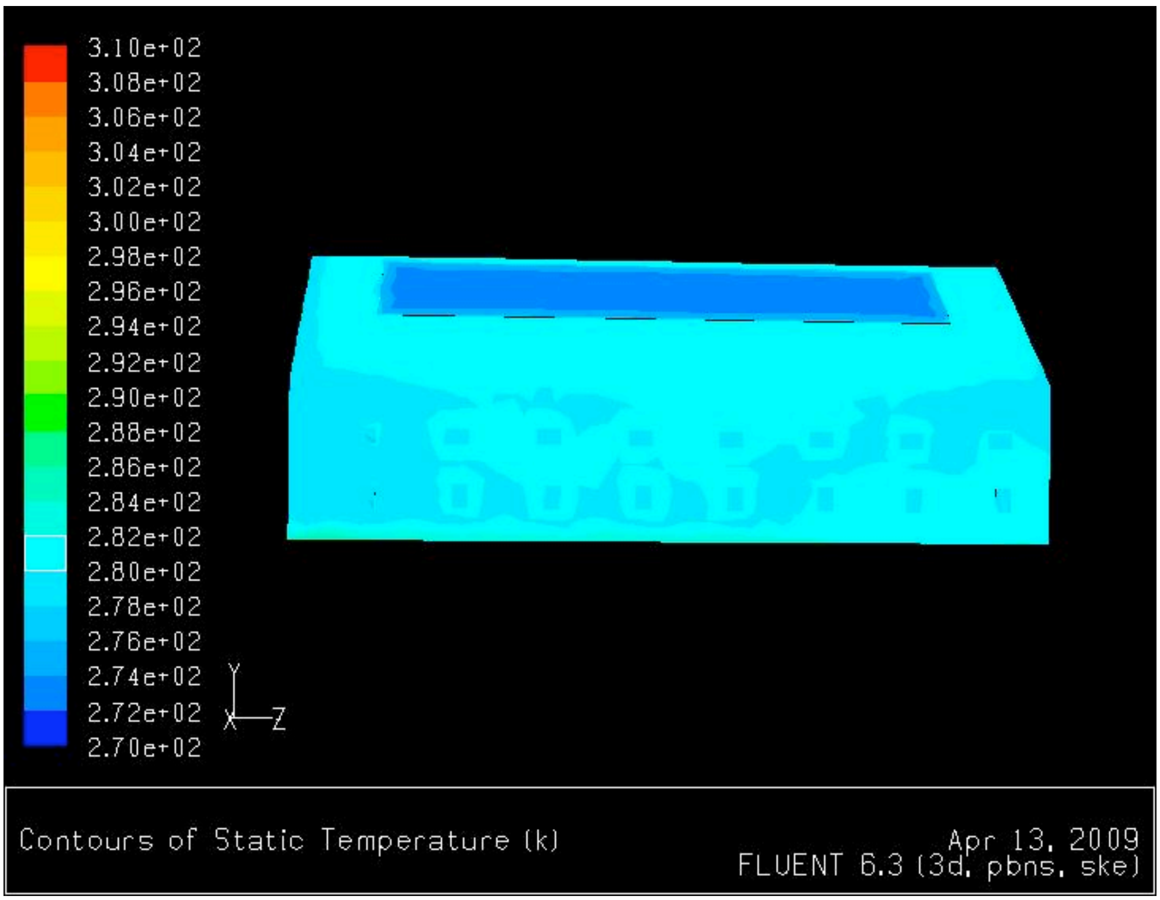


Figure 13-FLUENT Pool Model

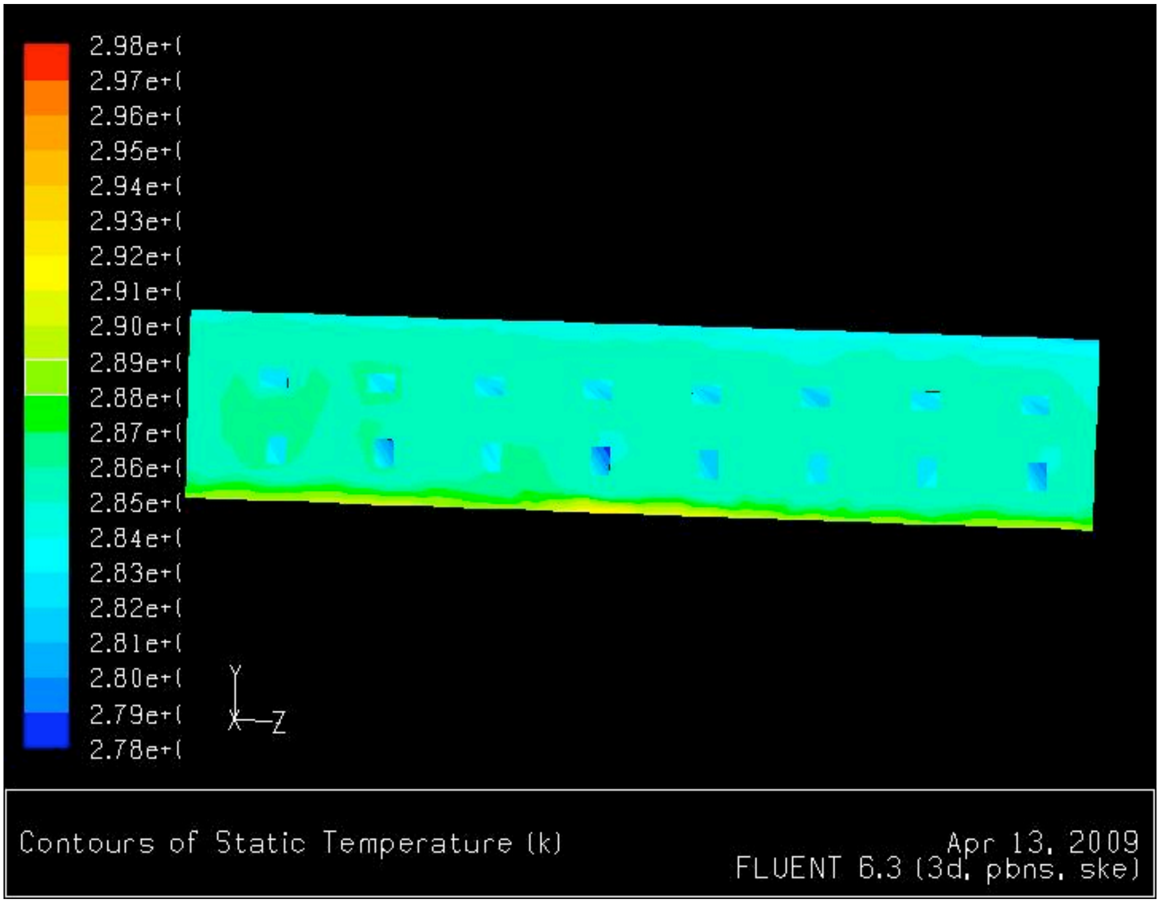


Figure 14-FLUENT Lowered Ceiling Model

There is approximately an 8 degree temperature difference between the installation of the ceiling and current conditions. The flux report gives a total heat loss savings of 29.6KW. The installation cost of the drop ceiling including labor is approximately $30,000.

ECM 6-Solar Pool Heating

Bay State Energy originally calculated the solar portion of the ECM options. This would be to install solar panels outside in order to heat the pool water using a closed loop system. The total yearly savings for heat loss in dollars is approximately $64,300. The total cost for the project is estimated to be $354,186 [10].

ECM 7-Ice Rink Recovery

The final ECM option is to install a heat recovery unit in a nearby ice skating rink. This would replace radiators on the rooftop units with heat exchangers. This would run through underground, insulated pipe to a heat exchanger on the poolside of the system. The ice skating rink has 3 chiller units each having a capacity of 17tons. The underground pipe insulation would also be ½ inch fiberglass construction. If the chillers are assumed to be at 50%-60% capacity, the efficiency of the heat exchangers is assumed to be approximately 50%, and the losses from the underground pipe is 5KW then the energy savings is 20KW. The initial cost of this option including labor is $95,000.

ECM Chart

ECM#	Description	**Annual Savings**			Initial Cost	**Payback Period (years)**
		Fuel (gal)	**Dollar Amount**	CO_2 (lbs)		
1	Pool Cover	701	**$2,460**	17,393	$4,000	**1.63**
2	Basement Pipe Insulation	161	**$567**	4,007	$600	**1.06**
3	Window Replacement	348	**$1,221**	8,633	$9,095	**7.45**
4	Skylight Replacement	603	**$2,118**	14,976	$16,500	**7.79**
5	Drop Ceiling Installation	693	**$2,432**	17,196	$30,000	**12.33**
6	Pool Heater Solar Array [10]	N/A	**$64,300**	N/A	$354,186	**9**
7	Ice Rink Heat Recovery	468	**$1640**	11,595	$95,000	**57.93**

Figure 15-ECM Option Chart

All energy conservation measures can be seen above in figure 15. All initial costs include material and labor and also a payback period per option. The payback period is in years but takes into account the fact that the pool is only open for the winter months and is under minimal use during the summer for heat. Also, all costs associated with the solar heating option are taken from Bay State Energy [10].

Conclusions & Recommendations

With the data for the analysis and results, some conclusions can be drawn about the future plans involving the Greenwood Memorial Bath House. These plans also suggest a multiphase plan for construction for the future.

When looking at the ECM options, a three-phase plan for the pool house is as follows:

Phase 1

•Pool Cover

•Basement Pipe Insulation

Phase 2

•Window Replacement

•Skylight Replacement

Phase 3

•Pool Heater Solar Array

The first phase of installing a pool cover and basement pipe insulation has already begun with the purchase of the new pool cover. The total cost associated with this option is approximately $4600 and has a very short buyback of approximately 2 years.

The second phase is to replace all of the windows in the main pool area, which as seen in figure 15 is approximately a 7-8 year payback period. Another recommendation beginning with phase 2 is to install a dehumidification system in the building. The measured value of relative humidity in the building is 90% and is a cause for concern when installing new materials. Installation of this system would reduce the chances of mold or fungus build up and lower future maintenance costs.

Phase 3 is to install the pool heater solar array. This is mainly because of the high cost savings and also the low payback period. This option would most lower the cost of building ownership and overhead and greatly reduce the buildings carbon footprint.

There were two options removed from the recommendations, which were, drop ceiling installation and ice rink energy recovery. This was mainly because the estimates for payback period and initial cost were too high to be reasonable options. Also, when installing a drop ceiling the structural load and building integrity must be taken into account, which could make the option completely unfeasible.

If future analysis were to be completed on this building, one suggestion would be to look at boiler efficiency and also the boiler feed system itself. Some options would allow for a possible 10%-15% increase in combustion efficiency. This would affect the system in a more positive way than any other option.

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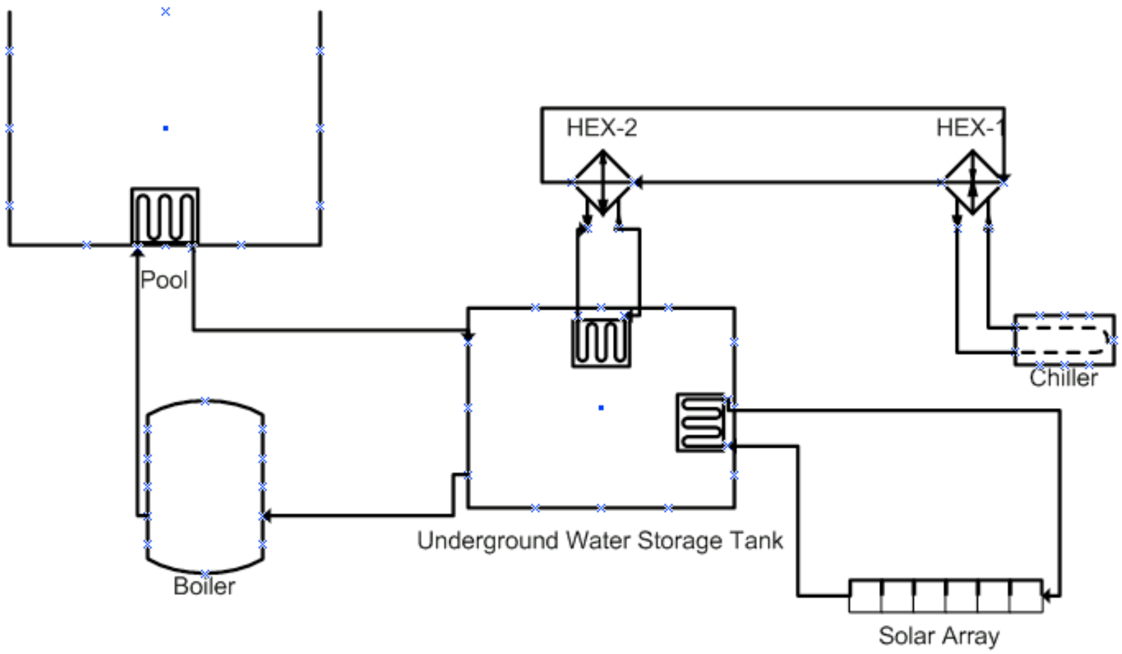
Appendix A: Solar & ERV Concept Diagram



Appendix B: Beacon Morris HB-60S Specifications

Steam Performance Data

Model No.	Output BTU/ HR*	Cond. lbs./hr.	Sq. Ft. E.D.R.	Final Air °F	Motor HP	RPM	Nominal CFM	Outlet FPM	Nom. Amps @ 115VAC	Nom. Fan Diam. (Inches)
HB-18	18,000	18.0	75	102	9 Watt	1550	395	395	.53	9
	16,200	16.2	68	105		1350	330	330	.53	9
HB-24	24,000	24.5	100	109	9 Watt	1550	450	450	.53	10
	21,600	22.0	90	112		1350	380	380	.53	10
HB-36	36,000	37.0	150	119	16 Watt	1550	550	550	1.1	10
	32,400	33.0	135	120		1350	480	480	1.1	10
HB-48	48,000	49.0	200	119	1/20	1000	750	550	1.4†	12
	43,200	44.0	180	123		900	630	460	1.4†	12
HB-60	60,000	61.0	250	121	1/20	1000	900	650	1.4†	12
	54,000	55.0	225	131		900	700	510	1.4†	12
HB-72	72,000	73.0	300	120	1/20	1000	1100	800	1.4†	14
	64,800	66.0	270	123		900	950	700	1.4†	14
HB-84	84,000	85.0	350	115	1/12	1000	1400	900	2.2†	14
	75,600	76.0	315	123		900	1100	750	2.2†	14
HB-96	96,000	97.0	400	123	1/12	1000	1400	930	2.2†	16
	86,400	88.0	360	132		900	1100	800	2.2†	16
HB-108	108,000	110.0	450	115	1/12	1000	1800	1000	2.2†	16
	97,200	98.0	405	120		900	1500	900	2.2†	16
HB-120	120,000	122.0	500	118	1/12	1000	1900	900	2.2†	18
	108,000	110.0	450	122		900	1600	800	2.2†	18
HB-132	132,000	134.0	550	121	1/3	1140	2000	950	4.5	18
	—	—	—	—		—	—	—	—	—
HB-144	144,000	146.0	600	120	1/3	1140	2200	1000	4.5	18
	—	—	—	—		—	—	—	—	—
HB-156	156,000	160.0	650	115	1/3	1140	2600	1150	4.5	18
	—	—	—	—		—	—	—	—	—
HB-180	180,000	190.0	770	135	1/3	1140	2200	800	4.5	18
	—	—	—	—		—	—	—	—	—
HB-204	204,000	208.0	850	124	1/3	1140	2900	1000	4.5	18
	—	—	—	—		—	—	—	—	—
HB-240	240,000	244.0	1000	123	1/3	1140	3500	900	4.5	20
	—	—	—	—		—	—	—	—	—
HB-280	280,000	280.0	1100	121	1/3	1140	4200	980	7.0	20
	—	—	—	—		—	—	—	—	—
HB-300	300,000	310.0	1250	117	1/3	1140	5000	700	7.0	24
	—	—	—	—		—	—	—	—	—
HB-360	360,000	366.0	1500	120	1/2	1140	5500	1000	9.0	24
	—	—	—	—		—	—	—	—	—

Performance based on 2# steam pressure at heater with air entering @ 60°F.
Maximum working pressure 150 PSI, 366°F
* For the lower output, an optional Speed Controller must be ordered.
† Stated AMP is average. AMP draw varies by manufacturer ± .2 AMPS.

Appendix C: 3M TL20 Specifications

Temperature Range and Accuracy	-20ºC to +30ºC: +/- 0.5ºC +30ºC to +60ºC: +/- 1.0ºC
Temperature Resolution	0.1ºC
Memory Capacity	12,000+ data points
Battery Life	Approximately 12 months (Lifetime will vary depending on amount of use.)
Data Logging Frequency	1 to 120 minutes
Auto Start-Up Delay	0 to 168 hours (7 days)
Manual Start-Up Delay	0 to 240 minutes (4 hours)
Upper and Lower Temperature Limits	-20ºC to +60ºC
Size	70 mm x 44 mm x 11 mm 2.8" x 1.7" x 0.4"
Weight	26 grams / 0.91 ounces

Appendix D: IRTN002Ci Infrared Thermometer Specifications

• Temperature Range -27° to 428°F (-33° to 220°C)
• Accuracy ±2% of reading or ±2°C
• 0.1° resolution for accurate readings
• Selectable temperature units F/C
• 1:1 Otics (distance-to-spot size ratio)
• Emissivity preset to 0.95
• LCD display
• Metal alloy case
• Lithium batteries (2 LR44 included typically
provide for 180 hours of continuous operation
• Low battery indication
• Automatic power OFF after 15 sec

Appendix E: Compuflow 8585 Specifications

SPECIFICATIONS		
range	VELOCITY VOLUME TEMPERATURE HUMIDITY	30-9999 fpm 0.2 - 2,600,000 cfm 14 - 140° F 5 - 95%
resolution	VELOCITY TEMPERATURE HUMIDITY	1 fpm 0.1° F 0.1%
accuracy	VELOCITY VOLUME TEMPERATURE HUMIDITY	Â±3% of reading or Â±3 fpm (whichever is greater) Â±3% of reading Â± 0.5° F Â±3%
display		4.5 digit LCD with backlight
battery life		minimum 24 hours continuous use

Appendix F: FLUENT Material Data

FLUENT
Version: 3d, pbns, ske (3d, pressure-based, standard k-epsilon)
Release: 6.3.26
Title:

Material Properties

Material: wood (solid)

Property	Units	Method	Value(s)
Density	kg/m3	constant	700
Cp (Specific Heat)	j/kg-k	constant	2310
Thermal Conductivity	w/m-k	constant	0.173

Material: Skylight (solid)

Property	Units	Method	Value(s)
Density	kg/m3	constant	2000
Cp (Specific Heat)	j/kg-k	constant	840
Thermal Conductivity	w/m-k	constant	2

Material: Lower Window (solid)

Property	Units	Method	Value(s)
Density	kg/m3	constant	2000
Cp (Specific Heat)	j/kg-k	constant	840
Thermal Conductivity	w/m-k	constant	1.05

Material: Upper Window (solid)

Property	Units	Method	Value(s)
Density	kg/m3	constant	2000
Cp (Specific Heat)	j/kg-k	constant	840
Thermal Conductivity	w/m-k	constant	0.95999998

Material: fiberglass (solid)

Property	Units	Method	Value(s)
Density	kg/m3	constant	200
Cp (Specific Heat)	j/kg-k	constant	387
Thermal Conductivity	w/m-k	constant	0.048

Material: concrete (solid)

Property	Units	Method	Value(s)
Density	kg/m3	constant	600

Cp (Specific Heat)	j/kg-k	constant	1000
Thermal Conductivity	w/m-k	constant	0.19

Material: air (fluid)

Property	Units	Method	Value(s)
Density	kg/m3	constant	1.225
Cp (Specific Heat)	j/kg-k	constant	1006.43
Thermal Conductivity	w/m-k	constant	0.0242
Viscosity	kg/m-s	constant	1.7894e-05
Molecular Weight	kg/kgmol	constant	28.966
L-J Characteristic Length	angstrom	constant	3.711
L-J Energy Parameter	k	constant	78.6
Thermal Expansion Coefficient	1/k	constant	0
Degrees of Freedom		constant	0
Speed of Sound	m/s	none	#f

Material: aluminum (solid)

Property	Units	Method	Value(s)
Density	kg/m3	constant	2719
Cp (Specific Heat)	j/kg-k	constant	871
Thermal Conductivity	w/m-k	constant	202.4