Mechanical Breadth

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Research

A hydronic system is the ideal solution for the heating system in many commercial buildings, including the Woolly Mammoth Theatre. This type of heating system provides many advantages over other systems that would benefit a theatre such as yours, including comfort, efficiency (which will result in lower operating costs), versatility, noise reduction, and reliability. All of these aspects are very important in a theater environment and should be taken into account when the heating system is designed for the Woolly Mammoth Theatre.

Comfort

There are many reasons why a hydronic heating system works so well, and these are closely related to the way the system works. A building needs a heating system so the occupants are comfortable in the space year round, including the frigid winter and the milder spring and fall seasons. Occupants are uncomfortable when they are not warm enough or are in a drafty room. When it is cold outside, a building loses heat to the exterior via conduction, convection and radiation. Many factors effect how quickly a space loses heat to the outside, including the amount of insulation in the walls and ceiling, the amount of glazing, how cold it is outside compared to inside, and how strong the wind is blowing. Also, heat moves from warmer objects to colder ones. As a building loses heat to the cold air, the occupants lose heat to the building and the colder objects in it (walls, windows, etc.). The heating system in a building must replace the cold being lost to the outdoors and at the same time not be drafty or create hot/cold spots in the building. (Bell & Gossett)

A hydronic system works to create a comfortable environment according to the previous provisions. In a hydronic heating system, boiler heated water is transported through pipes quietly and efficiently to radiators, baseboard convectors or radiant floors to heat up this equipment. In each space these warm surfaces are created. The occupants, as well as surrounding cold walls and ceilings, are then sent heat by the warm objects. (Energy)

In a hydronic system, there is no air blowing around the room. Therefore there is almost no draft to make people feel uncomfortable. In addition, because a hydronic system is heating objects and people through radiating surfaces rather than hot air, the air does not dry out as much. A hydronic system makes it easier to maintain a comfortable humidity level during the winter season, and does not overheat the air. Another plus in this type of system is the thermostat can be set at a lower temperature for each zone, and the room will still feel comfortable. (Bell & Gossett)

Figure 1.0a is the ideal situation for heating in a space. The thick vertical line represents the temperature at a range of locations between the ceiling and floor. Notice from this diagram that the line is rather flat from ceiling to floor, with the temperature being slightly warmer at the floor and slightly cooler at the ceiling. This situation will optimize occupant comfort. Figure 1.0b is the diagram representing a space heated by a hydronic

system. Hydronic systems offer a very even heating of a space because they use mostly radiant heating rather than convective heating. This diagram has a temperature line very closely matched to the ideal situation diagram. (Bell & Gossett)

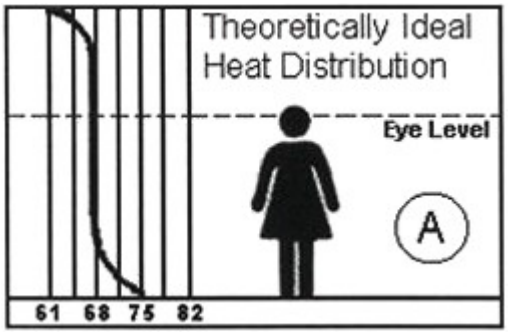

Figure 1.0a Ideal Heating System

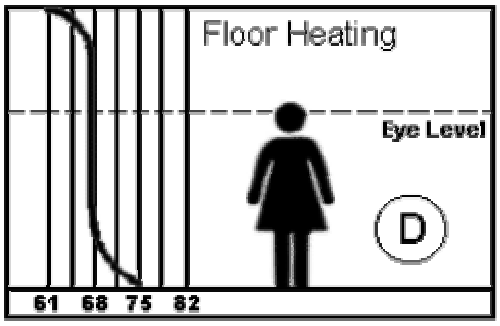

Figure 1.0b Hydronic Heating System

Efficiency

A hydronic system is more efficient than other systems. This is because water is a better carrier of heat than air. Water conducts heat twenty times faster than air. Air is a good insulator, but is not the best heating medium. A given volume of water can hold almost 3,500 times as much heat as the same volume of air, for the same temperature rise in each material. Water can move a lot of heat (BTU's) from one place, where it is produced, to another place, where it is used very efficiently. Also a hydronic system is more efficient because there is no heat loss through cracks, around doors and windows as with an air system. It is a completely sealed system. This is because the heat is mostly being radiated into the space rather than blown into it. Fewer BTU's need to be produced to keep the space feeling comfortable, because of the lower heat loss. (Bell & Gossett) A more efficient system will dramatically save on the operating cost for the heating system. Buildings utilizing hydronic heating systems have a 30% *or more* savings on heating bills. (US)

Noise

One of the most important and appealing advantages of a hydronic heating system for the Woolly Mammoth Theatre is that the system is virtually silent. The boiler is located away from the space, so there is no mechanical equipment noise. A loud heating system is detrimental to a theater. In a theater setting, the space must be completely free of extraneous noises. During a performance, patrons should not hear any mechanical equipment working. It will take away from the intimate connection the actors have with the audience during a performance. (Hurlcon)

Versatility

Hydronic systems are very versatile systems. With a hydronic system, 40,000 BTU's can be moved through a ¾" copper pipe through walls and between floors quietly and efficiently. With an air system, an 8" by 14" duct would be necessary to move that many BTU's into a space. (Bell & Gossett) Therefore, using a hydronic system is a space saver. The required ductwork of an air system is many times larger than the piping for a hydronic system. (BC) In the Woolly Mammoth Theatre, because of the unfinished concrete spaces, a small copper pipe would be much more inconspicuous than a large duct running across the ceiling. A hydronic system will not draw attention to itself and will let the architectural impression be more prominent.

A hydronic system has the flexibility to run off of many different fuel sources. It can be powered by gas, oil, electricity or even solar energy. Also, the type of fuel source used can be changed by just buying a new boiler for the new fuel source of choice. This aspect is very appealing because the lifespan of a building is a long time. Over that time period, the price or availability of a specific fuel may change. When electricity is being used, in some geographical locations special heating or off-peak rates are available to consumers. This can bring the cost equal to or less expensive than the use of other fossil fuels. (Warmly)

Zoning the building is very simple when using a hydronic system. A building can be zoned by rooms, floors or any way the owner would like. (Bell & Gossett) Each zone is thermostatically controlled by valves that regulate the flow of hot water to control the temperature in each zone. Any or all zones may operate at one time. (Stein)

Reliability

Hydronic systems are very reliable. The majority of maintenance is on the pumps and boilers. Most pumps are maintenance free, using water to lubricate the bearings. This allows for a more quiet and efficient life span. Usually pumps have an estimated life span of ten years. Boilers do require routine maintenance. Many installers of boilers will offer a yearly maintenance package, which includes cleaning and general up-keep. Different types of boilers will require different maintenance. (Warmly)

Other Factors

Hydronic systems are environmentally clean systems. The boiler heats the water, and is then circulated. Being a closed system, the radiators and natural convectors provide clean natural heat to the space. There is no forced air circulation through ducts that accumulate dust and allergens and distribute them throughout the building. (Hydronic)

Hydronic systems are also very modular and expandable. Radiators can be added as the needs of the building change. Once a boiler of the appropriate size is installed, radiators/convectors are able to be added as needed. If an extension or renovation is done on the building, the new area must be plumbed and the radiators/convectors added as

required. In an air system, an expansion is much more extensive and complicated. (Hurlcon)

Electric Heating System versus Hydronic Heating System

Existing Electric Resistive Heating System

Electric Heating Coils

Equipment	kW	Cost	
DH-1	15	$360.00	
DH-2	50	$655.00	
DH-3	20	$550.00	
DH-4	10	$510.00	
DH-5	25	$690.00	
DH-6	10	$410.00	
	130	**$3,175.00**	**Total**

Energy Consumption

Pepco Rating Periods

On-Peak Period	12:00 Noon to 8:00 PM
Int-Peak Period	8:00 AM to 12:00 Noon 8:00 PM to 12:00 Midnight
Off- Peak Period	12:00 Midnight to 8:00 AM Saturdays, Sundays and Holidays
For a 7 day week	
On- Peak	40 hr
Int- Peak	40 hr
Off- Peak	88 hr

EXISTING SYSTEM- MONTHLY ELECTRIC COSTS

		Billing Months of June- October	kW	Billing Months of November- May	kW
			130		130
GENERATION					
kW-hr Charge	On Peak	$0.08682 per kW-h	$451.46	$0.06889 per kW-h	$358.23
	Intermediate	$0.06632 per kW-h	$344.86	$0.07239 per kW-h	$376.43
	Off Peak	$0.05645 per kW-h	$645.79	$0.05757 per kW-h	$658.60
kW Charge	On Peak	$0.84507 per kW	$109.86		
	Maximum	$0.30248 per kW	$39.32	$0.30248 per kW	$39.32
TRANSMISSION					
All kW-h		$0.00111 per kW-h	$24.24	$0.00111 per kW-h	$24.24
kW Charge	On Peak	$0.71000 per kW	$92.30		
	Maximum	$0.59000 per kW	$76.70	$0.59000 per kW	$76.70
DISTRIBUTION					
Customer Charge		$20.93000 per month	$20.93	$20.90000 per month	$20.90
All kW-h		$0.01029 per kW-h	$224.73	$0.01029 per kW-h	$224.73
kW Charge	Maximum	$4.80000 per kW	$624.00	$4.80000 per kW	$624.00
Delivery Tax		$0.00770 per kW-h	$168.17	$0.00770 per kW-h	$168.17
Public Space Occupancy Surcharge		$0.00154 per kW-h	$33.63	$0.00159 per kW-h	$34.73
Reliability Energy Trust Fund		$0.00065 per kW-h	$14.20	$0.00065 per kW-h	$14.20
Gneration Procurement Credit		$0.00002 per kW-h	$0.44	$0.00002 per kW-h	$0.44
SUB-TOTAL			$2,870.64		$2,620.68
Subtracting once monthly charges			$109.86 $39.32 $92.30 $76.70 $20.93 $624.00		$0.00 $39.32 $0.00 $76.70 $20.90 $624.00
Billing for average 7 day week less demand and peak charges			$1,907.53		$1,859.76
Billing for 1 month less demand and peak charges			$7,630.11		$7,439.04
Billing for 1 month of electrical service			**$8,593.22**		**$8,199.96**
Yearly Cost of Electrical Service				**$100,365.80**	

Note: Cyan Boxes Denote Standard Monthly Charge

New Hydronic Heating System
System Assumptions

The average house of 2,000 SQ FT uses 100,000 Btu/hr. The Woolly Mammoth Theatre is 32,000 SQ FT. This is equivalent to 16 houses. Therefore the assumed heating load is 1.6 million Btu/hr or 1600 MBH.

The existing cooling system is a hydronic cooling system. The pipes for the new hydronic heating system would be the same pipes if the system is a 2 pipe system, and parallel pipes if the system is a 4 pipe system. Therefore the existing information on pressure was used. The new system is assumed to have 30' of head loss, and be two pumps in parallel.

The return and supply air temperatures were estimated. The return air is assumed to be 140 degrees F, while the supply air is assumed to be 160 degrees F. This gives a delta T of 20 degrees.

Calculations

$$Q = \dot{m} * C_p \Delta T$$
$$\dot{m} = Q / (C_p \Delta T)$$

$$C_p = 1.0 \text{ Btu} / (\text{lbm}°\text{F})$$
$$\Delta T = 20° \text{ F}$$

$$\dot{m} = (1{,}600{,}000 \text{ Btu/hr}) / ((1.0 \text{ Btu/lbm}°\text{F})*(20° \text{ F}))$$
$$\dot{m} = 80{,}000 \text{ lb/hr} = 160 \text{ gpm}$$

Hydronic Heating Equipment Sizing and Cost

The energy use for the coil was assumed to be 65,000 Btus. All equipment cut-sheets can be found in Appendix C. All equipment price data from Costworks 2005. Assumptions on the equipment selection can be found in Appendix C.

Load: 1.6 million Btu/hr or 1600 MBH
Flow Rate: 160 gpm
Pump Head: 30'

New Hydronic System

Equipment	Btu	Cost	
Boiler	2,000,000	$12,300.00	
Coils	60,000	$425.00	
Pumps (2)	100,416	1200	
	2,160,416	**$13,925.00**	**Total**

MODIFIED SYSTEM- MONTHLY NATURAL GAS COSTS			
			Therms (100,000 Btu)
			21.60
SYSTEM			
Heating and/or Cooling	$17.00000	per month	$17.00
Non-heating and Non-cooling	$11.75000	per month	$11.75
MONTHLY			
January	$1.0957	per therm	$23.67
February	$1.0957	per therm	$23.67
March	$0.9833	per therm	$21.24
April	$0.9833	per therm	$21.24
May	$0.9390	per therm	$20.28
June	$0.7543	per therm	$16.29
July	$0.7543	per therm	$16.29
August	$0.7331	per therm	$15.83
September	$0.8568	per therm	$18.51
October	$0.8603	per therm	$18.58
November	$0.9512	per therm	$20.55
December	$1.0957	per therm	$23.67
DISTRIBUTION			
First 125 therms	$0.30930	per therm	$6.68
Next 875 therms	$0.25030	per therm	$0.00
Over 1,000 therms	$0.19030	per therm	$0.00
SUBTOTAL MONTHLY COSTS			$35.43
Monthly Costs Incurred Over a Year			$425.17
Yearly Cost of Electrical Service			**$664.99**

Initial Cost Difference $10,750.00
Energy Cost Difference $99700.00
Payback Period 0.12 of a year = about 6 weeks

Conclusion

The hydronic heating system is a more efficient system than the electric resistive heating system. It also has many other advantages including comfort, versatility and reliability. If the Woolly Mammoth Theatre were to install this type of system, the payback would be a short time of about 6 weeks. This is a very good payback period, showing that the system is a better choice than electric resistive heating.