Radiant heating installations in Montana
by Leroy C Horpedahl

A THESIS Submitted to the Graduate Faculty in partial fulfillment of the requiremenrs for the degree of Master of Science in Mechanical Engineering
Montana State University

Abstract:
Radiant heating is not something very new. The Romans used it over 2,000 years ago, but it was not until 1908 that it was put on a commercial basis. There are many methods of supplying this form of heat to a dwelling. It may be done by passing hot air through ducts in floors, walls, or ceilings, or it may be accomplished by means of passing hot water through pipes in the same areas. This thesis concerns only the latter.

Montana State College was granted a sum of $5,000 by the Danforth Foundation to be used toward the erection of a campus chapel. Various departments have volunteered their services, both professional and manual, to help make this chapel a reality at a minimum cost and at a maximum of student interest. My contribution is the complete design of a radiant heating system for the chapel which is included in this thesis.

Radiant floor panels used with hardwood floors have been the desire of many citizens, hence a complete design and cost analysis is given with such a construction. This has been constructed and is in satisfactory operation.

Much can he learned from the mistakes and suggestions of others, hence a survey of radiant heating installations in Montana is included in this thesis. In connection with the survey, several inquiries were made concerning proper floor coverings to use with heated floors, The results of the research conducted on various types of floor coverings are also included in this thesis.

All calculations in this thesis were performed on a slide rule.

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LEROY C. HORPEDAHL

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Approved:

H F Muhlbauer

Head, Major Department

H F Muhlbauer

Chairman, Examining Committee

J. A. Nelson

Dean, Graduate Division

Bozeman, Montana
July, 1950

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ABSTRACT

Radiant heating is not something very new. The Romans used it over 2,000 years ago, but it was not until 1908 that it was put on a commercial basis. There are many methods of supplying this form of heat to a dwelling. It may be done by passing hot air through ducts in floors, walls, or ceilings, or it may be accomplished by means of passing hot water through pipes in the same areas. This thesis concerns only the latter.

Montana State College was granted a sum of $5,000 by the Danforth Foundation to be used toward the erection of a campus chapel. Various departments have volunteered their services, both professional and manual, to help make this chapel a reality at a minimum cost and at a maximum of student interest. My contribution is the complete design of a radiant heating system for the chapel which is included in this thesis.

Radiant floor panels used with hardwood floors have been the desire of many citizens, hence a complete design and cost analysis is given with such a construction. This has been constructed and is in satisfactory operation.

Much can be learned from the mistakes and suggestions of others, hence a survey of radiant heating installations in Montana is included in this thesis. In connection with the survey, several inquiries were made concerning proper floor coverings to use with heated floors. The results of the research conducted on various types of floor coverings are also included in this thesis.

All calculations in this thesis were performed on a slide rule.

A RADIANT HEATING SYSTEM FOR A PROPOSED DANFORTH CHAPEL ON THE CAMPUS OF MONTANA STATE COLLEGE

In the design of any building in Montana, careful consideration must be given to the type of heating system used with respect to cost, maintainence, and the ability to heat during extreme weather conditions. In a more specific case, such as the design of a chapel, other conditions must also be included, such as quietness of operation, comfort, and exclusion of elements which would tend to deviate from the modernistic theme of the contemporary chapel. With these restrictions in mind, radiant heating was suggested and the following design is proposed. Two complete systems are shown, one with ½" copper tubing and the other with 3/4" copper tubing. The selection of the ½" tubing system was chosen because of the better heat distribution in the concrete floor with shorter spacing distances. Also, the cost was slightly less.

The first step in any heating design is to calculate the heat loss of the building. In radiant installations, it is necessary to break up the heat losses into each individual room because the amount of panel installed in each room is a function of the heat loss for that particular room. In this particular case, recommendations for insulation and windows were made in conjunction with the heat loss calculations at the request of the architect. Heat loss calculations for both single and double glass windows were made to determine whether single glass would be feasible. As the calculations which

follow show, it would not be practical here in Montana to use the single glass over such a large area. First of all, frost formations would occur on the window with the resulting moisture on the walls and floor below. Secondly, it would be impossible to heat this chapel under extreme conditions with just a floor panel using radiant heat without exceeding an 85°F floor temperature. Wall or ceiling panels were not considered in this design because of the nature of their construction.

The heat loss calculations with the necessary recommendations and assumptions, follow. All heat transfer coefficients (U) and resistances (R) were taken from the ASHVE Guide (1949).

Heat Loss Calculations

A. Sanctuary and entry

1. Ceiling

	R
Inside air film	0.606
Insulating board ½" thick	1.52
3/4" air space	0.91
4" mineral wool insulation	14.80
8" air space	0.91
25/32" fir or yellow pine sheathing	0.98
Built-up roof (assumed 3/8" thick)	0.28
Outside air film	0.167
	R = 20.173

U = 1/20.173 = 0.05 Btu/hr-sq.ft.-°F

Ceiling area =

53 x 22½ - 2 x 6 - 5 x 2⅔ x 2½ = 1149 sq. ft.

Heat loss = 1149 x .05 x 90. = 5160 Btu/hr

2. Walls

	R
Inside air film	0.606
25/32" redwood	1.055
25/32" pine sheathing	0.98
4" mineral wool	14.80
25/32" pine sheathing	0.98
25/32" redwood	1.055
Outside air film	0.167
	R = 19.643

U = 1/19.643 = .051 Btu/hr-sq.ft.-°F

Wall area

$9\frac{1}{2}$ x 33.5 + $9\frac{1}{2}$ x 19 + $9\frac{1}{2}$ x 22.5 = 713 sq. ft.

Heat loss = 713 x .051 x 90 = 3270 Btu/hr

3. Doors (assumed thickness 1 3/4")

U = 0.51 Btu/hr-sq.ft.°F

Door area = 7 x 3 = 21 sq.ft.

Heat loss = 2 x 21 x .51 x 90 = 1928 Btu/hr

4. Stained glass window

U = 1.13 Btu/hr-sq.ft.-°F

Area = $9\frac{1}{2}$ x 6 = 57 sq.ft.

Heat loss = 57 x 1.13 x 90 = 5,800 Btu/hr

5. Skylights

U = .45 Btu/hr-sq.ft.°F

Area = 5 x 2.5 x 2.5 = 31.25 sq.ft.

Heat loss = 31.25 x .45 x 90 = 1,265 Btu/hr

6. Glass wall area

Area = $6\frac{1}{3}$ x 43 + $2\frac{1}{3}$ x 50 = 404 sq. ft.

(Assuming the use of double glass)

U = .45 Btu/hr-sq.ft.-°F

Heat loss = 404 x .45 x 90 = 16,350 Btu/hr

7. Infiltration--crack method

Windows

Factor for average window, non-weather stripped--
39.3 cu. ft./ft. crack/hr

Two.....$2\frac{1}{2}$' x 3' = 22 ft. of crack

One.....$2\frac{1}{2}$' x 5' = 15 ft. of crack

Total.....37 ft.

37 x 39.3 = 1454 cu. ft./hr

Doors

Factor....110.5 cu. ft./ft. crack/hr

Two doors....3' x 7' = 40 ft. of crack

40 x 110.5 = 4,420 cu. ft./hr

Total = 1454 + 4420 = 5,874 cu. ft./hr

Volume of sanctuary and entry

1180 x 10 = 11,800 cu. ft.

This only gives $\frac{1}{2}$ air change per hr., therefore,
assume 1 air change per hr.

Heat loss = 11,800 x .018 x 90 = 19,100 Btu/hr

Where .018 = .24 x .075

and .24 = specific heat of air

.075 = density of air, lbs./cu. ft.

8. Floor (ground loss)

	Heat loss, Btu/hr
Ceiling	5160
Walls	3270
Doors	1928
Stained glass window	5800

Skylights..... 1265
Glass wall.....16350
Infiltration.....19100
Total.....52873 Btu/hr

Assume ground loss 15% of total heat loss:

15% x 52873 = 7930 Btu/hr

Total = 7930 + 52873 = 60,803 Btu/hr

B. Sacristy

1. Ceiling area

Area = 17 x $11\frac{1}{2}$ - 7 x 5 = 160 sq. ft.

U = .05 Btu/hr - sq. ft. - $^{\circ}$F

Heat loss = 160 x .05 x 90 = 720 Btu/hr

2. Wall area

Area = $11\frac{1}{2}$ x $9\frac{1}{2}$ + 6 x $9\frac{1}{2}$ + $10\frac{1}{2}$ x $9\frac{1}{2}$ = 261 sq. ft.

U = .051 Btu/hr - sq. ft. - $^{\circ}$F

Door area = 21 sq. ft.

Window area = 21 sq. ft.

Total area = 261 - 21 - 21 = 219 sq. ft.

Heat loss = 219 x .051 x 90 = 1000 Btu/hr

3. Door area

Area = 21 sq. ft.

U = .51 Btu/hr - sq. ft. - $^{\circ}$F

Heat loss = 21 x .51 x 90 = 964 Btu/hr

4. Window area (assume double glass)

Area = $2\frac{1}{2}$ x $8\frac{1}{2}$ = 21 sq. ft.

U = .45 Btu/hr - sq. ft. - $^{\circ}$F

Heat loss = 21 x .45 x 90 = 850 Btu/hr

5. Infiltration--crack method

Windows

Factor---39.3 cu. ft./ft. crack/hr

One.....$2\frac{1}{4}'$ x $2\frac{1}{3}'$ = 9.5 ft. of crack

39.3 x 9.5 = 373 cu. ft.

Doors

Factor---110.5 cu. ft./ft. crack/hr

One.....3' x 7' = 20 ft. of crack

110.5 x 20 = 2210 cu. ft.

Total = 373 + 2210 = 2583 cu. ft./hr

Volume of sacristy = 160 x 10 = 1600 cu. ft.

Crack method gives approximately two air changes per hr. Use infiltration by crack method for heat loss.

Heat loss = .018 x 2583 x 90 = 4190 Btu/hr

6. Floor (ground loss)

	Heat loss, Btu/hr
Ceiling	720
Walls	1000
Doors	964
Windows	850
Infiltration	4190
Total	7724 Btu/hr

Assume ground loss = 15% of total heat loss

15% x 7724 = 1158 Btu/hr

Total = 7724 + 1158 = 8882 Btu/hr

Total Heat Loss For Chapel

Assumed Use of Double Glass in East Wall

Sanctuary and entrance

1. Ceiling	5160	
2. Walls	3270	
3. Doors	1928	
4. Stained glass window	5800	
5. Skylights	1265	
6. Glass wall	16350	
7. Infiltration	19100	
8. Floor	7930	
Total	60803	Btu/hr

Sacristy

1. Ceiling	720	
2. Walls	1000	
3. Doors	964	
4. Windows	850	
5. Infiltration	4190	
6. Floor	1158	
Total	8882	Btu/hr

Total heat loss..... 69,685 Btu/hr

Total Heat Loss For Chapel

Assumed Use of Single Glass in East Wall

Sanctuary and entrance

1. Ceiling	5160	
2. Doors	1928	
3. Walls	3270	
4. Stained glass window	5800	
5. Skylights	1265	
6. Glass wall	41100	
7. Infiltration	19100	
8. Floors	7930	
Total	85553	Btu/hr

Sacristy

1. Ceiling	720	
2. Walls	1000	
3. Doors	964	
4. Windows	850	
5. Infiltration	4190	
6. Floor	1158	
Total	8882	Btu/hr

Total heat loss..... 94,435 Btu/hr

Design of Floor Panels

Note:

Heat losses based on the use of double glass in all windows except stained glass mural.

Design temperature of water is 130°F with a 20°F temperature drop through the circuit.

Depth of bury is 2 inches.

A. Floor panel - ½" copper tube 9" and 6" O.C.

1. Sanctuary and entry

Heat loss = 60803 Btu/hr

Panel rating used = 50 Btu/hr-sq. ft.

Floor panel area required = 60803 ÷ 50 = 1215 sq. ft.

Actual floor area = 1160 sq. ft.

Use ½" copper tube 9" and 6" O.C.

Length of tube required = 1040 x 1.3 = 1352 ft.
120 x 2.0 = 240 ft.

Total..... 1592 ft.

2. Sacristy

Heat loss = 8882 Btu/hr

Panel rating used = 50 Btu/hr - sq. ft.

Floor panel area required = 8882 ÷ 50 = 177 sq. ft.

Actual floor area = 162 sq. ft.

Use ½" copper tube 9" O.C.

Length of tube required = 162 x 1.3 = 210 ft.

Total length of tube required = 1592 + 210 = 1802 ft.

3. Circuits

Use circuits of approximately 180 feet.

No. of circuits = 1802 ÷ 180 = 10--Approximately

Circuit	#1	184 Ft.
"	#2	186 "
"	#3	173 "
"	#4	181 "
"	#5	170 "
"	#6	186 "
"	#7	185 "
"	#8	191 "
"	#9	182 "
"	#10	166 "
	Total	1804 Ft.

4. Supply and return headers

Use 2" W. I. pipe, 4 ft. long each.

5. Pump

Use 1¼" standard or 1½" high head

6. Water heater

Recommend use of hot water converter similar to no. GC4-4 as supplied by General Fittings Co. and rated at 470 sq. ft. of hot water radiation (5 lb. steam).

7. Valves

Use stop and waste valves on the return header to facilitate removal of air during the filling operation.

Use gate valves on the supply header.

The general specifications, list of materials, and cost follows.

General Specifications:

Heat loss from the chapel is based on the insulation

quantities given below. Any deviation will possibly change the entire set-up, hence strict adherence is advised for satisfactory operation of the heating system.

I. Insulation:

(1) Ceiling....4" rock wool or equivalent

(2) Walls.....4" rock wool or equivalent

(3) Floor.....1" fiber glass insulation at exposed perimeter of slab. Extend 3' inside along the rock wall.

II. Windows:

(1) Sanctuary....double glazing throughout of a "thermopane" nature; three operating sections, one over each door approximately 2' 6" x 3' 0" and one in the end bay approximately 2' 6" x 5' 0".

(2) Skylights....double glass (18" airspace).

(3) Sacristy.....double glazing; one operating section approximately 2' 3" x 2' 6".

III. Doors:

(1) All doors are flush wood doors 1-3/4" thick.

IV. Floors:

(1) The floor is to be constructed of a 4" concrete slab poured on 6" crushed rock or extremely coarse gravel. The floor must be poured separately from the foundation and may have a concrete surface finish, tile, linoleum, or wood nailed to sleepers embedded in the concrete.

V. A 3/4" copper tubing supply and return line shall be imbedded in the concrete from the heating

room to the east wall to be used with radiant baseboards along the east wall of windows should it become necessary.

VI. Construction of the heating system will be done by the students taking the radiant heating course during the fall quarter under the direction of Dr. H. F. Mullikin, if agreeable.

VII. Bill of materials and cost:

1 circulator (1½" std. or 1¼" high head).....	$ 49.00
1 indoor thermostat (Perfex line voltage)...	11.50
1 converter (similar to GC4-4, General Fittings Co.)....	73.20
1 floating thermostatic trap (3/4").....	4.00
1 temperature regulator (no. 928-LC Fulton Sylphon-1½").....	80.00
1 expansion tank (20 gal.).....	16.00
1 automatic air vent.....	4.30
10 shut-off valves (1/2").....	13.50
10 stop and waste valves (1/2").....	15.00
1 supply header (4 ft. of 2" W.I. pipe).....	5.00
1 return header (4 ft. of 2" W.I. pipe).....	5.00
90 ft. of 3/4" copper tubing type L.....	20.00
1 check valve ½".....	6.00
1 reducing valve and 1 relief valve (combined) ½".....	12.00
1 altitude gage (thermometer included).....	7.50
1800 ft. of ½" copper tubing type L.....	282.00

4 shut-off valves 1½"..... 40.00

30 ft. 1½" water pipe @ 42¢ per ft..... 12.60

Miscellanious elbows, tees, etc..... 10.00

Total.....$666.60

VIII. The prices quoted above are subject to educational discounts which can be received if ordered through the Mechanical Engineering Department.

IX. The return header will be located in a pit slightly below the floor level to facilitate draining the system. A sewer outlet will be located in the pit.

X. The headers may be located along the north wall instead of the south wall as shown on the drawing. This will help prevent excessive heat in the utility room.

XI. At each joint in the concrete, wrap each tube with felt or some cloth-like material to prevent the tubes from shearing off due to ground movement.

B. Floor panel--3/4" copper tube 12" and 9" O.C.

1. Sanctuary and entry

Panel rating - 50 Btu/hr

Heat loss and panel area same as with ½" tube.

Length of tube required - 940 x 1 = 940 ft.
200 x 1.3 = 260 ft.
Total.....= 1200 ft.

2. Sacristy

Heat loss and panel area same as with $\frac{1}{2}$" tube

Length of tube required = 162 x 1 = 162 ft.

Total length = 1200 ÷ 162 = 1362 ft.

3. Circuits

Use circuits of approximately 280 ft.

No. of circuits = 1362 ÷ 280 = approximately 5

Circuit	#1	279 ft.
"	#2	290 "
"	#3	281 "
"	#4	270 "
"	#5	273 "
Total		1393 ft.

4. Supply and return headers

Use 2" W. I. pipe, 4 ft. each

5. Pump

Use $1\frac{1}{2}$" standard or $1\frac{1}{2}$" high head

6. Water heater

Recommend use of hot water converter similar to no. GC4-4 as supplied by General Fittings Co. and rated at 470 sq. ft. of hot water radiation (5 lb. steam.

7. Valves

Use stop and waste valves on the return header to facilitate removal of air during the filling operation. Use gate valves on the supply header.

The same general specifications will be used for the 3/4" tubing as for the $\frac{1}{2}$" tubing.

List of materials and cost:

1 circulator (1½" std. or 1¼" high head) B & G.....	$ 49.00
1 indoor thermostat (Perfex line voltage).....	11.50
1 converter (similar to GC4-4, General Fittings Co....	73.20
1 floating thermostatic trap (3/4").....	4.00
1 temperature regulator (no. 928-LC Fulton Sylphon-1½"	80.00
1 expansion tank (20 gal.).....	16.00
1 automatic air vent.....	4.30
6 shut-off valves (3/4").....	11.00
6 stop and waste valves.....	12.00
1 supply header (4 ft. of 2" W. I. pipe).....	5.00
1 return header (4 ft. of 2" W. I. pipe).....	5.00
1490 ft. of 3/4" copper tubing type L.....	332.00
1 check valve (1½").....	6.00
1 reducing valve and relief valve (combined) ½".....	12.00
1 altitude gage (thermometer included).....	7.50
4 gate valves (1½").....	40.00
30 ft. 1½" water pipe @ 42¢ per ft.....	12.60
Miscellaneous tees, elbows, etc.....	10.00
Total.....	$691.10

The cost of materials for the two systems is slightly in favor of the ½" system, but the added labor would put both of them about equal. It is recommended that the ½" system be used because the closer spacing will give a more uniform panel

temperature and the smaller tubing gives more turbulent flow and hence better heat transfer.

This chapel has been designed by the students of the Montana State College Department of Architecture. As many departments as possible will contribute toward its construction when sufficient funds are available.