PANEL HEATING AND COOLING

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By

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SYMBOLS

a = portion, expressed as a decimal, of the impinging solar radiation that is absorbed by the wall surface.

A = area of wall or roof, sq. ft.

F = portion, expressed as a decimal of the absorbed solar radiation that is transmitted to the inside.

H = total heat gain through a wall.

H_t = heat gain due to air temperature difference.

H_R = heat gain due to sun radiation.

I = actual intensity of solar radiation striking the surface, Btu per hr. per sq. ft.

U = coefficient of heat transmission, Btu. per sq. ft. per hr. per degree difference in temperature between room air and outdoor air.

THE RESEARCH HOUSE.

INTRODUCTION AND SCOPE

Panel Radiant Heating:

The object of heating or cooling living spaces is to provide healthful and comfortable conditions. The flow of heat between bodies may occur in one or more of three essentially different ways: direct contact, known as conduction; circulation of currents of gases or liquids, known as convection; and finally, passage of heat-carrying rays through space without having any pronounced effect upon its temperature, known as radiant heat, or radiation.

Historical:

Excavations uncovered the remains of many radiant heating systems constructed and used by the early Romans. The famous baths at Pompeii provide outstanding examples of engineering skill displayed in the design of these early warm air radiant heating systems. Wood or charcoal was the fuel. The products of combustion, warm air and smoke, passed through stone chambers under the masonry floors.

During the early part of this century interest in radiant heating was revived by the use of hot water coils in Europe. The first of the modern engineered installations appears to have been made in Britain under the direction of Professor A. Barker about 1907. Today, about two thousand installations of this type are operating in France and England. In the United States, radiant heating became firmly established with the first noteworthy installations in a small village school at Glen Park, Indiana, in 1909, and in a large Chicago garage in 1912.

Heat Radiation and Human Comfort:

Healthful comfort requires that heat shall escape from the human body at the same rate it is generated. The normally active human body generates heat at the rate of 500 Btu/hr. approximately. As only 100 Btu/hr. are required for internal, functional energy, the rate of heat dissipation is 400 Btu/hr. Any greater rate of dissipation causes a sensation of coldness, any lesser rate a feeling of hotness. Under normal conditions nature maintains a proper balance in accordance with the following table of heat dissipation:

190 Btu/hr by radiation,

110 Btu/hr by convection and evaporation, and

100 Btu/hr by exhalation.

400 Btu/hr

The body has other methods of disposing of heat but these are of negligible importance. With heat being dissipated at the previously mentioned rate and in the proportions indicated, the temperature of the body will remain normal at 98.6° F and an average overall temperature of the exposed parts of the body and clothes at 81° F.

However, in summer, when the outside temperature is high the average temperature of the exposed parts of body and clothes is also higher. Most people during the summer wear thinner and fewer clothes, so that a greater part of the body is exposed and, consequently, the average surface temperature is higher than for the winter time. This average temperature is found to vary between 85° F and 89° F depending on the amount and nature of the clothes, the temperature of the surrounding air surfaces, the air motion and a few other minor factors. Obviously the body will lose heat by convection to any surrounding atmosphere with lower temperature and by radiation to any adjacent solid surfaces, walls, ceiling, floor, etc, having a lower temperature. This latter temperature is called the Mean Radiant Temperature.

The single basic requirement of a heating or cooling system is to establish such conditions in any area so that the occupants will lose their heat through convection and radiation at a uniform hourly rate of approximately 300 Btu.

Advantages of a Panel System:

One of the outstanding advantages of panel heating systems is that the system is not apparent in the living quarters. This appeals very strongly to the architects and to the home owners. Also, thermal air currents are substantially reduced and less dirt is picked up to be deposited on walls, ceiling or draperies. This cleaner air establishes more sanitary condition in the home as there is a lesser concentration of the dust-borne disease germs in the air. Finally, the operating economics of circulating water may be utilized in the panel heating system.

Panel Location:

Panels may be located in the ceiling, in the floor, in walls, or in any combination of the three. At present there are two general preferences, one is to use the floor location and the other favors the ceiling.

If the panels are in the floor, then it is necessary to maintain a floor temperature below 90° F to avoid over heating the feet. Such a floor will emit about 35 or 40 Btu per hour square feet while if we locate the coils in the ceiling, the ceiling temperature can safely be raised to about 115° F. If these figures are applied to the experimental house, which has a floor area of 406 square feet, it is essential that the heat loss in the walls, ceiling, windows, infiltration will not exceed 16,000 Btu/hr at most. This means, therefore, that the construction of the house definitely must be checked before a floor panel system is applied.

On the other hand, if the coils are located in the ceiling, the ceiling temperature may safely be as high as 115° F. This temperature now raises the maximum heat loss or emission to about 40,000 Btu/hr.

It is apparent that a wall panel installation is a compromise between the floor and ceiling locations. Its main disadvantage is the presence of furniture which partly annuls the heating effect from the wall radiations.

The heating load of the experimental house was found to be about 35,500 Btu/hr. This, of course, eliminates the possibility of using the floor panels. On the other hand, the ceiling panels are barely adequate. If a wall installation is added to the ceiling system, then the combination should be satisfactory for the heating load.

For these experiments both the ceiling and wall installations were used. Some of the testing was performed with both panels in operation and the remainder of the testing with only the ceiling coils supplying radiant heat. During the period February 24, 1952 to March 4, 1952, both panels were in operation while during March 5, 1952 to March 26, 1952, only the ceiling panels were used.

The purpose of this work is to compare the effect of the ceiling installation with the ceiling and wall combination for comfort and distribution of heat throughout the room.

This research was carried on in the apartment "29 - D," in the College Courts in Stillwater, which is owned by the Oklahoma Agricultural and Mechanical College and is occupied by some of the college personnel.

Professor Robert R. Irwin designed and supervised the installation of the heating and cooling system as well as the recording devices. He also collected the cooling data.

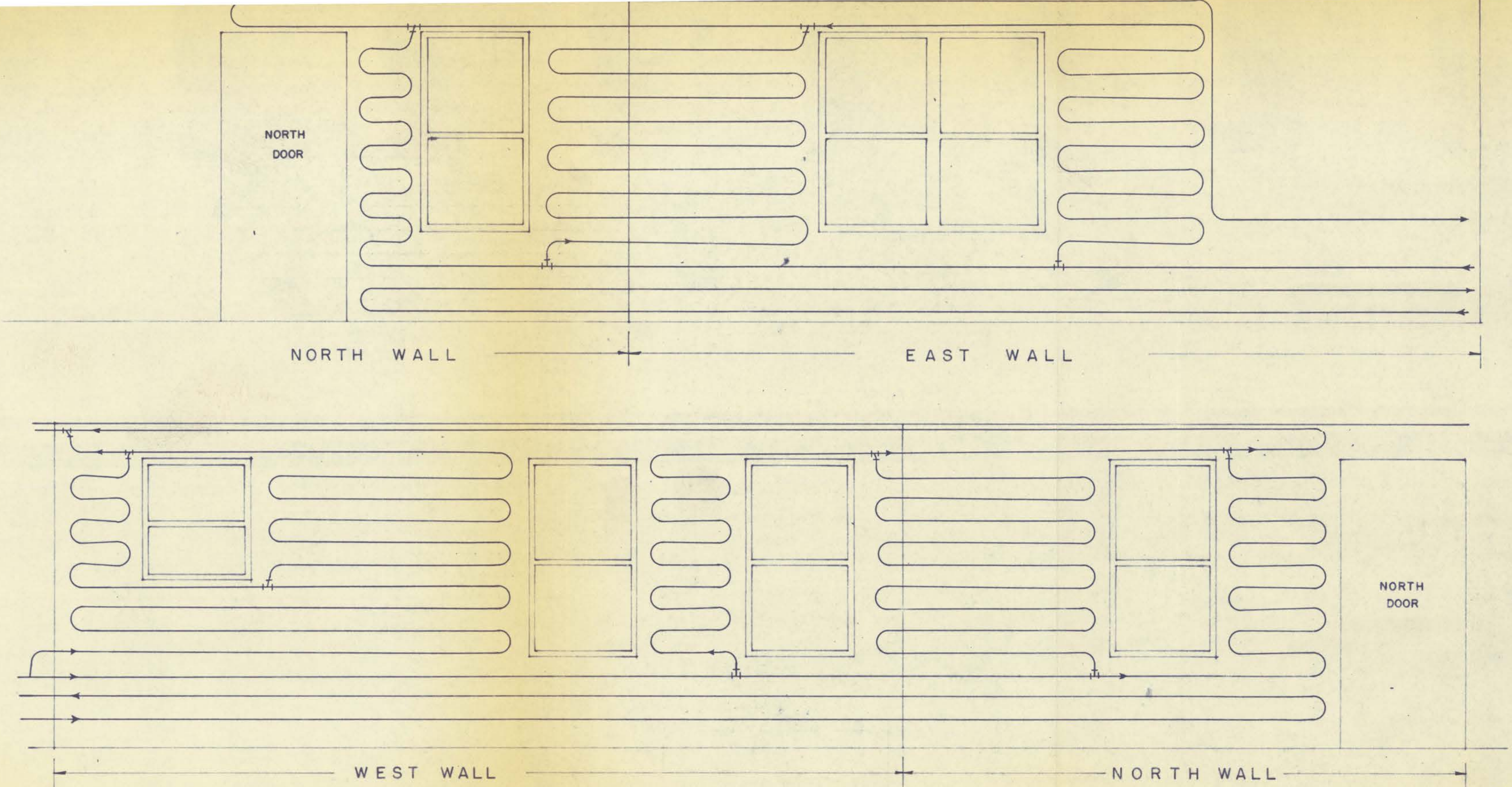
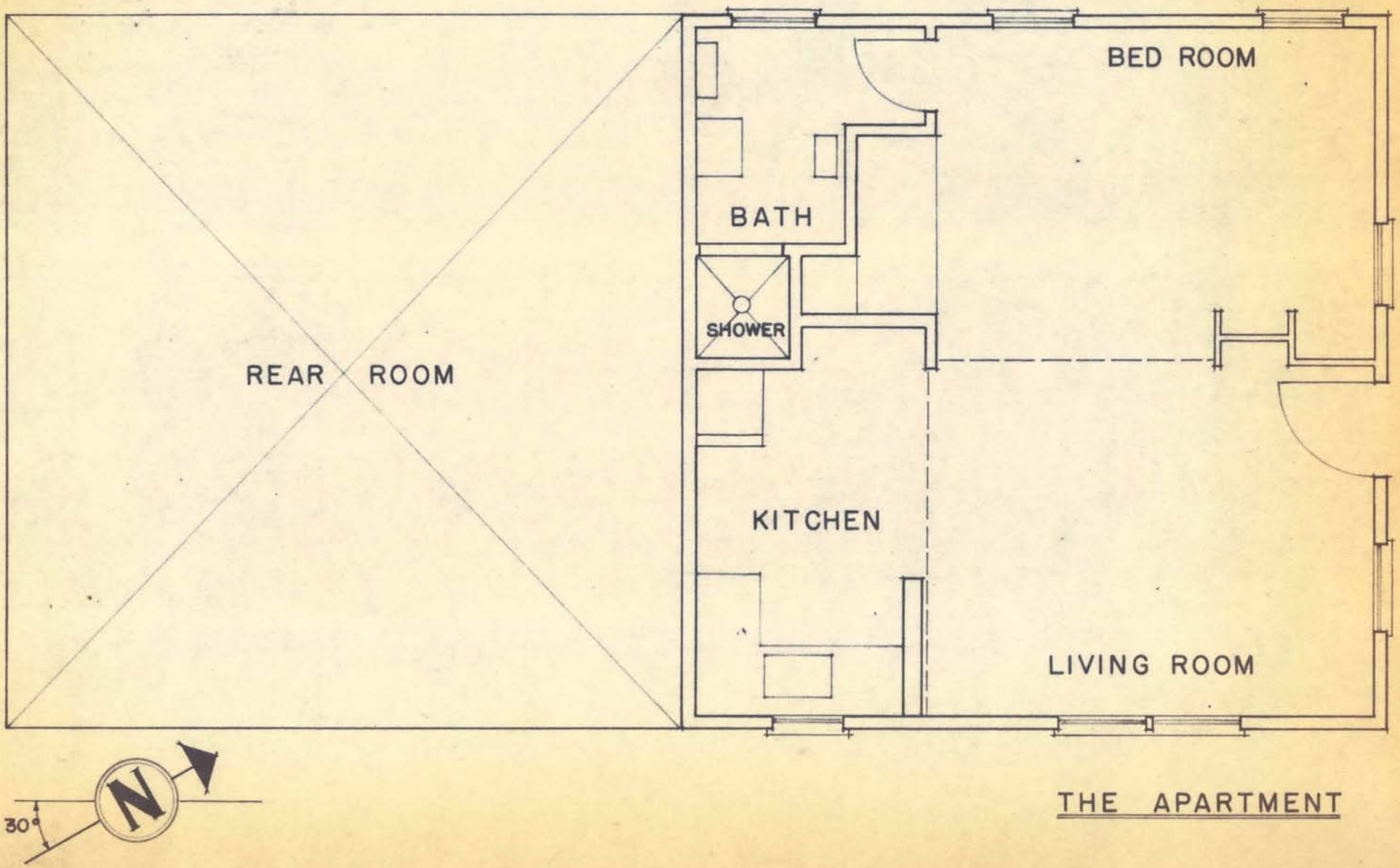


FIG "A"

WALL COIL LAYOUT



THE APARTMENT

THE HEATING AND COOLING SYSTEMS

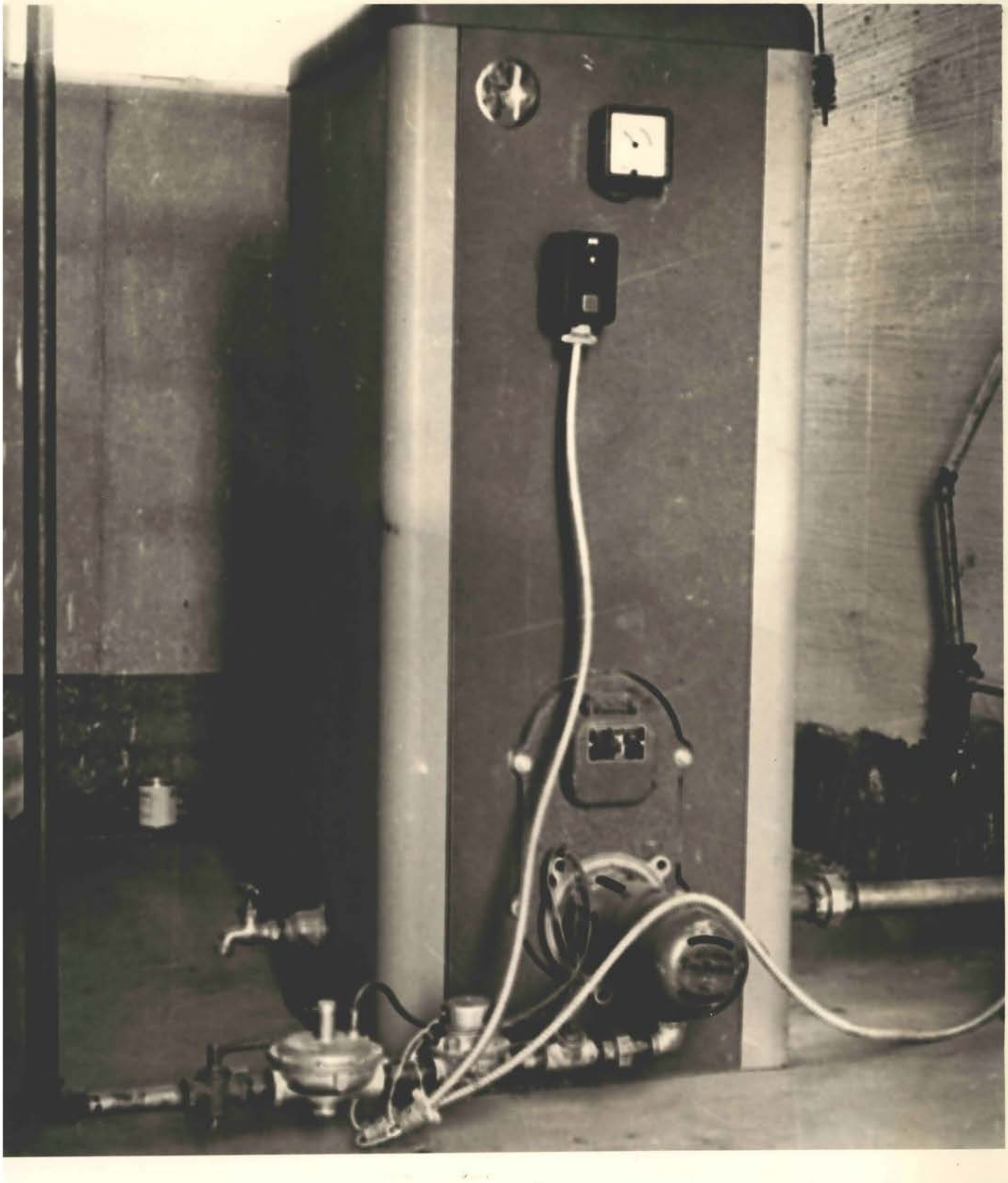


Fig. 2.

THE HEATING PLANT

The heating system is installed in the storage room on the south side of the apartment. The system consists of the following components:

1. The Boiler: The vertical fire-tube steel boiler (Fig. 2) for heating the circulating water is located in the middle of the storage room. It is gas fired and has a rated output of 77,000 Btu with a gas input rating of 144,000 Btu/hr. The boiler has a heating surface of 19 sq. ft., a fire box volume of 2.9 cu. ft. and a shell diameter of 20 inches.
2. The Pump: A small centrifugal pump is used to circulate the heating water. It is belt-driven by a 3/4 horse-power General Electric motor running at 1725 R. P. M.
3. The Piping: Figure "A" and Figure 3 show the piping system, the connections to the heating coils, the valves, and the method of venting.

METHOD OF CONTROL

If the outside temperature drops considerably, the drop will not be detected by the room thermostat valve until some time has elapsed. After the room thermostat responds to the cold by increasing the heat to the circulating water there will be an additional delay before the heat is delivered to the space. Then, after the temperature of the panel rises, the panel will continue to emit heat to the room for some time after the thermostat cuts off the heat because of the heat storage capacity of the circulating water. To avoid the uncomfortable conditions encountered in

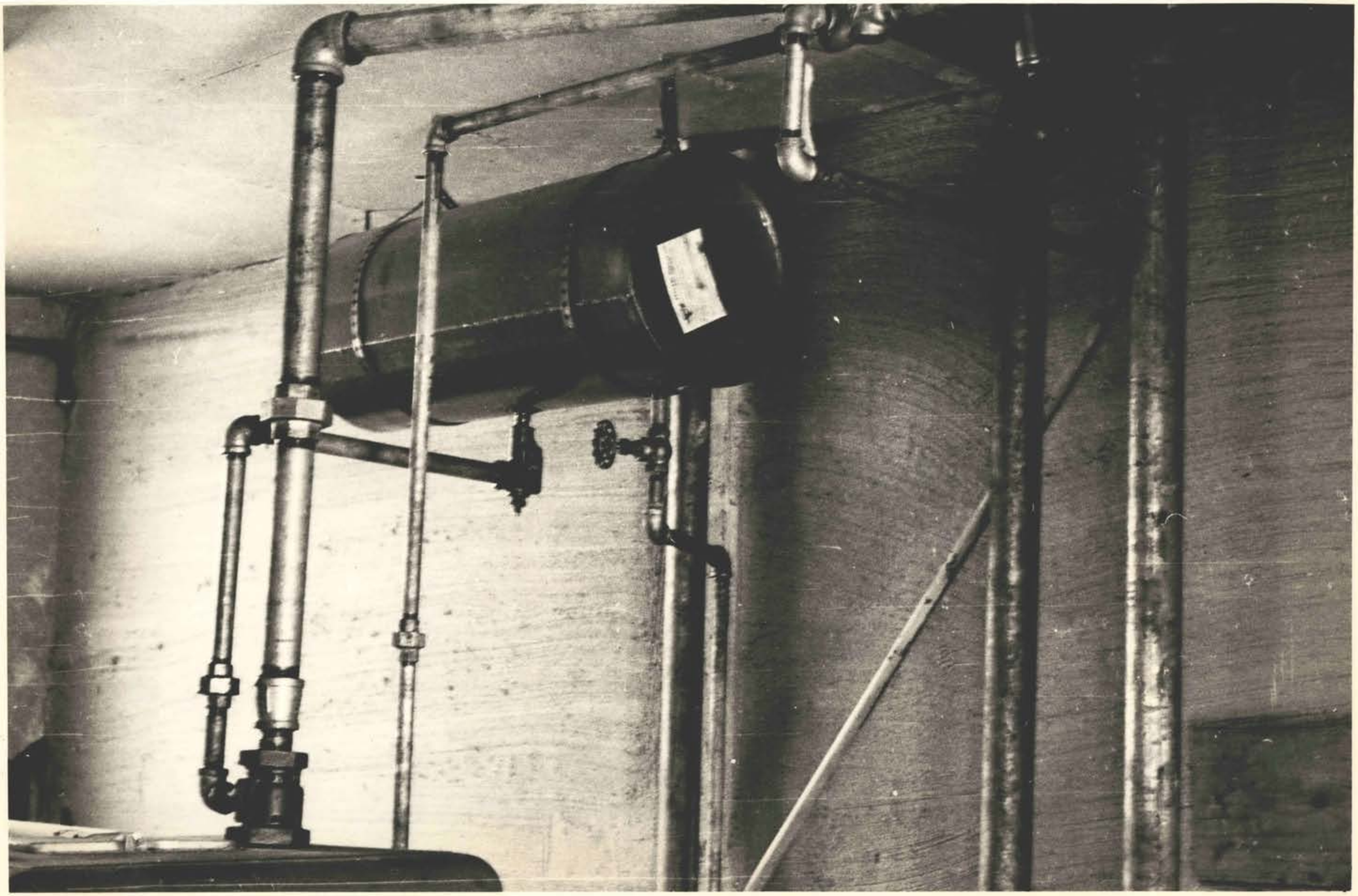


Fig. 3.

both of these cases, the following method of control is applied to the system. An immersion thermostat is installed in the hot water supply main so that it will be directly affected by the hot water circulated to the radiant coils.

An electronic relay picks up the responses of this thermostat and operates to control the gas burner in the boiler. The outdoor temperature variations are also transmitted to the relay through the outdoor thermostat.

Room Thermostat:

A sensitive electronic room thermostat is placed about 4 feet from the floor on the middle of the south wall of the apartment. In this location it is far removed from any outside door cold drafts, far from any appliance giving out heat and is unexposed to any possible mechanical injuries. It is also quite near the breathing level of people sitting or sleeping in the apartment.

Outdoor Thermostat:

This is a wall mounted device used in the electronic control system to measure the outdoor temperature. It is mounted high on the outside north wall in a shaded place and out of reach of inquisitive fingers.

Both the room and the outdoor thermostats are manufactured by Minneapolis-Honeywell.

The Control Circuit:

Fig. B shows the control circuits and its connections to the mechanical system. It also shows the location of the electronic relay and the switching relay in the circuit. These are also shown in Fig. 5.

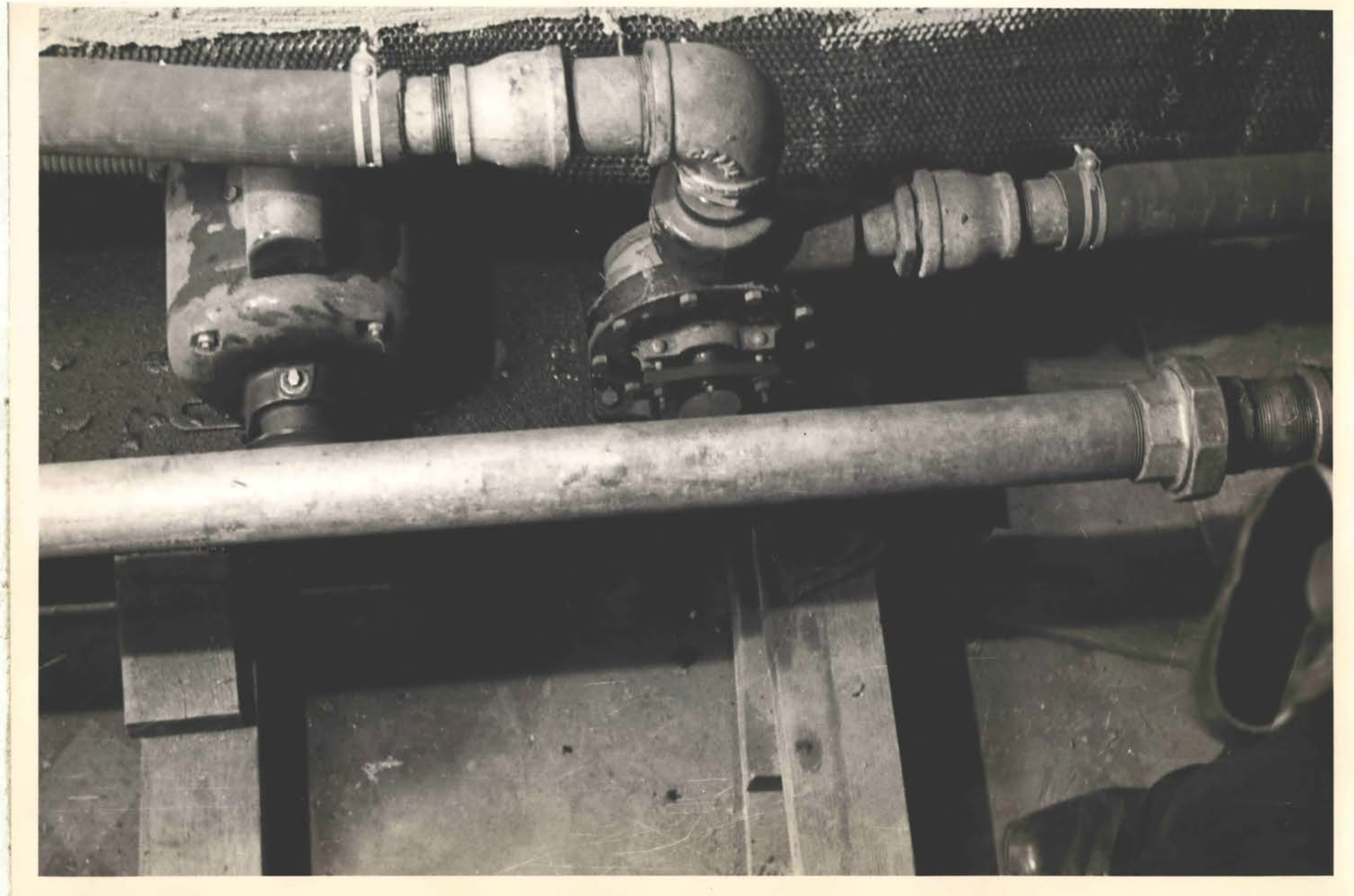


Fig. 4.

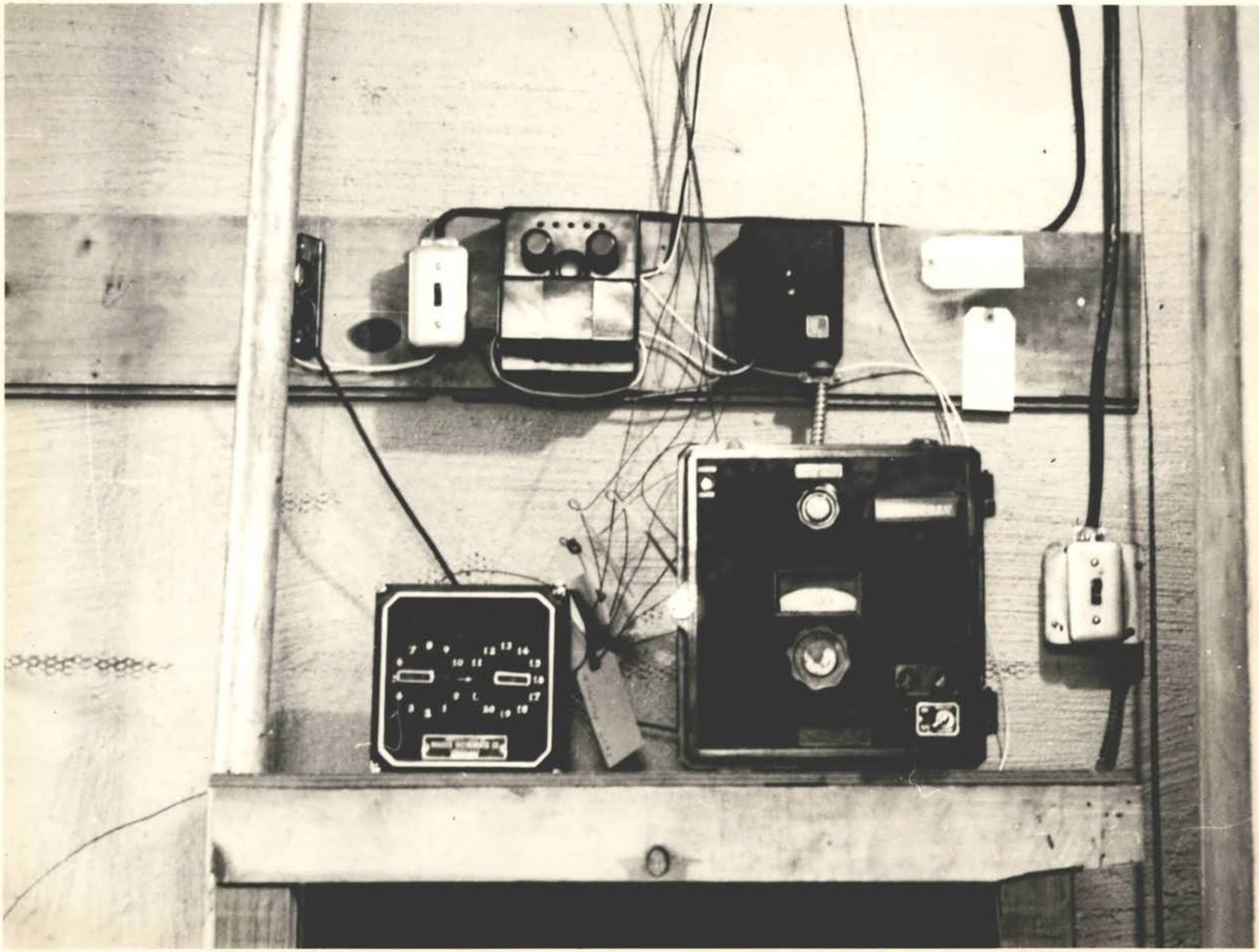


Fig. 5 .

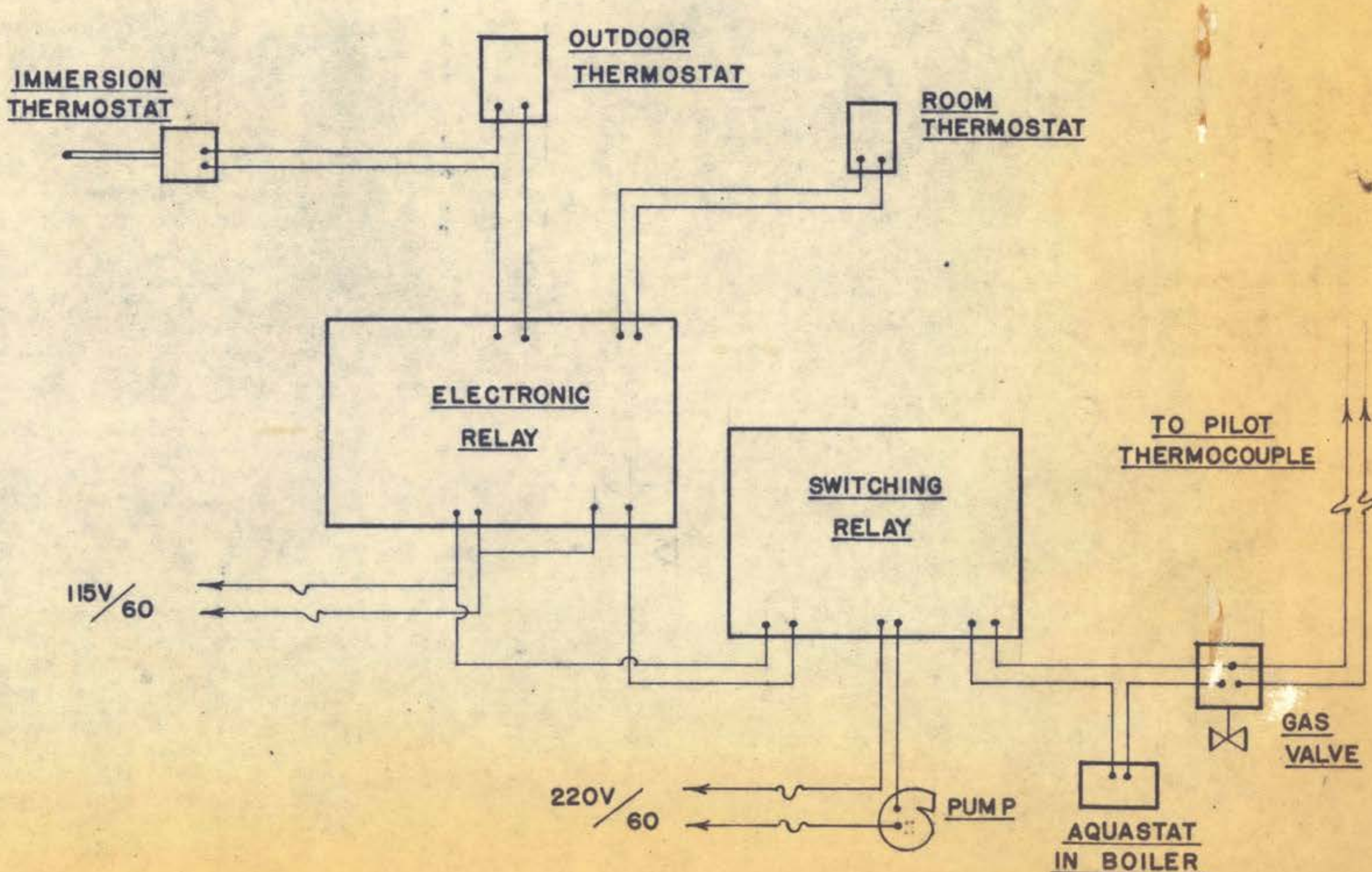

IMMERSION THERMOSTAT
OUTDOOR THERMOSTAT
ROOM THERMOSTAT
ELECTRONIC RELAY
SWITCHING RELAY
TO PILOT THERMOCOUPLE
115V/60
220V/60
PUMP
GAS VALVE
AQUASTAT IN BOILER

FIG. B

The Temperature-Recording for the Heating Plant:

Six thermocouples are strategically located in the apartment to measure the temperature variations. They are located on the following surfaces: the floor, the east wall, the wall pipe, the ceiling, the ceiling pipe and the water pipe. These thermocouples are connected to a potentiometer as shown in Fig. 5 on which the temperatures can be read at any time.

The Control and Temperature Recording for the Cooling System:

The cooling load data were measured before the control system was placed in operation. The cooling water adjusted its temperature according to the cooling load variations.

The recorded data were collected by using three temperature and humidity recording instruments. One of them was placed inside the apartment, one outside in the shade and the third to record the temperatures of the inlet and outlet cooling water. Although the first two instruments recorded the humidity, the recording is not precise because the instruments were not calibrated.

THE COOLING TOWER.

THE COOLING SYSTEM

1. Cooling Tower:

A small cooling tower which is located on the north east side of the apartment is primarily used for cooling the circulating water during the summer time. From the temperature recordings of the inlet and outlet cooling water to the coils it may be seen that the water is cooled from 4 to 6 degrees within the cooling tower.

2. Pump and Motor:

The same pump and its motor which are used for circulating the heating water are also used for circulating the cooling water.

Two valves have been used in the water pipes to by-pass either the cooling tower or the boiler as occasion requires.

Fig. 7 shows a picture of the cooling tower used.

Fig. 4 shows the circulating pump together with its driving motor and the main pipe lines.

THE PANELS.

THE HEATING AND COOLING LOADS

Calculations of both the winter heating load and the summer cooling load are presented here to illustrate the requirements from the heating and cooling systems and to discuss their ability to carry these loads.

CALCULATING THE WINTER HEATING LOAD

Design Temperatures:

Outside Temperature = 0° F.

Room Temperature = 70° F.

Area of floor and ceiling = 414 sq. ft.

Area of east and west walls = 160 sq. ft.

Area of north and south walls = 162.6 sq. ft.

Area of north wall glass = 19.1 sq. ft.

Area of west wall glass = 24.8 sq. ft.

Area of east wall glass = 19.1 sq. ft.

Area of outside door = 19.5 sq. ft.

Total area of glass = 63. sq. ft.

Total area of exposed walls = 482.6 sq. ft.

Net area of exposed walls = 482.6 - 63

= 419.6 sq. ft.

Area of cold partitions = 162.6 sq. ft.

Coefficient of heat transmission for floor = 0.30 Btu/hr sq. ft. ° F.

Coefficient of heat transmission for ceiling = 0.20 Btu/hr sq. ft. ° F.

Coefficient of heat transmission for walls = 0.06 Btu/hr sq. ft. ° F.

Coefficient of heat transmission for the cold partitions

= 0.12 Btu/hr sq. ft. ° F.

Coefficient of heat for transmission for the windows

= 1.13 But/hr sq. ft. ° F

Coefficient of heat transmission for the door = 1.13 Btu/hr sq. ft. ^{o}F.

Infiltration factor for windows, for 70^{o} F temperature-difference

= 140 C.F.M/Ft crack.

Infiltration factor for the door, for 70^{o} F temperature-difference

= 280 C.F.M/Ft crack.

Btu loss from exposed walls = 419.6 x 0.06 x (70 - 0)

= 1760 Btu/hr.

Btu loss from the cold partition = 162.6 x 0.12 x (70 - 0)

= 1370 Btu/hr.

Btu loss from the floor = 414 x 0.30 x (70 - 0) = 8700 Btu/hr.

Btu loss from the roof = 414 x 0.20 x (70 - 0) = 5800 Btu/hr.

Btu loss from the windows = 63 x 1.13 x (70 - 0) = 5000 Btu/hr.

Btu loss from the door = 19.5 x 1.13 x (70 - 0) = 1540 Btu/hr.

Btu loss due to infiltration from the windows = 49 x 140 = 6850 Btu/hr.

Btu loss due to infiltration from the door = 19 x 280 = 4500 Btu/hr.

Total Btu loss of the house = 35,500 Btu/hr.

CALCULATING THE SUMMER COOLING LOAD

Calculation of Heat Gain per Square Foot

of Walls and Glass

	Time	Time of load source	I	dT	U	F	Btu/hr. Sq. Ft. H_t	H_R	H
East Wall	9 AM	4 AM	0	8	0.06	0.0138	0.48	0.	0.480
(5 hrs.	11 AM	6 AM	56	5.4			0.324	5.510	0.734
lag)	3 PM	10 AM	152	19.2			1.15	14.70	15.85
	5 PM	12 Noon	26	25.7			1.54	2.51	4.05
	7 PM	2 PM	23.5	28.5			1.71	2.27	3.98
	9 PM	4 PM	17	30.1			1.805	1.64	3.445
Glass	9 AM		195	13.9	1.13	(F x a = 0.0966)	15.70	11.30	27.0
(Vene-	11 AM		94	22.5			25.40	54.55	79.95
tian	3 PM		21	29.7			33.60	12.18	45.78
Blinds	5 PM		11	29.5			33.30	6.38	39.68
58% I)	7 PM		2.5	24.5			27.70	1.45	29.15
	9 PM		0	18.2			25.55	0	20.55

Calculation of Heat Gain per Square Foot
of Walls and Glass (continued)

	Time	Time of load source	I	dT	U	F	Btu/hr. Sq. Ft.		
							H_t	H_R	H
West Wall	9 AM	4 AM	0	8	0.06	0.0138	0.48	0	0.480
(5 hrs.	11 AM	5 AM	4.5	5.4			0.324	0.434	0.758
lag)	3 PM	10 AM	23.5	19.2			1.15	2.27	3.42
	5 PM	12 Noon	26	25.7			1.54	2.51	4.05
	7 PM	2 PM	152	28.5			1.71	14.70	16.41
	9 PM	4 PM	211	30.1			1.805	20.38	22.185
Glass	9 AM		21	13.9	1.13	(F x a = 0.0966)	15.70	12.18	27.88
(Vene-	11 AM		25.5	22.5			25.40	14.78	40.18
tian	3 PM		195	29.7			33.60	11.30	44.90
Blinds	5 PM		162	29.5			33.30	94	127.3
58% I)	7 PM		6	24.5			27.70	3.48	31.18
	9 PM		0	18.2			20.55	0	20.55

Calculation of Heat Gain per Square Foot
of Walls and Glass (continued)

	Time	Time of load source	I	dT	U	F	H_t	H_R	H
North Wall	9 AM	4 AM	0	8	0.06	0.0138	0.48	0	0.480
(5 hrs.	11 AM	6 AM	49	5.4			0.324	4.73	5.054
lag)	3 PM	10 AM	54	19.2			1.15	5.22	6.37
	5 PM	12 Noon	26	25.7			1.54	2.51	4.05
	7 PM	2 PM	23.6	28.5			1.71	2.27	3.98
	9 PM	4 PM	17	30.1		(F x a = 0.00966)	1.805	1.644	3.445
Glass	9 AM		102	13.9	1.13		15.70	59.20	74.90
(Vene-	11 AM		28	22.5			25.4	16.24	41.64
tian	3 PM		21	29.7			33.60	12.18	45.78
Blinds	5 PM		11	29.5			33.30	6.38	39.68
58% I)	7 PM		2.5	24.5			27.70	1.45	29.15
	9 PM		0	18.2			20.55	0	20.55

Calculation of Heat Gain per Square Foot
of Walls and Glass (continued)

	Time	Time of load source	I	dT	U	F	H_t	H_R	H
South Wall	9 AM	4 AM		8	0.06		0.48		0.48
(5 hrs.	11 AM	6 AM		5.4			0.324		0.324
lag)	3 PM	10 AM		19.2			1.15		1.15
	5 PM	12 Noon		25.7			1.54		1.54
	7 PM	2 PM		28.5			1.71		1.71
	9 PM	4 PM		30.1			1.805		1.805
Roof	9 AM	7 AM			0.2				
(2 hrs.	11 AM	9 AM							
lag)	3 PM	1 PM							
	5 PM	3 PM		$(dT)_{max.} = 55^\circ$ F					
	7 PM	5 PM							$H_{max.} = 11.00$
	9 PM	7 PM							

Calculation of Heat Gains
in the House

Area of East and West Walls = 160 sq. ft.

Area of North and South Walls = 162.6 sq. ft.

Area of floor and Ceiling = 414 sq. ft.

Area of East Wall Glass = 19.1 sq. ft.

Area of West Wall Glass = 24.8 sq. ft.

Area of North Wall Glass = 19.1 sq. ft.

	9 AM	11 AM	3 PM	5 PM	7 PM	9 PM
East Wall	76.8	117.3	2540	650	637	552
East Glass	515	1522	875	757	556	392
West Wall	76.8	131.4	547	650	262	355
West Glass	690	995	111	3142	771	507
South Wall	78	52.6	187	250	278	293.5
Roof (Maximum)	4554	4554	4554	4554	4554	4554
North Wall	78	822	1035	660	648	560
North Glass	1430	795	875	757	557	392
Total Btu's	7498.6	8979.3	10724	11420	8263	3505.5

Occupants:

Considering 4 persons in the apartment,

Sensible Heat Loan = 4 x 300 = 1200 Btu/hr.

Latent Heat Load = 4 x 100 = 400 Btu/hr.

Total 1600 Btu/hr.

Lighting:

To calculate the heat gains due to lighting in the apartment an illumination of 2 watts per square foot of the floor area is assumed. No larger demand for electrical lighting is expected during the time of maximum cooling load. Therefore, the lighting effect is $2 \cdot 414 \cdot 3.413 = 7780$ Btu/hr.

Infiltration:

If 2 air changes per hour are assumed for the apartment which has no windows on three sides, the sensible heat gain due to infiltration in the apartment can be found to be

$$= \frac{2 \cdot 3100 \cdot 29.5}{55.2} = 3310 \text{ Btu/hr.}$$

Therefore, the maximum cooling load in the apartment may be found to be

$$= 11{,}420 + 1600 + 7780 + 3310 = 24{,}110 \text{ Btu/hr.}$$

THE HEATING AND COOLING DATA

THE HEATING DATA

RUN I: Using Both the Ceiling and Wall Panels

Date	Time	Outside Temp.	Floor	Wall-Pipe	Wall	Ceiling-Pipe	Ceiling	Water-Pipe
Sunday 2/24/52	11:30 AM	37	66	94	95.5	93	92	94.5
	3:00 PM	33	68	94	94	90	90	93
	12:00 PM	--*	70	93	92	89	87	92
Monday 2/25/52	10:00 AM	30.5	62.5	99	100	98	96.5	102
	3:00 PM	38	64	97	97	95	93	100
	6:00 PM	35	63	95	96	93	91	94
Tuesday 2/26/52	8:00 AM	--*	67	96	96	94.5	92	95
	12:00 Noon	39	65	94	94	91	90	93
	7:00 PM	37.5	70	93	92	90	90	94
Wednesday 2/27/52	9:00 AM	35	63	80	80	79	79	82
	12:00 Noon	57	67	88	83	81.5	79	105
	6:00 PM	67	70	92	92	93	92	91
Thursday 2/28/52	9:00 AM	43	64	85	86	81	81	92
	4:00 PM	60	69	88	89	86	85	95
Friday 2/29/52	10:00 AM	36	63	103	102	100	99	102
	7:00 PM	36	68	99	99	95	94	98
Saturday 3/1/52	10:00 AM	--*	62	105	102	99	95	105
	7:00 PM	--*	62	96	98	94	94	97
Sunday 3/2/52	12:00 Noon	57	68	90	88	85	85	100
Tuesday 3/4/52	3: PM	--*	67	98	96	96	95	102
	8: PM	--*	69	95	95	93	94	98

* These temperatures could not be recorded by the Meteorological Department.

THE HEATING DATA

RUN II: Using the Ceiling Panels Only

Date	Time	Outside Temp.	Floor	Wall-Pipe	Wall	Ceiling-Pipe	Ceiling	Water-Pipe
Wednesday 3/5/52	11:00 AM	--*	63	106	106	102	99	107
	6:00 PM	--*	67	99	99	97.5	96	108
Thursday 3/6/52	9:00 AM	--*	62	82	83	116	108	125
	3:00 PM	--*	65	88	87	102	101	106
Saturday 3/8/52	10:00 AM	--*	64	104	104	110	110	120
	7:00 PM	--*	70	92	92	98	97	107
Monday 3/10/52	9:00 AM	--*	65	80	80	80	80	80
	6:00 PM	--*	65	82	82	84	84	84
Tuesday 3/11/52	11:00 AM	--*	66	74	74	74	74	74
	5:00 PM	--*	70	78	78	78	78	78
Wednesday 3/12/52	1:00 PM	60	70	78	76	94	86	125
	6:00 PM	54	70	85	85	92	92	105
Friday 3/14/52	12:00 Noon	40	65	84	84	112	110	115
	6:00 PM	41.5	68	88	88	98	99	104
Saturday 3/15/52	9:00 AM	35	63	77	77	92	84	125
	12:00 Noon	42	70	84	85	96	98	98
Tuesday 3/18/52	9:00 AM	--*	65	85	85	94	94	98
	3:00 PM	52	67	83	83	89	89	100
Saturday 3/22/52	3:00 PM	34	66	79	79	87	86	90
	6:00 PM	30	68	83	82	84	84	95
Wednesday 3/26/52	10:00 AM	50	66	82	82	105	102	108

* These temperatures could not be recorded by the Meteorological Department.

COOLING DATA

Date	Temperature	2:00 AM	5:00 AM	8:00 AM	11:00 AM	2:00 PM	5:00 PM	8:00 PM	11:00 PM
1951									
July 22	Outside temp.	77	74	81	88	96	97	88	74
	Room temp.	76	74	75	78	80	82	80	78
	Inlet water temp.	--	--	--	--	--	--	--	--
	Outlet water temp.	--	--	--	--	--	--	--	--
July 23	Outside temp.	77	71	75	86	90	81	80	76
	Room temp.	76	75	75	76	87	78	78	76
	Inlet water temp.	--	--	--	--	--	--	--	--
	Outlet water temp.	--	--	--	--	--	--	--	--
July 24	Outside temp.	74	71	78	85	86	85	80	77
	Room temp.	75	74	74	75	77	79	97	77
	Inlet water temp.	--	--	--	--	--	--	--	--
	Outlet water temp.	--	--	--	--	--	--	--	--
July 25	Outside temp.	74	72	77	85	90	90	83	78
	Room temp.	75	74	74	75	76	79	80	78
	Inlet water temp.	--	--	--	--	--	--	--	--
	Outlet water temp.	--	--	--	--	--	--	--	--
July 27	Outside temp.	--	--	80	89	92	89	84	79
	Room temp.	--	--	73	75	77	79	79	77
	Inlet water temp.	--	--	--	--	--	--	--	--
	Outlet water temp.	--	--	--	--	--	--	--	--
July 28	Outside temp.	76	74	87	91	94	92	82	78
	Room temp.	75	75	75	76	78	79	78	76
	Inlet water temp.	--	--	--	--	80	80	76	73
	Outlet water temp.	--	--	--	--	82	82	81	80

COOLING DATA (continued)

Date	Temperature	2:00 AM	5:00 AM	8:00 AM	11:00 AM	2:00 PM	5:00 PM	8:00 PM	11:00 PM
1951									
July 29	Outside temp.	75	75	78	88	90	90	84	79
	Room temp.	74	74	74	75	76	79	77	75
	Inlet water temp.	71	71	73	75	79	75	77	75
	Outlet water temp.	77	77	77	79	80	81	79	78
July 30	Outside temp.	75	72	78	92	94	94	85	80
	Room temp.	74	74	74	76	77	78	78	76
	Inlet water temp.	72	71	74	75	77	77	75	73
	Outlet water temp.	77	77	77	79	80	80	79	78
July 31	Outside temp.	76	75	78	74	79	79	76	74
	Room temp.	74	74	74	74	74	75	75	74
	Inlet water temp.	72	71	74	77	78	79	78	74
	Outlet water temp.	77	77	77	80	81	81	82	79
Aug. 1	Outside temp.	72	72	76	86	88	89	80	75
	Room temp.	73	73	74	74	76	77	75	75
	Inlet water temp.	71	71	74	72	76	80	78	75
	Outlet water temp.	77	77	77	77	78	82	81	78
Aug. 2	Outside temp.	73	70	80	93	97	97	87	80
	Room temp.	73	73	73	75	76	78	78	76
	Inlet water temp.	71	70	73	76	78	78	76	73
	Outlet water temp.	77	76	77	78	80	81	79	78
Aug. 3	Outside temp.	77	72	82					
	Room temp.	74	74	74	75	77	79	79	77
	Inlet water temp.	71	70	75	76	79	79	78	77
	Outlet water temp.	77	76	76	80	83	84	81	79

COOLING DATA (continued)

Date	Temperature	2:00 AM	5:00 AM	8:00 AM	11:00 AM	2:00 PM	5:00 PM	8:00 PM	11:00 PM
1951									
Aug. 4	Outside temp.	--	--	82	91	98	97	87	85
	Room temp.	76	75	76	78	79	79	79	78
	Inlet water temp.	73	73	78	80	79	79	80	77
	Outlet water temp.	78	77	80	82	81	81	83	81
Aug. 5	Outside temp.	77	75	84	94	100	100	90	85
	Room temp.	76	76	76	78	79	80	80	78
	Inlet water temp.	75	74	75	80	81	81	80	74
	Outlet water temp.	80	79	79	81	83	85	82	79
Aug. 6	Outside temp.	81	78	86	98	--	--	--	--
	Room temp.	77	76	76	78	79	80	80	78
	inlet water temp.	75	74	76	76	80	83	80	78
	Outlet water temp.	80	79	79	78	83	84	83	82
Aug. 7	Outside temp.	--	--	--	--	105	103	93	88
	Room temp.	76	76	75	76	79	80	79	77
	Inlet water temp.	75	72	75	77	79	83	80	78
	Outlet water temp.	80	78	80	80	83	95	83	82
Aug. 8	Outside temp.	84	80	76	77	81	91	81	78
	Room temp.	75	74	74	74	79	80	79	77
	Inlet water temp.	71	72	72	72	79	79	76	73
	Outlet water temp.	77	77	77	77	84	82	81	79
Aug. 9	Outside temp.	76	71	70	69	80	84	78	74
	Room temp.	75	74	73	72	73	75	76	74
	Inlet water temp.	73	69	69	68	72	76	75	73
	Outlet water temp.	78	76	75	74	76	78	78	77

COOLING DATA (Continued)

Date	Temperature	2:00 AM	5:00 AM	8:00 AM	11:00 AM	2:00 PM	5:00 PM	8:00 PM	11:00 PM
1951									
August 10	Outside temp.	72	68	77	82	85	67	69	67
	Room temp.	73	73	73	74	75	73	72	70
	Inlet water temp.	71	69	71	74	74	74	67	66
	Outlet water temp.	76	75	75	77	77	78	73	73
Aug. 11	Outside temp.	66	65	70	82	84	85	82	75
	Room temp.	80	69	70	72	73	75	75	74
	Inlet water temp.	65	65	66	72	75	68	73	72
	Outlet water temp.	72	72	72	74	78	74	77	76
Aug. 12	Outside temp.	72	69	77	84	89	90	82	77
	Room temp.	72	72	73	74	74	77	77	75
	Inlet water temp.	70	68	69	74	77	77	76	74
	Outlet water temp.	75	74	74	76	79	80	80	78
Aug. 13	Outside temp.	74	72	70	84	90	93	83	77
	Room temp.	74	73	72	73	75	78	79	77
	Inlet water temp.	72	71	67	72	76	79	78	76
	Outlet water temp.	77	76	77	76	81	82	81	79
Aug. 14	Outside temp.	73	73	84	95	97	97	86	82
	Room temp.	75	74	74	75	76	78	77	75
	Inlet water temp.	75	73	73	75	76	76	75	72
	Outlet water temp.	76	74	75	76	77	80	79	77
Aug. 15	Outside temp.	78	75	80	86	86	85	75	71
	Room temp.	74	73	73	74	75	77	75	73
	Inlet water temp.	70	69	71	74	73	74	69	67
	Outlet water temp.	76	75	76	77	77	78	75	74

COOLING DATA (continued)

Date	Temperature	2:00 AM	5:00 AM	8:00 AM	11:00 AM	2:00 PM	5:00 PM	8:00 PM	11:00 PM
1951									
Aug. 16	Outside temp.	68	66	73	83	87	90	80	74
	Room temp.	71	70	70	72	74	75	76	74
	Inlet water temp.	66	65	66	70	72	74	74	72
	Outlet water temp.	73	72	72	74	76	77	78	76
Aug. 17	Outside temp.	72	70	84	95	102	96	82	80
	Room temp.	73	73	73	75	76	80	76	73
	Inlet water temp.	70	71	71	72	76	77	69	68
	Outlet water temp.	75	75	75	78	80	80	77	75
Aug. 18	Outside temp.	74	72	72	82	85	87	79	76
	Room temp.	73	73	73	74	76	79	78	75
	Inlet water temp.	72	71	71	74	77	78	76	73
	Outlet water temp.	76	76	76	77	80	79	80	78
Aug. 19	Outside temp.	72	70	80	93	95	96	85	79
	Room temp.	74	73	73	74	79	80	80	77
	Inlet water temp.	71	69	70	75	—	—	—	—
	Outlet water temp.	77	75	75	77	—	—	—	—
Aug. 20	Outside temp.	76	74	81	89	94	94	87	80
	Room temp.	75	75	83	75	77	78	79	75
	Inlet water temp.	—	—	—	—	75	75	76	73
	Outlet water temp.	—	—	—	—	79	80	79	78
Aug. 21	Outside temp.	77	70	69	71	—	—	—	—
	Room temp.	74	73	73	72	73	74	73	72
	Inlet water temp.	70	68	70	70	70	70	69	69
	Outlet water temp.	77	76	75	75	75	75	74	73

COOLING DATA (continued)

Date	Temperature	2:00 AM	5:00 AM	8:00 AM	11:00 AM	2:00 PM	5:00 PM	8:00 PM	11:00 PM
1951									
Aug. 22	Outside temp.	--	--	--	--	--	74	73	70
	Room temp.	68	68	68	68	69	71	72	71
	Inlet water temp.	69	68	68	70	67	69	67	64
	Outlet water temp.	73	73	73	73	70	71	71	70
Aug. 23	Outside temp.	68	67	69	72	77	81	79	72
	Room temp.	70	70	72	70	72	73	73	72
	Inlet water temp.	68	62	63	65	72	74	73	70
	Outlet water temp.	70	70	69	71	74	76	77	75
Aug. 24	Outside temp.	70	69	75	86	91	91	83	78
	Room temp.	71	71	71	72	74	76	77	75
	Inlet water temp.	69	68	79	77	78	76	74	72
	Outlet water temp.	74	74	74	78	80	80	78	77
Aug. 25	Outside temp.	75	73	82	79	94	92	80	77
	Room temp.	74	73	73	74	76	80	78	76
	Inlet water temp.	70	70	73	74	78	78	76	73
	Outlet water temp.	68	76	77	77	79	81	80	78
Aug. 26	Outside temp.	76	76	77	90	90	77	76	75
	Room temp.	74	73	73	74	76	76	75	76
	Inlet water temp.	71	69	69	75	77	74	73	73
	Outlet water temp.	77	75	75	77	79	78	78	77
Aug. 27	Outside temp.	73	74	82	84	98	95	86	83
	Room temp	74	73	73	74	76	77	78	75
	Inlet water temp.	71	70	71	72	--	--	--	--
	Outlet water temp.	77	78	78	77	--	--	--	--

COOLING DATA (continued)

Date	Temperature	2:00 AM	5:00 AM	8:00 AM	11:00 AM	2:00 PM	5:00 PM	8:00 PM	11:00 PM
1951									
Aug. 28	Outside temp.	80	78	86	96	100	99	89	84
	Room temp.	74	73	74	75	77	80	79	77
	Inlet water temp.	—	—	—	—	79	79	77	74
	Outlet water temp.	—	—	—	—	80	81	80	79
Aug. 29	Outside temp.	80	77	85	96	102	101	90	84
	Room temp.	75	74	74	75	77	80	80	77
	Inlet water temp.	71	69	70	76	—	—	—	—
	Outlet water temp.	77	76	75	78	—	—	—	—
Aug. 30.	Outside temp.	79	74	85	99	102	101	89	83
	Room temp.	75	74	74	77	79	79	79	78
	Inlet water temp.	—	—	—	—	78	78	76	75
	Outlet water temp.	—	—	—	—	80	81	80	78
Aug. 31	Outside temp.	78	74	85	99	104	102	92	84
	Room temp.	75	74	75	74	77	78	78	76
	Inlet water temp.	70	68	71	76	78	78	76	73
	Outlet water temp.	77	75	75	78	80	81	80	78
Sept. 1	Outside temp.	82	78	79	85	98	100	89	81
	Room temp.	75	74	74	75	77	78	78	76
	Inlet water temp.	71	71	73	76	78	78	76	73
	Outlet water temp.	79	79	79	80	82	81	80	79
Sept. 2	Outside temp.	75	72	79	90	96	97	82	74
	Room temp.	75	74	75	75	77	79	79	76
	Inlet water temp.	72	70	71	76	80	81	76	72
	Outlet water temp.	77	76	76	78	81	83	83	78

COOLING DATA (continued)

Date	Temperature	2:00 AM	5:00 AM	8:00 AM	11:00 AM	2:00 PM	5:00 PM	8:00 PM	11:00 PM
1951									
Sept. 3	Outside temp.	71	69	78	87	93	94	85	79
	Room temp.	74	74	73	74	76	78	78	77
	Inlet water temp.	70	69	71	76	78	79	78	75
	Outlet water temp.	77	76	76	78	80	81	81	80
Sept. 4	Outside temp.	75	72	72	83	92	95	85	79
	Room temp.	75	75	74	74	76	78	78	76
	Inlet water temp.	73	71	69	74	77	78	76	74
	Outlet water temp.	78	77	76	77	79	81	80	79
Sept. 5.	Outside temp.	65	67	69	80	84	72	69	68
	Room temp.	74	71	71	71	72	74	74	72
	Inlet water temp.	68	66	66	66	70	72	69	68
	Outlet water temp.	76	74	73	73	75	75	75	74
Sept. 6	Outside temp.	68	66	68	66	73	75	70	68
	Room temp.	71	70	70	70	72	73	73	72
	Inlet water temp.	67	67	67	---	70	71	69	68
	Outlet water temp.	73	73	73	---	75	76	75	74
Sept. 7	Outside temp.	69	65	64	64	65	65	65	64
	Room temp.	71	70	69	69	69	69	69	68
	Inlet water temp.	69	68	67	67	69	71	71	69
	Outlet water temp.	73	72	72	72	71	71	71	71
Sept. 8	Outside temp.	64	62	66	73	79	78	72	70
	Room temp.	67	67	67	69	71	73	73	71
	Inlet water temp.	64	63	65	68	70	71	---	---
	Outlet water temp.	70	70	70	71	73	75	---	---

COOLING DATA (continued)

Date	Temperature	2:00 AM	5:00 AM	8:00 AM	11:00 AM	2:00 PM	5:00 PM	8:00 PM	11:00 PM
1951									
Sept. 9	Outside temp.	69	70	68	70	67	68	68	65
	Room temp.	70	69	69	69	71	73	71	70
	Inlet water temp.	—	—	—	—	—	70	68	66
	Outlet water temp.	—	—	—	—	—	76	74	73
Sept. 10	Outside temp.	62	60	69	83	84	83	73	69
	Room temp.	67	67	67	69	71	72	73	70
	Inlet water temp.	64	62	62	67	71	71	69	67
	Outlet water temp.	71	70	69	71	74	73	74	73
Sept. 11	Outside temp.	69	69	75	86	87	86	78	77
	Room temp.	70	70	70	73	75	76	75	74
	Inlet water temp.	68	68	69	75	76	76	73	71
	Outlet water temp.	73	73	73	76	78	79	78	77
Sept. 12	Outside temp.	74	74	73	63	67	69	62	60
	Room temp.	73	72	72	72	70	70	70	67
	Inlet water temp.	71	70	71	65	65	64	62	60
	Outlet water temp.	76	75	75	73	72	71	70	69
Sept. 13	Outside temp.	57	53	62	72	74	74	68	62
	Room temp.	64	63	63	68	69	71	73	72
	Inlet water temp.	57	55	56	63	68	73	72	69
	Outlet water temp.	67	65	65	71	73	75	75	73

COOLING DATA (continued)

Date	Temperature	2:00 AM	5:00 AM	8:00 AM	11:00 AM	2:00 PM	5:00 PM	8:00 PM	11:00 PM
1951									
Sept. 14.	Outside temp.	59	56	64	77	82	83	70	63
	Room temp.	70	69	69	70	71	72	70	67
	Inlet water temp.	66	65	62	65	68	68	67	63
	Outlet water temp.	71	70	70	72	73	73	74	69
Sept. 15.	Outside temp.	57	55	62	73	70	70	65	57
	Room temp.	65	64	63	65	67	67	65	62
	Inlet water temp.	58	57	58	64	63	60	57	54
	Outlet water temp.	67	66	66	68	70	68	66	64
Sept. 16	Outside temp.	53	52	—	—	—	—	—	—
	Room temp.	60	60	60	62	63	65	65	65
	Inlet water temp.	54	53	53	58	61	61	60	63
	Outlet water temp.	63	62	62	64	66	67	66	67
Sept. 17	Outside temp.	—	—	62	75	79	77	67	59
	Room temp.	64	—	64	65	66	68	70	70
	Inlet water temp.	—	—	—	—	—	—	—	—
	Outlet water temp.	—	—	—	—	—	—	—	—
Sept. 18	Outside temp.	55	52	61	77	—	—	—	—
	Room temp.	68	67	67	68	—	—	—	—
	Inlet water temp.	—	—	—	—	—	—	—	—
	Outlet water temp.	—	—	—	—	—	—	—	—

DISCUSSION OF THE HEATING DATA

I. Using Both the Ceiling and Wall Coils

1. The Floor:

The temperature ranged from 62° F to 70° F; 62° F was recorded on a cold weather day, (unrecorded outside temperature), while 62.5°F was recorded at an outside temperature of 30.5° F. A rise in temperature of floor was noticed to occur in the afternoon, and in the evening and on fair weather days. It was also noticed that a floor temperature of 70° F was recorded when the outside temperature was near freezing. This high reading was observed when the occupants were in the house. Under occupation the floor temperature remained steady at 70° F during the recording period.

2. The Wall Pipe:

The temperature ranged from 88° F to 105°F. The lowest temperature of 88° F was recorded on a fair outside weather at 57° F. As the outside temperature decreased, the wall pipe temperature showed an increase. Thus, 103° F was recorded against an outside temperature of 36° F. The outside temperature was not recorded on March 11, 1951 at 10 A. M. when the wall pipe temperature was 105° F, but it was noticed that the outside temperature at this time was below freezing. The wall pipe temperature showed a quick response to the weather conditions in most of the recorded cases, although in one case it showed a temperature of 85° F on February 29, 1952 at 9:00 A. M. when the outside temperature was only 43° F.

3. The Wall:

The wall temperature ranged from 83° F to 102° F. 83° F was recorded against an outside temperature of 57° F, when the weather was mild and no appreciable amount of heat was required. The wall temperature showed a rise in temperature with the outside colder weather and a temperature of 100° F was recorded at 30.5° F. Also a temperature of 102°F was recorded against 36° F outside temperature. The wall temperature showed a good response to weather variations needs. It was sometimes higher than the temperature of the wall pipe itself.

4. Ceiling Pipe:

The temperature ranged between 81° F and 100° F. The highest temperature was recorded against an outside weather of 36° F. Also a temperature of 98° F was recorded on the outside temperature of 30.5° F. On the other hand, the lowest temperature recorded was 81° F against an outside rather cold weather of 41° F. This shows a weakness in the system to withstand the variations in the outside weather conditions.

5. The Ceiling Temperature:

The ceiling temperature showed a very slight temperature differential from that of the ceiling pipe. It varied from 79° F at the outside mild weather of 79° F up to 96.5° F at the coldest recorded temperature of 30.5° F. Except on February 27, 1952 and February 28, 1952 temperature showed a steadily increase with outside colder weather.

6. The Water Pipe:

The temperature showed a variation between 91° F and 105° F. The lowest temperature was recorded against the highest outside temperature recorded of 67° F. With some exceptions it showed a more or less good response to heat demands in the house.

Generally, considering the surface temperatures of the inside surfaces of the apartment, as a combination they showed a rise in temperature with cold outside weather with the exception of the floor which showed a decrease in temperature when the heat demands increased and when a higher floor temperature would be more desirable.

II. Using the Ceiling Coils Only

On March 10, 1952 and March 11, 1952, when the outside temperature was near freezing the system did not function properly due to some unknown reason. As the temperature recorded on these two days are misleading, the discussion of the system operation does not take these temperatures in consideration.

1. The Floor:

The temperature renged from 62° F to 70° F. The lower temperatures were recorded in cold weather conditions. The higher temperatures were recorded either during fair weather or in the afternoons.

2. The Wall Pipe and the Wall Temperatures ranged between 82° F and 106° F. The temperature was near the lower limit during cold weather.

3. The Ceiling Pipe Temperature:

This temperature ranged between 84° F and 116° F. High temperatures were recorded on cold weather, a temperature of 112° F was recorded against an outside temperature of 40° F. The system did not show a quick response to the heat demands as a ceiling pipe temperature of 84° was recorded against an outside weather of 30° F while a 92° F temperature was recorded when the outside temperature was either 35° F or 54° F.

4. The Ceiling Temperature:

This temperature varied between 84 and 110° F and was always very close to ceiling pipe temperature.

5. The Water Pipe Temperature:

With the exception of one case it varied between 95° F and 125° F. Higher temperatures were recorded when big heat demands were required.

Comparison Between the Two Cases:

The floor temperatures showed no variation between the two cases, indicating that there may be a fault in the construction of the floor itself.

Although the hot water circulation was cut from the wall piping in the second case, the wall temperature was high enough to indicate both that the room temperature was satisfactory and that the drop in the floor temperature was mainly due to rapid leakage of heat through the floor area, rather than due to a lack in the amount of heat handled by the system.

The ceiling pipe showed that it is capable of handling the required amount of heat in the second case. On the other hand, the recorded temperatures in the first case did not display a satisfactory indication of the characteristic ceiling pipe and ceiling temperatures.

The water-pipe temperature indicated a quick response to the heat demands. This was more apparent in the second case as the quantity of water circulated in this case was less and the temperatures were higher than in the first case.

THE DISCUSSION OF THE COOLING DATA

The outside temperature varied between 105° F on 2:00 P. M., August 17, 1951 and 52° F on September 16 and 18, 1951. The room temperature in the first case was 79° F and rose to 80° F at 5:00 P. M. with an outside temperature of 103° F. The highest room temperature recorded was 82° F. This was observed at 5:00 P. M., on July 22, 1951 and was measured against an outside temperature of 97° F. The room temperature was 60° F on September 16 and 67° F on September 18 when the outside temperature was 52° F. The 60° F temperature was the lowest inside temperature recorded during the testing period.

The maximum daily temperature variation between day and night times was observed on August 18. It amounted to 30° F, when the temperature was 72° F at 2:00 A. M. and climbed to 102° F at 2:00 P. M. The room temperature varied between 73° F at 2:00 A. M. and 76° F at 2:00 P. M. but it climbed up to 80° F at 5:00 P. M. when the outside temperature was 96° F.

The maximum daily room temperature variation was of the order of 10° F. It was recorded on September 13 between 5:00 and 8:00 A. M. and 8:00 P. M. against an outside temperature differential of 22° F. A room temperature differential of 7° F was recorded on August 17, August 25 and August 28 with outside temperature differentials of 30° F, 21° F and 25° F respectively.

The minimum daily room temperature variation was 3° F against an outside temperature variation of 15° F. This was observed on August 26, 1951.

The room temperature variation on an average day ranged between 4° F and 50° F over the 24 hours.

The inlet cooling water had a maximum temperature of 83° F on August 6 and August 7 at 5:00 P. M. The outside temperature in the second case was 103° F, the outside temperature in the first case could not be recorded but it seemed to be equally high.

The lowest inlet water temperature recorded during the testing period was 53° F on August 16 against an outside temperature of 52° F. Also, a temperature of 55° F was observed on September 13 against an outside weather of 53° F. In most of the cases, the inlet cooling water temperature ranged between 70° F and 75° F when the outdoor temperature varied between 75° F and 95° F. It rose to above 80° F on the extremely hot days and followed the outside temperatures when they fell below 70° F. The inlet water temperature was observed to be about 2° F below the room temperature in most cases although it was higher in a few instances.

The rise in the outlet cooling water temperature above the inlet cooling water temperature varied between 1° F and 7° F, but in most of the cases it was observed to be of the order of 5° F.

GENERAL REMARKS AND RECOMMENDATIONS

I. THE HEATING LOAD

As seen from the data collected during the heating season, the floor temperature never rose above 70° F. Many authorities claim that this temperature should be the minimum limit for the floor surface temperature. Reducing this temperature below 70° F was found to be objectionable even in the summer time to elderly people and to those who are subject to rheumatism.

The floor construction is a 2-inch concrete slab above the gravel layer. No insulation has been applied to the floor. This floor has an estimated U-factor of 0.50 which increases the heating load by 32.7 percent over a floor that has a U-factor of 0.10. This comparison is obtained from the heating load calculations. The test data and the load calculations indicate that the floor is the weak link of the heating experiment. The most obvious reason for this is the poor construction of the floor itself. The system seems to be quite capable of handling the required amount of heat. It keeps the temperatures of the walls and the ceiling reasonably high, but due to the quick leakage of heat from the space to the ground, a sufficiently high floor surface temperature could not be attained especially under severe cold weather conditions.

It appears highly desirable to cover the floor with a 2-inch cork slab which would prevent the quick leakage of the heating load from the space to the ground and which would in all probability keep the floor surface temperature reasonably high.

Also, it is observed that the door and windows are rather poorly fitted and none of them weather-stripped or equipped with a storm sash. This increases the heating load considerably in severe weather due to the great amount of infiltration taking place especially with cold stormy weather. Use of weather-stripped or storm-sashed windows and door is highly recommended. Calculations show that such door and windows may effect a decrease in the heating load by as much as 24.75 percent.

II. THE COOLING LOAD

The room temperature was found to be very close to the outside temperature in the period between 11:00 P. M. every night and 5:00 A. M. on the following morning. But a temperature differential between the indoor and the outdoor conditions would rise to about 15° F in the period between 2:00 P. M. and 5:00 P. M. This temperature differential was observed to climb to 27° F on August 31, 1951, with an outside temperature of 104° F and an indoor temperature of 77° F. Also, a temperature differential of 26° F was observed on August 7 at 2:00 P. M. and on August 17 at 2:00 P. M.

On many a cold morning, the indoor temperature was several degrees above the outside temperature. The room temperature was found to be 14° F above the outdoor temperature at 2:00 A. M. on August 11. Also, a difference of 13° F was noticed on September 14, at 5:00 A. M.

From the above observations, it may be concluded that the cooling system is capable of cooling the apartment even in the extremely hot weather conditions when the cooling load exceeds 24,000 Btu/hr. More comfortable conditions could be maintained in the apartment if the control system is applied to the cooling system. By means of control system, uncomfortably low temperatures could be avoided on cold mornings. The system would be set to stop the flow of cold circulating water if the indoor temperature fell below a certain limit. Also, the system could respond quickly to the changing requirements imposed by outside-temperature fluctuations.

The foregoing discussion dealt with the dry-bulb temperature. It is known that the wet-bulb temperature measures the total heat in the air and is, therefore, a basic factor in judging the cooling capacity of the system as well as its effect on human comfort. Unfortunately, due to some technical difficulties, correct values of the relative humidity could not be obtained and consequently, the wet-bulb temperatures could not be evaluated.

APPENDIX

APPENDIX

Selected average outside dry bulb temperatures for cooling load design. Based on maximum temperature of 100° F. Location: Stillwater, Oklahoma.

6:00 A. M.	75.4
7:00 A. M.	77.3
8:00 A. M.	80.3
9:00 A. M.	83.9
10:00 A. M.	89.2
11:00 A. M.	92.5
12:00 Noon	95.7
1:00 P. M.	97.2
2:00 P. M.	98.5
3:00 P. M.	99.7
4:00 P. M.	100.1
5:00 P. M.	99.5
6:00 P. M.	97.7
7:00 P. M.	94.5
8:00 P. M.	90.1
9:00 P. M.	88.2
10:00 P. M.	87.0

11:00 P. M.	86.0
12:00 Midnight	85.0
1:00 A. M.	84.0
2:00 A. M.	82.0
3:00 A. M.	80.0
4:00 A. M.	78.0
5:00 A. M.	77.0

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The content and form have been checked and approved by the author and thesis adviser. Changes or corrections in the thesis are not made by the Graduate School office or by any committee. The copies are sent to the bindery just as they are approved by the author and faculty adviser.

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