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NATIONAL BUREAU OF STANDARDS REPORT

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PERFORMANCE OF HOT-WATER PANEL HEATING SYSTEMS IN HIGH-RISE APARTMENTS OF THE CHICAGO HOUSING AUTHORITY

by

Selden D. Cole and Paul R. Achenbach

Report to
Chicago Housing Authority
and
Public Housing Administration

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

THE NATIONAL BUREAU OF STANDARDS

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Performance of Hot-Water Panel Heating Systems in High-Rise Apartments of the Chicago Housing Authority

by

Selden D. Cole and Paul R. Achenbach
Mechanical Systems Section
Building Research Division

Report to
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PERFORMANCE OF HOT-WATER PANEL HEATING SYSTEMS IN HIGH-RISE APARTMENTS OF THE CHICAGO HOUSING AUTHORITY

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ABSTRACT

A field investigation of the performance of the hot-water panel heating systems in two high-rise apartment developments of the Chicago Housing Authority was made during a period of cold winter weather to develop information on the effectiveness of a heated concrete slab at each level which delivered heat both upward and downward. Of principal interest were the distribution of temperature in the heated panels and in the living space, the adequacy of the control system and the exhaust ventilation system, and the effect of apartment location and room exposure on the thermal environment. The results observed indicated that this type system was able to provide adequate heating for the Chicago climate, but that the single-zone control system utilizing an outdoor thermostat did not provide close temperature control in the several apartments and that most apartments were overheated by varying amounts ranging up to about 9°F. About equal quantities of heat were delivered from the floor and ceiling surfaces, and the floor surfaces operated at a surface temperature in excess of 90°F during cold weather in some cases. The exhaust ventilation system provided an adequate amount of fresh air and was sufficient to prevent condensation on the outside walls. Readjustment of the temperature control system and rebalancing of the room temperatures in the various apartments were recommended for the existing buildings. A different type of balancing valve would facilitate adjustment of water flow rate in the various tube circuits. A multi-zone control system with a separate outdoor thermostat and circulating pump for each zone was recommended for future construction, with the outdoor thermostat designed to sense solar radiation and wind effects as well as temperature effects. The control system in the existing buildings could also be modified for multi-zone control to improve temperature distribution among the various apartments, but the modifications would be quite expensive and would be only partially effective in the Frances Cabrini Extension Project because of the design of the individual heating circuits. Regular cleaning of the exhaust ventilation grilles and a re-balancing of the ventilation rate among apartments was also recommended.

PERFORMANCE OF HOT-WATER PANEL HEATING SYSTEMS IN HIGH-RISE APARTMENTS OF THE CHICAGO HOUSING AUTHORITY

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1.0 Introduction

The Chicago Housing Authority constructs and operates a large number of high-rise apartment buildings for low-income families in metropolitan Chicago. Extensive use has been made of hot water panel heating systems in these apartment buildings with the heat being distributed from central heating plants. Records of fuel consumption over a period of three years indicate that some of the lower values of annual fuel consumption per room have occurred in buildings with this type of heating system.

At the request of the Chicago Housing Authority and the Public Housing Administration in Washington, a limited field investigation of the performance of the hot water panel heating systems in two high-rise apartment developments in Chicago was made during a period of cold weather in February 1963. The William Green Project together with the Frances Cabrini Extension Project were chosen for the investigation because they provided buildings of different orientation near to each other, and because the performance of heating systems in apartments near the middle of the buildings could be compared with that of end apartments exposed to the prevailing wind.

The broad purposes of the investigation were as follows:

(a) To evaluate the internal thermal environment for a range of outdoor temperature,
(b) To measure the panel temperatures and water temperatures for a range of outdoor temperature,
(c) To investigate the adequacy of the control system,
(d) To indicate the adequacy of the ventilation with respect to condensation control,
(e) To investigate the effect of apartment location in the building and building orientation on the thermal environment,
(f) To indicate possible improvements in operating economy and control of the interior thermal environment in these apartments, and
(g) To evaluate the suitability of hot-water panel heating systems for future apartment buildings for similar occupancy or for the aged.

The investigation comprised measurements of air temperatures at several levels between floor and ceiling, indoor relative humidity, floor and ceiling surface temperatures in the areas containing embedded hot water tubes, wall surface temperatures on the exposed walls, unheated globe-thermometer temperatures, the quantity of air exhausted from the apartment through the bathroom, the temperatures of the supply and return water in the apartment, and the outdoor temperature.

2.1 Description of Buildings and Apartments

Two apartment buildings were selected for detailed measurements: one at 1160 Sedgwick Street in the Frances Cabrini Extension Project, and the other at 1230 N. Larrabee Road in the William Green Project. The longer dimension of both buildings was oriented in a north-south direction. The two buildings were approximately 1200 feet apart.

The building selected from the William Green Project was one of five buildings of identical construction, each fifteen stories in height. The buildings were of reinforced concrete column and beam construction with a 7 1/2-inch reinforced concrete floor at each story. The outside curtain walls, front and back, consisted of insulating concrete spandrels 3'10" high and 8" thick, with 4-foot high windows the entire width of the exposed back wall, and 3'1" high windows the entire width of the exposed front wall. The front wall had a poured concrete wall section about 8 inches in height above the windows, made as an integral part of the ceiling construction above. The ceiling height was 7'10". The end walls consisted of reinforced concrete ranging in thickness from 10 inches at the first floor to 6 inches at the top floor, backed up by varying thicknesses of concrete block to comprise a total wall thickness of 12 inches. There were 134 apartments in the building investigated.

The building selected from the Frances Cabrini Extension Project was one of six buildings of identical construction, each nineteen stories in height. The buildings were of reinforced concrete column and beam construction with a 6-inch reinforced concrete floor at each story. The outside curtain walls consisted of 4 inches of brick on the outside separated by a 2-inch air space from 4-inch concrete block on the inside. Weep holes were provided in the brick masonry at 3-foot spacings. Windows, 4'3" high, were used in the front and back walls. There were 262 apartments in the building investigated.

All interior partitions in both buildings were made of 4-inch concrete blocks, and asphalt tile was used as floor coverings in all buildings. The interior surfaces of the walls and the ceilings were covered with latex paint.

The apartments were accessible from outside galleries at each floor level. One exterior elevator serviced the even-numbered stories and another the odd-numbered stories. Two interior unheated stairways serviced all of the galleries.

Each apartment consisted of living room, dining room, kitchen, bathroom, storage room, hallway, and from one to five bedrooms. In some cases, the kitchen and dining area were integrated and in others the kitchen, dining area, and living room were an integrated space with only partial partitions between the different functional areas. All bathrooms were interior rooms ventilated by a central exhaust blower on the roof.

One apartment was selected at about mid-length of each building and near midheight, and a corner apartment was selected on the end of each building at another floor level. Each center apartment had outside exposures principally on opposite sides of the building.

One corner apartment had exposures principally on adjacent sides of the building, and the other corner apartment had significant exposure in four directions. Descriptive data on the location, size, number of rooms, and heat transmission characteristics of each of the four apartments investigated are summarized in Table 1.

TABLE 1

Description of Four Apartments Investigated

Descriptive Item	Frances Cabrini Extension Project 1160 Sedgwick St.		William Green Project 1230 N. Larrabee Road	
Apartment Number	707	1405	601	906
Floor Level	7	14	6	9
Location in Building	Corner of West Wing	Center	East Wing-South End	Center
Exposures	North, West & East	East, West & South	North, South, East & West	East & West
Floor Area, ft^2	710	720	818	734
Exterior Wall Area, net, ft^2	407	302	584	174
Window & Door Area, ft^2	124	140	176	188
Ceiling Height, ft	7.83	7.83	7.83	7.83
Number of Bedrooms	3	2	3	2
Integrated Spaces	Kitchen, LR & DR	Kitchen, LR & DR	Kitchen, LR & DR	Kitchen, Dining Room
Observed Exhaust Ventilation Rate, Air Changes per Hour	1.47	3.19	0.75	0.89
Computed Design Unit Heat Loss,[a] Btu/hr (ft^2 floor area)	46.8	66.0	43.4	39.4
Computed Design Unit Heat Loss,[b] Btu/hr (ft^2 floor area)	41.4	41.3	46.2	40.9
Computed Unit Heat Loss,[a] Btu/hr (°F temp. diff.)	416	595	444	362

[a] Based on observed exhaust ventilation rate.
[b] Based on an infiltration rate of 1 air change per hour.

2.2 Description of Heating Systems

The William Green and Frances Cabrini Extension Projects were both supplied with heat from the same central heating plant. The heating plant contained five boilers fired with oil or gas, and four boilers operating on oil alone connected in parallel to furnish low temperature hot water to the underground heat distribution system. Boilers were fired up manually in sequence as needed to maintain a predetermined relation between the supply water temperature and the outdoor temperature. Each boiler could be operated at a low or high firing condition.

Each apartment building was equipped with a shell-and-tube heat exchanger in the basement. The boiler water was circulated through the primary side of the heat exchanger and two pumps circulated water through the secondary side of the heat exchanger and the various apartments in the building. A bypass line was provided between the supply and return lines on the secondary side of the heat exchanger. This bypass line was fitted with a modulating three-way valve whose position was controlled by an outdoor thermostat mounted on a shaded wall of the exterior elevator shaft on each building. The modulating control system was preset to vary the temperature of the water supplied to the apartments in the building in a fixed relation to the outdoor temperature.

The heating system in both projects consisted of copper tubes embedded in the concrete slabs between floor levels. The tubes were placed underneath the reinforcing bars and located 2 inches above the ceiling surface. The heating system for each apartment consisted of several tube circuits in parallel. Each parallel tube circuit contained a plug-type valve which was used to provide initial adjustment of the heat supplied to the various rooms and the various apartments. However, since each apartment was partially heated from the floor and partially from the ceiling, an independent adjustment of water flow and heat output could not be made for each apartment.

In the William Green Project the heating tubes were spaced 18 inches apart for a distance of 9 feet from the exterior perimeter of the building, with the first tube about 6 inches from the exterior wall. There were no heating tubes in the central area of each apartment except for the supply and return lines which connected to risers near the centerline of the building.

In the Frances Cabrini Extension Project the heating tubes were distributed over the entire apartment area. Generally, the tubes in the dining room and kitchen and in an exterior border 54 inches wide in the living room were spaced 6 inches apart, whereas the tubes were

12 inches apart for the rest of the ceiling area in the living room. The tube spacing in the bedroom with two exposures was 12 inches. In one of the bedrooms with one exposure the spacing ranged from 12 to 24 inches, and in the other it ranged from 12 to 30 inches. In each apartment, regardless of size, a perimeter tube circuit was spaced three inches from the enclosing outside walls.

3.0 Test Equipment and Procedure

Temperatures were determined in each of the four apartments using thermocouples made of thirty-gage copper and constantan wire, a Rubicon portable potentiometer, and an ice bath. An unheated 8-inch black globe was used to investigate the mean radiant temperature. The rate of air exhaust through the bathroom grilles was measured with a vane-type anemometer and stop watch. The wet- and dry-bulb temperatures were determined with a sling psychrometer.

In each apartment, temperature values were recorded at twenty to thirty different stations. These stations were similarly located in the living room of each of the four apartments investigated, as follows: (1) six stations on the ceiling, along a line perpendicular to the outside wall toward the center of the room and placed alternately underneath the tubes and between the tubes; (2) four stations on the floor located exactly below the four nearest to the exterior wall on the ceiling; (3) three stations in the air at room center, located 3 inches from the floor, 30 inches from the floor, and 3 inches from the ceiling, respectively; (4) a black globe 30 inches from the floor and adjacent to the station at room center thirty inches above the floor; (5) a position on the exterior wall between floor and window in the living room, usually 30 inches above the floor; (6) a station on the supply manifold tube for the several heating circuits; and (7) a station on the return manifold tube for the several heating circuits.

Thermocouples were placed at corresponding locations on the ceiling, floor, exterior wall, and in the air in one of the bedrooms in each apartment. Temperatures were observed at one or two miscellaneous stations in some of the apartments.

The positions for the thermocouple stations on the ceiling were determined by exploring the ceiling surface temperature at close intervals with a thermocouple and pyrometer. The high temperature spots indicated the location of the tubes and the low temperature spots indicated the midpoint between the tubes. This exploration indicated that the tubes were not always located in accordance with the drawings.

Temperature readings were taken in each of the four apartments in the forenoon and sometime in the late afternoon. Each one of the twenty to thirty thermocouple indications in each apartment was obtained with the poteniometer and recorded. The living room thermocouple used to measure air temperature 3 inches from the floor was inserted in the black globe immediately upon entering the apartment for a set of readings, inasmuch as the globe was transported from unit to unit and required time to come to room temperature conditions. After reading the globe temperature, the thermocouple was returned to its position 3 inches above the floor and observed as the last reading of the group. During several of the visits to the different apartments, the wet- and dry-bulb temperatures were determined in the living room and recorded, before the thermocouple readings were obtained.

Wet- and dry-bulb temperatures were obtained in several apartments in one of the buildings in the William Green Project that was not instrumented with thermocouples. Temperatures were taken on the fifteenth floor, the seventh floor, and on the ground floor in two apartments on each floor; one unit near the center of the building and one unit at the end of the building. Wet- and dry-bulb temperatures were also recorded in several apartments in the buildings at 1160 Sedgwick Street and 1230 N. Larrabee Road other than the four principal apartments under investigation.

A short duct, about 8 inches long, was fitted over the bathroom exhaust grilles to improve the conditions for measuring the air flow rate through these grilles. A vane-type anemometer was placed in each of several increments of area inside these ducts to obtain an average air flow rate. Readings were taken with interior doors open and shut, and with some windows open and all windows closed to evaluate the effect of these restrictions on the exhaust air flow rate.

4.0 Results and Discussion

Figure 1 is a graph of the outdoor temperatures that occurred during the time of the investigation based on hourly weather data reported for Chicago. Except for the first day, when but one apartment had been instrumented, the outdoor temperature did not rise above 25°F, and at three different times fell below zero. Figure 1 shows that the outdoor temperature decreased from 35°F to -6°F in about 38 hours from 6:00 p.m. on February 19 to 8:00 a.m. on February 21. Thereafter the diurnal temperature change was in the range from 10 to 20 degrees in most instances. The average rate of change of outdoor temperature was less than 1 degree per hour during the 40 hours from 3:00 p.m. on February 24 to 7:00 a.m. on February 26, and was in excess of 7 degrees per hour during the two hours from 7:00 a.m. to 9:00 a.m. on February 23. The changes in outdoor temperature were great enough to require manual adjustments in supply water temperature at the heating plant and to cause automatic change in the supply water temperature for the several apartments.

During most of the period of observation the prevailing winds came from the west or northwest with velocities ranging from 10 to 25 mph. However, on February 23 and 27 the prevailing winds were southerly in direction, but in the same velocity range.

The temperatures observed on ceiling, floor, and wall surfaces, on the supply and return headers to the tube circuits, and at selected levels in the air at the center of the living room and one bedroom of the four apartments are summarized in Tables 2-5, inclusive, for the duration of the field study. The data from two apartments in the building at 1230 N. Larrabee Road in the William Green Project are shown in Tables 2 and 3, and the data for two apartments in the building at 1160 Sedgwick Street in the Frances Cabrini Extension Project are shown in Tables 4 and 5.

Only apartment 906 at 1230 N. Larrabee Road had been instrumented in time to show the effect of the long steady decline in outdoor temperature from February 19 to February 21 on the indoor temperatures and the heating system temperatures. Table 2 shows that a decrease in outdoor temperature from 35°F at 5:00 p.m. on February 19 to -5°F at 9:15 a.m. on February 21 caused the following temperature changes in apartment 906:

(a) a rise in supply water temperature from 113°F to 144°F,
(b) a rise in return water temperature from 101°F to 119°F,
(c) a rise in ceiling surface temperature underneath the tubes in the living room from 100°F to 117°F, and only a small change in ceiling surface temperature between tube centers,
(d) a decrease in air temperature at the 30-inch level in the living room from 83°F to 78°F,
(e) a decrease in exterior wall surface temperature 30 inches above the floor in the living room from 67°F to 54°F,
(f) changes in the ceiling surface temperatures in the bedroom similar to those in the living room,
(g) decreases in the air temperature at the 30-inch level and of the exterior wall surface temperature in the bedroom nearly twice as great as those observed in the living room. The lower wall temperature and more variable air temperature in the bedroom may have been caused by the prevailing westerly winds to which the exterior wall was exposed, and
(h) the floor surface temperatures changed much less in both rooms than the ceiling surface temperatures. The temperatures on the floor were higher at the stations identified as being between tubes than at those over the tubes. This suggests that the tube locations were not the same distances from the exterior wall in the floor and ceiling of this particular apartment, and that the identification of the tube locations in the floor was inaccurate.

Assuming that the outdoor thermostat on this building modulated the supply water temperature in an inverse linear relation to the outdoor temperature in accordance with the design concept employed, the supply water temperature would range from 90°F to 148°F for a range of outdoor temperature from 65°F to -10°F, based on the observed data cited above.

The temperature data observed in apartment 906 from 8:45 a.m. on September 22 to 9:40 a.m. on September 26 were taken either between 8:45 a.m. and 9:40 a.m. during a steep rise in outdoor temperature two or three hours after the daily minimum, or in the late afternoon a few hours after the daily maximum. The outdoor temperature ranged from 0°F to 16°F at the times of these observations. Thus the temperatures observed inside the apartment are not representative of a steady state heat transfer or temperature distribution. During the entire period of observation in this apartment, the air temperature at the 30-inch level in the living room ranged from 78°F to 83°F, whereas the corresponding temperature in the bedroom ranged from 71°F to 83°F. With a few exceptions, the temperature of the unheated black globe was 2 to 3 degrees higher than the air temperature at the 30-inch level in the living room. This indicates a substantial impingement of radiant heat on the globe, and a mean radiant temperature 3 to 4 degrees above the air temperature.

Intermittent measurements of the wet-bulb and dry-bulb temperatures in apartment 906 showed that the interior relative humidity ranged from 17 to 31 percent during the period of observation. Thus, the effective temperature in the living room ranged from about 74°F on February 19 to about 69°F on February 26, based on dry-bulb temperature and relative humidity only. If the mean radiant temperature in the living room is taken into account, the effective temperatures would be 3 to 4 degrees higher than the above values, based on data reported in the 1961 ASHRAE Guide and Data Book. Thus, the effective temperature in the living room of apartment 906 was probably in the range from 72°F to 78°F, whereas the generally accepted value for optimum winter comfort is about 68°F.

The data in Table 2 taken after 10:00 a.m. on February 20 indicate that the surface temperature of the heated portion of the floor averaged about 15 degrees higher than the air temperature 3 inches above the floor in the living room, whereas the corresponding temperature difference in the bedroom was about 9 degrees. Thus, the floor panel output in the living room was about 29 Btu/hr(ft^2), whereas that for the bedroom was about 17 Btu/hr(ft^2) based on data reported in the ASHRAE Guide and Data Book. For the same period, the surface temperature of the heated portion of the ceiling averaged about 22 degrees higher than the air temperature at the 30-inch level in the living room, whereas the corresponding temperature difference was about 24 degrees in the bedroom. Thus, the gross ceiling panel output in the living room was about 22 Btu/hr(ft^2), whereas that for the bedroom was about 24 Btu/hr(ft^2) based on data reported in the ASHRAE Guide and Data Book.

TABLE 2

SUMMARY OF OBSERVATIONS
Apartment 906 - 1230 N. Larrabee Road

		Date and Time of Observation										
Observation Station		Feb. 19 12:30PM	Feb. 19 5:00PM	Feb. 20 10:00AM	Feb. 20 5:00PM	Feb. 21 9:15AM	Feb. 21 5:10PM	Feb. 22 9:30AM	Feb. 22 6:30PM	Feb. 23 9:30AM	Feb. 25 1:10PM	Feb. 26 9:40AM
Living Room Data												
Ceiling Surface Temp, Under Tubes,	°F	103.4	99.9	103.6	109.3	117.4	115.7	116.4	111.8	110.5	107.1	114.6
" " " Between Tubes,	°F	89.3	89.1	88.4	89.3	92.1	89.3	93.2	93.6	91.6	89.1	93.3
Avg. Ceiling Panel Temp,	°F	96.3	94.5	96.0	99.3	104.8	102.5	104.8	102.7	101.1	98.1	104.0
Floor Surface Temp, Over Tubes,	°F	87.2	87.2	86.4	87.9	88.5	89.1	90.1	90.1	89.4	86.4	90.7
" " " Between Tubes,	°F	90.5	90.6	90.6	91.9	95.2	95.2	97.4	95.9	95.1	92.0	96.2
Avg. Floor Panel Temp,	°F	88.9	88.9	88.5	89.9	91.8	92.2	93.8	93.0	92.3	89.2	93.5
Wall Surface Temp, 30" above Floor	°F	67.2	67.0	62.5	61.5	53.7	55.3	52.6	58.7	59.7	59.0	58.7
Air Temp,[a] 3" above Floor	°F	83.4	78.4	81.5	75.0	--	78.1	77.7	79.2	--	73.5	78.9
Air Temp,[a] 3" below Ceiling,	°F	87.0	91.5	84.7	87.1	83.4	87.6	86.5	90.2	88.5	86.2	88.5
Air Temp,[a] 30" above Floor	°F	82.5	83.0	80.1	82.7	78.2	79.2	79.9	83.0	81.6	78.5	82.2
Globe Therm.,[a] 30" above Floor	°F	--	--	--	--	80.6	79.9	83.2	82.1	84.5	80.8	79.6
Relative Humidity,[a] 30" above Floor,	%	31		26			21		23		17	
Dewpoint Temp,[a] 30" above Floor,	°F	48		42			36		41		31	
Effective Temp,[a,b] 30" above Floor,	°F	73.5		71.2			70.5		73.0		69.3	
Bedroom Data												
Ceiling Surface Temp, Under Tubes,	°F	103.2	100.4	102.3	108.6	114.9	113.6	115.4	111.4	110.4	108.8	113.7
" " " Between Tubes,	°F	89.0	89.3	86.6	86.3	88.1	89.3	91.5	91.9	92.0	92.5	92.9
Avg. Ceiling Panel Temp,	°F	96.1	94.9	94.5	97.5	101.5	101.5	103.5	101.7	101.2	100.7	103.3
Floor Surface Temp, Over Tubes,	°F	84.4	83.2	78.8	78.2	77.0	79.6	82.8	84.5	85.6	85.9	84.8
" " " Between Tubes,	°F	85.7	85.0	81.3	79.9	80.1	82.9	85.6	86.6	88.4	87.8	85.8
Avg. Floor Panel Temp,	°F	85.1	84.1	80.1	79.1	78.6	81.3	84.2	85.6	87.0	86.9	85.3
Wall Surface Temp, 30" above Floor,	°F	65.3	66.1	57.1	55.5	43.3	49.1	48.8	57.8	57.6	61.9	53.5
Air Temp,[a] 3" above Floor,	°F	81.1	80.1	73.7	69.2	66.4	68.8	71.3	77.0	81.4	81.4	77.7
Air Temp,[a] 30" above Floor,	°F	82.7	81.4	76.0	72.7	70.8	72.2	77.7	82.7	83.1	82.8	79.7
Air Temp,[a] 3" below Ceiling,	°F	87.0	86.5	84.6	83.7	83.4	84.4	87.0	83.5	86.3	89.1	90.5
General Data												
Supply Water Temp,	°F	118.9	113.1	122.3	132.0	143.7	140.8	142.1	132.8	132.5	128.3	136.9
Return Water Temp,	°F	104.9	101.4	105.7	110.1	119.3	118.0	119.4	114.6	103.8	111.2	116.0
Outside Air Temp,	°F	37.4	35.0	23.8	8.0	-5.0	0.0	5.0	15.0	16.0	14.0	9.0

a. Measured at Room Center
b. Based on Dry-Bulb Temperature and Relative Humidity Only.

For the average of the conditions observed in apartment 906 between 5:00 p.m. on February 20 and 9:40 a.m. on February 26, the difference in temperature between indoor air at the 30-inch level and the outdoors was 71 degrees F. Based on the materials of construction shown in the blueprints for the William Green Project, the corresponding calculated heat loss would be 25,700 Btu/hr. On the assumption that the results in the one bedroom represented the performance of the three rooms with a west exposure, and that the results in the living room represented the performance of the room with an east exposure, the calculated combined heat output of the floor and ceiling panels was about 23,400 Btu/hr with the heat output of the ceiling panels comprising about 53% of the total.

Apartment 601 in the building at 1230 N. Larrabee Road had its principal exposure toward the east with lesser areas of exterior wall facing north, south, and west. Temperatures were measured on the floor and ceiling panels along lines perpendicular to the east wall in the living room and to the south wall in one of the bedrooms. The temperature data from this apartment are summarized in Table 3.

A comparison of the data in Tables 2 and 3 shows that the supply and return water temperatures were nearly the same in the two apartments for corresponding times of observation. The ceiling surface temperatures over tube centers were about 4 degrees cooler in apartment 601 than for apartment 906 for both living room and bedroom. This could have been caused by a greater thermal resistance in the materials covering the tubes in apartment 601, or it may have been the result of having two exterior walls in each of the rooms in apartment 601 as compared to one exterior wall in each room in apartment 906. The room air temperature at the 30-inch level in the living room varied only 3.3 degrees F during the observation period with an average of 82.3°F. The corresponding variation in temperature and average temperature in the bedroom were 7.7 degrees F and 79.9 degrees F, respectively, during the same period.

The wall temperature 30 inches above the floor was much lower in the living room than in the bedroom. Since the heat transmission factors of the two walls were approximately equal, both were exposed to sunshine from the outside at different times of the day, and neither faced the prevailing wind; these factors probably do not account for the average difference in temperature of about 13 degrees. The wall thermocouple in the living room was located about 16 inches below the sill of the window directly above, whereas the corresponding station on the south wall was not beneath a window. It is probable that the cold air falling from the window surface above caused the low wall temperatures in the living room.

The temperature of a window pane in the east wall of the living room was measured with a thermocouple secured to the glass with transparent cellophane tape. The temperature of the window pane approximated the midpoint value between indoor and outdoor temperature, but was usually a few degrees lower than the midpoint value. It will be noted in Table 3 that the dewpoint temperature of the air in the living room was several degrees above the window pane temperature for each observation of the relative humidity in the apartment. This accounts for the frequent sweating of the living room windows. However, the dewpoint temperature was always a few degrees below the wall surface temperature at the 30-inch level in the living room, thus precluding sweating of the wall at this station of measurement. The occupants of this apartment did considerable cooking on the gas range during the day which probably accounts for the somewhat higher dewpoint.

The unheated globe thermometer temperature was higher than the air temperature at the 30-inch level in the living room by amounts ranging from 1 to 4 degrees in all but two cases. This indicates that the mean radiant temperature at this station exceeded the air temperature by somewhat greater margins and that the probable effective temperature in the living room of apartment 601 was also in the range from 72°F to 78°F.

The data in Table 3 for apartment 601 indicate that the surface temperature of the heated portion of the floor averaged 9 degrees higher than the air temperature 3 inches above the floor in the living room, whereas the corresponding temperature difference in the bedroom was 5.6 degrees. Thus, the floor panel output in the living room was about 17.5 Btu/hr(ft^2), whereas that for the bedroom was about 9.5 Btu/hr(ft^2) based on data reported in the ASHRAE Guide and Data Book. For the same period, the surface temperature of the heated portion of the ceiling averaged about 17.8 degrees higher than the air temperature at the 30-inch level in the living room, whereas the corresponding temperature difference in the bedroom was 18.4 degrees. Thus, the ceiling panel output in the living room was determined to be about 19.5 Btu/hr(ft^2) including the effect of infiltration, and that in the bedroom was determined to be 18 Btu/hr(ft^2) without adjustment for infiltration.

Since someone slept during the day in the bedroom selected for temperature measurement, the door to this room was closed during the day. Thus, it was assumed that the ventilation air exhausted through the bathroom grille had little opportunity to affect the heat transfer in that room. Assuming that the heat transfer rates determined for the bedroom apply only to the bedroom and that those determined for the living room apply to all the remainder of the 710 sq ft of heated panel, the combined heat transfer of the floor and ceiling panels in the apartment was calculated to be about 25,000 Btu/hr during the period of

TABLE 3

SUMMARY OF OBSERVATIONS
Apartment 601 - 1230 N. Larrabee Road

Observation Station		Feb. 20 11:05AM	Feb. 20 5:30PM	Feb. 21 8:45AM	Feb. 21 5:35PM	Feb. 22 8:45AM	Feb. 22 7:00PM	Feb. 23 9:00AM	Feb. 25 2:10PM	Feb. 26 9:15AM	Feb. 27 11:00AM
Living Room Data											
Ceiling Surface Temp, Under Tubes,	°F	101.5	104.5	110.1	109.9	111.5	107.3	107.8	104.4	109.3	106.4
" " " Between Tubes,	°F	89.0	89.9	91.4	92.8	95.2	94.6	94.4	91.6	94.6	94.2
Avg. Ceiling Panel Temp,	°F	95.3	97.2	100.8	101.4	103.4	101.0	101.1	98.0	102.0	100.3
Floor Surface Temp, Over Tubes,	°F	83.6	81.5	82.4	85.4	85.5	87.5	88.0	86.8	84.7	84.6
" " " Between Tubes,	°F	87.2	86.5	85.1	91.0	91.7	92.2	90.5	90.2	90.8	90.7
Avg. Floor Panel Temp,	°F	85.3	84.0	83.8	88.2	88.6	89.9	89.3	88.5	87.7	87.7
Wall Surface Temp, 30" above Floor,	°F	66.0	59.7	50.5	57.0	50.0	58.0	56.9	59.3	53.5	56.1
Window Surface Temp,	°F	50.2	49.5	51.2	31.7	40.8	42.5	47.5	41.0	45.5	46.5
Air Temp,^{a} 3" above Floor,	°F	--	77.7	81.2	77.4	76.1	79.4	80.7	78.5	73.2	80.8
Air Temp,^{a} 3" below Ceiling,	°F	90.8	89.0	91.0	89.6	91.7	90.2	90.8	91.5	95.2	93.3
Air Temp,^{a} 30" above Floor,	°F	83.6	82.0	83.2	81.0	82.8	82.7	83.0	82.7	82.0	80.3
Globe Therm.,^{a} 30" above Floor,	°F	85.5	81.4	84.1	81.0	85.4	84.1	85.2	84.4	85.0	84.2
Relative Humidity,^{a} 30" above Floor,	%	41			28	29	32	32	29	28	
Dewpoint Temp,^{a} 30" " "	°F	57			47	46	51	51	48	47	
Effective Temp,^{a,b} 30" " "	°F	75.4			72	73.6	73.8	73.8	73.4	72.8	
Bedroom Data											
Ceiling Surface Temp, Under Tubes,	°F	101.3	104.8	110.8	110.7	111.5	107.4	106.3	104.7	109.0	106.4
" " " Between Tubes,	°F	87.0	86.8	88.7	89.2	91.5	90.4	88.8	88.2	91.4	90.1
Avg. Ceiling Panel Temp,	°F	94.4	95.8	99.8	100.0	101.5	98.9	97.6	96.5	100.2	98.3
Floor Surface Temp, Over Tubes,	°F	84.6	83.5	85.7	90.3	87.9	87.2	87.5	86.4	87.3	87.4
" " " Between Tubes,	°F	76.5	74.4	73.6	76.2	77.1	79.1	78.8	77.4	77.6	76.2
Avg. Floor Panel Temp,	°F	80.6	79.0	79.7	83.3	82.5	83.2	83.2	81.9	82.5	81.8
Wall Surface Temp, 30" above Floor,	°F	72.6	70.4	66.6	68.8	69.0	71.6	71.6	72.4	70.5	69.4
Air Temp,^{a} 3" above Floor,	°F	75.4	72.7	77.5	72.5	80.1	75.6	78.9	77.4	77.5	73.7
Air Temp,^{a} 30" " "	°F	79.0	75.3	77.5	76.8	81.9	83.0	81.4	83.0	80.5	80.6
Air Temp,^{a} 3" below Ceiling,	°F	85.9	83.4	85.8	86.3	88.7	86.5	88.7	88.7	88.6	87.3
General Data											
Supply Water Temp,	°F	124.0	131.6	145.0	143.7	140.7	132.1	130.9	129.6	137.9	132.0
Return Water Temp,	°F	106.0	109.8	117.5	116.8	117.6	112.5	112.0	109.6	115.4	112.0
Outside Air Temp,	°F	19.0	8.0	-6.0	zero	zero	15.0	16.0	14.0	12.0	17.0

a. Measured at Room Center
b. Based on Dry-Bulb Temperature and Relative Humidity Only

observation. The computed heat loss of the apartment based on the materials of construction shown in the blueprints and the averaged observed temperature difference between inside and outside was about 32,000 Btu/hr.

A comparison of the results summarized in Tables 4 and 5 for the two apartments in the building at 1160 Sedgwick Street in the Frances Cabrini Extension Project with those already discussed in Tables 2 and 3 indicates the following conclusions for the observation period from February 22 to February 26:

(a) The supply water temperature was about 20 degrees F lower for the building at 1160 Sedgwick Street.
(b) The temperature decrease between supply and return water was considerably lower in the building at 1160 Sedgwick Street.
(c) The average ceiling surface temperatures under the four tube circuits nearest the outside wall were only slightly lower in the building at 1160 Sedgwick Street, perhaps because the tube spacing was closer in the building at 1160 Sedgwick Street.
(d) The air temperatures at the 30-inch level in apartment 707 were 5 to 6 degrees lower and those in apartment 1405 about 2 degrees lower than those observed at the corresponding stations in apartments 601 and 906 in the building at 1230 N. Larrabee Road of the William Green Project. However, some windows were partly opened in apartment 707 at the time of observation on February 23, 25, and 26, which may account for the lower air temperatures.
(e) Despite a measured exhaust ventilation rate in excess of 3 air changes per hour in apartment 1405, the relative humidity was a little higher than that in apartment 707, and was quite comparable with that in apartments 601 and 906 having much lower ventilation rates.
(f) Except for the conditions on February 25 and 26 in apartment 707 when some windows were partly open, the effective temperatures in the living room were only slightly lower in the building at 1160 Sedgwick Street than in the building at 1230 N. Larrabee Road.

The ceiling and floor surface temperatures observed in the two apartments at 1160 Sedgwick Street do not serve as a good basis for computing the total panel output because: (1) the thermocouple stations covered only a part of the heated panel in the two rooms used for observation, (2) the tube spacing was not constant in some of the rooms, and (3) the tube spacing was different in the various rooms. Consequently, no comparisons are made between calculated panel heat output and computed heat loss.

The range of temperatures observed in the four apartments instrumented with thermocouples are summarized in Table 6 for the period between February 22 and February 26 when observations were being taken

TABLE 4

SUMMARY OF OBSERVATIONS
Apartment 707 - 1160 Sedgwick Street

Observation Station		Date and Time of Observation						
		Feb. 21 4:30PM	Feb. 22 10:15AM	Feb. 22 6:15PM	Feb. 23 10:30AM	Feb. 25 10:15AM	Feb. 26 1:00PM	Feb. 27 10:00AM
Living Room Data								
Ceiling Surface Temp, Under Tubes,[a]	°F	102.4	108.2	104.6	106.3	99.5	106.6	104.8
" " " Between Tubes,[b]	°F	89.8	95.0	94.1	94.5	91.0	92.9	96.0
Avg. Ceiling Panel Temp,	°F	96.1	101.6	99.4	100.4	95.3	99.8	100.4
Floor Surface Temp, Over Tubes,[c]	°F	85.8	93.5	93.0	89.0	81.5	90.6	95.0
Wall Surface Temp, 20" above Floor,	°F	55.8	62.3	67.3	50.5	51.5	57.0	63.2
Air Temp,[d] 3" above Floor,	°F	66.3	75.0	76.9	71.7	68.1	73.0	74.7
Air Temp,[d] 30" " "	°F	72.4	79.2	80.3	76.8	73.0	77.5	79.9
Air Temp,[d] 3" below Ceiling,	°F	85.2	94.7	92.8	88.4	86.8	87.7	89.6
Globe Therm.,[d] 30" above Floor,	°F	75.6	81.5	79.7	79.0	75.3	78.1	82.1
Relative Humidity,[d] 30" above Floor,	%	--	16	24	--	17	16	--
Dewpoint Temp,[d] 30" " "	°F	--	27.5	39	--	27	27.5	--
Effective Temp,[d,f] 30" " "	°F	--	71	71	--	66	69	--
Bedroom Data								
Air Temp,[e] 3" above Floor,	°F	82.9[h]	86.7[h]	--	--	72.6	73.3	78.4
Air Temp,[e] 30" " "	°F	73.6	75.7	77.5	74.3	76.0	77.0	79.6
Air Temp,[e] 3" below Ceiling,	°F	92.6[g]	98.3[g]	96.3[g]	97.1[g]	80.2	80.7	83.3
General Data								
Supply Water Temp,	°F	114.0	118.6	114.0	117.6	109.1	117.1	112.7
Return Water Temp,	°F	101.2	104.6	101.4	104.7	99.7	103.1	103.6
Outside Air Temp,	°F	2.0	10.0	16.0	22.0	16.0	17.0	17.0

a. 5 stations under tubes
b. 1 station between tubes
c. 4 stations over tubes
d. Measured at room center
e. Measured 18 inches from exterior wall
f. Based on dry-bulb temperature and relative humidity only
g. On ceiling surface
h. On floor surface

TABLE 5

SUMMARY OF OBSERVATIONS
Apartment 1405 - 1160 Sedgwick Street

		Date and Time of Observation				
Observation Station		Feb. 22 5:45PM	Feb. 23 11:30AM	Feb. 25 9:30AM	Feb. 26 1:20PM	Feb. 27 9:20AM
Living Room Data						
Ceiling Surface Temp, Under Tubes,	°F	102.6	106.2	100.0	104.3	104.4
" " " Between Tubes,	°F	97.5	101.1	96.9	98.8	100.7
Avg. Ceiling Panel Temp,	°F	100.1	103.7	98.5	101.6	102.6
Floor Surface Temp, Over Tubes,	°F	89.7	92.7	89.8	89.5	91.8
" " " Between Tubes,	°F	79.7	82.7	82.0	79.8	80.4
Avg. Floor Panel Temp,	°F	84.7	87.7	85.9	84.7	86.1
Wall Surface Temp, 20" above Floor,	°F	64.4	66.6	67.4	63.1	62.0
Air Temp,[a] 3" above Floor,	°F	71.7	75.6	74.2	69.5	71.0
Air Temp,[a] 3" below Ceiling,	°F	87.3	88.8	87.6	85.5	87.6
Air Temp,[a] 30" above Floor,	°F	78.0	81.6	81.1	77.7	76.8
Globe Therm.,[a] 30" above Floor,	°F	79.4	83.0	81.7	78.0	79.3
Relative Humidity,[a] 30" " "	%	23	25	19	--	--
Effective Temp,[a,b] 30" " "	°F	70	72.3	71	--	--
Bedroom Data						
Air Temp,[a] 3" above Floor,	°F	72.3	78.2	76.0	77.7	78.5
" " ,[a] 30" " "	°F	79.0	81.7	81.0	77.7	78.5
" " ,[a] 3" below Ceiling,	°F	86.8	87.0	86.2	85.5	87.0
General Data						
Supply Water Temp,	°F	113.8	121.6	109.0	117.2	114.8
Return Water Temp,	°F	102.2	103.6	100.0	103.9	104.0
Outside Air Temp,	°F	17.0	23.0	17.0	17.0	12.0

a. Measured at room center

b. Based on dry-bulb temperature and relative humidity only at all four locations. It should be noted that an equal range of temperatures in two apartments does not necessarily indicate equal averages in the two cases. Table 6 provides a ready comparison of data in various apartments, but it does not cover a very wide range of outdoor temperatures.

Wet-bulb and dry-bulb temperatures were observed in a number of additional apartments to obtain a broader picture of dry-bulb temperature and relative humidity levels than was afforded by the detailed instrumentation of four apartments. These wet-bulb and dry-bulb temperatures and the corresponding values of relative humidity are summarized in Table 7 together with the outdoor temperature at the time of observation. It will be noted that the relative humidity was below 20% in seven apartments, was between 20 and 30% in seven apartments, and exceeded 30% in only one apartment. The corresponding dewpoint temperatures ranged from 27°F to 48°F. An exterior wall temperature of 43°F was observed in apartment 906 on February 21 when the outdoor temperature was -5°F, but the dewpoint was lower than 43°F during this period. The lowest wall temperatures were observed beneath windows where the cold downdraft from the window cooled the wall. At the same time this stream of cool air would have been in contact with the cold window surface and thereby dehumidified somewhat in marginal situations. Whereas, it appears that condensation could be produced on the exterior walls in these apartments by excessive use of the kitchen range for boiling liquids, none was observed during the tests, and the likelihood of any serious condensation problems seemed small.

Table 7 shows that the dry-bulb temperature in the building at 624 West Division Street ranged from 79°F in apartment 1505 to 84°F in apartment 1510 for an outdoor temperature of 15°F. In six apartments in the building at 1160 Sedgwick Street the dry-bulb temperature varied from 75°F to 80.5°F and in three apartments in the building at 1230 N. Larrabee Road the dry-bulb temperature varied from 79°F to 83°F at outdoor temperatures in the range from 10°F to 17°F. The low and high values of room temperature do not appear to be associated with particular locations in the buildings, or with particular exposures of the rooms in which the measurements were made.

The effective temperature, based on dry-bulb temperature and relative humidity only, ranged from 67°F in apartment 1905 in the building at 1160 Sedgwick Street to 72.5°F in apartment 1510 in the building at 624 West Division Street. Assuming that the mean radiant temperature was at least 2 to 3 degrees above the air temperature in all of the apartments listed in Table 7, as was observed in the four instrumented apartments, it is safe to conclude that none of the apartments listed in Table 7 was too cool and that most of them were somewhat too warm for optimum comfort.

TABLE 6

RANGE OF TEMPERATURES IN FOUR APARTMENTS
for the Period February 22 - 26, 1963

		Apartment Number			
Observation Station		906	601	707	1405
Supply Water Temp,	°F	128.3 - 136.9	129.6 - 137.9	109.1 - 117.6	109.0 - 121.6
Return Water Temp,	°F	103.8 - 116.0	109.6 - 115.4	99.7 - 104.7	100.0 - 104
Living Room Data					
Ceiling Surface Temp, Under Tubes,	°F	107.1 - 114.6	104.4 - 109.3	99.5 - 106.3	100.0 - 106.2
" " " Between Tubes,	°F	89.1 - 93.6	91.6 - 94.6	91.0 - 96.0	96.9 - 101.1
Floor Surface Temp, Over Tubes,	°F	86.4 - 90.7	84.6 - 88.0	81.5 - 95.0	89.5 - 92.7
" " " Between Tubes,	°F	92.0 - 96.2	90.2 - 92.2	---------	79.7 - 82.7
Air Temp, 3" above Floor,	°F	73.5 - 79.2	73.2 - 80.8	68.1 - 76.9	69.5 - 75.6
" " 30" " "	°F	78.5 - 83.0	80.3 - 83.0	73.0 - 80.3	76.8 - 81.6
" " 3" below Ceiling,	°F	86.2 - 90.2	90.2 - 95.2	86.8 - 92.8	85.5 - 88.8
Globe Therm. Temp, 30" above Floor,	°F	79.6 - 84.5	84.1 - 85.2	75.3 - 82.1	78.0 - 83.0
Wall Surface Temp,	°F	58.7 - 59.7	53.5 - 59.3	50.5 - 67.3	62.0 - 67.4
Bedroom Data					
Air Temp, 3" above Floor,	°F	77.0 - 81.4	73.7 - 78.9	72.6 - 78.4	72.3 - 78.5
" " 30" " "	°F	79.7 - 83.1	80.5 - 83.0	74.3 - 79.6	77.7 - 81.7
" " 3" below Ceiling,	°F	83.5 - 90.5	86.5 - 88.7	80.2 - 83.3	85.5 - 87.0
Wall Surface Temp,	°F	53.5 - 61.9	69.4 - 72.4	--------	--------

TABLE 7

OBSERVED RELATIVE HUMIDITY IN SELECTED APARTMENTS

Apartment Number	Location in Building	Dry-Bulb Temperature °F	Wet-Bulb Temperature °F	Relative Humidity %	Outdoor Temp. °F
		624 West Division Street			
1505	Center	79	57	23	15
1505	"	80	57	21.5	15
1510	S.E. Corner	83.5	56	13.5	15
1510	" "	84	56.5	14	15
710	S.E. Corner	80	56	19	15
710	" "	80	56	19	15
704	Center	81.5	55	14	15
704	"	82	55	13.5	15
107	Center	80	57.5	23	15
107	"	80	57	21.5	15
		1160 Sedgwick Street			
1905	Center	75	52	16	12
1902	End	78	55	19	12
1405	Center	80	57.5	23	17
805	Center	80.5	57.5	22	10
101	End	78	59	31	10
103	End	77	57	27	10
		1230 N. Larrabee Road			
906	Center	79.5	55	17	16
701	End	79	59	29	16
601	End	83	62	29	15

The observed exhaust ventilation rates measured at the bathroom grilles in four apartments are summarized in Table 8 for various conditions of window and door closure. The results show that the exhaust ventilation rate was affected very little by closing the bathroom door or by opening a few windows. This indicates that the provision for air flow beneath the bathroom door was adequate and that the resistance to air infiltration from outside the apartment was small compared to the other resistances in the exhaust duct system. The exhaust air flow rate was quite variable in apartment 707, presumably due to variations in wind velocity.

It was observed that the exhaust grilles in all four of the apartments where air flow rates were measured had a considerable accumulation of dust and lint in the grille openings. The grilles and the exhaust duct immediately behind the grilles were cleaned before the air flow measurements were made.

The drawings for the William Green Project indicate a design exhaust ventilation rate of 55 cfm for apartment 601 and 50 cfm for apartment 906. The drawings for the Frances Cabrini Extension Project indicate design exhaust ventilation rates of 70 cfm and 85 cfm in different groups of apartments. The observed ventilation rates were 50 to 60% in excess of the design values in apartments 601 and 906 and from 50 to 250% in excess of the design values in apartments 707 and 1405. If all of the exhaust grilles were obstructed with lint and dust like the four involved in this study, cleaning these particular four grilles may have caused abnormally high exhaust ventilation rates because of the high resistance at the other grilles.

5.0 Conclusions

The measurements and observations made in the apartment buildings of the William Green and Frances Cabrini Extension Projects of the Chicago Housing Authority indicated the following conclusions:

(a) The hot water panel heating systems provided ample heat for the design weather conditions in Chicago.

(b) Two features of the building design used in these two projects contributed to the economy of heating: first, the use of exterior galleries, stairways, and elevator shafts reduced significantly the amount of volume to be heated and, second, the use of a continuous concrete slab construction at each floor level together with the exterior stairways and elevators virtually eliminated air movement from floor to floor and caused each floor level to act as a one-story structure insofar as infiltration was concerned.

TABLE 8

OBSERVED EXHAUST VENTILATION RATE IN BATHROOMS OF FOUR APARTMENTS

Apartment Number	Avg. Exhaust Velocity	Exhaust Ventilation Rate	Window and Interior Door Positions
	fpm	cfm	
906	395	85	Windows closed - all doors open
	392	84	Windows closed - bathroom door closed
	403	86	3 windows open - all doors open
601	403	86	Windows closed - all doors open
	373	80	Windows closed - bathroom door closed
	415	89	2 windows open - all doors open
707	590 - 825[a]	127 - 177[a]	Windows closed - all doors open
	569	122	Windows closed - bathroom door closed
	637	136	2 windows open - all doors open
1405	1379	295	Windows closed - all doors open
	1450	311	Windows closed - bathroom door closed
	1380	296	2 windows open - all doors closed

a. Exhaust air flow rate varied with wind velocity outdoors.

(c) The observed ventilation rates ranging from 0.75 to 1.47 air changes per hour in three apartments were ample to provide fresh air and prevent condensation on the walls. The ventilation rate of 3.19 air changes per hour in apartment 1405 was excessive and should be reduced. The ventilation rate was almost independent of the position of interior doors.

(d) A regular schedule of cleaning for the exhaust air grilles should be instituted to maintain the desired ventilation rates and to maintain the proper balance between apartments.

(e) A high percentage of the apartments was overheated. Air temperatures from 80°F to 83°F at the 30-inch level were not uncommon in the living rooms and bedrooms. Considering the typical elevation of the mean radiant temperature of 2 or 3 degrees F above air temperature in these apartments, a dry-bulb temperature of 75°F would be adequate for optimum winter comfort even at relative humidities in the range from 20 to 30%.

(f) The regularly spaced heating tubes 18 inches apart in the apartments of the William Green Project produced about the same average ceiling panel temperature with a supply water temperature of 140°F as the non-uniformly spaced tubes 6 to 12 inches apart in the apartments of the Frances Cabrini Extension Project with a supply water temperature about 20 degrees cooler. The measurements did not indicate a significant difference in adequacy or comfort for the two tube arrangements, but considerably less heating tube was used in the William Green apartments.

(g) With a very few exceptions, each tube circuit in the buildings of the William Green Project was confined to the floor or ceiling area of one room, whereas many of the tube circuits in the buildings of the Frances Cabrini Extension Project extended into the floor or ceiling area of two or more rooms. In the latter project one tube circuit encircled the entire perimeter of the apartment near the outside wall and was used as an antifreeze protection since it could not be shut off by the tenant. It is obvious that the circuit pattern used in the Frances Cabrini Extension Project offered less opportunity for balancing the temperature among the several rooms in a given apartment by adjustment of flow valves in the individual circuits.

(h) The one-zone distribution system utilizing a three-way valve to modulate the supply water temperature identically in all tube circuits in each building in response to an outdoor thermostat did not provide sufficiently uniform air temperatures in the various apartments nor did it provide sufficiently uniform air temperature in a given apartment as the weather changed. In five or six apartments in each of two buildings the air temperature varied 5 degrees in each group. In the eight rooms instrumented for detailed study in four apartments, the air temperatures at the 30-inch level varied 3.3 to 4.8 degrees in four of the rooms and from 6.0 to 12.3 degrees in the other four rooms during the seven days of observations during which the outdoor temperature ranged from 37°F to -6°F.

(i) There was no direct evidence that the control of temperature and degree of comfort was less satisfactory in the rooms with two outside exposures than for those with one outside exposure.

(j) Exterior wall surface temperatures of about 50°F were observed in three rooms and a wall surface temperature of 43°F was observed in one room as a result of the large window areas used and the lack of insulation in the walls.

(k) Some floor panel surface temperatures in excess of 90°F were observed, but such occurrences would have been rare if the room air temperature had been maintained in the vicinity of 75°F.

6.0 Recommendations on Existing Buildings

The following recommendations are made with a view to improving the comfort and economy of heating in these two projects:

(1) Room dry-bulb temperature levels should be reduced to about 75°F to improve the comfort and to save fuel. The effective temperature in most apartments was considerably in excess of the 68°F level considered to represent optimum winter comfort conditions. Lowering the dry-bulb temperatures would entail resetting the proportioning control between the outdoor thermostat and the temperature-sensitive element in the main supply water main.

(2) The distribution of heat to the various apartments should be rebalanced. Steps to be taken in balancing hot-water heating systems in large buildings are listed on page 136 of the 1962 Applications Volume of the ASHRAE Guide and Data Book. It is especially important to perform this operation when the outdoor conditions are reasonably constant, such as during cloudy, rainy weather. The balancing operation should include checking the room temperatures in a given building at two outdoor temperature levels, considerably separated, in order to determine whether the correct slope of the curve representing the relation of supply water temperature to outdoor temperature has been achieved. When the optimum setting of the proportioning control has been obtained with respect to temperature level and slope, the only opportunity for balancing the temperature among the various apartments in a given building or among the several rooms in an apartment is to use the plug valves in the return tubes of the piping circuits to restrict the water flow to circuits serving rooms that are too warm. The plug-type valves used in the heating circuits of the William Green and Frances Cabrini Extension Projects are not well-suited to adjustment of flow since a quarter turn or less changes the valve from fully open to fully closed position. Another type of adjustable valve could be installed that provided better choice of intermediate positions between fully open and fully closed positions.

(3) The exhaust grille in each apartment should be cleaned at regular intervals and the exhaust ventilation rate at various floor levels should be measured after the first cleaning operation is completed to determine that the ventilation rate is approximately the same at each floor level.

(4) The balance of temperature in the several apartments in each building could probably be improved by using a multi-zone control system that took into account differences in solar exposure, the direction of the prevailing wind, the number of exposed walls per room, and the room function. Such a change could probably be accomplished in the existing buildings by grouping the supply and return lines in the basement for apartments or rooms with similar load characteristics, and providing separate pumps, three-way valves and outdoor thermostats for each zone. This modification would be quite expensive and might not be economically justified from a fuel-saving standpoint. The desirability of making such a modification to improve the temperature distribution should be evaluated on the basis of the effectiveness of the preceding three recommendations. It should be noted that the tube circuit patterns used in the Frances Cabrini Extension Project are not conducive to adjustment of the temperature on an individual room basis since many of the circuits cover two or more rooms.

7.0 Recommendations for Future Construction

This field study of the performance of hot-water panel heating systems in multi-story buildings for public housing purposes indicated that such systems are capable of providing adequate heating in cold climates. The records of fuel use of the Chicago Housing Authority indicates that this type system is economical. However, in our opinion, further use of this type system should be carried out in conjunction with and be contingent upon a better system of temperature control for individual apartments and rooms. Additional economy achieved with a better control system would pay for a part or all of the cost of the better control system.

All available published information on control systems for hot-water panel heating systems agrees that a modulation of the supply water temperature in response to an outdoor thermostat (and perhaps modified by an indoor compensator as a supplementary reset device) is essential for heating coils embedded in concrete slabs. Zoning control is frequently employed where a single heating system is used to heat a large number of areas or living units which do not have identical internal heating loads or identical exposure to outdoor conditions. For zoning purposes all spaces or units having the same internal load pattern and external response are grouped together on the same distribution circuit and controlled by a single control system. In our opinion, large multistory apartment buildings of the type investigated in this field study in Chicago should be zoned. The significant features of this application that indicates the need for zoning are:

(a) High winds in the range from 15 to 25 mph are prevalent in the Chicago area during the winter as indicated by the data collected during this field study.
(b) No shading from solar radiation was provided on the sides of the buildings opposite the galleries.
(c) Apartments in the center of the building typically have one exposure per room, but these are on opposite sides of the building; e.g., a north exposure would be exposed frequently to strong winds and receive no sunshine, whereas a south exposure in the same apartment would not receive the impact of the wind but would be unshaded from the sun.
(d) Apartments at the end of a building would typically have two exposures per room, one of which would often be exposed to the prevailing wind, and one of which would receive solar radiation.
(e) The kitchen, dining room, and living room were typically not separated by partitions so the heat and moisture release from cooking functions would tend to make this part of the apartment warmer than the bedrooms. Nearly all of the apartment designs incorporated a hallway between the bedrooms and the living-room-dining-room area, thus inhibiting heat exchange between these areas to a large degree.

Taking the building at 1230 N. Larrabee Road in the William Green Project to illustrate the possibilities of zoning, most of the bedrooms are located on the west side of the building and are exposed to the prevailing wind, and most of the living rooms, dining rooms, and kitchens have an east exposure adjacent to the galleries. In this building all of the rooms on the north and west sides of the building, including the bedroom on the southeast corner, could be placed in one zone with the supply water temperature controlled by an outdoor thermostat designed to compensate for the effect of wind velocity. All of the rooms on the south and east sides of the building, including the living room-dining room combinations in apartments 1 and 8 on the 3rd through 6th floors and in apartments 1 and 10 on the 7th through 12th floors could be placed in a second zone with the supply water temperature controlled by an outdoor thermostat located on the east side of the building. Neither of these outdoor thermostats would have to compensate for solar radiation since the quantity and duration of solar irradiation on east and west walls is small during the winter months in the latitude of Chicago. In this building only the living room-dining room area of apartment 2 has a significant glass exposure in a south wall.

In a building whose principal center line was in an east-west direction, such as those on Division Street, a somewhat different grouping of rooms would be required and the control system would have to take into account the effect of solar radiation on the many rooms with a south exposure. Adjustment for solar effect on the south exposure could be made with an indoor compensator overriding an outdoor thermostat if a representative indoor location could be found for the indoor compensator, or an outdoor thermostat designed to suitably integrate solar effect and outdoor temperature could be used by itself to modulate the supply water temperature.

In our opinion, no less than two zones should be used in apartment buildings such as those in the William Green and Frances Cabrini Extension Projects and, in some cases, three or four zones might be preferable depending on building orientation, amount of glass area in a given exposure, and the arrangement of bedroom areas and kitchen, living room, dining room areas in the buildings. In a zoned system, separate circulating pumps, three-way modulating valves, and outdoor thermostats would be required for each zone together with any indoor compensators that might be used to provide for solar or wind effects on room temperature. In general, it would be preferable to have solar and wind effects sensed outside the building because of the inherent lag in a panel heating system utilizing concrete slabs.

In our opinion, the use of one or more separate heating tube circuits in each room is preferable to a design which causes the circuits to overlap two or more rooms because it facilitates balancing the room temperatures with respect to each other. The use of one perimeter tube around an entire apartment, which cannot be shut off, to prevent freezing when the apartment is unoccupied would not ordinarily inhibit balancing to any appreciable extent. The need for such a perimeter circuit would depend on the duration of vacancies and the building management policy regarding the heating of unoccupied apartments.

Balancing valves with more gradual modulation and some means for knowing the degree of closure should be used in this type of building since balancing of temperatures among rooms and apartments is inevitable.

In any new construction, consideration should be given to lowering the heat transmission factor of the exterior walls, to the use of double glass for fixed windows, and to a reduction in the percentage of the total heat output to be delivered from the floor. Double glass should not be used without improving the insulating qualities of the exterior walls because of the possibility of condensation on the walls. A reduction in the heat output required from the floor would reduce the significance of the greater lag of the floor panel as compared to the ceiling panel and improve the quality of temperature control with changing outdoor temperature. A cost study would have to be made in any particular case to determine whether or not these improvements were economically feasible.

In our opinion, interior hallways, stairs, and elevators should be considered in any similar apartment buildings for the aged, even though such a design would increase the total heat requirement, because of the greater sensitivity of the aged to cold weather.

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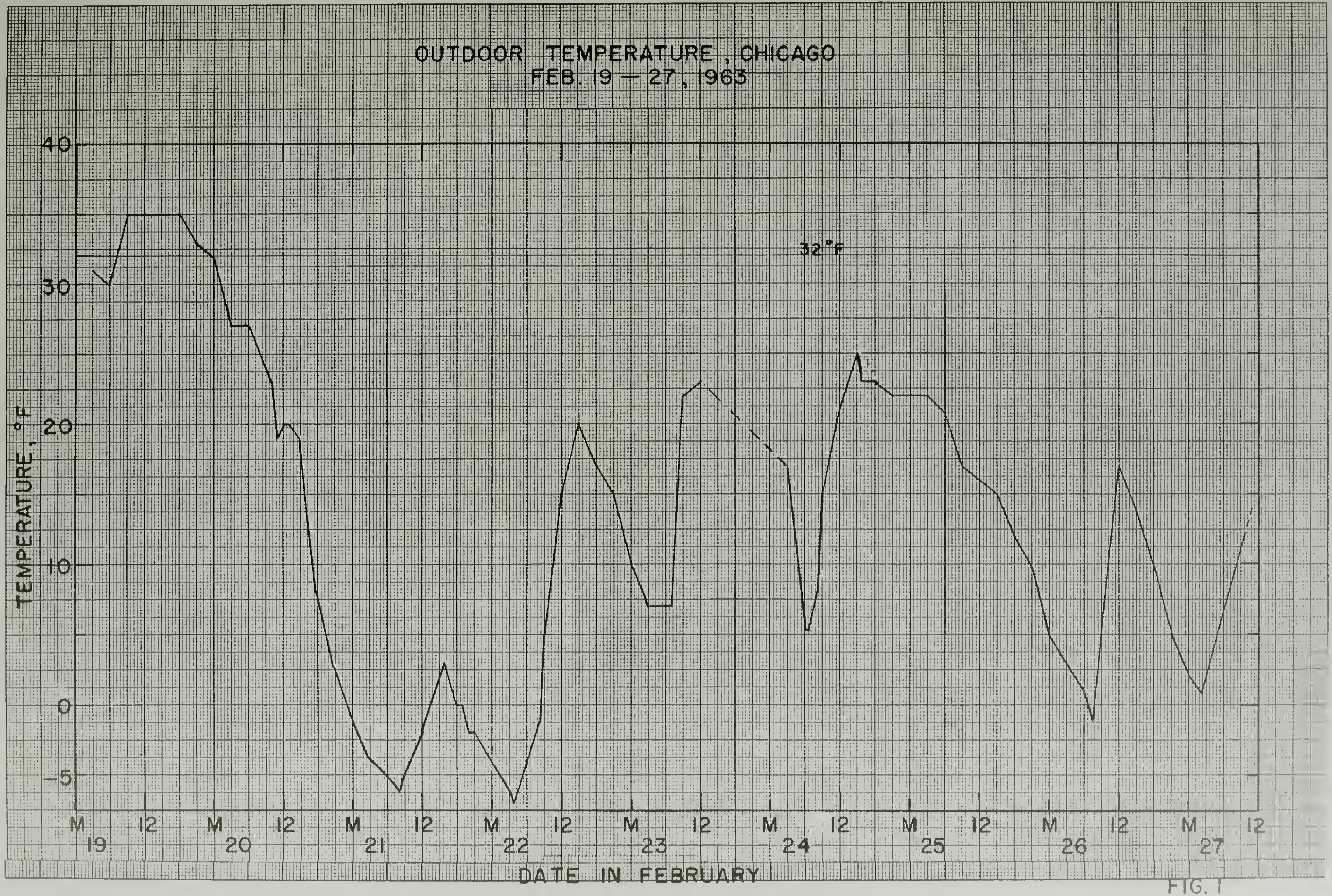

OUTDOOR TEMPERATURE, CHICAGO
FEB. 19 — 27, 1963

FIG. 1

U. S. DEPARTMENT OF COMMERCE
Luther H. Hodges, *Secretary*

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

THE NATIONAL BUREAU OF STANDARDS

The scope of activities of the National Bureau of Standards at its major laboratories in Washington, D.C., and Boulder, Colorado, is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section carries out specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant publications, appears on the inside of the front cover.

WASHINGTON, D. C.

Electricity. Resistance and Reactance. Electrochemistry. Electrical Instruments. Magnetic Measurements. Dielectrics. High Voltage. Absolute Electrical Measurements.

Metrology. Photometry and Colorimetry. Refractometry. Photographic Research. Length. Engineering Metrology. Mass and Volume.

Heat. Temperature Physics. Heat Measurements. Cryogenic Physics. Equation of State. Statistical Physics.

Radiation Physics. X-ray. Radioactivity. Radiation Theory. High Energy Radiation. Radiological Equipment. Nucleonic Instrumentation. Neutron Physics.

Analytical and Inorganic Chemistry. Pure Substances. Spectrochemistry. Solution Chemistry. Standard Reference Materials. Applied Analytical Research. Crystal Chemistry.

Mechanics. Sound. Pressure and Vacuum. Fluid Mechanics. Engineering Mechanics. Rheology. Combustion Controls.

Polymers. Macromolecules: Synthesis and Structure. Polymer Chemistry. Polymer Physics. Polymer Characterization. Polymer Evaluation and Testing. Applied Polymer Standards and Research. Dental Research.

Metallurgy. Engineering Metallurgy. Metal Reactions. Metal Physics. Electrolysis and Metal Deposition.

Inorganic Solids. Engineering Ceramics. Glass. Solid State Chemistry. Crystal Growth. Physical Properties. Crystallography.

Building Research. Structural Engineering. Fire Research. Mechanical Systems. Organic Building Materials. Codes and Safety Standards. Heat Transfer. Inorganic Building Materials. Metallic Building Materials.

Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics. Operations Research.

Data Processing Systems. Components and Techniques. Computer Technology. Measurements Automation. Engineering Applications. Systems Analysis.

Atomic Physics. Spectroscopy. Infrared Spectroscopy. Far Ultraviolet Physics. Solid State Physics. Electron Physics. Atomic Physics. Plasma Spectroscopy.

Instrumentation. Engineering Electronics. Electron Devices. Electronic Instrumentation. Mechanical Instruments. Basic Instrumentation.

Physical Chemistry. Thermochemistry. Surface Chemistry. Organic Chemistry. Molecular Spectroscopy. Elementary Processes. Mass Spectrometry. Photochemistry and Radiation Chemistry.

Office of Weights and Measures.

BOULDER, COLO.

CRYOGENIC ENGINEERING LABORATORY

Cryogenic Processes. Cryogenic Properties of Solids. Cryogenic Technical Services. Properties of Cryogenic Fluids.

CENTRAL RADIO PROPAGATION LABORATORY

Ionosphere Research and Propagation. Low Frequency and Very Low Frequency Research. Ionosphere Research. Prediction Services. Sun-Earth Relationships. Field Engineering. Radio Warning Services. Vertical Soundings Research.

Troposphere and Space Telecommunications. Data Reduction Instrumentation. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Spectrum Utilization Research. Radio-Meteorology. Lower Atmosphere Physics.

Radio Systems. Applied Electromagnetic Theory. High Frequency and Very High Frequency Research. Frequency Utilization. Modulation Research. Antenna Research. Radiodetermination.

Upper Atmosphere and Space Physics. Upper Atmosphere and Plasma Physics. High Latitude Ionosphere Physics. Ionosphere and Exosphere Scatter. Airglow and Aurora. Ionospheric Radio Astronomy.

RADIO STANDARDS LABORATORY

Radio Standards Physics. Frequency and Time Disseminations. Radio and Microwave Materials. Atomic Frequency and Time-Interval Standards. Radio Plasma. Microwave Physics.

Radio Standards Engineering. High Frequency Electrical Standards. High Frequency Calibration Services. High Frequency Impedance Standards. Microwave Calibration Services. Microwave Circuit Standards. Low Frequency Calibration Services.

Joint Institute for Laboratory Astrophysics-NBS Group (Univ. of Colo.).

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