

- $t_s$  = average panel surface temperature, Fahrenheit.  
 $t_w$  = average water temperature, Fahrenheit.  
 $q$  = heat flow to the panel, Btu per (hour) (square foot).

Table 2 shows some typical values for the thermal resistance factors for two types of metal panel ceilings which have been used in commercial installations. The thermal resistance may vary considerably depending on the type of bond achieved between the tube and the panel. This bond may vary with time, corrosion between lightly touching surfaces, and other factors. The actual thermal resistance of any proposed system should be verified by actual test whenever practicable. Resistance of plaster type panels is given in Chapter 10.

### SUSPENDED PANELS

When suspended type ceiling systems are used, metal water-cooled ceiling panels are frequently fabricated to mount integral with the remainder of the ceiling. In some cases, metal pans are made with curved sections to mount against the cooling pipes which are installed as separate grids. Other panels are made to snap into T-bars while pressing against water grids. Most systems using separate tubes and panels have a relatively high thermal resistance, and require that a relatively high percentage of the ceiling area be used for the panel. The first illustration in Table 2 shows an aluminum extrusion into which a copper water tube has been forced for permanent thermal bond by flattening the tube. This type of panel has a lower thermal resistance, and may frequently be used in separate ceiling sections because of its higher overall performance. This shape of panel has also been fabricated to mount into T-bar ceiling systems, and has been applied successfully around ceiling peripheries to absorb solar gains.

When partially paneled ceilings or discreet panel systems are employed, acoustical treatment may be applied to the remainder of the ceiling area. When such other sections are made of perforated metal, convection currents tend to equalize the temperature of the space above the ceiling with that in

the space below. In this case, the ceiling slab surface temperature becomes significant because the panels pick up some heat from the overhead floor slab by radiation, and to a very much smaller extent, by convection. This last quantity is roughly equivalent to convection from a cooled floor panel, and might be approximated by Equation 9.<sup>8</sup>

$$A_s = \frac{0.041(\Delta t)^{0.25}}{(D_s)^{0.25}} \quad (9)$$

In this case, the  $\Delta t$  is the temperature difference between the top of the cooling panel and the mid space of the ceiling. The temperature of the ceiling space must be determined by actual test, since it will vary with different types of panel systems. A typical temperature pattern in one type of system is shown later in this chapter.

If lighting fixtures are recessed into the suspended ceiling space, the top of the fixtures will raise the overhead slab temperature by radiation and will transfer heat to the ceiling space by convection. This energy will be absorbed at the top of the panels by radiation as in Fig. 1 and by convection, generally in accordance with Equation 9. The amount absorbed by the top of the panel depends on the particular type of system. Most manufacturers of specific systems have such empirical information available. The absorption at the top of flat panels rarely exceeds  $\frac{1}{2}$  the energy of the lighting system, or 50 percent of the transfer from the room to the panel by convection and normal radiation. Similarly, panels installed under a roof will absorb additional heat, again depending upon configuration.

### WATER COOLED LUMINAIRES

Much of the input energy from a commercial fluorescent luminaire can be transferred from the fixture in the form of conducted heat originating in the ballast and sockets. Furthermore, the long tubes lend themselves to an enclosure which is an excellent radiation trap, for all wavelengths. Such a configuration can also serve as an inverted collecting basin for convected heat from the tube surfaces. Fig. 1 of Reference 14 shows a cross section end view of such a fixture, which was developed by C. S. Leopold. Extruded aluminum sections form the sides and bottom extensions of the lighting fixtures. Luminaires of this type have been installed in two large office buildings. Extensive performance data on one of these systems under actual operating conditions was reported by W. F. Spiegel.<sup>14</sup> Fig. 9 shows the overall performance of one of these units, based on an in-place test. The bottom curve shows the convection and low temperature radiation characteristics of the unit as found in a darkened room with the electrical parts inoperative. The middle curve was obtained with the unit operating in the dark with the ballast feeding remote lamps. The distance between the middle and lower curves indicates the magnitude of direct conduction. The top curve is with normal operation. The distance between the top and middle curves represents the (IRT), which is seen to be an almost constant quantity, even with water at room temperature. With this fixture, conduction and (IRT) amounted to over 35 percent of the fixture input, and the heat equivalent of the lighting input was transferred to the water at an average water temperature only 10 F deg below the average space temperature. With a greater temperature difference, higher performance was obtained.

In applying units of this type, no other panel element is normally required in the interior zones, even in highly lighted spaces. Air must still be introduced to pick up moisture load and provide ventilation, but the quantity will be small as compared to an all-air system. Water-cooled luminaires installed in an exterior zone will pick up an additional amount

### Panel-Air Systems for Air Conditioning

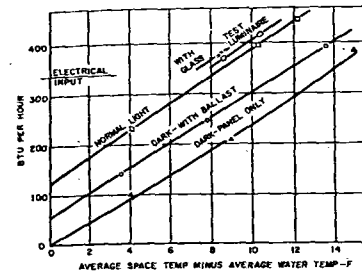


Fig. 9 .... Overall Performance of a 6-ft Water-cooled Luminaire

of solar (IRT) and increased radiation from warm exterior walls and glass surfaces.

### WATER PIPING

Conventional design is recommended for panel circuits. Two precautions should be followed:

1. Velocities should be maintained sufficiently high through all parts of the circuit to prevent sedimentation.
2. Panel circuits are extremely sensitive to noise. The panels can act as sounding boards. Velocities through piping, fittings, valves, etc. should be kept sufficiently low to avoid any sounds due to local or pipeline velocities.

Because of the large number of joints in the system, the pipe joining, or brazing techniques should be thoroughly checked to assure that proper joints are installed. Water treatment should be considered in any systems where pump glands are not absolutely tight.

Temperature drops through panel strings are usually recommended at from 3 to 5 deg, a balance between economics of water flow and thermal performance.

Piping should be so arranged that the heat removed by the panel water circuits from the interior of the building can be utilized to temper the ventilation air introduced into the building during the winter months. Thus the interior of the building can receive cooling from outdoor air without operating the refrigeration system. The requirement of continuously available cold water for winter south zone cooling is also met. The panel circuits also provide a practical heat source for a heat pump where such an application is indicated.

When exterior zone control of individual areas is required, piping can be arranged for 3-way bypass, throttling valve action, 3-pipe systems with zone return diverting valves, 4-pipe systems, and other combinations.

### CONDENSATION CONTROL

To minimize the possibility of condensation in a panel-air system, the water leaving the dehumidifier of the air supply apparatus should be used to cool water for the panel water circuit. If the main cooling coil is six rows or more, the leaving air dew point will usually be near the leaving water temperature. In addition, the panel water temperature should be controlled either by mixing with return water or by control valves around an interchanger. In order to safeguard against drift in the controls, it is recommended that the panel supply water temperature be maintained at least 3 deg above the room dew point temperature. There are also methods avail-

able where the air can be dried by chemical methods rather than refrigeration. For such applications, accurate dew point controllers of the hygroscopic chemical type are usually required.

### TEMPERATURE CONTROLS AND OPERATION

Cooling the panel water circuits with water leaving the dehumidifier is the major consideration in preventing condensation in a panel-air system. A second consideration is to assure that the panel water pumps cannot be started until a timed period after the main air fans are in operation with cool and dry air. Particularly after extended down periods, as after weekends, it is imperative to dry out the building space before starting the panel water system. Such delayed starting action may be obtained manually or with automatic devices.

Panel-air systems require two basic areas of temperature control: (1) exterior and under-roof control to compensate for transmission and solar load, and (2) control of interior zones to compensate for internal loads.

Panels lend themselves well to control systems which are scheduled by means of elements which sense solar and weather changes before these changes affect the space temperature. Window pane thermocouples have been used to schedule water temperatures in panels under a window sill, and photoelectric cells can be used to divert cold water into a peripheral ceiling panel, for example, to pick up the winter solar load on a south zone. Panel-air systems have also been zoned to provide individual temperature control in exterior offices, particularly in applications where there is a high lighting load.

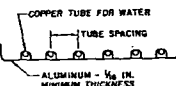
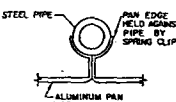
The temperature control of the interior air and panel water supply should not be functions of the outdoor weather. The normal thermostat drift is usually adequate compensation for the slightly lower temperatures desirable during winter weather. This drift should be limited to result in change of room temperature ranges of not more than  $1\frac{1}{4}$  F deg. Control of the interior zones is best accomplished by devices which reflect the actual presence of the internal load elements. Frequently used are time clocks and current sensing devices on lighting feeders.

Because air quantities are generally small, it is not advisable to use volume control in any part of the system. With the apparatus arranged to supply air of appropriate apparatus dew point at all times, it is possible to avoid any compromise on indoor conditions with a panel-air system throughout the year. As with all systems, the supply air dew point should be reduced during extremely cold weather in accordance with the type of glazing installed in order to prevent streaming on the window surfaces.

### COMFORT CONDITIONS

Both the mean radiant temperature in a space and the amount of air motion will influence the feeling of comfort; neither are shown in the normal comfort data. Raber and Hutchinson<sup>15</sup> report that a 1 deg depression in normal mean radiant temperature will raise the optimum comfort temperature by approximately  $\frac{1}{4}$  deg. In a full paneled ceiling, this effect will have considerable significance, but offsetting this effect is the extremely low terminal air velocity in the spaces of most panel-air systems. The combined effects produce conditions which do not deviate appreciably from the comfort criteria given in Chapter 8 of the 1961 GUIDE AND DATA BOOK. In discreet panel systems, such as those used with water-cooled luminaires, it has been observed that the decrease in air motion will depress the optimum summer temperature approximately 1 to  $1\frac{1}{4}$  F deg. However, it was observed with this type of system that the tolerance of individ-

Table 2 .... Resistance of Panels to Heat Flow

| Type of Panel                                                                                                                                                                                                        | Thermal Resistance to Heat Flow<br>(F deg) (sq ft) per Btu |       |    |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------|-------|----|
|                                                                                                                                                                                                                      | Spacing—Inches                                             |       |    |
|                                                                                                                                                                                                                      | 3                                                          | 6     | 12 |
| <br>COPPER TUBE FOR WATER<br>TUBE SPACING<br>— ALUMINUM — 1/2 IN. MINIMUM THICKNESS<br>Tube installed with forced mechanical bond | 0.07*                                                      | 0.15* | —  |
| <br>STEEL PIPE<br>PIN EDGE WELD AGAINST PIPE BY SPRING CLIP<br>— ALUMINUM PAN 0.032 IN. THICK                                     | —                                                          | 0.61* | —  |

\* See Chapter 10, Table 3.  
 \* Calculated from tests. See Reference 14.  
 \* Manufacturer's Data.