

SOME ASPECTS OF
ENERGY-INTEGRATION IN
MODERN BUILDINGS

by

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CHAPTER I

INTRODUCTION

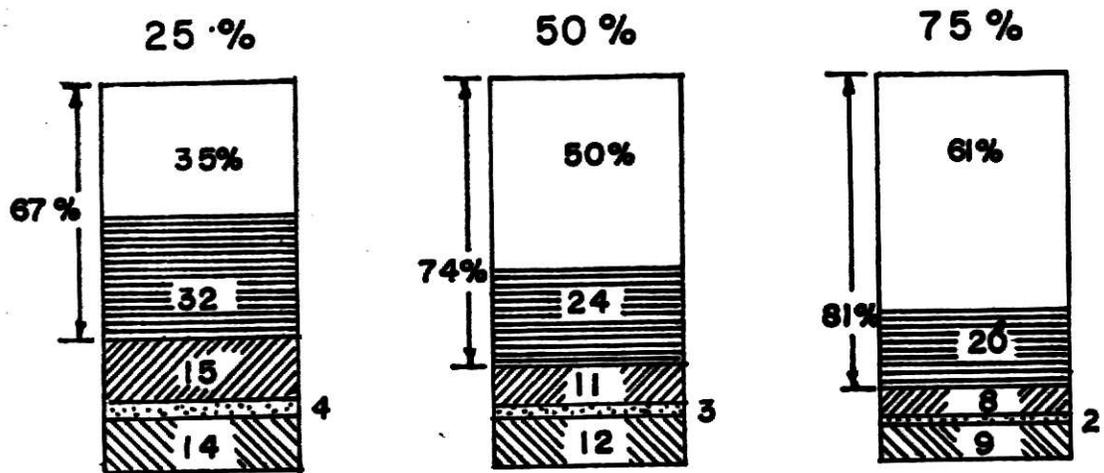
There has been continued development in the Twentieth Century of the products for environmental control, and among these products are electrical lights, air handling devices and devices for sound control. The effect of these products must be regulated simultaneously to keep desired conditions in the occupied space. This regulation should be an integrated attempt to create human comfort by coordinating all available energies with a maximum efficiency and minimum cost. Figure 1 illustrates a breakdown of the percentages of the heat gains in buildings with varying amounts of glass areas in exterior walls. The two major components, solar and light heat gains, represent 67% of the total space heat gain in a building having 25% of glass at the perimeter (1)*.

There have been some efforts in the past to minimize the glass areas to reduce the solar heat and employ lower lighting levels to reduce the cost of air-conditioning equipment.

There are other significant heat loads in a modern building, such as the heat of people and business machines. In a totally integrated system they may also be coordinated, but in the systems discussed in this report, only solar heat and the lighting heat are considered for integration.

* Numbers in parentheses designate References at the end of the report.

GLASS WITH VENETIAN BLINDS



- SOLAR HEAT INPUT
- LIGHTING HEAT
- CONDITIONING OF OUTSIDE AIR
- CONDUCTION THROUGH WALLS
- PEOPLE, EQUIPMENT & MISC.

BASIC CONSIDERATIONS:

FLOOR AREA	100 SQ FT / PERSON
LIGHTING	6 WATT / SQ FT
OUTSIDE AIR	0.3 CFM / SQ FT
OUTSIDE AIR COND	40 BTUH / CFM

Figure 1. Percentage of Total Heat Gain For A Building

Two systems, one using water as the medium of heat transfer and the other using air, are discussed in the report, though consideration is also given to some other methods. Comparison of the two methods and some conclusions are given.

CHAPTER II

LUMINAIRES AS HEAT SOURCES

Electric lamps are something less than 100% efficient as light sources, however, they are 100% efficient as heat sources. Each watt of electrical input to the lamp is totally converted to heat energy which can be classified as:

- 1) Conduction and convection energy,
- 2) Radiant energy including infrared, visible light and ultraviolet.

A 40 watt, 425 milliamp fluorescent lamp operating at 77° F. ambient conditions and 106° F. bulb wall temperature in still air produces the following percentages of energies (3).

TABLE 1

Type of Energy	Percent
Light	19.0%
Infrared	30.7%
Ultraviolet	0.4%
Conduction-Convection	36.1%
Ballast loss	<u>13.8%</u>
Total	100.0%

When the lamp is put in a luminaire housing or troffer, it is found that there is further degradation of energy. Only 8% to 10% is available as light and the balance goes out as heat.

The amount of energy reflected from a surface depends upon the material from which the troffer is made. The following table shows percent

reflectances of some of the materials commonly used for the construction of troffers (3).

TABLE 2

<u>Material</u>	<u>Reflectance At Indicated Wave Length (μ)</u>				
	<u>4</u>	<u>7</u>	<u>10</u>	<u>15</u>	<u>20</u>
Polished Aluminum	92	96	98	--	--
Diffused Anodized Aluminum	12	21	9	6	6
Synthetic Enamel on Steel	3	1	1	--	--
Porcelain Steel	5	3	9	6	13

As seen from the table, if the material used for the construction of the troffer is polished aluminum, most of that energy is reflected. If the material is synthetic enamel on steel, most of the energy is absorbed and eventually the troffer gets warmer.

Extensive data regarding the illumination characteristics of the lamps and troffers are available in the Illuminating Engineering Society's Committee Report. (3).

CHAPTER III

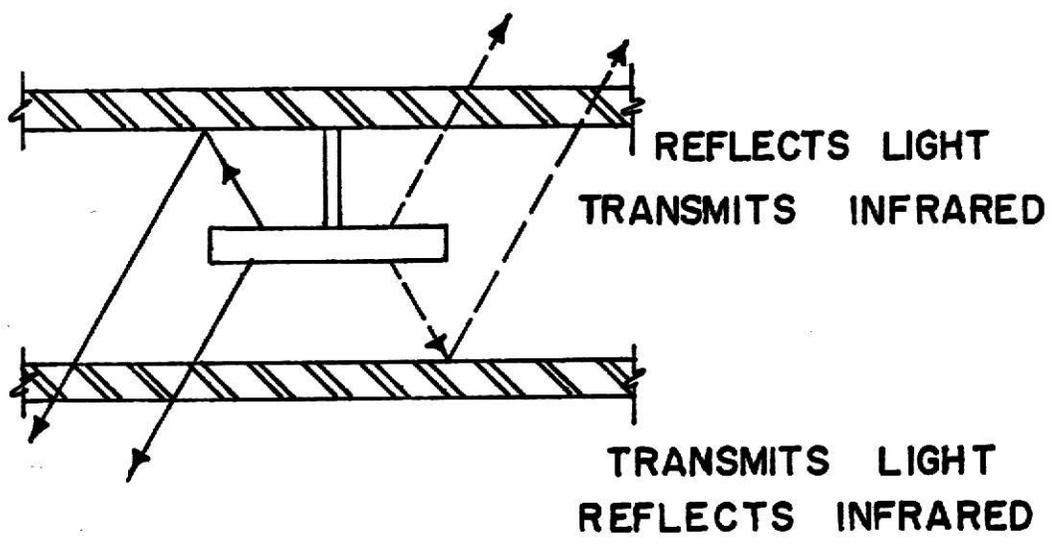
METHODS OF CONTROLLING THE LIGHTING HEAT

It will be shown here how lighting heat is distributed and how it can be controlled. The materials which can be used to transfer the lighting heat are gases, liquids and solids. The fluids which have been commonly used are air and water. Some of the possible methods of using them will be discussed here. In addition, filters can be used to control the heat. Figure 2 shows a sketch of a possible filter. It reflects visible light from the upper filter and transmits it through the lower filter and thus enables the light to reach the occupied space. Also, it transmits the infrared heat through the upper filter and reflects it from the lower filter and prevents it from entering the occupied space.

Methods Using Air As The Heat Transfer Medium

(1) Suspended Mounting

As shown in Figure 3A, the luminaire is suspended from the ceiling and its heat is removed by passing an airstream over it. The heated air is returned through the upper part of the ceiling where it carries off much of the heat and prevents it from entering the occupied space. This type of mounting results in a lighting distribution classified as Semi-Direct, where the distribution of lighting energy is about equal in upward and downward directions (20). About 40% of the total energy is removed by convection currents and the remaining is radiated. In this type of mounting, most of the energy will remain in the space.



PRINCIPLE OF A FILTER

Figure 2. Use of A Filter To Separate Light And Infrared.

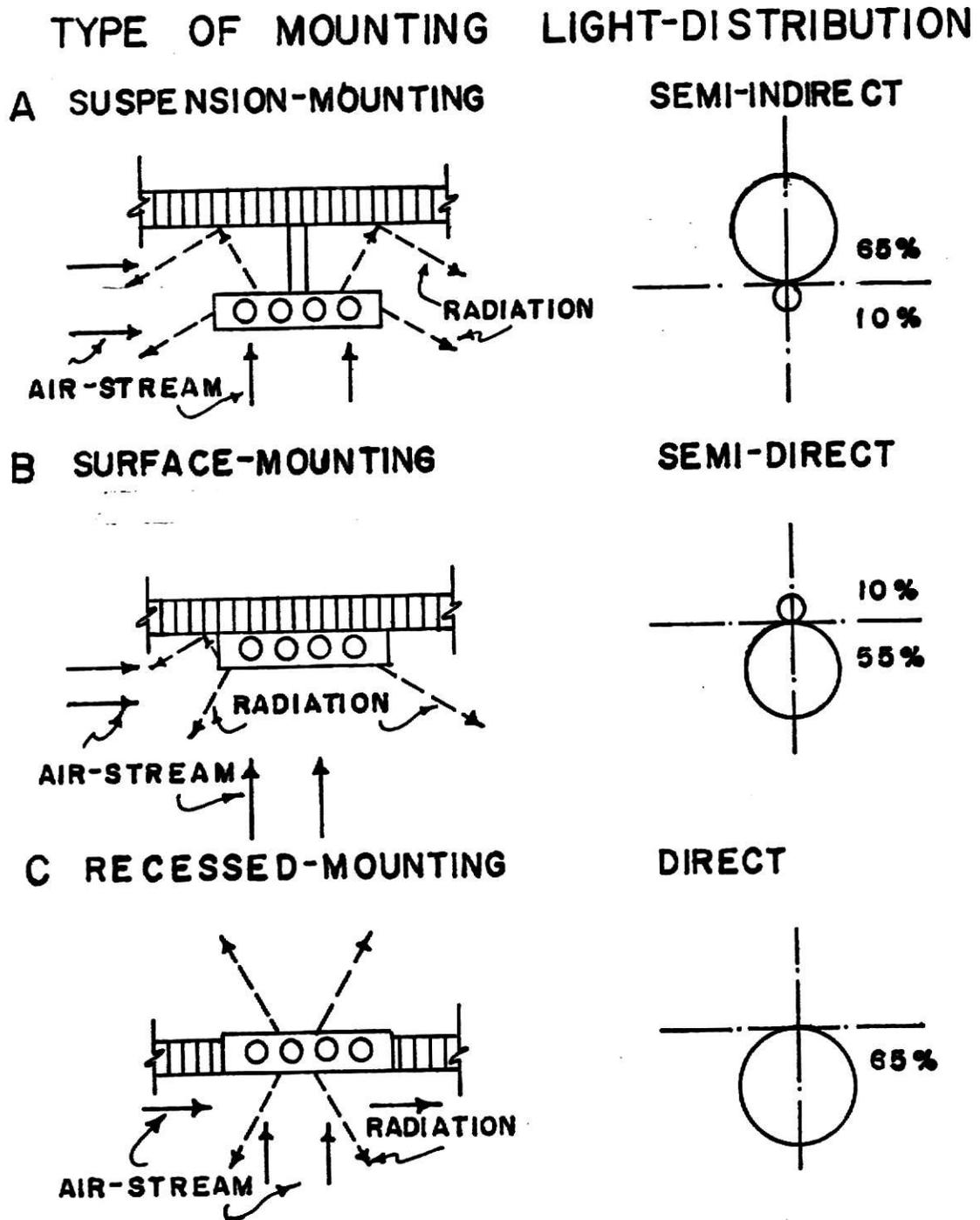


Figure 3. Use of Air For Controlling The Lighting Heat.

(2) Surface Mounting

As illustrated in Figure 3, the luminaire is mounted on the ceiling surface. It is essential here also to have the air return openings located in the ceiling to enable air to pick up most of the lighting heat. The illumination is classified as Semi-Direct where the distribution is predominantly downward (60%-90%) but a small component of light illuminates the ceiling and upper part of the walls. The heat transfer from the luminaire to the ceiling is mostly by the conduction process which depends upon the materials used for the construction of the luminaire and the ceiling. Generally, acoustical materials are used for the ceiling construction and they are poor conductors of heat. Thus, the heat will remain confined to the luminaire and it will reradiate and convect the heat to the room at a higher rate.

(3) Recessed Mounting

The luminaire is mounted as shown in Figure 3C. Air flows directly over the luminaires and more heat is removed due to better heat transfer between the luminaire and the air stream. The heated air is returned directly to the plenum. This type of mounting results in Direct lighting distribution. In this system, most of the heat is distributed upwards and less goes to the space.

Methods Using Water As The Heat Transfer Medium

(1) Suspended Mounting (Radiant Panel Ceiling)

In this type of mounting, a substantial part of the lighting heat is directed upward and is absorbed by the ceiling surface and in turn, by the circulating water in tubes (Figure 4A). The type of illumination is

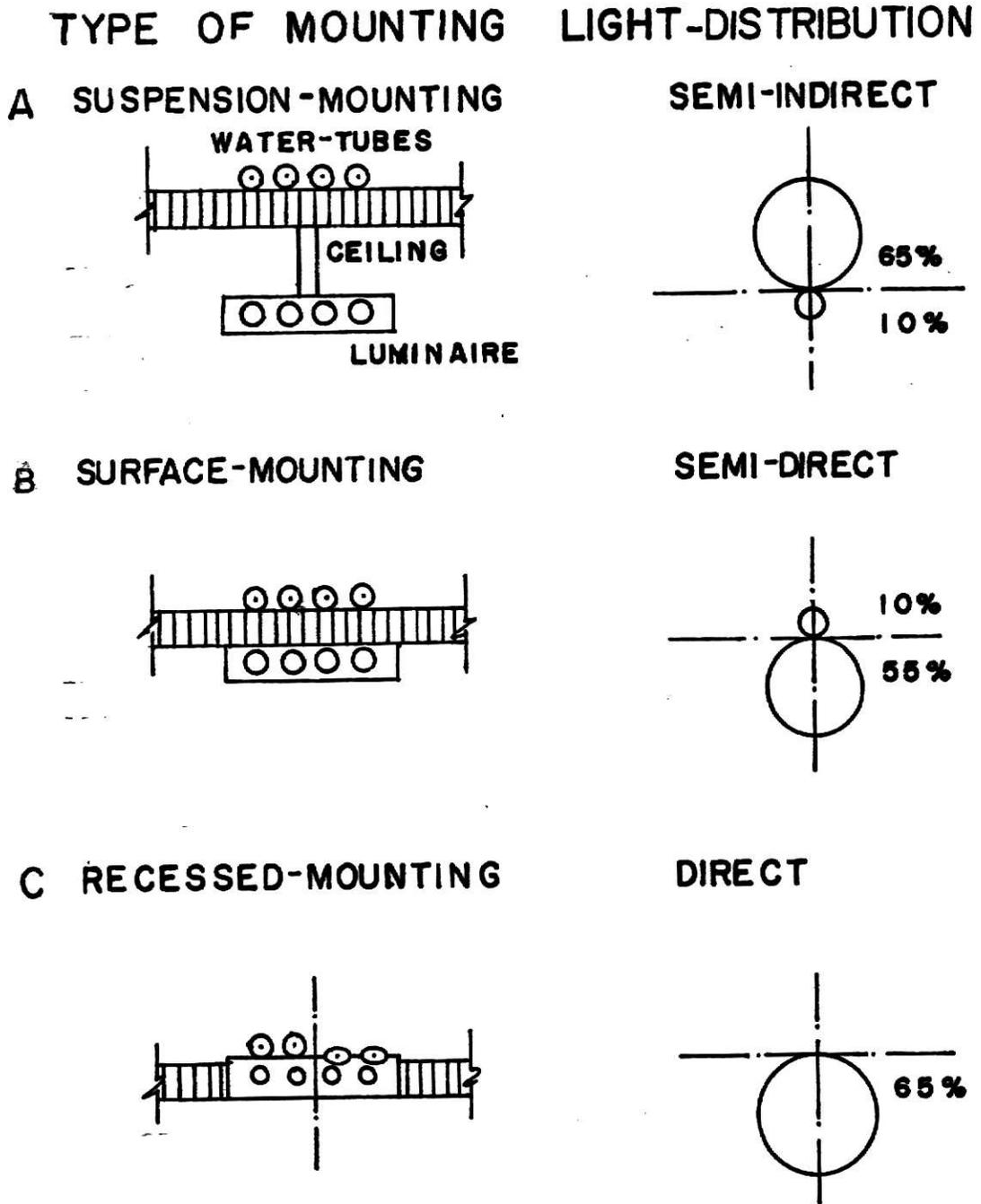


Figure 4. Use of Water For Controlling The Lighting Heat.

Semi-Indirect and is already referred to in the air-cooled system.

(2) Surface Mounting

Figure 4B shows the luminaire mounted on the ceiling surface giving Semi-Direct type of illumination. Most of the heat is conducted from the luminaire to the ceiling pans and into the circulating water. The heat transfer will be enhanced by using the materials of good conductivity for the luminaires and the ceiling.

(3) Recessed Mounting

As shown in Figure 4C, the water pipes are mechanically attached to the luminaire. There are two possible ways of producing a path for the circulating water. As shown in the left part of Figure 4C, the pipes are mechanically attached to the luminaire. At right, the housing of the luminaire is made of sheet metal having a hollow section which provides a path for circulating water. The illumination is of Direct type.

Method Using Heat Transfer By Both Air and Water

This method combines a water-cooled system with an air-cooled system. Figure 5 shows a possible system arrangement (1). Important elements of the system are: 1) a mixing box, 2) a water-cooled and air-cooled luminaire, 3) an evaporative cooler, 4) heat and air-conditioning unit.

The mixing box provides a constant volume of air to the space. It has one primary inlet which supplies make-up air for ventilation from the central plant. There are two secondary inlets and dampers to permit secondary air to enter through either one or both of these inlets. One of the two inlets is connected directly to the conditioned space and the other to the plenum.

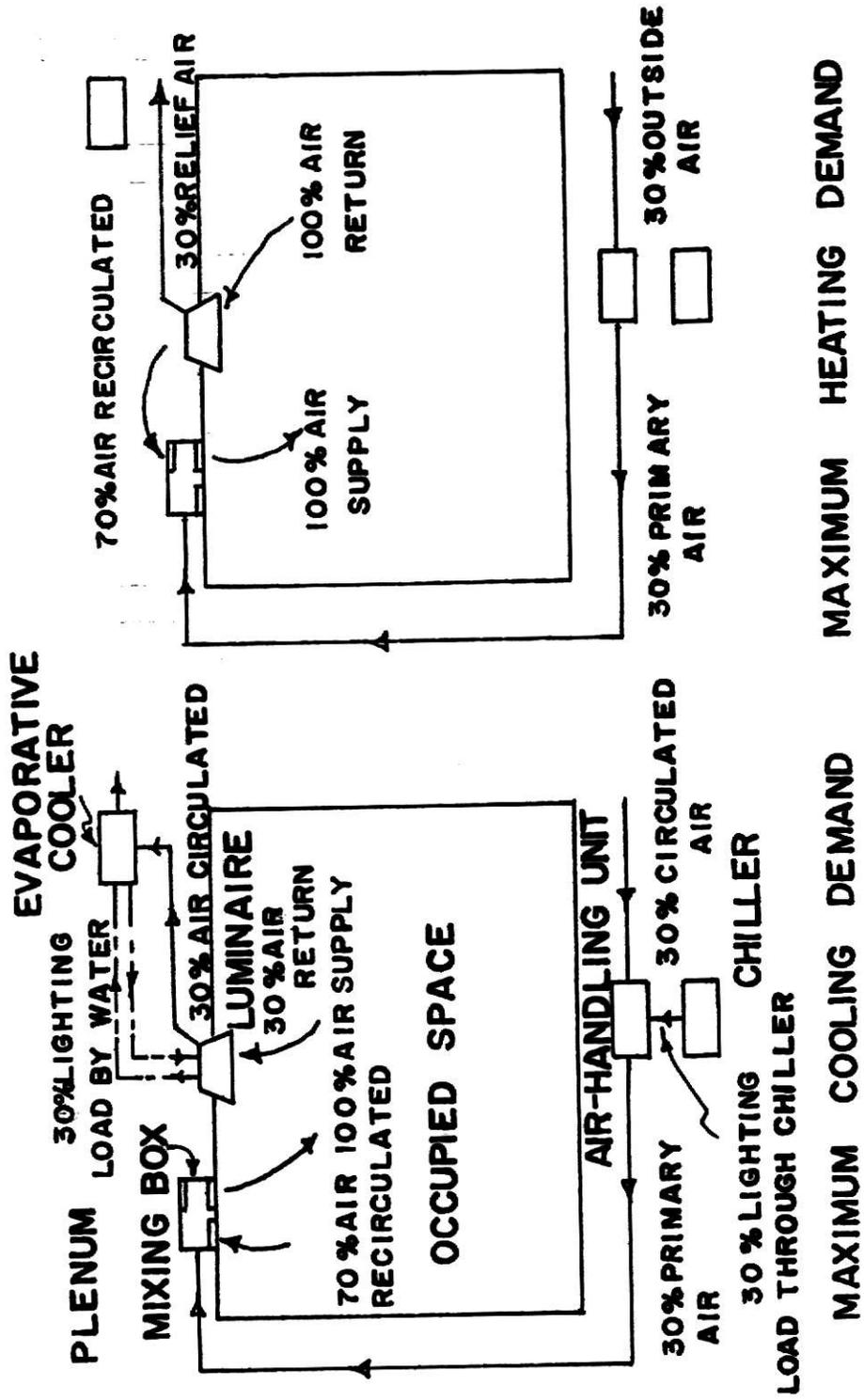


Figure 5. A System Using Both Air And Water.

The luminaire is designed to transfer the lighting heat with either water or air. During the maximum cooling demand the lighting heat is collected with water and exhausted through the evaporative cooler. The primary air provides cooling for the remaining lighting heat (30%-40%) as well as for other causes of air-conditioning such as people, solar heat gain etc. During the maximum heating cycle, water flow to the luminaires is stopped and the lighting heat is collected by passing the return air from the space through the luminaire to the plenum. The secondary dampers will operate to mix the heated air with the primary air. Intermediate damper positions can provide several temperatures depending upon the space demand.

Several possible methods of controlling the lighting heat have so far been discussed but only two of the methods will be discussed in detail and compared at the end. Both of these systems have the recessed type of lighting distribution. One utilizes air while the other utilizes water for controlling the heat. The results of two field studies employing their actual application are included at the end of each section.

CHAPTER IV

SYSTEM UTILIZING WATER AS HEAT TRANSFER MEDIUM

The Concept

The system discussed here is comprised of the following main components.

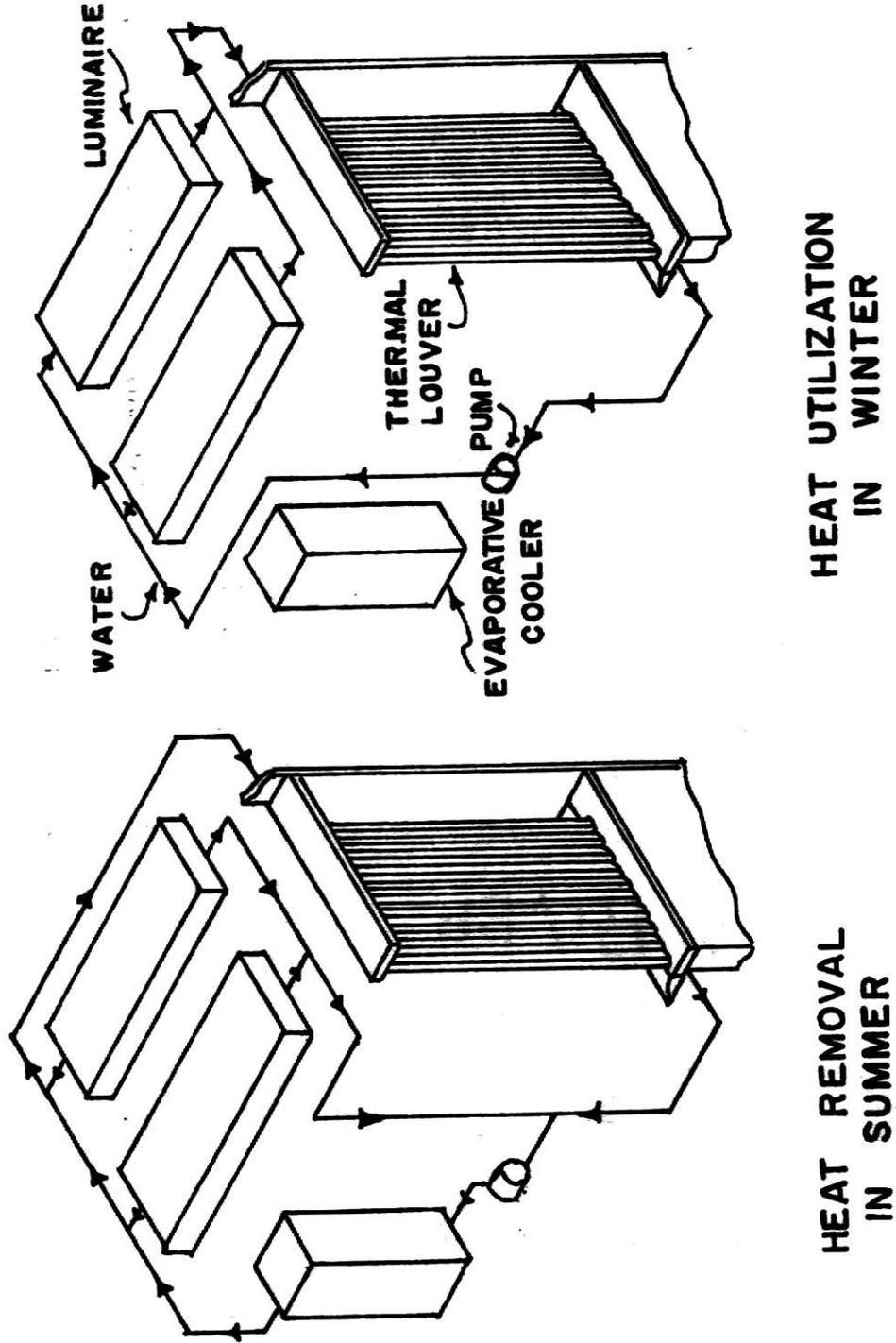
- 1) Water-cooled luminaires,
- 2) Water cooled louvers at windows,
- 3) An evaporative cooler,
- 4) A circulating water system connecting these elements and control valves.

The thermal louvers are designed in the form of inside, vertical venetian blinds through which water is circulated. Their function is to reduce solar load beyond that provided by the conventional shading devices.

During summer conditions, the lighting heat captured in the luminaires and the solar heat intercepted by the thermal louvers is removed from the space by circulating water and dissipated through the evaporative cooler. During winter conditions, the available heat from the luminaires is transferred directly to the louvers by the circulating water. Though the heat transfer process is accomplished by circulating water, air is still necessary for ventilation and humidity control. Figure 6 shows the sketch of such a system (1).

Water-cooled Luminaires

The amount of heat energy that can be recovered by the circulating



HEAT UTILIZATION
IN WINTER

HEAT REMOVAL
IN SUMMER

Figure 6. Concept of Energy Integration Using Luminaires And Louvers.

water depends upon the amount of heat generated by the lamp and the amount of heat intercepted by the luminaire housing. When the lamp is activated by electric current, the temperature of the outer surface of the lamp reaches 110° to 140° F., depending upon the type of lamp. The amount of heat captured by the housing depends upon the reflectance of the material used for the construction of the housing. In conventional systems most of this heat goes out into the space. By circulating water inside tubes encircling the housing, it is found that at water temperatures of 77° to 85° F., 70% of the radiant heat could be captured (1). The housing was kept relatively cool (77° to 80° F.) as most of the infrared energy is absorbed by the circulating water and this is the reason why the system is able to attain high heat recovery efficiency. Figure 7 shows the curves of percentage recovery rates against different water flow rates (10). As seen, more heat can be recovered if the water flow rate is increased.

Water-Cooled Louvers

These louvers are similar in appearance to vertical venetian blinds (4). They were tested by the University of Florida with the help of the ASHRAE calorimeter (1). A 4' x 4' louver shaded window was established for the purpose of testing. The louvers, as was observed in the tests, act effectively as thermal barriers between outside and inside spaces. In summer, the circulating water inside these tubes obstruct the solar energy to the space and the intercepted heat is removed and dissipated through the evaporative cooler. In winter, warm circulating water keeps the windows warmer and minimizes heat loss from the heated occupied space.

Figure 8 shows thermal performance at the windows with or without

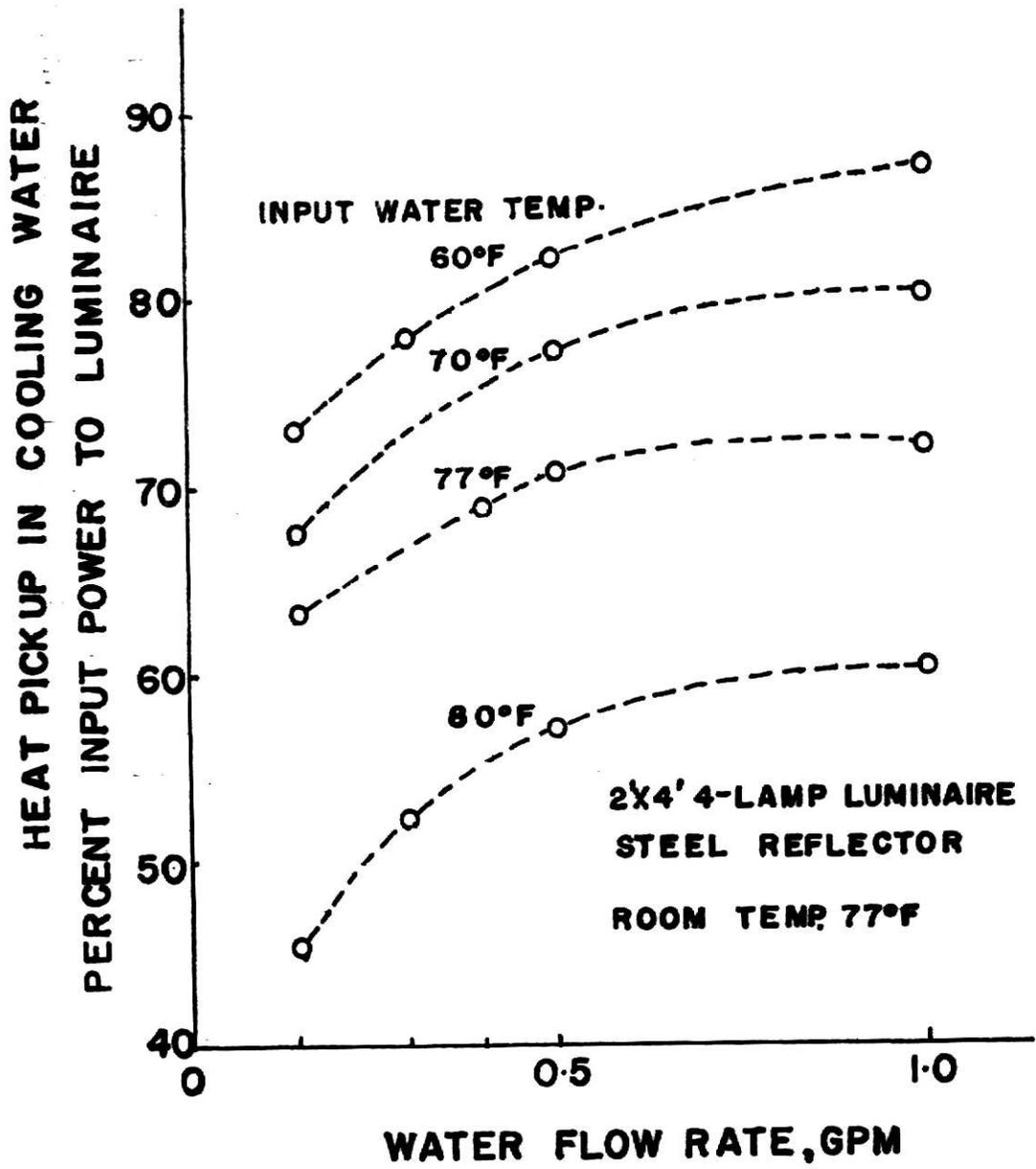


Figure 7. Thermal Performance Curves For Various Input Water Temperatures.

circulating water inside the louvers. Figure 8A shows the curves for a clear glass with no water circulating. As expected, the percentage of space load increases with increases in the outside temperature. With water circulating in the louvers, most of the solar load is removed by water and the space load is reduced considerably and the heat load to the louvers is increased. These results are shown in the Figure 8B. Figure 8C is for grey glass used at the windows. With grey glass used at the windows, the amount of reflected energy is much lower and there is a higher delivery to the outside through convection and radiation. This is due to the heat absorbing characteristics of the grey glass. As seen in Figure 8A, at 95° F. outside temperature, the solar load that enters the space is 65% of the total load and about 32% is reflected outside with circulating water, only 12% enters the space and 53% of the load is absorbed by water.

Calculating Shading Coefficient And Solar Heat Gains

The following calculations of heat gain will show the effectiveness of the louvers compared with the venetian blinds. As will be shown, the total space gain with the louvers set on the window is about 26 Btuh, while it is about 125 Btuh when the venetian blinds are used.

The window under consideration faces West at 4 p.m. in a building at 40 degrees North latitude, outdoor air is 95° F. and indoor air is 80° F. and the window has clear glass. From Table 14, Chapter 27 of the 1965 ASHRAE Guide and Data Book, the solar heat gain factor is 181 Btu/(hr.) (sq. ft.). With the louvers set at 20 degrees, as seen from the Figure 8B, the heat gain in space is 10.5% at 80° F. The transmission coefficient for regular glass is 0.86 and the shading coefficient is 0.105/0.86, or 0.12. The solar heat gain factor is $181 \times 0.12 = 22$ Btu/(hr.) (sq. ft.) (F deg).

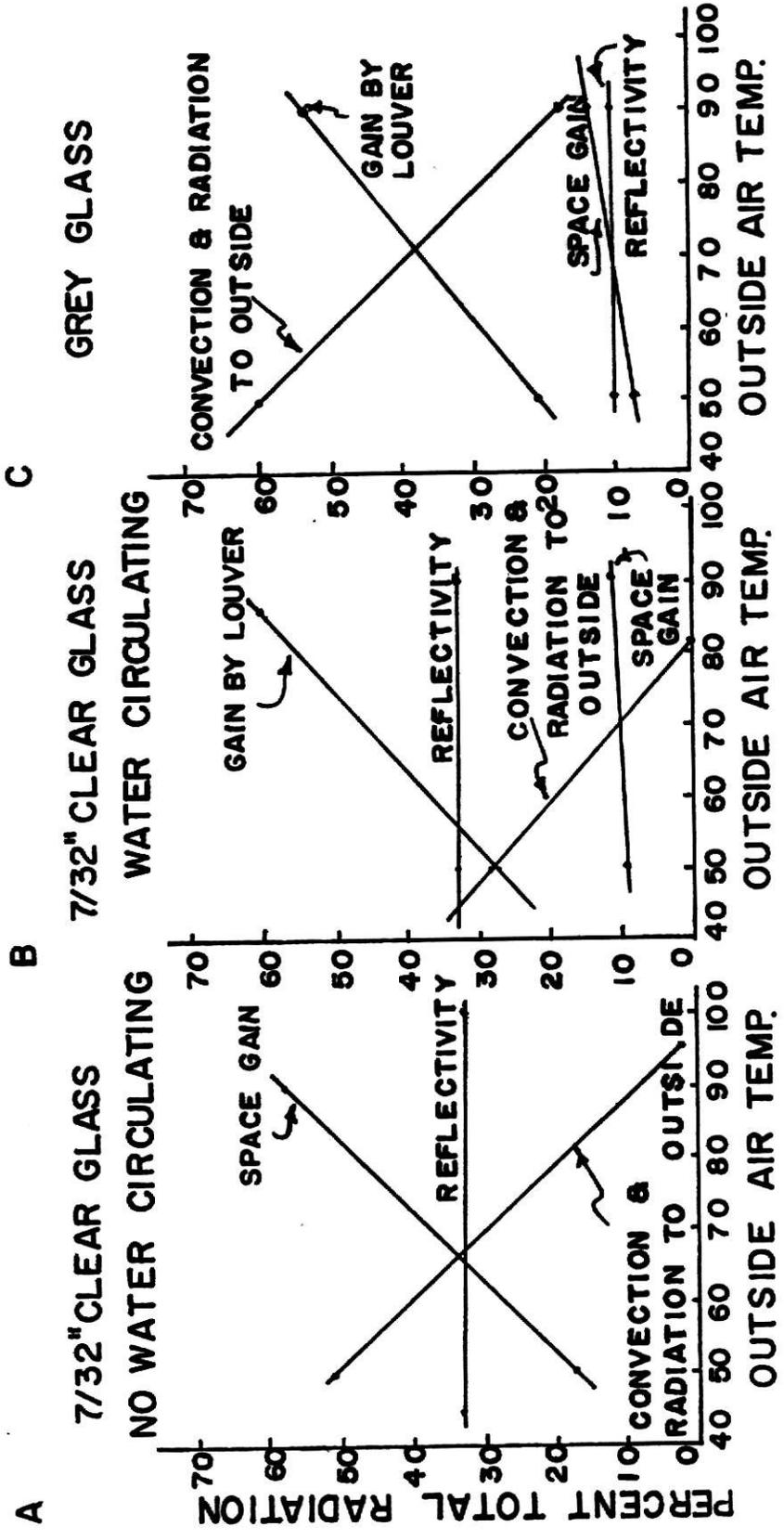


Figure 8. Comparison of Thermal Louvers And Conventional Shading Devices.

The space heat gain due to air-to-air temperature differential is 25% of the transmission load, or $0.25 \times 15 \text{ F. temperature difference} \times 1.06 \text{ Btu}/(\text{hr.}) (\text{sq. ft.}) (\text{F. deg.}) = 3.97$ or 4 Btuh. Total space heat gain is $22 + 4 = 26$ Btuh.

For the regular venetian blinds, the shading coefficient is 60% and the transmission coefficient is 100%. Therefore, the solar heat gain factor for the same window would be $0.6 \times 181 = 108.6$ Btuh, and the transmission load would be $15 \text{ F} \times 1.06 \text{ Btu}/(\text{hr.}) (\text{sq. ft.}) (\text{F. deg.}) = 15.90$ Btuh. The total heat gain would be $108.6 + 15.9 = 124.5$ or 125 Btuh.

Choice of Materials For Water Tubes

The criteria for selection of the material for the construction of water tubes for the luminaires would be as follows:

- 1) High heat transfer efficiency should be achieved,
- 2) The material should be least expensive and simple from the fabrication point of view,
- 3) The material should be corrosion resistant,
- 4) It should be light weight, strong and rigid,
- 5) The interfaces with electrical and plumbing systems should be considered.

Copper, aluminum and steel are the possible metals for the tubes (10). All-steel construction is strong but some corrosion preventive chemicals must be added for water treatment. All aluminum systems should not have copper anywhere in the system to avoid corrosion. Steel with copper should exclude air in the water circuit, as it helps corrosion.

Considering all other combinations, it is found that they require a high concentration of chemicals to prevent corrosion (10). All-steel construction should be chosen due to low cost but the water should not contain large quantities of chlorides and oxygen.

Figure 9A and 9B show that water passing through the tubes must be in good contact with the lamp in order to transfer the maximum of heat. The heat pick up efficiency as a percentage of heat recovery to the energy input to the lamp is greater if the water tubes surround the lamp from all sides.

Figure 9C shows that the temperature rise in the circulating water decreases with the increase in the temperature of entering water. This is an important consideration when arrangement between series and parallel types is to be decided. In the series type, the water from one unit becomes the input to the next. Thus, the subsequent temperature rise places an upper limit on the number of luminaires that can be placed in one circuit without losing the heat pickup efficiency in the subsequent luminaires.

Configuration of Water Channel

The geometry of the water channel is an important aspect in ensuring proper water flow with high efficiency and low pressure drop. An elliptical section was found better for the purpose and a curve for the pressure rise with the increase in the water flow rate is shown in Figure 9D (10). It is clear that the rate should be kept to a minimum in order to avoid excessive pressure drops.

Series or Parallel Arrangement

It was found for the tube shape, a flow rate of $\frac{1}{2}$ gpm would result in Reynold's number giving an optimum heat transfer (10). The table shown on the next page shows a comparison between the series and parallel arrangements (10).

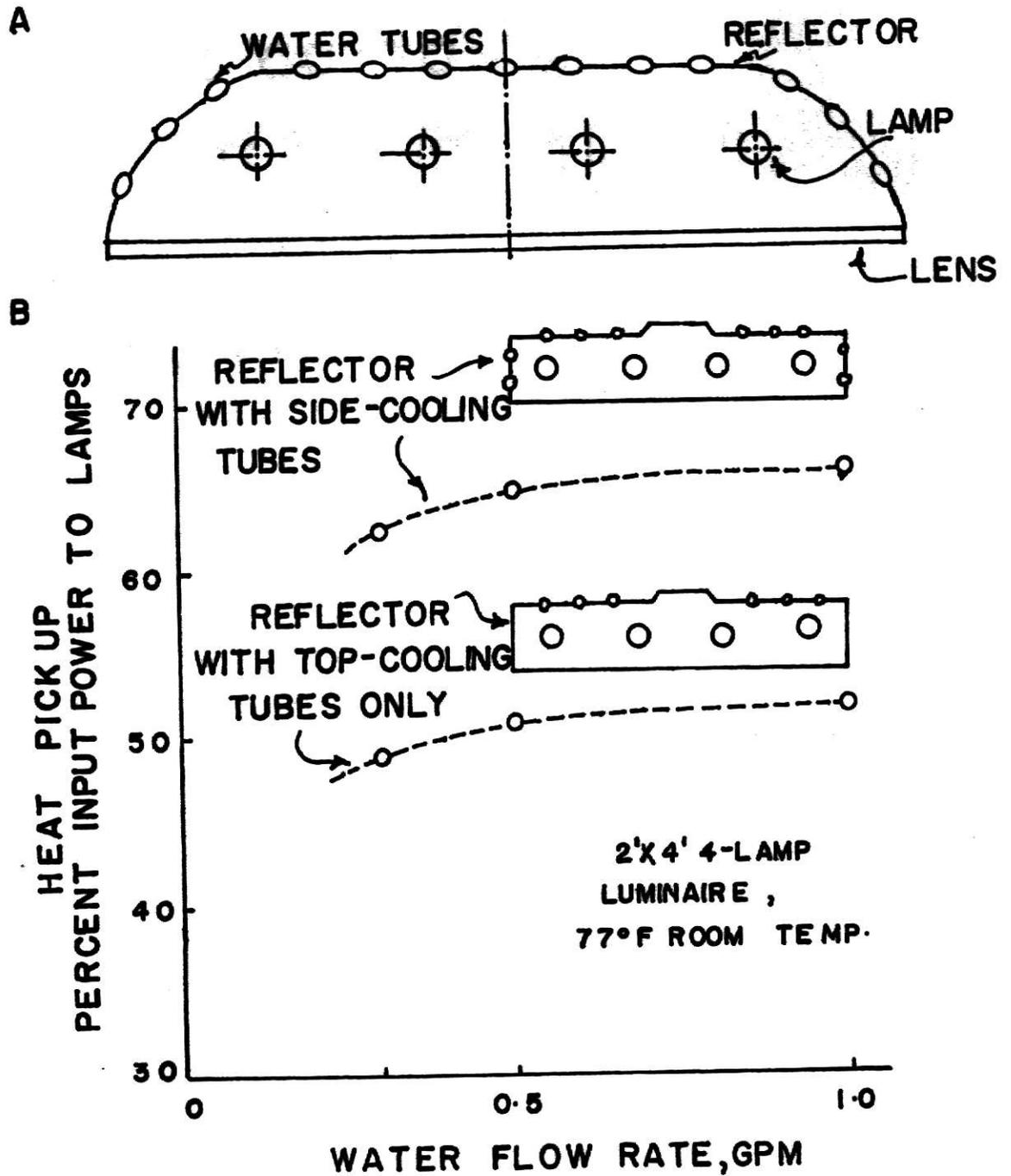


Figure 9(A). A Model of Water-Cooled Luminaire.

(B). Effect of Tube-Placement On Heat Pick Up Rate.

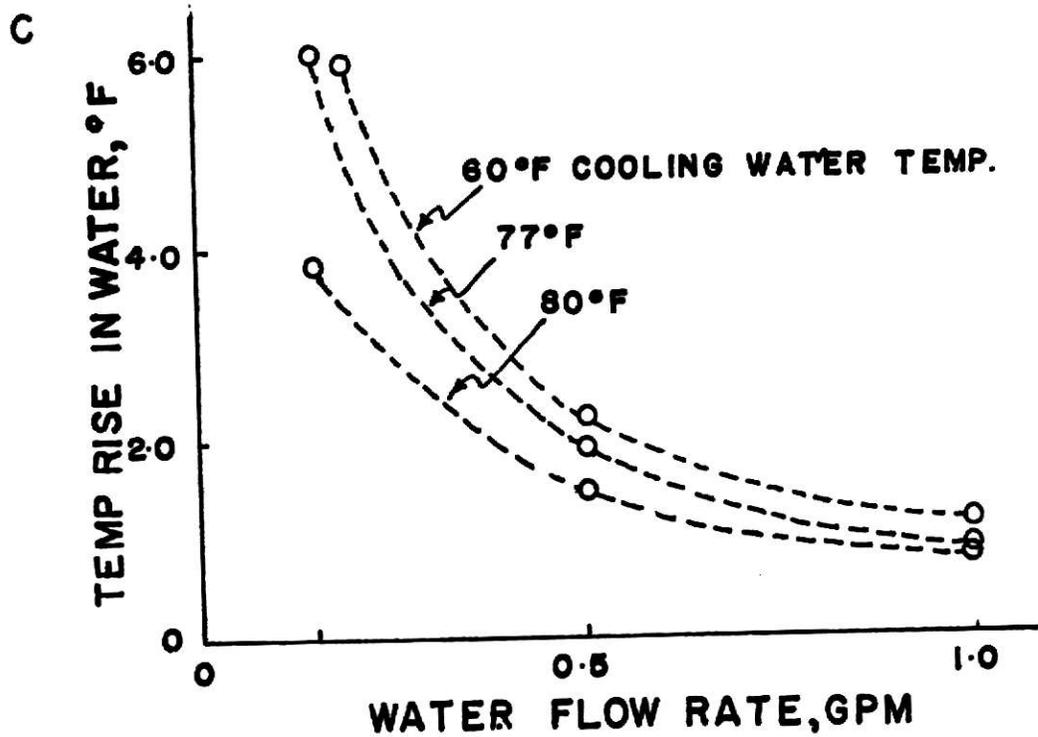


Figure 9(C). Temperature Rise For Various Temperatures.
2' X 4', 4-LAMP LUMINAIRE, 77° ROOM TEMP.

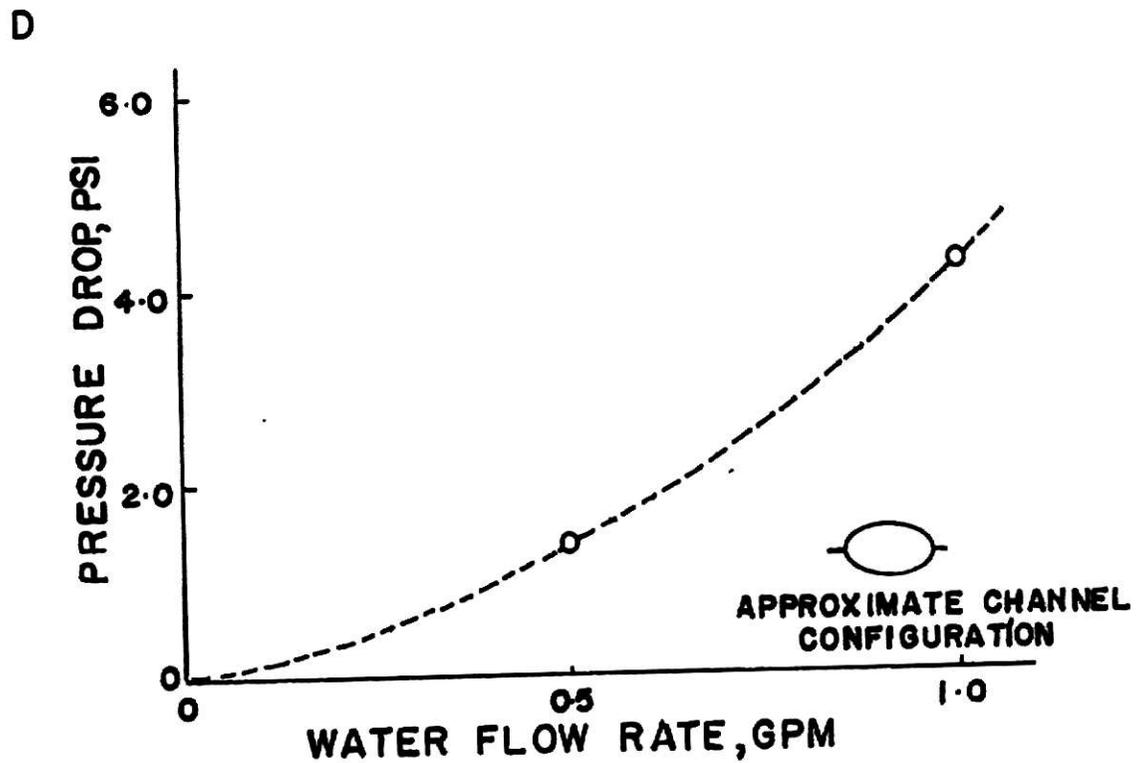


Figure 9(D). Pressure Drops At Various Flow Rates.

TABLE 3

Comparison Between Series and Parallel Arrangements.

<u>Type of Luminaire Circuit</u>	<u>Series</u>	<u>Parallel</u>
Flow rate/luminaire	0.5 gpm	1 gpm
Pressure Drop/luminaire	1.4 psi	1.2 psi
Temperature rise/luminaire	1.8° F.	0.75° F.

Parallel flow has the advantage of the lower pressure drop and the lower temperature rise, but it has other disadvantages. A greater rate means that more pump horsepower is required and it is difficult to bleed air out of the circuit or to check the proper flow through the luminaire. It is easy to bleed air out of the series circuit. An initial fill is made and a pumping rate of 5 gpm is sufficient to drive air out of the circuit. This scheme, however, cannot be used in the parallel flow, since air can remain in one tube while water by-passes it. This would result in reducing the heat pick up efficiency and increased corrosion problems due to the entrapped air. Also, it is not practical to establish an air-bleed device at each unit. A series path is therefore preferred.

Effect of Shielding by Lenses

Lenses can play an important role in the overall efficiency of the luminaire as seen from Figure 10A. The heat pick up efficiency is considerably reduced by removing the lens and exposing the luminaire to the space. Figure 10B shows the effect of the water inlet temperature on average rise in temperature of the lens. The lens will remain relatively cool if the inlet temperature is decreased without reducing the water flow rate below 0.5 gpm.

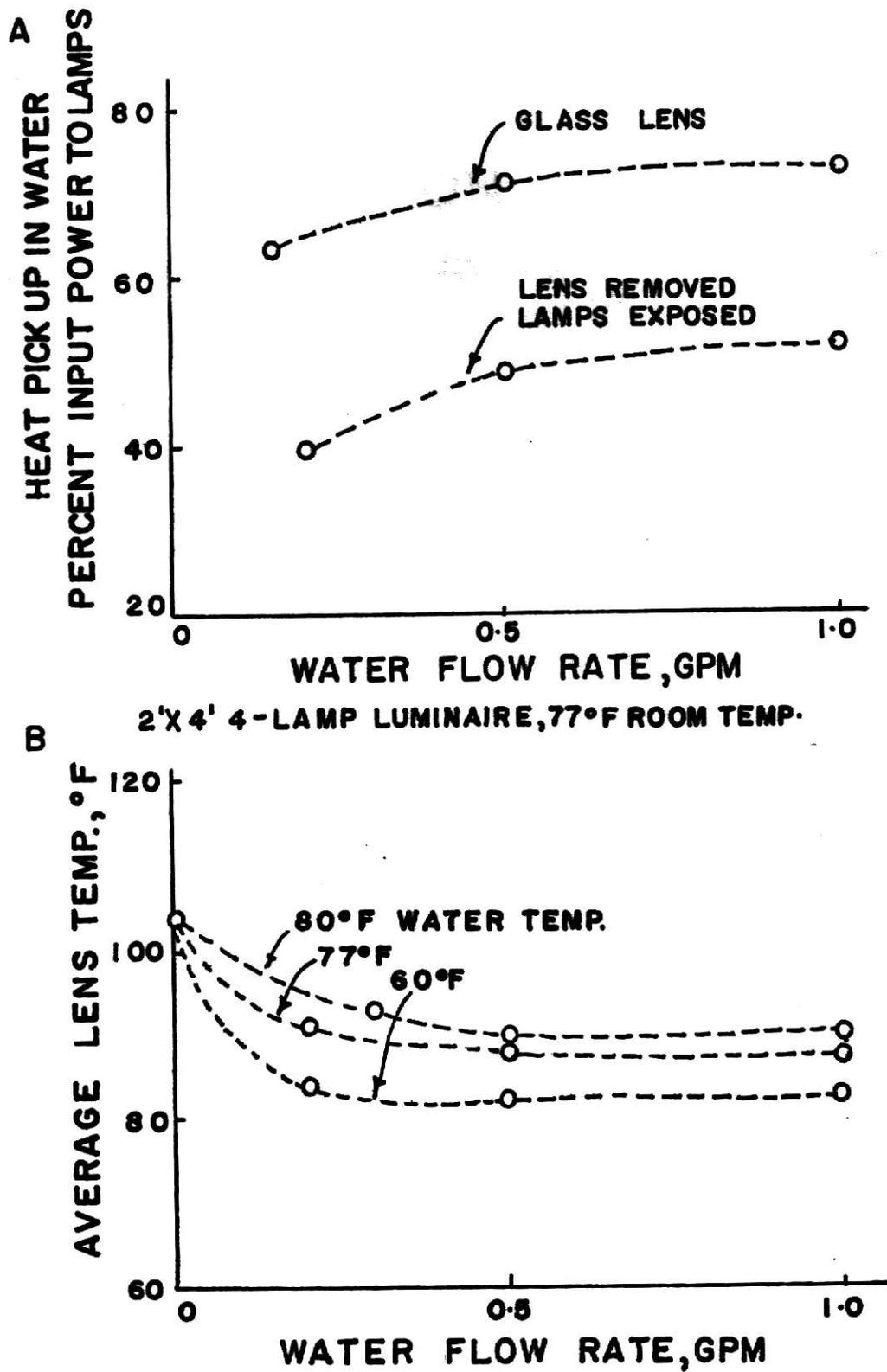


Figure 10(A). Thermal Performance With Or Without Lens.

(B). Temperature Variation of Lens For Various Water Temperatures.

A FIELD STUDY OF A WATER-COOLED SYSTEM

The analysis was made for a 120' x 120' building between (13):

- 1) A conventional perimeter induction system using glass with venetian blinds.
- 2) The same system utilizing the water-cooled louvers at the perimeter and the water-cooled luminaires.

Building Data

The building under consideration was a square building of 120' x 120'. It had thirteen floors and a continuous glass of 10' height on each floor with 15,600 sq. ft. of total glass for exposure. The perimeter setback was 12', the core area was 2,240 sq. ft., the perimeter area was 5,180 sq. ft., and the interior area for each floor was 5,160 sq. ft. (6,976 sq. ft. when the corridors were considered). The occupancy was 100 sq. ft. per person, with the ventilation of 0.4 cfm per sq. ft. and the electrical load was 6 watts per sq. ft. The building faced all four directions and the location was 40 degrees North latitude. The maximum summer design temperature was 95°F. ASHRAE Guide and Data book was used for all calculations except for the shading coefficient of the thermal louvers which was already shown to be 0.12 (13).

The quantities given in the next section are figures in tons and bhps but still they show the relation with the cost figures. The central plant refrigeration requirements include just the cost for the plant only and the other cost values for duct work, fans, supply and return registers etc are included under air-distribution requirements.

TABLE 4

Shading CoefficientsAll Design Values Are At August 21, 3 p.m.

	<u>Glass in Sun</u>	<u>Glass in Shade</u>
Regular plate glass and venetian blinds	0.55	0.60
Regular plate glass and thermal louvers	0.12	0.12

TABLE 5

Central Plant Refrigerating Requirements

	<u>Conventional System</u> (tons)	<u>Integrated System</u> (tons)
Solar (perimeter)	321	109
Lighting (perimeter)	115	40
Lighting (interior)	155	55
Occupancy (perimeter)	22	22
Occupancy (interior)	22	22
Ventilation (perimeter)	90	90
Ventilation (interior)	<u>90</u>	<u>90</u>
	815	428

TABLE 6

Air Distribution Requirements

	<u>Conventional System</u> (tons)	<u>Integrated System</u> (tons)
Solar (perimeter)	536	157
Lighting (perimeter)	115	40
Lighting (interior)	155	55
Occupancy (perimeter)	22	22
Occupancy (interior)	22	22
Ventilation (perimeter)	90	90
Ventilation (interior)	<u>90</u>	<u>90</u>
	1,030	476

Summary

- 1) Savings on the central plant requirement: 327 tons
- 2) Savings on the air distribution system : 554 tons

TABLE 7

Comparison of System bhp

	<u>Conventional System</u> (bhps)	<u>Integrated System</u> (bhps)
Refrigeration machines	776	402
Fans	316	166
Pumps	<u>141</u>	<u>141</u>
	1,223	709

Thus, the savings in bhps and the subsequent operating costs of the system is 514 bhp or 42%.

Advantages of the Integrated System

The quantitative figures given here are obtained after the actual analysis discussed earlier.

- 1) Removal of thermal load with water. This amounts to 50% reduction in air handling, duct work and refrigerating capacity with 60%-70% lighting input and 88% solar energy removed by water.
- 2) Glass areas and illumination levels can be increased without penalizing the air-conditioning system.
- 3) First cost saving of \$1.25 to \$2.50/sq. ft. of the floor area depending upon the lighting levels and glass areas.
- 4) Saving of \$0.75/sq. ft. with the duct work and the supply and return grilles.
- 5) Saving of \$0.50/sq. ft. with the air handling apparatus.
- 6) Annual operating cost saving of 30%-50%.
- 7) Saving of 5% in the building volume and 50% in space usually allotted for the mechanical equipment.
- 8) Improved lighting because most of the radiant heat is removed.
- 9) Reduction in floor to floor height.
- 10) Simultaneous heating and cooling in different parts of the same building can be achieved.

CHAPTER V

SYSTEM UTILIZING AIR AS THE HEAT TRANSFER MEDIUM

The Concept

The basic components of the system are:

- 1) A luminaire through which return air passes, extracting the lighting heat.
- 2) An air-induction unit.
- 3) Supply of primary air through the central fan system.
- 4) Return air system.

These basic components are shown in Figure 11 where the boundary between interior and exterior zones is arbitrary.

The function of the induction unit is to provide a mixture of primary air and relatively warm air to the conditioned space. The unit contains damper assemblies actuating in response to a thermostat. One damper controls the amount of primary air and another damper controls the induced air from the plenum.

When no heat is required in the space, only the primary air is supplied through the induction unit and the lighting heat is removed by the return air and returned to the central plant as shown in the Figure 11. When the space demands heating, the induction unit induces varying amounts of the heated air from the plenum in place of primary air. The plenum air is relatively warm because it removes heat from the luminaires while returning to the plenum. Thus, the volume of air delivered to the space is constant, only the temperature is varied.

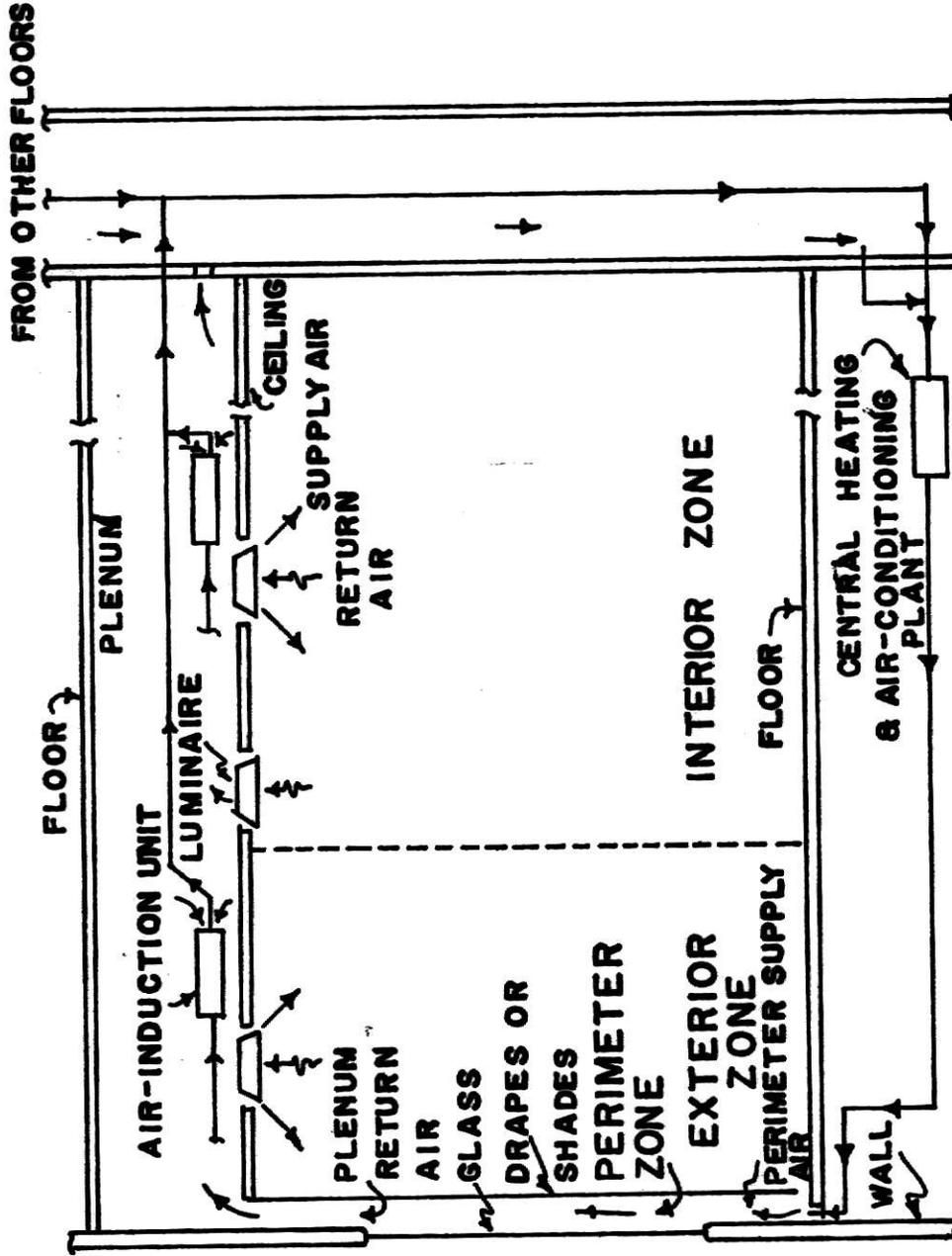


Figure 11. Air-Cooled System Using Perimeter Air Distribution.

In Figure 11, the space between outside glass and inside shading devices in the exterior zone is utilized for returning air from the central plant to the plenum. During winter conditions, heated air, which circulates through this area, offsets the heat loss at the glass. This system reduces a major load on the heating plant compared with the conventional system. During summer conditions, cool air distributed in the perimeter area will reduce the heat gain at the glass. Air quantities required for the operation will not normally exceed 10-12 cfm/lineal foot of the building perimeter (21).

A maximum of 25%-35% of the total solar load would be removed by air returning through the perimeter space and carried to the plenum. Another 25% of the solar load can be extracted by lowering the temperature of the perimeter air by cooling it before it enters the space between glass and the shading devices. To accomplish the purpose of reducing the solar load effectively, it would require a discharge velocity of 600-800 fpm for a ceiling height of 9-10 feet (21).

Figure 12 shows the performance of the system as the outdoor temperature varies from -20° F. to 100° F. The negative slope of the curve illustrates the working of the system at varying outdoor temperatures, ranging from -20° F. experienced during winter conditions to 100° F. experienced during summer conditions. The performance of the system at different outside temperatures can be divided into three main parts. For an outdoor temperature range of -20° F. to 40° F., the heat of the lamps would not be sufficient to offset the heat loss and as shown, and the system would require additional auxiliary heat. For a temperature range of 40° F. to 75° F., the heat of the luminaires will be sufficient to reduce the space heat loss. After the outdoor temperature crosses 75° F. temperature, no

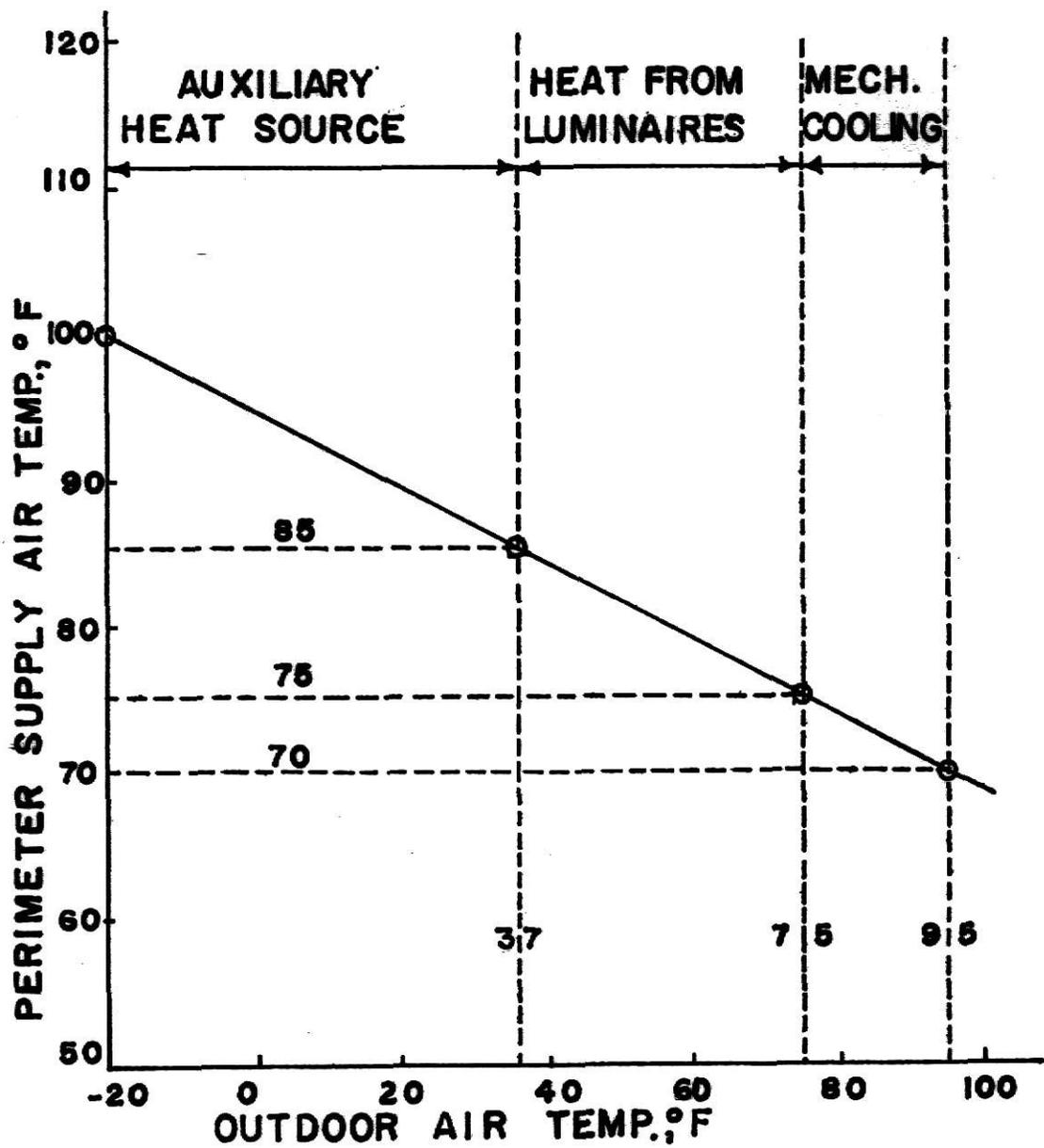


Figure 12 . Performance of Air-Cooled System At Various Outdoor Temperatures.

lighting heat is required and the system will call for mechanical cooling of the primary air before it enters the perimeter area.

The Luminaires

Recessed lights are used and troffers are of the sizes, 1' x 4', 2' x 4', 2' x 2', or 3' x 3'. The return air from the conditioned space is exhausted through the luminaires and while going through them, it picks up most of the lighting heat. Part of the heat is recovered by conduction and convection heat transfer from the luminaires to the ceiling plenum and a part is recovered by the return air. But all the received heat does not reach the central plant, as some percentage of the heat finds its way back to the space through the ceiling and air ducts. This heat must be accounted for as heat gain to the space and used in the air-conditioning calculations.

Air-Conditioning Calculations

Most of the calculations would be conventional. A major exception will be that all the lighting heat is not a space load. There is a heat flow from the ceiling to the space if the ceiling is at a higher temperature than the space. There is also a heat flow from the ducts depending upon their insulation. These heat flows will depend upon the respective temperatures at various levels in the ceiling, the space, and the ducts, and moreover they are interdependent. A trial and error method must be used to calculate these temperatures and a computer may save time in the calculations.

Air Induction Units

There are two basic types of air induction units. Some of the them provide control by simultaneously reducing primary air and increasing the

amount of heated air from the luminaires. The result is a constant volume of supply air to the space at variable temperatures. In the other type, the temperature of the supply air is kept constant and the volume is varied. The units used in the integrated system are constant volume types. They provide air of induction ratio of 0:1 to 0.5:1. This is the ratio of induced air from the plenum to the primary air. When the system demands full cooling, the primary air damper is at maximum open position and the induced air damper is fully closed. As a reduction in cooling is required, the induced air damper gradually opens and the primary air damper gradually closes.

The units are located above the suspended ceiling. If they are located over the interior zone, they are readily accessible for balancing and maintenance. Larger units should be located above areas where the ambient sound level is high. For example, the general office area should be preferred over the conference or private room.

The ability of the induction units to induce plenum air is dependent on the upstream static pressure and the downstream resistance. There will be large load fluctuations in the exterior areas and the inlet static pressure should be high enough to obtain the maximum induction. In the interior zone, the load fluctuations will be smaller and lower static pressures may be sufficient.

Design of the Ducts

The amount of primary air required for different areas of the building depends upon the orientation, the type of structure, etc. Therefore, the primary ducts should be sized according to the demand of the primary air in different areas. The static regain method will save some of the operating costs (21).

Fan Selection

In the integrated system, the volume of air handled by supply and return fans are not fixed. Thus, the fans must have a stable operation over a wide range of air volumes. This can be achieved if they have some kind of load regulating devices. The regulation can be accomplished by:

- 1) Inlet regulating vanes.
- 2) Variable speed devices.
- 3) Discharge dampers.

Figure 13 shows the performance characteristics for the inlet vane control (Figure 13A) and the variable speed control (Figure 13B). With the inlet vane type of fan, all the curves for various vane openings originate from a single point when there is no air flow. The static pressure decreases as the air flow is increased and as the vane openings are switched from a wide open position to a 50% open position.

With the variable speed type, the static pressures are different at different speeds when there is no air flow. There is comparatively small change in the static pressures over the load variations from no air flow to 100% air flow.

The inlet vane type is less expensive to operate and has almost the same efficiency as the fan with the variable speeds (21). On a small system using packaged air handling equipment, it may not be feasible to install the inlet vane type or the variable speed drive, so discharge dampers are provided at critical locations in the duct system to accomplish the changes in the air flow.

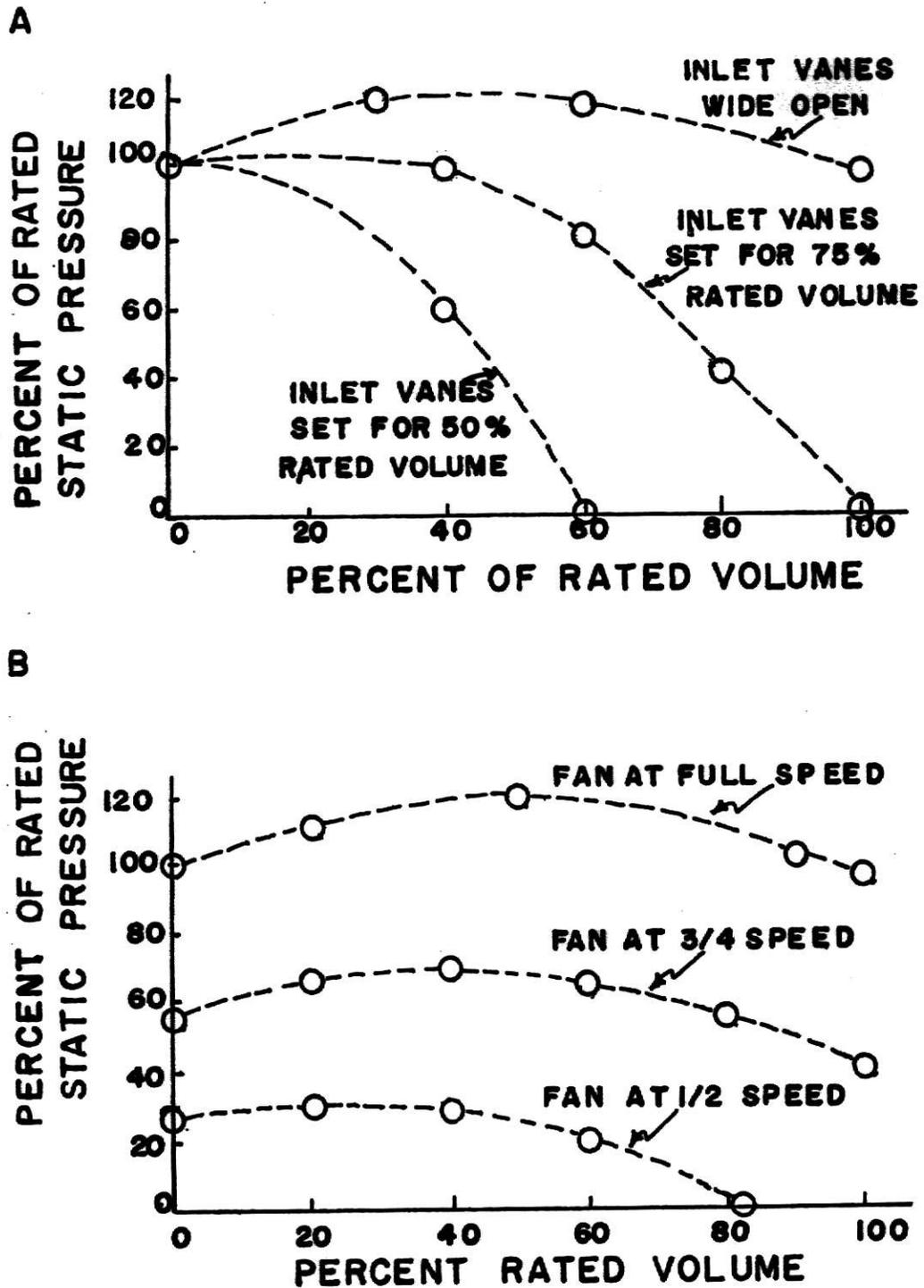


Figure 13 (A). Fan Curves For Inlet Vane Control.

(B). Fan Curves For Variable Speed Control.

A FIELD STUDY WITH THE AIR-COOLED SYSTEM

The building under consideration is an eighteen story office building in San Diego, California (6). At the time of designing, three systems were considered:

- System I: Original design using conventional luminaires of recessed type.
- System II: Heat transfer luminaires were used through which return air passes.
- System III: Same as II, except the lenses were coated with infrared reflecting materials to increase upward component of heat flow.

There were 352 luminaires with supply air of 65 cfm and return air 20 cfm per luminaire.

Lighting Design

System I

At the 150 foot-candle level the total heat gain for 352 luminaires will be $84 \text{ watts/luminaire} \times 352 \text{ luminaire} = 29.6 \text{ kw}$ or 100,900 Btuh. Total heat gain in the building from all the sources is 308,400 Btuh, so the lighting heat is 32.4% of the total load.

Systems II and III

The lighting heat gain was found to be 110,500 Btuh or 34% of the total load.

Figure 14 shows the theoretical heat distribution in the three systems

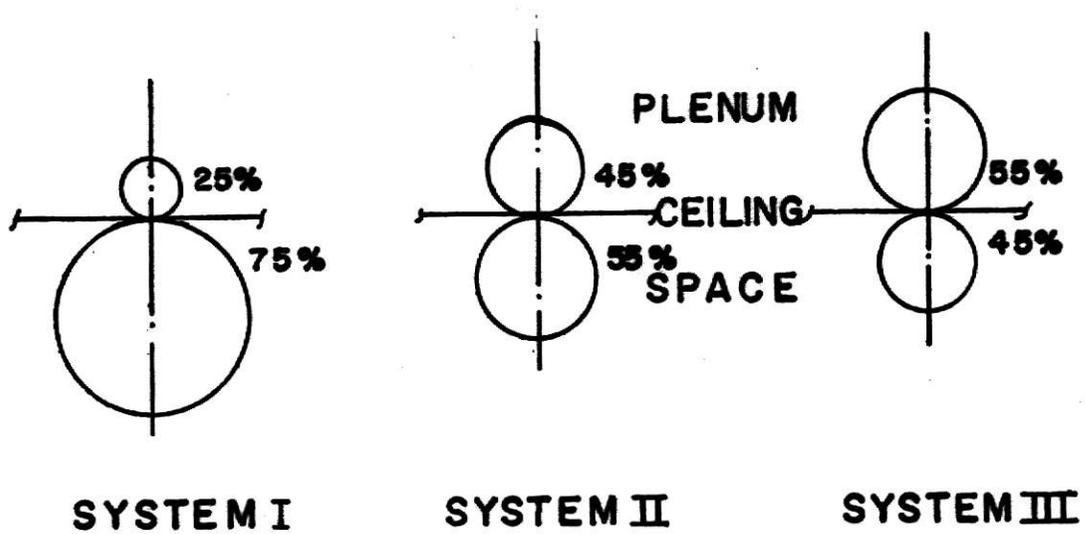


Figure 14. Theoretical Heat Distribution.

Economics of Lighting

The cost of installation was assumed to be equal in all the systems. The cost of luminaires with their air handling components is given in the following table.

TABLE 8

<u>Air Handling Fixture Cost</u>	<u>System I</u>	<u>System II</u>	<u>System III</u>
Owner cost	\$201,029	\$217,800	\$221,430
Added cost over System I	-----	16,771	20,401
Added cost over System II	-----	-----	3,630

Initial Costs of Air-Conditioning

The same size of ducts were kept in all the three systems. There would have been some savings in Systems II and III but the sizes were not changed to maintain lower static pressures, lower air velocities and less noise levels.

TABLE 9

Air-Conditioning Equipment Required

Description	I	Systems II	III	Difference of III and I	Percent of difference
1) Supply fan (cfm)	99,250	93,400	88,500	10,750	10.9
2) Motor hp	150	125	125	25	16.7
3) Return fan (cfm)	87,300	81,400	76,600	10,700	12.3
4) Motor hp	100	75	75	25	25.0
5) Cooling coils (8 rows) in sq. ft. at 550 fpm face velocity	181	170	161	20	11.1
6) Filters at 500 fpm face velocity	200	187	177	23	11.5
				Average %	14.6

TABLE 10
Cost of Air-Conditioning System Over System I

	I	Systems II	III
Supply fans	---	\$420.00	\$420.00
Return fans	---	367.00	367.00
Cooling coils	---	232.00	360.00
Filters	---	<u>97.00</u>	<u>160.00</u>
One fan system		\$1,116.00	\$1,307.00
Two fan system		\$2,232.00	\$2,614.00

Operating Costs of the System

Assuming equal maintenance costs for all three systems, the operating costs based on bhp are given in the following table.

TABLE 11
Operating Costs

	I	Systems II	III	Difference between III and I	Percent of the saving
Supply fans (bhp)	115	92	78		
Return fans (bhp)	63	50	40		
Total bhp/system	178	142	118	60	33.7%
Reduction over 1st	---	36	60		
Reduction/2 fans	---	72	120		
Equivalent kw		67.2	112.0		
$\frac{\text{bhp} \times 746}{\text{efficiency} \times 1,000}$					
$\frac{\text{bhp} \times 746}{0.8 \times 1,000}$					
Savings		\$5,420	\$9,040		
$\frac{\text{Hours}}{\text{Years}} \times \frac{\text{Cost}}{\text{kwh}} \times \text{kw}$					
$\frac{6670 \times \$0.0123}{\text{kwh}} \times \text{kw}$					
				Difference = \$3,630	

It is shown by Dunn, Gilleard, Schmidt (6) that the added cost due to the infrared reflecting lenses is \$3,630 and savings in the operating cost for one year happens to be \$3,630. It can be concluded that the savings will more or less balance the added cost in one year.

The added cost due to luminaires of the system III over system I is \$20,401. Due to reduced equipment cost, the savings would be \$2,614, leaving a balance of \$17,787. The savings in operating costs is \$9,040 and so the balance could be made in about two years.

Though these figures of costs might vary in different situations, they give a general picture of how system III could be economical in the long run compared with the conventional system.

CHAPTER VI

DISCUSSION

Discussion and Comparison

Different aspects of integrated systems have so far been discussed in relation to the water-cooled and the air-cooled methods of heat transfer. Both of these methods have many things in common. They are applicable in buildings where there are higher lighting levels and appreciable glass exposures. The systems considered in this report have recessed lighting, and lenses are recommended to increase the heat pickup efficiency of heat transfer. The field studies given at the end of each system show that significant savings are possible by using the integrated systems over the conventional one. Now, it is intended to compare them.

Development of the Efficient System

Various combinations of the luminaires were used to study the thermal performance of the water-cooled and the air-cooled system. The water-cooled system of heat transfer was found the most effective in obtaining the maximum energy utilization (11).

The earlier work in this field was done by C. S. Leopold and Spiegel. Most of their efforts of integration of heat transfer from luminaires involved lamps in an open space without shielding by a lens. A large percentage of the energy was flowing to the space where it was absorbed by people and objects and reradiated back into the space. That is why only 40% of the input energy was removed by the water. Meckler and others

employed a reflecting lens and this lead to as much as 70% of the input energy being recovered.

Radiant cooling by Water Compared With Air-Cooling

The tests conducted by Meckler show that 70% of the heat radiated by a lamp in the form of infrared radiations can be removed by water circulating at the temperatures of 77° to 85° F. (1). When activated by electric current, the lamp reaches a temperature of 110° to 140° F. and the luminaire housing is kept comparatively cool at 77° to 80° F. This starts radiation of infrared wave lengths from the lamp to the housing. This process is enhanced when a infrared reflecting lens is attached to the bottom of the luminaire.

The air-cooling method cannot attain this high efficiency of heat removal. The return air removes the lighting heat by conduction and convection, but the luminaire housing is still kept comparatively hot and most of the radiant energy is reradiated to the occupied space. A large portion of this extracted energy still finds its way back to the space by conduction through the ceiling, the floor, and the supply return air ducts. Most of the return air is returned to the central plant where it becomes a load for the refrigerating plant.

Function of Air Supply in the Water-Cooled Luminaires

In the water-cooled system, the heat of the luminaires is removed by the circulating water, but a small air supply is still necessary for ventilation and humidity control. This air supply can be less than one-third of that required in all-air systems. This leads to reduction in the duct capacity, the building volume, and fan horsepower. The reduction in quantity of air obtained in air-cooled system may be very small compared

with the water-cooled system. The rate of ventilation required is about 0.4 cfm/sq ft which is just outdoor fresh make-up air. The total circulation rate will be about 0.7 to 0.8 cfm/sq ft (11). The conventional systems have flow rates up to 2.44 cfm/sq ft.

In addition to the savings in the air handling capacity, the water-cooled system might be specially useful for hospitals. The transmission of microorganisms and contamination is a major problem in designing an air-conditioning system in hospitals. The health regulations require certain minimum air changes in different rooms in a hospital. If the quantity of air flow is reduced as is done in a water-cooling method, this will lead to more effective control of the environment and savings in the air-conditioning plant.

Water-Cooled Luminaires in Series

If the luminaires are operated in series, the successive lamps become warmer. This leads to a prediction that the successive lamps would give lower output and there might be some color shifts, but it was observed that the average temperature rise of water and housing was moderate and there were no color shifts (11). By maintaining the luminaire temperature at 70° to 80°F., it was also observed that the illumination levels were increased by 35% and the electrical input was simultaneously reduced by 5%.

Expected Life of Luminaires Using Water-Cooling

Water has a tendency to corrode the tube materials used for the construction of luminaires. Some kind of water treatment procedures must be followed to improve the life of the tubes and maintain their efficiencies in the long run.

Apparently Complex System

In the all air system, the return air which is always available passes around the lamp and recovers heat while passing. As shown earlier, this apparently simple procedure does not give a high heat pickup efficiency. Most of the radiant energy flows to the space and a part of the recovered heat leaks to the space through the ceiling, the floor, and the ducts.

The water-cooling system extracts almost all of the input energy because the removal of the radiant energy is very effective and there is comparatively little leakage. This system though efficient seems complicated because water and air both are used simultaneously. But the integration of the energies by using both air and water is itself the essence of this efficient system. The amount of air used in the system is just sufficient for the ventilation and humidity control while the circulating water integrates the lighting and the solar heats.

Response of the System

It is desired that indoor conditions remain constant as climatic changes occur outside. In the process of maintaining the indoor conditions, each component of the system takes some time to respond. The response time of the wall structure, valves, etc., may be different depending upon their sensitivities. As a result, the entire system is never in equilibrium but the performance should not be oscillatory.

The water-cooled system was tested for the response time and it was found that the response was adequate after using materials of high conductivity (23). No such data for the air-cooled system is available.

Flexibility for Future Applications

The Illuminating Engineering Society's data reveal that there is an

increasing trend of using higher illuminating levels in modern buildings. The levels may approach the 400 foot candle level. The conventional and the air-cooling systems will require high rates of air distribution and as a result the system will be more expensive. There may be complaints of drafts by the occupants. Moreover, the noise levels may limit the air velocities and the ratio of duct areas to distribute air and water may be 200-300 to 1 for such a building. Thus, by using an all-air system the nonproductive volume of the building will be increased. A water-cooling method might be the answer to this. Cost of an evaporative cooler, cost of the expensive louvers, and the luminaires and extra care in water treatment has to be added. In the long run, the operating cost will compensate the extra initial costs. Also, the initial cost of air-conditioning system will be less compared with the conventional system.

Comparison of Costs

Two field studies with the air-cooled and the water-cooled systems were presented earlier in this report. Those field studies were conducted on two separate buildings at different times and there are many variables involved. Due to the many variables involved it is not possible to compare the costs of the two systems with the available data.

CHAPTER V

CONCLUSIONS

The water-cooled system of heat transfer is proved to be the most effective in obtaining the maximum energy utilization as compared with the air-cooled system. By employing a reflective lens about 70% of the input energy to the lamps can be removed and eliminated from the space or used in the thermal louvers. The water-cooling method attains this high efficiency because most of the radiant energy is captured by the circulating water.

In the water-cooled system a small air supply is still necessary for ventilation and humidity control. This leads to reduction in the duct sizes, the building volume and the fan horsepower. The low air supply also makes the system more useful in hospitals. The savings in the first and the operating costs of the heating and air-conditioning plant will be more in case of the water-cooled system.

Proper care must be taken in the water-cooled system to prevent corrosion of the various components. Extra costs incurred in designing such elements as luminaires, louvers should be taken into account before final judgment..

The I.E.S. data shows that the illumination levels have gone in the range of 100 to 400 foot-candle levels depending on their application such as drafting rooms, museums or forge-shops. At such a high level of lighting, the most efficient and the most economical method of heat transfer should be considered.

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**SOME ASPECTS OF
ENERGY INTEGRATION
IN MODERN BUILDINGS**

by

HEMANT S. KAVATHEKAR

B. E., Shivaji University, Kolhapur, India, 1968

AN ABSTRACT OF A REPORT

submitted in partial fulfillment of the

requirements for the degree

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Scope and Method of Study: Modern trends of efficient electric illumination lead to higher lighting levels in a building. Higher illumination levels introduce a large amount of heat which acts as a thermal load on the occupied space and the air conditioning system. Also, solar heat from the windows form a major part of load on the air conditioning system. There are other loads, too, inside a building which must be coordinated to create the desired conditions for the occupants. The integration of the two major loads is the subject of this report.

Following is the method of study:

- 1) To show how the heat associated with lights is distributed.
- 2) To illustrate various methods of controlling that heat.
- 3) To give detailed information on the water-cooled and the air-cooled systems along with their field studies.
- 4) To discuss and compare these two systems.

Findings and Conclusions: The water-cooled system was found to be more efficient of the two systems. The data available regarding their costs was not sufficient to conclude which method is most economical. Data further shows that the integration of lighting loads into the design of building heating and air conditioning systems is an economic necessity.

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