SOME ASPECTS OF
ENERGY-INTEGRATION IN
MODERN BUILDINGS

by

HEMANT SHANKAR KAVATHEKAR

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

A MASTER'S REPORT

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Mechanical Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1972

Approved by:

Major Professor

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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.

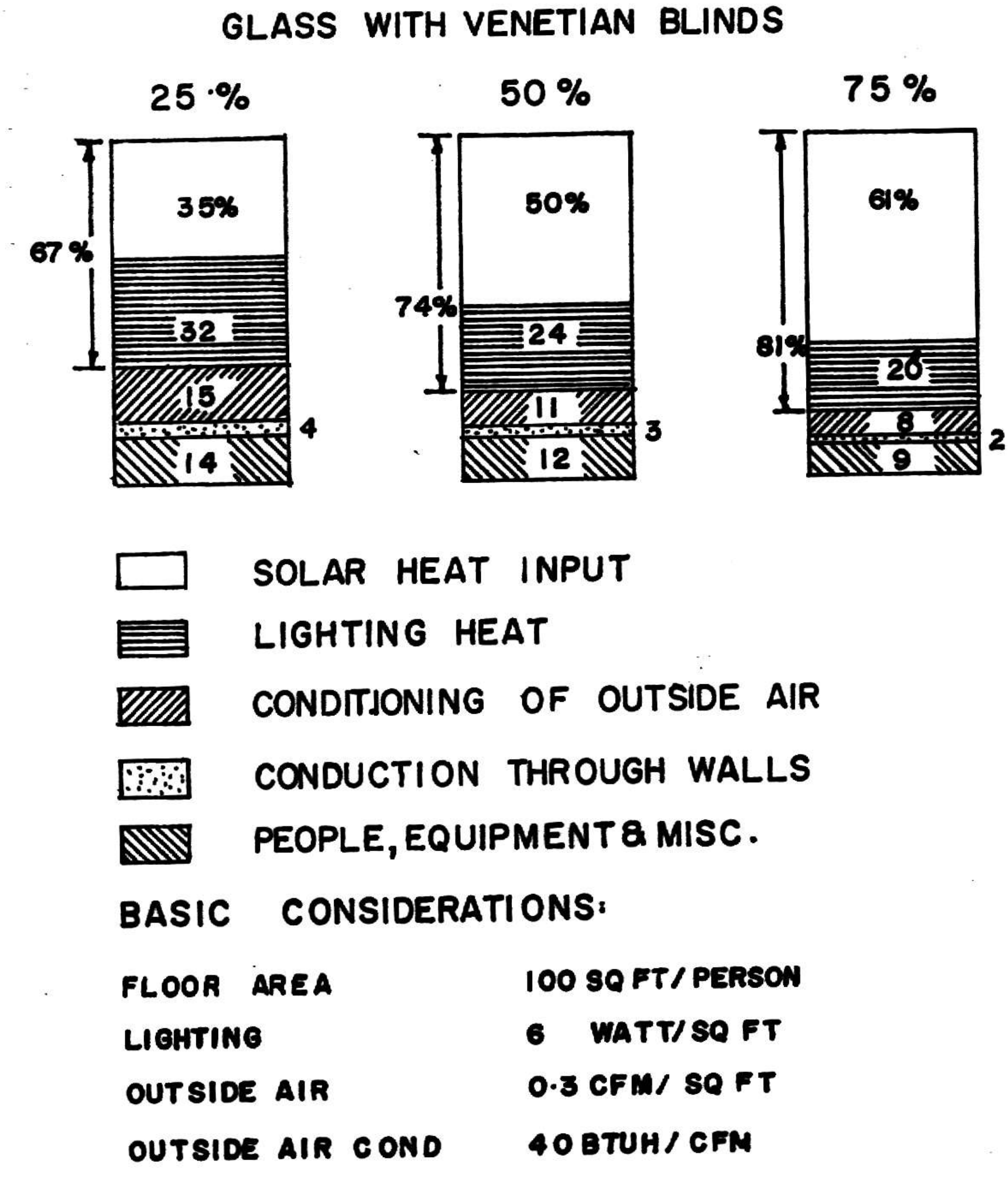

Figure 1. Percentage of Total Heat Gain For A Building

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. blub 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	13.8%
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

Material	Reflectance At Indicated Wave Length (μ)				
	4	7	10	15	20
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 abosrbed 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.

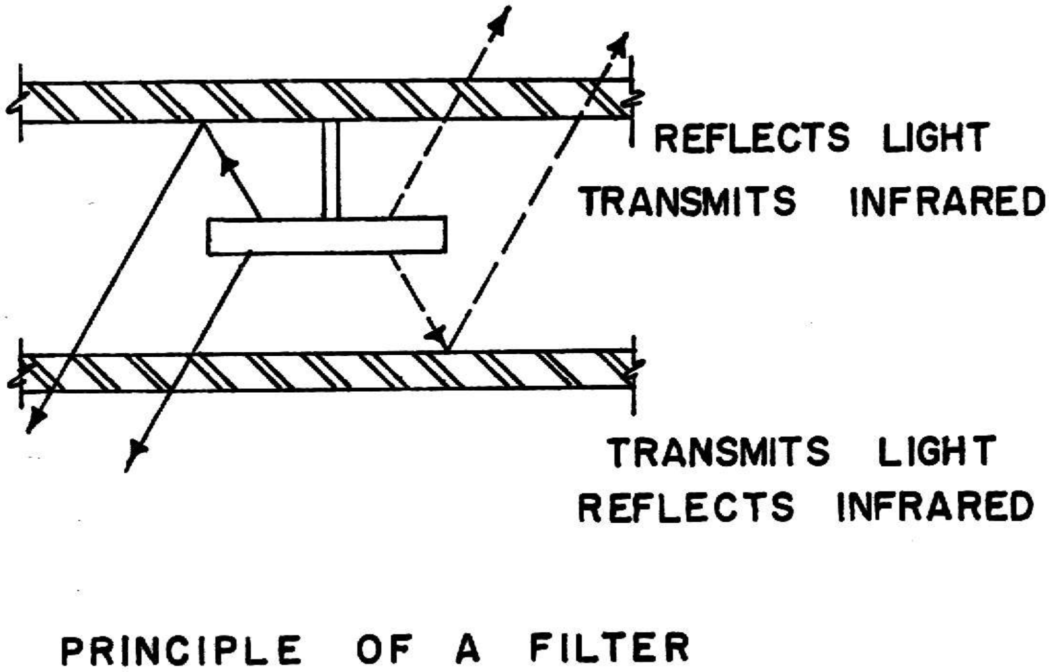

Figure 2. Use of A Filter To Separate Light And Infrared.

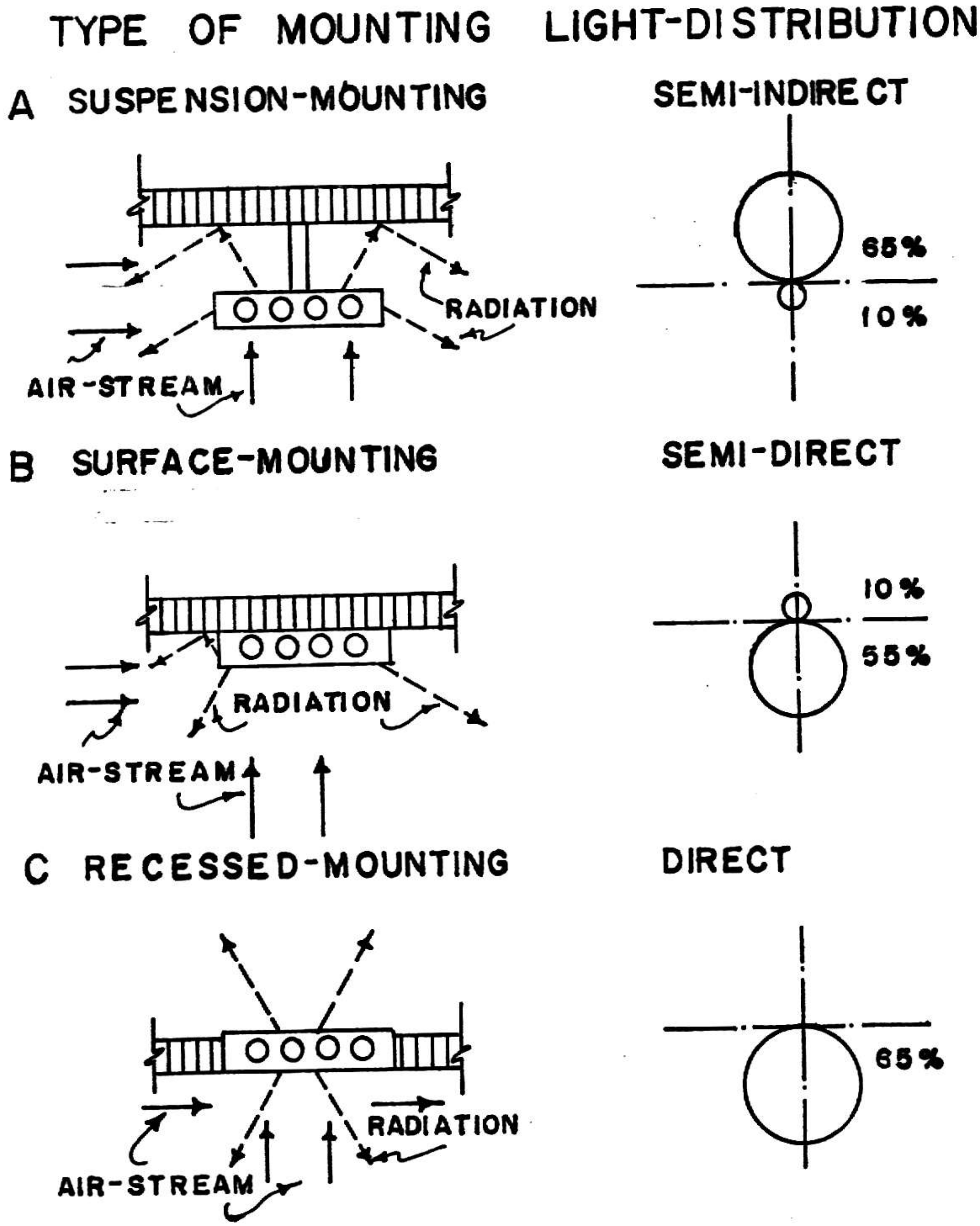

Figure 3. Use of Air For Controlling The Lighting Heat.

(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 predominently 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

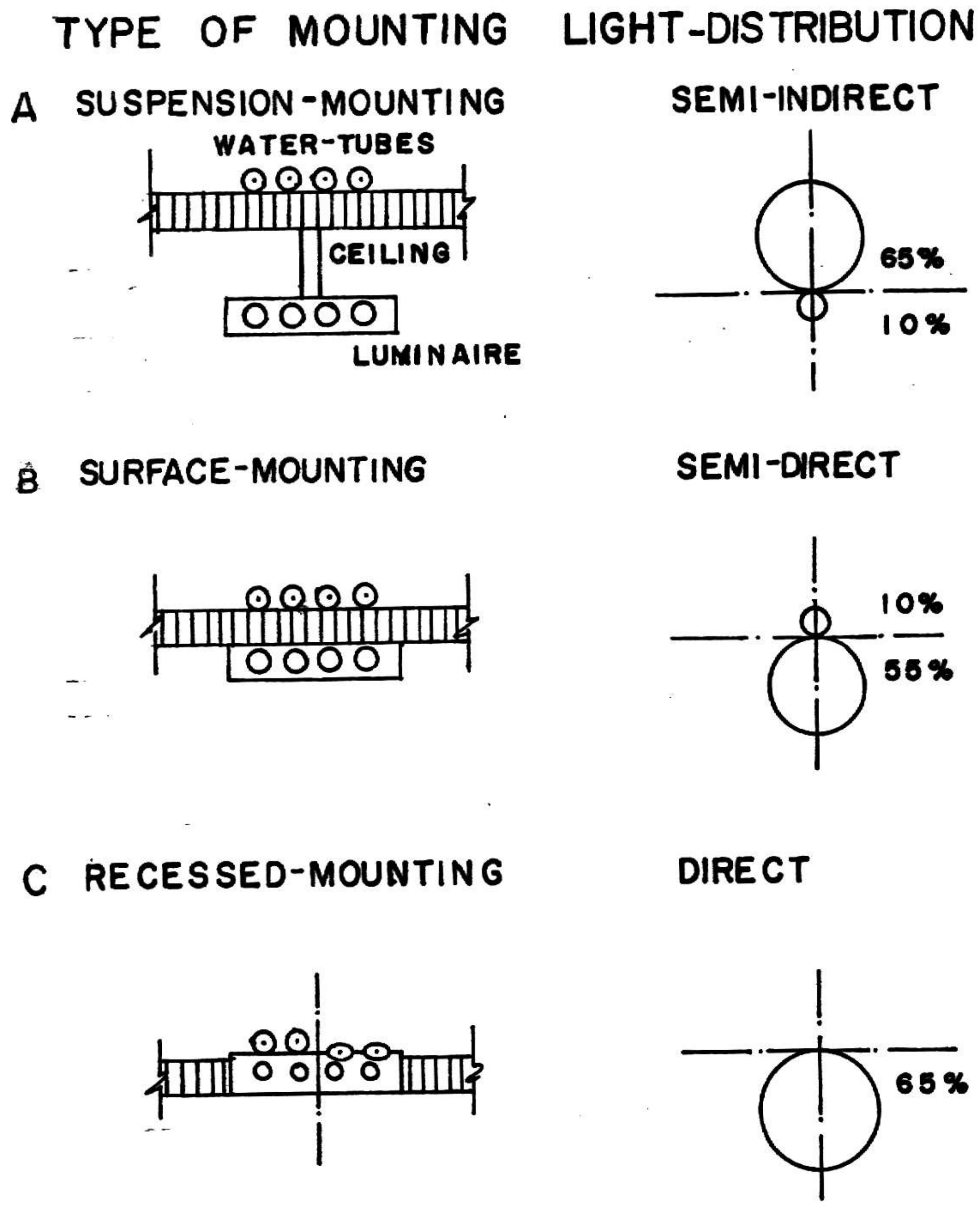

Figure 4. Use of Water For Controlling The Lighting Heat.

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.

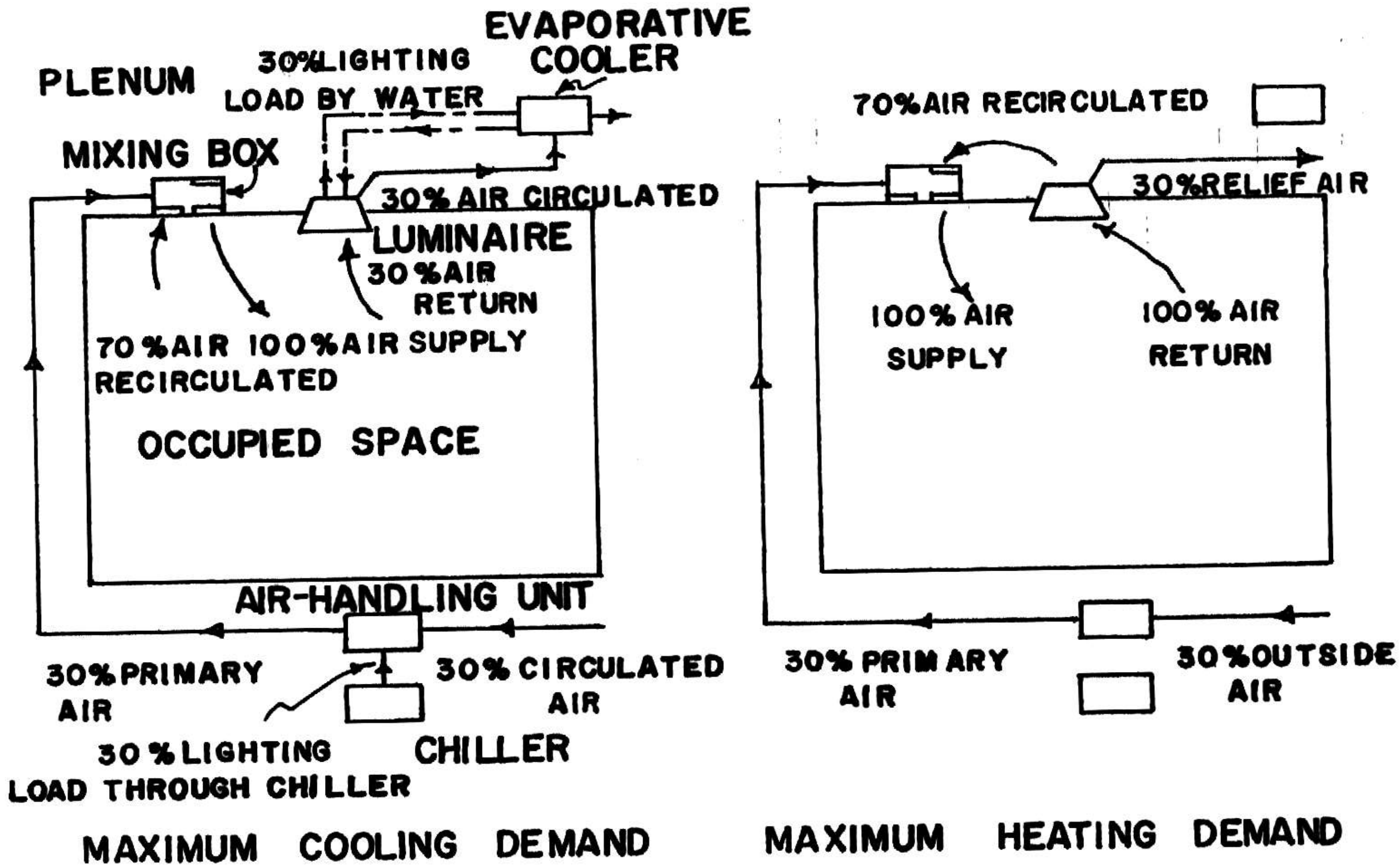

Figure 5. A System Using Both Air And Water.

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

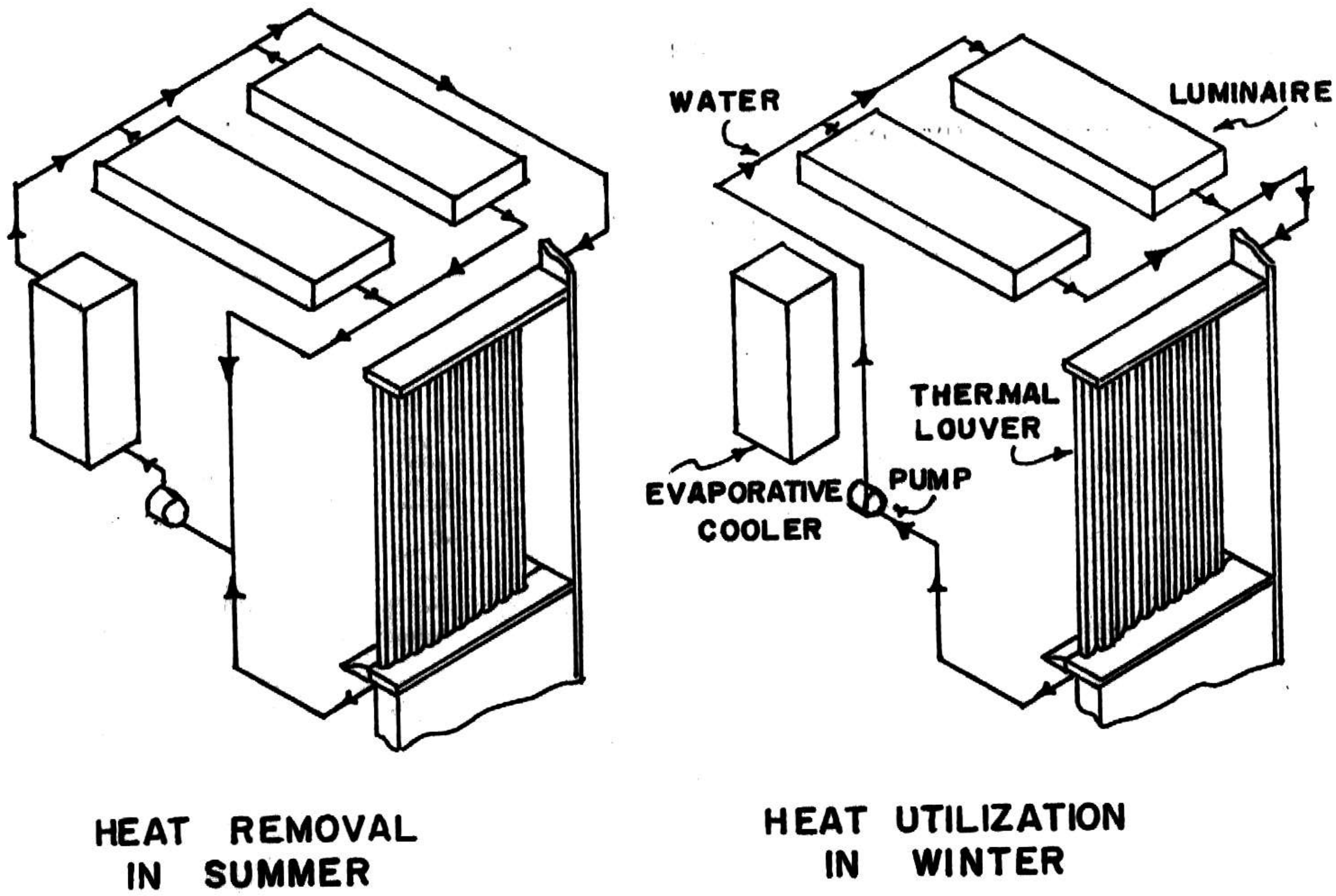

Figure 6. Concept of Energy Integration Using Luminaires And Louvers.

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

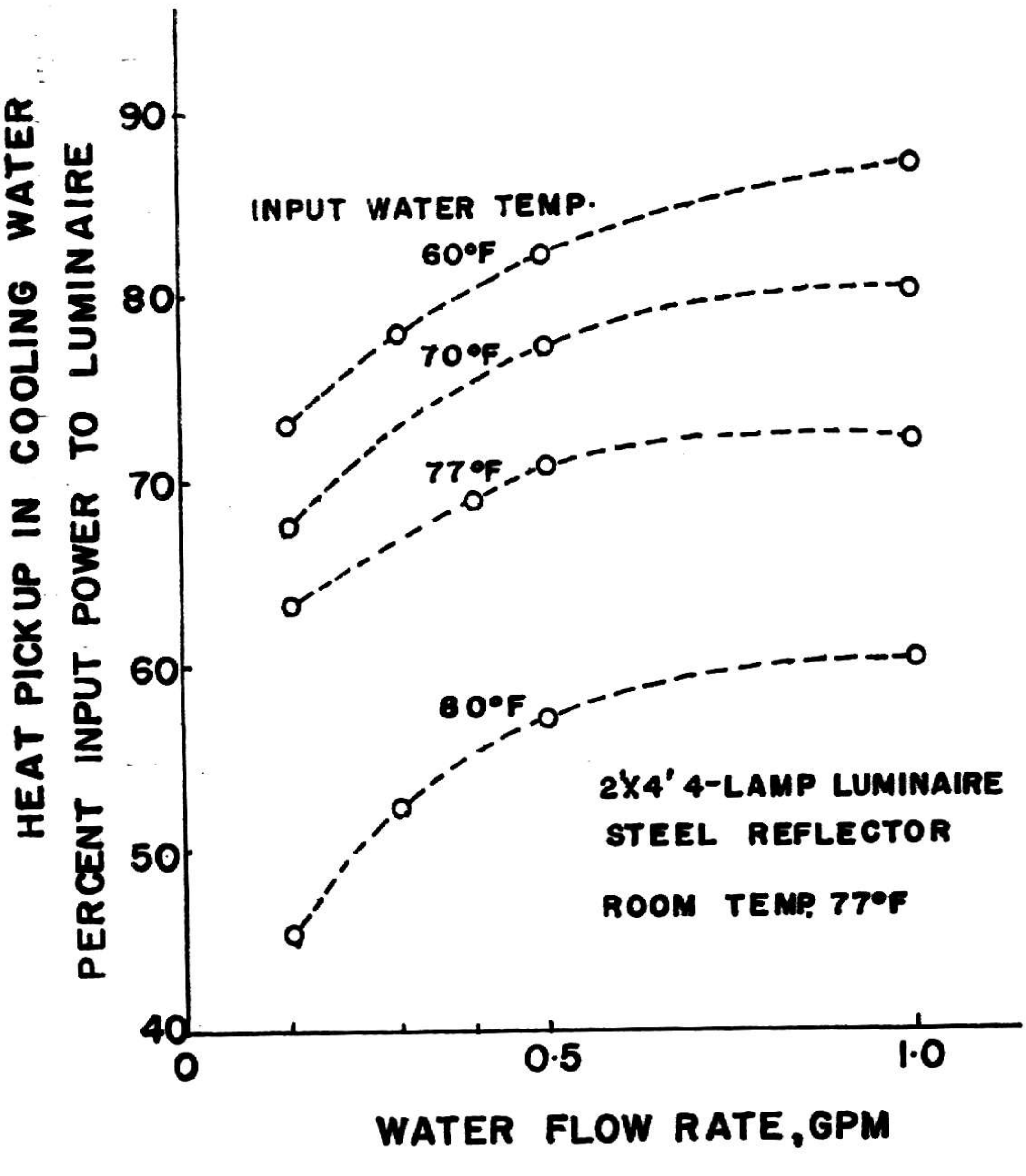

Figure 7. Thermal Performance Curves For Various
Input Water Temperatures.

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 x 0.12 = 22 Btu/(hr.) (sq. ft.) (F deg).

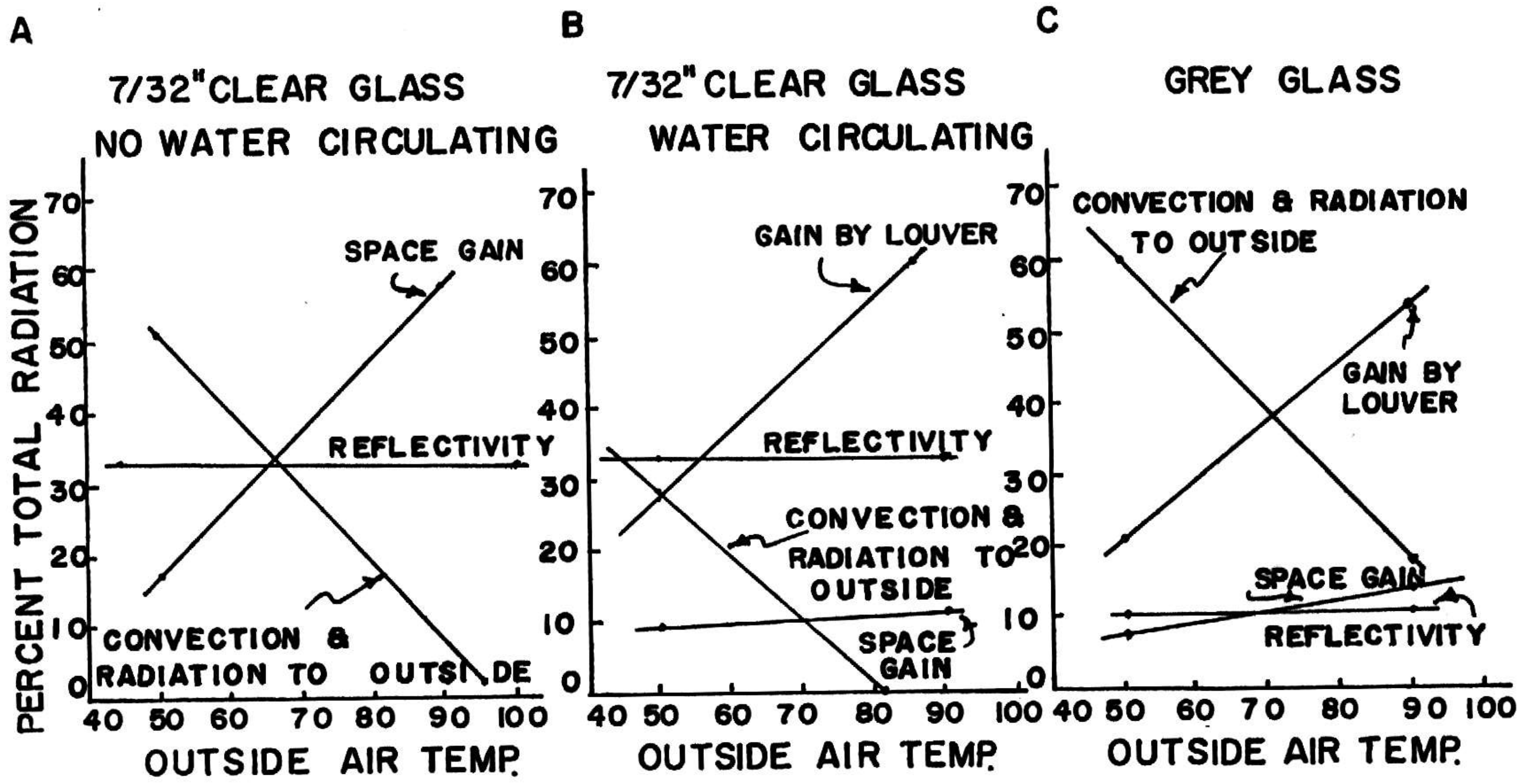

Figure 8. Comparison of Thermal Louvers And Conventional Shading Devices.

The space heat gain due to air-to-air temperature differential is 25% of the transmission load, or 0.25 x 15 F. temperature difference x 1.06 Btu/(hr.) (sq. ft.) (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 x 181 = 108.6 Btuh, and the transmission load would be 15 F x 1.06 Btu/(hr.) (sq. ft.) (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 ½ 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).

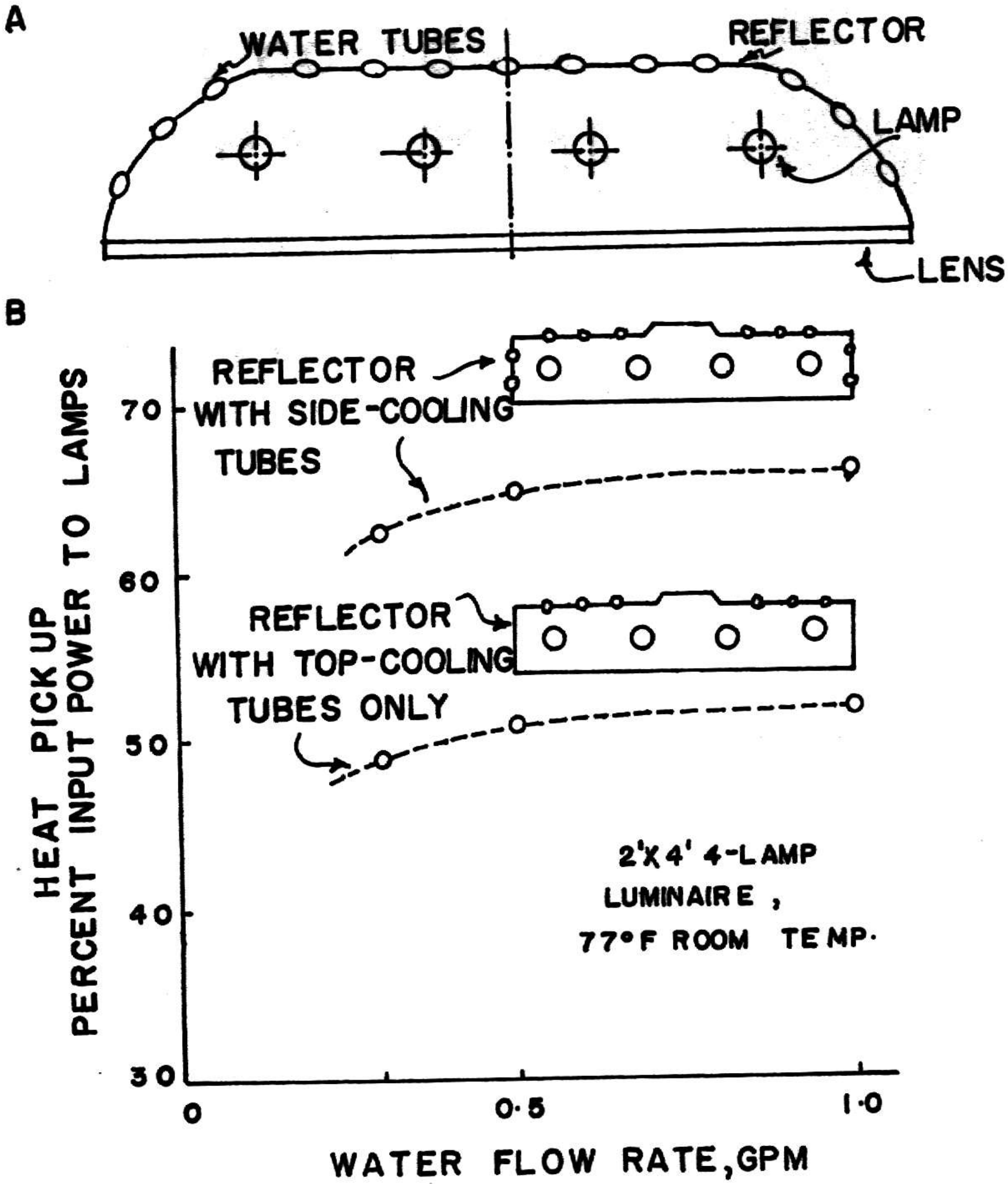

Figure 9(A). A Model of Water-Cooled Luminaire.

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

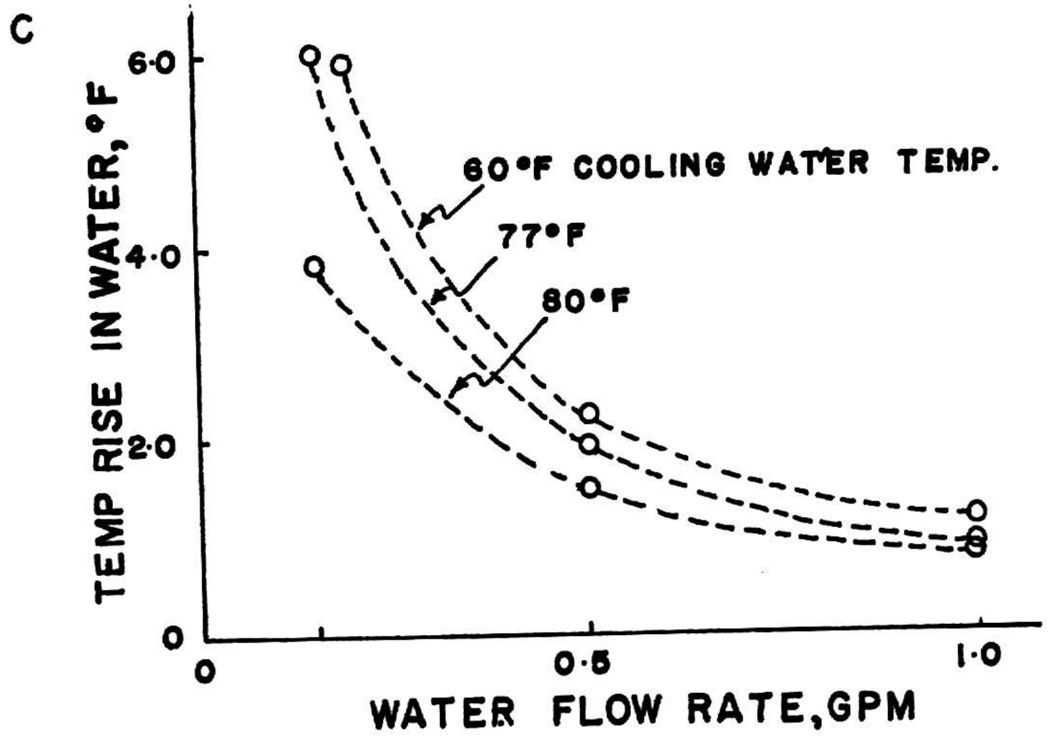

Figure 9(C). Temperature Rise For Various Temperatures.
2'X 4', 4-LAMP LUMINAIRE, 77°ROOM TEMP.

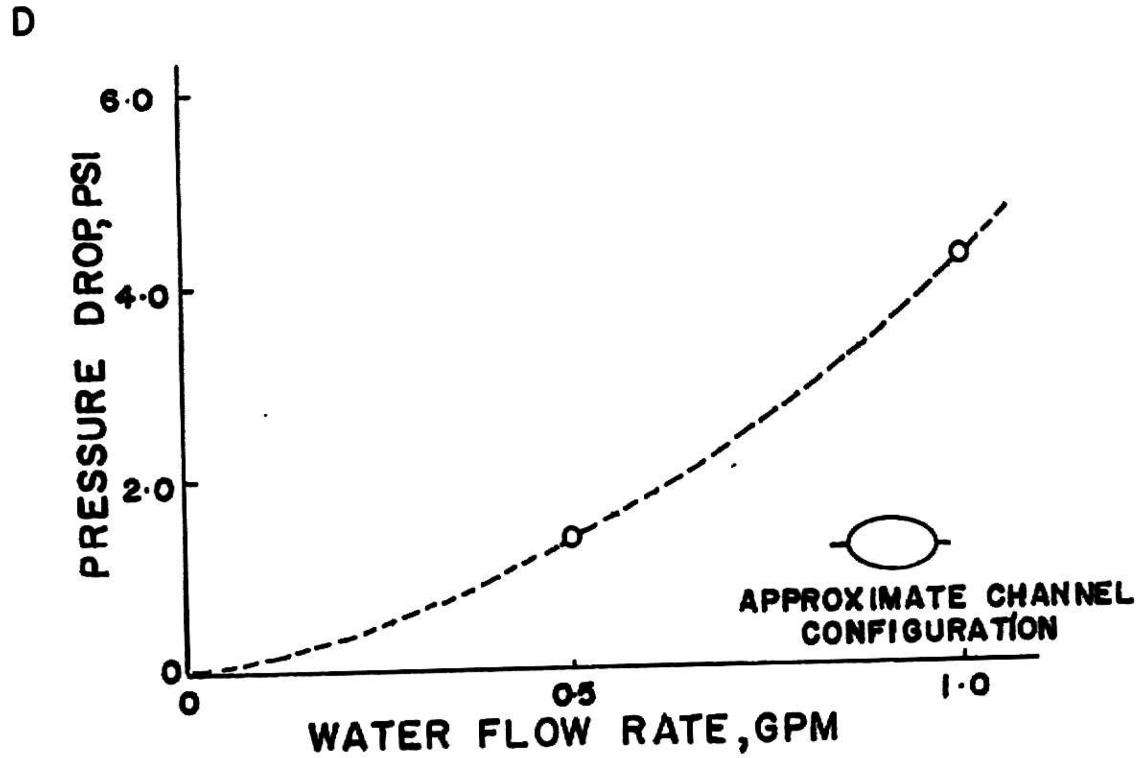

Figure 9(D). Pressure Drops At Various Flow Rates.

TABLE 3

Comparison Between Series and Parallel Arrangements

Type of Luminaire Circuit	Series	Parallel
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 expsing 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.

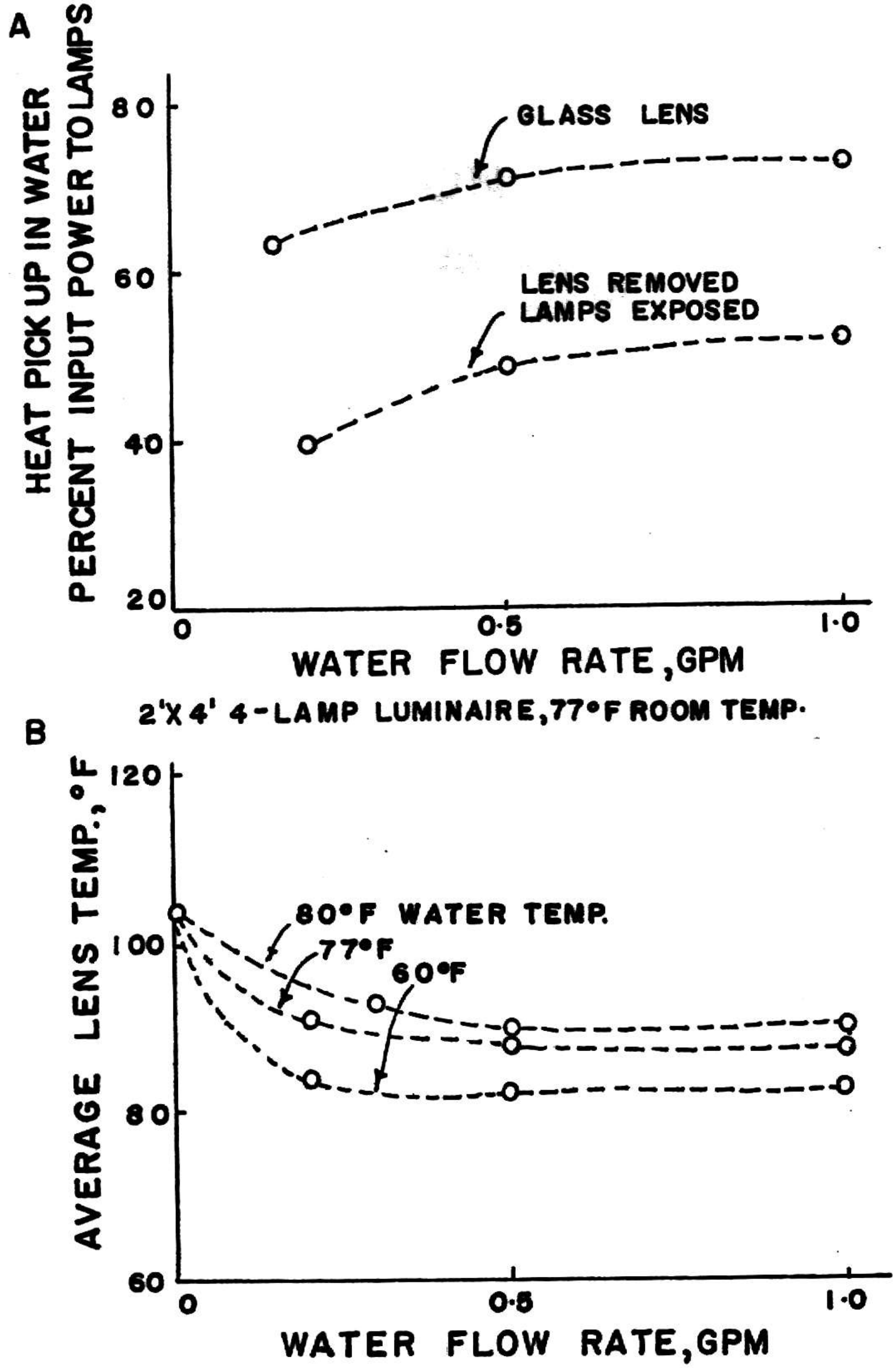

Figure 10(A). Thermal Performance With Or Without Lens.

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