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Comments on the need for integrated design of lighting, heating, and cooling systems. In order to eliminate the penalty of refrigerating the lighting heat, minimize the building non-usable space, and optimize the total energy input, a "systems approach" is recommended. This system would employ heat-recovery techniques based on the ability of the system to minimize the refrigeration and air handling equipment as well as the system energy associated with lighting heat removal. An additional feature of this system is its ability to utilize the same equipment to provide heating requirements of the building. Laboratory tests are cited with illustrations. (RH)

Energy Integrated Design of Lighting, Heating, and Cooling Systems, and its Effect on Building Energy Requirements

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It is important to reflect on what has taken place in the evolution of building environmental requirements and its effect on energy requirements of lighting, heating, and air-conditioning systems. In the past, heating systems were fuel-fired and arranged to offset heat losses at the skin of the building during winter season. Space cooling, at first, was considered a luxury and was installed only in some special-use facilities, such as theaters and retail stores. When it was provided, it was designed separately and independently of the heating system and arranged to operate on a seasonal basis during summer season to offset outdoor climatic conditions. The lighting heat generated within the building was not accounted for or utilized in the heating system operation.

The development of air conditioning technology has been based upon the fundamental principle of utilizing refrigerated air systems to maintain simultaneous control of temperature and humidity. Therefore, in order to maintain proper conditions during summer operation, air conditioning systems have been designed to provide for total sensible heat removal at the proper humidity level for comfort, supplying air to occupied space in the range of 55-60F, the quantity of air being established by the total cooling load of the space.

The underlying philosophy in the development of electric illumination technology has been the continuing development of more efficient lamp sources. As a consequence of the increased efficiency of lamp sources, higher standards of minimum footcandle levels were established, and it became practical to more adequately meet the requirements for good visual acuity.

Up to this time, increased use of lighting has been a direct result of high lamp efficiency (lpw).

It is interesting to note that the major development of lighting technology was well established before air conditioning became a basic requirement for occupied space. The development of air-conditioning technology and equipment was based on maintaining comfort for people by the simultaneous control of temperature and humidity, and heat from lighting was not a factor during this development because lighting levels were very low.

Modern lighting practice calls for illumination levels which result in quick, accurate, and comfortable vision. Recent research to establish minimum illumination levels needed to achieve a conservative speed of accurate seeing for a wide variety of typical visual tasks resulted in the recommendation that minimum footcandle levels for specific requirements be doubled. These requirements for interior artificial illumination have introduced into the building a large amount of electric energy and its associated heat which acts as a thermal load on the occupied space and associated refrigeration equipment. The amount of heat generated by the lighting system is more than five times greater than the amount of heat given off by people. Refrigerated air is required in order to maintain comfort conditions for people, but the amount of refrigerated air required because of high temperature radiant loads such as lighting has established a thermal barrier beyond which the air-conditioning system becomes impractical to install and operate because of its space, air, and refrigeration requirements.

It has been predicted that in order to meet optimum visual requirements footcandle levels will again be doubled within the next ten years. Continued growth and development of lighting technology is not just a matter of making a better lamp source, but it is a matter of designing the lighting system and the air-conditioning system as functional components of a total environmental system. In order to eliminate the penalty of refrigerating the lighting heat, minimize the building non-usable space, and optimize the total energy input, we must utilize the "systems approach," employing heat-recovery techniques based on the ability to minimize the refrigeration and air handling equipment as well as the system energy associated with lighting heat removal and the ability to utilize the same equipment to provide heating requirements of the building.

The continuous control of interior environment in summer, winter, and during the intermediate seasons has greatly changed the way in which energy is consumed in buildings. I think we must further define a distinction with respect to total building energy input. Building energy requirements fall into two categories: (A) "System Energy," and (B) "Fuel Energy." "System Energy" includes the energy to drive fans, compressors, pumps, etc., which is a function of system design. "Fuel Energy" includes the energy to be utilized to offset winter heat losses. It is the intent here to illustrate a system that reduces the energy required for collecting and removing lighting and solar heat for cooling and provides a means for utilizing interior heat by transferring it to the perimeter for heating. The combination of these features in one system results in a system with a minimum total energy requirement.

The radiant heat associated with the lighting and solar energy is the largest single factor contributing to occupant discomfort and the high cost of air-conditioning systems. Figure #1 illustrates a breakdown of the percentage of total heat gain in buildings with varying amounts of glass in the exterior walls or perimeter. These percentages are based on 6 watts of lighting and one person per 100 square feet of office occupancy, with a ventilation rate of 30 cfm per person. We can readily see that the two major components, solar heat gain and lighting, represent 67% of the total space load requirements for refrigeration and air conditioning in a building consisting of approximately 25% glass at the perimeter. The percentage of these two major components increases to 74% with 50% glass and goes as high as 81% in a building with 75% glass.

When we consider lighting from the thermal point of view, we find that what we really have is primarily an electric resistance heating element that also produces some visible light. A 40 watt, 425 milliamp lamp, operating at 25°C ambient condition produces only about 19% light. The rest of the energy is converted into other forms of heat; 31% infrared radiation, 33% conduction and convection, and 17% ballast loss. From the higher energy 1500 milliamp lamp, we get increased heat, but the amount of light is primarily the same; we get more infrared or a shift in the heat relationship, but we still get only 18 to 19% light. When we put the lamp in a troffer, we find there is a further degradation of energy, and we end up with 8 to 10% light, the balance going into heat.

It's important to note what happens at the interface of the troffer in terms of light properties and thermal properties. When the lamp is energized, the glass envelope reaches a temperature of 110 to 140°, depending upon the type of lamp. At those temperatures, the infrared radiation associated with the lamp produces wave lengths in the range of 5 to 15 microns. This means that the lamp is producing visible light of short wave length, and is simultaneously producing infrared radiation in long wave lengths. As shown in Figure #2, the reflectance of these wave lengths depends upon the material from which the troffer is made. If the material is polished aluminum, most of that energy is reflected, but if it happens to be synthetic enamel on steel or aluminum, most of the energy is absorbed, giving us an absorber of heat and a reflector of light, or a separator of light and heat at the interface of the troffer. Actually, the troffer gets hot, absorbing the infrared radiation and holding it, then reflecting it into the space. Conventional practice is to remove all of the lighting heat at low temperatures, with some type of refrigeration system. It is always necessary to introduce some refrigerated air, because we must maintain humidity conditions in the space, but, we realized that if we could remove the lighting heat load at a temperature higher than 55° we could eliminate the requirements for refrigeration associated with conventional lighting systems.

A laboratory was built and a series of tests were performed to establish the thermal recovery properties of the lighting system. We found that by using non-refrigerated water as a heat transfer medium we could remove large amounts of the energy input. At water temperatures as high as 77° to 85° we can actually remove 70% of this radiant heat. The significance of this discovery is that we can remove heat without refrigeration, and the lighting fixture can become something more than just a lighting device which requires the payment of a penalty in additional energy to refrigerate the lighting system. It can become an efficient energy converter. By circulating 77° to 85° non-refrigerated water through tubes in the troffer we capture 70% of the energy input which we can either reject from the building without refrigeration energy input or redistribute if we want to utilize the energy elsewhere for heating. This gives us a converter which utilizes a high grade energy (electricity) and separates it into light and heat, both required in the space, one not being a penalty for the other. It also gives us a dual-system product which is not only a lighting device and not only a cooling device, but, rather, a component common to two systems, the mechanical and electrical systems, allowing us to split energy and control it. Figure #2 shows a thermal breakdown of the K.W. input energy to a non-refrigerated water-cooled luminaire, and Figure #3 shows a water-cooled luminaire as constructed.

The water-cooled luminaire is able to achieve this heat pickup efficiency because the troffer is kept cool (77° - 80°F) by the absorption of the 30% to 40% of energy input that comes off in the form of infrared radiation. An air-cooled luminaire cannot approach this efficiency of heat extraction because the luminaire housing still remains relatively hot. The 30% to 40% of infrared radiation cannot be captured by the air and has its infrared spectral reradiated into the occupied space. The portion of heat extracted by an air-cooled luminaire is basically conduction and convection, and with a ceiling plenum system a large percentage of this extracted heat still finds its way back into the space by conduction through the ceiling. Air-cooled luminaires may reduce space load to some degree, but the conditions of ceiling return air leakage and conduction of extracted load back to the space make the space load reduction a variable which is very difficult to determine. Moreover, the total lighting input energy has its full load still fall completely on the central plant refrigeration system.

Reviewing the heat transfer characteristics of the luminaire combined with an analysis of the various forms of energy output by lighting and the effect of these forms of energy on the luminaire, it becomes apparent that it is only with the water-cooled luminaire that the optimum of input energy can be reclaimed and utilized if required through a simple non-refrigerated water energy-transfer system, or completely rejected to the outdoors if not required, without imposing a load on the space or central plant refrigeration.

As noted earlier in Figure #1, the heat transfer or energy balance that takes place at the skin of the building, or the perimeter, is also a significant factor in the heat load. With the solar input varying, depending upon the amount of glass used and the lighter materials used in buildings today, the thermal properties of the structure respond rapidly to instantaneous load. Frequently, heat gains and heat losses occur simultaneously, creating both a heating and cooling requirement, depending upon exposure.

In Figure #4 we see a plotting of the monthly solar intensity through a good venetian blind for 30° to 40° latitudes, which brackets the United States. It is interesting to note that whether we are in the southern or northern part of the country, the north wall is thermally stable with respect to solar gain. In other words, we get no variation throughout the year anywhere in the United States in terms of solar input on the north wall. However, during the so-called winter season, the solar gain through eastern and western exposures may vary from 70 Btu to 90 Btu per square foot of glass, depending upon whether we are in the north or south. As we go into spring and summer, solar intensity from the east and west reaches a maximum of around 140 Btu per square foot, But, it is the southern exposure which is subject to the greatest variance in solar intensity. Particularly interesting, in the southern part of the United States, the solar gain from the south reaches its maximum during the winter months and its low point during the summer months.

This means that during the so-called winter season, depending upon the amount of glass we have, the outdoor conditions, and the energy level inside the building, we could very well have a reversal of load -- a demand for cooling due to sun gain on the south side. It's this interaction and this variation of sun input on the walls of a building, coupled with the level of lighting in the interior that creates the serious problem in terms of environmental control. Because this solar load is radiant by nature, it can only be removed after it enters the space and is absorbed by objects within the space. It is the interaction of this kind of energy plus the energy input within the space that really affects our comfort because it affects the thermal balance. Because of these energy balance problems, conventional systems are often over-controlled, resulting in aggression between different components of a same system attempting to respond to a partial heating and/or cooling situation.

We felt that if the same principle could be applied at the perimeters as that applied in the interception of interior heat in the lighting system, we could take advantage of the fact that solar heat also enters the space at elevated temperatures and likewise intercept this radiant energy at a temperature level above that of the occupied space. Again utilizing the concept of non-refrigerated water, we made a prototype of a thermal louver assembly, similar in appearance to a vertical venetian blind (See Figure #5).

We used the University of Florida's ASHRAE calorimeter to measure the properties and test the ability of the blind to remove heat at temperatures in excess of the room temperature. The University of Florida's Solar Calorimeter is used to measure the thermal properties of glass and sun effects on walls; it is used to establish all the values taken into consideration in designing air-conditioning systems, the "U" factors, the shade factors for various glass combinations and shading devices. We established a 4' x 4' section and measured the sun input; the amount reflected, and the amount that was transmitted and absorbed into space. We could vary this and orient it to any or every angle, and series of more than 85 measurements were made.

To test our new theory, we put the thermal louvers inside the calorimeter, but did not circulate any water. We found that approximately 65% of the sun gain actually came into the space and would have to be removed by refrigeration. Approximately 32% was reflected. This is about the same performance we get with an ordinary venetian blind. Then we circulated water through the louvers and found that, even at a water temperature as high as 95°, only 12% of this radiant heat entered the space. In other words, the shade factor dropped from 65% all the way to 12%, with the difference being absorbed in the louver and taken out by non-refrigerated means. Figure #6 graphically shows the results of these tests.

Figure #7 shows the variations between the various shading devices. With nothing on the window, about 210 Btu come into the space. With a good conventional venetian blind, approximately 140 Btu per square foot of glass enter. If we go to a reflecting glass, approximately 90 Btu, and with an outside solar screen, approximately 60 Btu. However, with the non-refrigerated water-cooled thermal louver, only around 26 Btu was allowed to enter the occupied space. The peaks on the right hand side of this graph represent the refrigeration and air associated with the various shading devices, and, as may be noted, there is a considerable reduction in refrigeration usually associated with the thermal load in the space by blocking out or intercepting the solar input before it enters the occupied space. The water-cooled louver, then, is also a dual-purpose product, giving us two components which optimize energy utilization. Figure #8 graphically recaps the effects of the non-refrigerated water-cooled thermal louvers on solar radiation.

By inter-relating these dual-purpose products, we have designed an environmental system which relates the thermal energy balances associated at the skin of the building with the internal energy generated within the building and simultaneously intercepts the solar radiation input through the exterior glass areas and the heat energy from the lighting system, responding automatically to changes in climate, ensuring total indoor comfort throughout the entire year.

The heat which is captured in the non-refrigerated water circulating through the troffers and the thermal louvers may be removed through a closed circuit cooling tower, by-passing the air handling, chilled water, compressor, and condenser water, thereby skipping four steps of conventional heat transfer. This means that we can reduce the air handling to just that required for people within the space, bringing back into balance the humidity requirements as well as the essential requirements of the space. Equally valuable, during the so-called winter season, we can transfer this available heat from our lighting system directly to the thermal louvers. Our thermal louvers become a heating device in a sense. They can either heat or absorb heat, depending upon the need. In other words, the solar input and the outside temperature affect the system, which responds and gives up energy, always maintaining comfort within the space and neutralizing the space from both the radiant input of the lighting system and the radiant input of sun, making available to us the energy from the lighting system when we need it. Figure #9 illustrates this new concept of optimum energy utilization.

Conventionally, lighting has been considered a penalty because of the production of heat associated with it. But, we now have the opportunity to take advantage of that heat if we begin to look at energy in terms of how it affects architecture. We bring energy in at a relatively high level; high grade energy that is generated at a power plant in large blocks. Yet, when we bring it into the building, the <u>utilization</u> of this energy becomes our real problem. The important aspect of today's design is how we utilize the inherent efficiencies we have when the energy comes into the building. By using sound, basic principles, we can make the efficiency of utilization equal to the efficiency of generation. The electrical power we bring in can perform many jobs -- it can produce heat, it can provide light, communications systems, computing systems -- it can do many things within the building. We bring this energy directly into the space to provide our visible environment, and now, at the same time, we have the opportunity to trap the heat and use it where we need it or discharge it without paying the penalty of additional energy to remove it. This is the concept that is important from the standpoint of interrelating energy and structure.

Specific mechanical systems have been applied to installations where energy and structure have been interrelated. Figure #10 is an Indirect Transfer System employing non-refrigerated water and single-zone air distribution at constant temperature to supply both interior and perimeter areas. When heating is required, heat removed from the luminaires is redistributed by the water from the split condenser to the air through zone reheat coils in the ducts. This condenser water also supplies heat to the thermal louvers when required. When heat removal is required, the non-refrigerated water removes the heat from the luminaires and louvers and expels it through the evaporative cooler.

In order to take full advantage of the temperature control and heat removal capabilities of dual-purpose products using non-refrigerated water, attention must b given to interrelating the refrigerated air handling system and the non-refrigerated water system.

One of the workhorse systems for many buildings, which came into its own in the 50's, is the dual-duct system, shown in Figure #11, consisting primarily of a hot duct and a cold duct arranged to serve mixing boxes throughout the building with the central air handling and refrigeration system in the equipment room. The significant thing about the dual-duct system is that building spaces may be easily re-arranged as required by occupancy. In other words, a building may be designed before the occupancy is established, and the boxes can be added at a future date, depending upon the occupancy requirements. This became a very significant system, and it is still widely used because it has the ability to serve any size room and provides temperature control in any area or zone. However, from an energy standpoint, this is the most wasteful of all systems because we have to provide both a hot duct and a cold duct for space temperature control; we have to provide cooling for all the heat load, and we have to provide another duct to do the heating. At the same time, we have to refrigerate the entire load.

A more recent development (also shown in Figure #11) eliminates the hot duct by introducing a variable volume induction-mixing box that utilizes the heat drawn through the lighting fixtures. On so-called "heating cycle" heat gain from the fixture may be utilized and mixed with cold air to effect temperature control. This system caught on because, on the surface at least, the hot duct in the dual-duct system can be eliminated, the amount of cold air may be reduced because of the heat pickup of the air exhausted through the fixture, and temperature control may be afforded in the space. The important limitation of this system is that it is still necessary to circulate all the cold air required for the space, so there is no opportunity to reduce refrigeration associated with lighting. On mixing cycle, when air is mixed to achieve temperature control, the highest supply air temperature available is somewhere around 70°, which does not permit lighting heat to be used for heating. The variable volume system was a step in the direction of interrelating lighting, energy, and air conditioning, but, while it allows the reduction of some of the duct work, it does not provide the opportunity to reduce the refrigeration or to raise supply temperature above room temperature.

Figure #12 shows a system arrangement which combines our non-refrigerated system with a minimum air system and allows us to reduce the air circulation and eliminate the penalty of refrigerating our lighting system. We use non-refrigerated water to take out about 70% of the heat gain from our lighting system and in our central plant we bring in the outside air required for people and dehumidification, which represents about two- to three-tenths cfm per square foot. That air comes up and enters the mixing box, which is arranged to provide constant volume primary air. This gives us the opportunity to take air from the space and recirculate it and discharge it into the space, or to take air through the fixture, then to the mixing box, and then into the space. This system allows us to maintain any recirculation rate needed in the space while eliminating refrigeration of our lighting system, but, at the same time, it makes available to us the heat from our lighting system to be utilized as heat for occupied space. We can discharge air at 80 to 82°, or even as high as 85°, into the space and introduce air anywhere from 60 to 80°, maintaining temperature control by distributing only minimum ventilation air. This is the next step in relating lighting and air conditioning and energy, minimizing the physical equipment, maximizing the use of available energy, and minimizing the use of penalty energy.

Figure #13 shows this constant volume induction box, arranged to provide primary air (recirculated air from the plenum or room) with a constant volume of dehumidified air, and this is only minimum ventilation air. This provides temperature control with minimum distribution and gives us the opportunity to reheat the air without refrigerating the reheat.

A constant volume of primary air is supplied to the box at 1" static pressure, and an equal volume of secondary air is induced and mixed with this primary air. A constant-volume valve in the primary air inlet controls air volume. The box is arranged with two secondary air inlets and dampers to permit the secondary air to enter through either one or both of these inlets. One inlet is connected directly to the conditioned space and the other to the plenum.

This box is used in conjunction with a luminaire (Figure #14) which is designed to collect lighting heat with either water or air. During the maximum cooling cycle the lighting heat is collected with water and the remaining load is removed with conditioned air consisting of primary air and secondary air induced directly from the space. During the maximum heating cycle the water flow to the lights is stopped and lighting heat is collected by passing air from the room, through the fixture, into the plenum. The secondary air dampers on the box close the space air inlet and open the plenum air inlet. The warmed plenum secondary air is then mixed with the primary air, warming it for temperature control in the zone. Intermediate damper positions provide a range of temperature control capabilities.

A clearer picture of the significance of this system can be gained by looking at an energy-flow diagram (Figure #15). This diagram shows the distribution of energy that takes place in such an air-conditioning system employing non-refrigerated water and induction boxes. It shows the various loads that come into the space and where they go throughout the system. 20.4 Btuh per square foot of building floor area out of a total load input of 47.8 Btuh per square foot enters as electrical energy for lighting. In most air-conditioning systems this all becomes a load on the refrigerated air system. With this system, 14.3 Btuh per square foot is funneled off to the evaporative cooler, by-passing the air and refrigeration systems. If lighting heat is needed for space temperature control, the mixing box provides a means for diverting part or all of this 14.3 Btuh per square foot back into the space under controlled conditions.

Solar and transmission loads amount to 16.1 Btuh per square foot of building floor area for this typical building, and 7.8 Btuh per square foot can be intercepted and carried off in the non-refrigerated water system.

If a typical dual-duct system were employed to cool this building, an electrical energy input to drive compressors, fans, and pumps would be needed that would amount to 19.9 Btuh per square foot of building floor area. With the non-refrigerated system, the comparable figure is 9.0 Btuh per square foot. The over-all system coefficient of performance (C.O.P.) is doubled by taking advantage of the economies permitted by dual-purpose products employing non-refrigerated water.

The use of energy-flow diagrams based on standard modular loadings allows us to compare various systems for handling the space loads on a total energy basis and establish coefficients of performance for the various systems.

Figure #16 illustrates the distribution of energy for a dual-duct system utilizing return troffers. To handle the 47.8 Btuh per square foot space load, a power input of 19.9 Btuh per square foot is required, giving a C.O.P. of 2.40. All the space load except that lost in the relief air must be handled by the chiller. The chiller requires an input of 10.6 Btuh per square foot. The air handling unit must supply enough cfm to handle the space gain, which requires an input of 6.6 Btuh per square foot. The amount of air required to handle the space load necessitates large ductwork.

Figure #17 illustrates the energy distribution for a variable-volume system. By reducing the amount of supply air required, a power input of 15.6 Btuh per square foot is required to handle the 47.8 Btuh space load for a C.O.P. of 3.06. All the space load except that lost in the relief air must still be handled by the chiller.

In Figure #18 we take a look into the future. Figure #18 illustrates a breakthrough in utilization of waste heat associated with artificial illumination to provide air conditioning and temperature control for the enclosed space. This arrangement consists of an integrated lighting, cooling, and heating device that utilizes thermoelectric couples to absorb the waste heat given off by the lamps and, as a consequence, generate a DC current which will then serve other thermoelectric couples which act as cooling elements for radiant cooling of the space. This allows us not only to heat with light, but also to cool with light.

The integrated luminaire consists of a radiant cooling panel, or refrigeration element, a heat collection section, a heat rejection section, and thermoelectric couples. The waste heat from the lighting fixture is absorbed by the heat collection section which, through a thermoelectric couple, utilizes this heat to produce a DC current. The generated current serves another thermoelectric couple which performs as a refrigeration element. The refrigeration thermoelectric couple is attached in heat-transfer relationship to a radiant cooling panel to absorb heat from the occupied space. The absorbed heat is transferred from the radiant panel through the thermoelectric refrigeration element to a heat rejection section through which water (150°) in a closed circuit is circulated, acting as a heat sink.

Referring to Figure #19, we see the over-all system illustrated in an energy-flow diagram. This diagram illustrates the fact that even though the over-all coefficient of performance of thermoelectric refrigeration is inherently poor, when combined with a luminaire to create total environmental control, thereby utilizing the lighting heat as an energy source, it becomes very practical since we have sufficient low grade energy available from the lighting system to provide the required capacity to meet the space cooling requirements, eliminating the need to utilize additional input energy for refrigeration.

Utilizing a chemical dehumidifier to provide dehumidified outside air to the space at room state, we can achieve an over-all system coefficient of performance of 12.6, which approaches an ultimate over-all system efficiency from an energy standpoint.

In the illustrated example, the thermoelectric luminaire requires an energy input of 27.3 Btuh per square foot (8 watts) for lighting. 4.1 Btuh (15%) initially enters the space as light. This energy is degraded in the space and ultimately becomes a thermal load to be removed by the radiant panel. The remaining 23.2 Btuh is available to be utilized by the thermoelectric couple to produce the refrigeration effect of the radiant cooling. The radiant panel has sufficient capacity to handle the heat gain from people, floor power, and the lighting input (15%).

All of the sensible heat ultimately absorbed by the heat sink is transferred to the regenerator section of the chemical dehumidifier and becomes the energy input for dehumidification of the outside air.

The underlying philosophy of this system is to eliminate the energy waste associated with conventional systems which require high grade energy to provide refrigeration in order to collect high temperature lighting heat. To achieve this objective, the lighting, heating, and cooling systems must be interrelated so that we can utilize the available internal energy of lighting to provide both the heating and cooling requirements of the occupied space, creating temperature control on a modular basis throughout the structure.

This is the answer to lighting, heating, and air conditioning in the future. The thermoelectric luminaire provides heat-by-light, but, more important, it also provides cooling-by-light without additional refrigeration.

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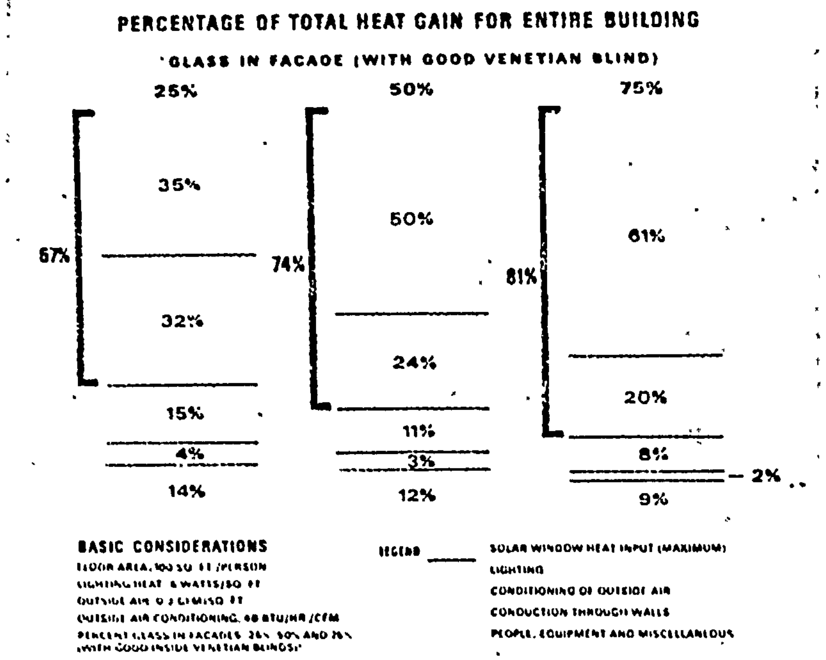
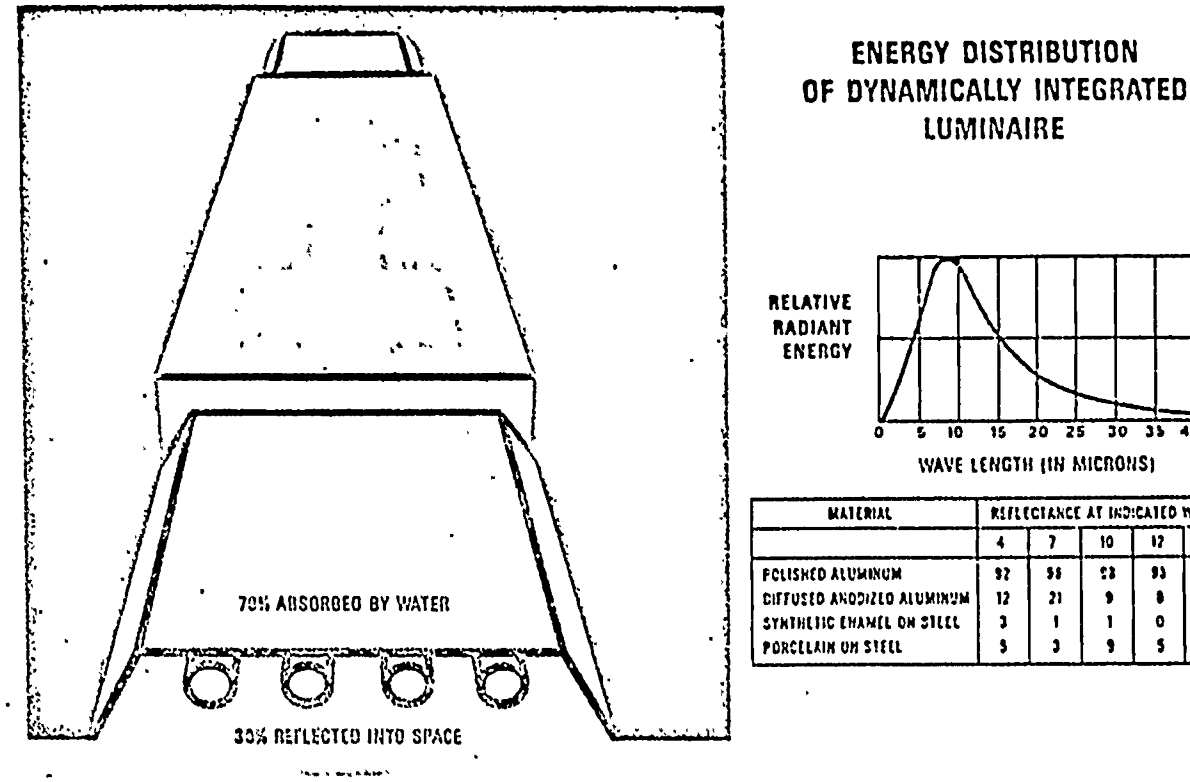


Figure 1.



MATERIAL	REFLECTANCE AT INDICATED WAVE LENGTH					
	4	7	10	12	15	20
POLISHED ALUMINUM	92	98	98	93	—	—
DIFFUSED ANODIZED ALUMINUM	12	21	9	8	6	6
SYNTHETIC ENAMEL ON STEEL	3	1	1	0	0	0
PORCELAIN ON STEEL	5	3	9	5	6	13

Figure 2.

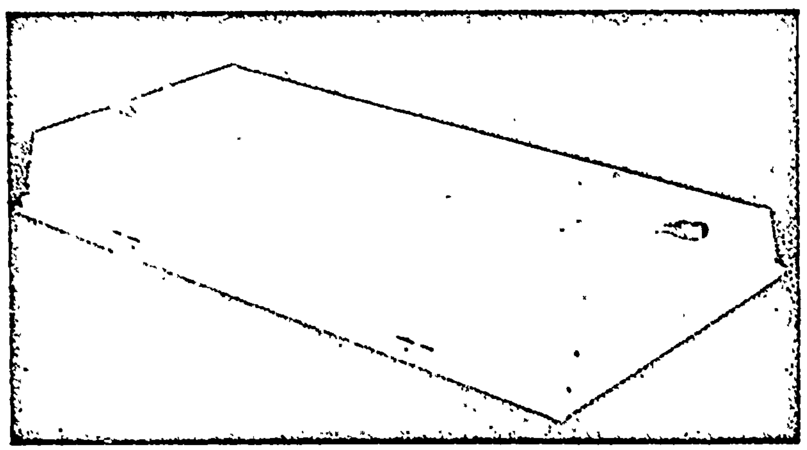


Figure 3.

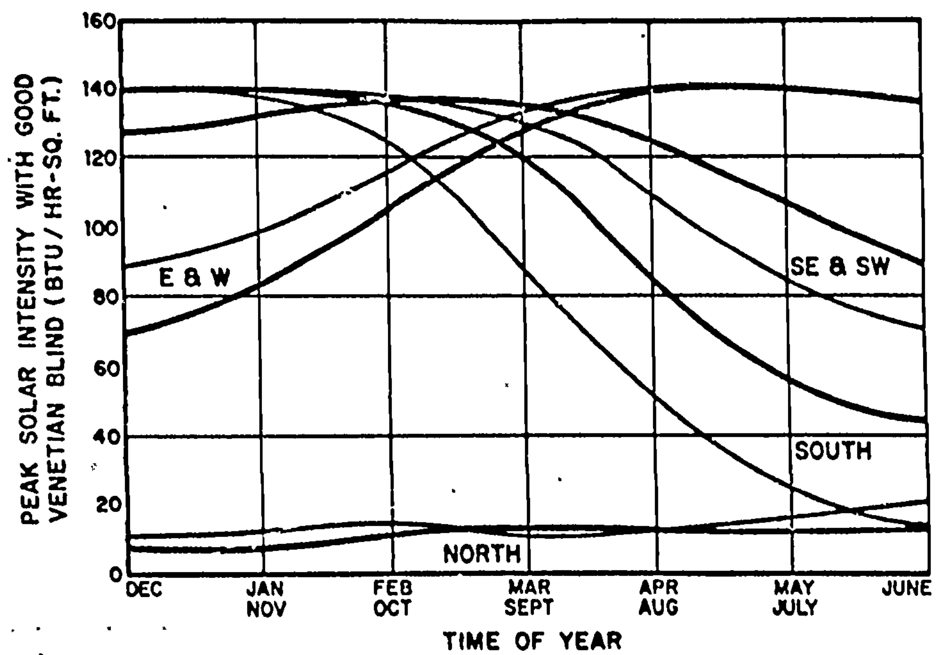


Figure 4.

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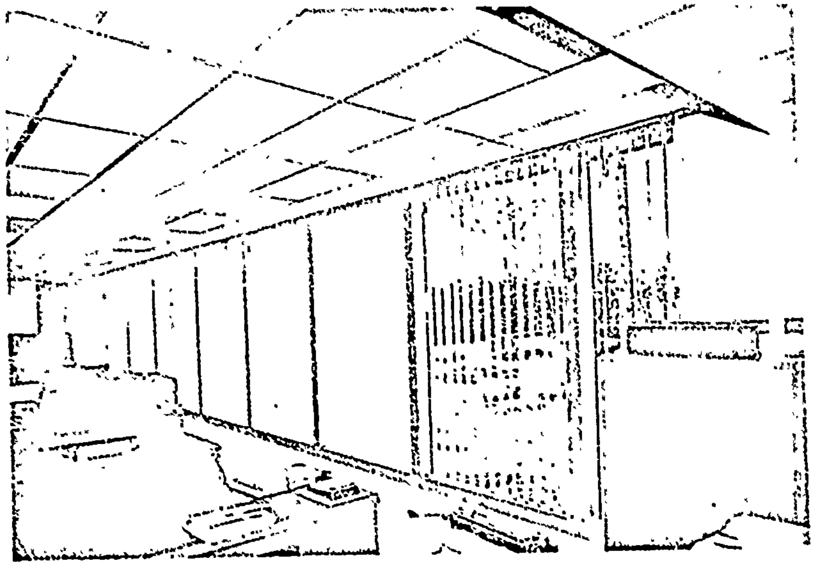


Figure 5.

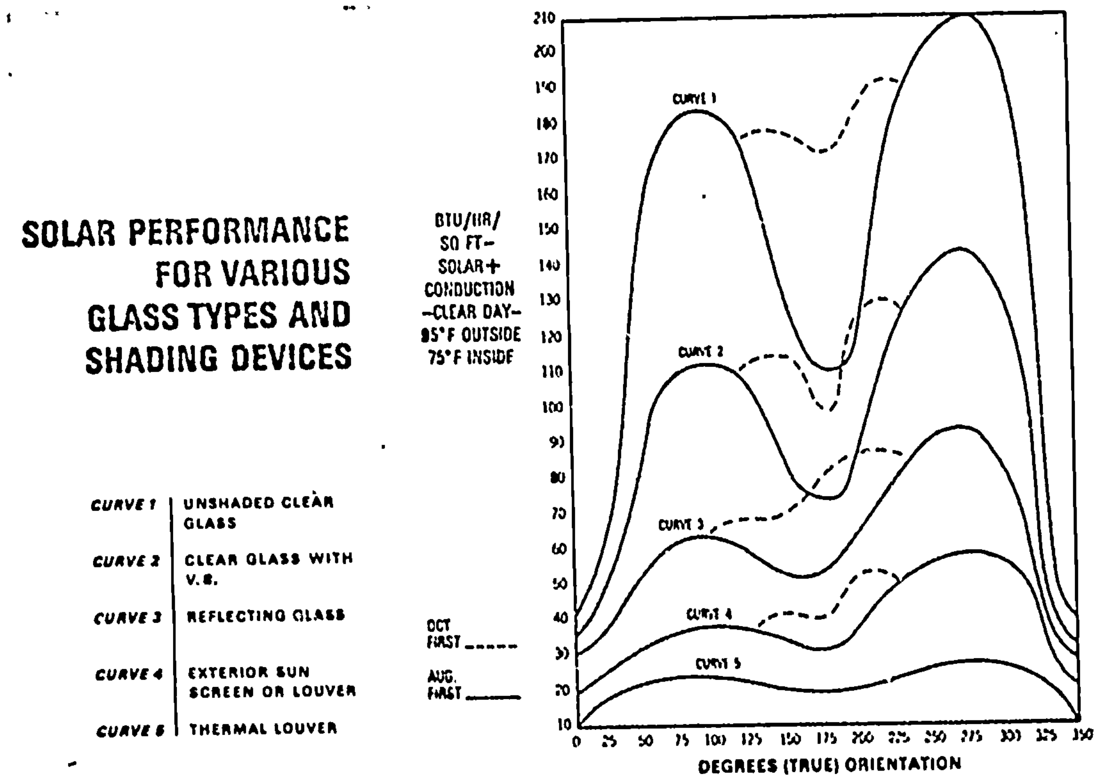


Figure 7.

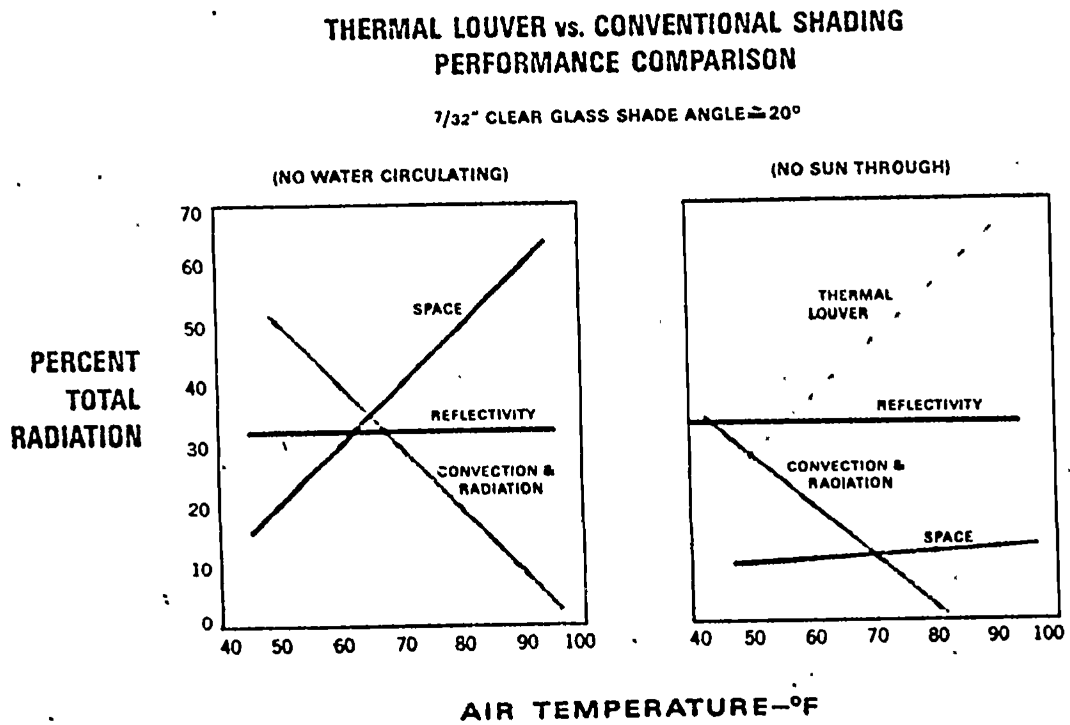
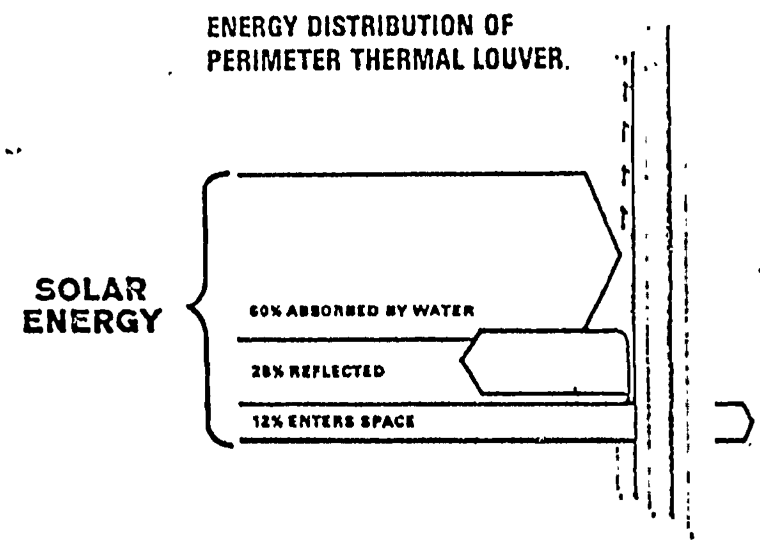


Figure 6.



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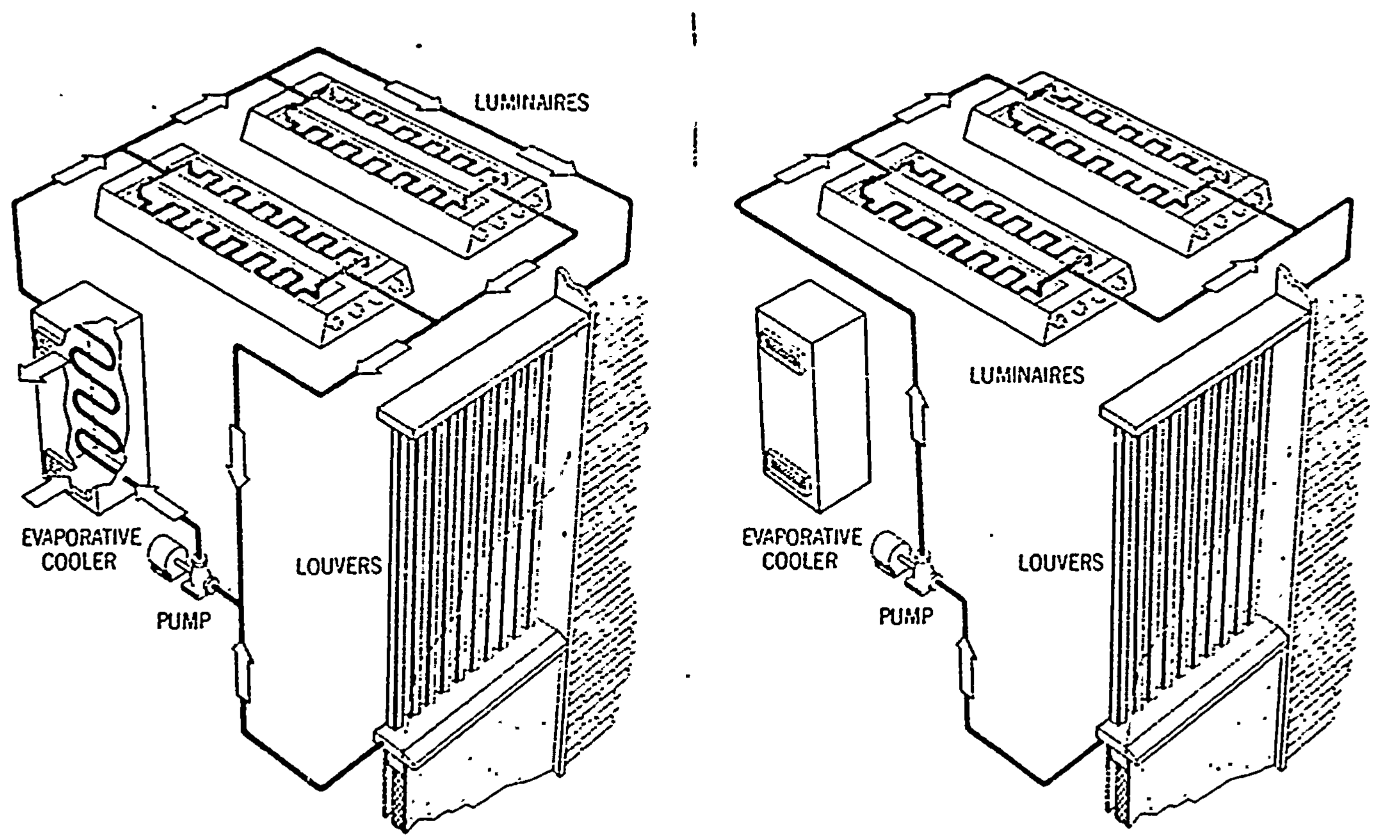
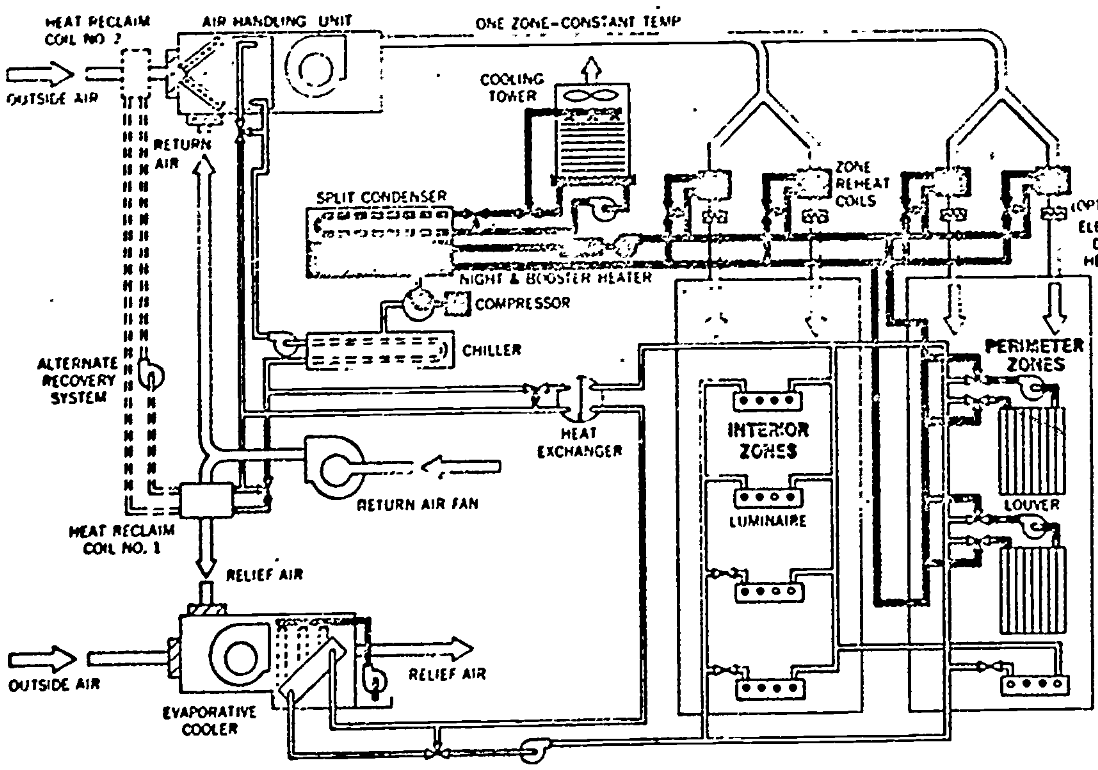


Lite-Therm Heat-Removal Arrangement -- Non-refrigerated water circulates continuously through Lite-Therm luminaires and Lite-Therm louvers. The water captures up to 70% of lighting heat and 88% of solar heat and rejects it through an evaporative cooler.

Lite-Therm Heat-Utilization Arrangement -- Heat from Lite-Therm luminaires is transferred to the Lite-Therm louvers to offset heat losses at the perimeter glass areas.

Figure 9.



Indirect Transfer Lite-Therm System -- A system using condenser water for radiant lighting heat redistribution in winter and non-refrigerated heat removal in summer.

Figure 10.

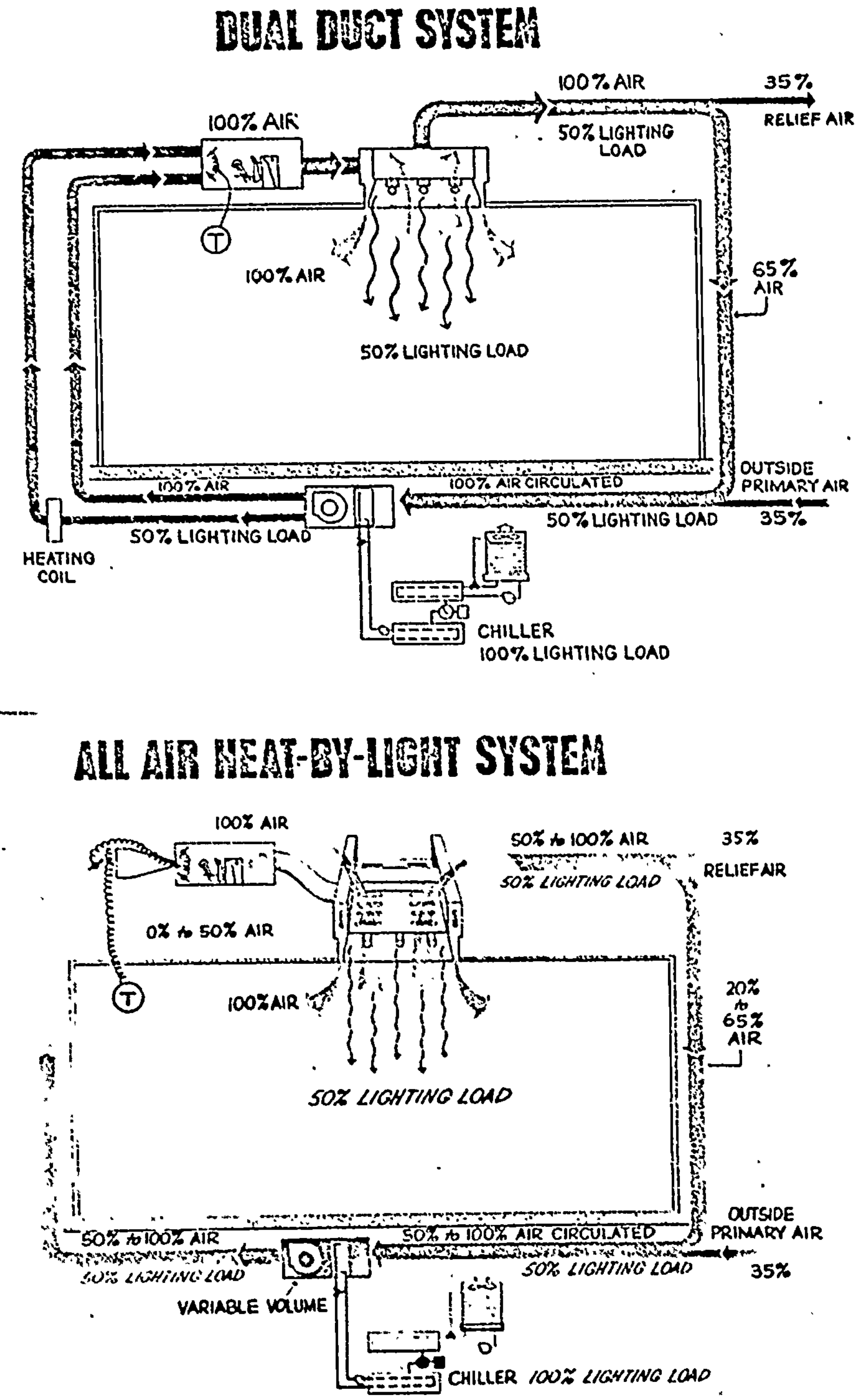


Figure 11.

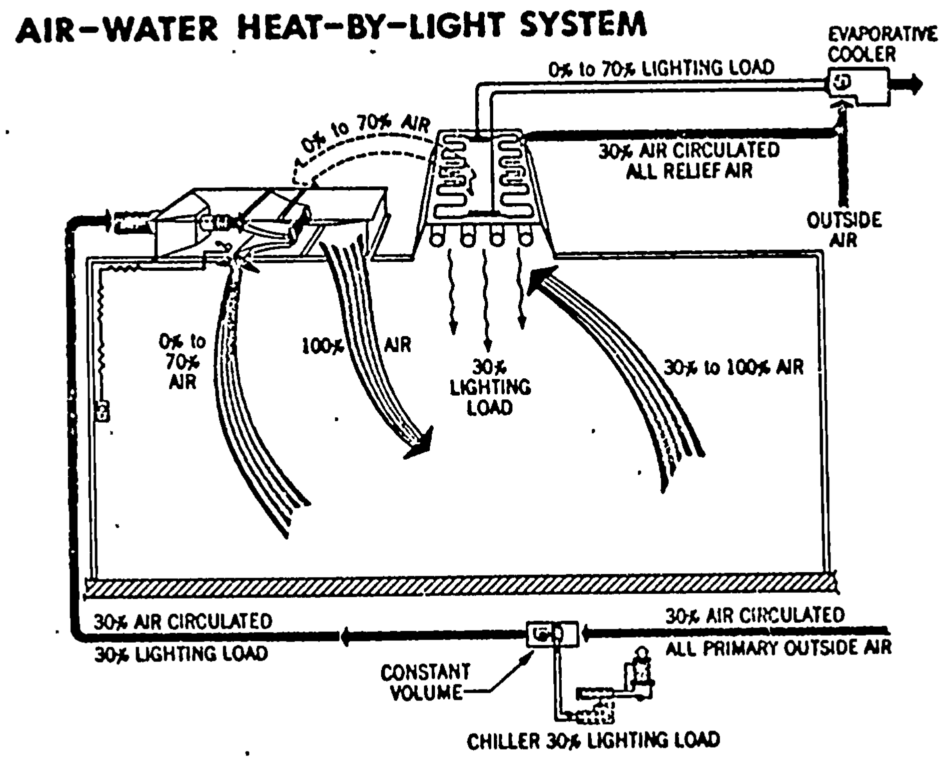
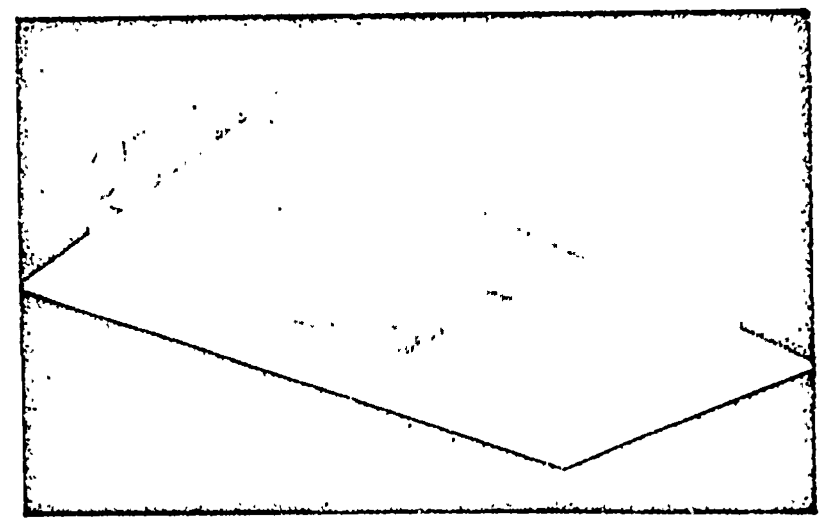


Figure 12.



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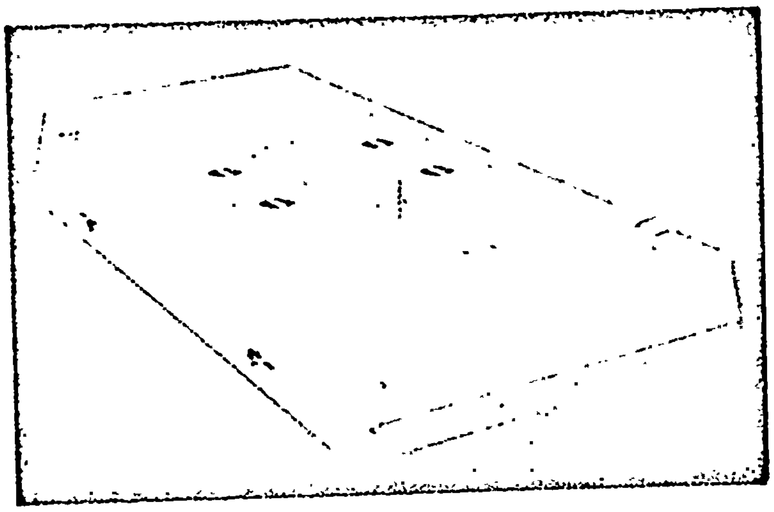

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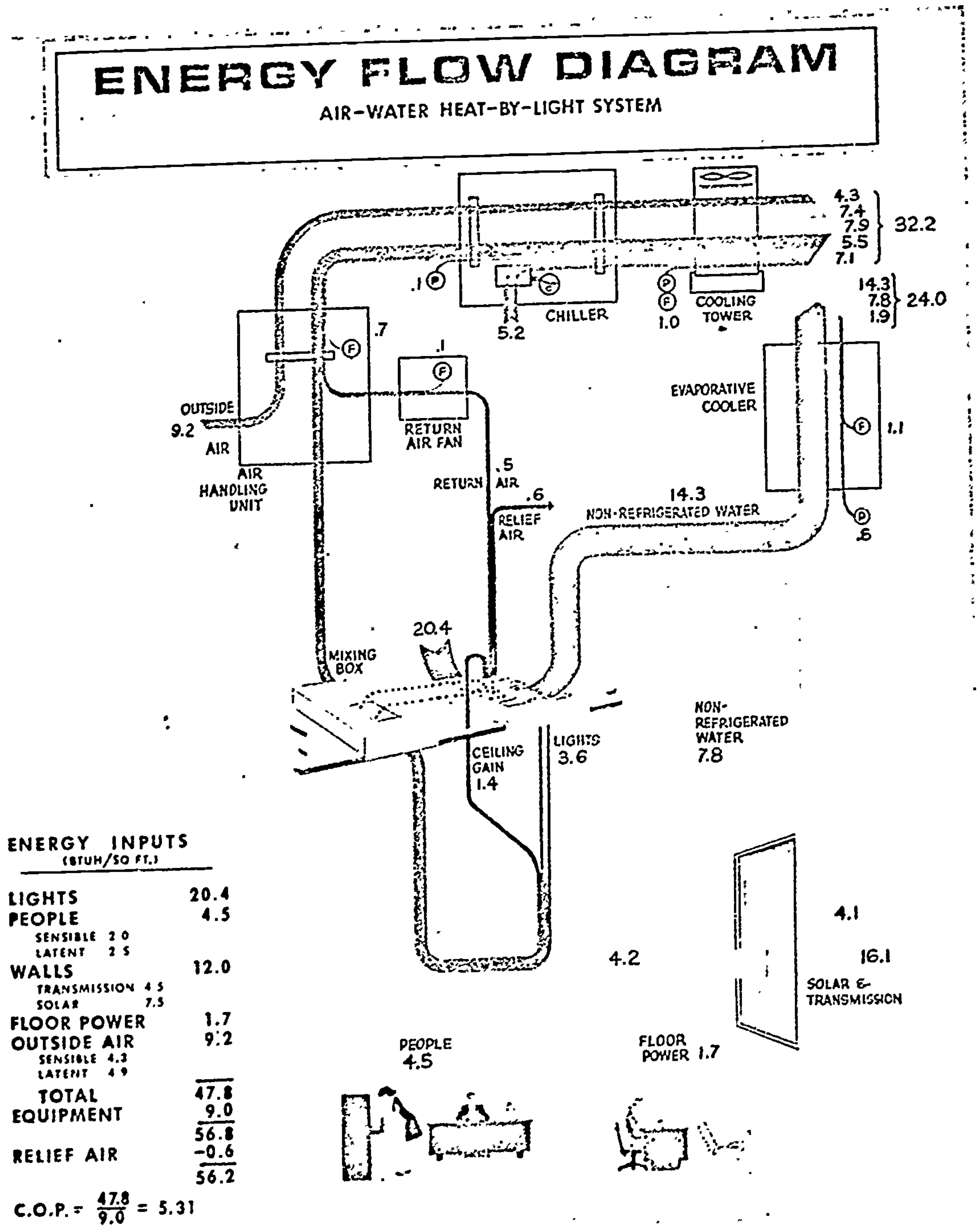

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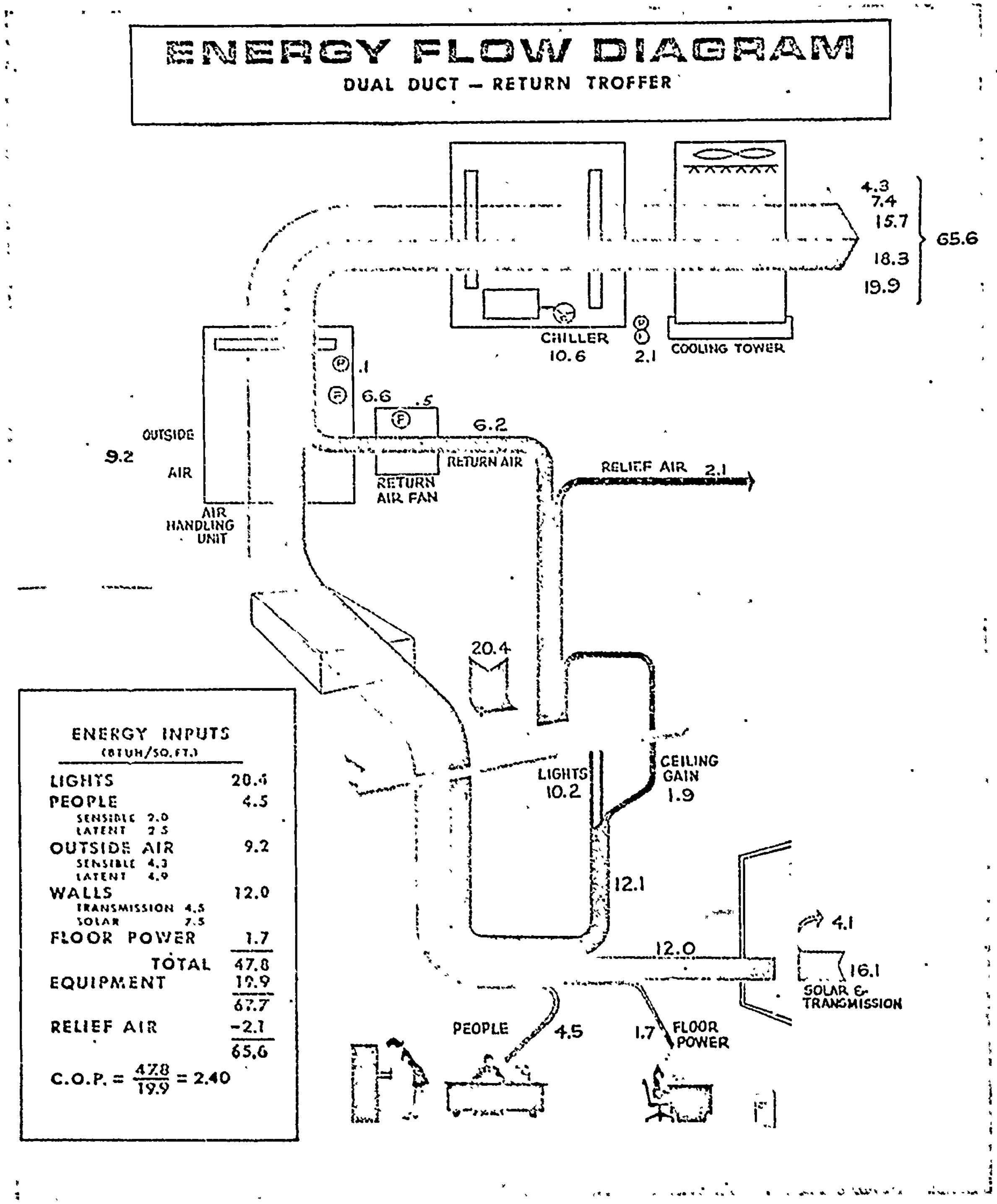
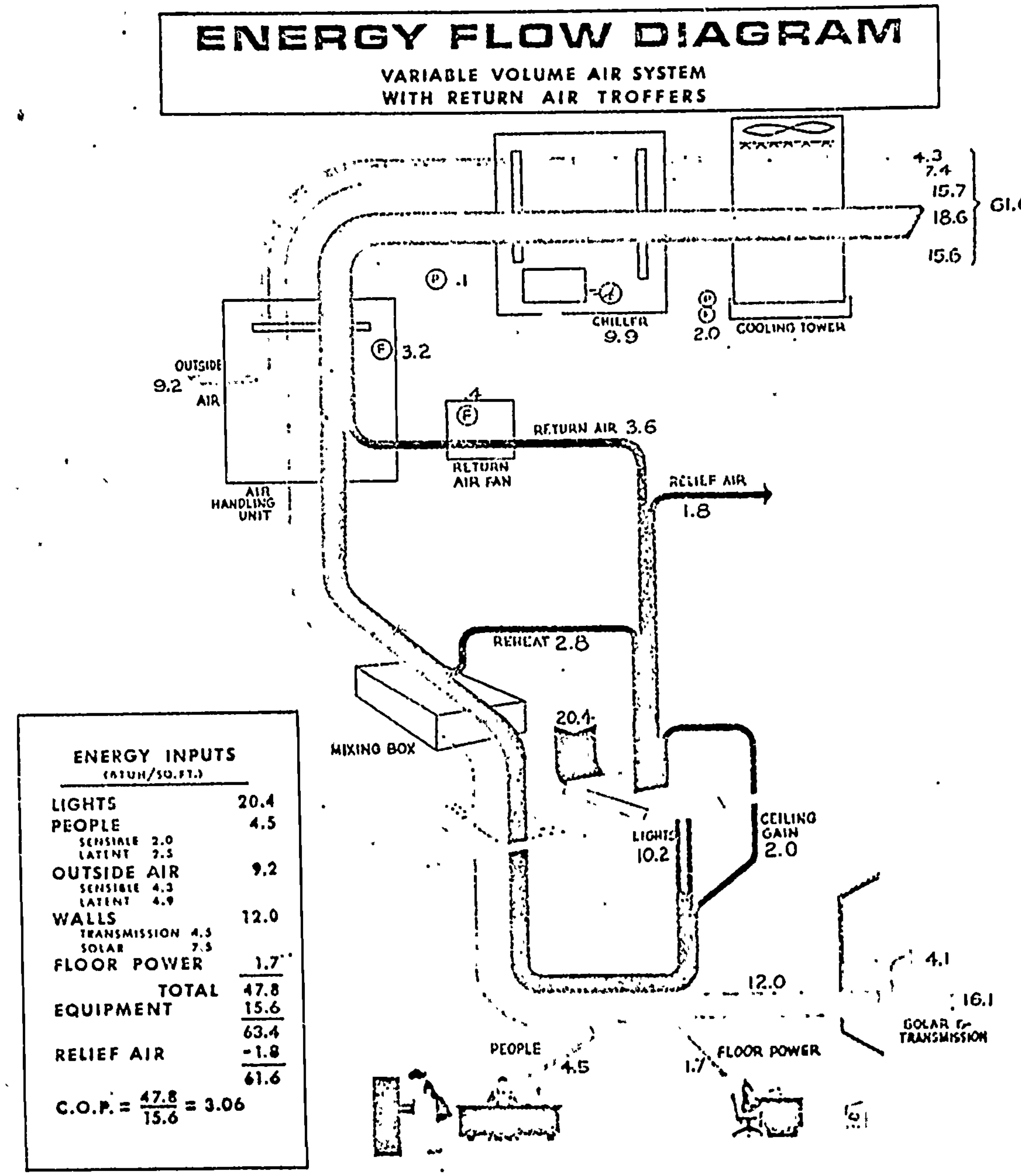


Figure 16.



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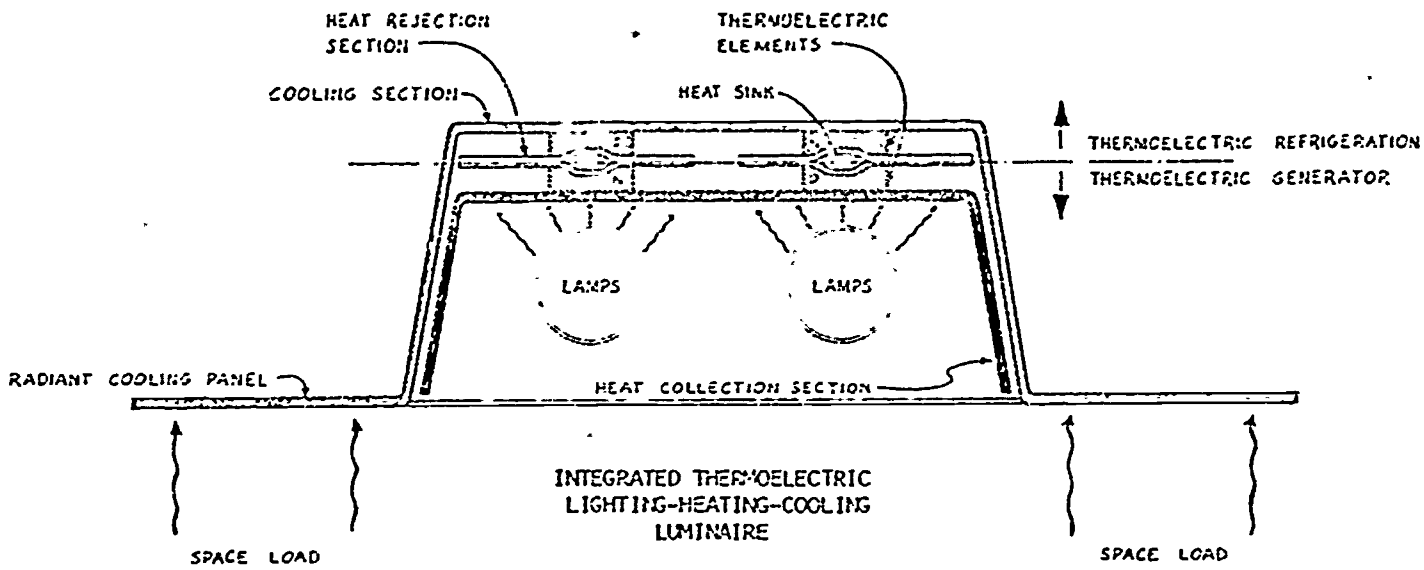

Figure 18.

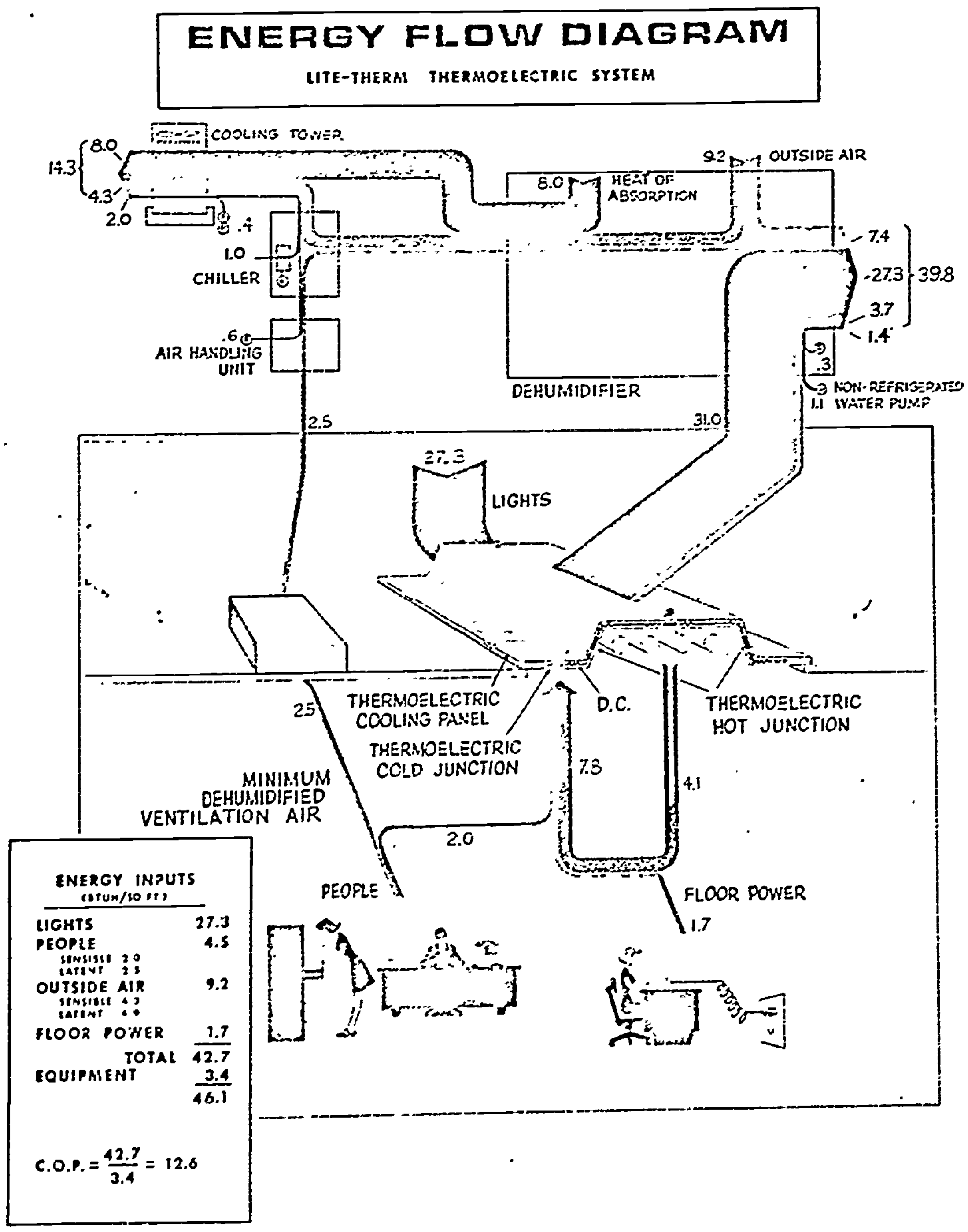

Figure 19.