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ABSTRACT

This publication attempts to provide some basic descriptions of the various systems and components of climate control and to point out some of the factors to be considered in the selection of the mechanical equipment. The principles of heat gain and loss and ventilation as they relate to a comfortable temperature are discussed. Illustrative figures accompany the written text. (Author)

Thermal Environment in Schools

$2.00

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Introduction

Guessing the occupation of people by the meaning they attach to the word "environment" is a favourite parlour game of semanticists. The economist, the social worker, the politician, the architect, the artist, the town planner, the agronomist, each attach a different or different shades of meaning to the word "environment". For the purposes of this report "environment" describes the "micro-climate" of spaces intended for teaching and learning, ie., schools.

After food man's most basic need is his need for shelter against the hostile elements of nature. Man is well equipped to survive wide fluctuations in his natural environment. If properly clad, he can withstand temperatures of —40°F for limited periods. On the upper scale he can survive in temperatures of 120°F. But man's optimal range of comfort, efficiency, and health lies in a relatively narrow spectrum. In his struggle for survival against the hostilities of nature, man has tried to improve the livability of his shelters by various means. From the open fire of the cave man and the wetted mats used to provide cool breezes for the Ancient Egyptians to the Victorian teacher alternately opening and closing windows, we have relics of man's attempt to control the micro-climate of his shelter in order to improve the "thermal environment". Although we have not reached the stage where the use of "space suits" is economically feasible, we have at our disposal techniques and technologies that enable us to achieve proper thermal environment by conditioning the spaces within which we live.

The aim of this publication is to provide some basic descriptions of the various systems and components, and to point out some of the factors to be considered in the selection of the mechanical equipment.

Although cooling systems are discussed at some length, there is no presumption that all or even a substantial number of schools will be so equipped. Where a school board determines that such a system is required, it may find some helpful comments in this brochure.

Thermal Equilibrium

Since in a purely thermal sense people are heat engines with 20% efficiency, the 80% inefficiency must be catered to at all times. Thus, the proper thermal environment must be provided in order to maintain the required equilibrium with our surroundings.

A balance sheet of BTU gains and losses in the "typical classroom" (see figure 1) indicates the prevalence of the following conditions:

	BTU/HR.	
	Debit	Credit
1. 35 bodies, each producing 400 BTU per hour		+14,000
2. Lighting of approximately 70 foot-candles at 3 watts per square foot x 3.4 BTU per watt x 720 sq. ft.		+7,400
Thus 21400 BTU per hour heat must be removed (or harnessed) every hour in order to maintain thermal equilibrium.		
3. Assuming 720 sq. ft. of insulated roof, 250 sq. ft. of insulated outside wall area, and 150 sq. ft. of single glazed window area, heat loss at 0°F outside temperature	—24,000	
Thus on a cloudy 0°F winter day this typical classroom would have a deficit of —2,600 BTU per hour and require supplementary heat.		
At +10°F on a cloudy day this room would be in thermal equilibrium. During +10°F periods of sunshine the solar gain through glass facing east or west in September would represent a credit of 29,600 BTU per hour for east or west exposures. Even in December the south exposure would have an excess of 21,000 BTU per hour due to solar heat gain.		

It is thus apparent that the removal of excess heat can be more important than the addition of heat during most of the school year.

A study of meteorological data in a southern Ontario city reveals a graph (as shown in figure 2) indicating the mean average of the number of the minimum and maximum days when the maximum outside temperature would likely exceed the indicated isothermal lines. In order to provide an indoor temperature of approximately 75°F utilizing approximately 1,000 CFM of air, a supply air temperature of 55°F would be required. The graph indicates that, even ignoring the summer months, about 40% of school days would have outside air temperature in excess of 55°F. This indicates the need for artificial cooling in order to provide thermal equilibrium in the classrooms during the school year.

Figure 1: Heat gain and loss

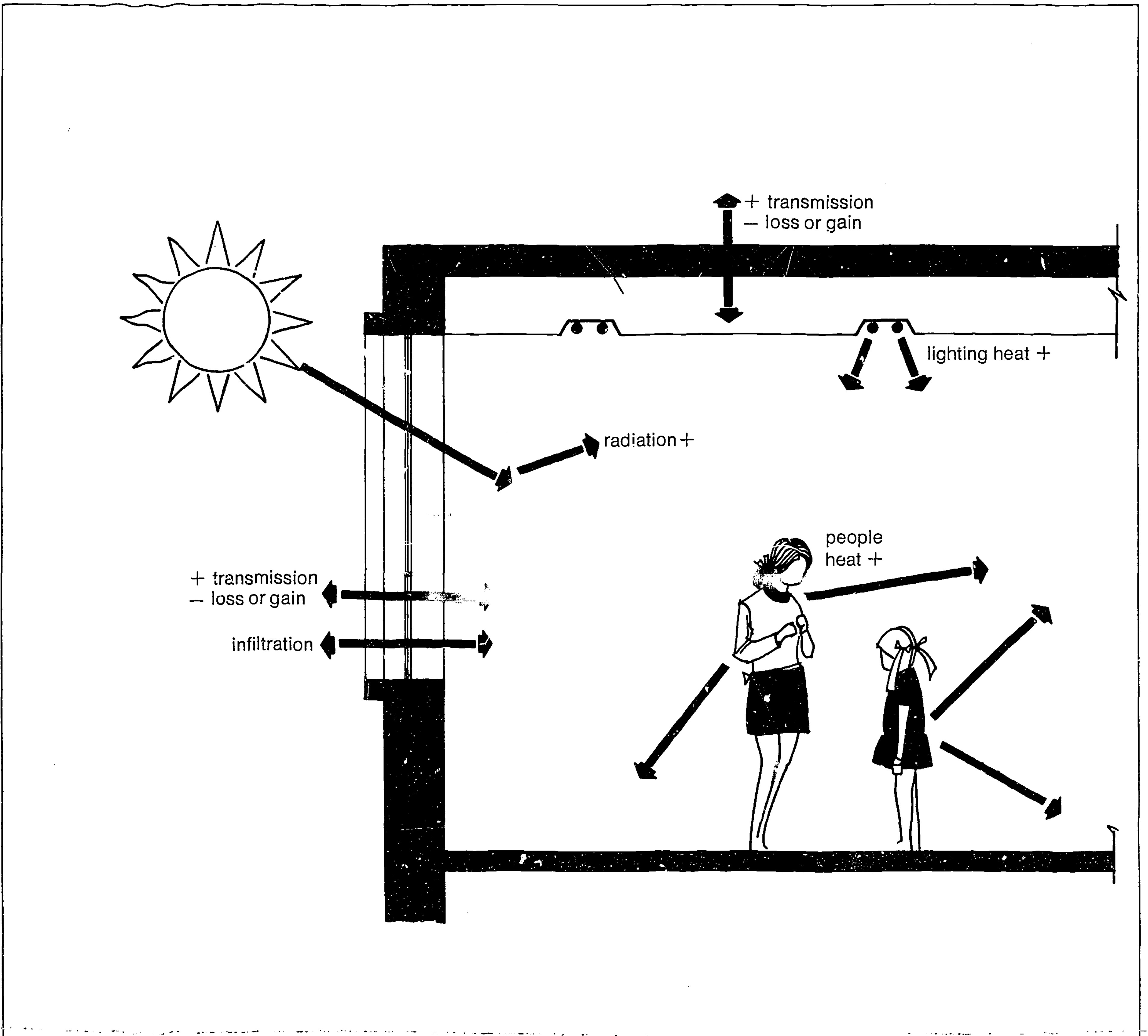


Figure 2: Mean of minimum and maximum number of days when maximum temperature exceeds indicated temperature

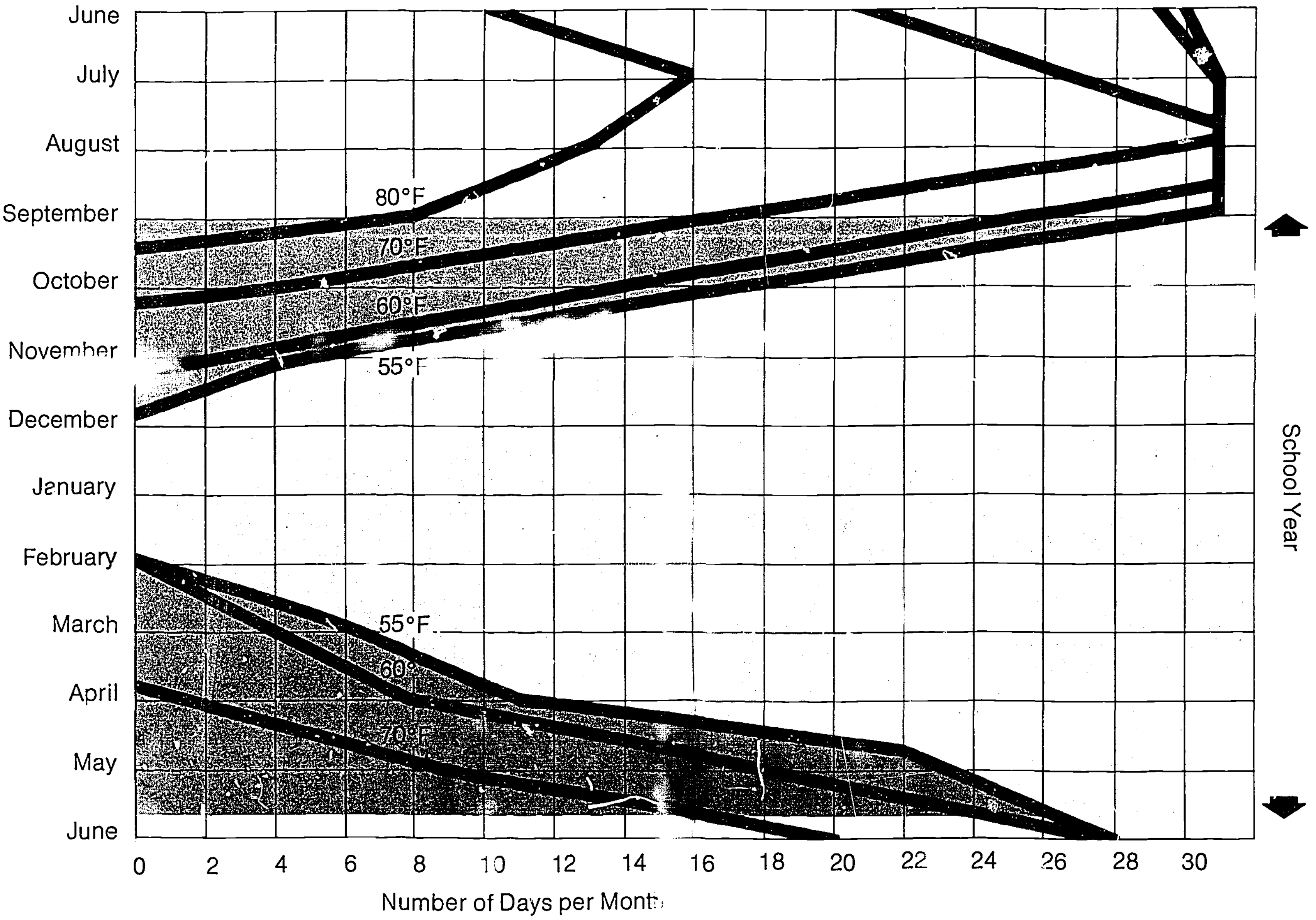


Figure 3: Relationship of parameters

	A. Environment	**B. Activity**	**C. Cost**
1	A1 *Temperature* heating temperature tolerance cooling temperature tolerance	B1 *Metabolism* sex age dress activity: I/lying (290 BTU/HR) II/sitting (420 BTU/HR) III/walking ([illegible] BTU/HR) IV/running ([illegible]0 BTU/HR)	C1 *Capital Cost* mechanical electrical structural architectural construction time
2	A2 *Humidity* dehumidifying humidifying	B2 *Health* shock respiratory	C2 *Operational cost* fuel electricity personnel maintenance operation period
3	A3 *Air motion and changes* velocity stratification total air changes	B3 *Contamination* from within space: — smoking from other sources: I/chimneys II/building exhausts from adjacent spaces: I/food II/dust	C3 *Owning — operating cost* amortization depreciation taxes obsolescence
4	A4 *Ventilation* fresh air quality fresh air quantity air pressure control	B4 *Air patterns velocity*	
5	A5 *Air cleanliness*	B5 *Selectivity*	
6	A6 *Noise and vibration*		
7	A7 *Flexibility*		

Relationship of Parameters

An analysis of space conditions and functions leading to the best selection of systems involves the simultaneous evaluation of many parameters which can be classified under three interrelated headings:

a) Environment
b) Activities
c) Costs

(Refer to the accompanying illustration — figure 3)

Metabolism
The heat regulatory mechanism of the human body ensures that the vital inner organs remain protected. Adjustments in the circulatory system, control of muscular activities, and such regulative processes as perspiring maintain the required deep body temperature of 98.6°F.

The human body has adequate tolerance to withstand very wide fluctuations in environment for limited periods. However it performs best in a relatively narrow range — between 60°F to 80°F — particularly over a lengthy period. Optimum efficiency and health seem to coincide with the comfort range.

Clothing naturally affects this equilibrium state in that it moderates the effects of environment.

A person's *sex* seems to have a bearing on his or her temperature requirements. The skin temperatures of women are approximately 1.8 degrees lower than those of men. Their heat regulation is in equilibrium over a wider range than that of men. They seem to prefer temperatures about 1 to 2 degrees warmer than those preferred by men.

Age also has a bearing on temperature requirements. As people get older their metabolism decreases, and they require a temperature that is about 1 or 2 degrees higher than that preferred by younger people.

Health. Observations in industry indicate that the influence on performance is considerable. High accident rates are related to excessive temperatures. Climatic variations can result in increased spreading of communicable diseases. An increase in intestinal infections and heart conditions has been related to environments characterized by high temperatures, and a similar in [illegible] in respiratory infections has been noted under conditions marked by low temperatures. The effect of humidity on efficiency and comfort is pronounced, but with a wider latitude than temperature.

Effective Temperature

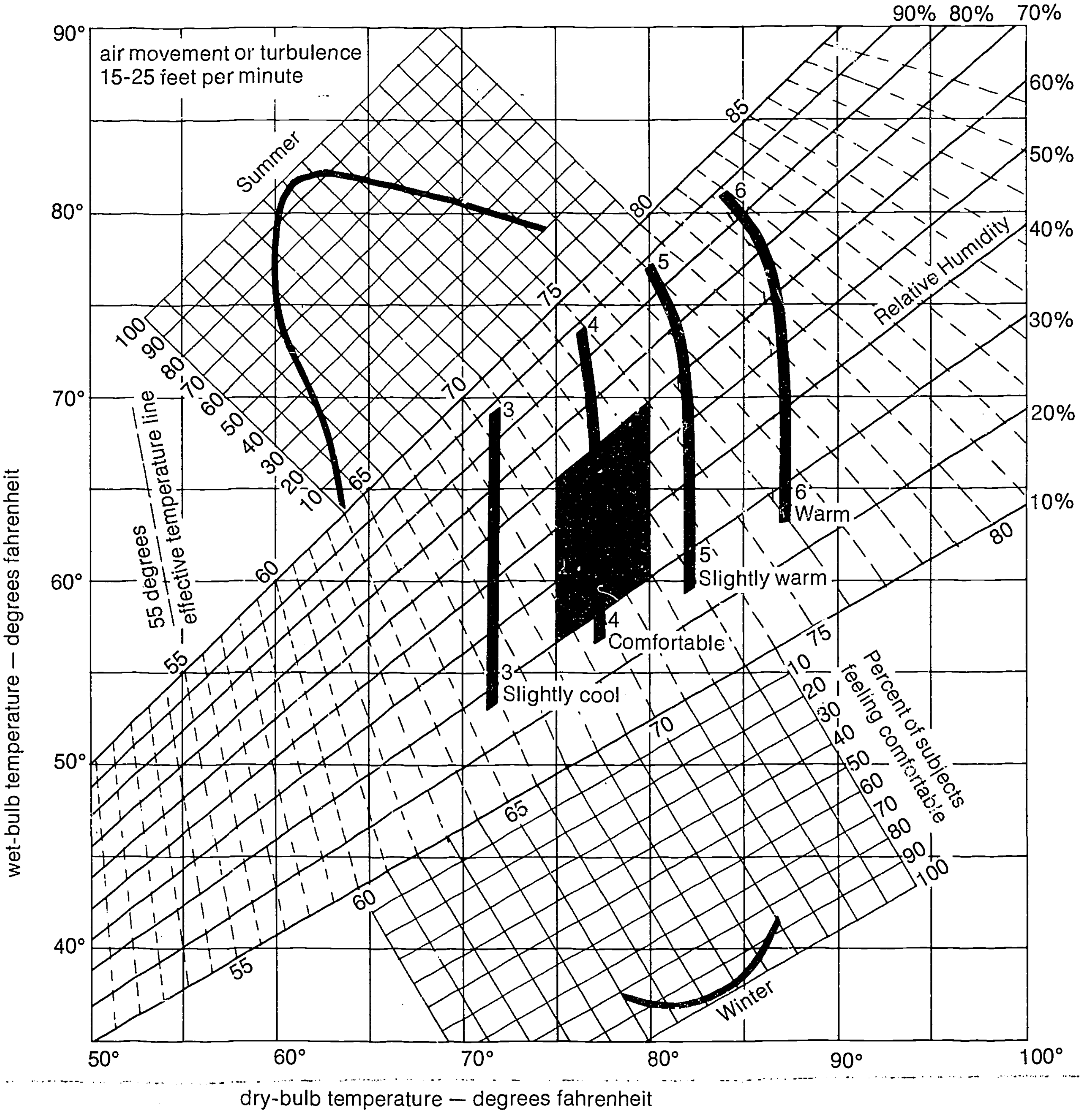
figure 4

To describe relative comfort in numerical values researchers established an index called "effective temperature". This is a function of dry bulb temperature and relative humidity and is related to air velocity. The effective temperature chart is produced on a base velocity of 25 feet per minute by plotting combinations of relative humidity and dry bulb temperature. Experiments based on the reactions of test subjects exposed to various room temperatures indicated a preference for around 71.5 dry bulb in summertime and 67 to 69 degrees under winter conditions. However, recent tests indicate that for sedentary individuals the most comfortable range is around 76° dry bulb temperature, with relative humidity varying between 30% to 60%. These lines of relative comfort appear to be constant in summer and winter, which is probably due to the fact that our modern summer and winter clothing seem to vary little. The chart indicates that changes in relative humidity have a greater bearing on comfort at elevated temperatures.

Rate of Temperature Change
Most people will not be conscious of a 2 to 3 degree effective temperature change if it is imposed gradually. However sudden changes of even half a degree will be noticed by most people.

Radiation
Radiation between the human body and its surroundings has considerable effect on comfort. In the effective temperature range of 70° to 80°F a drop of 1.4°F in effective temperature can be compensated for by a 1.0°F rise in the mean radiant temperature of the space. (Mean radiant temperature is the arithmetic average of all surface temperatures of the space.) It should be remembered that conduction and convection heatflow vary directly with temperature, while radiant interchange is a function varying with the difference of absolute temperatures to the fourth power. Uncontrolled radiation will be the cause of great discomfort. Sunlight streaming through windows, high radiant output lights or apparatus will cause discomfort even in spaces with effective temperature control. This problem may be particularly acute in such places as auditoriums or classrooms where an interchange of radiation occurs among people seated in close proximity to one another. To compen-

Figure 4: Effective temperature



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Ventilation

sate for higher radiant effect, a lower effective temperature may be helpful.

It is possible that an environment maintained at theoretically comfortable temperatures and humidity may still cause discomfort. High radiant sources such as lamps and low air velocities may have to be offset by lower effective temperatures. Similarly, in spaces where large numbers of people are gathered, such as auditoriums and assembly rooms, generally higher air change is desirable. A 70° - 72° room temperature may be comfortable for an audience entering a space, but after being seated for an extended period they will find it too low. A space temperature of 75° or 76° would be more desirable, but must be accompanied by a higher air change rate.

In safeguarding the body, metabolism reacts by producing both sensible and latent heat. This is a function of the effective temperature and the body's activity. The total basal heat production of a body at rest is 290 BTU per hour, of which approximately half is sensible heat and half latent. With activity, the total heat capacity increases rapidly, but while the sensible heat will rise to 580 BTU per hour the latent heat increases to 1,200 BTU per hour.

In addition to providing a comfortable thermal environment, the atmosphere of an enclosed space should be free from undesirable odours and irritants, such as dust, smoke, and fumes. Ventilation may consist of the replacement of air within an enclosure by air drawn from the outside or the recirculation of air within an enclosure; in either case, it includes, theoretically at least, processes whereby the air is treated, heated, cooled, filtered, humidified or dried. The minimum fresh air requirement for purposes of dilution is dependent upon the number of occupants, the space per person, the purity of the air, and the activities of the occupants (see figure 5). To replenish the oxygen requirements of the space requires only 1 cfm per person. To get rid of the harmful effects of carbon dioxide within the space requires 4 cfm per person. The quantity of air required to remove odours is a function of space per person. The curve indicates that 30 cfm of odour-free air are required for a hundred cubic feet per person. At about 250 to 300 cubic feet per person this requirement is reduced to about 15 cfm. Since in Southern Ontario we must provide 4 tons of refrigeration for every 1,000 cubic feet per minute of outside air, the fresh air component of total air circulation must be scrutinized closely.

Consideration must be given to the occupants' activities in conjunction with the population density of the space. Tobacco smoke has a great effect upon the amount of air required for ventilation. Cigarette smoking requires about 25 cfm of odour-free air per person and cigars need 50 cfm per person.

An auditorium with one person for every 8 to 12 square feet must be considered differently from an office. Due to the close proximity of people in an auditorium, odour control is extremely important, but the provision of fresh air above the minimum requirement per person becomes extremely costly. On the other hand, the relatively large allowance of space per person in a private office reduces the sensitivity to odours, and the cost of providing the quantity of fresh air required per person for a limited number of offices is not exorbitant.

With the increasing pollution of our air, the amount and quality of outside air to be mixed with recirculated air should be based on an evaluation of "fresh" air quantity versus the degree of treatment of the air mixture.

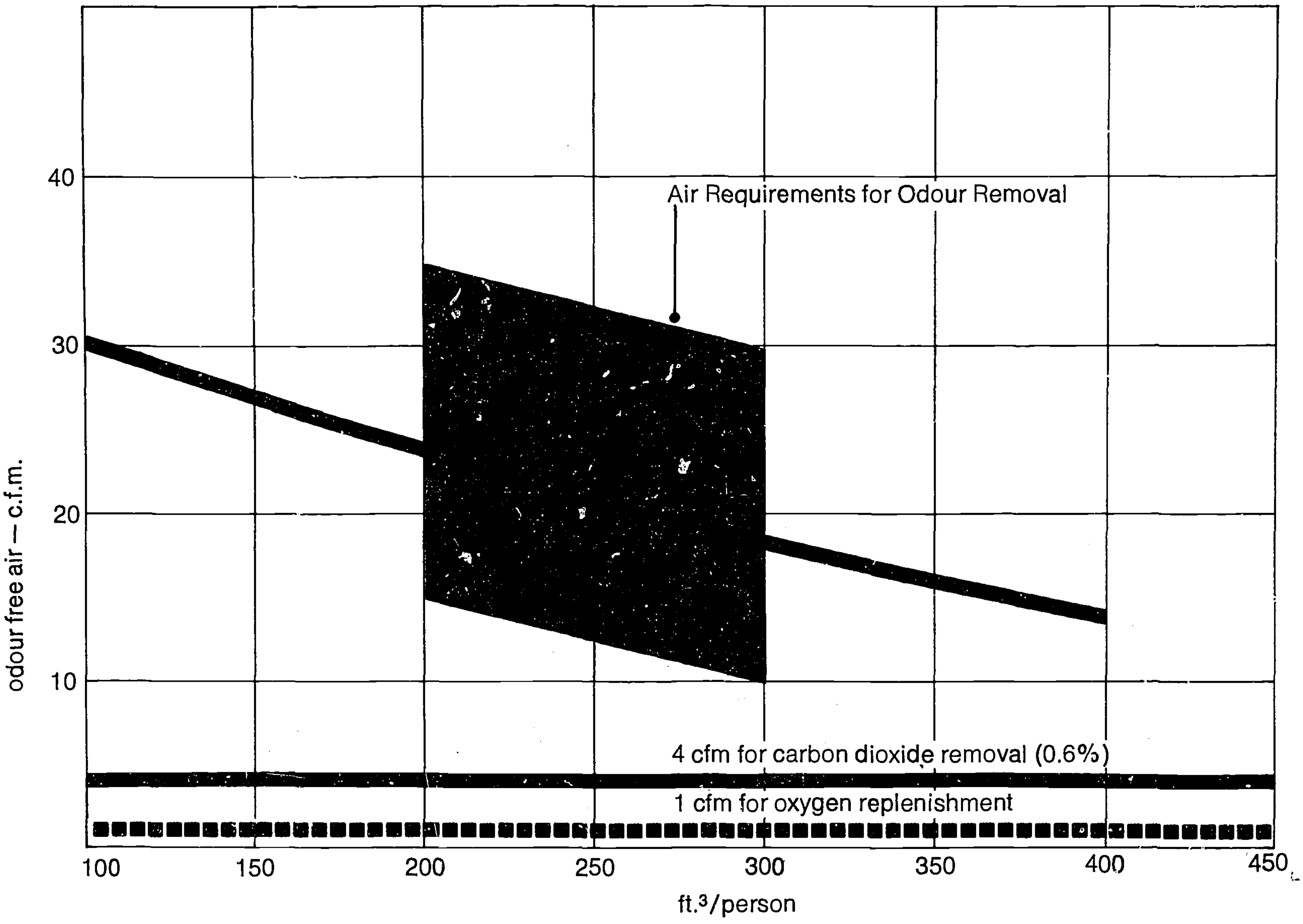
For optimum comfort and efficiency the total treated air circulation is a function of the space per person, the percentage of outside to total air, and the activities and duration of peak attendance periods. Even though the required effective temperature may be maintained with less air circulation, the total should be at least four to six air changes per hour for lightly populated spaces, or 15 cfm per person in assembly areas.

Areas with heavy air contamination, such as kitchens, laboratories, or shops can be best served by removing the irritants at or close to the source by means of hoods and canopies. The shape of the hood, its capturing velocity, and its location will determine its efficiency. If all the experiments in a laboratory could be performed within the hoods, their function would be most effective and the cost of replenishing exhaust air could be at a minimum. Open-face hoods are dependent on the capturing velocity across their face area. The air velocities entering a hood or a grille have a parabolic velocity pattern so that the capturing velocity of a hood diminishes in relation to its distance from the source. Hood face velocities should be between 75 to 150 feet per minute. The quick opening of a door results in an equivalent velocity of 100 feet per minute. It is apparent that hoods should be located as far as possible from disturbing traffic.

Air Pressure Control

Closed spaces can be pressurized by increasing the fresh air component of the total air circulated to a quantity above that of the air being exhausted or relieved. Odour- or dust-producing areas should be kept at a slightly negative pressure in relation to their surrounding spaces. Factors of construction and movement make it difficult to control relative pressures within degrees of accuracy and stability that can be instrumented. The porosity of walls and the air gaps around windows or doors allows a certain amount of air to migrate. The movement of air caused by opening doors, wind

Figure 5: Ventilation for people



pressures, and thermal activities within spaces can upset the recommended pressure balances.

In high-rise buildings the natural Stack Effect introduces another variable into air pressure relationship. In cold weather the lower floors will be under a negative pressure with resulting infiltration of outside air, while floors above the neutral axis of the building will have excess pressure with the heated inside air escaping to the outside. Smoke produced by fire moves quickly from positive to negative pressure zones. Since the danger to occupants resulting from the spread of smoke is even greater than that of fire, increasing attention must be paid to the relative pressures between excavation routes, such as corridors and stairs, and areas that present potential fire hazards, such as laboratories, shops, or storage areas.

Since warm air is lighter than cold air, *stratification* can result in the vertical (and in some instances in the horizontal) plane. Air inlets and outlets as well as control locations should be selected to prevent this pocketing and deviation from space temperature setpoint.

Drafts

Different parts of the human body react to drafts with varying degrees of sensitivity. The neck and ankles are particularly sensitive. Air velocities much in excess of 40 feet per minute should be avoided around these regions. Higher velocities may be permitted at the level of the forehead, where they contribute to comfort. Sudden fluctuations in air motion will result in excessive draft. Relatively low air velocities accompanied by cold temperatures will have the same result, while higher velocities accompanying warmer temperatures will produce acceptable air movement.

Filtration

Outside air and recirculated air must be cleaned of dirt particles. Dirt is classified by its origin, weight, volume, physical state, and chemical composition. Large particles which are the heaviest, are normally captured by roughage filters whose efficiency is measured in percentage by weight of particles captured. The greatest number of dirt particles in the air by volume is five microns or less. These small particles contribute most to the dirt that accumulates on ceilings, furniture, and clothing. They must be captured by high efficiency bag-type or electronic filters. The efficiency of these filters is measured in optical comparisons of grayness.

Odours may be introduced by occupants, by their activities, or by the introduction of outside air. Sensitivity to smells varies among people. Nasal membranes become quickly desensitized to odours. Thus people within odiforous spaces may be relatively unaware of an unpleasant atmosphere, while the newcomer will be acutely conscious of it. Sensitivity and reaction to odours will vary from time to time and person to person, depending on state of health, age, sex, and recentness of exposure to odours.

Odour perception is related to space temperatures and humidity. Irritation due to smoke and odours will be minimal in the 45% to 60% relative humidity range. Some of the materials used in the construction or decoration of a building will absorb odours and emit them, particularly under high humidity conditions. For the same reason, the amount of "fresh" outside air to be introduced and the type of treatment required to "purify" the mixed air require continual study and financial evaluation. With the ever increasing pollution in our downtown areas, the location of fresh air inlets in relation to odour or gas emitters is very important. Height and location of building chimneys and fume outlets in relation to building air inlets are very important, since the leeward suction zones created by the wind envelope around buildings can contribute to self-pollution.

Noise and Vibration

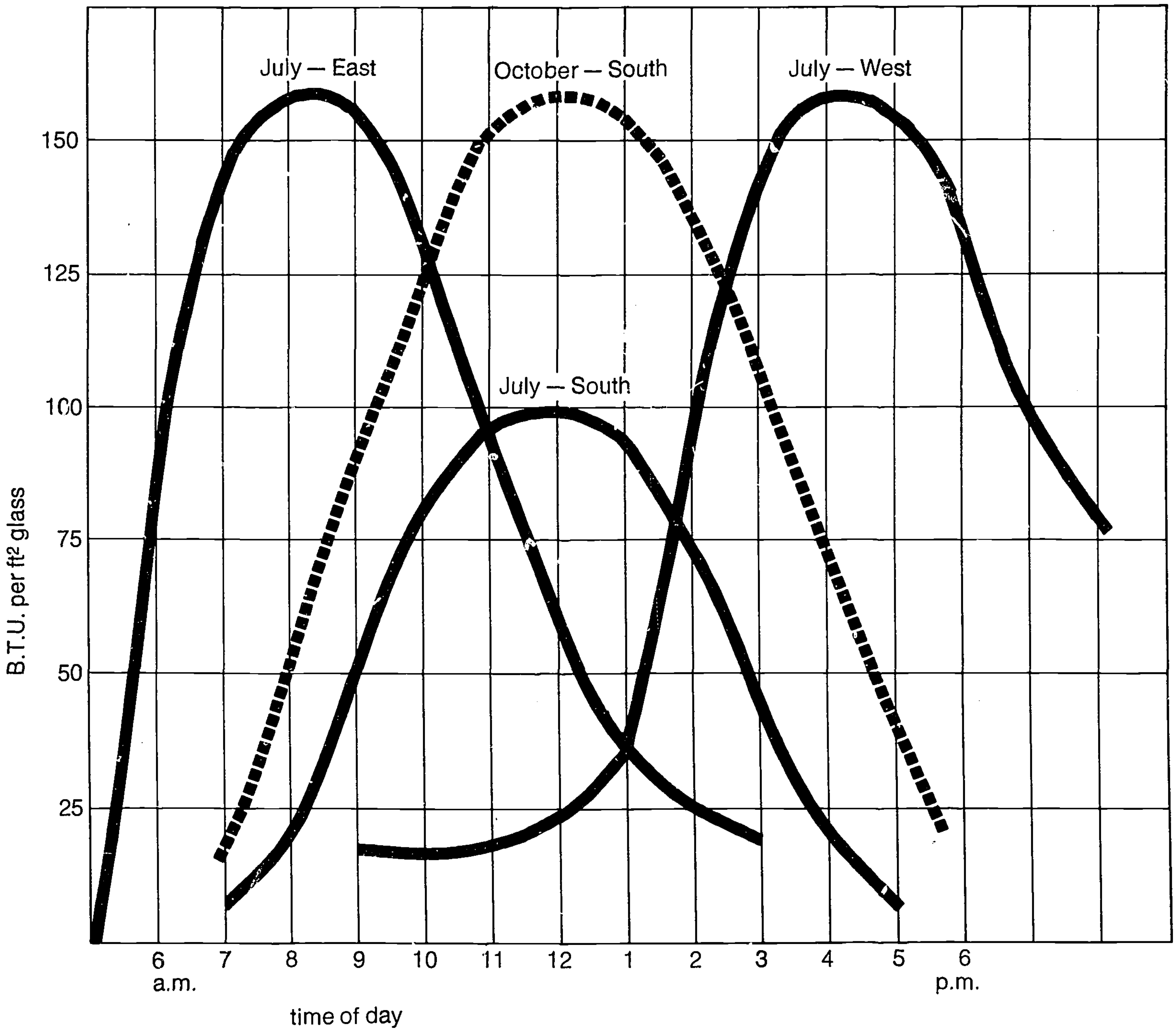
Reciprocating and rotating equipment generate noise and vibration. Equipment selection and design, treatment of the premises where the equipment is kept, and their location in relation to the noise-sensitive regions of the building determine the amount of sound being transmitted. Care must be exercised not only in the selection, location, and installation of the equipment, but also in the elimination of sound and vibration that might be transmitted through piping and ducting systems. Similarly, noise created by fluids flowing through conduits and sounds emitted through space terminals must be eliminated.

A factor termed *flexibility* requires consideration. The variables to be considered in assessing the impact of "flexibility" on the environment include the type of space usages, the duration of each designated activity, and the number of usage changes for various periods (ie., number of changes during a school day per curriculum period, or during a building life span). Provision for any of these factors can seriously affect capital and operational costs.

The term *"module"* may be a suitable dimension designation when used in connection with construction and design of structure, ceiling grid, and even lighting, but could be inappropriate if applied to mechanical systems. The variables involved in the thermal environment, such as, inside and outside temperature and humidity, numbers of people, and lighting changes, are important factors in the selection of the economical "thermal" module.

The *selectivity* criteria for temperature and humidity require careful consideration. With innovations such as the "open plan" for teaching areas, allowing movement of students and audio-visual teaching in darkened rooms the selection of space temperatures and the ranges required may vary between time modules. An active seminar room and a quiet teachers' study may require different temperature selections. When a space is darkened for showing slides or films, it will produce a different load and require a different response than when it is used, for example, as a laboratory. The humidity selectivity can be carried over a broader range. It should be remembered, however, that the area requiring the highest humidity will affect all other areas. It is nearly impossible, without exercising considerable precaution in the construction and placement of air locks, to have a variation greater than 10 per cent relative humidity between various portions of a building. Condensation on the inside surfaces of cold walls or windows will often have a detrimental effect on achievement of the highest humidity that can be carried safely.

Figure 6: Solar intensity curve, Toronto, Ontario



Building Envelope and Thermal Environment

The surfaces surrounding a space are an integral part of the environment of a space. The climate outside and the "micro-climate" inside a building affect the inside surface temperatures and the stability of the building skin. In the Southern Ontario climate, with its annual variations of temperatures between −[illegible]0°F to 100°F and with varying sunlight, allowances must be made for stresses and strains, vapor transmission, and the possibility of freezing of free or trapped water particles. Heat transmission by conduction and convection varies directly with the difference of temperature inside and outside and with the thermal composition of the member. For a single sheet of glass, the only insulation values are the inside and outside films of air. Cold surfaces, such as single glazing, result in a waterfall effect with the cold air cascading down the surface. To offset resulting drafts, these cold surfaces should be blanketed with air from a warm source.

Solar gain peaks from all quadrants, except for north, are of equivalent magnitude (approximately 1 ton of refrigeration equivalent heat gain for every 75 sq. ft. glass). (see figure 6). East and west peaks occur in July and August, in the morning and evening respectively, while the peak gain for south is in October and March. This heat gain is equivalent to twice the window heat loss for an outside temperature of −10°F. It is obvious that the main concern is to eliminate or reduce this highly variable heat gain/loss source. Buildings with any appreciable glass areas must be carefully oriented and designed to provide shading or screening.

Costs

The first yardstick in evaluating the *capital costs* is the mechanical system, including the heating, ventilating, and air conditioning (HVAC) and the plumbing. Then the following must be taken into account: electrical wiring, switchgear, and standby equipment; the effects on structure such as static and dynamic weights and vibration; the effects of the location of equipment and ducting in the structural system; loss of space; size and location of duct shafts; depth of ceiling spaces and type of ceilings. Other considerations include the effects of structural features on the occupants of the building, on programs, and on aesthetic appearance.

Operating Costs

Although capital costs are a prime concern in building design and construction, it should be remembered that a savings of ten cents per square foot per annum in operational costs is equivalent to seventy-five cents of capital cost on a ten-year, six-per-cent amortization basis. Therefore, it is advisable to evaluate operating costs as well as annual fixed charges in selecting systems and in determining the overall design. Since it is almost certain that the trend towards increasing operating costs per year will continue during the life of the building, a very careful evaluation of all pertinent factors is in order.

An operational analysis should include cost of heating fuel and a comparison based on total annual consumption. (see figure 14). Since in many localities electricity is charged on a total power received basis, the comparison between electrical heating and other fuel should be based on an annual total power and lighting estimate.

In some isolated instances "total energy" may pay for itself, but only if the building has a high utilization demand of power on a continuous basis, a relatively favourable cost of fuel versus electricity, and an attractive capitalization basis.

The cost of *personnel* must be given due consideration. In Ontario, steam and high or medium temperature hot water plants require full time licensed operators. Similarly, compressors using high pressure refrigerant, if larger than 30 tons, require licensed operators.

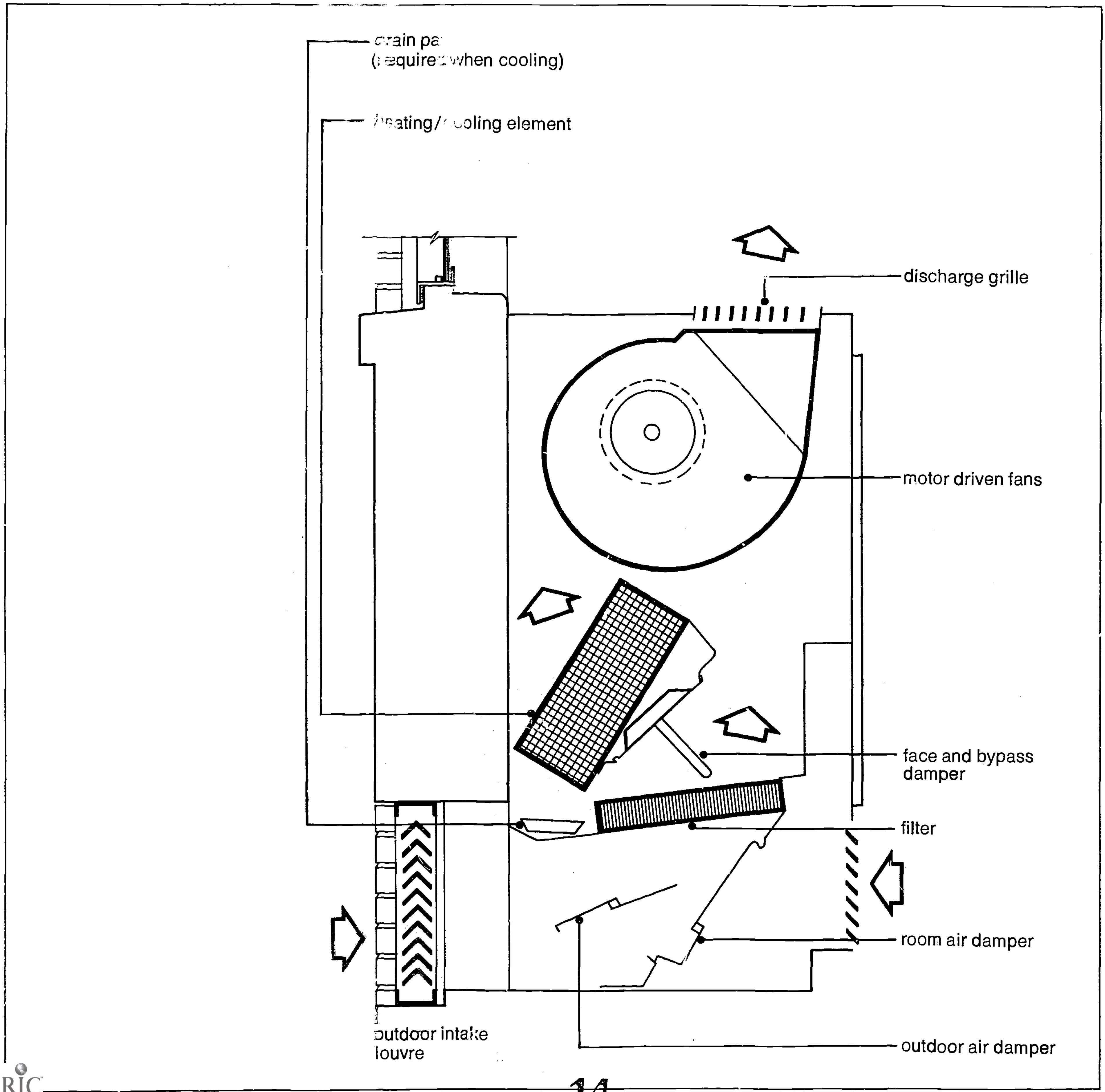
Maintenance

For plants not requiring specially skilled attendants, consideration should be given to using in-house staff as opposed to maintenance contractors.

The operational periods, calculated on an annual basis with due allowance for working hours and non-working hours, should be included in the analysis.

Owning-Operating Cost considerations should include *amortization* with a realistic cost of money over the estimated life span of the building. *Depreciation* allowance may have to be broken up into several parts, making different allowances for piping, ducting, and non-moving parts, and primary equipment. Insurance and taxes must be included. *Obsolescence* should be evaluated in order to provide weighting factors in the appraisals.

Figure 7: Unit ventilator

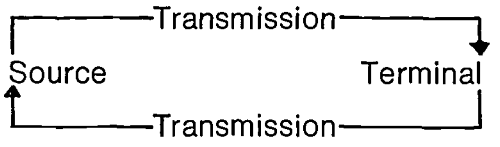


Systems

Terminals

One confusing problem that has remained with us since the infancy of air conditioning is the multiplicity of performance specifications. When used for space conditions, the performance expected of a system in relation to the inhabitants and the space conditions should be related to outside and inside conditions, activities and their duration, the range and tolerance of control. Performance expected from equipment and system components should be stated in relevant terms of energy units from and at a specified level, with corresponding ranges and tolerances.

Mechanical systems can be categorized into three components: a *source* (generation), a *terminal*, and a means of *transmission* (distribution).



Simultaneously, mechanical systems can be classified as *Heating*, *Ventilation* and/or *Cooling*.

The requirement of a *terminal* is to maintain space conditions that ensure the physical comfort of occupants.

Heating Terminals

The best locations for these terminals are areas where some natural ventilation occurs, such as windows, doors, and uninsulated walls. If they are located where cold air could infiltrate or where downdraft could be produced due to cold surfaces, variations from the space average can be kept to a minimum, resulting in uniformity.

The evaluation of terminal capacity should include the following factors: warming-up allowance requirement of the space; response to changing loads; the selectivity requirements of the space or the occupants; the temperature range required; the tolerance allowable; the inertia effect of the space and of the terminals; aesthetic considerations; the space requirement; the flexibility of space usage; noise generation; ruggedness of terminals.

These terminals are available as radiators, convectors, baseboard or continuous fin elements. They can be made out of cast iron, steel, copper and/or aluminum. For large heat losses, or for spot heating, unit heaters can be utilized. They consist of motor-driven fans blowing or pulling air across finned heating coils. Suspended units with propeller fans are available for vertical or horizontal discharge.

The noise ratings of these heaters are relatively high. Cabinet unit heaters with centrifugal fans are considerably quieter.

Radiant panels can be located in the ceiling, in the floor, or in the wall. They can be high-intensity for spot application, but normally they are used to provide low temperature output. If the floor is used as a panel, the floor surface temperature should not be above 85°F for ideal comfort. Higher temperatures can be used in ceilings, but the height of high-temperature ceilings in relation to people's heads should be given careful evaluation.

Hot air can be supplied through ceiling diffusers, wall registers, or floor grilles. Combination heating-cooling terminals are available in air-water, air-electric, and air-steam systems. Elements can be manually or automatically (thermostatically) controlled.

Ventilation Terminals

Air for dilution can be introduced through openings in the ceiling, wall, or floor. Manufactured grilles made out of steel or aluminum are available in various shapes and sizes. The selection, based on manufacturers' ratings, is a function of noise criteria, minimum and maximum throw, mounting height, and temperature differential between room air and supply air. The purpose of the selection is to provide uniform air diffusion without any drafts or stagnant spots.

On a unitary basis, ventilation can be provided by a "unit ventilator" (see figure 7). This unit is basically a high-capacity, cabinet unit heater with the addition of fresh and return air dampers mixing room air with outside air before discharging the mixed (filtered) air through a heating coil. These units can be manually or thermostatically controlled. They can be utilized with fixed or variable outside air supply. With the latter cycle, provisions should be included for automatic central relief of excess air.

Wing extensions are available on some unit ventilators to allow blanketing of window surfaces projecting beyond the normal discharge pattern of the unit ventilator.

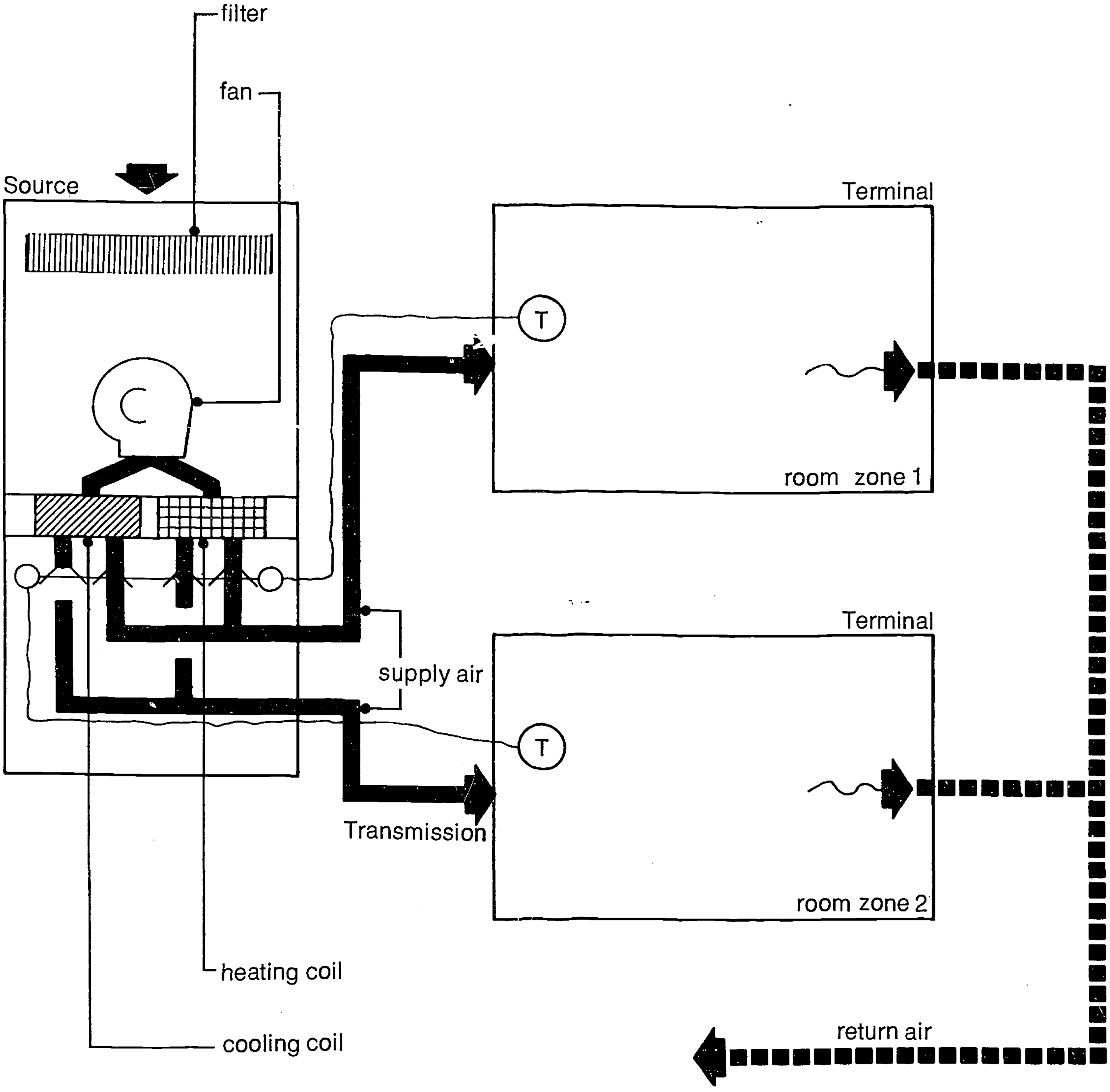
Return-Exhaust Terminals

The location of return air terminals is generally not as critical a consideration as that of supply terminals. Unlike the jet stream emanating from a supply outlet, the exhaust openings have air entering in a parabolic pattern. Thus restraints at the openings or high terminal velocities will result in undesirable pressure losses and noise generation. Therefore the openings are normally sized for low average velocities.

Cooling Terminals

Air used for cooling spaces may be introduced through grilles or diffusers in the ceiling, wall, floor, or window sill. For reasons of economy, the greatest practical temperature differential between room air and supply air is selected (provided that the minimum air requirements for ventilation and total circulation are met). With a low supply air temperature it is particularly important to circumvent chances of creating drafts. Therefore the type, size, number,

Figure 8: Multi-zone system



Distribution (Terminal) Systems

and location of air inlets must be carefully selected.

Perforated ceilings expressly manufactured to allow easy flow of air supply are available on the market. These are normally designed to work in conjunction with a pressurized ceiling cavity forcing air uniformly through slots or holes in the ceiling membrane, at a very low velocity. This system then depends on careful workmanship in the provision of ceiling plenum compartments and careful balancing. Great care is required to avoid plugging small holes with paint, construction dirt or insulation fibres. Other problems that should be avoided are condensation on wall surfaces or materials adjacent to pressurized ceilings and stratification of temperature in conditioned spaces. To compensate for lack of air motion, a lower than normal effective temperature should be provided.

Radiant cooling panels can be used to remove part of the sensible heat gain. Enough air must be introduced to satisfy the ventilation and air circulation requirements of occupants. The panel surface temperature should not be below the space dew point, or condensation may occur.

Where space or occupancy requirements warrant many individual controls, several systems are available. These can be categorized as variable temperature, variable volume, or unitary type.

Multi-Zone
As illustrated in figure 8, filtered air in a central air supply unit is blown through a cooling and then a heating coil. A mixing damper for each controlled zone adjusts the air mixture to the required supply air temperature. From the mixing chamber, each individual duct leads the air to its respective zone.

Double Duct
In a double duct system (figure 9), two ducts originating from the central air apparatus lead cold and warm air to individual mixing boxes serving each respective zone. The dampers are controlled from a space thermostat to mix air to the required supply air temperature.

Terminal Reheat
The supply air leaving the central apparatus is set to satisfy the zone requiring maximum cooling (figure 10). Reheat coils located in ducts serving each zone provide an artificial heat gain, thus reducing the temperature differential between space temperature and duct air to a satisfactory level.

Induction
Processed primary air from the central air apparatus is supplied to various terminal units (figure 11), which consist of a primary air pressure reduction box with discharge nozzles, a secondary finned coil, and an enclosure. The primary air being discharged through nozzles creates an induction effect on the secondary air stream, pulling room air across the coil. Two types of units are available with secondary room air reheat coils. In one type, the primary air does all the cooling; in the other, the function is performed by secondary cooling/heating coils. In the latter, the primary air shares the cooling function with the secondary air stream.

Induction systems can be designed with chilled water in the coils providing a constant, metered cooling source, while the primary air temperature is varied in accordance with a preselected outdoor air schedule. If "free cooling", when available, is to be utilized, the system can be designed to include change-over control. This would change the primary air to a constant supply air temperature, while the water in the coil is changed to a variable temperature supply.

Terminal Fan Coil
By using combined heating-cooling coils, (or separate heating and cooling coils), a drain pan, and insulated casing, a cabinet unit heater can be made to serve the dual functions of heating and cooling.

These units can be located vertically under windows or walls or suspended horizontally in or below ceilings.

Variable Volume
Instead of varying the temperature difference and supplying a constant volume, the volume is varied sequentially with the load while the temperature difference remains constant (see figure 12). This system was not entirely successful when first tried, due to inadequate hardware which did not allow throttling without adverse air dumping and/or noise generation.

However, a variable volume system designed to operate within prescribed limits of the throttling range can provide adequate control at very reasonable operating costs. Optimum conditions are difficult to achieve in spaces where activities such as film showings and heavy smoking take place. Even under the circumstances, when balanced by a decrease in occupants, the selection of this system is not recommended.

Dual Conduit
This perimeter system, designed to reduce operating costs, utilizes two ducts from the central apparatus to terminal mixing boxes. One duct carries primary air at variable temperature and constant volume to offset building transmission losses (cold air in summer and warm air in winter). The other duct supplies cold air at constant temperature and variable volume to regulate variations in solar, lighting, and occupancy loads.

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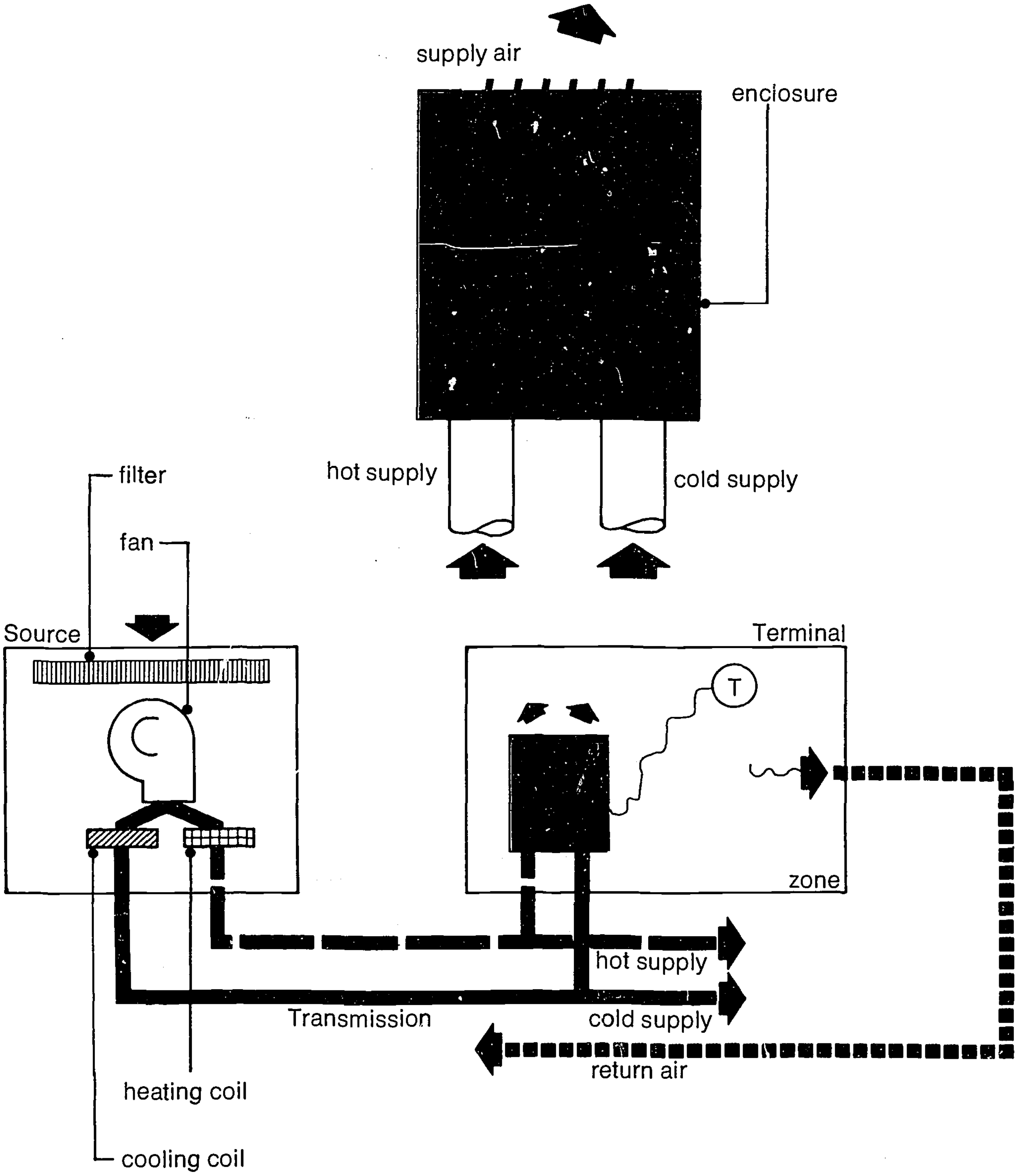


Figure 9: **Dual-duct air system**

Figure 10: **Terminal reheat system**

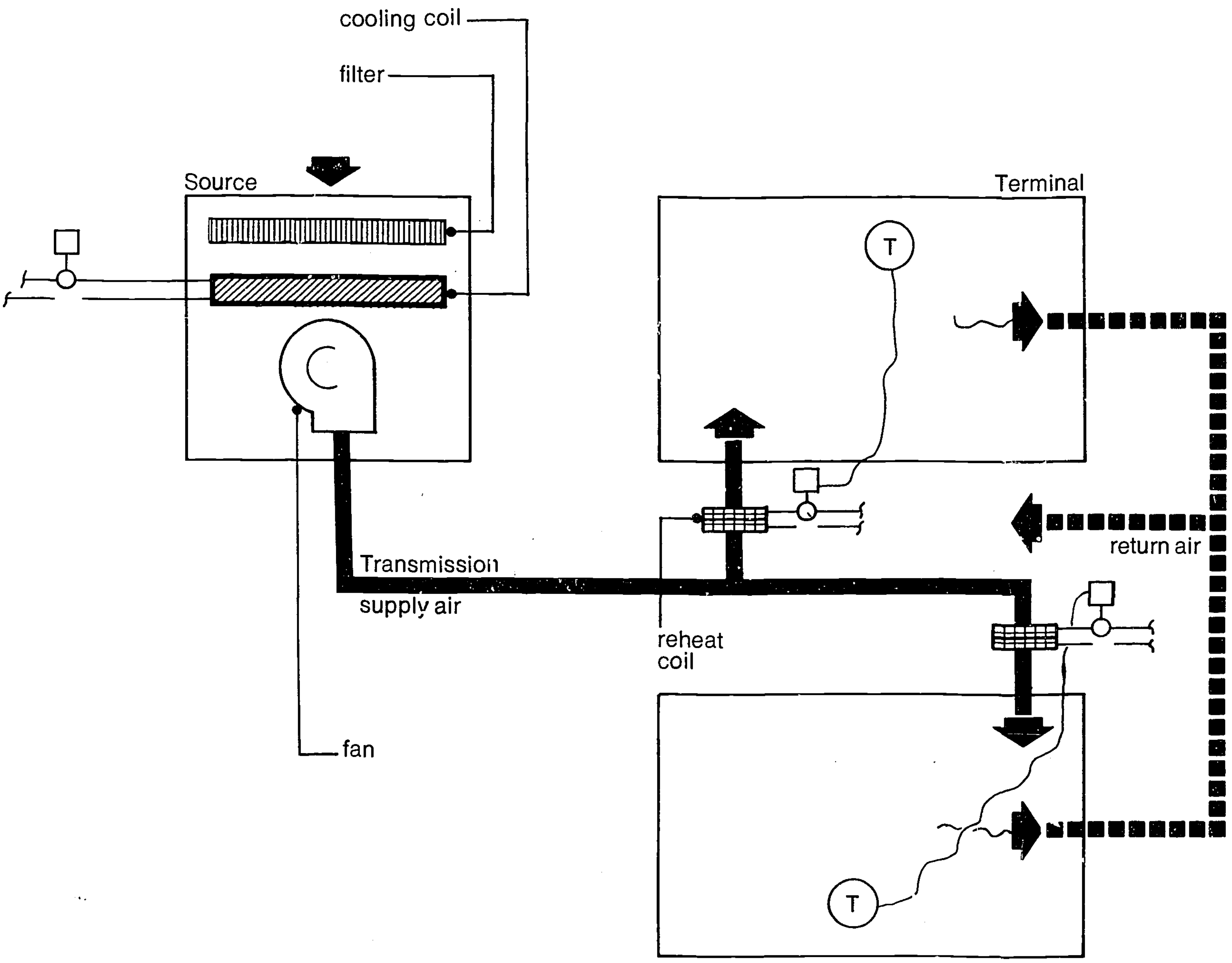
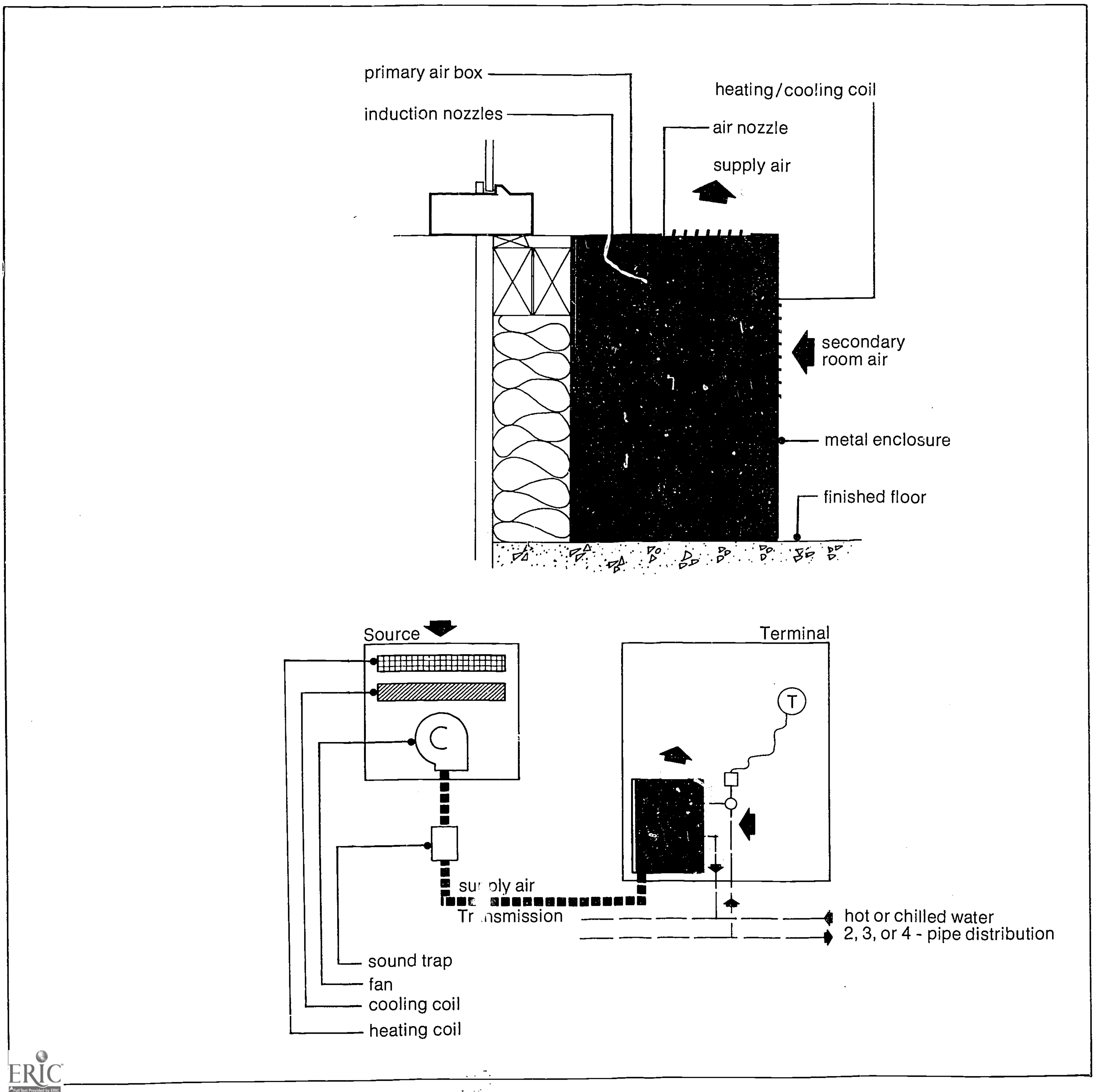


Figure 11: Single-duct induction unit (air and water system)



System Transmission

Heat transmission systems available are Steam, Hot Water, Hot Air, and Electricity.

Steam has a high heating capacity. Each pound of steam has a latent heat of vaporization which is liberated when steam is converted by heat transfer to condensate. Steam can be conveyed at high pressures or, if the condensate is pumped through a vacuum pumping system, at low above-atmospheric or low sub-atmospheric pressures. Valves are required for throttling and shut-off, and steam traps are needed for separating steam from condensate and keeping air out of the pipes. The pressure of the steam as generated is used to convey it through pipes and heat exchangers. The steam pipe is normally about twice the size of the condensate pipe. Pipes are usually sloped to allow easy drainage of condensate.

Care must be exercised to prevent corrosion of steam traps and condensate lines by reducing make-up of fresh water and leakage of gases to a minimum. If space does not permit condensate return by gravity, transfer pump sets can be provided. A certain amount of noise generation accompanies the functioning of traps, particularly with increasing wear. Therefore regular maintenance of traps is essential. The load response on heating, particularly for the warming-up periods, is excellent. Steady control for gradual supply of heat under varying conditions is difficult to achieve; the use of a vacuum system to reduce the steam pressure below the atmospheric pressure can improve control. Steam allows little flexibility for alterations or additions, as new piping connections have to be made. However, the system can be designed to allow for addition of future loads.

Hot Water in most modern applications, is distributed by pumping. The capacity of forced hot water distribution is a function of the temperature of the medium, the temperature difference of the water, and the velocity of the circulating water which is related to noise and pressure drop. Supply and return pipes are normally of equal size. Pipes can be run flat but are normally sloped to prevent pocketing of air at high points.

Since water expands when it is heated, an expansion tank must be located in the g circuit.

The availability of different piping systems allows selection in accordance with varying parameters, the capital available, the balancing system required, and future expansion. The most popular systems are the two-pipe direct return, the two-pipe reverse return, one pipe with Venturi-T fittings and the primary-secondary loop pumping system.

Provision should be made for drainage to allow maintenance, alterations, or extensions. With a well-designed, properly installed hot water piping system, maintenance is minimal. Hot water is an excellent medium when it comes to compensating for variation of load, since the average water temperature can be scheduled inversely with outside air temperatures. Operational cost analysis should include cost of pumping.

Hot air can be utilized for heating but it is a much less efficient transmission medium than water or steam. Compared with water, which has a specific heat of 1 and a specific weight of 62.4, air has a specific weight of 0.075 and a specific heat of .24. Thus larger spaces are required (see figure 13). The response and control flexibility of air is very good.

Electricity is becoming increasingly popular as a distribution medium for heating. The elements available are designed to suit either residential or commercial uses. Response to load changes is quick, but capacity is limited at 3.4 BTU per watt. Electric heating can be regulated by the use of a silicon-controlled rectifier that controls the voltage input, thus providing fully modulated control. Step control can be achieved now at a reasonable cost.

As a conveying medium electricity is very efficient, requiring a minimum of space. Conduits carrying wires can be run within concrete slabs or outside walls, allowing easy concealment with no risk of freezing or leaks. Electricity has the great advantage of allowing for flexibility, both for internal changes and for future addition. Capacity of wiring of heaters affects transformers and primary and secondary switchgear. Design considerations may change the utilization voltage of the project. The greatest drawback of electricity for heating lies in the high cost per BTU.

Cooling transmission systems available are Air, Chilled Water, and Refrigerant Piping.

Air as a Ventilation and Cooling Medium. The cooling potential of air introduced into a space is in proportion to the temperature difference between room air and supply air. One of the limiting factors of the supply air temperature is the dew point of spaces through which the duct runs. Another limiting factor is the heat gain or loss of duct surfaces which are affected by the temperature of the surroundings. Insulation of supply ducts will reduce both problems, but increase the capital cost. Other design parameters are velocity and corresponding pressure drops and noise generation. Depending on such factors as the sound level that may be tolerated in the space to be served, the size of system required, the length of duct runs, and the amount of capital available, low velocity systems are selected from a conveying velocity range of 300 to 2,000 ft. per minute.

Where space considerations and/or pressure requirements of air terminals demand a higher velocity, 2,000 to 5,000 ft. per minute, high pressure ductwork can be used. This is normally cylindrical to avoid staying and bracing of the weak cross-sectional rectangular ducts. High pressure ducts, fans, and pressure reducing boxes are more expensive than the conventional low pressure systems, but savings of space and sheet metal reductions may offset the higher capital and operating costs.

Return Air. For the proper functioning of a system, spaces conditioned must be in a pressure balance. Air supplied to a space must be exhausted.

A slight positive pressurization can be achieved, but attempts at excess pressures will result in noisy air leakage through openings and cracks, and may possibly upset the desirable atmospheric conditions.

Return air can be ducted through low pressure ducts, pressure reduction boxes, or medium pressure ducts. If the distances are relatively short and the velocities low, a return air plenum can be used if the materials flanking the plenum are fireproof. It is important to ensure a very low friction loss for the air egress through openings and

continued on page 27

Figure 12: **Single duct variable air volume**

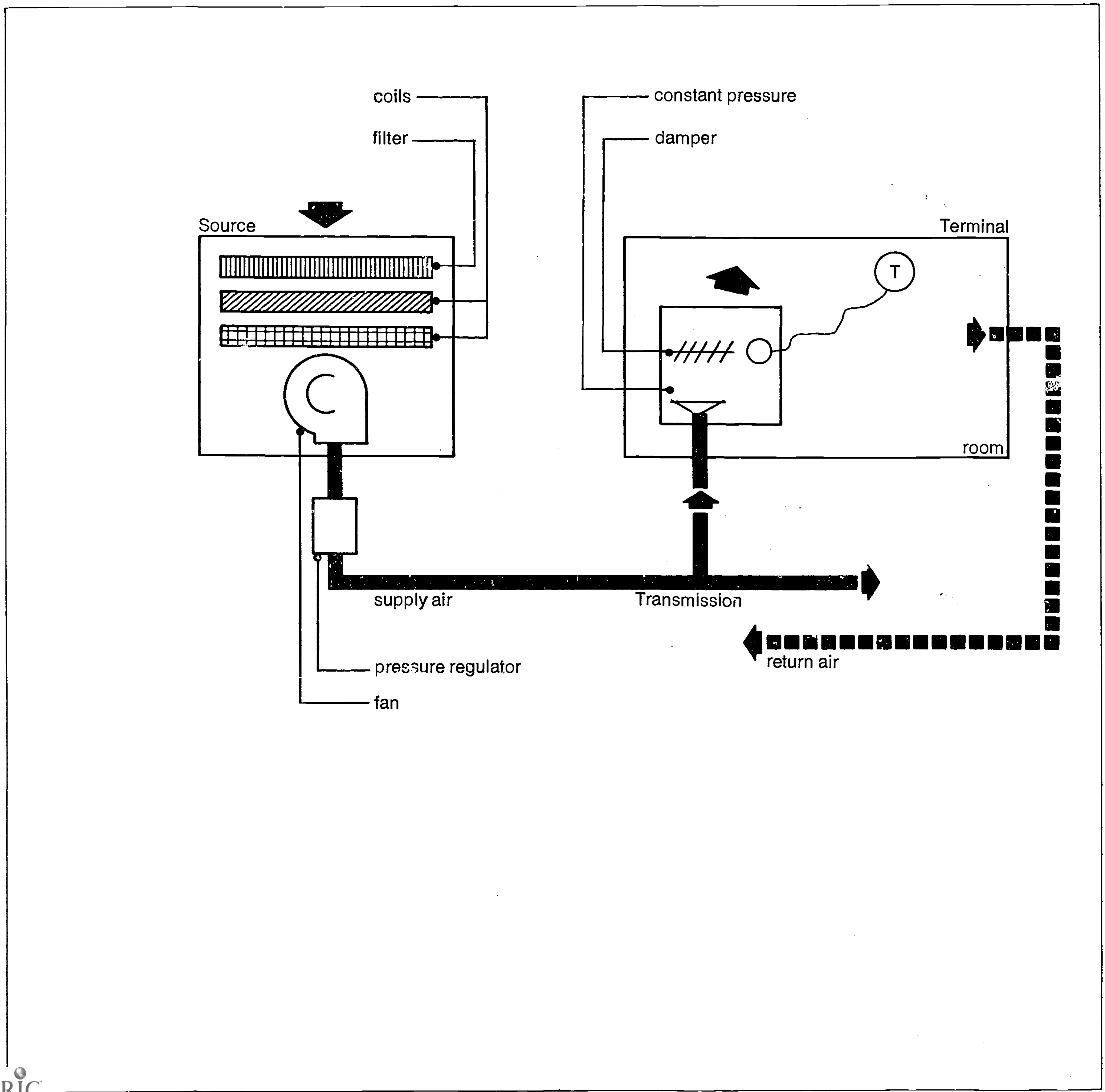


Figure 13: Comparison of heat transmission 50,000 B.T.U.

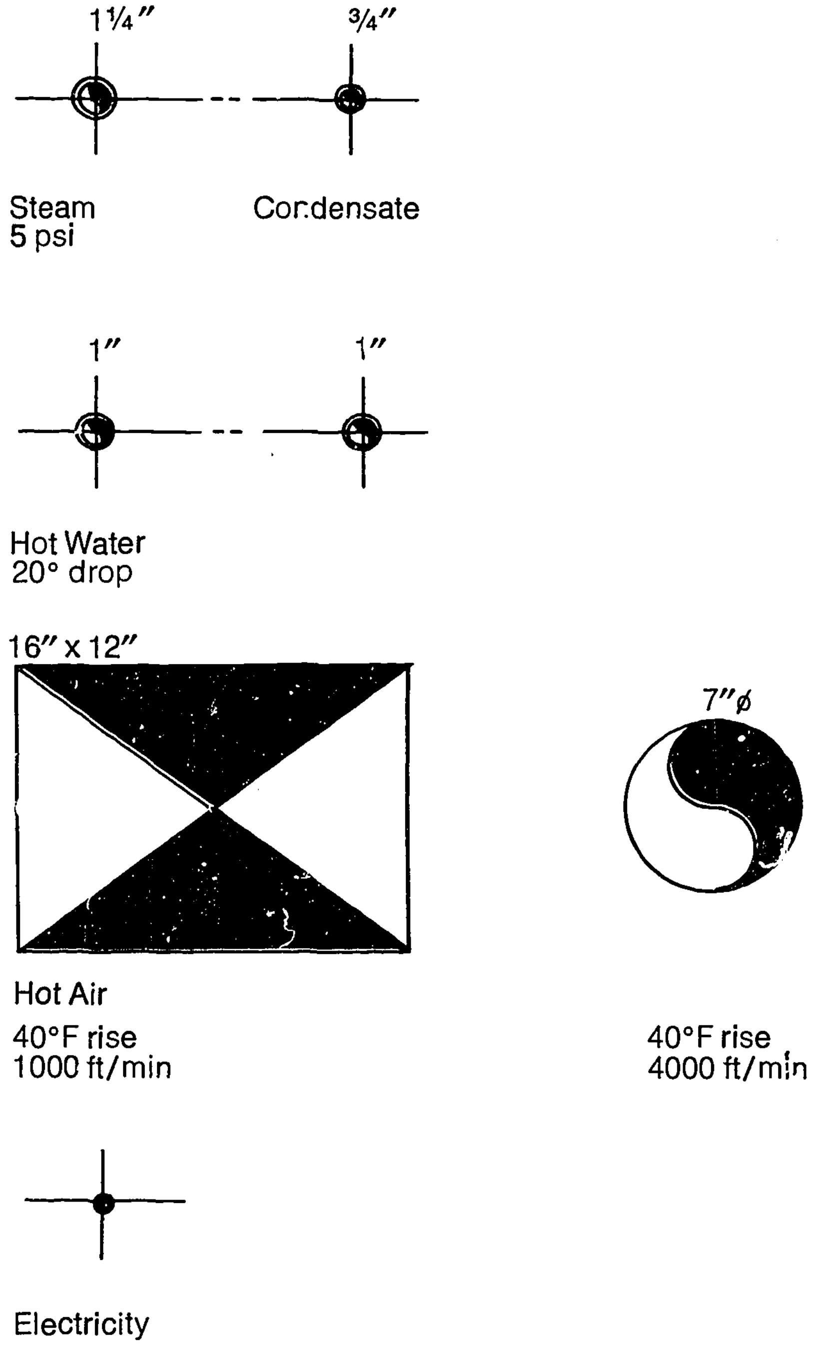
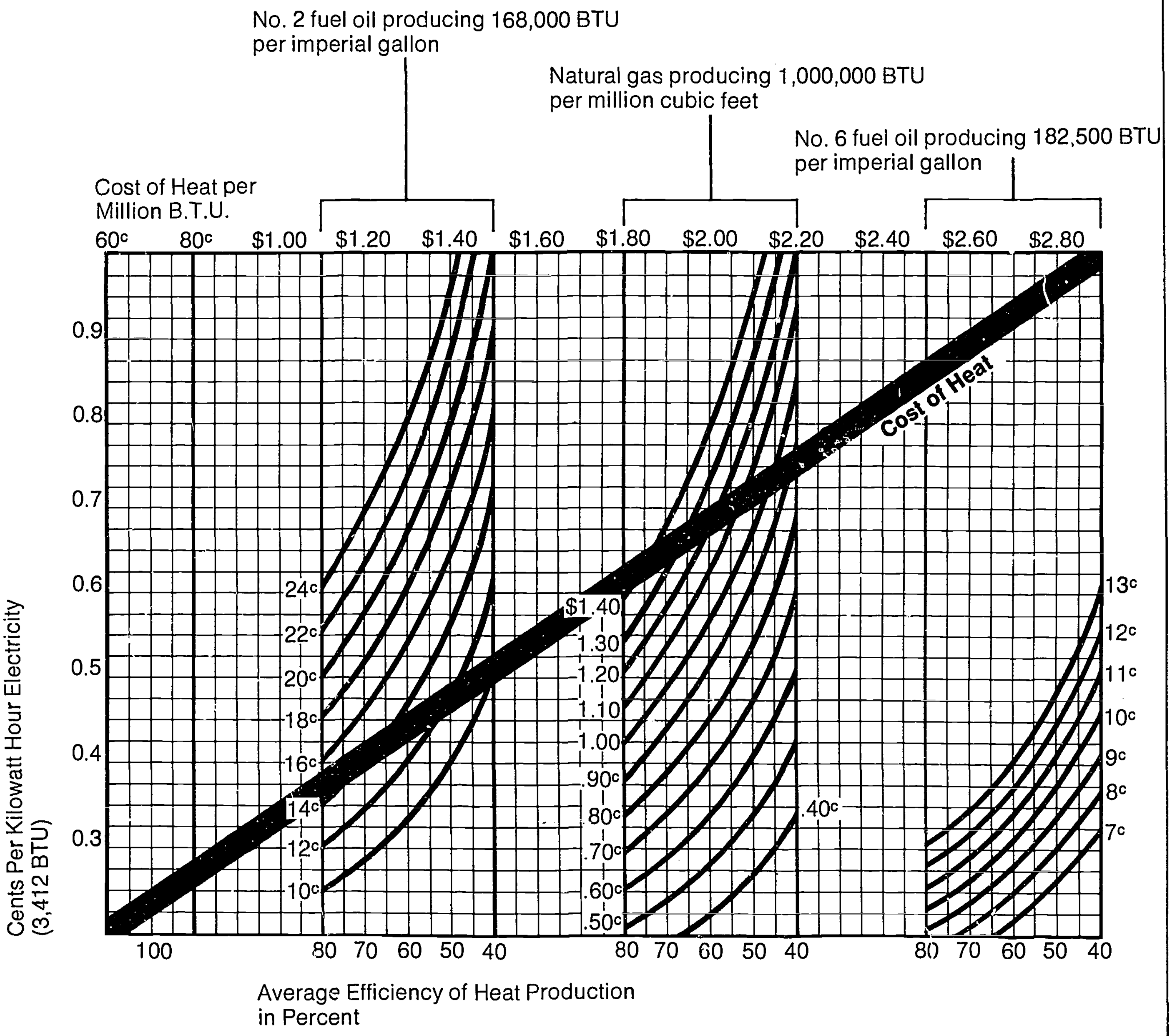


Figure 14: Cost comparison of fuels



Instructions for using "Cost of Heat" chart

To compare fuel costs: Draw a horizontal line across the graph through the factors known about any fuel.

These factors are: cost per unit of fuel and efficiency of heat production for the device in which the fuel is used.

Where the horizontal line intersects the "cost of heat" line read up to find the cost per million BTU.

All fuels through which the line passes will produce heat at the same cost.

Any fuel cost lying above this line is more expensive and any fuel cost below this line is less expensive.

Useful formulae

1 KWH = 3,412 BTU
1 KW = 3,412 BTU per Hour (BTUH)
1 Boiler HP (BHP) = 10 KW (Approx.)
= 34.5 lbs. steam per hour
= 33,472 BTUH
1 lb. steam = 970 BTU (from and at 212 F)
1,000 lbs. steam = 1,000,000 BTU (Approx.)
1 Therm = 100,000 BTU — 100 MBTU

Example #1

Assume electricity is available at 0.8¢/KWH. Draw a horizontal line through 0.8¢ electricity. The cost of heat is $2.35 per MMBTU. All other fuels through which the line passes will produce heat at the same cost.

If the average annual efficiency of a gas furnace is 50% then the equivalent gas price is $1.18/1000 cu. ft. If the local gas price is higher than this, electricity is competitive. If the local price is lower, it is not.

In the same way, the competitive price for #2 oil at 50% efficiency is 20¢/LG.

Example #2

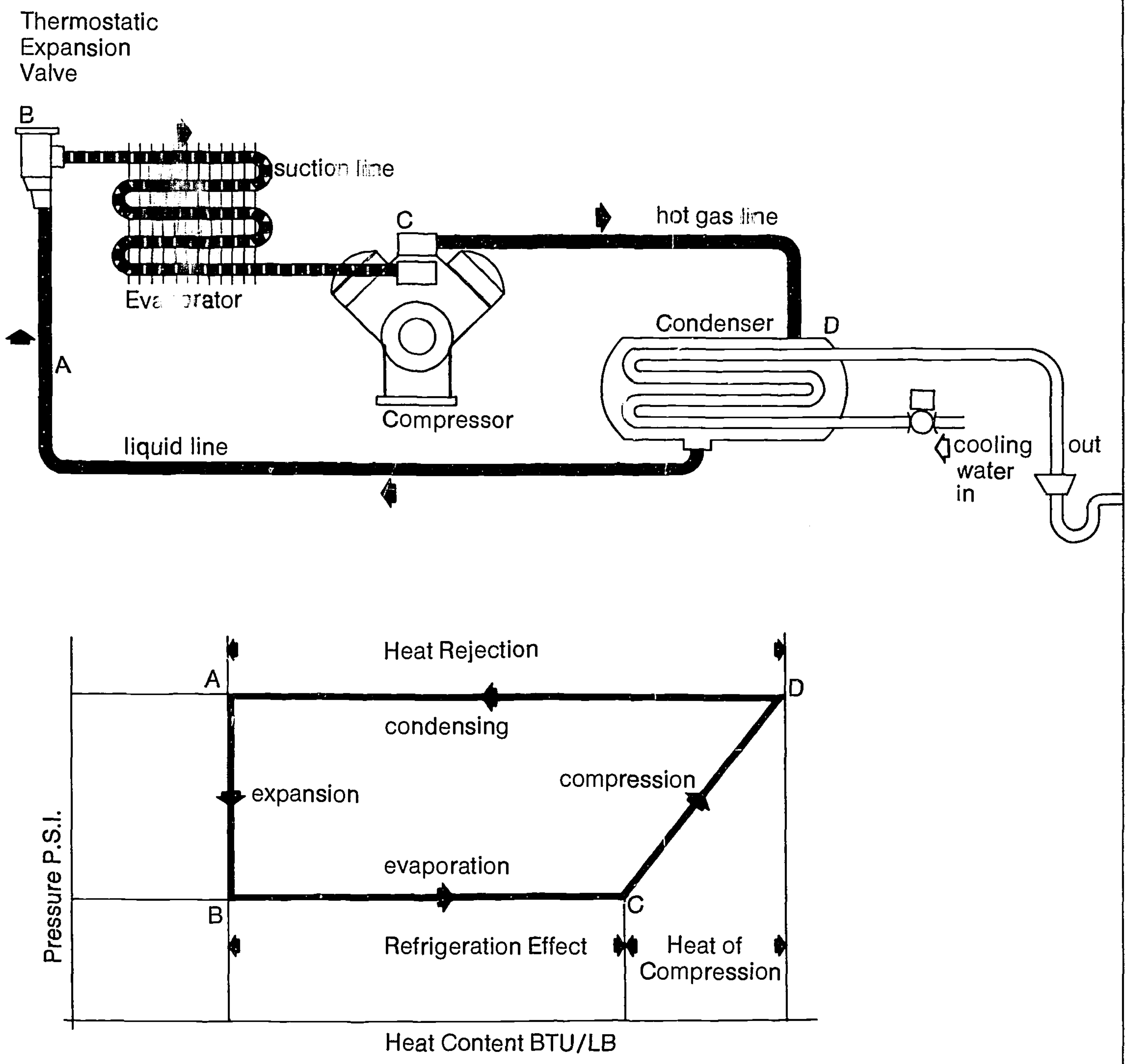
A customer buying #6 oil at 9.6¢/IG and using it in a burner having 60% average efficiency wishes to know if he can use electricity instead. Draw a horizontal line through this point on the graph. It intersects the "cost of heat" line at 88¢ per MMBTU and the electric rate line at 0.3¢/KWH. If electric power is available to him at this rate. usually off-peak, he could economically convert to electric heat. A further extension of the horizontal line indicates that gas would have to be available at 60¢ per 1000 cu. ft. or less. You will note here an allowance for slightly higher efficiency when burning natural gas, rather than #6 oil. This is partly due to the cost of pre-heating #6 oil necessary before entering the burner. #2 oil is not at all competitive in this application.

Example #3

A customer uses #2 oil, for which he pays 15¢ per I.G. to heat his plant and offices. Average annual efficiency is believed to be 50%. He has off-peak power available and can install a hot water storage tank and circulate hot water through his present radiators. What is the maximum price he must pay for electricity to equal or better his present fuel cost?

Draw a horizontal line through #2 oil at 15¢ and 50% efficiency. The cost of heat is therefore $1.75 per million BTU. The equivalent electrical rate is .6 cents per KWH. Since off-peak electric power is available at 0.3 cents per KWH, or 88¢ per million BTU, the saving would help pay off the cost of the conversion.

Figure 15: Direct expansion compression cycle



System transmission
continued *from page 21*

plenum to maintain stable space conditions.

Chilled water piping systems are similar to pumped hot water systems. In most instances they operate on a smaller temperature differential, thus requiring greater flow capacity. Except where the chilled water temperature is close to the space dew point temperature, the piping must be insulated to prevent condensation.

Refrigerant piping is limited in application to relatively short distances between a compressor or evaporator and a condenser.

System Sources (Generators)

Heat Sources

Except where a district heating system or electricity presents an economical fuel source, fossil fuels supply the heating energy. Although bituminous coal at 14000 BTU/lb. is the cheapest fuel available, the attendant costs and problems of storage and handling, ash removal, and resulting pollution have made it increasingly unpopular. Anthracite is a cleaner fuel, but its higher cost, accompanied by storage and handling problems, presents less advantage to the user than oil or gas. The light, industrial type of oil with 140,000 BTU/U.S. gallon capacity is relatively clean to burn and presents no storage problems. Its ash and sulphur content is minimal. Heavy "Bunker" oils must be stored in large quantities to be economical (4,000 gallons per dump), and require preheating for conveying. The heaviest oils (No. 6) require preheating at the burner also. The most recent air pollution regulations require virtually sulphur-free fuels. Bunker oils are available to meet this specification, but at a premium price.

Gas (at 1,000 BTU/cu. ft.) is available on a steady supply basis, or as an interruptible fuel, in which case an alternate fuel must be stored. The cost of gas on an interruptible basis is roughly equal to that of heavy oil (However, allowance must be made for the cost of oil for a predicted interrupted period.) Non-interruptible gas is sold for heating at varying rates. In the Toronto area it averages at 95¢ per MCF. No storage is needed. For higher pressure gas reducing valves are required. Gas is a relatively clean fuel with a minimal or no sulphur content.

As far as smoke abatement regulations are concerned, the diameter and height of chimneys are determined by provincial regulation, which take into account such factors as type of fuel, sulphur content, rate of burning, shape and height of building, proximity to other buildings, and wind speed.

As fuel, the cost of electricity is roughly three times that of non-interruptible gas. However this can be reduced by utilizing reclaim systems or peak storage systems. Evaluation should be made on an annual basis, taking into account capital cost of mechanical and electrical systems, extra insulation, and double glazing. (See figure 14.) If refrigeration is used for air-conditioning, the waste heat normally pumped from the condenser to the cooling tower can be reclaimed as a heat source.

Heat Generator

There are several types of boilers available:

a

Cast iron sectional: suitable for all fuels, requires low head room and no tube pulling space; available in limited capacity.

b

Fire box: steel fire tubes, suitable for all fuels (oil, gas, or stoker or hand firing of coal).

c

Scotch Marine: Dry Back or Wet Back design; steel fire tubes; internally fired chambers surrounded by secondary passage flue gas tubes: suitable for gas and/or oil. Available in designs of two, three, or four passes of flue gas, with corresponding degrees of efficiency and maintenance and cleaning problems.

d

For high temperature hot water or for high pressure steam, large water tube drum-type boilers are available. There are two varieties — field-erected or shop-fabricated types. These may be coal, gas or oil fired.

e

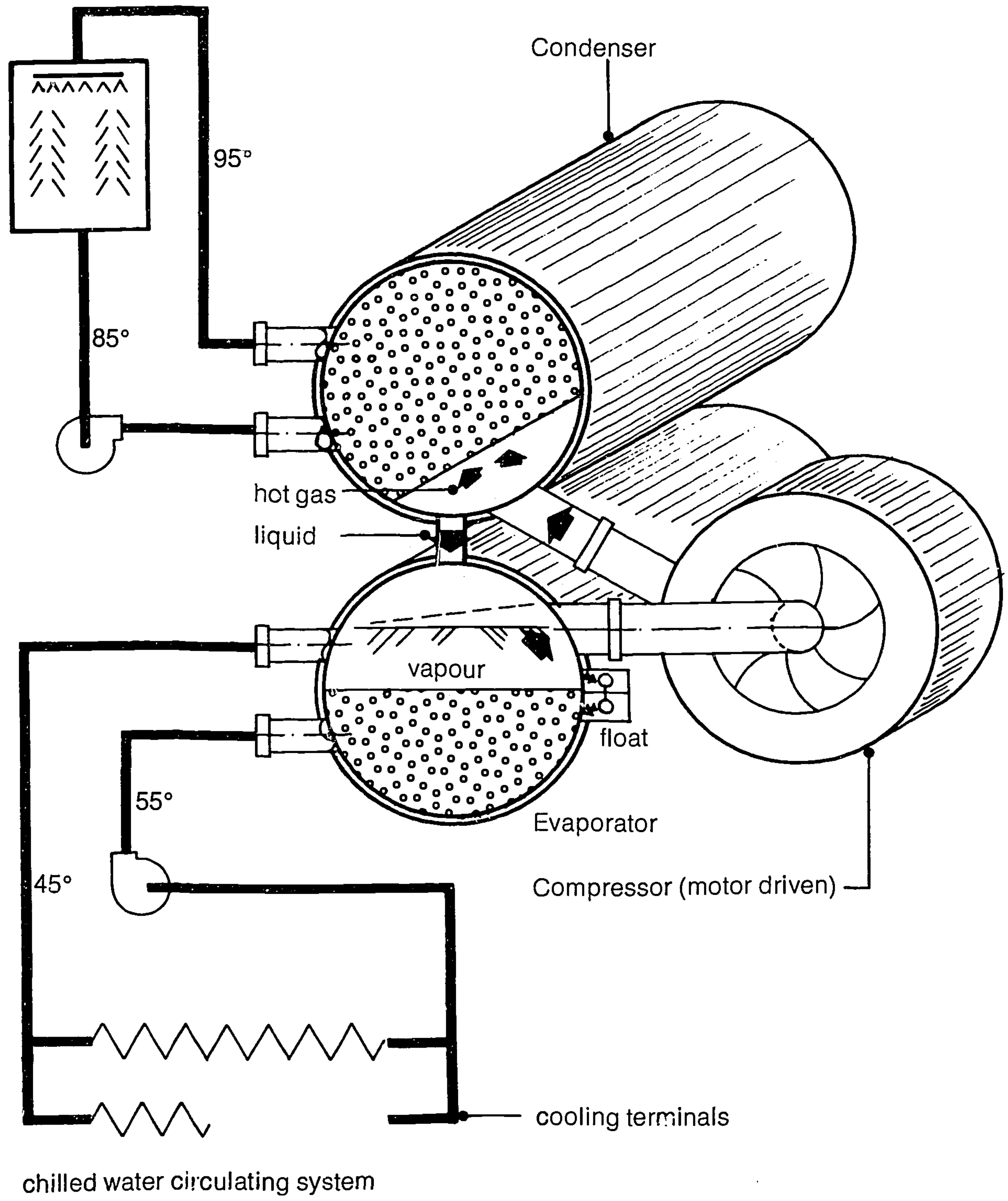
Small internally gas-fired water tube boilers. These have been used in multiple units extensively in apartments and some institutional projects. At present the only flue requirements are small individual chimneys projecting only a few feet above the roof. The actual life expectancy of these units under "normal" usage is not established.

When using internally fired boilers (Scotch Marine of multiple water tube type), the choice of location may effect some economy. Penthouse, intermediate floors, or basements can be utilized. Attendant problems of sound control, fire exits, structure support, and chimney arrangements should be investigated before making an analysis.

Steam and high temperature hot water boilers larger than 5,000,000 BTU per hour generating capacity require classified attendants when in operation.

continued

Figure 16: Centrifugal refrigeration machine



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Cooling Generators

Dehumidifying (removal of moisture from the air) and cooling (lowering the dry bulb temperature) are commonly achieved simultaneously by providing a "cold source" to which heat can flow and be absorbed.

It is feasible to use blocks of ice as a "cold source" and pass air across their surface to achieve cooling, This, however, is a cumbersome, bulky, expensive, and wasteful method. In a modern cooling system a multi-row, finned-tube coil replaces the ice blocks. A similar effect to that achieved when the melting ice absorbs heat from the warm air can be achieved by allowing a refrigerant to expand at high pressure through the tubes of the cooling coil. Provided that the boiling temperature of the refrigerant gas is lower than that of the air, the ensuing change of state of vaporization will cool the warm/moist air. Since most non-toxic, non-flammable gases with suitably low boiling points are expensive, a closed cycle of refrigeration is employed, involving recovery of the expanded gas which is recompressed and made available for continuous cooling.

Refrigeration Cycle

Figure 15 illustrates the essential components of a closed refrigeration cycle. At point "A" a pressure-reducing valve allows the high-pressure liquid refrigerant to expand and flash into a vapour (change of state). The resulting release of energy in the expanding vapour is absorbed by the warm (moist) air stream moving across the coil surfaces (B-C). In order to re-energize the refrigerant, the next step of the cycle requires a refrigerant compressor to convert work energy into potential energy by pressurizing the refrigerant (C). The high-pressure refrigerant vapour is then liquified in a condenser heat exchanger. A heat-absorbing fluid (air or water) removes the excess heat given off by the condensing refrigerant (D).

The sliding parts of reciprocating compressors wear out in a relatively short time. They use high-pressure (greater than 15 psi) refrigerant. In the province of Ontario, high pressure refrigerant compressor units of sizes larger than 30 HP require statutory attendants when in operation.

[illegible] expansion (DX) applications are generally restricted by the distances between evaporator coil(s), compressor, and condenser, the number of coils served, and the height to which the refrigerant is lifted. For multi-terminal applications and/or long distance distribution, chilled water is employed as a cooling and transporting medium. A tube bundle inserted into a closed vessel acting as the refrigerant evaporator acts as a secondary heat exchanger serving multi-terminal systems.

Centrifugal Chiller

In a centrifugal refrigerant (compressor) package, the evaporator becomes a shell and tube heat-converter in which the refrigerant absorbs the heat given off by pumped chilled water (see figure 16). The evaporator is close-coupled to a shell and tube condenser and a high-speed centrifugal compressor. The compressor can be driven by a turbine engine or by an electric motor in an "open" machine. These machines would normally be manufactured to use a high-pressure refrigerant, which would categorize them for mandatory registered attendance.

With the development of special electrical insulators, hermetic compressors using the refrigerant as a cooling medium for special high-speed electric motors have become popular. They can provide a compact, lightweight application. Machines that utilize low-pressure refrigerant do not require attendance by statute. They are available in a capacity range of 75 to 1,500 tons. From about 150 tons they become more economical than the reciprocating compressors. The centrifugal compressor is ideally suited for comfort conditioning since it can provide almost linear variation of capacity versus load over a range of 10% to 100%.

Absorption Chilling Machine

The absorption refrigeration cycle provides cooling through chemical evaporation of a salt solution. Figure 17 illustrates the principle of salt solution in one chamber (the "absorber") soaking up water from the second chamber (the "evaporator"). The water in the coil located in the "evaporator" is cooled and then pumped to various cooling terminals. To keep the salt solution at its proper concentration, a "generator" chamber is provided where excess water vapour is boiled off by heating. The reconcentr [illegible] ution is returned to the absorb [illegible] ater vapour from the weak sa [illegible] collected and cooled in a fourth cham [illegible] (the "condenser"), and then returned to the evaporator, thus completing the cycle.

An absorption machine can be constructed by locating the four chambers, their baffles, traps, and tubes within one or two cylindrical drums, with the required solution pumps packaged within one enclosure. The only moving parts required are the small solution pumps.

The absorption system is available in small packages up to a capacity of 25 tons, using gas as the heat source in the "generator" Larger capacity units using steam or 240°F hot water for the "generator" are available from 100 to 1,000 tons.

Although vibration from moving equipment is reduced to a minimum, percolation and flashing cause crackling noises.

Condensing Units

The simplest method of condensing is to use municipal or well water supply. In most instances municipal ordinances forbid the wasteful use of city water except for a small tonnage (5 tons) per building.

Remote fan cooled condensers with a capacity of 30 tons per cell can be installed in locations with easy access to outside air. These units use about 800 cfm and 0.15 KW per ton. With special protection they are suitable for use in a low ambient temperature of about −20°F. They consist of propeller fans drawing air across deep row finned coils containing refrigerant. They are suitable for mounting on a horizontal or vertical plane.

Evaporative condensers are available in sizes ranging from 20 to 200 tons of heat rejection. Recirculated water is sprayed across deep row finned refrigerant condenser coils. Air is drawn across the wetted coil surfaces by a centrifugal fan. About 5% water make-up is required to compensate for evaporation and drift. With ordinary water spray these units are not suitable for freezing temperatures. The units use 250 cfm and 0.10 KW per ton. They are suitable for indoor or outdoor installation. If they are concealed they can accommodate ductwork.

Figure 17: Absorption refrigeration system
(lithium bromide - water)

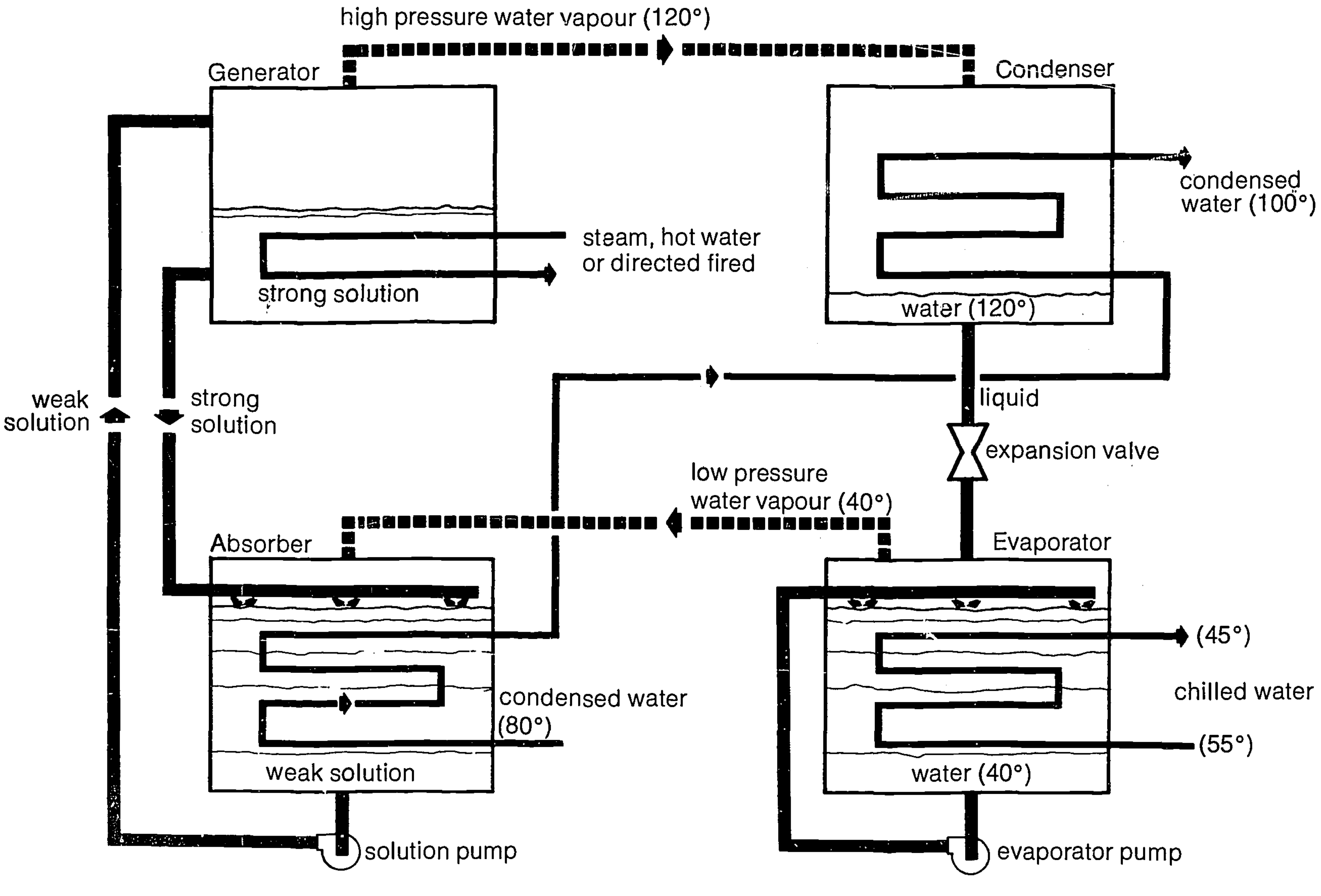


Figure 18: Cooling tower

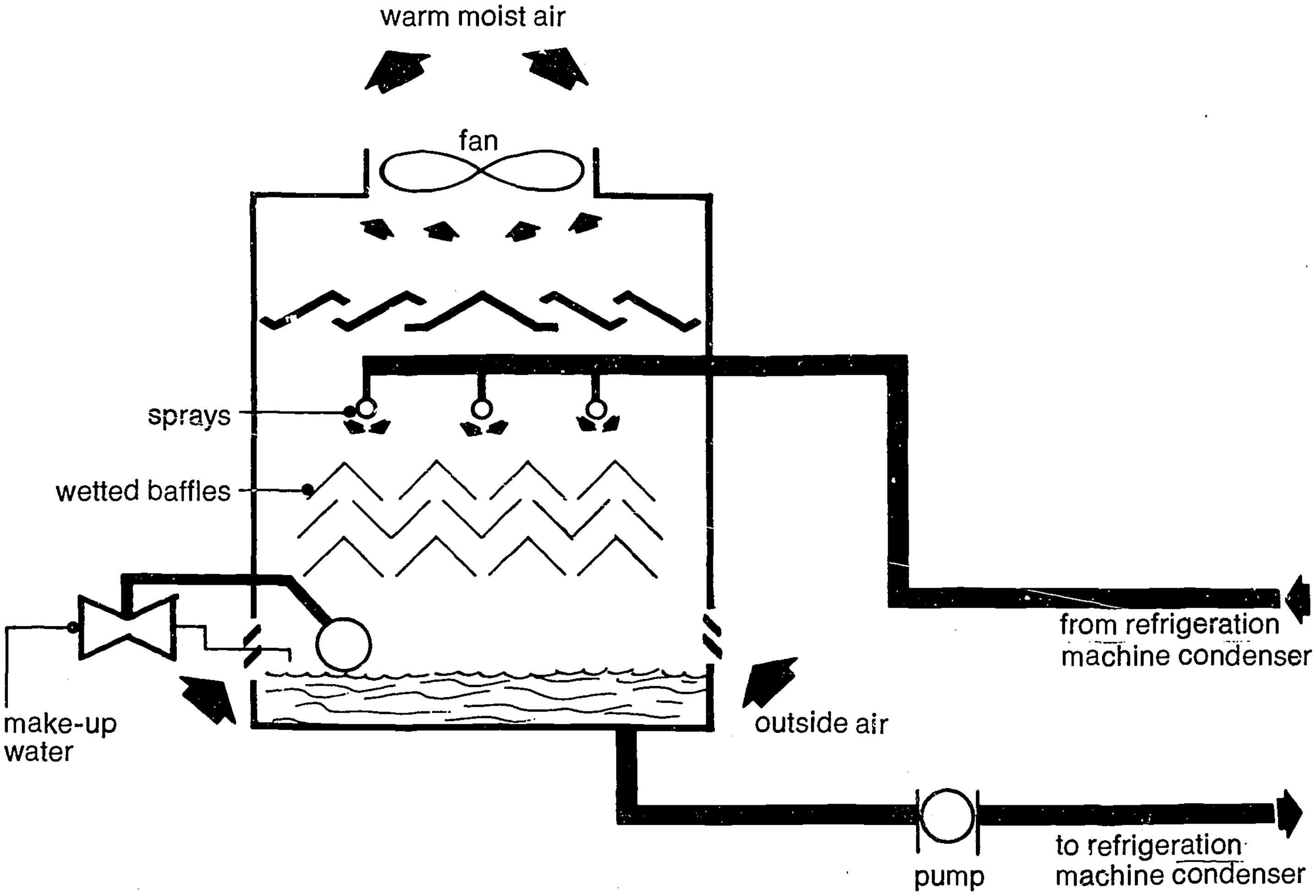
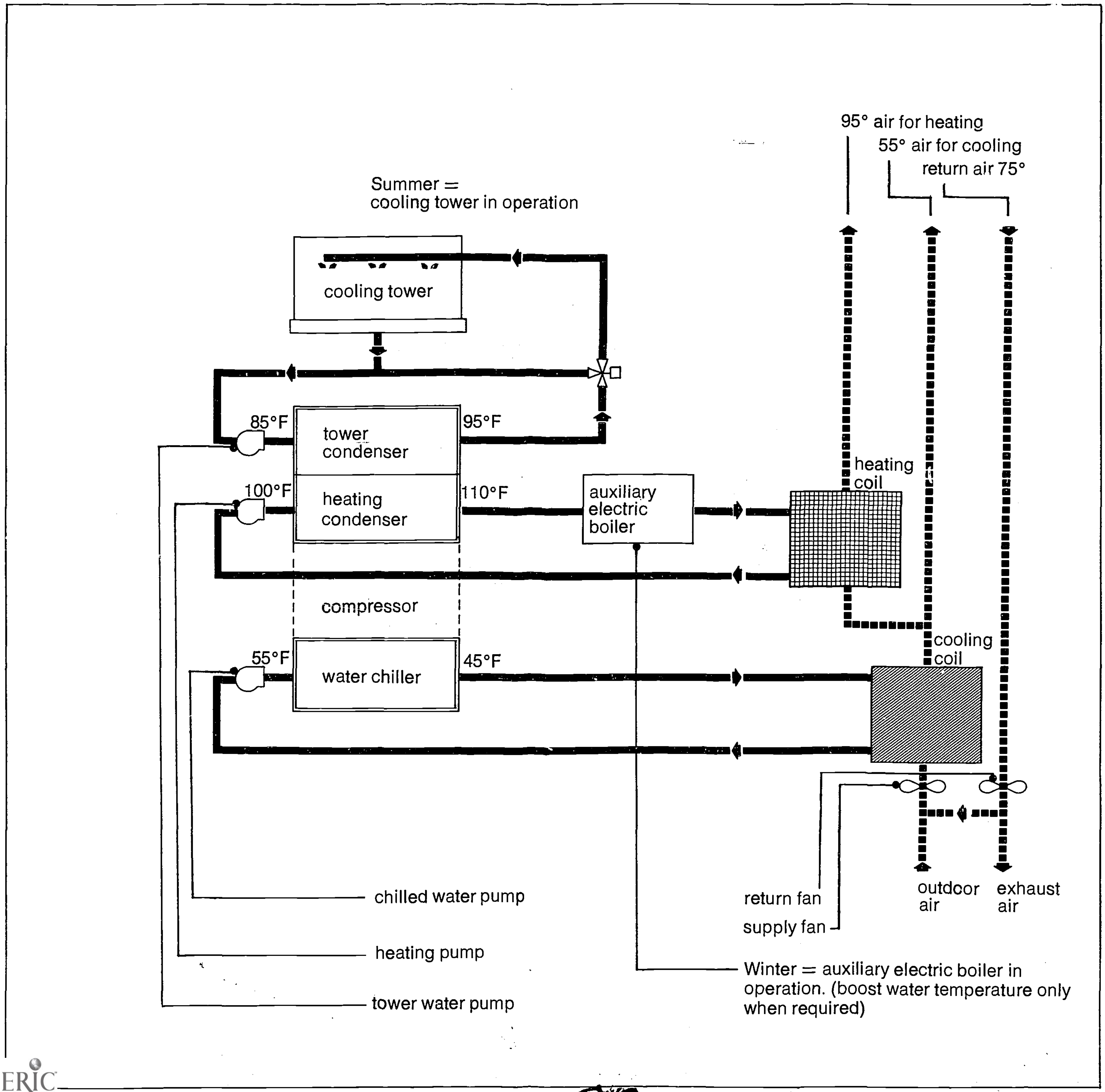


Figure 19: Internal source heat pump



Cooling Towers

Although natural spray ponds have been used effectively to cool condenser water, the very large wetted surfaces and the cost of chemical treatment make their use impractical in all but special cases. Cooling towers are both highly efficient and require relatively little space. In this method, condenser water is passed along many surfaces and air is forced across the wetted surfaces. Natural draft towers, due to their great height and cost are normally used only in industrial projects. Air can be induced or forced by using centrifugal fans or propeller axial fans with inclined blades. (see figure 18.) These towers use approximately 400 cfm and 0.06 KW per ton. By using multiple cells, any required condensing capacity can be achieved.

To prevent growth of algae and other impurities that may clog condenser tubes, a constant bleedoff is needed. Make-up water is chemically treated. The chemical additive may stain or otherwise damage some building materials.

Cooling towers and air-cooled condensers should be located so as to prevent air starvation of the units, short circuiting between air outlet and inlet, and pick-up of moisture-laden air by air system intakes.

The generation of noise and its effect on adjacent buildings must be carefully considered. In residential areas, particularly if the towers or condensers are operated at night or weekends, provision should be made for attenuation and/or screening.

Heat Pump

If it should prove economically feasible to harness the excess heat rejected by the condenser and channel it to locations requiring heat, this can be accomplished in several ways.

For unitary refrigeration compressor installations, a condensing element with a switching arrangement can be utilized by ducting cold or warm air to terminals.

For large single-source centrifugal applications, a split condenser can be provided. One half of the split condenser is pumped to a remote cooling tower to reject hot water at 105°F when not required. The second half is connected to heating nals. The main reason for the split condenser is to keep cooling tower water with its entrained air, gases, and treatment impurities out of multiple small-bore heating terminal coils.

It is necessary to install heating units that can utilize low temperature hot water efficiently (eg., cabinet fan units).

If the heat balance proves periodically faulty, additional heat source must be provided. This may be achieved by means of electrical resistance duct heaters or electric boilers and/or storage tanks (see figure 19).

Moving Equipment

Fans

In selecting a fan the following factors should be considered:

- its capacity; measured in cubic feet of air per minute (cfm)
- its efficiency in generating air flow
- its horsepower requirements
- the noise generated.

Propeller Fans. The air flow through this type of fan is axial. Propeller fans are intended to operate against little or preferably no static pressure. Units can be direct-driven or belt-driven.

Axial Fans. The air flow through these fans is in a longitudinal direction parallel to the axis of the fan. They are used mainly in industrial plants, where their relatively high noise level is not objectionable. Their compactness, firm support, ease of installation, and relatively low cost make them well worth considering for commercial and institutional applications. Great caution must be exercised in their selection, and the correct methods of treatment employed.

Centrifugal Fans. In these fans air flows inward at the eye of the impeller and is projected radially outward by the impeller blades. These fans are manufactured for a wide capacity range from 300 to 300,000 cfm and for service from 0 to over 12 inches water pressure. Centrifugal fans can be of single or double width, with single or double inlet, and can be supplied with various arrangements of drive, motor location, and discharge.

Air Handling Apparatus

Air handling apparatus can consist of any or all of the following components in addition to the fan (see figure 20).

Outside air intake and bird screen. Metal multi-blade louvres and/or baffled enclosure are constructed to prevent entry of snow and rain into the apparatus. Bird screens, mounted within easy access, are adjacent to the opening and prevent entry of foreign matter such as trash, paper, or birds.

Dampers. These are used to provide shut-off and prevent air leakage, to control and mix air, and to by-pass heat-transfer equipment.

Air Filters. Mechanical or throw-away filters are used to capture large dirt particles and prevent them from soiling apparatus and components.

Electronic or deep-bag after-filters are used to capture small particles of dirt.

Preheat coils. These coils are used if the minimum mixing temperature is too low. They may be used with steam, hot water, glycol, or electricity.

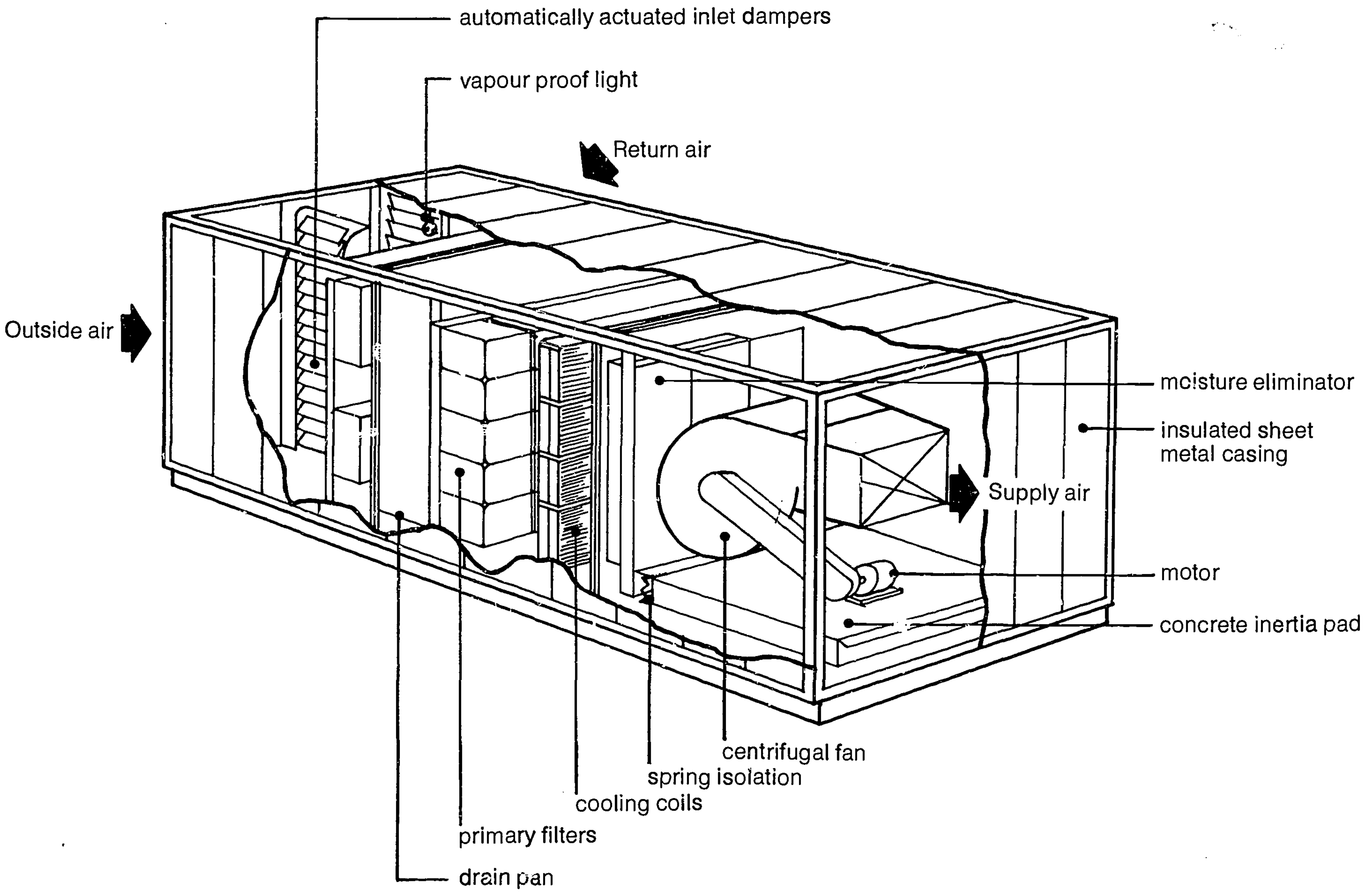
Reheat coils. If located in the air apparatus, reheat coils are sized to compensate for duct heat losses and early morning load pick-up.

Cooling coils. Direct expansion refrigerant coils or chilled water coils are the main determinants of the cross-sectional area requirements of air handling apparatus. The maximum face velocity of air across the coil is determined by the coil's ability to cool and dehumidify without moisture carry-over into the supply air stream.

Spray chambers. These are used for washing, humidifying and/or dehumidifying air. A series of spray heads on piping manifolds distribute an even mist of water into the air stream. The surplus water which is not absorbed by the air-water mixture is collected in a pan and recirculated by a spray pump. Eliminator plates are located on the downstream side to prevent entrained water from carrying over into the supply air ducting. For humidification, either the air is preheated by a preheat coil or the spray water is heated by a jacket heater.

Dehumidifiers. Dehumidifiers consist of

Figure 20: Prefabricated air handling unit



water sprays in conjunction with a cooling coil. Wetting the coil improves the heat transfer and allows a closer approach between the coil surface and the air leaving the coil. During mild, dry weather when refrigeration is shut off, spray water can provide adiabatic cooling of the air stream to let the dry bulb air approach the wet bulb temperature.

Humidifiers. Humidifiers can be classified into two main categories: those that utilize water and those that utilize steam. Water humidifiers use either sprays for vaporization and/or heat for evaporation. Vaporization is accomplished by pressurized water ejected through spray nozzles or by a mechanical device, such as a high-speed rotating wheel, atomizing water injected at its periphery.

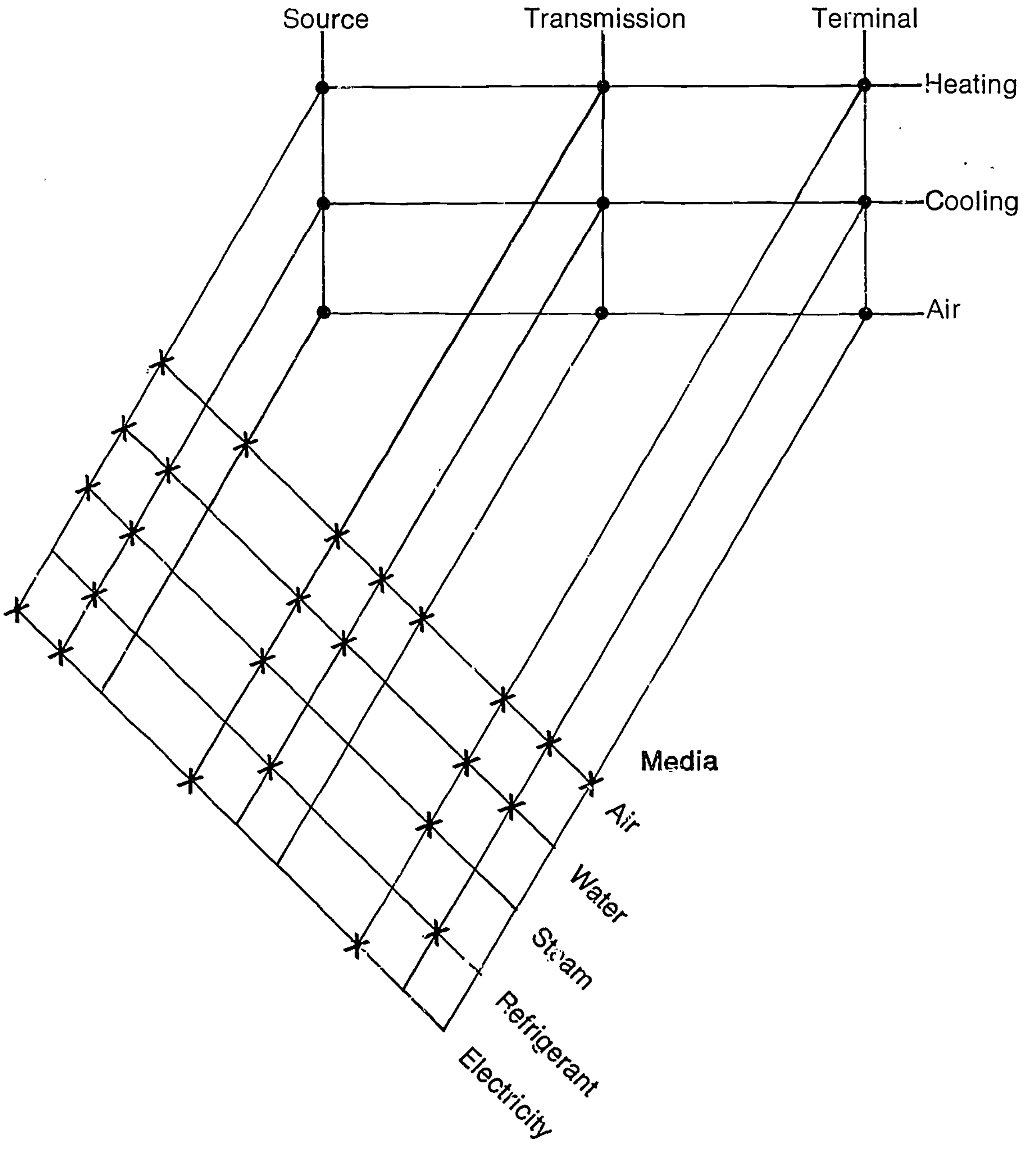
Steam humidifiers utilize pans, grids, perforated pipes, spray nozzles or funnels to inject the steam vapour into the air stream after separating the steam condensate.

Since steam flow can be controlled by an automatic valve, it provides generally a simpler, less expensive and more precise means of humidifying.

Apparatus casings. Casings can consist of masonry or insulated sheet metal braced with angles or channels and covered with a fireproof, abrasion-resistant housekeeping jacket. Hinged doors are provided to allow inspection, cleaning and maintenance of the various apparatus components. Vapour-proof (marine) lights installed inside casings permit proper inspection. Drains are provided in cold air and mixing chambers and for water run-off of coil assemblies.

Provision must be made for access to all equipment. The apparatus can be completely fabricated and assembled at the job site or it can be completely factory-assembled and tested then shipped to the site. In the latter instance, the fan and coil can be partially preassembled before delivery.

Environmental Systems



Design of Mechanical Systems

In order to select and design the system and components that will best maintain the required environment, suit present and future activities, and fall within the available capital and operational cost budget, the following steps must be taken: careful analysis; suitable spatial organization; priority grading and selection of parameters.

The interrelationship of all parameters (as illustrated in figure 3) can be represented by a mathematical expression:
System(s) =
Cost ± Activities ± Environment

With properly evaluated "weighting factors" applied to all pertinent parameters, system selection can be computerized. Without the availability of suitable computer "hardware" and "software", a partly quantitative and partly qualitative priority assessment by the design/program development team can be utilized to optimize the System = Cost ± Activity ± Environment equation (see Evaluation Table of Typical Spaces, page 38).

Spatial organization, vertically and/or horizontally based on total or partial compatibility of adjacent spaces, can result in cost and environmental benefits. High costs or unsatisfactory performance can result from mixing spaces requiring high ventilation with those requiring low ventilation, close tolerance with wide tolerance (of temperature, humidity or noise), and long period occupancy with short period occupancy.

Coupling a wide selectivity range program or a close temperature tolerance requirement, with a widely fluctuating thermal external stimulus (eg., solar gain through unshaded glass) will tax the budget severely.

Unitary Equipment

Current conditions of escalating prices, changes in curriculum and "life style", and general accent on flexibility necessitate close scrutiny and a great degree of self-discipline on the part of the various members of the Owner-Programmer-Designer-Constructor-Occupant Team. Institutional buildings and their systems have traditionally been designed along conservative lines.

Industry, on the other hand, has adapted to a hard-nosed philosophy years ago. Many factories select mechanical systems and system components on the basis of cyclical renewal. The North American automobile industry, which is geared for trade-in of automobiles every two to three years by many owners, is but one example. Thus, often in industry the short-term life expectancy of systems and components matches the anticipated production schedule of the plant. In other words, if a product cannot guarantee a twenty-year manufacturing life, there is little point in selecting a system component that has a twenty-year life expectancy for the plant where it will be manufactured. Moreover, it has to be assumed that over a twenty-year period many drastic changes will occur in production, occupation, and managerial philosophy and standards.

With the increased marketing and improved quality of unitary heating-cooling-ventilating equipment, the focus is on selection and choice rather than on the provision of a long-life centralized system. Anticipated number of occupants, estimated building program for a five- to ten-year period and the availability of funds may determine the selection of a central heating and chilling plant.

On the other hand, short-life equipment should be purchased only if a short-term sinking fund is established and a system devised to deal with the greater maintenance and replacement requirements.

Unitary equipment may include heating, chilling and air generation, transmission, and terminals, or only some of these features. It is available in various degrees of quality and sophistication from various manufacturers. As with components of conventional mechanical systems, products from one manufacturer should not be replaced with similar products from another. They may differ in performance, in system application, in quality, and in serviceability of the units. In addition, the servicing policy in a particular locale may not apply to substituted components and technical personnel may have difficulty with unfamiliar parts.

Examples of unitary equipment are unit ventilators, package air conditioners, floor mounted furnaces, roof-top furnaces, and roof-top heating and cooling units.

The degree to which a system and/or

components should be "unitized" is one of choice. It is also a matter of choice as to whether pre-fabricated manufactured or field-manufactured and erected equipment is used.

Price Control

If a single project is of sufficient size, or if a sufficient number of projects are designed similarly and simultaneously, customizing prefabrication and mass purchasing can result in reduced costs or equal costs with improved quality and performance.

Utilizing standard materials can help reduce prices, since custom-made products are generally costly. Similarly, off-site prefabrication may result in savings.

The equation for evaluating the advantages of pre-fabrication and off-site production should include the cost of production, labour, control efficiency, quality control, transportation, taxes, and the relative wages of construction workers versus the manufacturing selling prices F.O.B. site.

Documents

In view of the increasing complexity of mechanical systems, escalating costs, "tight" money policies, and short time allocations for design, construction, and commissioning for occupancy, conflicts arising from improperly prepared specifications and keenly competitive prices must be avoided.

Terms of partial occupancy, temporary heating, and power for construction and/or early occupancy should be resolved clearly in contract documents. Use of equipment and the effect of partial acceptance on guarantees and warranties and on training of personnel are factors that affect costs and should be recognized.

The success of a project is a function of time, skill, and money. A mechanical system, in particular, made up of varied components and parts and performing many functions, is affected by the skill and integrity of the installers. Shortage of time and money, and the complexity of assembling various components into a working model without prototype studies or mock-ups make it necessary to reduce the chances of misinterpretation to a minimum. It follows that clarity of documents is very important: the legal responsibility for the total project may rest with a single contractor, but it should be remembered that he relies upon sub-contractors, and they, in turn, rely on their sub-bidders. Moreover, in the absence of any or all of the three necessary constituents (time, skill and money), specific directions and quality specifications are essential.

The documentation should be explicit and compiled for easy understanding by the specific sub-trade.

Safety

The factor of safety must be paramount in the design and execution of projects and in the operation of the systems.

Codes and recommendations of municipalities, provincial, and federal authorities, including Department of Labour, Department of Energy Resources, Fire Marshall, Canadian Standards Association, Hydro-Electric Power Commission of Ontario, and unofficial bodies such as the Canadian Underwriters should be recognized and adhered to.

Such safety features as belt-guards and railings should be included to protect the operation and maintenance personnel.
The possibility of explosion, fire, smoke, or gas generation should not be forgotten and steps should be taken to ensure that if any of the above occur, the danger will be confined and isolated to special areas.

Evaluation Table of Typical Spaces

Table — Systematized qualitative evaluation of requirements of typical rooms relative to activity, comfort, and cost

Parameter	*Assigned Priority* Seminars	Classrooms	Labs	Shops
A. Activity (Functional) Criteria				
1. *Bodily Functions (Metabolism)*				
Sex	—	—	—	—
Age	—	—	—	—
Dress	—	—	—	●
Activity				
— lying (230 Btuh)	—	—	—	—
— sitting (420 Btuh)	●	●	●	●
— standing (490 Btuh)	●	●	●	●
— walking (600 Btuh)	—	—	●	●
Smoking	—	—	—	—
Cooking (other smells)	—	—	●●●	●
2. *Health Factor*				
Shock	—	—	—	—
Respiratory	—	—	●	●●
3. *Contamination*				
Within space recirculation	—	●	●	●
To/from other spaces cross-contamination	●	●	●●	●●
From other sources — buildings, chimneys	—	—	●	—
4. *Air Velocities and Patterns*	●	●	●●●	●
5. *Selectivity of temperature and humidity*	●	●●	●●	●
B. Environmental Criteria				
1. *Temperature (Tolerance)*				
Heating	●	●	●	●
Cooling	●	●●	●●	●
2. *Humidity*				
Dehumidifying	●	●	●	●
Humidifying	●	●	●	●
3. *Air Changes and Movement*				
Air Velocities	●	●	●●	●
Stratification	●	●	●●	●●
Total Air Changes	●	●●	●●	●●
4. *Ventilation*				
Fresh Air Quality	●	●●	●●	●
Fresh Air Quantity	●●	●●	●●	●●
Air Pressure Control	—	—	●●●	●●
5. *Air Cleanliness*	●	●	●●	●

Parameter	Assigned Priority			
	Seminars	Classrooms	Labs	Shops
6. *Noise and Vibration*	●	●	●●	●●●
7. *Flexibility for Changes*	●●	●●	●●	●●●
C. Cost Criteria				
1. *Capital Cost*				
Mechanical	●●	●●	●●●	●●
Structural	●	●	●	●
Architectural	●	●	●	●
Electrical	●	●	●●	●●
2. *Operating Cost*				
Fuel	●	●	●●	●●
Electricity	●	●	●	●
Personnel	●	●	●	●
Maintenance	●	●	●●	●●
Operating Period	●	●●	●●●	●●
3. *Owning-Operating Cost*				
Amortization	●	●	●	●
Depreciation	●	●	●	●
Taxes	—	—	—	—
Obsolescence	●	●●	●●●	●●

Minimum Priority — ●
Maximum Priority — ●●●

Cost of heat chart on page 25 by permission of the Hydro-Electric Power Commission of Ontario.

Figure 4. Page 8. Copyright by Ashrae by permission from Ashrae Handbook of Fundamentals 1967.