49

Preheating outdoor air with transfer fluid systems

The problems associated with the heating of outdoor air under critically controlled temperature requirements need no restating. However, it may help to redefine the premise under which freeze-ups occur in makeup air-heating coils. Hence, this chapter is limited to the discussion of design criteria relating to the heating of makeup ventilation air. The following interrelated parameters must be satisfied:

1) Add heat to relatively large quantities of outdoor air being introduced into an occupied space.
2) Control the temperature of the heated air within close tolerances.
3) Control quality of air within relatively close tolerances.
4) Achieve this process with minimum consumption of energy.

The method discussed herein is the outgrowth of more conventional methods which have been employed over the past few decades, to wit:

1) Heating air by direct firing into the air stream, using staging and modulated firing to achieve temperature control.
2) Heating with high- or low-pressure steam in finned coils, achieving temperature control by steam flow modulation.
3) Heating with high- or low-pressure steam in finned coils, two position steam flow control, achieving temperature control with face and bypass dampers.
4) Heating with pumped hot water through finned coils using mixing valves for water temperature control with constant flow rates.
5) Heating with pumped hot water through finned coils using fixed water temperature and flow, and face and bypass control.
6) Heating with pumped "nonfreeze"-type fluid (low triple point), using either face and bypass, varying flow, or varying fluid temperature control.
7) Heating with fuel through a combustion chamber-heat exchanger device.
8) Heating with electric resistance coils.

There may well be other alternatives, but those given are the most commonly used methods. Rather than undertake a rigorous review of the advantages and disadvantages, and application and misapplication of each, an analysis with which most readers are familiar, the common criteria always used in selecting one of the above eight alternatives in preference to the others in any design application is summarized. The questions that must be asked are:

1) Will it satisfy the need for maintaining temperature control within limits established?
2) Will it be relatively nuisance and maintenance free?
3) What heating fluid or fuel is available at the point of need?
4) Does the selection justify the investment and operating cost?
5) Does it minimize energy consumption?

The use of these five criteria, with the result-

This chapter was reprinted from *ASHRAE Transactions*, Jan. 1972 and was originally entitled, "Preheating Outdoor Air with Transfer Fluid Systems." Appearance of this material in *Energy Engineering and Management for Building Systems* does not necessarily suggest or signify endorsement by the American Society of Heating, Refrigerating or Air-Conditioning Engineers, Inc.

ing application to designs of many of the preheater devices mentioned, leads to a value analysis of the alternative systems. In an ensuing effort to find a "better way," this value analyis produced a "hybrid" answer that seems to fulfill virtually all of the design criteria. Such a system would have to:

1) Satisfy the need for maintaining even temperature distribution across the entire section of the intake duct.
2) Minimize energy consumption.
3) Operate with any available fuel, heating fluid, or energy source.
4) Be virtually trouble-free and require minimum maintenance.
5) Provide first cost economics comparable to alternatives.

Needless to say, for air preheaters to be "trouble-free" infers, in addition to normal operational reliability, freedom from "freezing."

The value analysis referred to above was actually stimulated by the growing tendency among systems designers to negate freeze-up problems by designing complete central hot and chilled water-circulating systems to operate with nonfreeze fluids. The most popular such system is an aqueous ethylene glycol solution. (Some basic characteristics of a 50 percent solution, with a freezing temperature of approximately -3 F are shown in Fig. 49-1.) Applying the appropriate heat transfer, heating capacity, and flow relationships, a significant percentage difference in design and operational energy requirements between this system and a comparable water system is indicated, with a relatively large increase in both heat transfer surface and pumping horsepower as the result. An additional, and perhaps even more significant, problem introduced by this solution to the freeze-up problem is the diligence with which maintenance of the proper level of glycol in the system must be assured. For if this is not done, a false sense of security that the system is "freeze-proof" could lead to disaster in the entire building system.

"Nonfreeze" fluid used

The device selected therefore was a system which actually heats the air through a finned

	45 F		180 F	
	Water	Glycol	Water	Glycol
Specific Heat BTU/lb.	1.003	0.775	1.002	.85
Specific Gravity	1.+	1.07	0.977	1.03
Viscosity (Cp)	1.3	6.0	0.35	0.90
Piping System Δp	1.20	1.70	1.0	1.20

[Flow Rate] lb.m/Time = Heat Requirement/(Sp. Ht.)(Δt)

Pump H.P. = lb.m/min. × Ft. Hd./33,000

Approximate Increases In Pumping Horsepower
(Not Considering Decreases In Efficiency)

Cooling	Heating
82%	40%

Fig. 49-1. Characteristics of 50% aqueous ethylene glycol solutions versus water.

coil with a "nonfreeze"-type fluid on the inner surface. This coil is close-coupled to a heater section wherein the fluid is heated with whatever fluid or energy source is available. This approach, when applied to a factory-made quality-controlled and tested unit, appeared to satisfy all of the foregoing criteria. A flow diagram showing the basic components and control logic of such a unit is shown in Fig. 49-2 and illustrates the simple concept upon which the proposed solution was based: a nonfreeze-type fluid, fluid heater, and finned heating coil, factory-made and charged to stated specification requirements. The introduction of the intermediate fluid in a hermetically sealed system or assembly satisfies immediately several of the design criteria: (1) isolation of the primary heating fluid from the freezing environment; (2) stabilization and dampening of the control system response through the response time constant created by the intermediate fluid; (3) isolation of the exotic fluid to the closed hermetic system (in preference to a field-fabricated piping system throughout the building).

As is shown on the simplified diagram, the basic control logic concept is a temperature-sensing device in the air stream and directly controls the rate of heat input.

Now let us look at the alternative concepts in the two basic components: (1) the fluid system or cycle; (2) the heater and heat source. The other subsystems or assemblies, including the air heater, control loop or logic, circulator, etc., are essentially dependent on these two, except for an isolated system design which is discussed later.

The single-phase fluid cycle

The first fluid cycle discussed is the single-phase cycle (i.e., no change of phase) which utilizes a liquid throughout the cycle. The basic theory behind operation of the single-phase cycle is identical to that between the so-called gravity circulation hot water heating system or the forced circulation hot water heating system. Continual research is being conducted to determine more desirable fluids. But all fluids which to date have shown favorable characteristics from the standpoint of stability and freeze protection, although showing desirable properties of buoyancy, have been relatively viscous, thus defeating efforts to achieve adequate control response with gravity circulation systems. Thus, the prototype single-phase systems were developed with forced circulation and hermetically sealed pumping devices. Again, the hermetically sealed unit is in keeping with the quality and nuisance control criteria. (Figure 49-3

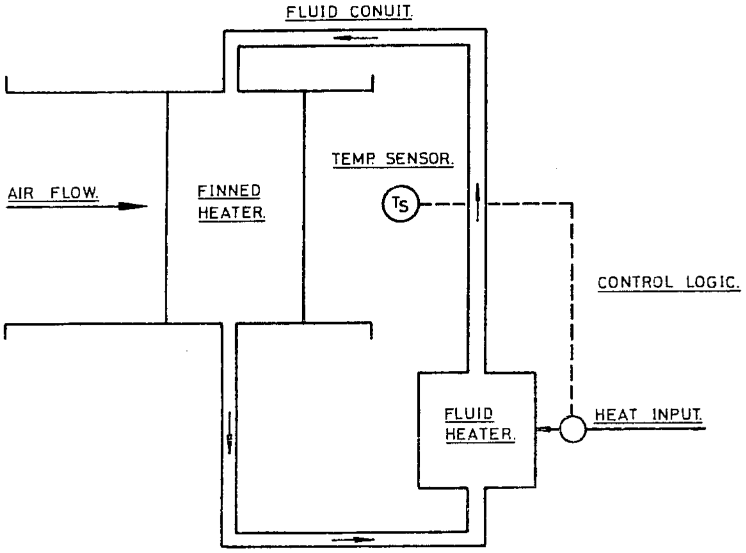

Fig. 49-2. Basic flow diagram.

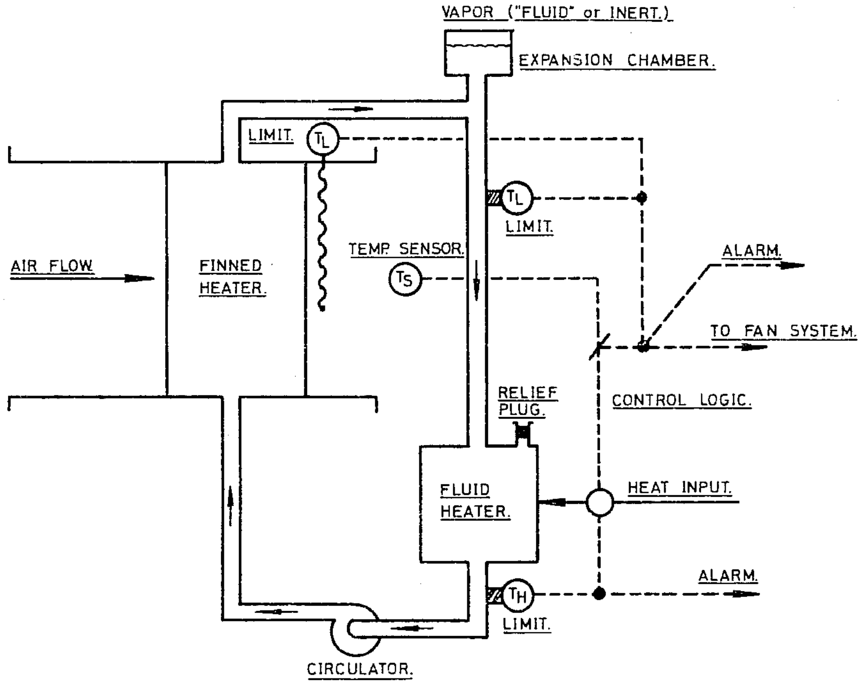

Fig. 49-3. Single-phase pump system.

shows a more fully developed flow diagram of the single-phase system.)

Note that Fig. 49-3, in addition to the circulator, has added an expansion chamber, two low-temperature sensors, one high- or over-temperature sensor, and a relief plug. The logic of the low- or under-temperature sensors is somewhat different from that of the standard freezestat on normal air-handling apparatus. The coil face sensor, upon sensing dangerously low temperatures at the coil face, will override the controlling thermostat in signaling the heat input actuator to accelerate the rate of input (i.e., it will tend to correct the problem by assuming control from the normal controller). When this occurs, alarm contacts are closed to indicate failure on the part of the primary control or heat source. If the correction is not successfully achieved, the "panic button" takes the form of a low-temperature switch on the fluid line leaving the air heater. When this fluid temperature approaches 32 F, the normal sequence of shutting down the fan and closing the dampers occurs. A high- or over-temperature sensor in the fluid line leaving the heater throttles the heat input and closes an alarm signal to notify of the malfunction.

The two-phase fluid cycle

The second basic fluid system is the two-phase cycle. In this cycle, the principle of the old vapor-type steam system is employed (Fig. 49-4). The concept is to add heat at the heater, or evaporator, evaporating the refrigerant-type fluid which quite logically flows thence to the air-heating coil where it gives up its heat to the air stream. Theoretically, the cycle development could end with this basic concept if the ideal fluid were available; however, a search of fluids to date has not yielded a safe fluid with adequate pressure-temperature characteristics to provide the quality of leaving air temperature control required over the entire anticipated operating range. Thus, as with the single-phase system, a compromise in the basic conceptual simplicity was found to be necessary. Again, the problem was readily solved by the simple addition of a hermetic return pump. Figure 49-5 shows a more fully developed diagram of the two-phase system including its primary control logic.

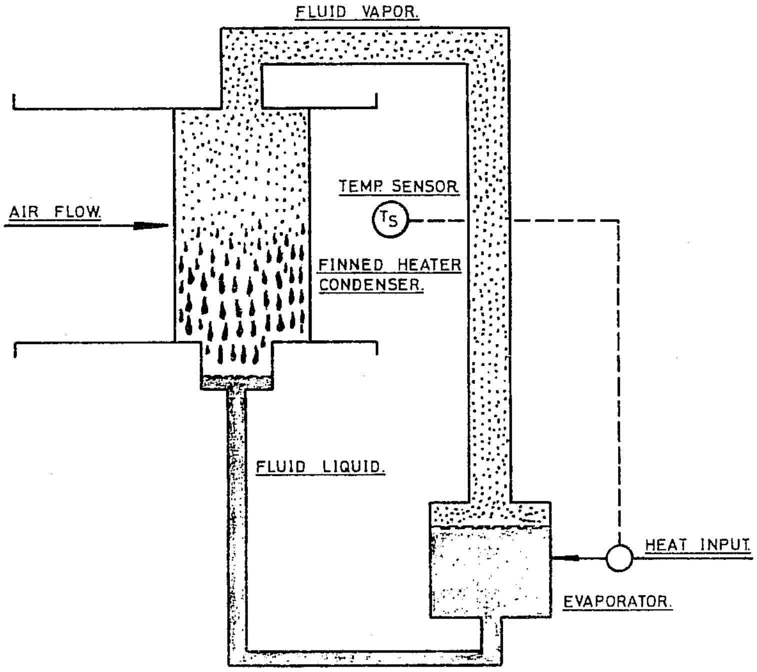

Fig. 49-4. Two-phase simple system.

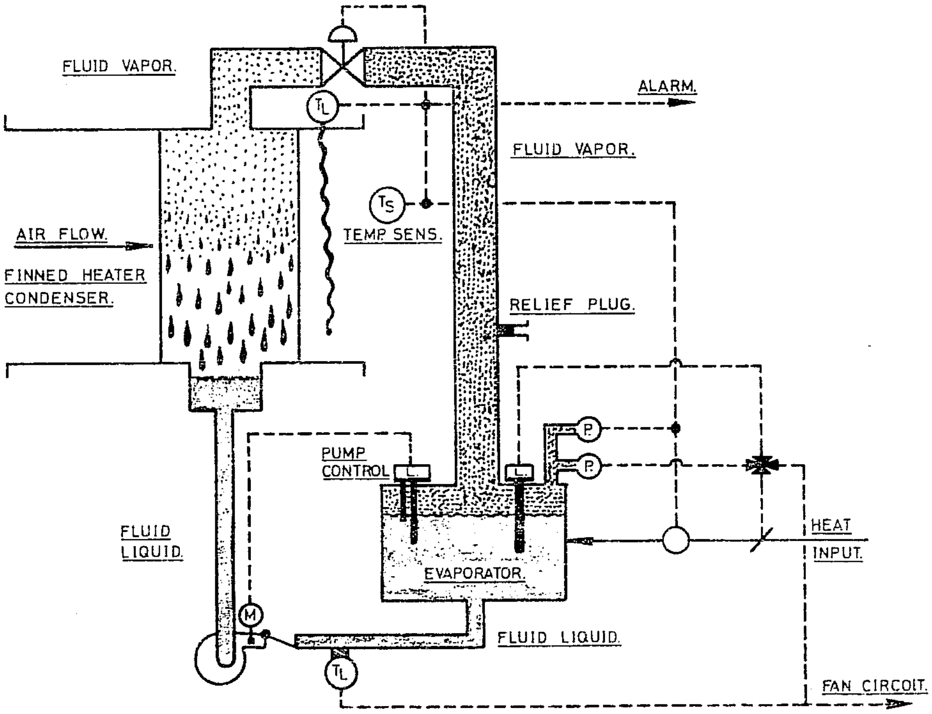

Fig. 49-5. Developed two-phase system.

The control logic of the two-phase system is somewhat more complex than that of the single-phase system. The air temperature control signal positions the fluid valve supplying the air heater and allows the evaporator heater control cycle to function. As in the single-phase system, this circuit is overridden by the low air temperature control on the leaving face of the coil. Evaporator control, initiated by a call for heat from the air sensor, is simply achieved by a variable output or two-position pressure sensor. In the event of overpressure, underlevel, or low fluid temperature, the respective control restricts the heat input; additionally, the low fluid temperature control also stops the fan in the normal "safety" fashion. The pump is simply operated from a probe-type level control. Continued development is being undertaken to bring out the desirable features in the basic concept of the two-phase system. It is strongly felt that some fluid or Azeotrope fluid can be found that will allow use of the high latent heat of vaporization and natural pressure differential flow motivation while dispensing with the complexities of the return pump and fluid control valves.

Primary heating fluid sources

As stated, one of the concepts of the intermediate fluid heater was that it would be applicable to any fuel or primary heating fluid source. Current development has been aimed at five basic heat sources: (1) low- or high-pressure steam (5 to 120 psig); (2) medium- or high-temperature water 210 to 350 F; (3) electricity; (4) natural gas; (5) light oil.

The low- and medium-pressure steam units, whether single phase or two phase, are basically shell and tube heat exchangers with the steam in the shell and the fluid in the tubes. The air temperature sensing controller simply controls the "throttle" of inlet steam valve, and the unit is normally provided with a single float and thermostatic trap or inverted bucket trap with a thermostatic vent port. In keeping with what is believed to be the "coming" field of application in completely closed steam vapor systems, a vacuum breaker is connected from the exchanger to the return line rather than to the atmosphere.

Medium- and high-temperature water units are constructed much like the steam units, utilizing shell and tube heat exchangers and water flow modulating valves controlled by the leaving air temperature sensing controller. With proper sizing of valves to match the unit performance, and built-in stability or stablized time constant, normally one valve is capable of providing flow regulation down to the lowest load requirement. Also, the secondary fluid concept coupled with the dual safety control, provides a more than adequate safeguard against water freeze-up on both the water and steam units.

In the electrically operated system the fluid is circulated through a shell or chamber in which the resistance heating elements are immersed in protective wells. Although this requires appreciably more heating surface than would be necessary were the elements exposed to the fluid, the "well system" maintains the integrity of the hermetic fluid system. The control is quite simple, and an inexpensive method, in that the air temperature controller drives a sequence switch which cycles the heating elements in steps. The introduction of the intermediate fluid dampens the step effect to achieve the end result of variable modulation, thus eliminating the need for expensive solid-state rectifying or clipping of the power wave. More sophisticated high-frequency induction heating from external power probes, with a frequency modulation control, is planned for future consideration.

Probably the most challenging design concept being experienced is the accomplishment of some degree of control and performance for those systems wherein a raw fuel (gas or oil) is the most economical and conveniently available heat energy source. We all think in terms of parameters such as 5 sq ft per boiler HP when considering the problem of heating a fluid via a burner with a fuel. However, some very interesting product research has been conducted over the past decade which resulted in the development of unbelievably compact fuel converter/fluid heaters. Studies currently underway are aimed at incorporating these devices into both the single-phase and the two-phase cycle. The two-phase cycle will utilize a single-phase heater and flash chamber to obtain the vapor.

Consider the heat pipe

Before concluding, consider two other alternate product concepts not yet mentioned. The first one is believed to be the most trouble-free of all the alternative devices discussed, although its application at this stage of development is limited to systems wherein central steam or hot water distribution is available as the energy source for the air heater. On this premise, a unit is proposed which utilizes the refrigerant-motivated heat exchanger known as the heat pipe.

As is widely known, the heat pipe (Fig. 49-6) utilizes a hermetically sealed tube, a wick material, and a refrigerant charge. As one end of the tube is heated, the refrigerant vaporizes, the other end or cold terminal of the tube condenses the refrigerant vapor and creates a low-pressure region to "draw" additional vapor from the vaporizing end. The liquid return system is simply a "wick" or porous capillary material which, by the principle of adhesion, pumps the liquid back to the "evaporator" end. By placing the evaporator end in a "heat source" chamber, and a finned coil condensing end in the air stream, the entire piping and pumping system can be eliminated. Investigatory analysis indicates, however, that the criteria of even-temperature gradient distribution across the intake air duct may not be satisfied, as the gradient along the tube varies considerably. However, it is felt that this problem will be solved by geometric configuration in the not too distant future.

Enter heat-recovery systems

The other product to come out of this development study is one which seems to carry an attractive label these days, that is, heat recovery. Again, from the standpoint of control stability, energy consumption per cfm, and maintenance costs, a highly efficient heat-recovery system has been developed by providing a double-coil system, utilizing the exhaust air coil as the generator or evaporator (as the case may be), and appropriate control logic. However, in comparing energy economics to cost economics, the device is found to be economically unfeasible at this time since no effective efficiency method during the cooling cycle has as yet been achieved. The approach currently explored is that between the conditions of 95/78 and 75/50 percent, 40 percent

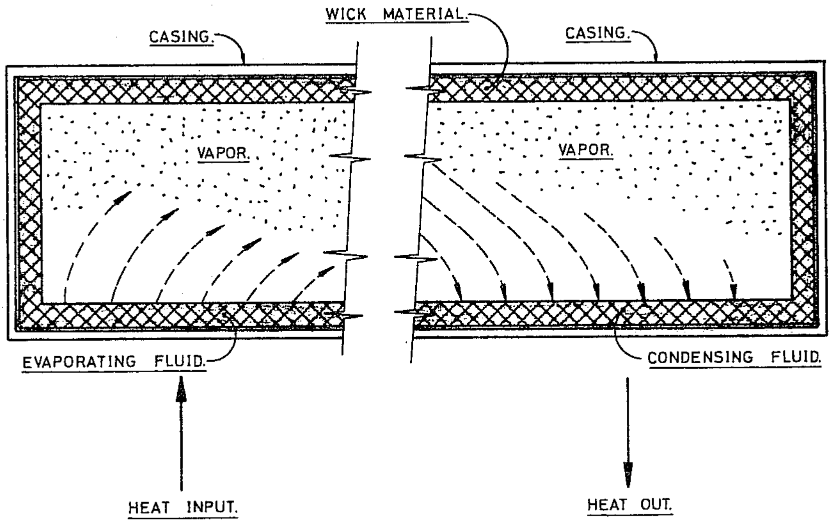

Fig. 49-6. Elementary heat pipe.

of the cooling is sensible; at the same dry bulb temperatures and lesser outdoor wet bulbs (which is normally the case for more operating hours per year), the percentage of dry bulb energy (enthalpy) increases. It is on the basis of this theory that in preliminary studies, tandem heaters (or coolers), utilize the energy source (or sink) from the exhaust air stream, supplemented (in series) with a source (or sink) from a central building system, to provide year-round controlled conditions of the intake ventilation air. Such a system would provide: (1) near optimum energy conservation; (2) an absolutely nonfreeze air preheat system; (3) a precool system which would allow the designer added flexibility in terminal systems control to achieve any desired space-temperature-humidity tolerances.

Heating devices have been previewed in this chapter which will become available in the near future. In the process, a product concept has been provided based on sound engineering principles that will resolve the current problem of coil freeze-up which has plagued both designers and operating personnel for decades. The ensuing savings in time, effort, and actual expense to industry as well as users should prove to be considerable.