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ABSTRACT

Much of the innovative work in the design and application of heating, ventilating, and air conditioning (HVAC) systems is concentrated on improving the cost effectiveness of such systems through optimizing energy use. One approach to the problem is to reduce a building's HVAC energy demands by designing it for lower heat gains and losses in the first place. Another approach taken by designers in response to their awareness of the need to optimize HVAC energy has been to seek new systems and equipment. This booklet is a conceptual review of the state of the art of HVAC systems and components that have come out of continuing efforts toward more efficient use of energy through technology. (Author/MLF)

design concepts for optimum energy use in HVAC systems

state of the art

The desire for comfort is the incentive for all invention in the field of heating, ventilating and air conditioning. It has stimulated HVAC technology to where it is possible now to closely maintain an inside environment within practically any chosen set of temperature/humidity design conditions. Despite this accomplishment, innovative work in the design and application of HVAC systems is continuing, probably at a faster rate than ever before. Much of this work is concentrated on improving the benefit/cost ratio of HVAC systems so that the comfort they provide can be enjoyed by more people in more places.

The approaches to improving the benefit/cost ratio are largely directed at optimizing energy use in HVAC systems. Or, stated more simply, getting the most comfort for the fewest Btu's.

The architect and the consulting engineer share the joint responsibility of seeing to it that HVAC energy is used to best effect. One approach to the problem is direct: reduce a building's HVAC energy demand by designing it for lower heat gains and losses in the first place. The designers clearly should be credited with the new emphasis placed on design decisions involving thermal insulation, ventilation rates, types of window glass, ratio of glass to opaque wall area, solar shades and screens and the orientation of a structure on its site.

The second approach taken by designers in response to their awareness of the need to optimize HVAC energy has been to seek new systems and equipment. Although some of the developments evolving from this search are remarkably ingenious and complex, their common aim is a simple one: reclaim energy that might otherwise be wasted and put it to good use. What follows is a conceptual review of the state of the art of HVAC systems and components that have come out of the continuing efforts toward more efficient use of energy through technology.

HEAT WHEELS

Powered ventilating systems exhaust conditioned air from inside a structure and replace it with up to 100 percent outside air, which must then be treated to bring it within the design limits for temperature and humidity. This exchange of conditioned inside air for outside air represents a considerable expenditure of energy, particularly in buildings such as schools and hospitals that may require one or more total air changes every hour. And in well insulated structures in which heat gains and losses through the exterior of the structure are diminished ventilation losses loom proportionately larger There are, therefore, decided economic advantages to be realized by providing some means for reclaiming the conditioning effect of exhaust air. Numbered among the proven methods for so doing are those employing heat wheels, runaround systems, static heat exchangers and heat pipes.

There are two types of heat wheels the first transfers only sensible heat while the second handles latent heat as well Each consists of a motor-driven wheel frame packed with a heat-absorbing material such as aluminum or stainless steel mesh, or a corrugated asbestos-type material. The wheels are designed to be installed in the ventilation air system with the outside and exhaust air being kept separate.

As it turns, a sensible heat wheel continuously transfers heat from the warmer stream to the cooler one The construction of the wheel is such that cross-contamination is normally low enough for most applications, but a purging section can be incorporated to reduce contamination even further Purging is accomplished by returning a portion of the makeup air to exhaust after it has passed through the wheel

A total heat wheel which employs a filler of lithium chloride-impregnated asbestos, makes it possible to more fully utilize the concept of energy optimization under summer conditions by using conditioned exhaust air to cool and dehumidify makeup air Lithium chloride is a desiccant which absorbs moisture as well as heat, thus achieving the transfer of both latent and sensible heat exhaust air heat recovery

RUNAROUND SYSTEM

A limitation in the application of the exhaust air heat recovery concepts covered thus far is that inlet and exhaust ducts must be close to one another. This proximity requirement is avoided in the runaround system which employs two heat exchangers connected to one another by a loop of pipe. As shown in the sketch one unit is installed in the exhaust duct and the second, in the outside air inlet. A motor-driven pump continuously circulates an antifreeze solution of ethylene glycol and water through the heat exchangers. The exhaust air that is drawn over finned coils in the first unit warms or cools the solution, while in the makeup air unit the process is reversed. The runaround system can be as efficient in energy transfer as the heat wheel provided the heat exchangers have sufficient capacity. However, if a heat exchanger's capacity is increased by adding rows of finned tubing, the pressure drop through it increases considerably. The gain in efficiency, therefore, may be partially offset by the higher fan power required.

exhaust air heat recovery

AIR-TO-AIR HEAT EXCHANGERS

HEAT PIPES

The air-to-air heat exchanger, which has no moving parts, represents a static means for transposing heat between exhaust and outside air streams which pass through it in counterflow fashion. It resembles an open-ended steel box with a rectangular cross section that is compartmented into a multiplicity of narrow passages in a cellular format. Every other passage carries exhaust air, alternating with those carrying makeup air. On the heating cycle, energy is transferred from the exhaust air streams to the makeup air streams by conduction through the walls of the passages so that contamination of the makeup air cannot occur.

A transfer of energy between incoming and outgoing air can be accomplished by banks of devices known as heat pipes which are installed through the adjacent walls of inlet and outlet ducts and which have their opposite ends projecting into each air stream. A heat pipe consists essentially of a short length of copper tubing, sealed at both ends, which contains a snug-fitting porous cylindrical wick and a charge of refrigerant. A temperature difference between the ends of the pipe causes the liquid in the wick to migrate by capillary action to the warmer end where it evaporates and absorbs heat. The refrigerant vapor then returns through the hollow center of the wick to the cooler end where it gives up this heat, condenses and starts to repeat the cycle. These units promise to be highly efficient and, because they are sealed and have no moving parts, maintenance should be minimal.

recovering lighting heat

Ducted air systems can be designed to provide a direct means for controlling and redistributing heat dissipated by lighting fixtures, which are the prime sources of internal gains. What makes this possible is a lighting fixture provided with slots through which return air is drawn into the ceiling plenum. As it passes over the lamps, ballasts and sheet metal of the luminaire, the air picks up as much as 80 percent of dissipated heat and carries it into the plenum. The addition of the lamp heat raises the cavity temperature above that of the occupied space. Some heat is lost through the ceiling to the cooler space below; some escapes through the building floor above; and some is lost to the cold ducts within the plenum. Despite these losses, 50 to 65 percent of the lamp heat is retained above the ceiling.

There are many ways in which plenum heat can be put to use in space conditioning systems. In a double-duct system, for example, the plenum can be the source of air for the hot deck, with supplementary heat being supplied by duct heaters or water coils piped to the space conditioning water side of a double-bundle condenser. The diagram shows a portion of a single-duct heat recovery system as it could be installed in the interior zone of a building requiring simultaneous wintertime heating and cooling. A key element in this system is the induction box with thermostatically controlled dampers. The velocity of the air in the cold duct, combined with the damper arrangement, enables this unit to induce up to 50 percent warm cavity air.

When full cooling is required, 100 percent cold primary air is delivered to the space. When warmer air is indicated, warm air from the ceiling cavity is gradually induced into the unit and is mixed with a correspondingly reduced quantity of cold primary air. The plenum air may also be used for heating the perimeter zones of the building, aided again by some type of supplementary heaters. This arrangement is well suited for controlling interior zone temperatures in systems that employ outside air for wintertime cooling.

The use of air return fixtures can be beneficial in summertime conditions also because lighting heat can be drawn off and vented to the outside, thus reducing the cooling load. This benefit may result in economies in the sizes of ducts and chillers. An added advantage is that, because the lighting fixtures operate at lower temperatures, they produce up to 13 percent more light output for the same energy input. The two basic approaches to the venting of lighting heat are designated as the total return and the bleed-off systems.

TOTAL RETURN SYSTEM

BLEED-OFF SYSTEM

In a total return system, air is introduced into the room through conventional air diffusers and all of it is returned through the luminaires. A fixed portion of the return air is exhausted to the outside for ventilation purposes, while the remaining air may be recycled or exhausted, all or in part, depending on outdoor temperature and humidity conditions.

Total return has the advantage of maximizing light output from fluorescent fixtures while reducing the temperature of the luminaire surfaces thus minimizing radiant heating effects. This is accomplished with little change in the cooling tonnage required from that of a conventional ducted air system.

In a bleed-off system most of the air entering a space is returned to the air handling unit directly through conventional registers. Only a portion is drawn off through the lighting fixtures and this is vented directly to exhaust. This bleeding-off of ventilation air through the lighting fixtures offers the greatest potential reduction in cooling capacity of all air handling methods, especially in those applications where high ventilation rates are required. Lighting efficiency is increased and radiant heating effects diminished but not as much as in total return systems. Both total return and bleed-off systems usually permit a reduction in the number of air changes because of the direct re-oval of lighting heat, which may be translated into economies in air han-ng and distribution equipment.

recovering lighting heat

WATER-COOLED LUMINAIRES

Water is another medium that has proven practical for effective transfer of heat energy from lighting fixtures. Hydronic systems employ special luminaires equipped with aluminum reflector housings that are formed in such a way as to provide integral water passages. The liquid circulating through these passages absorbs heat from the lamps and ballasts and carries it away.

The water-jacketed fixtures transfer about 70 percent of the lighting load to the circulating liquid. In one type of hydronic system, the fluid is pumped through an evaporative heat exchanger to dissipate this energy and minimize internal heat gain during the cooling season. If, for example, lighting accounts for 50 percent of the total heat gain, then the 70 percent absorption of lighting heat directly from the fixtures is translated into a 35 percent reduction in the total load. This permits the use of smaller fans, ducts and refrigeration equipment and results in lower operating costs.

With this type of system the circulating pump can be stopped during the winter and all of the lighting heat allowed to enter the space. In a more sophisticated hydronic system the pumps operate year round and the luminaires can be used in conjunction with aluminum water-filled louvers installed across windows of a building, usually on the sunny sides. In the cooling season, a pump draws water from both louvers and luminaires and delivers it to a cooling tower. The cooling tower serves to maintain water temperature in the 75F to 85F range by removing excess heat and venting it to the atmosphere. The benefit of this arrangement is that it limits solar heat gain as well as that from the lighting.

During the winter, the cooling tower is isolated from the circuit and water flows from the luminaires directly to the louvers. The warm water moving through the louvers offsets heat loss through the window areas and minimizes drafts.

The diagram below illustrates the application of water-cooled luminaires a refrigeration-type heat recovery system.

HEAT PUMPS

Reduced to essentials the objective of all of the concepts discussed up to this point for optimizing energy use in HVAC systems is to transfer heat. Because heat transfer is also the basic function of the refrigeration cycle, it is not surprising that apparatus using the principle has found valuable service in the field of heat recovery.

By virtue of its name alone, the heat pump deserves the attention of designers concerned with optimizing energy use through heat transfer. The heat pump is essentially a heat-transfer refrigeration device that puts the heat rejected by the refrigeration process to good use. It offers the engineer a single equipment installation that:

(1) can provide either heating or cooling;
(2) can switch from one to the other automatically as needed; or
(3) can supply both simultaneously if so designed.

Heat pump operation may or may not involve reversal of the direction of refrigerant flow.

Like any heat pump, the reversible-cycle heat pump is similar in design to a conventional refrigeration machine and has the same three basic components: compressor, condenser and evaporator. In this type of heat pump the direction of the refrigeration cycle is reversed by the operation of valves and the roles played by the heat exchangers are interchanged when the interior spaces switch from heating to cooling or vice versa.

The heat pump has the unique ability to furnish more energy in the form of heat than is put into it in the form of electric power because it can remove heat from a source such as outside air (in the case of an air-to-air heat pump). Outside air has some heat even at relatively low temperatures. In a sense the heat absorbed by the evaporator coil is "free" and electric energy is required only to move it. This free heat is what makes it possible for the heat pump to supply more energy than it consumes. With an easily attained heating coefficient of performance (ratio of useful heat output to electric gy input) of two and more, the heat pump has the lowest operating cost ny electric heating/cooling equipment.

refrigeration-type heat recovery

AIR-SOURCE HEAT PUMP TRANSFER SYSTEM

In the systems described so far, any additional heat, over and above reclaimed heat must be drawn from storage or provided by some form of auxiliary heaters. An interesting alternative to such systems makes use of an air-source heat pump which not only can transfer internal heat when it is available, but also can resort to the atmosphere as a source when there is no surplus internal heat

The diagram shows an air-to-air heat pump applied as a heat recovery machine in a double-duct system capable of simultaneous heating and cooling. In this mode of operation the compressor delivers hot gas to a heat exchanger (condenser) in the hot deck where the refrigerant condenses, then passes through the cold deck heat exchanger (evaporator) and returns to the compressor via the suction line. The effect of this cycle is to recover heat from the cold deck and deliver it to the hot deck. During unoccupied times when there is no surplus internal heat to be recovered, the refrigerant circuit is automatically switched from the cold deck to a roof-mounted heat exchanger (evaporator) and heat is abstracted from the atmosphere. For summertime cooling the refrigerant circuit is automatically switched again, this time from the hot deck to the roof-mounted heat exchanger which then serves as a condenser rejecting heat to the atmosphere. No hydronic circuits e involved because all heat transfer is accomplished directly through the frigerant refrigeration-type heat recovery

WATER-SOURCE HEAT PUMP TRANSFER SYSTEM

Water-to-air heat pumps are the key elements in a space conditioning system designed specifically for optimizing energy use in multiple zone structures. The system is actually a hybrid configuration; while it has some of the characteristics of a decentralized system with independent in-zone heating/cooling units, it also requires some remote equipment that is common to all of the zones.

In this system there is a heat pump unit in each zone of the building. The water-to-refrigerant heat exchangers of all of these units are connected together by a closed loop of circulating water. Heat is rejected into the water by heat pumps on the cooling cycle and absorbed from the water by units on the heating cycle. Also connected into the water loop at a central location are a boiler and an evaporative cooling tower, which operate as necessary to maintain loop water temperature between 60F and 95F year round. Water at temperatures within this range makes possible very efficient and reliable performance of the heat pumps.

A major advantage of this system is that it recovers excess heat from one zone and transfers it to another that requires it. Since no exposure to outside air is needed, there is great latitude in locating the heat pumps. The system provides all the operating flexibility of three- or four-pipe systems with only two pipes, which require no insulation because of the moderate water tem-ature in the loop. The choice of temperature in each zone is completely ependent regardless of the season or mode of operation in other spaces.

CHILLERS AS HEAT RECOVERY MACHINES

To appreciate the prominence that chillers have achieved as heat transfer machines consider an ordinary application where chilled water is pumped through fan/coil units to cool a building by carrying off unwanted heat. As the water circulates the absorbed heat is brought to the evaporator section where it is removed and transferred by the refrigeration process to the condenser. At this point the hot refrigerant comes in contact with a bundle of water tubes located within the shell of the condenser. Condenser water is circulated through a cooling tower where the heat removed from the building spaces is finally dissipated into the atmosphere.

Now consider the case of a building that at certain times has some spaces that require cooling while other spaces are calling for heat. Btu's must be subtracted from some and added to others. It can easily be visualized that if both the evaporator and condenser sides of a refrigeration machine are piped to appropriately located fan/coil units, the same machine can supply both cooling and heating needs simultaneously. This is exactly what is done in a refrigeration-type heat recovery system although in an actual application, the refrigeration machine is equipped with a refinement known as a double-bundle condenser.

DOUBLE-BUNDLE CONDENSER

A double-bundle condenser is constructed with two entirely separate water circuits enclosed in the same shell. Hot refrigerant gas from the compressor is discharged into the condenser shell where its heat is absorbed by either one of the water circuits or by both simultaneously depending on the requirements of the system at a given time.

One of the circuits is called the building water circuit and the other, the cooling tower circuit. The reason for splitting the condenser into two independent hydronic circuits is to prevent contamination of the building water and its associated pipes, coils, pumps and valves with cooling tower water, which may contain dirt and corrosive chemicals. When a double-bundle condenser is added to a standard refrigeration machine the heat rejected by the compressor is made available to the building water circuit. Condenser water temperature, which is normally in the range of 100F to 105F, can be boosted by adding some form of supplementary heating, such as immersion heaters or a boiler, to the circuit. Higher water temperatures can also be obtained by employing two liquid chillers with their hydronic circuits connected in tandem. Hot water at 150F can be obtained from the second liquid chiller which receives 100F water from the first.

In certain heat recovery applications the amount of heat it is possible to reclaim during occupied hours may exceed the daytime heating requirements of the perimeter zones. This excess heat can be stored for release during times when the building is unoccupied. A system for doing this would include a water storage tank as shown in the diagram. The temperature of the condenser water is held at about 100F by mixing storage tank water with return water. Some hot return water flows through the tank and some is bypassed and mixed with cold water withdrawn from the tank. This continues until the tank reaches its maximum design temperature, whereupon it is locked out of the circuit. If the system continues to supply an excess of reclaimed heat, condenser water is pumped to the tower for cooling.

At night the water in the tank is pumped through the evaporator where it serves as a "false" heating load on the refrigeration machine. When the nk temperature drops to a predetermined point, the refrigeration machine shut down and the boiler energized to provide hot water directly.

heat recovery from food service refrigeration

Long lines of cold cases for refrigerated and frozen food items are familiar sights in modern supermarkets. Associated with these cabinets are multiple compressor and condenser installations which are the source of large quantities of heat that in most cases is dissipated as waste. There is now a strong trend in supermarket design to recapture this heat and use it to provide comfort heating and humidity control in the sales areas.

Shown here is a schematic of a system for recovering heat energy from service refrigeration equipment. In this layout hot refrigerant gas from the individual compressors is fed into a common manifold. When the store is to be heated the manifold gas is piped to heat exchangers located in the air supply ducts, which may be arranged in two or more independent zones depending on the size and floor plan of the store. In warm weather hot gas from the manifold is routed directly to an outside condenser and its heat content dissipated into the atmosphere. Cooling of the sales areas is achieved by one or more separate condensing units that supply direct-expansion or chilled-water coils in the ducts.

Another type of heat recovery system designed for supermarkets is similar in concept but employs a closed hot water loop to transfer energy from the refrigerant manifold to the duct coils or closed-circuit cooling tower. Air-to-water heat pumps and duct heaters, singly or in combination, could supplement recovered heat in this system.

some thoughts on tomorrow's HVAC systems

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The concepts covered in this brochure must be considered only as representative of the present state of a continuing art. All of them are products of technology and our technological resourcefulness is far from being exhausted. Already on the near horizon appear developments that should have decided impact. Among them are these possibilities:

Rotary Heat Exchangers These are similar in appearance to a squirrel-cage centrifugal fan, but with hollow, curved blades through which fluid can be pumped. As the unit rotates there is a rapid heat exchange between the fluid and the surrounding air. Rotary heat exchangers transfer energy two or more times more effectively than static heat exchangers of equivalent size. Among applications contemplated for the rotary heat exchangers is an air-to-air heat pump with two of the units, serving as condenser and evaporator, mounted on a common motor-driven shaft. The rotating heat exchangers would themselves provide all of the required air flow without auxiliary fans or blowers.

Screw Compressors The screw or helical rotary compressor shows promise of exerting a major influence on refrigeration machinery design. It consists of two helically cut rotors, one male and one female, operating within a stator housing. As the enmeshed members counterrotate, they pump a refrigerant gas from inlet to outlet ports, compressing it in the process. The screw compressor combines the positive displacement benefit of the reciprocating machine with the low-friction operation of the centrifugal compressor and is easily modulated for varying loads.

Water-Cooled Transformers The distribution transformers leading to the electric load centers of large buildings are sources of appreciable heat that normally is dissipated into the atmosphere. Water cooling these transformers could reclaim energy for domestic water heating or space conditioning.

Waste-Water Heat Recovery Heat exchangers installed in soil pipes exiting from buildings could serve as an economical means for reclaiming the heat content in waste water, particularly in larger structures.

In the years soon to come, this collection of design concepts for optimum energy use in HVAC systems will surely be added to and refined.