Chapter 12

Energy Conservation Measures

Contents of Chapter 12

Instructions

Read the material of Chapter 12. Re-read the parts of the chapter that are emphasized in the summary and memorize important definitions.

Objectives of Chapter 12

There are three primary objectives in Chapter 12:

First we will introduce some basic ideas about energy conservation.

The second objective is to introduce *ASHRAE/IESNA Standard 90.1-2004, Energy Standard for Buildings Except Low-Rise Residential Buildings*[1] (*Standard 90.1*). This standard, produced cooperatively by ASHRAE and the Illuminating Engineering Society of North America, is becoming the minimum standard for new buildings in the United States.

Lastly, we are going to look at four ways that HVAC systems can be designed to use less energy.

After studying the chapter, you should be able to:

Explain energy conservation and some basic ways of thinking about it.
Describe, generally, the contents of *Standard 90.1*.
Describe the equipment and operation of the heat wheel, heat pipe, and runaround methods of heat recovery.
Describe the process of evaporative cooling and be able to provide examples of uses.
Explain the significance of building pressure.

12.1 Introduction

During this course we have mentioned and discussed the differences between initial cost and cost-in-use that are relevant to various types of equipment. In many instances, the savings on the initial cost of equipment is squandered because the equipment is more expensive to run, due to excessive energy costs that are incurred over the life of the building.

The objective of energy conservation is to use less energy. This is accomplished by various methods, including recycling energy where useful. Energy conservation should be part of the entire life cycle of a building: it should be a consideration during the initial conception of a building, through its construction, during the operation and maintenance of the building throughout its life, and even in deconstruction.

It is important for everyone who participates in the design, operation, and maintenance of the building to realize that, however energy efficient the system as initially designed and installed, the energy efficiency will degrade unless it is operated correctly and deliberately maintained.

In order to improve the energy performance of buildings and provide a benchmark for comparison ASHRAE/IESNA has issued *Standard 90.1, Energy Standard for Buildings Except Low-Rise Residential Buildings*. This standard sets out minimum criteria for the building construction and mechanical and electrical equipment in the building and we will discuss it later in the chapter.

12.2 Energy Considerations For Buildings

The energy consumption of a building is determined from the very first design decisions through to final demolition.

Conception and design

In the very beginning of the design process, many architectural choices can be made to significantly increase, or decrease, the energy consumption of a building. For example, large unshaded windows that face the afternoon sun can greatly increase the cooling load. Alternatively, the same windows, facing north produce a relatively small cooling load.

It is at the early design stage that the mechanical designer should become seriously involved in the building design as a whole. Historically, the architect would design the building, and then send a set of plans to the mechanical designer to design the HVAC. This model does not work well to produce energy-efficient buildings, because many early design choices can facilitate energy conserving design or make them totally impossible or uneconomic.

Consider this example:

In cold climates, a perimeter hot water heating system is often used to offset the heating losses through the wall and windows. Because modern windows are available with insulation values that approach the insulation value of traditional walls, if the architectural design specifies walls and windows with higher insulation values, the perimeter heating system requirements could be avoided. However, this is a suggestion that would typically be made by the mechanical designer, and the choice can only be made very early in the project. If the mechanical designer suggests a more energy efficient design, this could have a negative impact on the mechanical design fee. Why? Building owners often contract with the design team members for a fee that is based on a percentage of their individual portion of the building cost. In the example just given, the fee for the mechanical designers would include a percentage of the cost of the perimeter heating system. As a result, if the mechanical designers suggest that the perimeter heating be omitted in favor of higher priced windows, they could be forfeiting a substantial portion of their fee. Hardly an incentive to the engineer to suggest the idea!

Since this method of calculating the mechanical design fee does not encourage energy conservation, what other alternatives are available?

Imagine an alternative fee structure, where the total design fee for the mechanical design would be calculated as a percentage of the cost of the completed building, rather than of the specific mechanical design elements. Then, the mechanical designers could make design suggestions that would not have a negative impact on their design fees. Furthermore, imagine what would happen if the contract also specified that an objective of the building design included energy savings, and provided the entire design team with financial bonuses based on achieving the energy savings. Then the design team would have an incentive to spend time on designing energy efficient buildings!

How could this bonus incentive be structured? Consider what would happen if the bonus represented half the energy savings that were achieved during the first five years after the building was completed (based on the estimated energy costs for a conventional building design). In this case, the design team would have an incentive to design for maximum energy savings. The result would be that the operating expense for the owner would be reduced by half the energy cost reduction during the first five years, and all future energy-related savings after that. In this scenario, the owner could save money by setting up the contract to encourage desired behavior! Notice that there is not necessarily any additional capital cost to the owner, only the likelihood of operational cost savings: a huge return based only on some contract wording.

In case you are thinking it would never work, you should know that many owners are willing to contract to have energy conservation specialists come back, after construction is completed, and to pay them a significant fee, in addition to retrofit costs, to fix what could have been achieved as part of the original design at a fraction of the cost. We will discuss energy conservation that can be achieved through retrofit in the section entitled: "Turn it in."

Construction

The best possible building plans can be made a mockery by poor construction. If windows and doors are not sealed to the walls, or if insulation is installed unevenly and with gaps, the air-leakage can be costly in terms of both energy and building deterioration. The mechanical plant must be installed and set working correctly. Many systems are surprisingly robust, and gross errors in installation can go undetected, making the building less energy efficient—and less comfortable—than it was designed to be.

Operation

If the staff does not know how a system is meant to work, there is a very high probability that they will operate it differently and, more than likely, not as efficiently. It is really important that staff be taught how the systems are designed to work and provided with clear, easy to understand, written instructions for later reference. A pile of manufacturer's leaflets may look pretty but it does not explain how all the bits are meant to work together.

Maintenance

With limited maintenance, even the best equipment will falter and fail. Controls do not hold their calibration and work indefinitely. Control linkages wear out; damper seals lose their flexibility; cooling towers fill up with dust; the fill degenerates; and chiller tubes get fouled with a coating which reduces their heat transfer performance. The list of maintenance requirements is very long, but critical for maintaining energy-efficient building performance.

Three ways to save energy

The mantra of energy savings is: Turn it off. Turn it down. Turn it in.

1. Turn it off

This is the simplest, and almost always the least expensive method to implement, and it has the highest saving. If a service is not required, can it be turned off? There are usually several alternatives that can be considered to shorten the running time to the minimum.

Opportunities to "Turn it off" can be found at the design phase and at the operational phase of a building's life cycle.

Let us take a simple example of stairway lighting in a mild climate. For this example, we will ignore any local issues of safety or legislation:

A four-story apartment building has stairs for access. If the stairs are fully enclosed, the lights must be "on" all the time for people to see their way up and down the stairs.

The first alternative for energy savings can be identified early in the design phase of the building. Designing the stairs with large windows allows the lights to be turned off during daylight hours. The light switching can easily be done with an astronomical clock, or better still, a photocell. The astronomical clock allows for the changing lengths of the day, while the photocell senses the light level and switches on and off at a preset light level.

At both the design and the operation phases of the building's life cycle, a second savings opportunity exists. To discover it, consider asking the question: "What is the objective of having the lights on?" The lights are to provide illumination for people to go up and down the stairs. The next question is, "Is there a way to provide illumination when it is required, and yet not have the lights on when it is not required?" Several solutions come to mind. A low tech solution could be the installation of a pneumatic push-button timer switch at each level. Then, people entering the stairwell could push the button and turn the lights on for, say, ten minutes. The advantage is that, now, we have a simple system that provides the required service when it is required. However, there is an education requirement with a system like this. People need to be shown where the light switch is located. And they need to be taught that, even if the stairwell has been illuminated because an earlier person turned the switch "on," they still have to reactivate the switch, in order to provide continuous illumination while they are in the stairwell. For example, if one person has entered the stairwell and depressed the switch, the stairwell will be illuminate for ten minutes. Nine minutes later, a second person enters the stairwell and, because the light is "on," does not look for a switch. While that second person is in the stairwell, the lights will go off, leaving that person in the dark. As a result, graphics-based signage would be required, to manage issues based on language and reading skills. To alleviate these signage issues, the switch could be wired to detect the opening of the lobby door, or motion detectors could be used to turn the lights "on."

The above example illustrates how a building design choice—in this case windows—allowed a substantial reduction in operating hours. Then thinking about "What is the objective?" allowed a further, large, reduction in operating hours.

Determining design parameters based on a requirement to "turn it off" may seem extreme, but it is the norm in many parts of the world. You would probably be surprised at how many opportunities you could find in your own experiences where things could be turned off, and energy could be saved, if the focus was on providing only what is needed.

Now let's go on to the second approach, which tends to be more complicated, and therefore more costly, to work out and implement.

2. Turn it down

"Turn it down" means reducing the amount of heating, cooling, or other process while still providing the required service. In Chapter 4, when we covered CO_2 control of ventilation air, we discussed the idea of only providing the required amount of a service at the time it is needed. As you recall, CO_2 was used as a surrogate (indicator) for assessing the room population and deciding how much outside air was required for the current occupants. Using CO_2 as a surrogate allowed the amount of outside air to be turned down when the room population was low.

There are numerous examples of using "turn it down" as an energy conservation tool. Two that are commonly implemented include:

Heating reset: In Chapter 8 we discussed resetting the heating water temperature down, as the load drops. This reduces piping heat losses and improves control. However, on a variable speed pumping system, lowering the water temperature increases water volume required and so increases pumping power. The issue is finding the best balance between temperature reset and pumping power.

Chilled water temperature reset: The chilled water system is designed for the hottest and most humid afternoons that happen a few times a year. The rest of the time the chilled water system is not running to full capacity. Except in a very humid climate, where dehumidification is always a challenge, the chilled water temperature can probably be reset up a degree or two or more. This improves chiller performance and generally saves energy.

3. Turn it in

"Turn it in" means "replace with a new one." This is the third way of saving energy. It is almost always the most difficult to justify, since it is the most costly. For example, your building may have a forty-year-old boiler with a seasonal efficiency of only 50%. A modern boiler might raise the seasonal efficiency to 70% and provide a fuel saving of 28%. Although the percentage saving is substantial, it can be frustrating to find that it would take 12 years to pay for a new boiler out of the savings. Typically, a 12-year payback is too long for the financial officer to accept.

It almost never pays in energy savings to replace building fabric. For example, replacing single pane windows with double or triple pane or replacing a roof with a much better insulated roof usually have energy savings that pay for the work in 30 years or more. However, if the windows are going to be replaced because they are old and the frames have rotted, then it is almost always worth spending a bit extra on a higher energy-efficient unit. Here, one is comparing the extra cost of better windows against the extra energy savings, and it is usually an attractive investment.

While it almost never pays to replace building fabric, we should also note that it is usually economically worthwhile to repair the building fabric, particularly where there are air holes. For example, many industrial buildings have concrete block walls up to the roof. Over time, the block walls may well drop a bit, leaving a gap between wall and roof. Plugging this gap with expanding foam is a simple task and can reduce the uncontrolled flow of air into, and out of, the building. In a humid climate, this can substantially reduce the dehumidification load; in a cool climate, it could provide substantial heating energy saving.

It is exactly the same for the plant. The boiler may be 40 years old but it will work better if the burner is regularly serviced.

Chillers are another area of consideration. Due to the regulated phase-out of CFC refrigerants, many owners are being forced to consider chiller replacement. If the chiller is to be replaced anyways, it is worth taking the time to calculate the extra savings that are available from a high efficiency unit as compared to the extra cost for the unit. It is highly likely that the difference in cost for the high efficiency chiller will have a speedy payback in energy savings.

Having introduced three ways of saving energy—Turn it off, Turn it down, Turn it in—let's move on to a standard that sets minimum requirements for energy saving in new buildings and major renovations.

12.3 ASHRAE/IESNA Standard 90.1-2004

ASHRAE and the Illuminating Society of North America (IESNA) wrote ANSI/ASHRAE/IESNA Standard 90.1, *Energy Standard for Buildings Except Low-Rise Residential Buildings* (Standard 90.1) as a joint venture. The Standard is on "continuous maintenance." This means that addenda to the Standard are considered, developed, sent for public review and revision and then adopted by ASHRAE and then ANSI. These addenda then become part of the Standard. This is a continuous process, rather than one triggered by date. Every three years the Standard is reprinted with all addenda incorporated. The latest printed edition is 2004, which was used for this text. There is a detailed, well-illustrated, and explanatory companion document, 90.1 *User's Manual, ANSI/ASHRAE/IESNA Standard 90.1-2004, Energy Standard for Buildings Except Low-Rise Residential Buildings*.[2]

The stated purpose of the Standard is "to provide minimum requirements for energy-efficient design of buildings except low-rise residential buildings."

It is a minimum standard and it defines two methods for achieving energy efficient design:

1. Complying with the "Prescriptive and Performance Requirements"
2. Complying with the "Energy Cost Budget Method"

The Standard thus serves as a minimum for the use of building code officials as well as providing a solid baseline from which to compare considerably more energy efficient buildings.

Prescriptive and Performance Requirements

The Standard is divided into sections that often relate to different members of the design team. The first section of the Standard is the "Administration and Enforcement" section, to help designers and code officials. It then has six prescriptive sections that define the performance of the components of the building. Finally, it concludes with a calculation method, the "Energy Cost Budget Method" section.

The following is a brief introduction to the sections.

Standard 90.1 Section 5: Building Envelope

Typically, this section is used by architects to guide their design choices about the building fabric: the roofs, walls, floors, doors and fenestration (windows).

The objective of the Standard is to ensure that design choices reflect the requirements of different climate types to produce buildings that are both energy-efficient and cost-effective. Therefore, for example, the insulation requirements are more demanding in the colder climates.

The Standard divides climates into eight temperature bands with some further division depending on whether the climate is humid, dry or coastal. The temperature bands range from the continuously hot, with no heating demands, through to the sub-artic continuous heating with no cooling requirements. The designer chooses the temperature band relating to the building location, and, in a single table finds the thermal transmission requirements for the building fabric.

The Standard often requires slightly higher performance for residential buildings, since they are generally in operation 24 hours of every day. In comparison, many non-residential buildings are in full operation for less than half the hours in a week.

One of the major problem areas of modern buildings is the sealing the building envelope. The building envelope includes the entire perimeter of the building: the windows, doors, walls, and the roof. The allowable leakage around most factory-produced windows and doors is limited to a specific test value. Unfortunately, there is no overall leakage standard for buildings, so the actual thermal performance may vary considerably depending on how meticulous the construction sealing is carried out.

The Standard allows some trade-off between the various sections of the building envelope as long as the required overall envelope performance is maintained.

Standard 90.1 Section 6: Heating, Ventilating, and Air Conditioning

Typically, this section is used by mechanical designers to guide their design choices about the HVAC equipment and operational specifications.

For buildings of one or two floors and less than 2,300 m^2 there is a simplified approach to HVAC design using single-zone air-conditioning units serving single zones. The Standard includes a number of simple requirements that guide equipment choice and operation. It also provides tables of required operating efficiencies. This enables designers for many smaller buildings to quickly choose packaged equipment from a catalogue based on the calculated loads and fairly simple performance criteria.

For larger buildings and multi-zone systems there are numerous requirements for minimum equipment efficiencies and control strategies. Minimum cooling equipment performance is defined in two ways: Coefficient of Performance, "**COP**"; and Integrated Part-Load Value, "**IPLV**."

COP, Coefficient Of Performance, is the ratio of heat removal to energy input in consistent units. For air-cooled chillers of all sizes, the minimum requirement is COP of 2.8. This means that the chillers must provide 2.8 kW of cooling capacity for every 1 kW of input power. In contrast, water-cooled chillers are much more efficient: a centrifugal water-cooled chiller under 528 kW has a required minimum COP of 4.45, and a chiller that is over 1055 kW has a required COP of 6.1. The large water-cooled centrifugal chiller has over twice the cooling capacity per input watt of the air-cooled machine.

In Chapter 10.1, we discussed the statement that "big plant is more efficient." In the case of chillers, this is very true. Unfortunately, COP efficiency is not the only relevant consideration. Other energy costs for the central plant include the energy for pumping the chilled water to end use and the condenser water to the cooling tower. In addition, the chilled water distribution-pipe heat gains must be deducted from the useful plant cooling capacity.

In addition to the other energy inputs, many central plant units spend a significant part of their operating life operating at below full-load. To ensure that the poor part-load performance does not seriously impact overall performance, a minimum **Integrated Part-Load Value**, IPLV is specified for larger equipment. **IPLV**, is a weighted average value of COP based on full and part load performance and is used instead of COP on larger electrically-driven coolers.

Having defined minimum equipment performance, the Standard then goes on to establish rules about controls and installation including insulation, system balancing, commissioning, and user operating manuals, to ensure minimum equipment utilization efficiency. We have already discussed some of the controls requirements in the previous chapter.

Standard 90.1 Section 7: Service Water Heating

The section on service water heating covers hot water for domestic washing and laundry, similar commercial uses, and swimming pools. The requirements cover heater efficiency, standby losses, distribution-piping design, insulation, and control requirements.

Standard 90.1 Section 9: Lighting

On average, in the USA, buildings use about 35% of their total energy for lighting. This provides a big opportunity for savings. The Standard allows a specific number of Watts per square meter, W/m^2, however, the designer is given a certain amount of leeway in the calculations: The allowed W/m^2 can be calculated on the basis of type of building or on a room-by-room basis. The Standard allows trading between non-decorative areas and between lighting and HVAC, as long as the net energy cost through the year is not increased above the prescribed allowance.

The Standard recognizes variation in use of the same type of space in different types of buildings. So, for example, corridors generally have an allowance of $5\,W/m^2$ but, for hospitals, this allowance is raised to $11\,W/m^2$.

Standard 90.1 Section 11: Energy-Cost Budget Method

The energy-cost budget is a way to allow designers to have the flexibility to design the building according to their needs, as long as it does not cost more in energy than the Standard permits. To use the Energy-Cost Budget Method, the design team is instructed to calculate the energy-cost budget for a prescriptive building and equipment, then to compare that to the cost of the energy that is required by the building fabric and equipment that the design team has selected.

The Energy-Cost Budget, ECB, requires the use of hour-by-hour building energy analysis software. No particular software is specified, but software performance is mandated. Local utility rates are used in the simulation. The building has to be analyzed, using the prescribed building envelope and equipment efficiencies, to obtain the 'energy-cost budget' and again with actual envelope and equipment. Compliance is achieved when the 'design energy-cost' does not exceed the 'energy-cost budget.'

Many organizations, and energy reduction programs, like **Leadership in Energy and Environmental Design**, **LEED**, are interested in building to a higher energy efficient standard than the minimum. For example, **LEED**, encourages buildings that are designed to have a lower design energy cost than the same building would have had if it had been designed using the prescriptive and performance requirements. Designers can aim to design a building with an energy cost that is some specific percentage lower than the energy cost for a minimum standard design. As an example, the LEED program gives increasing acknowledgement for design energy costs from 15% to 60% below the Standard 90.1 prescriptive building energy costs.

Finally, others are concerned about the relative energy consumption as against energy cost. To provide a consistent method of measuring and controlling energy consumption, an informative, non-mandatory part, of the Standard, Appendix G, is included. This appendix is written to assist in comparing highly energy-efficient building designs based on energy efficiency instead of energy cost.

If you become involved in using Standard 90.1, remember that the User Manual provides a clear, easy-to-follow explanation of how to use and apply the Standard.

12.4 Heat Recovery

When designing to comply with the Standard, designers can minimize energy use by reducing the energy requirements of a building, and/or by energy recovery. During design, always aim first to minimize energy use before considering energy recovery. The reason is that heat recovery is almost always involved with "**low-grade heat**." Low-grade heat is heat that is at a temperature relatively close to the temperature at which it can be used at all. Low-grade heat requires oversized heat transfer surfaces and can often only fill a part of the load. For example, the condenser water from a chiller at 35 °C can be used to preheat domestic service water to 32 °C but no hotter. This is a valuable contribution, but it does not do the whole task, since 60 °C is the typical requirement.

There are cases where systems can be deliberately chosen to integrate with low heat sources. A good example of this is the use of **condensing boilers** with radiant floor heating systems. The **condensing boiler** is a boiler with an additional flue gas heat recovery section. In this additional flue gas cooling section, the water vapor in the flue gas is condensed, causing it to give up its latent heat. This increases the boiler efficiency from a maximum of about 85%, with a flow temperature of 82 °C, to about 95% with a 40 °C flow temperature. Since radiant flooring operates at low water temperature, the condensing boiler is an excellent match for the radiant floor. Note that condensing only begins to occur below 57 °C, so buying a condensing boiler and running it near 57 °C will reduce the boiler efficiency since it will not condense the flue gas water vapor.

Energy Recovery Coils: Run-Around Coils

One way to achieve energy recovery is with run-around energy recovery coils. A typical run-around coil arrangement is shown in *Figure 12-1.*

In summer, the conditioned exhaust air cools the fluid in the exhaust air coil. This fluid is then pumped over to the supply air coil to pre-cool the incoming outside air.

In winter the heat transfer works the other way: the warm exhaust air heats the fluid in the exhaust air coil, which is then pumped over to the supply air coil to heat the cold incoming air.

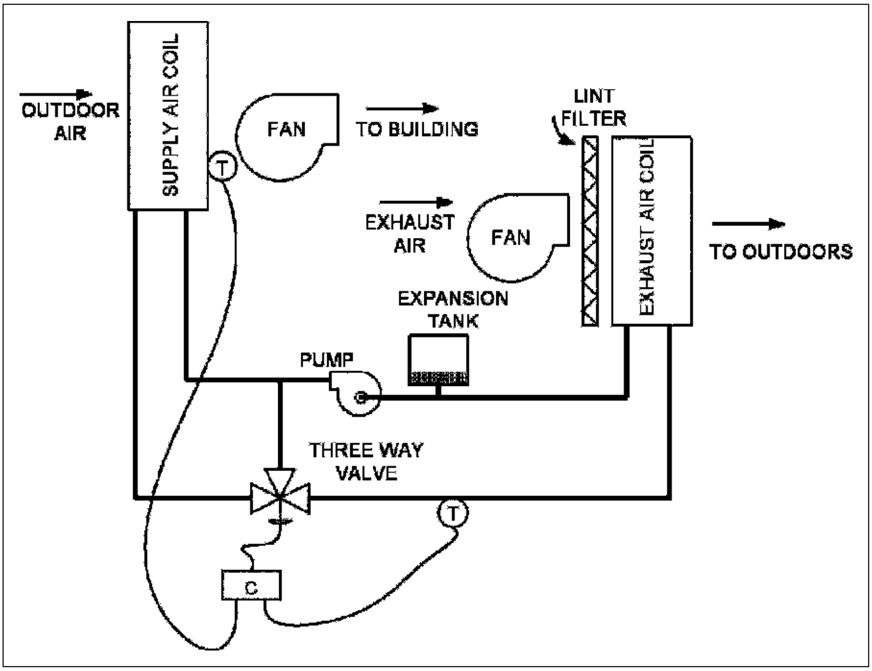

Figure 12-1 Run-Around Energy Recovery Coils

At intermediate temperatures the system is shut off, since it is not useful.

When outside temperatures are below freezing, the three-way valve is used with a glycol antifreeze mixture in the coils. In cold weather, some of the fluid bypasses the supply air coil, to avoid overcooling. The mixture of very cold fluid from the supply air coil and diverted fluid mix to a temperature that is high enough to avoid causing frost on the exhaust air coil. The maximum amount of cooling that can be achieved with the exhaust air coil is limited by the temperature at which frost starts to form in the coil. This frosting of the exhaust coil effectively sets a limit to the transfer possible at low temperatures.

In *Figure 12-1*, a filter is shown in front of the exhaust air coil. It is important to include this filter, since omitting it will soon cause a clogged coil. This is particularly true if the coil runs wet with condensation in cold weather.

The run-around coil system has three particular advantages.

1. There is no possibility of cross contamination between the two air streams. This factor makes it suitable for hospital or fume hood exhaust heat recovery.
2. The two coils do not have to be adjacent to one another. A laboratory building could have the outside air intake low in the building and the fume hood exhaust on the roof, with the run-around pipes connecting the two coils.
3. The run-around coils only transfer sensible heat, and do not condense the water in the exhaust, making them suitable for swimming pool recovery systems.

Heat pipes

A heat pipe is a length of pipe with an interior wick that contains a charge of refrigerant, as shown in *Figure 12-2*.

The type and quantity of refrigerant that is installed is chosen for the particular temperature requirements. In operation, the pipe is approximately horizontal and one end is warmed, which evaporates refrigerant. The refrigerant vapor fills the tube. If the other half of the tube is cooled, the refrigerant will condense and flow along the wick to the heated end, to be evaporated once more. This heat-driven refrigeration cycle is surprisingly efficient.

The normal heat pipe unit consists of a bundle of pipes with external fins and a central divider plate. *Figure 12-3* shows a view down onto a unit that is

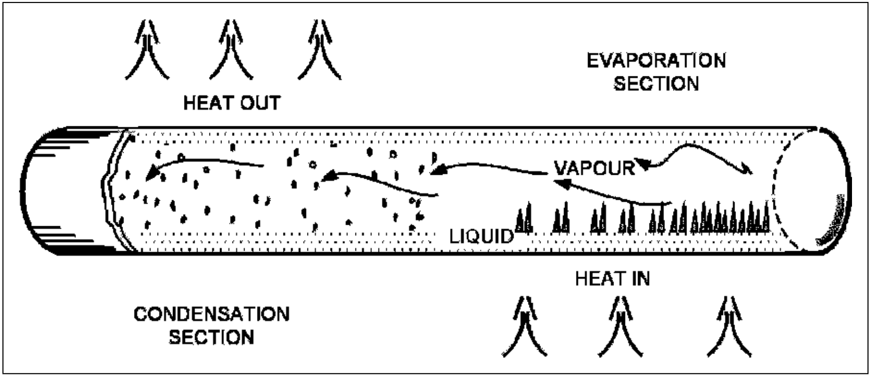

Figure 12-2 Cutaway Section of a Heat Pipe

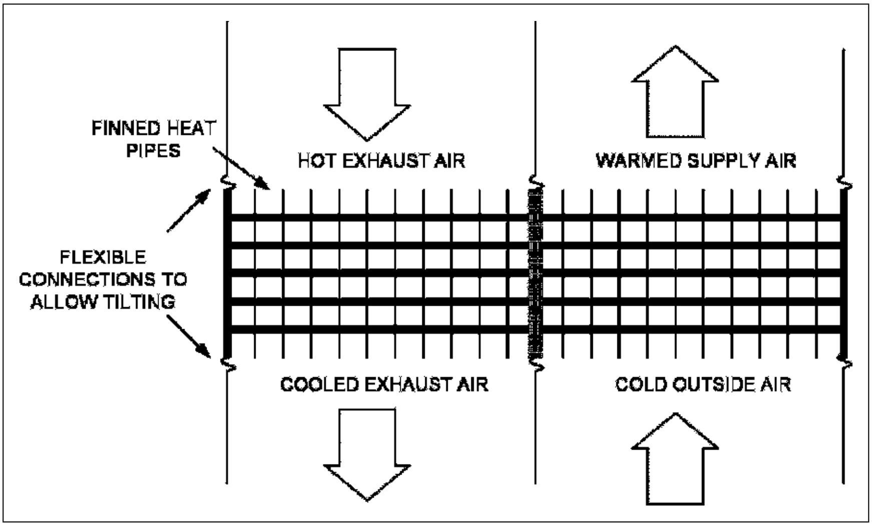

Figure 12-3 Heat Pipe Assembly in Exhaust and Outside Air Entry

mounted in the relief and intake air streams to an air-handling unit. Flexible connections are shown which facilitate the tipping. To adjust the heat transfer, one end or the other end of the tubes would be lifted.

The outside air is cold as it comes in over the warm coil. This warms the air, and the tube is cooled. The cooled refrigerant inside condenses, giving up its latent heat, which heats the air. The re-condensed refrigerant wicks across to the exhaust side and then absorbs heat from the exhaust air. This heat evaporates the refrigerant back into a vapor which fills the pipe, and is again available to warm the cold outside air.

The usual heat-pipe unit must be approximately horizontal to work well. A standard way to reduce the heat transfer is to tilt the evaporator (cold) end up a few degrees. This tilt control first reduces, and then halts, the flow of refrigerant to the evaporator end, and the process stops.

Figure 12-3 was based on winter operation. In summer, the unit only has to be tilted to work the other way and cool the incoming outside air as it heats the outgoing exhaust air.

The unit is designed as a sensible heat transfer device, though allowing condensation to occur on the cold end can transfer worthwhile latent heat. Effectiveness ratings range up to 80% with 14 rows of tubes. However, each additional row contributes proportionally less to the overall performance. As a result, the economic choice is ten or fewer rows.

A major advantage of the units is very low cross-contamination.

Desiccant Wheels

Desiccants are chemicals that are quick to pick up heat and moisture, and quick to give them up again if exposed to a cooler, drier atmosphere. A matrix, as indicated on the left of *Figure 12-4*, may be coated with such a chemical and made up into a wheel several centimeters thick. In use, the supply air is ducted through one half of the wheel and the exhaust air through the other half.

Let us suppose it is a hot summer day, so the exhaust is cooler and drier than the supply of outside air. The chemical coating in the section of the coil in

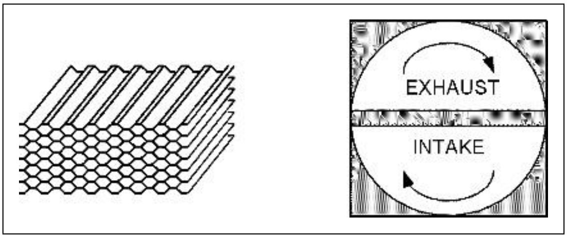

Figure 12-4 Desiccant Wheel Matrix and Operation

the exhaust stream becomes relatively cool and dry. Now the wheel is slowly rotated and the cool, dry section moves into the incoming hot, humid air, drying and cooling the air. Similarly, a section is moving from hot and humid into cool and dry, where it gives up moisture and becomes cooler.

The wheel speed, a few revolutions per minute, is adjusted to maximize the transfer of heat and moisture. Control of wheel speed to truly maximize savings is a complex issue, since the transfers of sensible and latent heat do not vary in direct relation to each other.

The depth of the wheel is filled with exhaust air as it passes into the supply air stream, so there is some cross-contamination. There are ways of minimizing this cross-contamination, but it cannot be eliminated. In most comfort situations, the cross-contamination in a well-made unit is quite acceptable.

12.5 Air-Side and Water-Side Economizers

Air-Side Economizers

In the previous chapters, you have been introduced to the air-side economizer on air-handling units. It is the mixing arrangement that allows up to 100% outside air to be drawn in and relieved in order to take advantage of cool outside air, providing “free cooling.” Nothing is free! The air-side economizer equipment costs extra to purchase, there are more components to maintain, and, depending on the climate, the hours when the economizer is actually saving cooling energy may be very limited. In climates that are warm and humid, the number of hours when the outside air has a lower enthalpy than the return air enthalpy may be very few. Thus, Standard 90.1 does not require air-side economizers in most of Florida.

One critical issue with economizers is that their controls must be integrated with the mechanical cooling. This prevents the economizer from increasing the mechanical refrigeration load.

Standard 90.1 has very specific requirements on the control of economizers and, in particular, prohibits the use of mixed air control for economizers on systems that serve more than one zone. Instead, the Standard requires that a supply air thermostat be used to control the cooling coil and economizer. This control method works well as long as the chilled water valve and, if there is one, the heating valve, close fully. If the valves do not close, due to being worn or incorrectly set up, it is possible for the system to use much more energy than expected. Therefore, when this control method is used, it is important that the system be maintained, or that a control sequence be included that will indicate that one of the valves is not closing correctly. This control sequence was discussed in Section 11.5.

Advantages of the air-side economizer

- A low air pressure drop.
- Substantial mechanical-cooling energy savings.
- Reduced water usage in cooling tower systems.

Disadvantages of the air-side economizer

- Extra capital cost for the 100% intake and relief air equipment, which includes a return fan on larger systems.
- A higher ongoing electrical operating expense.
- A potential requirement for additional humidification during winter operation.

Water-Side Economizers

The water-side economizer consists of a water-cooled coil, located in the air stream just before the mechanical-cooling coil. The coil can be supplied with water directly from the cooling tower or via a plate heat exchanger. If the water is supplied directly from the tower, the water treatment and cleaning process must be of a high standard, to ensure that the valves and coil do not clog up with dirt. If a heat exchanger is used, there is the additional cost of the exchanger, and the heat transfer will be less efficient, since there has to be a temperature rise across the exchanger for it to work.

There are several possible arrangements, depending on the particular equipment and sizes. One example for packaged units is shown in *Figure 12-5*. The three-port valve determines how much of the tower water flows through the economizer coil, and the two-port valve determines how much water bypasses the condenser to avoid the condenser being overcooled.

Note that the three-port valve can be replaced with two two-port valves, as shown in the detail. The valves would be sequenced so that, as one opens, the

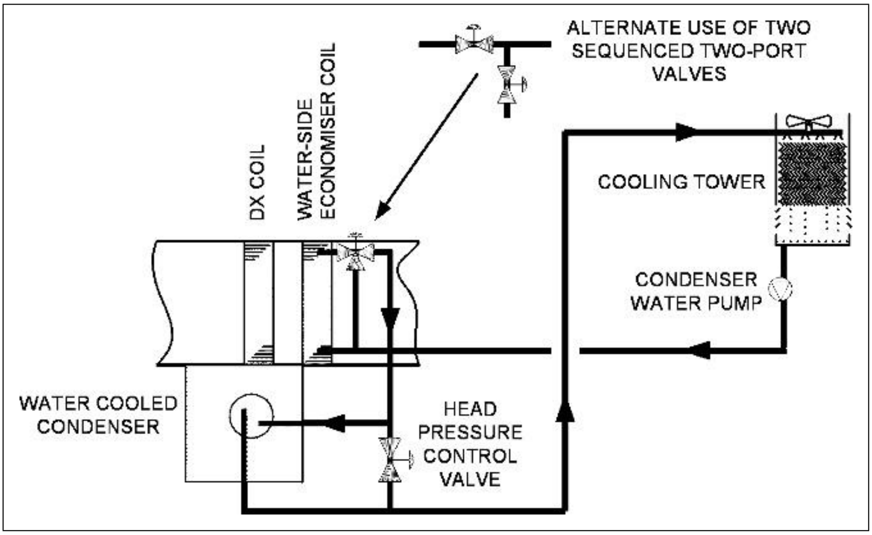

Figure 12-5 Water-Side Economizer and Alternate Use of Two-Port Valves

other closes, to provide the same effect as the mixing valve, but often at lower cost in small sizes.

The "**head pressure**" is the pressure in the refrigeration condenser. If the head pressure falls below the required pressure, the valve is opened to reduce water flow through the condenser. On cool days, when the tower produces very cold water, the valve will stay open, since adequate cooling is provided at well below full design flow.

Advantages of water-side economizers

- Water-side economizers reduce compressor energy requirements by pre-cooling the air.
- Unlike air-side economizers, which need full-sized intake and relief ducts for 100% outside air entry or for 100% exhaust, water-side economizers simply require space for two pipes.
- Unlike the air-side economizer, the water-side economizer does not lower the humidity in winter, saving on possible humidification costs.

Disadvantages of a water-side economizer

- Higher resistance to airflow, therefore higher fan energy costs.
- Increased tower operation with consequent reduction in tower life span.
- Increased water and chemicals cost.

12.6 Evaporative Cooling

You have been introduced to the idea of evaporative cooling several times so far in this course. In Chapter 2 the process of using direct evaporation was introduced in connection with the psychrometric chart.

Direct Evaporative Cooling

The direct evaporative cooler simply evaporates moisture into the air, reducing the temperature at approximately constant enthalpy. In a hot dry climate this process may often be enough to provide comfortable conditions for people.

In medium to wet climates, the increase in moisture content is frequently not acceptable for sedentary human comfort but is considered acceptable for high effort work places and is ideal for some operations, such as greenhouses.

Indirect Evaporative Cooling

An indirect evaporative cooler uses evaporation to cool a surface, such as a coil, that is then used to cool the incoming air. The indirect evaporative cooler, which reduces both temperature and enthalpy, can be very effective in all but the most extreme conditions. The two processes are shown on the psychrometric chart, *Figure 12-6*.

A previous figure, *Figure 12-5* showed the indirect cooler as the "water-side economizer," located before the mechanical cooling coil. That is just one arrangement of two-stage cooling.

Figure 12-7 shows an alternative to this arrangement.

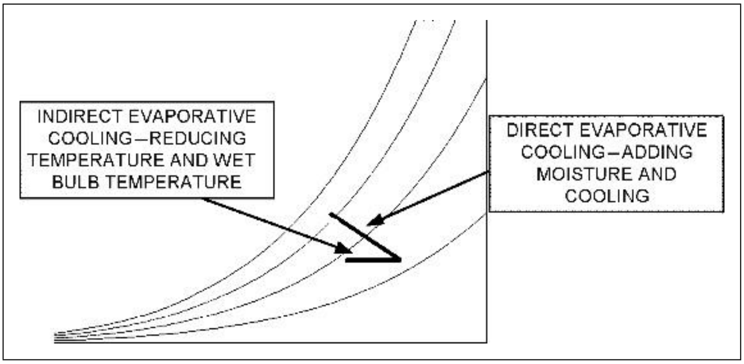

Figure 12-6 Psychrometric Chart Showing Direct and Indirect Evaporative Cooling

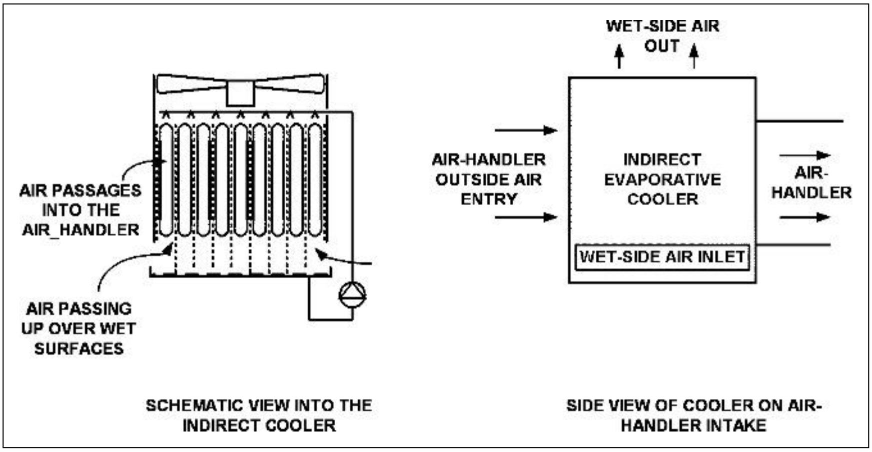

Figure 12-7 Indirect Evaporative Intake Cooler

In this indirect evaporative-intake cooler, water flows down the outside of the air intake passages. As it flows down, outside air is drawn up over the water, causing evaporation and cooling. The cooled water cools the intake air passages and hence the intake air. This is shown diagrammatically on the left side of *Figure 12-7*. The unit is mounted at the intake to the air-handler as shown on the right-hand side of *Figure 12-7*.

Depending on the local climate, a unit like this can reduce the peak mechanical refrigeration by 30% to 70% with a very low water and energy requirement from the indirect cooler. The performance may be improved even further if the relief air from the building is used as the air that passes over the evaporative surface.

To quote from *2000 ASHRAE Handbook—HVAC Systems and Equipment*,[3] Chapter 19:

> "Direct evaporative coolers for residences in desert regions typically require 70% less energy than direct expansion air conditioners. For instance, in El Paso, Texas, the typical evaporative cooler consumes 609 kWh per cooling season as compared to 3901 kWh per season

> for a typical vapor compression air conditioner with a SEER 10. This equates to an average demand of 0.51 kW based on 1200 operating hours, as compared to an average demand of 3.25 kW for a vapor compression air conditioner."

The main advantages of evaporative cooling include:

Substantial energy and cost savings
Reduced peak power demand and reduced size of mechanical refrigeration equipment
Easily integrated into built-up systems.

The big disadvantage for evaporative cooling is that many designers don't understand the opportunity!

12.7 Control of Building Pressure

Control of building pressure can have a significant effect on energy use, drafts through exterior doors, and comfort. In a hot and humid climate, it is valuable to keep the building at a slightly positive pressure. This ensures that dry air, from inside the building, enters the walls rather than allowing humid air from outside to enter the building through the wall and likely cause mold growth. In a cold climate, the building should be kept close to outside pressure, or slightly negative, to prevent the warm, moist air from inside the building from entering the wall where it could cause condensation or ice.

When an economizer is running with 100% outside air, the same amount of air must also leave the building. On small systems, no return or exhaust fan is provided, on the assumption that the washroom exhaust plus leakage will be adequate to balance the amount of air coming in.

In milder climates, intermediate size plants can be accommodated with "**barometric dampers**." Barometric dampers blow open when there is a slightly greater pressure than outside the building. But keep in mind that the wind can make a huge difference to the pressure at different points around a building. If the wind is blowing toward the damper, it will tend to keep it shut. On the other hand if the damper is on the leeward side of the building, the wind will tend to open it.

On the larger economizer systems, typically the ones shown in the figures in this text, complete with a return fan, the return/relief fan and relief damper can be used to control building pressure. The least efficient method is to separately control the relief damper and effectively throttle the relief fan flow. It is better to add a speed control for the return fan so that it maintains a set minimum outlet pressure. This will ensure adequate return air for the main supply fan and allow the relief damper to control the building pressure.

The Final Step

Chapter 13 is the final chapter. In it we cover two groups of topics that did not fit into the flow of the previous chapters. The first group deals with heating and heat storage. The second group deals with air distribution in rooms and separate outdoor air systems.

Finally, there are some suggestions for you for future courses and other sources of information.

Summary

12.2 Energy Considerations in Buildings

The objective of energy conservation is to use less energy and to recycle energy where useful. In the design of new facilities it is very important that the whole design team, including the client, have energy conservation as an objective. There is considerable synergy to be gained from a group effort. The client has the ability to set up a design contract that encourages energy conservation to the mutual financial benefit of the team and the client.

There are three ways of achieving energy conservation: **Turn It Off**, turning equipment off, **Turn It Down**, reducing equipment output, and **Turn It In**, by replacing equipment with something more efficient. Of these three ways, "turning equipment off" is usually the most cost effective, with "turning down" second. Replacement is often not economic.

12.3 ASHRAE/IESNA Standard 90.1-2004

To assist in energy conservation *ASHRAE/IESNA Standard 90.1-2004, Energy Standard for Buildings Except Low-Rise Residential Buildings*, was produced, and it is now being adopted in parts of the United States. This standard sets minimum requirements for the building envelope, electrical systems including lighting, and the HVAC, under a prescriptive approach. The HVAC section covers the efficiency of individual equipment, as well as how they are to be interconnected and controlled. In addition, the design team may choose to meet the Standard using the performance route, the Energy Cost Budget Method, in which the design team demonstrates that their design will have no higher energy cost than the prescriptive design would have cost.

The requirements are designed to be easily cost effective and many programs, such as the LEED program, require substantially lower energy consumption than the Standard requires.

12.4 Heat Recovery

Heat recovery is the reuse of surplus heat from a building, often the exhaust air. Methods of recovering heat from the exhaust were described. These included:

Run-around coils, which is a system where a fluid—water or glycol mixture—is pumped through coils in the exhaust and outside air intake. This transfers heat from the intake air in summer and adds heat to the incoming air in winter. The system has advantages of no cross-contamination and the intake and exhaust can be remote from each other, interconnected only by the pair of run-around coil pipes.

The heat pipe and desiccant wheel were also described. Both require the intake and exhaust air to pass by each other, and have a cross-contamination challenge. On the other hand, they are often less costly and more effective than the run-around coil.

12.5 Air-Side and Water-Side Economizers

The air-side economizer is the use of outside air to provide cooling when the outside ambient temperature and humidity can provide "free cooling." The system is not economic in very hot, humid climates and it creates a low humidity indoors in cold weather.

The water-side economizer uses water, cooled in a cooling tower, to lower the incoming air temperature by means of a pre-cooling coil. The system takes up little space and does not require the large intake duct that the air-side economizer requires. It also has the advantage of not lowering the indoor humidity in cold weather.

12.6 Evaporative Cooling

Evaporative cooling can be direct or indirect. Direct evaporative cooling reduces the temperature and raises the humidity by direct evaporation of water in the air. For human comfort, this is a very acceptable situation in a hot, dry climate but not useful in a hot and humid climate. For some industrial processes and greenhouses, in particular, it can be very effective in all but the most humid climates.

Indirect evaporative cooling uses water that has been cooled by a cooling tower, or by direct evaporation on the outside of a coil, in the incoming air stream. Indirect evaporative cooling lowers both the temperature and the enthalpy. In many climates this can significantly reduce the required size of the mechanical cooling and drastically cut the electrical consumption by lowering the load on the mechanical cooling system.

12.7 Control of Building Pressure

If the building pressure is much higher than outside pressure, there will be leakage outwards. Similarly a low inside pressure draws air in through all the building cracks and leaks. Neither is desirable, since they cause discomfort, energy waste, and deterioration of the building fabric.

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2. ASHRAE. 2004. 90.1 *User's Manual*. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.
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