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Fact Sheet EES-26

Heat Recovery From Air Conditioning Units[1]

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Air conditioning units are designed to remove heat from interior spaces and reject it to the ambient (outside) air. Heat rejection may occur directly to the air, as in the case of most conventional air source units, or to water circulating from a cooling tower. The circulating water eventually rejects the heat to the ambient air in the cooling tower. While this heat is of a "low grade variety," it still represents wasted energy. From an energy conservation standpoint, it would be desirable to reclaim this heat in a usable form. The best and most obvious form of heat recovery is for heating water.

HOW MUCH HEAT IS AVAILABLE?

Before deciding whether heat recovery makes sense for your application, it is useful to know just how much recoverable heat is available. At first glance, you might be tempted to say that the heat available for recovery is the heat that is removed from the room or space. This is only partially true since there is additional heat available due to the compression of the refrigerant in the compressor. Therefore, the total heat available is the heat removed from the space plus the heat of compression. A simplified block diagram of an air conditioning system showing the energy flows is presented below. Note that most of the electrical energy input to the compressor shows up in the compressed refrigerant in the form of heat that may be recovered.

The actual amount of heat available varies as the load on the system changes. For example, a 20 ton reciprocating chiller operating at full capacity might reject 24 tons of heat while the same unit at 30% capacity might reject only 13 tons of heat. Since the space load and outside conditions vary during the day as well as during the season, it becomes more difficult to predict the actual performance without a rather complex analysis. However, using some rules of thumb and a few conservative judgments, it is possible to estimate the heat available for recovery.

First, the heat of compression should be estimated. For a typical 20 ton unit the heat of compression might range from 2.8 to 4.3 tons, depending upon load conditions. It would be more meaningful, however, to consider this heat in relation to the rated capacity. This means considering how many tons of compression heat is available per ton of cooling capacity. Using this rule of thumb allows us to estimate the compression heat for any size chiller. This value will vary, but using a figure of 1 ton of compression heat for every 6 tons of rated cooling capacity is conservative. For our example of a 20 ton chiller this yields (Equation 1):

The second step in estimating the heat available for recovery is to take into account that, on the average, the unit will only operate at 70-80% of its full-rated capacity. Taking the middle of the range as 75%, we can now estimate the heat available for recovery due to

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$$\frac{20 \text{ ton capacity} \times 1 \text{ ton of compression heat}}{6 \text{ ton capacity}} = 3.3 \text{ tons of compression heat}$$

Equation 1.

heat removed from the conditioned space as shown in Equation 2:

$$20 \text{ ton capacity} \times 0.75 \text{ average capacity utilization} = 15 \text{ tons of heat removed}$$

Equation 2.

It is now a simple task to add the two elements of heat rejection to obtain the total average heat rejected by the unit, as shown in Equation 3. Remember that these are slightly conservative figures.

Recoverable heat
= 15 tons of heat removed + 3.3 tons of compression heat
= 18.3 tons

Equation 3.

All of this can be reduced to a simple equation that could be used for most air conditioning units (Equation 4):

$$\text{Recoverable heat (tons)} = \frac{\text{rated capacity}}{6} + \text{rated capacity} \times 0.75$$

Equation 4.

AMOUNT OF HEAT THAT CAN BE RECOVERED

We have looked at the amount of heat that is available from an air conditioning unit. The estimates provided represent conservative rules of thumb. However, the amount of this available heat that can be turned into useful heat in the form of hot water is further limited. In a typical application the refrigerant line leaving the compressor will be connected to a heat exchanger unit. A return line from the heat exchanger will then be attached to the condensing unit. In this way, the hot refrigerant gases will flow from the compressor, through the heat exchanger, and then to the condenser.

The heat exchanger has water circulating through it that is heated by the hot refrigerant gases. When a cooling tower is used, the cooling tower water instead of the refrigerant might circulate through the heat exchanger. In both cases, heat is given up by the hotter fluid to the colder water circulating through the heat exchanger.

EXCHANGER EFFECTIVENESS

It would take an extremely large heat exchanger to allow the water and refrigerant to achieve the same final temperature. A heat exchanger of this size would not be economical to produce. Therefore, a term called "heat exchanger effectiveness" is used to describe how closely a particular heat exchanger approaches the performance of one of extremely large size. Good heat exchangers have an effectiveness of 60-80%. Taking the middle of the range, we end up with a heat exchanger effectiveness of 70%. This effectiveness is applied to the heat available for removal to determine the amount of heat actually transferred to the water. Using our same 20 ton unit as an example, we find the total heat (on the average) transferred to the water, as shown in Equation 5:

Heat transferred to water
= 18.3 tons of heat available x 0.70 = 12.8 tons

Equation 5.

Putting this into the form of a generalized equation results in the following (Equation 6):

Heat transferred to water
= heat available for recovery x 0.70

Equation 6.

TRANSLATING HEAT RECOVERED INTO ENERGY SAVED

Once the amount of heat that may be transferred to the water is determined, it is then appropriate to view this energy recovery in terms of the energy savings that may be achieved. One ton of heat removal is equivalent to 12,000 BTU/hr. Thus, using our example, we find with Equation 7:

Heat transferred to water
= 12.8 tons x 12,000 BYU/hr = 153,600 BTU/hr
ton

Equation 7.

Every gallon of water requires 8.34 BTUs of heat addition to raise its temperature 1 degree F. If we are using a thermostat setting of 110 degrees F on the hot water heater (recommended for saving energy), and assuming 70 degrees F for entering cold water, then we can calculate the energy required per gallon to heat the water to 110 degrees F (Equation 8):

Energy to heat gallon of water to 110 degrees F
= 8.34 BTU/gal x (110 - 70) deg F = 334 BTU/gal
1 degree F

Equation 8.

We have already calculated for our example the amount of heat available per hour. By simply dividing this figure by the energy required per gallon, we can find the gallons per hour (on the average) of hot water that can be produced using this heat recovery unit (Equation 9):

Gallons of hot water/hour
= 153,600 BTU/hr recovered
334 BTU/gal required
=460 gal/hr

Equation 9.

To put this in the proper perspective, it is like getting 460 gallons of hot water per hour free. Free is relative since the equipment has some costs attached. If the example chiller ran 12 hours daily, the heat recovery unit could produce 5520 gallons of hot water each day Assuming the alternative was to heat the water electrically, the heat recovery unit would provide savings of $32 per day based on electricity costs of 6 cts per kilowatt hour. To get overall savings, simply multiply hourly savings by the hours/day of operation. Then consider the number of days/year that cooling is required.

Several other considerations are important:

- By adding heat recovery, you can slightly increase the capacity of the air conditioning unit.
- Since installation of a heat recovery unit requires the addition of other components in the refrigerant lines, your warranty or service agreement may be affected.
- Heat recovery units recover heat only when the chiller is operating. Therefore, savings will be reduced if the chiller operating hours are reduced.
- Long runs of refrigerant or water lines can add to the cost, as well as resulting in additional heat loss in the system.
- If the unit produces hot water faster than it can be used, the excess capacity may be wasted, thereby reducing potential savings.
- All heat recovery units should be provided with bypass valves that allow the unit to be isolated from the system in case of leaks or required maintenance.
- Heating water to temperatures higher than recommended results in lower output in gallons per hour.

- Heat recovery units may also be installed on large refrigeration units with good results.

- Heat recovery systems are currently available for air conditioning units from as small as 2 tons up to the largest chillers available.

- In general, a heat recovery unit performs better when used with hot water systems employing a recirculating hot water loop.

The equations here were developed based on conservative estimates to help you estimate the amount of heat available for recovery as well as the amount that would ultimately be transferred to the hot water. Combining these equations using the assumptions stated, and including the conversion from tons to BTU/hr, results in the following simplified expression, shown in Equation 10:

$$\text{Heat transferred to water (BTU/hr)} = 7680 \times \text{rated capacity (tons)}$$

Equation 10.

Remember that this expression provides only a reasonable estimate of the waste heat you can recover. A poorly designed system may fall short of this expected performance. You should, therefore, consult a reliable contractor or engineer before making a final decision on a heat recovery unit.