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Integration of Refrigeration And HVAC in Grocery Stores

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Grocery stores are among the most energy-intensive commercial buildings, consuming two to three times as much energy per unit floor area as office buildings. The single-largest energy end use component of grocery building consumption is refrigeration. In current practice, most of the energy extracted from refrigerated cases and walk-in coolers is rejected to the outdoors. Significant gains in efficient operation of grocery stores can be achieved by recovering this rejected heat to meet various low-grade heating requirements within the stores. The recent *Advanced Energy Design Guide for Grocery Stores: Achieving 50% Energy Savings Toward a Net Zero Energy Building*[1] offers a number of ways the design of the refrigeration and HVAC systems in grocery stores may be integrated to achieve this savings.

Introduction

Modern grocery stores are complex environments designed to enable quick purchase of needed goods and to encourage more lengthy visits that might result in impulse purchasing. To that end, the stores attempt to reconcile high visibility display of goods with sufficient thermal comfort to encourage the longer stay. To the extent that many of the displayed goods require a refrigerated low-temperature environment to remain fresh and to avoid spoilage, the two goals can be at odds.

Both display and walk-in cases operate continuously to maintain a significant temperature differential between the case and the surrounding store space. The heat extracted from these cases is actually heat that has transferred from the store space, providing a cooling effect to that space. For stores with an abundance of open cases, the cooling effect is often larger than the total internal and envelope heat gains to the space, requiring heating for the space even at an elevated ambient outside temperature. Many grocery stores, furthermore, now offer a significant variety of ready-to-eat foods, prepared and cooked on site, requiring significant housekeeping and sanitation and accompanying increased use of service hot water. For these two functions, grocery stores can have a significant need for low-grade heat, even in warmer climates.

In maintaining food storage and presentation areas at low temperatures, the refrigeration systems continually reject a large amount of heat, including both the heat extracted from the cases and the electric energy used by the compressors to implement the cooling function. Recovered heat from the refrigeration system can be a convenient and cost-effective source of low-grade heat to provide comfort maintenance and to preheat service hot water, if the system is designed to deliver that heat in an energy-efficient and low first-cost fashion. The *Advanced Energy Design Guide for Grocery Stores* (AEDG), published in 2015, provides a comprehensive presentation

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of how refrigeration heat recovery can benefit grocery stores and reduce overall energy consumption.

Refrigeration Basics

Refrigeration systems consume approximately half of the total energy consumed by a typical grocery store, and compressors are the largest energy-consuming component within a refrigeration system. The energy consumed by the compressor is a function of two main variables, in addition to the efficiency of the compressor:

- The compressor "lift," the pressure differential across the compressor, which is a function of the temperature difference between the heat source (evaporator) and the heat sink (condenser).
- The mass flow of refrigerant, which largely determines the refrigeration capacity.

Modern electronic expansion valves enable adjustment of the evaporator temperature in response to the load, and many modern condenser controllers enable optimization of condensing temperature for combined energy consumption of the condenser fan and compressor. By adjusting the evaporator temperature up in response to reduced loads and allowing head pressure to float down in response to moderate ambient conditions, compressor energy is minimized.

The heat rejected by a refrigeration system can be considered to have two components, *superheat,* which can be recovered by reducing the temperature of the gas leaving the compressor down from its discharge temperature to its condensing temperature, and *latent heat,* which is recovered by condensing the gas at the condensation temperature. Superheat is available at temperatures ranging from up to 150°F (65.6°C), but only represents 10% to 20% of the total heat available. The relationship between superheat and latent (condensing) heat is shown in *Figure 1*. To recover all the rejected heat, both superheat and condensing heat, a more complex condensing heat exchanger is required.

Exploitation of heat recovery opportunities should recognize that recovery of heat should minimize additional compressor energy. In some cases, increasing the temperature and pressure of the discharge gas from the compressor is necessary to achieve a minimum useful temperature of the recovered heat, but calculations of effective coefficient of performance (COP) for the recovered heat should be made to determine whether the application is useful.

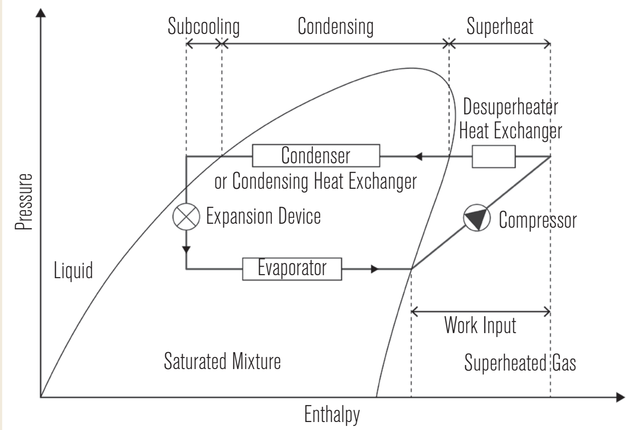

FIGURE 1 The refrigeration cycle showing condensing heat and superheat.

Heat Recovery

In current standard practice, the refrigeration systems, the space conditioning system, and the service water heating system of a grocery store are entirely separate systems, often constructed by and serviced by entirely separate parties. Heat recovery from refrigeration systems, at one time, however, was widely used to provide most of the heating requirements in grocery stores in the United States. As years passed, however, refrigerant heat recovery has become less common, most likely because of issues with refrigerant charge leakage. Recently, higher energy costs and lower profit margins have encouraged grocery store operators to reconsider this energy conservation measure.

In fact, California's Building Energy Efficiency Standards for Residential and Nonresidential Buildings (Title 24, Section 120.6(b), 4) since 2013 requires that new grocery stores greater than 8,000 ft^2 (743.2 m^2) use at least 25% of the heat from refrigeration for space heating. Achieving the goal of energy efficiency through heat recovery, however, requires an integrated approach to the design of all systems involved.

Design of a heat recovery system will vary depending on climate, type of refrigeration system, and the type of HVAC system. The amount of heat required will also depend upon climate, services and products sold, the exhaust air volume, density and type of refrigerated display cases, and hot water use for kitchen sanitation. Even with the many combinations of refrigeration and HVAC system types, numerous configurations are possible to obtain at least 25% heat recovery, and often higher recovery rates are both feasible and cost-effective.

Refrigerant Heat Recovery for Service Water Heating

The simplest form of heat recovery from refrigeration is the desuperheater service water preheater.

The hot water recovery tank, a refrigerant to water tank-type heat exchanger installed between the compressor and the condenser, preheats service hot water as shown in *Figure 2*. Incoming water from the city supply makes a single pass through the heat exchanger on its way to the primary water heating tank. The hot gas from the compressor is cooled almost to its condensing temperature in the process of heating the incoming water stream. The compressed gas, now near the saturation point, is then routed to a condenser where the process of heat rejection is completed as the gas condenses to liquid refrigerant.

Superheat represents only 10% to 20% of the total heat to be rejected from the refrigerant, but the desuperheater heat recovery device is much simpler and requires less active control than a condensing heat recovery device. In fact, desuperheater heat recovery devices are available as a retrofit for existing refrigeration systems.

To avoid complication of the refrigerant piping system, to reduce potential for refrigerant leakage, and to reduce overall refrigerant volume, a refrigeration system should incorporate only one desuperheater heat recovery device. However, desuperheater heat reclaim can be used with distributed point-of-use water heaters by using a single central heat recovery device and supplying preheated water from the device to distributed point-of-use water heaters.

A recirculation line from the point-of-use water heater back to the heat recovery device will keep water temperature in the line close to the discharge temperature of the desuperheater tank. Heat losses from the recirculated line are reduced, because the temperature of the preheated water is likely much closer to the ambient building temperature than is the discharge temperature of the water heater.

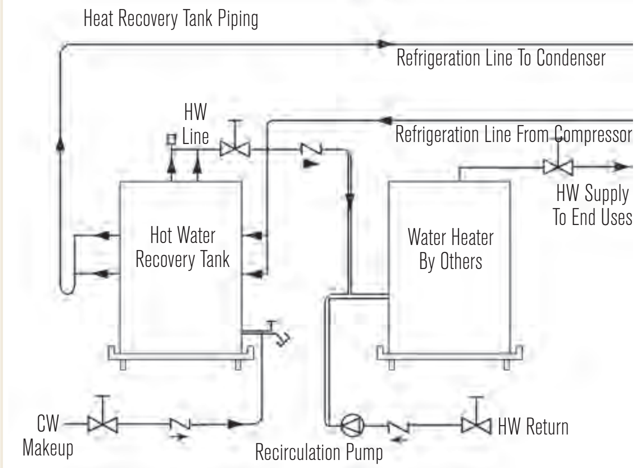

FIGURE 2 **Desuperheater heat recovery for service water preheat.** Credit: *Advanced Energy Design Guide for Grocery Stores—Achieving 50% Energy Savings Toward a Net Zero Energy Building*

Integration of Commercial Refrigeration with HVAC

Achieving greater use of the heat rejected by the refrigeration system in the grocery store requires a more sophisticated system capable of recovering the condensing heat of the refrigerant, while avoiding compromise of refrigeration efficiency and maintaining refrigerant liquid management. The effectiveness of this measure varies with climate zone, with the heat-recovery temperature available from the refrigeration system and the coincident heating requirements for ventilation and/or the occupied space.

Heat recovered from refrigeration should be at the lowest possible useful temperature to minimize the impact on refrigeration efficiency. While superheat recovery can achieve relatively high temperature, condensing heat generally is limited to 110°F (43.3°C) to 115°F (46.1°C) to limit compressor energy. Often, the heat recovery condenser is piped in series with, and upstream of, the final outdoor condenser.

A holdback or inlet pressure-regulating valve on the outlet of the heat recovery condenser is used to maintain that device at a higher pressure and thus a higher saturated condensing temperature (SCT). The holdback valve allows the final condenser to operate at a low temperature and pressure consistent with the ambient outdoor temperature and the optimized operation of condenser fans and compressor, while maintaining higher-temperature recovered heat. The holdback valve increases the compressor discharge pressure and slightly decreases the refrigerant mass flow, resulting in greater energy consumption and minor loss of capacity during some operating conditions.

The effective COP of the holdback valve system can be calculated from the amount of additional heat reclaimed during low ambient conditions divided by the additional energy consumption generated by the increased compressor discharge pressure during those conditions.

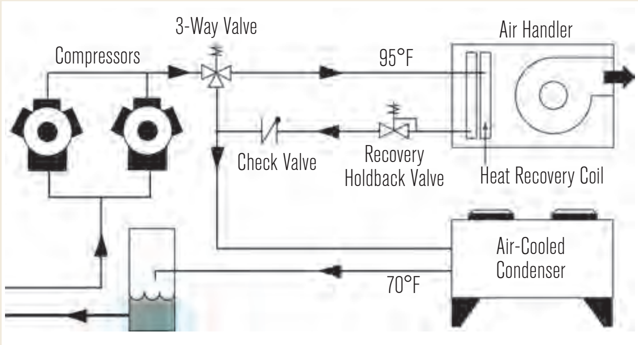

FIGURE 3 **Condensing heat recovery system using air coil.** Credit: *Advanced Energy Design Guide for Grocery Stores—Achieving 50% Energy Savings Toward a Net Zero Energy Building*

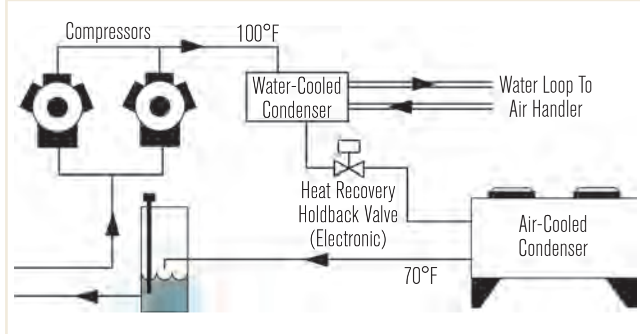

FIGURE 4 **Condensing heat recovery using a water-cooled condenser.** Credit: *Advanced Energy Design Guide for Grocery Stores—Achieving 50% Energy Savings Toward a Net Zero Energy Building*

Increased fan energy from the additional pressure drop across the heat recovery coil may often be ignored, because the coil is substituted for another heating device. In stores with a large requirement for low-grade heat, in cooler climates, the COP for the recovered heat can be quite high.

Figure 3 shows a heat recovery design with a three-way diverting valve, a heat recovery condenser coil, and a holdback valve. The heat recovery coil is piped in series with the outdoor condenser such that all heat not rejected in the air handler is rejected outdoors. The holdback valve shown in the figure allows the pressure and condensing temperature in the heat recovery coil to be set at a temperature sufficiently higher than the incoming air (e.g., 95°F [35.0°C] SCT) that the refrigerant will condense in the coil, heating the air. The holdback valve allows the SCT in the heat recovery coil to be independent of that of the air-cooled condenser, so the condenser can operate at the same control point whether the system is in heat recovery mode or not.

The system will still benefit from floating head pressure, maintaining the cooling capacity per pound of refrigerant flow consistent with the lower final condensing temperature. System capacity is only marginally affected, and the energy penalty comes in the form of increased compressor energy required per pound of refrigerant flow.

An alternative to condensing heat recovery coil in an air-handling unit is the inclusion of a water-cooled condenser upstream of and in series with the holdback valve and the final air-cooled condenser, as shown in *Figure 4*. As with the air coil system, the holdback valve enables a much higher SCT in the water-cooled condenser, while allowing the final condensing temperature to float to optimum, preserving the system capacity per pound of refrigerant flow.

Refrigeration systems in grocery stores with water-source heat pump systems (WSHP) can use water-cooled condensers, without an air-cooled condenser, so the entirety of heat rejected by the refrigeration system enters the tempered water circulating loop. While this additional heat will undoubtedly increase cooling tower energy and water consumption, it can dramatically decrease makeup heating requirements for the loop. The water-cooled refrigeration systems for grocery stores located within large mixed-use developments, using WSHPs for residential conditioning, can minimize makeup heat requirements, dramatically reducing the energy consumption of the entire complex.

Detailed analysis of the annual energy balance of these systems should precede incorporation of this measure into the design of the refrigeration and HVAC systems. Increased complexity of the refrigeration system can result in an increase of refrigerant charge, increased refrigerant leakage, and increased maintenance and regulatory issues.

Heat Recovery System Design Considerations

The energy-efficiency benefit of heat recovery in grocery stores is maximized by minimizing the required temperature for the recovered heat.

- In cooler climates, outdoor ventilation air should be heated by heat recovery, rather than mixed or recirculated air, because the outdoor air will more often be at a lower temperature.
- If recirculated air is to be heated, return air inlets located near the floor and ducted to the air-handling unit will result in low-temperature return air, while reducing stratification and comfort complaints in the store.

• Heating requirements in stores with extensive open cases can be much higher than expected, with the balance point of the store (the ambient exterior temperature below which heating is required in the store) sometimes reaching 80°F (26.7°C).

• Substituting glass door cases for open cases will significantly reduce the annual heating requirement of the store and will reduce the economic performance of the heat recovery system.

• Significant cooking activities and the requisite exhaust makeup air can also increase annual heating requirements in temperate and cool climates. In these climates, heat recovery can heat incoming outdoor air that is delivered to the shopping area and transfers to the cooking area to fulfill makeup exhaust requirements providing a very efficient and cost-effective solution.

The *Advanced Energy Design Guide for Grocery Stores*

This document published in 2015 was the eleventh of the *Advanced Energy Design Guide* (AEDG) series. The AEDGs are designed to jump-start design teams desiring to achieve significant energy savings compared with ASHRAE/IES Standard 90.1. The documents are authored by a project committee of energy-efficiency and building type experts under the guidance of the steering committee. ASHRAE has performed a management role for the guides since their inception. The guides can be downloaded for free from www.ashrae.org/freeaedg.

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