Supermarket Refrigeration Systems and How They Consume Energy

Numerous components consume energy in a refrigeration system. To keep product cases cool, fans move air across an evaporator coil which causes the refrigerant inside it to boil, absorbing heat from the circulating air. Heat is introduced to the cases from the warmer store environment, lights, defrost and anti-sweat heaters, and the fans themselves. The greater these heat gains, the greater the amount of work the entire system must do. In addition, three of four of these heat gains are caused by components which consume electricity themselves. This refrigerant is piped to compressor(s) which raise its pressure and temperature (consuming electricity). The hot gas from the compressor is piped to an outdoor condenser coil where a fan (consuming electricity) moves outdoor air across coil, cooling the refrigerant back to liquid so it can return to the cases to repeat this cycle. A typical supermarket will have many cases connected to a refrigerant “circuit” and each circuit will usually have multiple compressors. Three to six circuits will serve each market, each dedicated to different temperature cases or areas of the store.

Alternative Refrigeration Systems

Recently some variations on this design have emerged in response to concerns about the global warming contribution of the inevitable leakage of conventional refrigerants. These involve the use of CO2 or glycol.
“brines” in place of typical refrigerants in some components of the systems. As these systems are still rare, they are not detailed here. Recent analyses have shown that energy use of these variations range is equivalent or somewhat greater than conventional systems, but have savings in greenhouse gas emission (due to reduced refrigerant leakage) that more than offset the GGHG emissions associated with increased energy use. Many of the applicable EEMs for typical systems also apply to these variations. (E.g. reducing case heat gain will reduce energy use in any system.)

Utility Incentive Programs in California

New Construction
Incentives for more efficient supermarkets are provided through the Savings By Design program, and energy savings must be calculated by modeling the proposed market against a baseline market. This modeling is provided by a few specialist firms, using a special refrigeration version of the eQUEST/DOE-2.2 program. The baseline supermarket is currently based on recent historical typical construction.

Retrofits
The utilities have differing programs using different methods to determine savings or incentives for retrofits to supermarket systems. All except SDG&E provide prescriptive incentives for particular retrofits.
PGE utilizes a program called Energy Smart Grocer which deploys a subcontracted firm to audit, provide recommendations and calculate savings for this sector.
SCE & SMUD provide both “Custom” (calculated savings) and “Express” (prescriptive) incentives.
SDG&E utilizes a subcontractor to implement measures across this segment, and provides them with incentives.

Energy Saving Opportunities
Given the interacting energy consuming components in supermarkets, many opportunities exist for both energy waste and savings.

Store Lighting and HVAC
The ambient store lighting is not covered in this E-Newsletter, as the applicable EEMs are generally the same as those used in other large retailers. For restaurant operations within supermarkets, the EEMs are similar to those for any restaurant operation.) Special HVAC systems are often used to dehumidify air for supermarkets, but simulation analysis has shown limited savings for conventional methods of providing this extra dehumidification in California.

Refrigerated Cases
The entire refrigeration system must be designed to remove heat that enters or is generated within the cases, so this is the first place to look for energy savings. Federal standards for new supermarket refrigerated cases will take effect in 2012, and some features which have been optional will become standard to meet the new standard.

Doors and Open Cases: Many case types never have doors, some may have doors, and others always have doors. On average, where the choice exists, choosing a case with doors will save energy, but care must be taken to minimize lighting and anti-sweat heater energy consumption in cases with doors. The thermal gains through doors can be reduced by utilizing better glazing and frames. Condensation on the inside of these doors may increase, but anti-fog films are available to minimize this. Night curtains will effectively reduce the loads on open cases during unoccupied periods, if any. Door gaskets deteriorate with time and should be replaced when this is apparent.

Anti-Sweat Heaters: In CA, these heaters, which prevent exterior condensation on doors and cases, should be needed only occasionally. Controls to make sure these heaters stay off as long as possible are typically installed but may not be commissioned or maintained properly. Some newer case doors are designed with low-conduction glass and frames, eliminating the need for these heaters, however the cases themselves will still typically have ASHs, and the store will still need to control these ASHs.

Case Lighting: Standard lighting in cases has been florescent, but both LED lighting and fiber-optic lighting systems are now available with comparatively less energy consumption. The fiber-optic lighting appears to reduce overall energy use to the greatest degree, in part because more of its heat is left outside the case, where it often beneficially warms the store, instead of adding to case heat gains. Any lighting can be switched off by a timeclock. LED lighting can be controlled by a motion sensor and be turned off when the area in front of a case is vacant, and this may be required in non-24 hr stores under the 2013 Title 24.

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where a condenser which can switch between evaporative cooling and air cooling. A tradeoff is always made between the energy use of the condenser and the compressor, because the condenser fans must run harder to produce the cooler refrigerant condensing temperatures and pressures that allow compressors to run more efficiently. Because the compressors use more energy than the condenser, the most efficient systems use controls which adjust the pressure the condenser is trying to achieve in response to outside drybulb or wetbulb temperature, particularly when the fans are operated by VSDs.

Heat recovery is the use of additional refrigerant heat exchangers to reject heat to coils in the store's heating system or domestic hot water system. These typically save considerable heating energy, more than offsetting the small compressor power penalty which will occur while in this heating mode.

System and Piping

While most of the EEMs discussed above relate to individual components, the overall design of the store and systems will contribute to the energy consumption. The maximum achievable efficiency decreases with the temperature of the lowest temperature case on a system. So in general energy consumption will be minimized by maximizing the number of circuits as long as this is done so that the temperatures on each circuit are similar. Greater pressure drops
Summary of Proposed 2013 Title 24 Supermarket Mandatory Measures as of September 12, 2011. (Claim CASE Item 27)

**Floating head pressure** – require controls to float refrigeration system SCT to 70°F during low-ambient temperature conditions, with ambient-following control logic and variable speed condenser fans

**Condenser specific efficiency** – require a maximum fan power per unit of capacity on air-cooled and evaporative-cooled refrigerant condensers

**Floating suction pressure** – require controls to reset refrigeration system target suction temperature based on refrigerated display case or walk-in temperature, rather than operating at a fixed suction temperature setpoint

**Mechanical subcooling** – require liquid refrigerant to be subcooled to 50°F or less for low-temperature loads

**Display case lighting control** – require automatic controls to turn off display case lights during non-business

**Refrigeration heat recovery** – require equipment and controls to utilize rejected heat from refrigeration system(s) for space heating, with a limited increase in refrigerant charge

**CO₂ secondary or cascade cooling** – require that refrigerated display cases and walk-in coolers and freezers utilize carbon dioxide (CO₂) for cooling to reduce HFC refrigerant charge

Annual Energy Simulation of Supermarket Systems

In CA, supermarkets have been modeled using the DOE-2.2R program to determine incentives under the Savings By Design program. Because of the complexity of refrigeration systems, this modeling is performed by a few select consultants. The DOE-2.2R program has also been used to analyze measures for inclusion into Title 24.

The DOE-2.2R program requires numerous specific inputs for refrigeration components. For instance, the representation of a fixture through components will increase compressor energy consumption. Some piping designs may decrease efficiency of condenser operation. Systems are now being installed which distribute smaller compressor/condenser units around a store roof, closer to the case groups served, reducing piping runs and refrigerant inventory.

Liquid-to-suction heat exchangers (LSHXs) cool the hot refrigerant before it enters a case through heat exchange with cool refrigerant leaving the case. Simple LSHXs are common, but high-performance LSHXs significantly improve the efficiency of low temperature circuits, and some medium temperature circuits.

Mechanical subcooling (use of medium-temperature circuits to reduce the load on low-temperature circuits) is a common cost-effective feature in new stores and may be required by the 2013 T24.

Some components in refrigeration systems can be de-activated on a call for load shedding, qualifying for further incentives. Defrost can be deferred, and some case lighting can be switched off.

Retrofits

Energy cost savings can justify the replacement of some components of the refrigeration system. These are typically either case components or controls. Published results from a program in San Diego reported savings averaging 309,000 kWh per market. The distribution of those savings is shown in the following chart.
or case includes 130 input values, though not all would be needed for any given case. Some of these inputs are not clearly evident from manufacturers’ literature. The program also makes assumptions about operation of controls that may not be always be achieved in actual operation.) All programs share these issues.

Other Programs

The EnergyPlus program has been updated to include detailed models of refrigeration system components, libraries of American components, secondary loops and new refrigerants. The EnergyPlus representation of components generally requires fewer inputs than the DOE-2.2R; for instance a case is represented by a maximum of 35 inputs. This program is being used at NREL to model prototype markets to develop Advanced Energy Design Guidelines for supermarkets and to model energy efficiency measures for specific supermarket design projects.

CyberMart is a Swedish program with simplified inputs and libraries of European components.