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ENERGY CONSUMPTION OF AN EXPERIMENTAL COLD STORAGE

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Abstract

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Energy consumption of an experimental cold storage was measured for different storage temperatures. Suction temperature and pressure temperature of the compressor and working time of the compressor were determined to reach evaporator set up temperatures. Capacity of compressor, condenser, and evaporator were 10460 kJ/h, 12552 kJ/h, and 10460 kJ/h, respectively. An axial fan located back of the evaporator was used to distribute the cooled air into the cold store. An electrical heater was used to defrost. Refrigerant was R22.

The compressor suction and pressure temperatures varied between 1.8°C-14°C, and 37°C-44°C, respectively. Condenser output temperature changed from 28.8 to 45.5°C. Electrical energy consumption were measured as 0.001 kWh for 5°C, 4°C, and 3°C and 0.003 kWh for 2°C, 0.006 kWh for 1°C, 0.001 kWh for -1°C, 0.109 kWh for -2°C and 0.120 kWh for -3°C. Mean energy consumption of the compressor was 0.035 kWh/°C for positive cold storage temperatures (from 5°C to 0°C) and 0.093 kWh/°C for negative temperatures (-1°C, -2°C, and -3°C). Working time of the compressor was changed from 207 s to 25049 s for test temperatures.

Key words: energy consumption, cold storage, refrigeration

Introduction

Refrigeration is a remarkable tool for preserving perishable food. In addition to preventing deterioration, refrigeration has real economic importance, since it promotes international trade and maintains the quality of agricultural and fishery products. The application of refrigeration to a wide variety of perishable foodstuffs has become firmly established in little over a century since its introduction. One of the most important factors affecting the quality, safety and storage (or shelf) life of agricultural and food products is temperature. In order to maintain the highest quality of food, the immediate refrigeration processing (cooling and/or freezing) after the harvest and storage and transportation in a low temperature environment are recommended for perishables. The low temperature environment can be achieved and maintained through a cold chain in which the temperature is consistently at required levels. Today the majority of foodstuffs being treated and maintained by refrigeration, for instance, in Europe supermarket sales, account for 70% of all food sales. The minimum temperature of the cold chain is maintained at negative and the refrigeration system is required, therefore the energy is consumed through the completely cold chain (Huan, 2008).

Energy saving opportunities determined as given by Anonymous (1999): The need to address CFC/HCFC phase-out presents an ideal opportunity to implement energy efficiency measures. A high proportion of the energy wastage from cold stores arises from incorrect operation of equipment and poor commissioning of controls, so significant savings can be achieved for little to no cost. The main stages in assessing potential energy saving opportunities are audit existing refrigerating equipment, check controls and set points, reduce heat loads, improve defrosting,· reduce temperature lifts in refrigerating plant, optimize compressor and system operation, institute planned maintenance.

Energy use in a cold storage facility is affected by the amount of heat the refrigeration equipment must remove and the efficiency of the equipment. The main sources of heat in a facility for long-term storage are transmission through walls, evaporator coil fans, lights, air leakage, and respiration of the stored commodity (Thompson, 2001).

The effect of airflow blockage and guide technology on energy saving for spiral quick-freezers were investigated by simulating and analyzing the airflow field and measuring of the velocity distribution in the freezing zone for different designs. The k–” turbulence model was used. The velocities and temperatures of the air in the freezing zone for different designs of airflow blockage and guide boards were measured. The study shows that the airflow pattern plays a key role on energy efficiency, freezing time, and production rate. In the study case, through the optimization of the airflow blocking boards and the guide boards, the average air velocity in the freezing zone would be enhanced to 2.5–2.7 times compared with the original design. Correspondingly, for bean curds in a stationary condition, the freezing time would be shortened by 78–85%, energy efficiency and the production rate would be increased by approximately 18–28% individually **(**Huana et al., 2003).

Cold stores (Europe) or Refrigerated Warehouses (US) are facilities where perishable foodstuffs are handled and stored under controlled temperatures with the aim of maintaining quality. Preservation of food can occur under chilled (above zero) or frozen (below zero) temperatures. For some products, other conditions besides temperature control might be required: for living products (e.g. fruit) the moisture content and/or the composition of the surrounding atmosphere has to be changed as well. CA (Controlled-Atmosphere) storage or ULO (Ultra-Low-Oxygen) storage are some of the techniques available (Duiven and Binard, 2002).

The electric energy consumption of existing cold stores ranges between 30 and 50kWh/m^3/year for storage. It is depends on the quality of the building, on the activities (chilled or frozen storage), room size, stock turnover, temperature of the incoming produce, outside temperatures, etc. The total cost of electric energy is about 10 to 15% of the total running costs of a store. Improving Energy Efficiency (EE) has two goals: cost reduction and environmental protection (Duiven and Binard, 2002).

The objectives of the study were to analyze performance characteristics during partial load operation and to calculate energy consumption amount of H_2O/LiBr absorption chiller with a capacity of 210 RT. The effect of cooling water flow rate and cooling water inlet temperature on the absorption performance and energy saving is quantified during the partial load operation. It is found that the performance of absorption system is more sensitive to the change of inlet water temperature rather than the cooling water flow rate. Even if the cooling water flow rate is reduced to 60% of the standard value, the capacity is recovered if the temperature of cooling water decreases about 2.0^{0}C. The pumping power of cooling water is 4 times higher than that of cooling tower during the partial operation mode and the pumping power of cooling water becomes more significant with decreasing the partial load. It is concluded that when the partial load is in the range of 100–40%, the reduction of the required power by 23% can be realized by decreasing the cooling water inlet temperature of 1.0^{o}C (Park et al., 2004).

An alternative solution to reduce energy consumption in industrial refrigeration systems is proposed and introduced in an article (Buzelin et al., 2005). A typical industrial refrigeration system was conceived, built and modified in the laboratory, receiving a novel power law control system, which utilizes a frequency inverter. The operation and energy consumption of the system operating either with the new control system or with the traditional on-off control were compared to realistically quantify the obtained gains. In this manner, the measured temperature data acquired from several points of both systems and the energy consumption in kW h during a 24 h experimental run period are compared. The closed-loop power law controlled system shows a much smaller variation of the cold chamber internal temperature and electrical energy consumption economy of 35.24% in comparison with the traditional on–off system, under the same operating conditions (Buzelin et al., 2005).

The energy consumption characteristics of the refrigeration equipments from the processing facilities, cold stores, refrigerated transportations, refrigerated display cabinets, to the domestic refrigerators are introduced and thereafter the energy saving opportunities in food refrigeration industry are presented in terms of the system design, equipment selection, construction, operation, management and monitoring of the cold chain (Huan, 2008). The results indicate that the substantial energy savings could be achieved if the design and operation of cold chain facilities were optimized in terms of heat loads on the cold chain, system design and operation of the refrigeration system.

An analysis of the performance of well freezers, chest freezers, frozen and chilled door cabinets (solid or glass door) and open fronted chilled cabinets under EN441 test conditions demonstrated that maximum temperatures in cabinets were generally in the most exposed (to ambient) areas and that minimum temperatures were located in the least exposed areas.

Detailed positions of maximum and minimum temperature varied between cabinet types. In chest freezers, 95% of the maximum temperature positions were located in the top layer and 95% of the minimum temperature positions were located in the middle layer of the cabinets. In full door frozen cabinets, the maximum temperature position was in the majority of cases on the top shelf (64%) with most maximum packs being at the front of the top shelf (53%). In the chilled full door cabinets, 94% of the maximum temperature packs were situated at the front of the cabinet. In open fronted cabinets the majority of maximum temperature packs (97%) were located at the front of the cabinet, the largest number (60%) being at the front of the base of the cabinet. In well cabinets, the majority of maximum temperature packs (81%) were located in the top layer of the cabinet and the majority (91%) of minimum temperature packs was located in the bottom of the cabinet. Large differences in energy consumed by cabinets of similar size and temperature performance were found indicating that large reductions in energy and CO_2 emissions could be achieved by selection of the most efficient cabinets [9] (Evans et al., 2007).

There is very little published data on the energy consumption of cold storage systems for foods (Evans, 2009). In this research, energy consumptions of a cold storage were measured for different storage temperatures. In addition, energy consumption of components such as compressor, evaporator and condenser in the cooling system were also determined and evaluated according to the storage temperatures.

The efficiency of refrigeration systems is very sensitive to the evaporating temperature– even a small temperature rise can provide useful savings. In this project, the British Frozen Food Federation (BFFF) has investigated the potential to reduce energy usage and CO_2 emissions by raising the temperature control set point of cold stores and by raising the associated evaporating temperatures. The project involved the collection of data from 8 factories producing frozen food. In particular, it included the temperature monitoring of pallets of frozen food as they are transported from a food-manufacturing site to cold storage warehouses (Anonymous, 2009).

Energy consumption is continuously increasing around the world and this situation yields research to find sustainable energy solutions. Demand for cooling is one of the reasons of increasing energy demand. This research is focused on one of the sustain-able ways to decrease energy demand for cooling which is the solar-powered adsorption cooling system. In this study, general theoretical performance trends of a solar-powered adsorption cooling system are investigated using TRNSYS and MATLAB (Taylan, 2010).

Combined cooling, heating, and power (CCHP) is a cogeneration technology that integrates an absorption chiller to produce cooling, which is sometimes referred to as trigeneration. For building applications, CCHP systems have the advantage to maintain high overall energy efficiency throughout the year. Design and operation of CCHP systems must consider the type and quality of the energy being consumed. Type and magnitude of the on-site energy consumed by a building having separated heating and cooling systems is different from a building having CCHP. Therefore, building energy consumption must be compared using the same reference which is usually the primary energy measured at the source. Site-to source energy conversion factors can be used to estimate the equivalent source energy from site energy consumption. However, building energy consumption depends on multiple parameters. In this study, mathematical relations are derived to define conditions a CCHP system should operate in order to guarantee primary energy savings (Fumo and Chamra, 2003).

Objective of this research is to determine energy consumption of a cold storage for different storage temperatures. Energy consumption of the system elements such as compressor, condenser and fan of the evaporator were measured and evaluated. In addition, suction and pressure temperatures of the compressor, condenser output temperature and required time to reach to the each set up temperature were determined and evaluated.

Materials and Methods

Cold store

Dimensions of the experimental cold storage built in Namik Kemal University were 4.52 m in length x 1.90 m in width x 2.22 m in height (Figure 1). The cold storage volume was 19.07 m^3 (Akdemir and Arin, 2003).

The cold store was made of reinforced concrete and isolated by using foam-glass. Then a coverage material formed steel rush was placed on the wall surface to cover the foam glass. Finally, ceramics were used to cover the walls. Door of the cold store sizes was 90x190 cm (Akdemir and Arin, 2003).

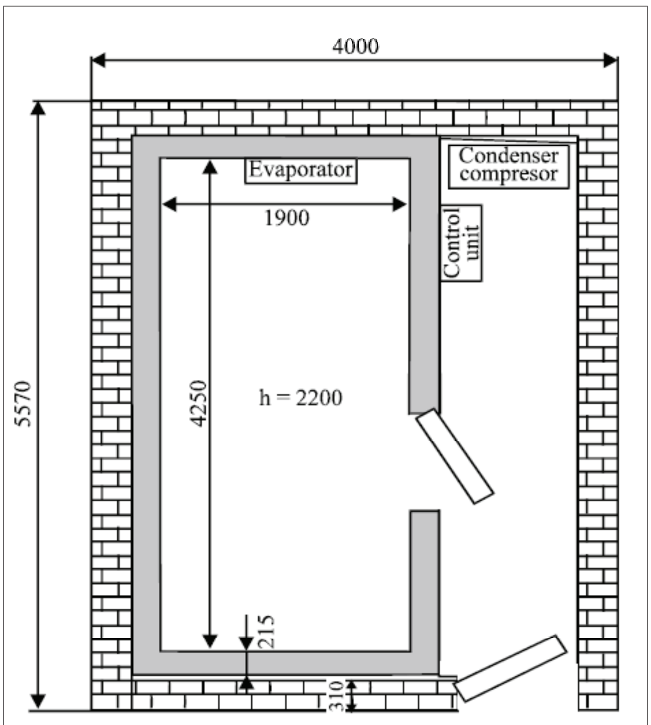

Fig. 1. Cold store

Cooling system

A compressor was located in the corridor of the cold storage (Figure1). A condenser, a condenser fan, a fluid hopper and a drier were gathered as a group inside the compressor chassis. Evaporator was located on upper side of the wall. Thermostatic expansion valve was fitted in the evaporator inlet and on the high-pressure side of the compressor. A control panel, which includes a thermometer-thermostat, a manometer and a humidity gauge, were placed on one of the outside wall of the cold store (Akdemir, 2002).

The compressor was hermetic type and capacity 10460 kJ/h. An electrical motor of 1.49 kW powered the compressor. The condenser type was air-cooled. Capacity of the condenser was 12 552 kJ/h. The evaporator was made of copper pipes and outside surface covered with aluminum plates. An axial fan was located on the back of the evaporator to distribute the cooled air into the cold store. An electrical heater was used to defrost. The capacity of evaporator was 10 460 kJ/h. Refrigerant was R22 (Akdemir, 2002).

Measurement devices

Measurement devices were electricity meter, temperature sensor and chronometer. Technical specifications of the electricity meter used to determine electrical energy consumption was given in Table 1.

Measurement range of the temperature sensors were -40^{o}C and +99^{o}C. Accuracy of the temperature sensors was 1%. The temperature sensors were located on pipes of inlet and outlet of the compressor, outlet of the condenser and evaporator.

A stopwatch chronometer was used to measure working time of the cooling system for each set up temperature.

Table 1
Technical specifications of electricity meter

Specification	Value
Voltage, V	220 V
Current, A	10 (40) A
Frequency, Hz	50 Hz
Revolution per 1 kWh, rev/min	600 (rev/min)

Methods

The experimental cold storage was empty during the measurements. The electrical energy consumptions of the cooling system components were measured from +5°C to -3°C for each cold storage set up temperatures. Starting and last values of the electricity meter were read the compressor worked to each to the cold storage set up temperatures. Differences between the starting and the last values of the electricity meter were calculated as the electrical energy consumption for each test.

The electrical energy consumption of the evaporator fan was measured when the compressor stopped and started to work another set temperature. Differences between these two values were calculated as electrical energy of the evaporator fan. In addition, mean energy consumption as kWh/°C for each cold storage temperature was calculated by using data established from the electricity-meter for compressor and evaporator fan. The required time to reach to the set up temperature was measured for 5°C, 4°C, 3°C, 2°C, 1°C, 0 °C, -1 °C, -2 °C and -3°C.

Results and Discussions

The suction and pressure temperatures of the compressor and condenser were given in Table 2.

The suction temperature and the pressure temperatures of the compressor changed from 11.2°C to 1.8°C, 44 °C to 45.3°C., respectively. The output temperature of the condenser varied from 28.8°C to 37.0°C.

Electrical energy consumptions and working time are given in Table 3.

Electrical energy consumptions of the compressor were same as 0.001 kWh for 5°C, and 4°C and 3°C storage temperatures. Then the electrical energy consumption of the compressor started to increase after the 3°C and varied from 0.003 kWh to 0.120 kWh for other storage temperatures. Mean energy consumption of the compressor was approximately 0.035 kWh/°C for positive cold storage temperatures (from 5°C to 0°C). Mean energy consumptions of the compressor was calculated as 0.093 kWh/°C for minus set up temperatures (-1°C, -2°C, and -3°C).The working time of the compressor was changed from 207 s to 25049 s for the set up temperatures.

Energy consumption of the evaporator fan (kWh) and working time (s) are given in Table 4.

The electrical energy consumptions were same for each positive storage but increased after minus storage temperatures.

According to the results, outlet temperatures of the condenser for positive storage temperatures were stable but they are increased for negative storage tem-

Table 2
Inlet (suction) and outlet (pressure) temperature for compressor and condenser

	Cold storage setup temperature, °C								
	5°C	4 °C	3 °C	2 °C	1°C	0 °C	-1°C	-2°C	-3°C
Compressor suction temperature, °C	11	14	9.7	13	11	10	8.5	8.8	1.8
Compressor pressure temperature, °C	44	43	43	44	42	42	42	41	45
Condenser output temperature, °C	29	29	29	29	29	29	31	36	37

Table 3
Electrical energy consumption (kWh) and working time (s) of the compressor

	Cold storage setup temperature, °C								
	5°C	4 °C	3 °C	2 °C	1°C	0 °C	-1°C	-2°C	-3°C
Electrical energy consumption, kWh	0.001	0.001	0.001	0.003	0.006	0.007	0.05	0.109	0.12
Time, s	207	273	372	667	1253	1558	9840	20233	25049

Table 4
Energy consumption of the evaporator fan (kWh) and working time (s)

	Cold storage setup temperature, °C								
	5°C	4°C	3°C	2°C	1°C	0°C	-1°C	-2°C	-3°C
Electrical energy consumption, kWh	0.001	0.001	0.001	0.001	0.001	0.001	0.004	0.005	0.005
Time, s	178	177	178	177	178	177	178	177	178

perature. The outlet temperatures of the compressor were decreased when storage temperatures decreased. The inlet temperatures of the compressor for the storage temperatures were stable. Energy consumption of the compressor for positive cold storage temperatures (from 5°C to 0°C used widely for cold storage of agricultural products) was 0.035 kWh/°C.

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