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Dual-Purpose Air Conditioner

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By

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Abstract

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A dual-purpose air conditioner was designed to cool the air in the sunroom at my house in New York State while simultaneously heating the water in my pool. During the summer, the air in the sunroom reaches temperatures over 120°F, which has damaged electronic equipment in the room and makes the room undesirable to use. The proposed system utilizes a stainless-steel tube-fin cross flow exchanger to transfer heat from the air in the sunroom to the water in the pool. The system was designed to use a 115V fan kit to circulate the air at 520 CFM and a 2/25 HP circulation pump to circulate the pool water at 4 GPM. The overall heat transfer coefficient of the heat exchanger was used to predict the air and water outlet temperatures using recorded air and water inlet temperatures. The capital and operating costs of the proposed system were then compared to that of an alternate system containing a window air conditioner and heat pump style pool heater to determine if the dual-purpose air conditioner is a cost-effective system.

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Problem Definition

I live in New York State and have a straight eave glass sunroom and swimming pool at my house. Temperatures in the pool and sunroom were recorded from August 11, 2016 to September 28, 2016 using an AcuRite Digital Humidity and Temperature Comfort Monitor as high as 120°F. The temperature range on this thermometer is 32°F to 122°F with an accuracy of ± 2°F, which indicates that temperatures could have been higher, but that the thermometer reached the upper limit of its workable range [1]. The thermometer recorded the maximum and minimum temperatures in a 24-hour period. The average maximum temperature in the sunroom for this period was 111°F. Having temperatures in this range make it undesirable to be in the sunroom during the summer and has damaged electronic equipment, such as televisions and stereo systems. As a family, we believed that it would be expensive and wasteful to operate a window air conditioning unit in this room, so alternative options were explored.

I determined that the most feasible and efficient solution was to utilize the pool water, which averaged 80°F, to cool the sunroom using a heat exchanger. During this process, the pool water would also be warmed, which makes this system a dual-purpose air conditioner. The problem explored in this report is to design the main components of the dual-purpose air conditioner, such as the heat exchanger, fan, and pump, where the main function is to cool a sunroom using pool water and the secondary function is to heat the pool water with the air in the sunroom. The operational cost of this system will be compared to that of operating a pool heater and air conditioner simultaneously to draw conclusions regarding the effectiveness of the proposed system.

Design Requirements

The heat exchanger tubing must be compatible with chlorinated pool water due to its corrosiveness. Because of this requirement, copper tubing cannot be used, which is the most common material used for tubing in cross flow heat exchangers. Compatible tube materials include titanium, copper-nickel, and stainless steel [2] [3]. The heat exchanger and associated fan must fit within a 2’ x 2’ x 2’ space that is available in the sunroom.

The desired range of outlet temperatures from the heat exchanger to the sunroom is 95°F to 100°F when the temperature in the sunroom reaches its maximum recorded value, i.e. when it is between 110°F and 120°F. The desired temperature of the water returning to the pool is around 85°F, but this is not as strict of a requirement as that of the air temperature.

To be considered a cost-effective system, the operating cost must be less than that of a heat pump pool heater, which is currently installed, and a window air conditioning unit. The pool pump runs 8 hours per day, but the heat pump pool heater and window air conditioner would not operate continuously during this time. It is assumed that the pool heater and air conditioner operate 6 hours per day, so the dual-purpose air conditioner is also assumed to operate for 6 hours per day. This assumption is based on the system running on and off during the warmer part of the day between 09:00 and 18:00. Assuming the pool is open from the beginning of June to the end of September, both systems are assumed to run for 90 days per year at 6 hours per day for a total of 540 hours per year. Using data from Central Hudson Gas & Electric, the utility company in my area, the cost of electricity is assumed to remain constant at $0.17 per kWh [4].

Background

Pool Heaters

Swimming pool heaters are beneficial in the northern climates to extend the operating season of swimming pools. According to energy.gov, the most efficient pool heaters are heat pump, gas, and solar pool heaters [5]. Heat pump pool heaters are more efficient than gas pool heaters if a consistent water temperature is desired, but become less efficient as the outdoor temperature decreases. However, gas pool heaters are not dependent on the outside temperature and are more effective than the heat pump variant at increasing water temperature if the pool is not used daily, such as increasing the water temperature prior to a party [6]. On the other hand, solar pool heaters utilize a solar collector to heat the pool water and have much lower operating costs than heat pump and gas pool heaters [5]. The heat pump and gas pool heaters use heat exchangers to heat the water while the solar pool heater uses solar collectors.

Heat Exchangers

Heat exchangers come in various configurations where their usage depends on the type of fluid and the method of heating. Heat exchangers transfer heat from a higher temperature source to a lower temperature sink. They can be used to transfer heat from a solid to a fluid, or from a fluid to another fluid. In gas pool heaters, metal tubes containing the pool water are heated with a flame in the burner [7]. During this process heat is transferred from the hot metal tubes to the cooler pool water. Figure 1 details the entire gas pool heating system, and the part labeled “Heating Coils” represents the heat exchanger.

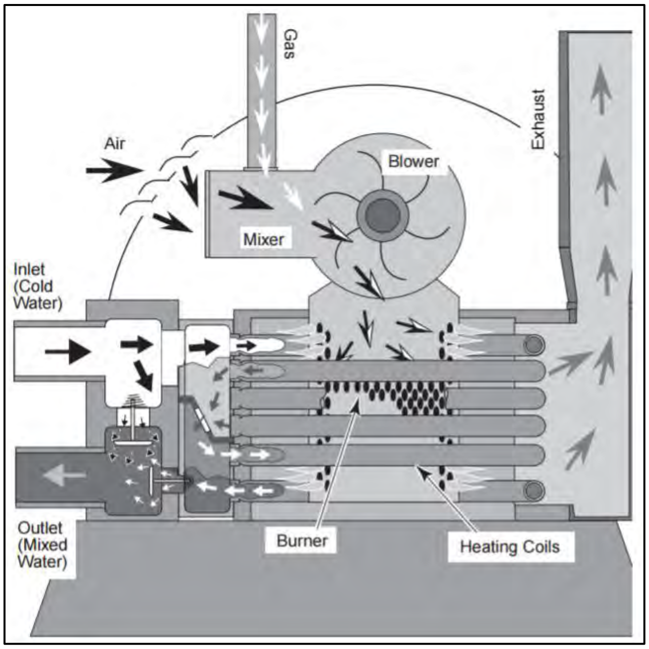

Figure 1: Gas pool heater diagram [7]

Heat pump pool heaters use a cross-flow heat exchanger where hot outside air is forced over metal tubes containing a refrigerant to heat the refrigerant. The refrigerant then heats the pool water in a concentric tube heat exchanger. This concentric tube heat exchanger uses forced convection to transfer heat by passing the pool water, which is in the outer portion of the heat exchanger, over the inner tubes of the heat exchanger containing the hot refrigerant. The efficiency of a heat pump pool heater decreases as the outside air temperature decreases because less heat can be transferred to the refrigerant, and thus the pool water. Figure 2 illustrates the heat transfer process in a heat pump pool heater.

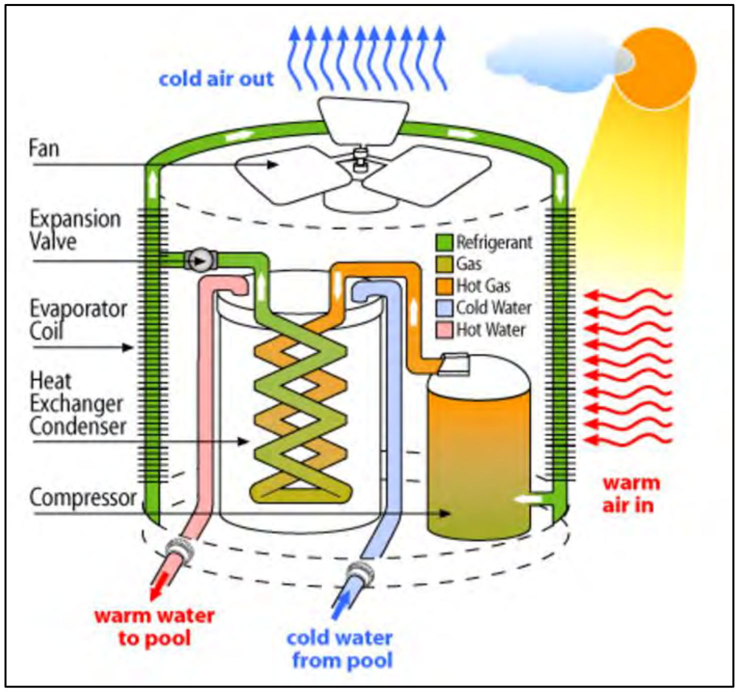

Figure 2: Heat pump pool heater diagram [8]

Sunroom

A sunroom, or solarium, is "an enclosed room or area designed to make maximum use of sunlight, as by having all or most of the exterior surface composed of clear glass or other materials that do not inhibit the passage of light" [9]. Figure 3 depicts a straight eave sunroom, which can have a glass or solid roof.

Figure 3: Straight eave glass sunroom [10]

Because sunrooms are designed to make maximum use of sunlight, they tend to become exceptionally warm during the summer months unless properly ventilated, shaded, or air conditioned. Shading of the roof windows would greatly reduce the solar heat gain and the vertical windows would still permit sufficient sunlight. Another viable option to regulate the temperature in a sunroom during the summer months is an air conditioning system, but this can be costly to operate due to the extreme heat gain in the sunroom. Due to the amount of solar heat gain, sunrooms are effective sources of heat for other systems, such as swimming pools. If used as a heat source for swimming pools, the sunroom performs as a solar pool heater, but has the benefit of being a living area as compared to traditional solar pool heaters. The sunroom and pool are complementary because as the air in the sunroom is used to heat the pool water, the air will be cooled.

Design Description

Overview

The dual-purpose air conditioner is designed to use a cross flow tube-fin heat exchanger with the air in the sunroom and the water in the pool as the working fluids. The air is to be circulated across the heat exchanger using two fans that attach directly to the heat exchanger. The pool water is to be circulated through the heat exchanger using a separate pump and water line from the rest of the pool system. Because this system is separate from the main pool filtration system, it can be operated independently and does not require the filtration system to be operating.

Heat Exchanger

The heat exchanger to be used in this design is a cross flow tube-fin heat exchanger. The specific model to be used, shown in Figure 4, is the 4320G10SB-M9 Stainless Steel Tube-Fin Heat Exchanger from Lytron Direct with a 115V fan kit. This heat exchanger has stainless steel tubes and copper fins to maximize the amount of heat transferred.

Figure 4: 4320G10SB-M9 Stainless Steel Tube-Fin Heat Exchanger [11]

As shown in Figure 5, this model heat exchanger measures 23” long x 9” tall x 6” deep with the fans attached, which meets the design requirements of 2’ x 2’ x 2’ [11]. The dimensions are in inches and [mm].

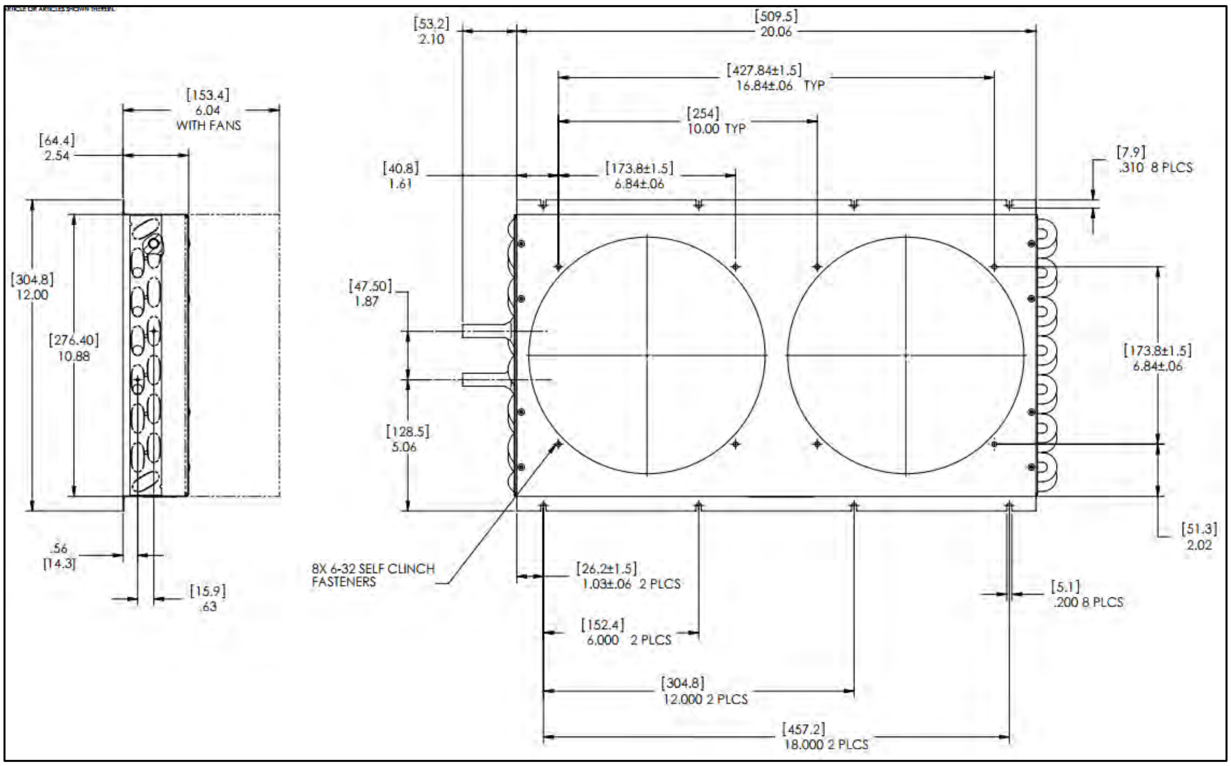

Figure 5: Detailed drawing of heat exchanger [11]

This heat exchanger was chosen because it contained stainless steel tubing for the water supply, met the performance and size requirements, and it comes with mountable fans that are designed to fit this heat exchanger. This unit, with the fans, costs $2,453 [11]. The heat exchanger outlet temperatures, required flow rates, and amount of heat transferred are provided in Table I.

Table I: Heat Exchanger Performance

Temperature (°F)				Flow Rate		Heat Transferred (BTU/Hr)
Air Inlet	Air Outlet	Water Inlet	Water Outlet	Air (CFM)	Water (GPM)	
85	82.3	80	80.7	520	4	1,450
90	84.6	80	81.5	520	4	2,901
95	86.9	80	82.2	520	4	4,351
100	89.2	80	82.9	520	4	5,801
105	91.5	80	83.6	520	4	7,251
110	93.8	80	84.4	520	4	8,702
115	96.1	80	85.1	520	4	10,152
120	98.4	80	85.8	520	4	11,602

Pump

The current pool pump, a 3/4 HP Hayward Super Pump®, has a flow rate of 61 GPM, which is greater than the required flow rate through the heat exchanger, so separate pipes and a pump must be installed for this new system [12]. The pump must overcome an 8-psi pressure drop through the heat exchanger at 4 GPM in additional to any head loss associated with the piping system [11]. A 2/25 HP single speed pump is required for this application [13].

Operating Cost

The 2/25 HP electric pump requires 0.24 kWh of energy per day, which corresponds to an operating cost of $0.06 per day and $5.48 per operating season using the operating assumptions of 6 hours per day and 90 days per year. The two fans on the heat exchanger are 115 V, 60 Hz fans that require 33 W of electric power each [14]. This corresponds to a total of 0.26 kWh of energy per day, $0.07 per day, and $6.06 per operating season. The total operating cost for this system is expected to be $11.54 per operating season.

Analysis

Performance Curve

The performance curve of the heat exchanger indicates the maximum operating conditions at a specified water flow rate based on the relationship between the air flow rate in CFM and the amount of heat transfer per initial temperature difference in BTU/Hr-°F. The performance curve of the 4320G10SB-M9 heat exchanger is provided in Figure 6. The performance curve was created for specific water flow rates and the operating point of the system must lie on or below the performance curve at the specified water flow rate.

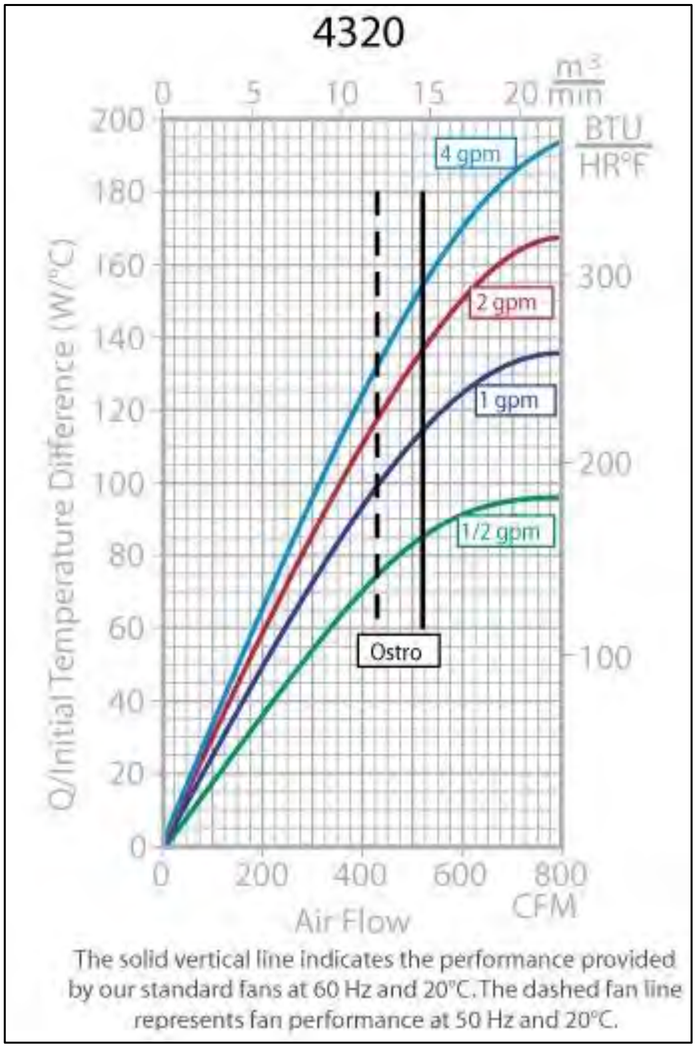

Figure 6: Performance Curve of Heat Exchanger [11]

The equation of the performance curve was obtained by plotting 8 data points from Figure 6 and using MATLAB's curve fitting tool to fit a cubic function through the points. This curve fit had a R^2 value of 0.9993, which indicates that the cubic function fits the curve well, as the maximum possible value of R^2 is 1. The curve fitting tool result is provided in Figure 7.

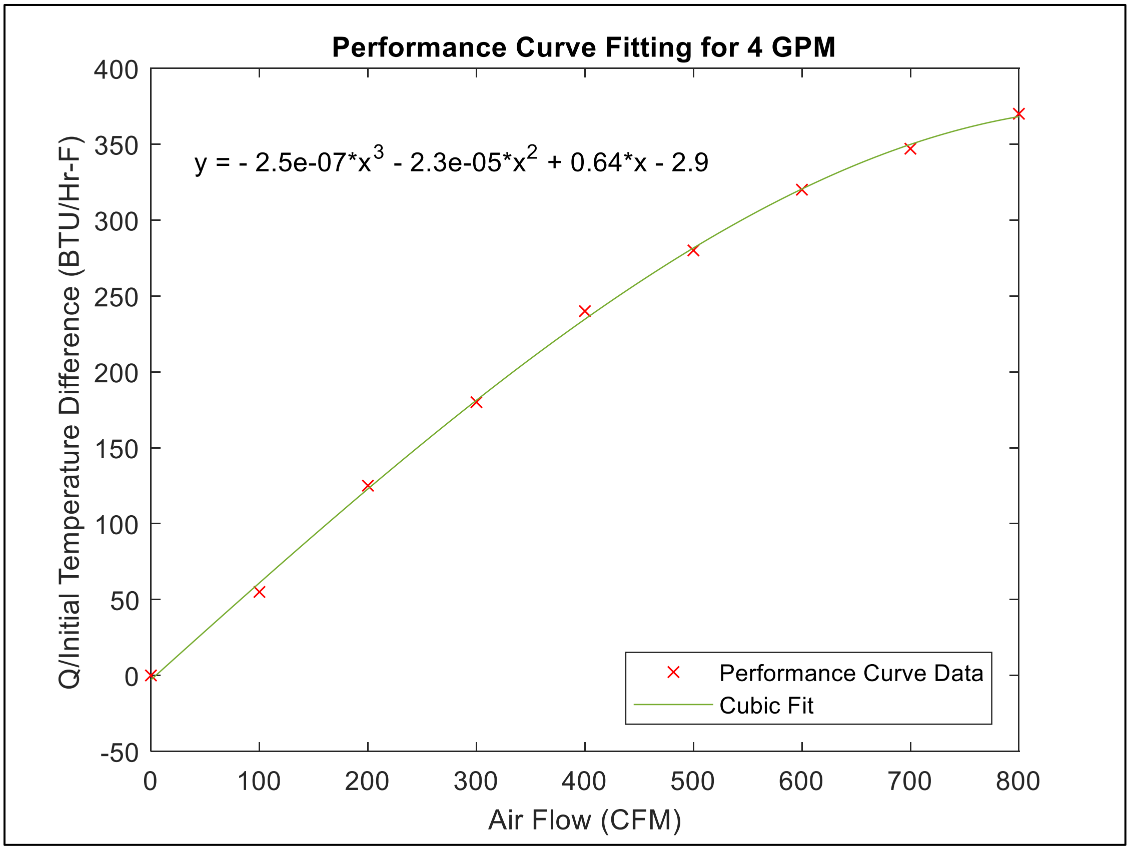

Figure 7: Performance Curve for 4 GPM from MATLAB

Inlet Temperatures

From the performance curve, the maximum amount of heat transfer that can be obtained from the heat exchanger at a given air and water flow rate is dependent on the inlet temperature difference between the air and water. The inlet water temperature was assumed to be a constant 80°F based on temperature recordings from August 11, 2016 to September 28, 2016. However, the inlet air temperature was varied from 85°F to 120°F in increments of 5°F to determine the outlet air and water temperatures at various sunroom air temperatures throughout the summer.

Flow Rates

According to the manufacturer, the performance of the Ostro fan operating at 60 Hz is 520 CFM, so this air flow rate was assumed to be constant for each inlet air temperature [11]. The water flow rate was assumed to remain constant at 4 GPM based on the maximum allowable flow rate through the heat exchanger [11].

Heat Transfer

The fluid properties were evaluated at average temperatures of 82°F for water and 95°F for air. The properties were obtained using interpolation in Tables B.5 and C.2 of Janna [15].

The maximum heat exchanger performance, or the amount of heat transfer per initial temperature difference, was calculated by substituting the 520 CFM air flow rate into Equation (1) which was obtained from Figure 7.

$$UA = (-2.5\times10^{-7})\dot{\forall}_{air}^{3} - (2.3\times10^{-5})\dot{\forall}_{air}^{2} + 0.64\dot{\forall}_{air} - 2.9 \qquad (1)$$

Where *UA* is the overall heat transfer coefficient in BTU/Hr-°F and $\dot{\forall}_{air}$ is the volumetric air flow rate in CFM. The overall heat transfer coefficient is also defined as

$$UA = \frac{Q}{T_{air,i} - T_{water,i}} \qquad (2)$$

where Q is the amount of heat transfer in BTUs, $T_{air,i}$ is the inlet air temperature in °F, and $T_{water,i}$ is the inlet water temperature in °F. Solving Equation (2) for Q yields

$$Q = UA(T_{air,i} - T_{water,i}) \qquad (3)$$

The amount of heat transfer calculated from Equation (3) is equivalent in magnitude to the amount of heat transferred from the air in the sunroom to the pool water. Because air is an ideal gas and water is assumed to be incompressible, the outlet temperatures can be calculated by manipulating Equation (4) into Equations (5) and (6).

$$Q = \dot{m} c_p \Delta T \tag{4}$$

$$T_{air,o} = T_{air,i} - \frac{Q}{\dot{m}_{air} c_{p,air}} \tag{5}$$

$$T_{water,o} = T_{water,i} + \frac{Q}{\dot{m}_{water} c_{p,water}} \tag{6}$$

Where $\dot{m}$ is the mass flow rate of the air or water in lbm/hr, c_p is the specific heat of the air or water in BTU/lbm-°F, and $T_{air,o}$ and $T_{water,o}$ are the outlet air and water temperatures in °F, respectively.

The results of the heat transfer analysis are provided in Table II.

Table II: Heat Transfer Results

Temperature (°F)				**UA (BTU/Hr-°F)**	**Heat Transferred (BTU/Hr)**
Air Inlet	**Air Outlet**	**Water Inlet**	**Water Outlet**		
85	82.3	80	80.7	290	1,450
90	84.6	80	81.5	290	2,901
95	86.9	80	82.2	290	4,351
100	89.2	80	82.9	290	5,801
105	91.5	80	83.6	290	7,251
110	93.8	80	84.4	290	8,702
115	96.1	80	85.1	290	10,152
120	98.4	80	85.8	290	11,602

Economic

An economic analysis was conducted on the 4320G10SB-M9 heat exchanger/fan combination, a 2/25 HP circulation pump, a Heat Pro 21104T heat pump pool heater, and a GE AEL08LV window air conditioner. The economic analysis consisted of calculating the daily and seasonal operating cost, and the purchase price of the equipment. In addition, the savings between the dual-purpose air conditioner and the window air conditioner/heat pump pool heater combination were calculated.

The daily energy usage was calculated using the electric power input and the assumed runtime of 6 hours per day. The daily operating cost was calculated using the assumed \$ 0.17 per kWh and the seasonal operating cost was calculated assuming a 90-day season. The equipment cost results are included in Table III and the system cost comparison results are included in Table IV.

Table III: Equipment Costs

Equipment	**Daily Energy Usage (kWh)**	**Daily Operating Cost**	**Seasonal Operating Cost**	**Purchase Price**
Heat Exchanger/Fan	0.396 [14]	\$ 0.07	\$ 6.06	\$ 2,453 [11]
Circulation Pump	0.358	\$ 0.06	\$ 5.48	≤ \$ 500
Heat Pump Pool Heater	34.2 [16]	\$ 5.81	\$ 523	\$ 2,955 [17]
Window Air Conditioner	3.96 [18]	\$ 0.67	\$ 61	\$ 229 [18]

Table IV: System Cost Comparison

System	**Seasonal Operating Cost**	**Purchase Price**
Dual Purpose Air Conditioner	\$ 12	\$ 2,953
Air Conditioner and Heat Pump Pool Heater	\$ 584	\$ 3,184
Savings	**\$ 572**	**\$ 231**

Conclusions

The designed dual-purpose air conditioner uses a 4320G10SB-M9 copper fin, stainless steel tube heat exchanger with a 115V Ostro fan kit from Lytron Direct. The fan is intended to circulate air in the sunroom at 520 CFM while a 2/25 HP single speed pump is required to pump the pool water through the heat exchanger at 4 GPM. The estimated operating cost of this system is $12 per year with a capital cost of $2,953.

An alternate system would use a heat pump pool heater with a window air conditioner. This alternate system has an estimated operating cost of $584 and a capital cost of $3,184. When comparing the two systems, the dual-purpose air conditioner is estimated to save $572 per year and $231 in capital costs.

Although the dual-purpose air conditioner costs less to purchase and operate than the alternate system, it does not cool the sunroom as much as a window air conditioner, nor does it heat the pool as much as a heat pump pool heater. However, sunrooms are intended to be warmer than other rooms in the house, so cooling the sunroom to 75°F with a window air conditioner is not necessary. Although the outlet pool water temperature of the dual-purpose air conditioner is shown to range from approximately 81°F to 86°F, the average pool water temperature will likely not change a noticeable amount because the amount of water flowing through the dual-purpose air conditioner is 94% less than the amount of water in the pool. At a flow rate of 4 GPM, 1,440 gallons of water will circulate through the dual-purpose air conditioner per day while the pool contains approximately 26,000 gallons of water. This is beneficial for the dual-purpose air conditioner because the inlet water will approximately remain constant at 80°F to maximize the amount of heat transfer to cool the sunroom, which is the primary purpose of the system.

The dual-purpose air conditioner meets all the design requirements except for increasing the average pool water temperature to 85°F. The heat exchanger and fan kit fit within the 2' x 2' x 2' space that is available in the sunroom, and the tubes are made of stainless steel which is compatible with the chlorinated pool water. When the air in the sunroom is between 110°F and 120°F, the outlet air temperature is estimated to be 94°F to 98°F which meets the requirement of 95°F to 100°F. The system also costs less to operate than a heat pump pool heater and window air conditioner, so the dual-purpose air conditioner meets the cost-effective design requirement. Even if a solar polar heater was installed, which would not have any operating costs, instead of a heat pump pool heater, the dual-purpose air conditioner would cost less to operate due to the $61 seasonal operating cost of a window air conditioner. Therefore, the dual-purpose air conditioner is a feasible and efficient solution to cool the sunroom.

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