Energy Conservation using Heat Pump System for Drying Applications in Laundry

Kanchan A. Nandeshwar[1], Milind Chittawar[2], Rajesh Deshpande[3]

Department of Chemical Engineering

Parul Institute of Technology, Parul university, Vadodara, Gujarat[2], SEE-Tech Solutions Pvt. Ltd., Nagpur, Maharashtra

Energetic Consulting Private Limited, Mumbai, Maharashtra[2]

Email: *kanchan.nandeshwar8923@paruluniversity.ac.in[1]*

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Abstract

The topic of interest these days is finding or developing innovative ways that lead to sustainability and energy conservation. Energy conservation has become even more significant in the commercial and residential sector with rising electricity bills. With increasing commercialization in India, electricity consumption in this sector is growing rapidly at 11-12% annually.

Since the past decade, the hospitality industry is growing with a great pace worldwide, consuming a significant amount of energy with an extremely low level of energy-efficiency. Hence, a significant amount of research is being done on energy saving opportunities in hotels, for making them energy efficient. An important factor to be considered for making the hospitality industry energy efficient is to consider the energy consumed by various appliances. One such appliance is the electric tumble dryer.

Tumble dryers are common in hospitals and hotels as a complement to the washing machine. They do, however, considering a large number of units, use large amounts of electricity. The main objective of this thesis is to identify means of reducing the electricity use for the tumble-drying of clothes and to check if a heat pump retrofit is technically and economically feasible for the conventional electric dryer. Heat pump clothes dryers (HPCD) can be much more energy-efficient than conventional electric CDs but have not emerged in the Indian market yet. A heat pump system as retrofit for conventional electric clothes dryer was designed and modelled in Aspen HYSYS (v10). The HPCD system performance was analysed through its power consumption. About 51% energy consumption reduction potential was observed as compared to a typical electric CD that is currently in use at Hotel Taj, Bekal, Kerala. Aspen HYSYS ver.10 is used to design a heat pump clothes dryer capable of saving 46% of the energy used by residential clothes dryers yielding a payback period of 10.2 months

Keywords: *- Clothes dryer; Heat pump dryer; Energy conservation; Energy efficiency; Energy savings, Aspen HYSYS.*

INTRODUCTION

The topic of interest these days is finding or developing innovative ways that lead to sustainability and energy conservation. With decreasing non-renewable energy resources and increasing energy prices, this has become need of the hour. Energy conservation has become even more significant in the commercial and residential sector with rising electricity bills. With increasing commercialization in India, electricity consumption in this sector is growing rapidly at 11-12% annually [1].

Central Electricity Authority (CEA) estimates that the country is currently facing an electricity shortage of 9.9% and peak demand shortage of 16.6% [2]. It is estimated that the total national power demand can be reduced by as much as 25% by 2030 by increasing energy efficiency in buildings and other sectors such as agriculture, transportation, and appliances [3]. Since the past decade, the hospitality industry is growing rapidly worldwide, consuming a significant amount of energy with an extremely low level of energy-efficiency [4]. Hence, a significant amount of research is being done on energy saving opportunities in hotels, for making them energy efficient [5]. At present, the number of 5-star hotels in India is 104, representing huge saving potential. An important factor to be considered for making the hospitality industry energy efficient is to consider the energy consumed by various appliances. One such appliance is the electric tumble dryer.

Electric tumble dryers are common in commercial buildings like hotels and hospitals as a complement to the washing machine. The advantage that it offers is less time consumption for the drying cycle. This works irrespective of geographical location and weather conditions prevailing at that location. However, since the hospitality industry has a considerably large number of electric dryer units, it consumes large amount of electricity.

When electrical consumption of Hotel Taj Palace, New Delhi, was measured for the month of September-2018, it was found that electric tumbler dryers consumed approximately 40% of the total electricity consumption and same is the trend for almost every month, and for all major hotel buildings in India. Venting out hot air through the exhaust vent wastes a large amount of heat. There is a potential for energy saving if this hot exhaust is used for heat recovery, thereby reducing the overall power consumed by the electric clothes dryer. Heat Pump clothes dryer addresses the solution to this problem.

NEED OF THE STUDY

From literature, it was seen that heat pump clothes dryers (HPCD) consume less electricity when compared to conventional electric dryers. These have already emerged in European, Japanese and Australian markets, and have the potential of growing [6].

Electrolux was the first to bring HPCD in Europe in 1997. There were several European HPCD manufacturers in the year of 2007: Schulthess, Arcelik, and Electrolux, and later such as Miele, Metall Zug AG, Bosch, and Siemens. The market share of HPCD was about 4% in 2009. About 90 different HPCD models were available in European markets provided by 18 different manufacturers in 2012, as reported in the Topten Survey [6]. In Germany, Austria and Italy, about 40% is dominated by HPCD [7]. The clothes-drying industry expects that in Europe the HPCDs will continue to gain in market share [6]. However, there are no HPCD manufacturers available in the Indian market yet.

This study provides the design analysis of HPCD, which can be used as a retrofit for the existing electric clothes dryer to increase its energy efficiency and also for developing improved HPCD models.

OBJECTIVES AND SCOPE OF THE STUDY

The primary objective of this project is to design a heat pump system as a retrofit for conventional electric clothes dryer and analyse the energy savings over conventional ECD. Also, aim of the project is to find if a retrofit is technologically and economically feasible for the conventional dryer.

Therefore, this project is about developing a heat pump clothes dryer (HPCD) model which:

- uses less energy than the conventional electric dryer,
- without compromising on drying time, and
- yields minimum payback period.

TECHNICAL APPROACH

A model is designed from off-the-shelf components that can meet the project's efficiency goals and is economically affordable. A heat pump system for laundry applications is modelled based on the design that achieves significant energy savings.

A heat pump system is proposed to be implemented that enable higher energy efficiency. Heat pumps reduce the power consumption of a dryer by recycling heat from humid drum exhaust air to the incoming dry air. However, while designing the system, it was found that condenser of the heat pump is able to heat the incoming ambient air to a temperature of 63 ºC, while the conventional resistive heating element heats up the air to a temperature of 80 ºC showing that it is difficult with available heat pump technology to heat the incoming air as hot as an electric element, which may result in much longer drying times. Hence, an electric heater was added in combination with a heat pump as shown in figure 1.

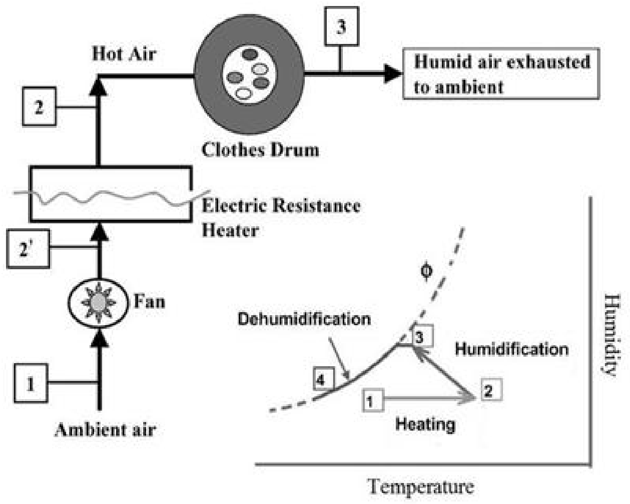


Figure 1: Schematics of HPCD (Large arrows indicate air flow, thin arrows indicate refrigerant flow)

CONVENTIONAL ELECTRIC CLOTHES DRYER

1. Specifications of Existing System

The dryer that is currently in use at the site, i.e. Hotel Taj, Bekal is manufactured by Accurate Technologies, Thailand. This is an electric DE series tumble dryer with a maximum capacity of 34 kg dry clothes.

The conventional electric dryer consists of a fan or a blower, an electric resistance heater, drum, a motor to rotate the drum and ducting to vent out the exhaust humid air into the atmosphere. The working principle of conventional ECD is shown in figure 2.

Working Principle

The drying process inside the drum is represented on the psychrometric chart in figure 1. The fan draws ambient air into the cabinet of the electric clothes dryer. The electric resistance heater heats up the air to the temperature required for drying. The heating process is essentially constant humidity process, as the amount of water present in the air remains constant, but relative humidity during this process changes. The hot air passes through the dryer's drum, picking up the moisture from the clothes. The driving force for the evaporation of water in the drum is the difference in partial vapour pressures between saturated air near the wet clothes and the hot air that is being sent into the drum. Hence, we increase the driving force for the humidification process by heating the ambient air using an electrical resistance element. The humidification process inside the drum is an isenthalpic process as the latent heat of vaporization of water from clothes is balanced the sensible cooling of hot air. This is the reason as to why the exit temperature of the air is always lesser than the drum inlet air temperature. The exhaust humid air carries moisture in it, along with some amount of heat that is not been utilized.

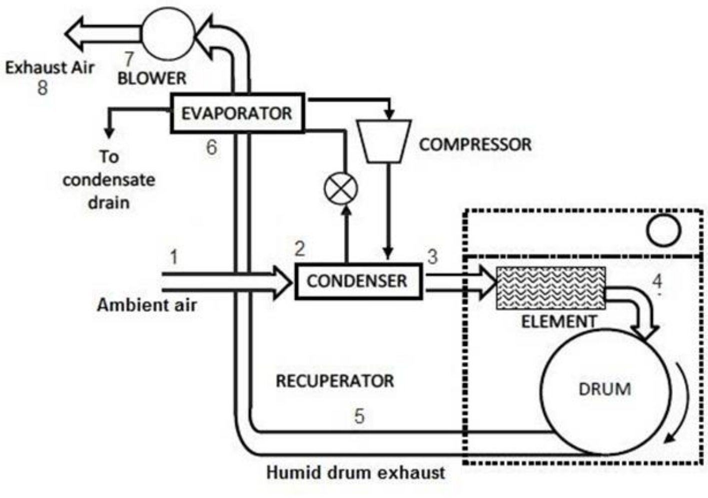


Figure 2: Schematics of Electric Clothes Dryer flow

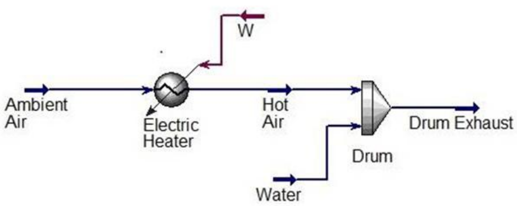


Figure 3 Aspen HYSYS flowsheet of the conventional electric dryer

The conventional drying process is relatively simple, easy and effective, reliable and cheap but wastes a significant amount of energy by venting out the humid air. Ducting to the outdoors to vent out humid air is essential as indoor ducting may cause moisture problem and also damages the interior surfaces of the room, making the atmosphere in the laundry room uncomfortable to stay in.

2. Energy Consumption of Electric Clothes Dryer

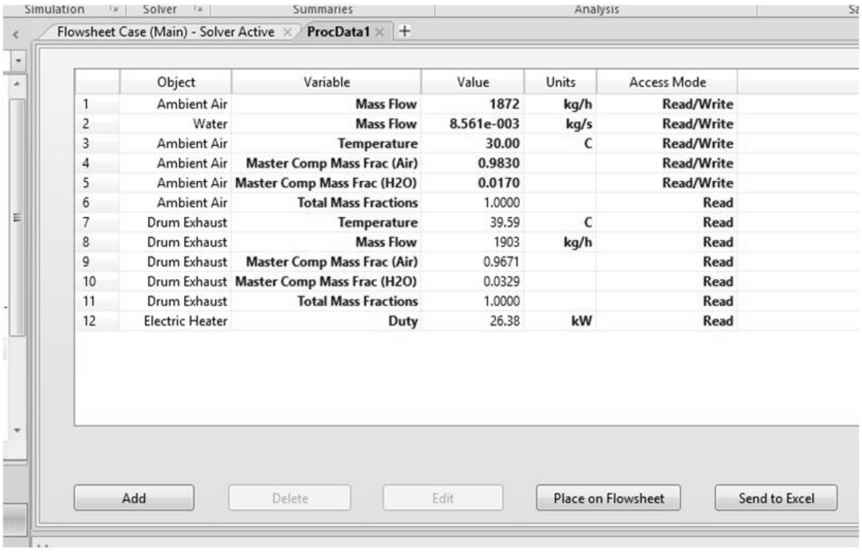
The electric resistance heater consumes most of the energy compared to the fan and other components of the conventional ECD system. The energy efficiency of the dryer is measured by a parameter called Specific Moisture Extraction Rate (SMER), which can be defined as the energy consumed by the dryer per kg of moisture evaporated from the wet clothes for a drying cycle. The conventional electric dryer that is in operation at the site, consumes 28.5 kW (electric heater consumption = 27 kW; motor power = 0.75 kW, blower power consumption= 0.75 kW) of power to evaporate 23.12 kg moisture from wet clothes.

3. Conventional Electric Clothes Dryer Simulation

The clothes drying process that is in operation at Hotel Taj, Bekal is a batch process. The electric clothes dryer operates for 45 minutes for a load of 34 kg dry clothes. A clothes dryer model was developed in Aspen HYSYS, Version 10, a commercial process simulation software package, to reflect the original batch drying process. The Aspen HYSYS flowsheet is shown in figure 3.

Ambient air first passes over the electric heater representing the resistance heating element. The drum unit operation is a mixer in which liquid water added to the air evaporates, reflecting the drying process inside the drum. The exhaust humid air from the drum is then vented out.Ambient air at 30 ºC and 65% relative humidity was heated to a temperature of 80ºC.This hot air is sent into the drum, carries the moisture from the clothes and vents out at 39.59 ºC and 40% relativehumidity.

From figure 4, it can be seen that the Aspen HYSYS simulation model is able to reflect the conventional electric dryer currently in use at the site. The model predicted parametric values as that of the original dryer with an error of 2.29%.



	Object	Variable	Value	Units	Access Mode
1	Ambient Air	Mass Flow	1872	kg/h	Read/Write
2	Water	Mass Flow	8.561e-003	kg/s	Read/Write
3	Ambient Air	Temperature	30.00	C	Read/Write
4	Ambient Air	Master Comp Mass Frac (Air)	0.9830		Read/Write
5	Ambient Air	Master Comp Mass Frac (H2O)	0.0170		Read/Write
6	Ambient Air	Total Mass Fractions	1.0000		Read
7	Drum Exhaust	Temperature	39.59	C	Read
8	Drum Exhaust	Mass Flow	1903	kg/h	Read
9	Drum Exhaust	Master Comp Mass Frac (Air)	0.9671		Read
10	Drum Exhaust	Master Comp Mass Frac (H2O)	0.0329		Read
11	Drum Exhaust	Total Mass Fractions	1.0000		Read
12	Electric Heater	Duty	26.38	kW	Read

Figure 4:Aspen HYSYS simulation results for electric clothes dryer

Energy Efficiency Requirement

Specific moisture extraction rate (SMER) of the conventional ECD is 0.924 kW/kg. In order to achieve higher energy savings, SMER should be less than 0.924 kg/kW. This implies our designed system should consume power less than 28.5 kW for evaporation rate of 30.82 kg water per batch with comparable drying time.

DESIGN AND MODELLING OFHEAT PUMP CLOTHES DRYER

1. PROCESS DESCRIPTION

The heat pump clothes dryer incorporates a vapour compression refrigeration (VCR) cycle for clothes drying application. The evaporator in the VCR cycle condenses the moisture that is present in drum exhaust, thereby recovering the heat from dryer exhaust. The evaporated refrigerant carries this recovered heat to the compressor, gets even more compressed, increasing its temperature and passes through the condenser of the heat pump. The condenser is our heating equipment, which is used for heating the ambient air

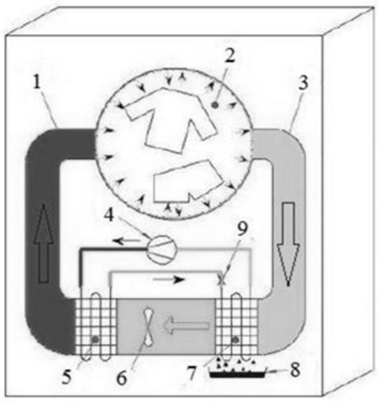


Figure 5: Schematics of Heat Pump Clothes Dryer

I. Refrigerant Selection

A refrigerant is a substance, usually a fluid, used in a heat pump and refrigeration cycle. In most cycles it undergoes phase transitions from a liquid to a gas and back again. Many working fluids have been used for such purposes. Fluorocarbons, especially chlorofluorocarbons, became commonplace in the 20th century, but they are being phased out because of their ozone depletion effects [8]. Other common refrigerants used in various applications are ammonia, sulfur dioxide, and non-halogenated hydrocarbons such as propane.

The choice of the working fluid for heat pump should take into account several considerations like environmental, economic, safety, efficiency, thermodynamic properties. At present, synthetic refrigerants are mostly used for vapour compression refrigeration cycle; hence these dominate the Indian market.

For the proposed system, we need a working fluid that could heat up the air to 80 ºC in the condenser. Therefore, we need condensing temperatures of refrigerant higher than 80 ºC to prevent temperature cross in the condenser.

Moist air from the drum is exhausted at around 38-43 ºC with 70-75 % relative humidity. We aim to condense the moisture from this humid air, so that exhaust heat can be recovered in the evaporator. This suggests us to condense the humid air to its wet bulb temperature so that its moisture will get condensed out and the latent heat of condensation of water from the air could be used for evaporating refrigerant in the evaporator.

Some of the most important properties tobe considered for selecting a refrigerantinclude:

- high critical temperature
- low-pressure range
- non-flammable
- non-toxic,
- low Global Warming Potential

- low Ozone Depletion Potential etc.

The major consideration for refrigerant selection in this work was a low-pressure range of the working fluid, and availability of compressor for the selected working fluid.

From figure 6 above, it can be seen that the pressure ratio for R-123 to reach a temperature of 95 ºC is the least, followed by R-600a and R-134a. Also, R-22 should not be considered for this work as its critical point is lower than what the application demands. Hence, compressors with R-123 as working fluid should be preferred for maximum energy saving.

HEAT PUMP CLOTHES DRYER SIMULATION

The HPCD model includes the electric dryer model. The Aspen HYSYS flowsheet for the simulation of HPCD is shown in figure 7. The heat pump system is represented by the additional unit operations. The evaporator, compressor, condenser, and expansion valve are the typical components of a vapour compression heat pump system used in a refrigerator or air conditioner. The flash tank or water separator is included for the convenience of tracking the amount of water that is condensed from the drum exhaust. The condensate water will need to be collected in a collector and pumped to a drain, but the water pump is not The HPCD model includes the electric dryer model. The Aspen HYSYS flowsheet for the simulation of HPCD is shown in figure 7. The heat pump system is represented by the additional unit operations. The evaporator, compressor, condenser, and expansion valve are the typical components of a vapour compression heat pump system used in a refrigerator or air conditioner. The flash tank or water separator is included for the convenience of tracking the amount of water that is condensed from the drum exhaust. The condensate water will need to be collected in a collector and pumped to a drain, but the water pump is not represented in the model.

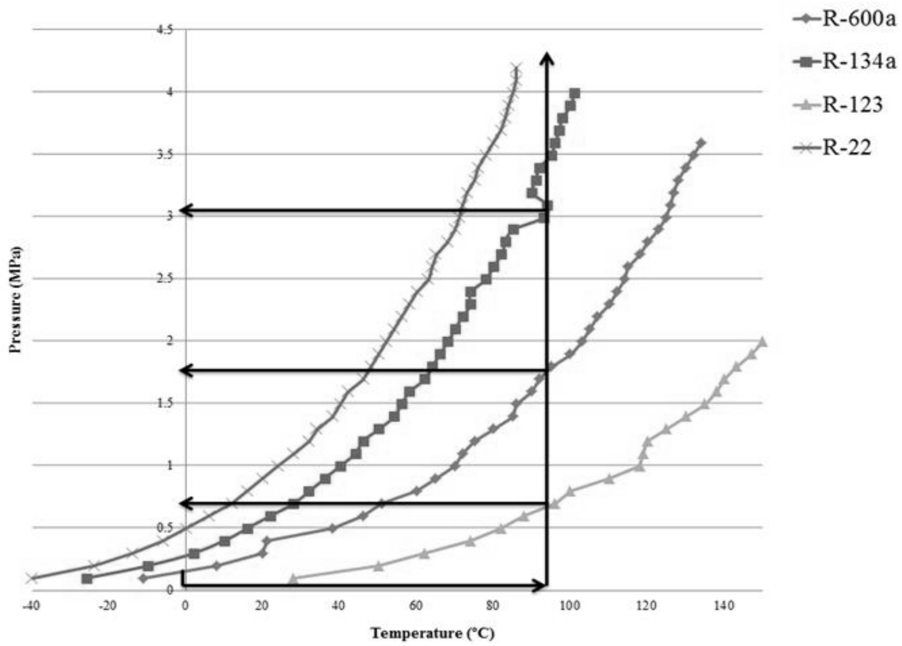


Figure 6: Discharge Pressures of various Refrigerants for same outlet Temperature

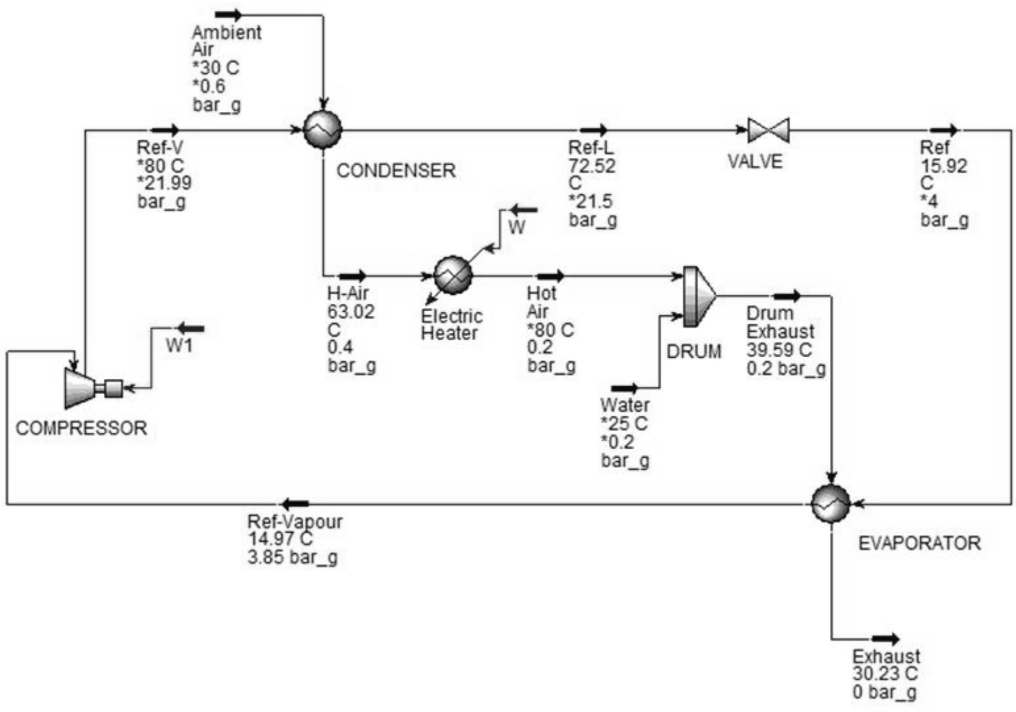


Figure 7: Aspen HYSYS flowsheet of Heat pump Clothes Dryer

During trial and error of designing the system in Aspen HYSYS, and also from the result studied by Prasertsan et al. (1997) [9], it is known that heat pump dryer of open type has better performance. Therefore, heat pump dryer of open type (venting out the exhaust) is developed and recommended for practical use.

The model sets the high and low side pressures of the refrigeration cycle with specifications for the compressor and expansion valve, respectively. The high side pressure is set by specifying the outlet pressure of the compressor. The low side pressure is specified by setting the bubble point of the refrigerant exiting the expansion valve.

Standard off-the-shelf tube-fin heat exchanger coils are anticipated for the evaporator and condenser components.

The steady-state Aspen HYSYS simulation model of HPCD showed that the condenser of the heat pump could heat up ambient air to a temperature of 63.02 ºC. To attain a temperature of 80 ºC, we need to use the electric heater, but with a low rating. The model predicted a resistive heating element of 8.998 kW, and compressor power consumption 4.752 kW. Hence total power consumed by the HPCD dryer is 13.74 kW, which is lesser than the power consumed by ECD.

Figure 8 shows the simulation results and the performance of HPCD model. The simulation model predicts the power consumption of 15.25 kW (electric heater consumption = 8.998 kW; compressor power consumption = 4.752 kW; motor power = 0.75 kW, blower power consumption= 0.75 kW) by HPCD model and SMER of 0.494 kW/kg, which was the design target.

Flowsheet Case (Main) - Solver Active | Shell&Tube Exchanger Design/Rating-CONDENSER | Exchanger Details: CONDENSER-2

	Object	Variable	Value	Units	Access Mode
1	Ambient Air	Mass Flow	0.5200	kg/s	Read/Write
2	Water	Mass Flow	8.561e-003	kg/s	Read/Write
3	Ambient Air	Temperature	30.00	C	Read/Write
4	Ambient Air	Master Comp Mass Frac (Air)	0.9830		Read/Write
5	Ambient Air	Master Comp Mass Frac (H2O)	0.0170		Read/Write
6	Hot Air	Temperature	80.00	C	Read/Write
7	Hot Air	Master Comp Mass Frac (Air)	0.9830		Read
8	Hot Air	Master Comp Mass Frac (H2O)	0.0170		Read
9	Drum Exhaust	Master Comp Mass Frac (Air)	0.9671		Read
10	Drum Exhaust	Master Comp Mass Frac (H2O)	0.0329		Read
11	Electric Heater	Duty	8.998	kW	Read
12	COMPRESSOR	Duty	4.752	kW	Read
13	COMPRESSOR	Delta P	18.50	bar	Read
14	COMPRESSOR	Delta T	66.34	C	Read

Figure 8: Aspen HYSYS simulation results for HPCD model

ENERGY SAVING AND MONETARY BENEFITS

The saving potential of HPCD model was calculated taking April-2018 to April-2019 as the base year for power consumption. Unit electricity rate in Bekal, Kerala is ₹ 8.34/- Simulation result shows the saving potential of HPCD is 37.407%

PAYBACK ANALYSIS

The payback period is the amount of time required for an investment to recover its initial expenditure in terms of profit or savings. Financial quotations of the proposed Heat pump system were collected from vendors and fabricators. The payback period for the proposed heat pump system is 0.852 year or 10.23 months.

Payback period = investment/(savings)

= 2,64,160/(3,09,755)

= 0.852 years

CONCLUSIONS

The proposed heat pump system is technically and economically feasible to be incorporated into the conventional electric dryer. The proposed system offers energy saving of almost 51.75 % over conventional electric dryer with a payback of 0.852 years. The operation cost of HPCD is much lower than ECD. Besides, the safety issue is no longer the troublesome affair using the heat pump system for the clothes dryer. These would be a better approach to convince the proprietor of laundry in Hotel Taj, Bekal to accept heat pump clothes dryer as the main equipment for their use.

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