Exergetic Efficiency Assessment of Key Psychrometric Processes

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Abstract--- The study focused on finding exergy efficiencies for basic psychometric processes, such as heating, heating with humidification, cooling with dehumidification, and Adiabatic mixing. The effect of ambient air temperature, ambient relative humidity, and change in inlet air temperature on exergy efficiency was investigated by using three different definitions given by cengel, wepfer and kangolu. Experimental and theoretical analysis is carried out for all above processes by using three different definitions. This all psychrometric process was carried out on air conditioning experimental set up. The range of parameters covered included atmosphere air temperature (T0=273 - 317k) and relative humidity (RH0 = 50-90%), and mass flow rate of air (0.157kg/s). All three approaches are reasonably correct, the third efficiency is more suitable for psychometric processes. Exergy efficiency of psychrometric process is very low there for energy consumption higher in HVAC System. So this observation also implies that there is great potential for improving the performance of such system.

I. INTRODUCTION

Today's people are like to live in luxury life so in historian environment where weather is very hot in summer and very cold in winter, for living life they innovate a machine which not only controls heat but also the relative humidity. Maintaining a living space or an industrial facility at the desired temperature and humidity requires some process called air-conditioning process & which controls these processes called air conditioning system. Today modern air conditioning systems can heat, cool, humidify, dehumidify, clean & even condition the air to people desires.

It is all known that, air conditioning is extensively based on the use of electrical energy. Air-conditioning systems use up to 50% of the total electricity utilization in the office building. In summer season the demand of electricity in increases due to the extensive use of Heating ventilation and air-conditioning systems.

Study of psychrometric processes is very essential for a better design of heating ventilating air conditioning and refrigerating (HVAC&R) systems. One cannot design a HVAC&R system without having a thorough and true knowledge of psychrometric processes. Psychrometrics is defined as a study of moist air which is a mixture of dry air and moisture. It is then considered to be the science of air and water vapour and deals with the properties of moist air. A thorough understanding of psychrometrics is of great significance, particularly to the HVAC&R community. It plays a crucial role, not only in heating and cooling processes and the comfort of the occupants, but also in building insulation, roofing properties, and the stability, deformation, and fire resistance of building materials. [1]

The first law of thermodynamics deals with the quantity of energy and asserts that energy cannot be created or destroyed. This law merely serves as a necessary tool for the bookkeeping of energy during a process and offers no challenges to the engineer. The second law, however, deals with the quality of energy. More specifically, it is concerned with the degradation of energy during a process, the entropy generation, and the lost opportunities to do work; and it offers plenty of room for improvement. The second law of thermodynamics has proved to be a very powerful tool in the optimization of complex thermodynamic systems.[2]

Due to many efficiency equations given in the different book, there was a strong need to develop exact definitions for key psychrometric processes and compare with what are available in the book. There are two prominent exergy efficiency definitions available in the different book. The first exergy definition is by Cengel and Boles which states that exergy efficiency is a function of the useful work and the maximum possible (reversible) work. The second exergy definition is by Wepfer an, who define the exergy efficiency in terms of product and supply exergies. Although these two exergy efficiency definitions differ from each other but in both the cases an exergy efficiency value cannot exceed 100%. The differences in exergy efficiency definitions result in exergy efficiency values that can vary vastly from one definition to another as also shown in a research paper published by Qureshi and Zubair. Due to such differences and discrepancies in the exergy efficiency definitions, there has been a strong need to study all possible legitimate definitions and compare the results for practical psychrometric applications.[1]

II. LITERATURE REVIEW

The energy needed to process and circulate air in buildings and to control the humidity and temperature has increased continuously during the last decades especially in developing countries. This energy demand was caused by the increase of thermal loads to fulfill occupant comfort demands, climate changes, and architectural trends. Energy and fuel cost savings and air conditioning system optimization are becoming more important in engineering design of psychrometric processes. In the case of an air conditioning system design, generally energy consumption can be minimized by analyzing losses in the system. One tool of analyzing losses is to analyze the exergy efficiency of a system. Exergy or availability of a system represents its maximum work potential at a given state. Therefore, exergy loss is a key factor to evaluate the thermodynamic performance of a system. By doing such an analysis, one can determine the parameters which have greater effect on the system and can be improved.

Kanoglu Mehmet, Ibrahim Dincer, Rosen, Marc A[3] carried out studied on Exergy Analysis of Psychrometric Processes for HVAC&R Applications. Mass, energy, entropy, and exergy balances and exergy efficiency relations are developed for common air-conditioning processes that include simple heating and cooling, heating with humidification, cooling with dehumidification, evaporative cooling, and adiabatic mixing of airstreams.

Bilal .A. Qureshi, Syed M. Zubair[4] carried out study on Application of exergy analysis to various psychrometric processes. In this paper, they discuss thermodynamic analysis of various psychrometric processes using the concept of exergy. A parametric study of each of the processes is carried out to determine the variation of second-law efficiency as a function of mass flow rate, relative humidity and temperature.

T.A.H. Ratlamwala , I. Dincer[5] has worked on Efficiency assessment of key psychrometric processes. The study focuses on defining energy and exergy efficiencies based on three different types of approaches. For each of five key psychrometric processes, such as heating or cooling, heating with humidification, cooling with dehumidification, evaporative cooling, and adiabatic mixing, parametric studies are carried out. Two efficiencies are newly proposed here in this study, and the third efficiency is taken from the literature for comparison purposes. The results show that for heating process exergy efficiency varies from 0.012 to 0.48 with rise in ambient temperature. Increasing ambient temperature results in variation of exergy efficiency from 0.014 to 0.29 for heating with humidification process. For cooling with dehumidification process exergy efficiency varies from 0.002 to 0.73 with rise in ambient temperature. The exergetic efficiency of evaporative cooling process varies from 0.64 to 0.03 with an increase in ambient temperature. For adiabatic mixing process, exergy efficiency varies from 0.65 to 0.94 with rise in ambient temperature.

Ertac Hurdogana, Orhan Buyukalacaa, Arif Hepbaslib, Tuncay Yılmazc[7] perform Exergetic modeling and experimental performance assessment of a novel desiccant cooling system. The exergetic efficiency values for the whole system on the exergetic product/fuel basis are calculated to range from round 32% to 10% at the varying dead (reference) state temperatures of 0–30 ◦C.

Mehmet Kanoglua, Ali Bolattu rkb, Necdet Altuntopc[8] had study Effect of ambient conditions on the first and second law performance of an open desiccant cooling process. An open desiccant cooling process is presented and applied to ventilation and recirculation modes of the system operation. The cooling system consists of a desiccant wheel, a rotary regenerator, two evaporative coolers, and a heating unit. Certain ideal operating characteristics based primarily on the first law of thermodynamics are assumed for each component As an additional study, a non-ideal system operation is considered and it is determined that both the COP and cooling load decrease with increasing ambient temperature and relative humidity, and they approach zero at high values of ambient temperature and humidity.

Mehmet Kanoglu , Melda Ozdinc ,Carpinlioglu, Murtaza Yildirim[9] carried out Energy and exergy analyses of an experimental open-cycle desiccant cooling system. The energy and exergy formulations are applied to the experimental unit using the data collected during a typical operation of the unit Desiccant wheel has the greatest percentage of total exergy destruction with 33.8% followed by the heating system with 31.2%. Rotary regenerator and evaporative coolers account for the remaining exergy destructions.

A. Alahmer , M.A. Omar , A. Mayyas, Shan Dongri[10] has worked on Effect of relative humidity and temperature control on in-cabin thermal comfort state: Thermodynamic and psychrometric analyses. The results show that changing the RH along with dry bulb temperature inside vehicular cabins can improve the air conditioning efficiency by reducing the heat removed while improving the Human comfort sensations as measured by the Predicted Mean Value PMV and the Predicted Percentage Dissatisfied PPD indices.

XIA Xiao-xia, WANG Zhi-qi, XU Shun-sheng[12] investigate study on Exergy Analysis of Energy Consumption for Primary Return Air Conditioning System. Combined with actual example the exergy loss of equipments and the exergy efficiency of system were calculated both in summer and in winter. The results show that the exergy efficiency is very low in two conditions. The exergy loss focuses on air-conditioned room. The exergy loss of reheater has obvious difference between summer and winter. Based on this, the improvement measure was proposed, which can provide guide for the energy conservation of equipments and system.

Majed M. Alhazmy[13]carried out Analysis On The minimum work required for air conditioning process. The air conditioning process for hot and humid climates involves reducing air temperature and humidity. In the present analysis the inlet state is the state of the environment which has also been chosen as the dead state. The final state is the human thermal comfort fixed at 20 °C dry bulb temperature and 60% relative humidity. The general air conditioning process is represented by an equivalent path consisting of an isothermal dehumidification followed by a sensible cooling.

III. EXERGY ANALYSIS

The first exergy definition is by Cengel and Boles which states that exergy efficiency is a function of the useful work and the maximum possible (reversible) work. The second exergy definition is by Wepfer and Dincer and Rosen who define the exergy efficiency in terms of product and supply exergies. The third definition of efficiency is based on the formula provided by Kanoglu et al. The formula provided states that efficiency of the system is defined as the exergy of output stream to the amount of exergy added input energy to the system plus exergy of the input stream. Although these two exergy efficiency definitions differ from each other but in all the cases an exergy efficiency value cannot exceed 100%. The differences in exergy efficiency definitions result in exergy efficiency values that can vary vastly from one definition to another as also shown in a research paper published by Qureshi and Zubair (2007). Due to such differences and discrepancies in the exergy efficiency definitions, there has been a strong need to study all possible legitimate definitions and compare the results for practical psychrometric applications.

A. For Heating Process

The first definition of efficiency states that efficiency is a ratio of change in exergy by exergy input to the system. In this definition change in exergy means the difference between the exergy of the stream entering the system and exergy of the stream leaving the system. Moreover, this definition states that exergy input to this system is heat provided to the system.

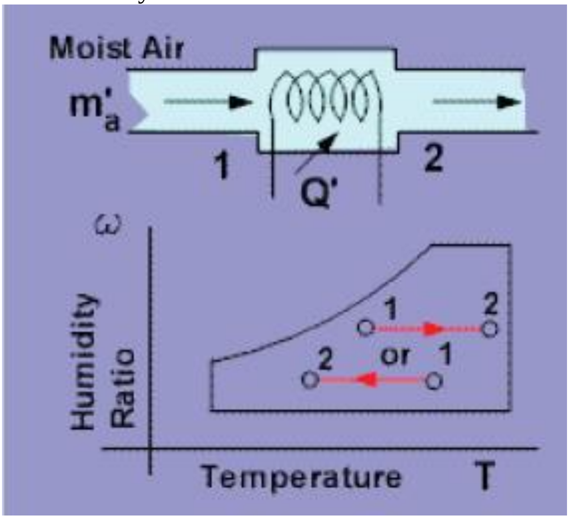

Fig. 1: Schematic And Representation of Heating Process on Psychrometric Chart

The exergy efficiency based on first definition is written as

ηex,1 = (m_a2 ψ_2-m_a1 ψ_1)/(⌊1-T_0/T⌋ Q_in) (1)

The second definition of efficiency is based on the thinking that the required output of the system is the exergy of the stream leaving the system and the required exergy input to the system is the amount of heat added to the system to acquire the desired output. The exergy efficiency based on second definition is expressed as.

ηex,2 = (m_a2 ψ_2)/(⌊1-T_0/T⌋ Q_in) (2)

The third definition of efficiency is based on the formula provided by Kanoglu et al. The formula provided states that efficiency of the system is defined as the exergy of output stream to the amount of heat added to the system plus exergy of the input stream. The exergy efficiency based on third definition is calculated using

ηex,3 = (m_a2 ψ_2)/(⌊1-T_0/T⌋ Q_in+m_a1 ψ_1) (3)

Table 1 Mass Balance, Energy Balance, Exergy Balance of Simple Heating Process

Mass Balance	$m_{a1} = m_{a2}$, $m_{w1} = m_{w2}$
Energy Balance	$Q_{in} + m_{a1}h_1 = m_{a2}h_2$
Exergy Balance	Ψ1 =(h1 –h0) – T0(s1 – s0),
	$\Psi_2 =(h_2 - h_0) - T_0(s_2 - s_0)$
	Exdest = T0Sgen
	$= T_0 (m_{a2}s_2 - m_{a1}s_1 - \frac{Q_{in}}{T})$
	Qin(1- T_0/T) + ma1ψ1 - ma2ψ2 - Exdest = 0

B. For Heating With Humidification Process

The first definition of efficiency is based on the thinking that the desired output of the system is the amount of exergy gained by the system and the required input to the system is the exergies added to the system via heat and hot water. The desired output is found by subtracting exergy of the stream leaving the system to the exergy of the stream entering the system. While, the required input to the system is found by adding the heat added to the system and exergy carried by the hot water entering the system. The exergy efficiency based on first definition is expressed as

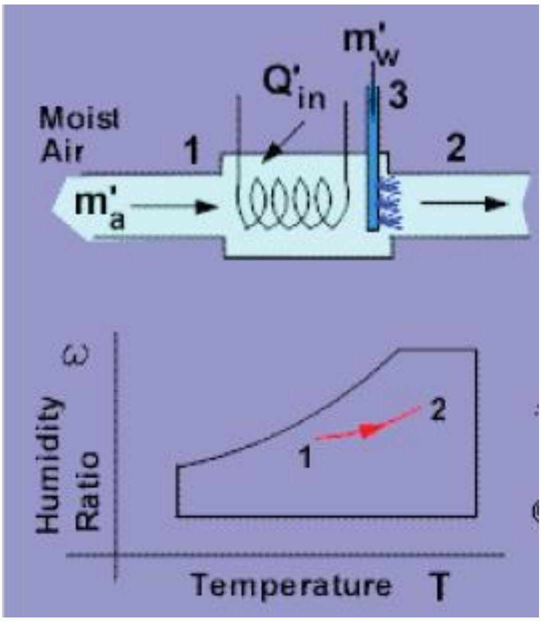

Fig. 2: Schematic And Representation of Heating With Humidification Process on Psychrometric Chart

ηex,1 = (m_a3 ψ_3-m_a1 ψ_1)/(⌊1-T_0/T⌋ Q_in+m_w ψ_w

The second definition of the efficiency is based on the opinion that the desired output of the system is the amount of exergy carried by the exiting stream and the required input is the amount of exergy added to the system through heat addition and stream of hot water. The exergy efficiency based on second definition is found using

ηex,2 = (m_a3 ψ_3)/(⌊1-T_0/T⌋ Q_in+m_w ψ_w) (5)

The third definition is based on the formula provided by Kanoglu et al. (2007b) which states that the desired output of the system is the exergy carried by the exiting stream and required input is the heat added to the system, exergy carried by the inlet stream and exergy carried by the hot water. The exergy efficiency based on third definition is defined as

ηex,3 = (m_a3 ψ_3)/(⌊1-T_0/T⌋ Q_in+m_a1 ψ_1 +m_w ψ_w) (6)

Table 2 Mass Balance, Energy Balance, Exergy Balance of Simple Heating With Humidification Process

Mass Balance	ma1 = ma2 = ma3, mw1 = mw2
	mw2 +mw =mw3,ma2w2 + mw = ma3w3
Energy Balance	Qin + ma1h1 +mwhw = ma3h3
Exergy Balance	Ψ1 =(h1 –h0) – T0(s1 – s0),
	Ψ2 =(h2 –h0) – T0(s2 – s0)
	Ψ3 =(h3 –h0) – T0(s3 – s0),
	Ψw =(hw –hw,0) – T0(sw – sw,0)
	Qin(1- T_0/T) + ma1ψ1 - ma2ψ2 - Exdest = 0
	ma2ψ2 + mwψw – ma3ψ3 - Exdest = 0
	Qin(1- T_0/T) + ma1ψ1 + mwψw - ma3ψ3 - Exdest = 0
	Exdest = T0Sgen = T0 (ma3s3 – ma1s1- mwsw - Q_in/T)

C. For Cooling With Dehumidification Procees.

In this process, the exergetic efficiencies based on first definition are defined as the ratio of heat released by the system and exergy carried by the exiting stream to the exergy carried out by the incoming stream.

The exergy efficiency based on first definition is expressed as

ηex,1 = (〖[1-T_0/T] Q_out+m〗 _a2 ψ_2)/(m_a1 ψ_1)

The second definition of efficiency is based on the idea that the efficiency of the system should be defined as the ratio of exergy carried by the exiting stream to the heat rejected by the system. This definition believed that the purpose of the system is to cool the incoming stream therefore; heat rejected by the system is the actual input to the system. The exergy efficiency based on second definition is found using

η ex,2 = (m_a2 ψ_2)/([1-T_0/T] Q_out) (8)

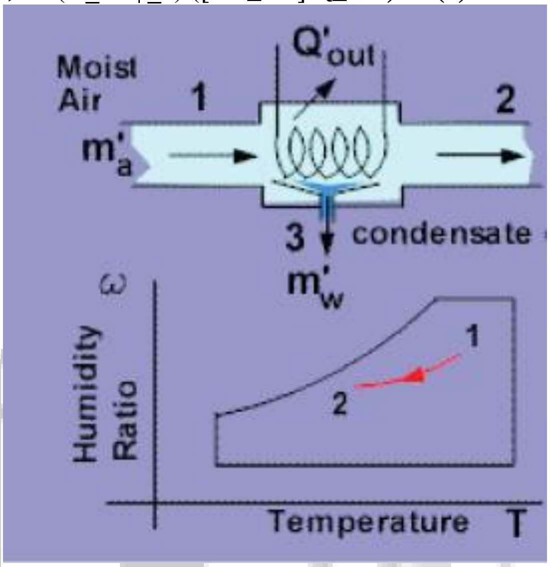

Fig. 3: Schematic And Representation of Cooling With Dehumidification Process on Psychrometric Chart

The third definition of the efficiency is taken from Kanoglu et al. (2007b) and it states that the desired output of the system is the addition of heat released by the system, exergy carried by the exiting stream, and exergy carried by the water.

However, required input is the exergy carried by the entering stream. The exergy efficiency based on third definition is calculated using

ηex,3 = (〖[1-T_0/T] Q_out+m〗 _a2 ψ_2+m_w ψ_w)/(m_a1 ψ_1) (9)

Table 3 Mass Balance, Energy Balance, Exergy Balance of Simple Cooling With Dehumidification Process

Mass Balance	ma1 = ma2
	mw2 +mw =mw1,ma2w2 + mw = ma1w1
Energy Balance	ma1h1 = Qout + ma2h2 + mwhw
Exergy Balance	Ψ1 =(h1 –h0) – T0(s1 – s0),
	Ψ2 =(h2 –h0) – T0(s2 – s0)
	Ψw =(hw –hw,0) – T0(sw – sw,0)
	ma1ψ1 - Qout(1- T_0/T) - ma2ψ2 - mwψw - Exdest = 0
	Exdest = T0Sgen = T0 (ma2s2 + mwsw + Q_out/T -ma1s1)

D. *For Adiabatic Mixing Process.*

For this process only one efficiency definition is possible. The efficiency definition of this process states that the efficiency of the system is the ratio of exergy carried by the exiting stream to the exergy carried by two entering streams. The exergy efficiency is expressed as

ηex,1 = (m_a3 ψ_3)/(m_a1 ψ_1+m_a2 ψ_2) (10)

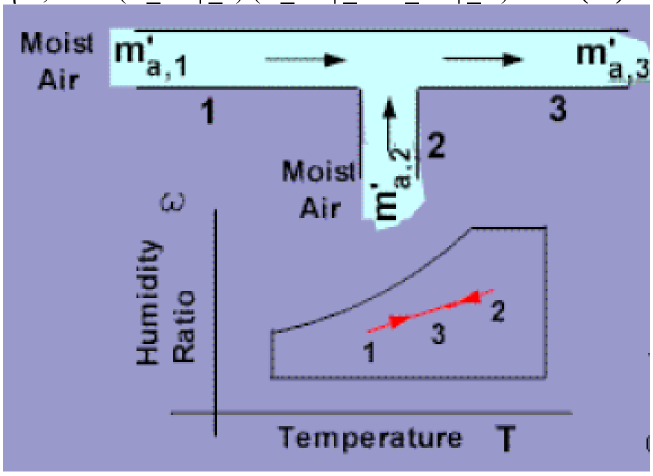

Fig. 4: Schematic And Representation of Adibatic Mixing Process on Psychrometric Chart

Table 4.Mass Balance, Energy Balance, Exergy Balance of Simple Mixing Process

Mass Balance	ma1 + ma2 = ma3
	mw1 +mw2 =mw3,ma1w1 + ma2w2 = ma3w3
Energy Balance	ma1h1+ ma2h2 = ma3h3
Exergy Balance	Ψ1 =(h1 –h0) – T0(s1 – s0),
	Ψ2 =(h2 –h0) – T0(s2 – s0)
	Ψ3 =(h3 –h0) – T0(s3 – s0)
	ma1ψ1 + ma2ψ2 – ma3ψ3 - Exdest = 0
	Exdest = T0Sgen = T0 (ma3s3 - ma1s1 - ma2s2)

IV. RESULT AND DISSCUSION

Exergy efficiency for heating, heating with humidification, cooling and dehumidification, adiabatic mixing process are plotted by changing the Ambient temperature, Ambient relative humidity, inlet temperature of air by using theoretical and experimental data.

A. *Heating process:*

Fig.5. show how exergy efficiencies are varying with increasing ambient temperature of the air. It is observed that when inlet temperature is varied from 270 K to 290 K all three exergy efficiencies reduce as seen in Fig.5.1. All three exergetic efficiencies are found to be varying from 0.4202 to 0.001404, 0.7083 to 0.1252, 0.5499 to 0.1114, respectively while having ambient relative humidity fixed at 90%.

Fig.6. shows how exergetic efficiencies respond to change in ambient relative humidity. Exergetic efficiency based on first definition shows a constant value of 0.1952, however, exergetic efficiency based on second and third definitions increase with increase in the ambient relative humidity.

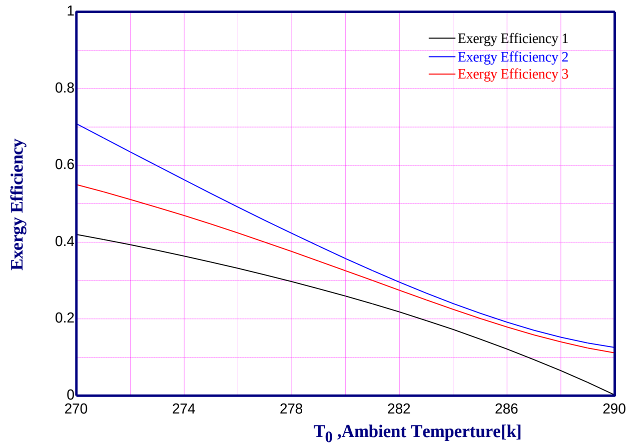

Fig. 5: Exergy Efficiency vs. Ambient Temperature of Air for Heating Process

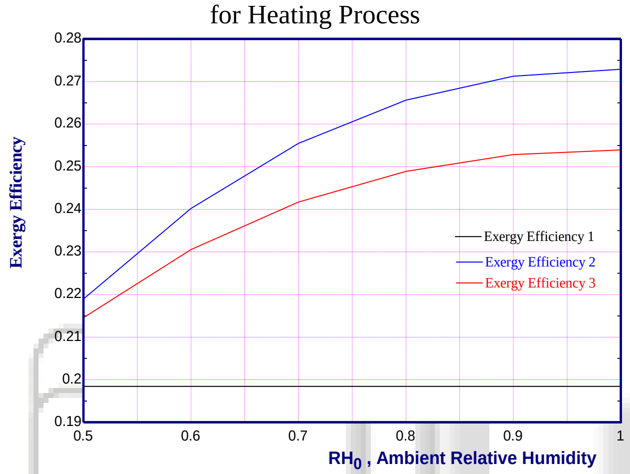

Fig. 6: Exergy Efficiency vs. Ambient relative humidity of Air for Heating Process

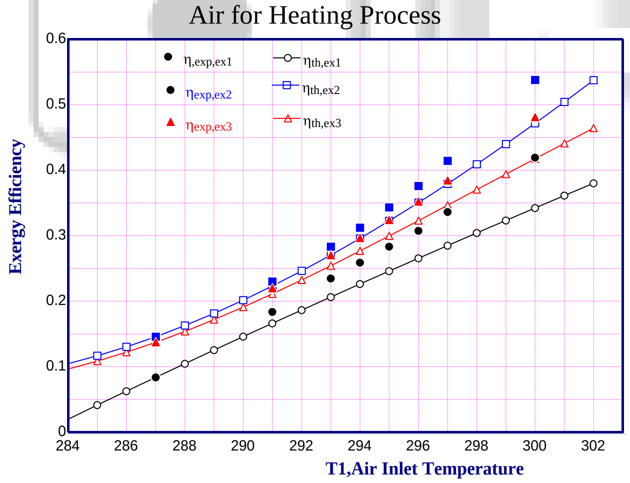

Fig. 7: Exergy Efficiency vs. Inlet Temperature of Air for Heating Process

The exergetic efficiencies based on second and third definition increase from 0.2131 to 0.269, and 0.2094 to 0.2505, respectively with increase in ambient relative humidity from 50% to 90%.

Fig.7.shows the variation in exergy efficiencies based on three definitions with increases in inlet temperature. All three exergy efficiencies is increase with increase in inlet temperature of air. All three exergetic efficiencies vary from 0.01975 to 0.3801, 0.1045 to 0.5374, 0.0861 to 0.4644, respectively with increase in inlet temperature. These variations in efficiencies show that changes in operating conditions have considerable effect on the performance of the heating process. Experimental exergetic efficiencies are also near to theoretical exergy efficiency

B. Heating with humidification.

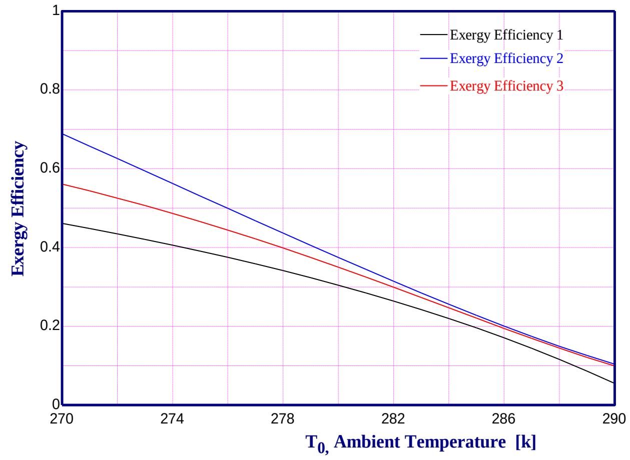

Fig. 8: Exergy Efficiency vs. Ambient Temperature of Air for Heating and humidification Process

The second psychrometric process studied is heating with humidification.figs.8 to 10 shows how exergy efficiencies vary with variation in operating conditions. Fig.8. shows that exergetic efficiencies based on all three definitions are reduces with increase in the ambient temperature. These three exergetic efficiencies are found to be varying from 0.4613 to 0.05475, 0.6887 to 0.1038, and 0.5611 to 0.09899, respectively with increase in ambient temperature from 270 K to 290 K.

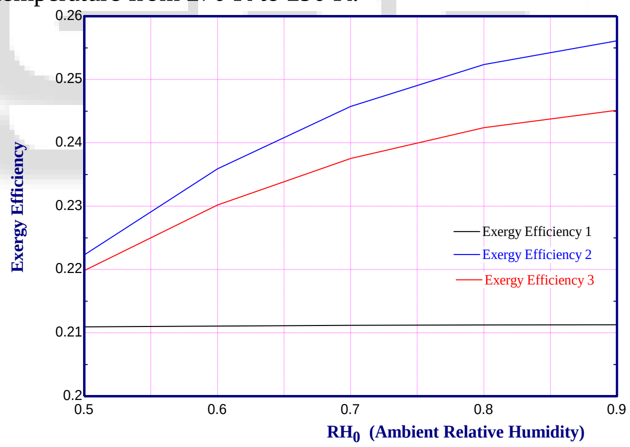

Fig. 9: Exergy Efficiency vs. Ambient relative humidity of Air for Heating and humidification Process

The effect of ambient relative humidity on the exergetic performance of the system is shown in Fig.9. Exergetic efficiencies based on second and third definitions increase from 0.2223 to 0.2561, and 0.2198 to 0.2451, respectively with increase in the ambient relative humidity from 50% to 90%. However, exergetic efficiency based on first definition showed no change to increase in ambient humidity ration and its value is found to be 0.2109.

Fig.10. illustrates the variation in theoretical and experimental exergetic efficiencies with increase in inlet temperature. All three exergy efficiencies is increase with increase in inlet temperature of air. All three exergetic efficiencies vary from 0.01423 to 0.3964, 0.06725 to 0.4538, 0.0727 to 0.5117, respectively with increase in inlet temperature.

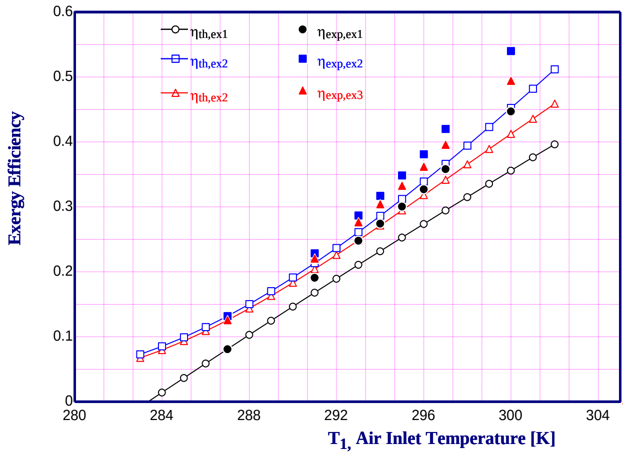

Fig. 10: Exergy Efficiency vs. Inlet Temperature of Air for Heating and humidification Process

Experimental exergetic efficiencies are also near to theoretical exergy efficiency. These changes in efficiencies with changes in operating parameters are observed because variation in operating parameters results in variation in rate of exergy destructed by the system. Each of the three definitions have different way of expressing efficiencies and therefore, the amount of exergy destruction based on all three of the definitions vary for a giving condition.

C. *Cooling and dehumidification.*

The third process studied is cooling with dehumidification. The effects of different operating parameters on the exergy efficiencies of the process are displayed in fig.11 to 13.

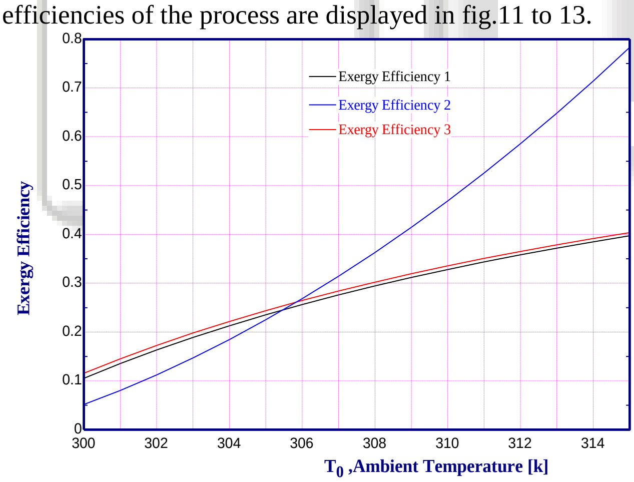

Fig. 11: Exergy Efficiency vs. Ambient Temperature of Air for cooling and dehumidification Process

Fig.11. shows change in exergy efficiencies based on three definitions varies with increase in the ambient temperature. All three efficiencies increases with increases the ambient temperature of air. First and third definition of exergetic efficiencies give similar values and they vary from 0.1052 to 0.3972 and 0.1156 to 0.4037, respectively with increase in ambient temperature from 300 K to 315 K. However, exergetic efficiency based on second definition increases from 0.05137 to 0.783 with increase in the ambient temperature.

Increase in ambient relative humidity affects the performance of the system in a positive manner based on all three exergetic efficiencies definition as displayed in Fig.12. These efficiencies are seen to be increasing from 0.523 to 0.5238, 0.6069 to 0.7695, and 0.5293 to 0.5301, respectively with increase in ambient relative humidity from 50% to 90%, respectively.

Fig.13. explains how variation in inlet temperature affects the performance of the system exergetically based on three different definitions of exergetic efficiencies theoretical and experimental.

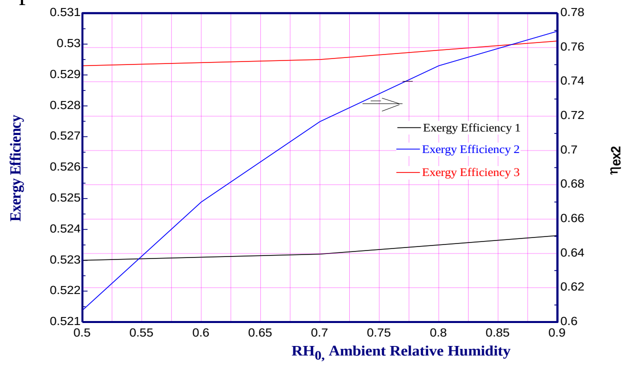

Fig. 12: Exergy Efficiency vs. Ambient relative humidity of Air for cooling and dehumidification Process

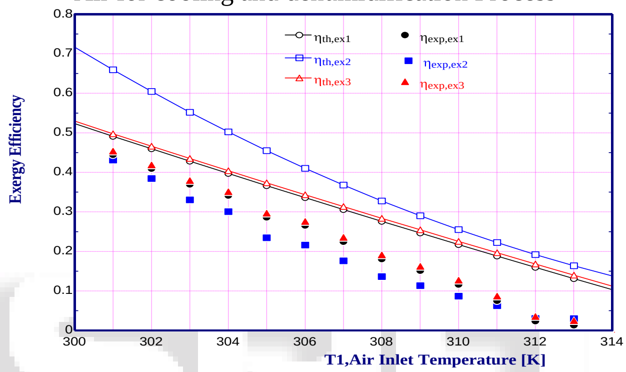

Fig. 13: Exergy Efficiency vs. Inlet Temperature of Air for cooling and dehumidification Process

Exergetic efficiencies based on all three definitions are found to be decreasing from 0.5232 to 0.103, 0.7168 to 0.1377, and 0.5295 to 0.1119, respectively with increase in the inlet temperature from 300 K to 314 K. The variation in exergetic efficiencies also indicates the variation in the rate of exergy destroyed in the system.

D. *Adiabatic mixing*

The last basic psychometric process is adiabatic mixing. In this process all different schools of thoughts agree to one exergetic efficiencies definition.Fig.14.shows how exergetic efficiencies change with changes in ambient temperature.

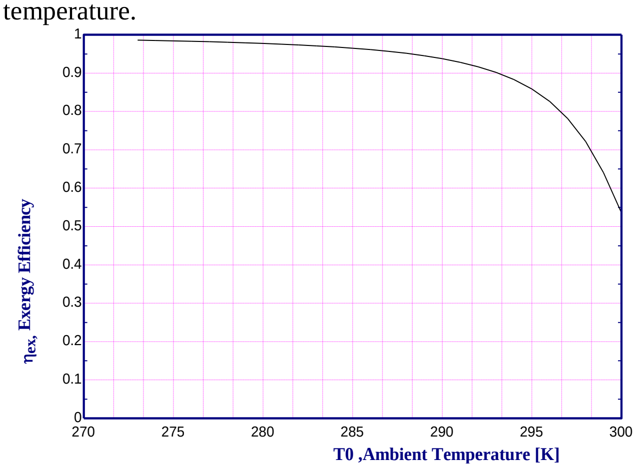

Fig. 14: Exergy Efficiency vs. Ambient Temperature of Air for adiabatic mixing Process

The exergetic efficiency decreases from 0.986 to 0.5358 with increase in ambient temperature from 273 K to 300 K. The exergy destruction during the mixing process increases with increase in ambient temperature and as a result lesser exergetic efficiency of the process is obtained.

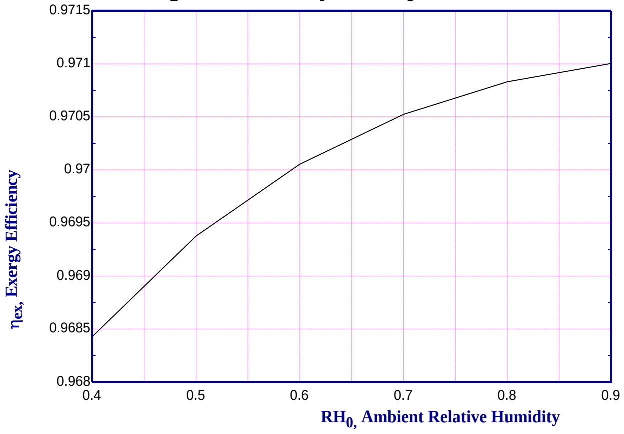

Fig. 15: Exergy Efficiency vs. Ambient relative humidity of Air for adiabatic mixing Process

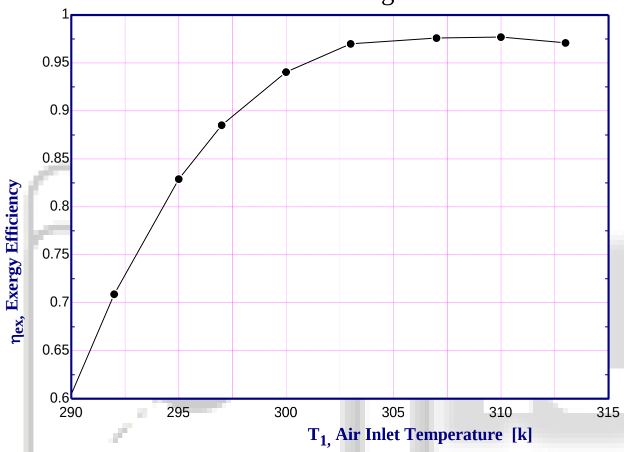

Fig. 16: Exergy Efficiency vs. air inlet temperature of Air for adiabatic mixing Process

Fig.15. show the effect of ambient relative humidity on the performance of exergy efficiency. These efficiencies are seen to be increasing from 0.9684 to 0.971 with increase in ambient relative humidity from 50% to 90%, respectively.

Fig.16. explains how variation in inlet temperature affects the performance of the system exergetic efficiencies based on experimental data. Exergetic efficiency is found to be increase from 0.6047 to 0.971 with increase in the inlet temperature from 290 K to 313 K. The exergy destruction during the mixing process reduces with increase in air inlet temperature.

V. CONCULASION

In this research work we study three exergy efficiency definitions for four psychrometric processes. Effect of change in ambient air temperatures, change in relative humidity and change in inlet air temperature on exergy efficiency is found out. Exergy efficiency of heating and heating with humidification process is reduces with change in ambient temperature by all three definitions. For cooling and dehumidification exergy efficiency is increase with increase in ambient temperature by all three definitions. And for adiabatic mixing it is reduced.

Increase in relative humidity of the incoming air stream increase exergy efficiency for the all psychrometric processes by all three definitions.

Increase in inlet air temperature increases exergy efficiency of heating and heating with humidification and reduce for cooling and dehumidification process.

All three approaches are reasonably correct, the third efficiency is more suitable for psychometric processes.

Exergy efficiency of psychrometric process is very low there for energy consumption higher in HVAC System. So this observation also implies that there is great potential for improving the performance of such system

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