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An Approach to Make a Cost-Efficient, Lightweight and Eco-Friendly Heat and Energy Recovery Ventilator (HERV)

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Abstract- *Nowadays, throughout the whole world household air-conditioning is a matter of importance. As the air-conditioning system being costly, a number of people cannot afford it easily. In this paper, it is tried to find out if it is possible to make an air-conditioning system in a short budget. An existing design of a heat recovery ventilator has been taken and modified with new ideas. The designed heat exchanger, which is also an HVAC system gives up outgoing warm airs' heat to incoming cold air in winter. During summer cool air blows through the heat exchanger stealing heat from incoming hot air and makes it cool. The main difference between an existing HERV and this one is the structural design. No gasket has been used. On the basis of cost and thermal conductivity, the material of the heat transferring plates is chosen whereas the material of the outside frames was selected according to its' cost, being lightweight and ease of manufacturing. Geometrical data of plate and channel have been assumed. The number of required heat-conducting plates is determined with the help of spreadsheet program and the general physical model is made then. Experimentally the device is capable of changing around 6°C temperature with less power consumption by a manufacturing cost of USD 34.00 only.*

Keywords: HERV, HVAC, PFHX, climate, eco-friendly, cost-efficient.

1. INTRODUCTION

The worlds' population and economic growth are expanding at a high rate day by day. As a result, number of both residential and commercial buildings is increasing which causes more energy consumption and spread of heating, ventilation and air-conditioning (HVAC) system [1]. An ideal house should contain the properties of circulating fresh air, bringing in oxygen, removing odors and reducing the risk of mildews [2]. It is needed to hold cool air inside during summer and keep it out during winter, then it will called Energy-Efficient. Heat recovery is that system which is increasingly used to reduce the heating and cooling demands of buildings.
By recovering the residual heat in the exhaust gas, the fresh air introduced into the air conditioning system is pre-heated (pre-cooled), and the fresh air enthalpy is increased (reduced) before the fresh air enters the room or the air cooler of the air conditioning unit performs heat and moisture treatment [3]. Unintentional airflows reduce the performance of ventilation efficiency [4]. For this reason Heat recovery is being used widely in building applications in high latitude countries [5] [6]. Heat or energy recovery device removes in terms of extracts, recovers heat or mass from one stream of air and transfers that to another stream of air [7]. Typical heat recovery system is shown in Fig.1 which is installed in building ventilation system contains ducts, blower fans, heat exchanger core.

Based on structure there are many types of heat recovery system, such as fixed plate (membrane-based), rotary wheel, heat pipe etc. The main idea is to exchange the air between inside and outside without losing the expected temperature range inside the room. In a fixed plate heat recovery system which is basically a PFHX is manufactured by thin plates which are stacked together or separated in different solid panel. Fig. 2(a) shows a cross-flow mechanism of heat exchanging which is being used in the HERV available in the market [9]. Fig. 2(b) shows desired heat-exchanging method, which is simpler in understanding, more saver in electricity consumption and cheaper in manufacturing. The main difference is in

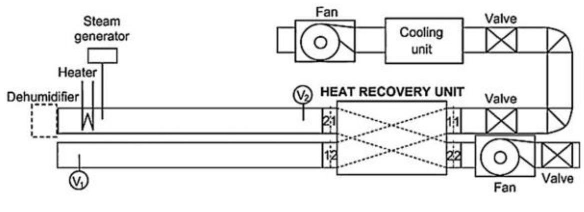
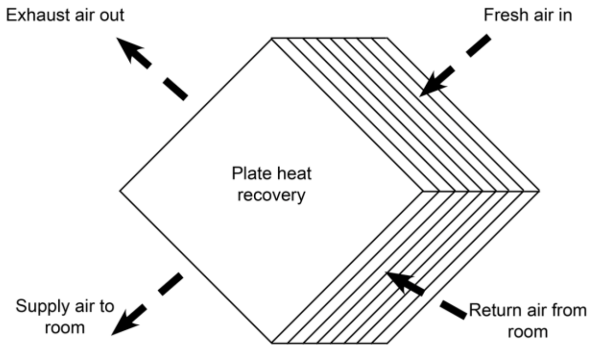
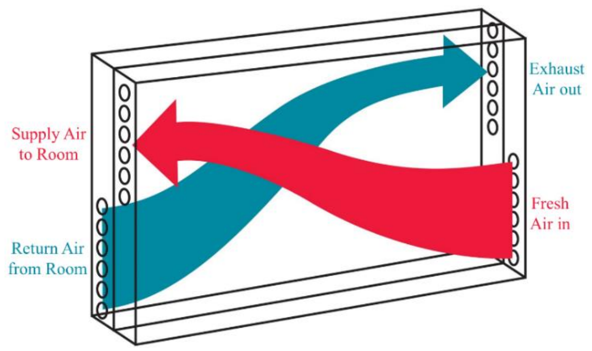


Fig.1: Experimental facility layout of heat recovery system. [8]

the structural design of the heat exchanging-core. Here no fluid is mixing, just the heat is exchanged with each other by the plates and no complexity in structure. A study to investigate the effect of weather on the efficiency, performance and power consumption of the plate-type heat recovery ventilator has been performed by Han et al. [10]. It is found that the efficiency in winter



(a)



(b)

Fig.2: Mechanism of (a) Available membrane based Fixed-plate heat recovery [9] and (b) Designed HERV

season is higher than in summer due to internal heat generation of fan. In Bangladesh the temperature in winter is low but in summer it is very high. So, it is necessary to trap the heat inside the room in winter and vice versa in summer. But if the heat is trapped inside room in winter and the opposite in summer by air-sealing the room, then the trapped air inside the room will be polluted for having high CO_2 density very shortly. So, circulating the air inside the room and the outside must be ensured. For this purpose ventilation system is required. But the HERVs existing in the market cost around USD 200.00 [11] and those consume higher electricity. The aim is to bring a developed solution of this problem.

2. METHODOLOGY

Initially a 3d drawing has been made in Solid Works platform. With the engineering concept finally an HERV is manufactured after several calculations with the help of Microsoft Excel.

2.1 Concerned Formulas

The formulas for heat transfer and Plate Frame Heat Exchanger have been taken from [12] [13].

$$Q = \left[\dot{m}C_p(T_i - T_o)\right]_{hot} = \left[\dot{m}C_p(T_o - T_i)\right]_{cold} \quad (1)$$

$$LMTD = \frac{\left(T_{i,hot} - T_{o,cold}\right) - \left(T_{o,hot} - T_{i,cold}\right)}{ln\left(\frac{T_{i,hot} - T_{o,cold}}{T_{o,hot} - T_{i,cold}}\right)} \quad (2)$$

$$LMTD_C = F_t \times LMTD \quad (3)$$

$$NTU = \frac{|T_i - T_o|}{LMTD} \quad (4)$$

$$Q = U_o A F_t (LMTD) \quad (5)$$

$$A_p = LW \quad (6)$$

$$N_p = \frac{A}{A_p} \quad (7)$$

$$N_c = N_p + 1 \quad (8)$$

$$A_c = sW \quad (9)$$

$$D_e = 2s \quad (10)$$

$$\dot{m} = (\rho A_c u) N_c \quad (11)$$

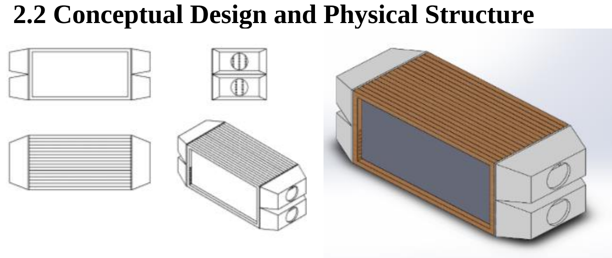
$$Re = \frac{\rho u D_e}{\mu} \quad (12)$$

$$Nu = \frac{hD_e}{K} = 0.26 \times (R_e)^{0.65} (P_r)^{0.4} \quad (13)$$

$$\frac{1}{UA} = \frac{1}{h_{hot}A} + \frac{1}{h_{cold}A} + \frac{L}{KA} + F \quad (14)$$

$$e = \left|\frac{U_o - U}{U_o}\right| \times 100\% \quad (15)$$

2.2 Conceptual Design and Physical Structure



(a)

(b)

(c)

(d)

(e)

(f)

(g)

Fig. 3:.(a) Assembly of the parts (b) Sectional Views of designed HERV (c) Making the frames with drilled wood (d) Joining the frames after attaching aluminium sheets in the gaps between every two of the them (e) Attaching the hoods after air-sealing (f) Mounting the fans (g) Final appearance

2.3 Design Calculation

The calculation based on the conceptual design is done by several iterations and assumptions of Uo through Microsoft Excel. The properties of aluminum, wood and air for several temperatures have been taken from IFI/Plenum Data Corporation [14] [15]. The overall heat transfer coefficient (Uo) has been assumed 15 W/m2°C according to optimum error and overall cost and using the concerned formulas. During calculation temperatures of outside, room and incoming air have been taken 16°C, 26°C and 22°C respectively. Determined outgoing temperature is 20.31°C, when the LMTD is 4.15°C.

Table 1. Collected and determined properties of hot air, cold air and aluminium at corrected LMTD

Properties	Hot Air	Cold Air	Aluminum
K (W/m°C)	0.0245	0.0257	230
ρ (kg/m^3)	1.27	1.2045	
μ (Pa.s)	1.74 x 10^{-5}	1.82 x 10^{-5}	
Pr	0.7114	0.713	
C_p (J/kg°C)	1005	1005	
ṁ (kg/s)	0.0254	0.02409	
u (m/s)	0.694	0.694	
Re	1.29 x 10^3	1.17 x 10^3	
Nu	23.818	22.370	
h	22.975	22.635	

Aluminum plates are used whose length, width and thickness are 57.1 cm, 26.7 cm and 0.3 mm respectively. The spacing between two plates is 12.7 mm. The factors F_t and F are 0.96 and 5000 W/m2°C respectively [16]. The total heat transfer is calculated 145.26 Watts. Number of required plates is 16 and channels is 17. U is determined 11.35 W/m2°C which gives 24.33% error.

2.4 Materials

Materials of optimum cost with better characteristics are chosen here. The frames are made of cheap solid wood which are insulated. Particle wood is used to make the hoods for the fans. Both woods are light in weight. Every unwanted gap is tightened by silicone adhesive against the air. 300 mL of OCI Orgasil 103 is used which is an 80% acetic silicone sealant with high performance adhesion which cures with atmospheric moisture to form a rubberlike seal. Aluminum sheets with 0.3 mm thickness have been used as the heat transfer media. Sheets of copper can be used which is more conductive in nature than aluminum, but also more costly. Another cheap and available option can be Stainless Steel Sheet. But the conductivity will be compromised at a great extent by using this. Four cooling fans of 120x120x38 mm have been used. All the parts are fastened with screws.

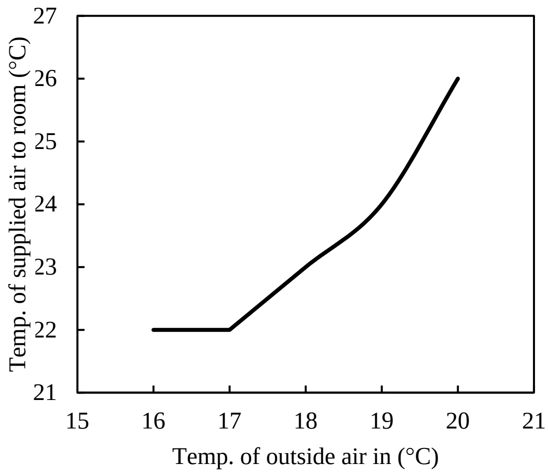
3. RESULT AND DISCUSSION

The newly manufactured HERV has been used in different times of day in different seasons. Obtained results are given below

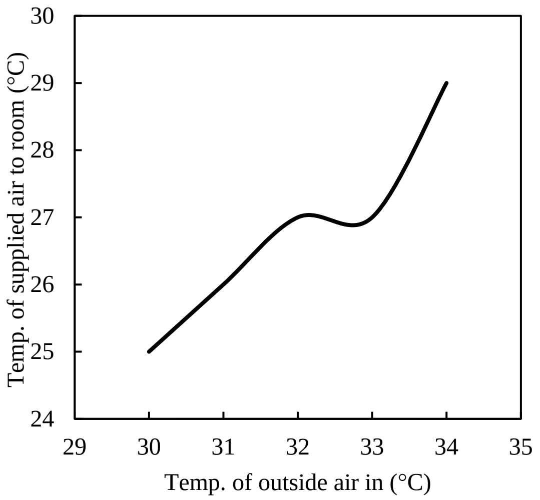
Table 2. Results of performance test with corresponding date

Test No.	Date	Outside Air In	Supply Air to Room	Temp. Change
01	Jan 16	19°C	24°C	5°C
02	Jan 16	20°C	26°C	6°C
03	Jan 19	16°C	22°C	6°C
04	Jan 19	18°C	23°C	5°C
05	Jan 20	17°C	22°C	5°C
06	Jan 20	17°C	22°C	5°C
07	Mar 20	32°C	27°C	5°C
08	Mar 20	34°C	29°C	5°C
09	Mar 23	31°C	26°C	5°C
10	Mar 23	30°C	25°C	5°C
11	Mar 24	33°C	27°C	6°C
12	Mar 24	34°C	29°C	5°C

The study shown in Fig.4 inherits that the temperature of supplied air to room in both winter and summer differs 5~6°C from the outside temperature and maintains almost linear relationship. The deflection in linearity are caused due to the internal heat generation by cooling fans which could not be avoided. Increasing the number of plates increases the efficiency. But the number of plates is found to be directly proportional with the cost while making a single HERV. That is why a Cost-Efficiency graph has been plotted based on theory which is shown in Fig. 5(a) and optimum plate number is chosen for construction across a minimum cost. It is observed that

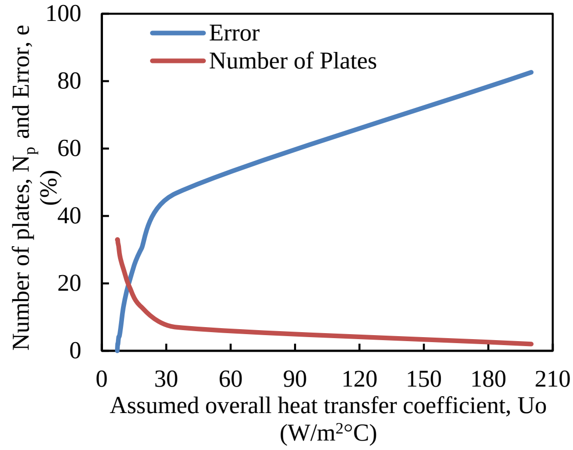


(a)

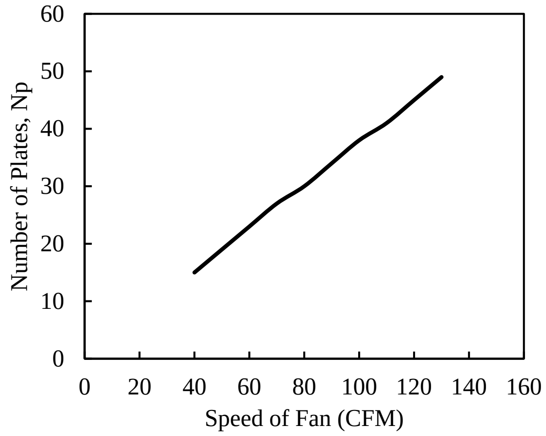


(b)

Fig.4: Relation between the temperature of outside air in and supplied air to room during (a) winter and (b) summer



(a)



(b)

Fig. 5: (a) Cost-Efficiency Chart (Error and Number of Plates vs Uo graph) and (b) Required number of plates according to increase of the speed of fans (Number of plates vs Speed of Fan graph)

the distance between two curves increase drastically after Uo of 30 W/m2°C. Because the experimental value of overall heat transfer coefficient for air-air heat exchangers varies from 10 to 40 W/m2°C [11]. Fig. 5(b) shows that increasing the speed of fan increases the number of required plates linearly as well as the manufacturing cost from equation (8) and (11). A value of U was assumed in 'Design Calculation' with 24.33% error. If U was assumed 7.22 W/m2°C instead of 11.35 W/m2°C, there would be no error but the number of required plates would increase to 33. Double weight and manufacturing cost would increase efficiency but it would collide with our purpose of study. The weight of this HERV is about 5.5 kg which is lighter than the commercial ventilators weighing around 20 kg. All the components are eco-friendly and does not cause any harm to nature atmosphere. It can run well at a power of 40 Watts, whether the commercial HERVs consume about 80 Watts of electricity power. So 50% electricity consumption can be reduced through this. The costs of the 2.6 Kg aluminum, cooling fans, wood and adhesive are USD 10, 12, 7 and 3 respectively. Total cost for this HERV is only BDT 2800.00 or USD 34.00.

4. CONCLUSION

With the pace of the new competitive world, technologies are being modified and consumers are going for the device of optimum price, safety and running cost. It is emphasized that HVAC system is not economically available till now for the mass people in Bangladesh. The aim of the study is to solve this real life problem and reach people with a modified heat and energy recovery ventilator with specified advantages. The manufactured ventilator is basically a Plate frame heat exchanger. The 83% cheaper, 72% lighter, 50% less electricity consumer and pollute-free HERV is surely a positive approach to the highly expected solution.

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6. NOMENCLATURE

Symbol	Meaning	Unit
A	Effective area required	m^2
A_c	Channel Area	m^2
A_p	Plate Area	m^2
C_p	Heat capacity	J/kg°C
D_e	Hydraulic diameter	m
e	Error	%
F	Fouling factor	W/m^2°C
F_t	Correction factor	Dimensionless
h	Convection heat transfer coefficient,	W/m^2°C
k	Thermal conductivity,	W/m°C
L	length	m
LMTD	Log mean temperature difference	°C
$LMTD_C$	Corrected LMTD	°C
$\dot{m}$	Mass flow rate	kg/s
N_c	Number of channels	Dimensionless
N_p	Number of plates	Dimensionless
NTU	Number of transfer units	Dimensionless
Nu	Nusselt number	Dimensionless
Pr	Prandtl number	Dimensionless
Q	Transferred heat	W
Re	Reynolds number	Dimensionless
s	Spacing	m
t	Aluminum sheet thickness	m
T_i	Inlet temperature	°C
T_o	Outlet temperature	°C
u	Channel velocity	m/s
U	Overall heat transfer coefficient	W/m^2°C
U_O	Assumed U	W/m^2°C
W	Width	m
ΔT	Temperature difference	°C
μ	Dynamic Viscosity	Pa.s
ρ	Density	kg/m^3