Review on Heat Exchanger used in Heat Recovery Ventilation System

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Abstract: Generality of today's houses are built to be airtight. While this provides a better control over indoor temperature and particulates such as dust and pollen, proper ventilation is often neglected. This leads to a ventilation problem that most of the heating ventilation and air conditioning (HVAC) contractors work to solve. Ventilation is necessary for many different reasons such as negative pressure. The aim is to review the literature on types of Heat Exchangers used in Heat Recovery Ventilation System. Considering the review done, different types of heat exchanger are used either in heat recovery or in heat recovery ventilation, but each heat exchanger have its specific work and efficiency. Regarding heat recovery ventilation system, one of the most efficient and suitable is membrane plate heat exchanger. Based on this, we will use membrane plate heat exchanger as the model in our proposed HRV system, to be published in a separate paper.

1. Introduction

The rapid development in the global usage of energy has raised worries about source, energy reduction, and environmental effects [1]. Ozone layer depletion and climate change are some of main problems that people are facing these days [2]. Based on some literature, the use of energy in building, currently accounts for 40% of the overall global energy demand [3 4]. More so, heating, ventilation, and air conditioning systems (HVACs) are estimated to use up to 60% of energy use in a building, a rate that varies with the climate [2]. At the same time, this consumption of energy results in higher greenhouse gas emissions, mainly the production of carbon dioxide. As a result, this increase in the emission of carbon dioxide might cause a vast climate change [5]. Consequently, governments are putting in place policies that aim to save energy, and develop building technologies that are environmentally friendly [6].

Generality of today's houses are built to be airtight. While this provides a better control over indoor temperature and particulates such as dust and pollen, proper ventilation is often neglected. This leads to a ventilation problem that most of the heating, (HVAC) contractors are needed to solve this problem. Ventilation is necessary for many different reasons such as negative pressure. This problem is in the airtight houses that have negative pressure due to the exhaust systems that suck the air from the house to the outside, that result a negative pressure. In addition to the indoor air pollutants, according to the U.S. Environmental Protection Agency (EPA), the bad indoor air quality is one of the top five health hazards that affect today's houses. This is due to the accumulation of volatile organic compounds (VOCs), that are continuously emitted by paint and plastics. They are harmless in small amounts, can cause respiratory problems, as well as create conditions where mold can thrive, without proper indoor ventilation these pollutants.

When designing buildings, engineers consider the heating and cooling loads of the building. These loads i.e., HVAC systems, consume up 40–60% of a building's energy needs [7-9]. According to the calculations of engineers, they install insulators to address the heating loss. These actions can lead to decrease of air exchange, and decline of indoor air quality (IAQ) [10], possibly negatively affecting the quality of life of the people remaining in the room [11-13]. Mechanical ventilation is then employed to improve the air quality in rooms, causing a big loss in the amount of heat through exhaust air. One way to cut energy consumption is to recover the heat energy enclosed in the exhaust air stream [10].

Designing and installing a heat recovery ventilation system (HRVS) assumes that indoor and fresh air would preferably mix if the flows stated in the guidelines are implemented. What actually takes place is that air is not renewed due to the various air inlets and outlets, increasing the air amount to reach a minimum IAQ, resulting in an increase in the amount of energy consumed [10]. An additional rise in energy consumption is due to the use of highly effective filters that eliminate dust particles, described a major public issue [14].

The use of energy in old buildings is continues and may also keep rising. For that, it is crucial to restructure these buildings to reduce energy use and CO2 emissions [15]. One option to address this issue is to install hybrid ventilation systems or decentralized facade ventilation [16 17]. Using ventilation systems by means of heat recovery in order to decrease the usage of heat and cooling energy is common ever since the 70s [18]. Heat recovery use in sealed buildings could decrease yearly energy consumption of heating and cooling by around one-third [19 20]. When considering heat recovery, one also consider cost-effectiveness, building guidelines and the space of renovation [10]. A study by Carlsson et al. [21] came to the conclusion that closing the building envelope along with ventilation and the use of heat recovery can make up to a 78% reduction in total energy for space heating and up to 83% reduction in greenhouse gas emissions. Based on what preceded the objective of this paper is to review the existing literature review on heat exchanger. This review is the first stage of a project where we will design a heat recovery ventilation system that will be efficient and will use environmentally friendly.

2. Review of research on heat recovery and heat exchanger

During the Last decade, research on heat recovery ventilation (HRV) systems has been increasing, as evident from the number of articles published. Recent studies are mostly aimed at developing more efficient HRV systems, modelling of new systems and its implementation in various fields. Topics include free ventilation, advances in systems, improving the indoor air quality (IAQ), improving performance of heat exchangers, materials used in heat exchangers, high efficiency of HRV system, and in the last couple of years the importance and function of HRV during the COVID-19 pandemic. In addition, research was around improving ventilation systems in schools and hospitals.

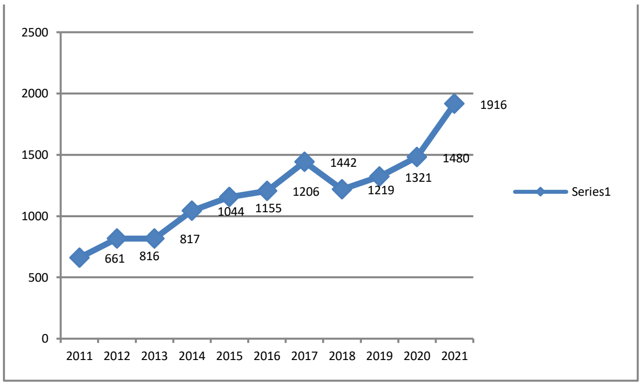

Figure 1 Number of Published articles on the topic of Heat recovery ventilation systems on science direct during the last 10 years

A. Review of Heat recovery

Heat recovery is defined as a device working amongst two different air sources at diverse temperatures, that transmission energy from one side to the other. That is, it works by preheating the air arriving inside by recycling the wasted energy. Currently, one heat recovery system is able to recuperate from 60 to 95% of wasted energy, a promising ration for future application [22]. The main four categories of heat recover system used in residential buildings are fixed-plate, rotary wheel, heat pipe, and run-around heat recovery systems. A typical heat recovery system in a residential building is typically made of a heat exchanger core, an inlet for fresh air and isolated contaminated air exhaust outlet, and a fan, Mardiana- Idayo et al [23]. Heat exchangers are a vital part of the heat recovery systems. The heat exchanger is an energy employment device with a wide usage in power engineering, petroleum refineries, food industries etc. [24-26]. They are usually two categories of heat exchangers, indirect and direct contact types. [27].

B. Review of Types of HX

a) Double pipe

A Double Pipe Heat Exchanger (DPHE) is equipped with two concentric circular pipes. The inner and outer pipes have different diameters, and the inner tube pass and the annulus pass are flow regions. The dominant heat transfer path inside a DPHE is through the wall of the inner pipe [28]. One fluid flows in the inner pipe and the other flows in the annulus between pipes in a counter flow direction for the ultimate performance for specified surface area [11]. Several double pipe heat exchangers can be joined in various series and parallel arrangements to meet pressure drop and mean temperature difference requirements. Their regular applications are suitable for small spaces, typically less than 30 m2 owing to its high cost per unit surface area [29].

b) Shell and tube

Shell-and-tube heat exchanger (STHE) is an important and broadly used device for heat transfer processing, and account for more than half of all HEs. Shell and tube type heat exchangers are usually constructed as a bundle of round tubes mounted in a cylindrical shell with the tube axis parallel to that of the shell [27]. One fluid runs through the tubes whereas other one flows over the tubes to transfer the heat between two fluids. The fully developed design codes and worldwide fabrication standards make STHEs the primary choice for many applications [28]. In many process-based industry, it is widely used by more than 90% due to their robustness and capacity to handle high-pressure processes [22].

c) Coiled (spiral) tube

Coiled tube heat exchanger (CTHE) consists of one or more spirally wound coils fitted in a shell [27]. Its most noticeable feature is how a large number of tubes are enwound in a helix manner around the central tube. The tubes have multilayers, with a commonly small diameter. The direction of the enwinding has no limitations, as long as the tubes are collected from the surface of the central tube [28]. The heat transfer coefficient of a coiled tube heat exchanger is higher than that of a straight tube heat exchanger. Common materials used are aluminum alloys for cryogenics and stainless steels for high temperature applications. Thus, they are expensive in terms of the material costs, high labor input in winding the tubes and the central mandrel [22].

d) Plate-type heat exchangers

Plate heat exchanger are broadly adopted in many fields, although less prevalent than tubular HEs, while the unique structure and particularities remain unique. Plate-type heat exchangers are made from thin plates that form flow channels. They are typically used for transferring the heat for any mixture of gas, liquid and two-phase streams and it uses metal plates to carry out the heat transfer. Plate-type heat exchangers are not suitable for greater ranges of temperature and pressure [27]. They are less widespread that the tubular heat exchangers. Plate-type heat exchangers are classified as gasketed plate, spiral plate, plate coil and lamella heat exchangers.

e) Fixed plate heat exchanger

Fixed-plate heat exchangers are made of thin plates put together to build flow channels [23].

We can categorize airflow arrangement into three separate types, which comprise parallel flow, counter flow, and cross flow. Thermal conductivity and moisture permeability are the main properties, in order to create an enthalpy heat exchanger. One experiment investigated an innovative enthalpy recovery system with a micro heat and mass cell cycle core. Sensible energy efficiency results were up to 66%, while latent energy results were 59% [30]. Likewise, Nasif et al. presented a fixed-plate heat recovery (FPHR) system employing a porous membrane material. The new system had a thermal effectiveness of around 75% of the sensible energy efficiency and 65% for the latent equivalent [31]. That types that made of plastic, metal and other types are not moisture absorbing, the geometry and thermal conductivity of the material becomes crucial as a requisite for sensible heat recovery. Usually, sensible heat recovery reaches a rate of heat exchange of 50% to 80% [32]. Several factors change the efficiency of temperature transfer of (FPHR), such as: plate kinds and structures [33 34], heat exchanger materials [31 35] and flow pattern [36]. Lately, new commercial products reached an improved heat exchange rate. An example of enhanced fixed-plate heat recovery system was able to reach a 93% of heat recovery rate [37]. Hence, fixed-plate type heat exchangers are promising for achieving greater thermal performance if applied in residential building.

f) Membrane plate heat exchangers

The most common materials used in fixed plate heat exchangers are metals and alloys, research interest is now significantly focused on porous membranes which are capable of transferring both sensible and latent heat. One study that used porous membranes material for total energy recovery devices [38], showed that sensible and latent heat recovery is probable with membrane modelling across a fixed plate heat exchanger. The membrane is placed between two layers to provide structure to the plates; the supports do not get in the way with heat or mass transport. Al-Wakedetal [39] CFD modelling of the membrane heat exchangers showed that total energy recovery from fixed plate heat exchangers is an efficient method, transferring heat and moisture through convection and conduction. Another study by [40] showed that Supported Liquid Membranes (SLM) are able to transfer heat and mass, offering a promising area of membrane based fixed plate heat exchanger. SLM have a moisture diffusivity coefficient of up to 3–4 orders of magnitude higher than solid membranes [41]; allowing for higher moisture transfer and recovering more latent heat than traditional metal/alloy fixed plates. It was determined after studying different plate materials and characteristics that the plate thickness is the defining fact or in the efficiency of the heat exchanger along with channel height between the plates [42 43]. Zhang and Jiang [44] showed that the pressure difference across the exchanger must be high with high membrane intensity, for reliable performance. In another study, Nui and Zhang [45] noted that the efficiency of this form of recovery is similar to highly effective enthalpy rotary wheels but do not have the problems of frost and condensation common with rotary wheels. O'Connor et al 2016 study [9] showed that combining a wind tower passive ventilation system and a fixed plate heat recovery device could provide an effective combined technology to recover waste heat from exhaust air and cooling coming warm air with zero energy demand. Though no quantitative data for the ventilation rates within the test room was provided, it can be assumed that due to the high-pressure loss across the heat exchanger that these were significantly reduced from standard operation of a wind tower.

g) Run-Around

The run-around heat recovery system is composed of two heat exchangers along with a coupling liquid. The heat is transferred from one stream using the pump to the other side [23]. In this structure, run-around heat recovery avoids cross contamination since the two heat exchangers are separated [46]. Under normal conditions, run-around heat recovery heat exchange rate varies between 45% and 65% [23]. Is also does not consume energy when used in buildings [47]. As for thermal performance, experimental results from Vali et al.'s indicated that the most efficient exchangers for a certain heat transfer area of exchangers, maximum sensible effectiveness was attained in exchangers that have a small aspect ratio [46]. Moreover, run-around heat recovery effectiveness is highly related to the outdoor conditions.

3. Conclusion

Considering the review done, different types of heat exchanger are used either in heat recovery or in heat recovery ventilation, but each heat exchanger have its specific work and efficiency. Regarding heat recovery ventilation system, one of the most efficient and suitable is membrane plate heat exchanger. Based on this, we will use membrane plate heat exchanger as the model in our proposed HRV system. The proposed HRV system will be designed using SolidWorks and the finite element analysis using ANSYS. The final step will be to manufacture an efficient HRV system that has best performance of HX, material cost and manufacturing cost.

4. Acknowledgment

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