A novel heat exchanger for enhancing heat recovery in buildings

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Residential gas furnaces are known to reject a considerable amount of heat through exhaust ducts. The purpose of this project is to design and analyze a rotary heat exchanger that uses this waste heat to preheat the return air entering the furnace. The heat exchanger design focuses on using phase change process as the heat transfer mechanism. Phase change material has the ability to store large amounts of latent heat when in a liquid state and then release the heat during solidification. The design tasks were divided among team members under these topics: thermal calculations, shaft and bearings, movement system, CAD and CFD, and flow separators. First, the overall size must allow the device to be small enough for one person to handle. The overall dimensions of the final product have a width of 18.5 in. and a height of 26 in. The performance requirement assumes the heat exchanger is built to retrofit a two-ton unit. This requires the volume flow rate of both the supply and return air to be approximately 1000-1200 CFM. Finally, the thermal performance expectation of the heat exchanger sets the heat output at 1-2 kW. The chosen phase change material (PCM) is an inorganic salt with 34°C as the melting temperature. The calculations consider the furnace exhaust gas as the supply air, which has a temperature at approximately 100°C. The return air, which solidifies the PCM, is initially assumed to fall in the 21-24°C range. An inorganic salt was chosen over a paraffin-based wax because the thermal conductivity of the salt is found to be two times higher than that of most paraffin PCM. The PCM is contained in 120 aluminum tubes. The tubes are evenly spaced on five circular patterns on a thin carbon steel tube sheet. The tube sheet is suspended in the center of the heat exchanger on a shaft allowing the tube sheet to rotate between both the exhaust and return ducts giving the final mechanism for the heat transfer. The phase change time, limited the rotational velocity of the tube bank. This required velocity, 0.16 RPM, limits the use of most common electric motors and the solution was to use a stepper motor turning in 1.8° increments. The motor is controlled with a USB controller to operate the motor at the desired speed. Two centrifugal fans, both having a volume flow rate set at 1000 CFM, were used to simulate the supply and return air of a 2-ton unit. A propane torch provided heat, functioning as exhausting flue gas. Temperature at various locations were monitored with seven thermocouples. Since the tube bank rotates, wireless temperature sensors were necessary to measure the PCM temperatures. Useful data were collected to prove the concept and verify the calculations. The final outcome of the testing proved the concept of the design by showing the return air to have a 5.5°C increase in temperature by transferring approximately 1 kW of heat. With the tube bank thermocouples showing a complete phase change, the final goal was met using PCM to store large amounts of latent heat and making the otherwise wasted heat useful. The tests found the heat transfer coefficient to be, on average equal to 143.5 $W/m^2 \cdot K$. The average log-mean temperature difference was found to be 5.5°C.