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PROTOTYPING A HEAT RECOVERY VENTILATION SYSTEM

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ABSTRACT: This paper presents the, prototyping, and assembly process of a novel Heat Recovery Ventilation System (HRVS) in order to increase the indoor air quality (IAQ) without consumption energy. This HRVS plays the role of heat transfer between hot and cold air with high efficiency confirming thermal comfort. Out of careful prototyping and assembly techniques, an efficient HRVS unit have developed that can be introduced in residential buildings in a compact size. This paper discusses the 3D printing of the components, including heat exchangers and air distributer with PLA material. In addition, installing the fans and the control system to achieve comfort behaviour ventilation without energy cost. Moreover, the performance of the HRVS will be tested in order to assess the real-world environments.

KEYWORDS: HRVS Assembly, Prototyping HRVS, PLA 3D printing.

1. INTRODUCTION

At the industrial scales, it is crucial to design efficient heat exchangers for both cooling and heating processes, to allow heat transfer from a high temperature fluid to a low temperature fluid [1, 2]. In order to achieve efficiency, materials to be used should possess high heat transfer rates with minimum thermal expansion for big working temperature ranges [3]. One example is metal materials that possess excellent thermal and mechanical properties, for example high thermal conductivity, wide working temperature ranges, high melting temperatures, high yield, among others [4]. Stainless steel, aluminium, and alloys are metal materials usually employed in making conventional heat exchangers [5]. Nonetheless, these materials have some disadvantages, such as heavy weight [5], fouling [6], corrosion [7] and high production costs [8]. Metal heat exchangers are exposed to degradation through gaseous (e.g. acid or alkaline vapours) corrosion [9]. Also, insoluble particulates are likely to deposit on the inner surface of the metal heat exchangers, which can block the pathways of heat flow [7]. Therefore, it is advised to replace metal with other materials that can offer comparable heat exchange efficiency, and anti-fouling and anti-corrosion properties. For example, polymer heat exchangers are an option. They gained a lot of attention in recent times [10, 11] owing to their low costs, easy manufacturing, anti-fouling and anti-corrosion properties, and low energy consumption in production [12]. Thus, they were used in several industries such as air conditioning [13], Li-ion battery thermal management [14] and membrane distillation [15]. Among the most acknowledged advantages is their environmentally friendly and economically competitive properties. They require two time less energy to produce one unit mass of materials than metal materials and they can save significant weight and space for heat exchangers [16]. Though, if compared with metal materials, the intrinsic thermal conductivity of polymers is lower, that reduces the heat transfer efficiency of polymer heat exchangers [17].

On the other hand, additive Manufacturing (AM), i.e. 3D printing, is a technique extensively employed in prototyping, in addition to obtaining functional parts for many applications [18], with a variety of employable materials, such as polymers, metals, ceramics and composite materials. The filament-based technology Fused Filament Fabrication (FFF) is one AM technique commonly used in industrial applications, such as automotive [19], and biomedical [20], using both thermoplastic polymers and polymer-based composites with improved mechanical [21, 22], electrical [23], thermal [24], magnetic [25] and sensing [26] properties. The FFF method involves the extrusion of a polymeric filament through a heated printing head and the layer-by layer deposition of the molten material to form a three-dimensional object. FFF advantages over other 3D printing techniques, includes less capital investment, reduced material waste, in addition to being able to process several materials at once and thermoplastic-based composite materials [27].

One extensively used materials in the FFF-printing technology is Polylactic acid (PLA), prevailing over other 3D-printable polymers from the environmentally and sustainability point of view, since it is a biodegradable biopolymer. PLA raw material is usually made of biological resources (corn) and is part of the aliphatic polyester family [28, 29]. Recently, PLA, as a bio-based and biodegradable substitute for traditional fibers, films or bulk components, is being used more and more in food [30], packaging [31], textile [32] and automotive [33] industries. In addition, PLA is classified as a low VOCs (volatile organic compounds) emitter, reducing the health risks on users [34, 35]. It is also broadly used as medical suture material, for the drug sustained-release, and as support and repair material in tissue engineering [36] due to its good biocompatibility and cytocompatibility [37]. Several research studies have shown that 3D-printed PLA preserves good mechanical strength [38-40]. Still, research is lacking on their failure strength coupled with numerical modelling.

Based on what preceded, the objective of this paper is prototyping HRVS. The prototyping process will do to manufacture the HRVS using a 3D printer [41-42]. This process helps to know the performance of many 3D printers PLA material, and know the best one. In the other hand, the assembly process helps to know if the HRVS will function efficiently.

2. MANUFACTURING PROCESS

As mentioned before the manufacturing process of the HRVS will be done using a 3D printer. As known, there are many types of 3D printer that used in industry, such as CREALITY, WANAHO duplicator i3 plus and many other 3d printers. The parts of the HRVS needed to print [43] are heat exchanger (HX), air distributer (AD), nozzle and diffuser.

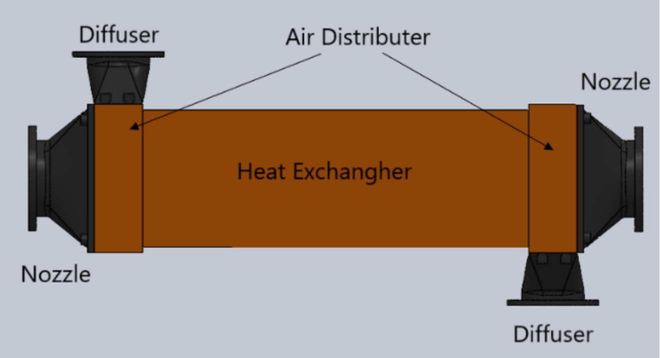


Figure 1. Heat Recovery Ventilation System [43]

2.1 3D Printing of Nozzle and Diffuser

The nozzle and diffuser are of same shape and dimensions as shown in figure (1), printing them is an easy work due to easy design. It just needs to insert a support to hold the object. After using the printer CREALITY LD06, the result was the required one as shown in figure (2).

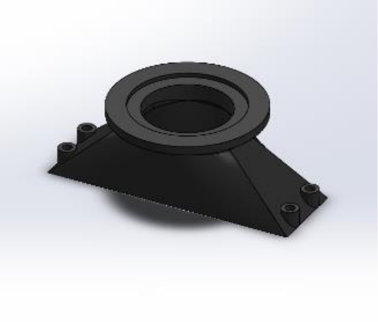


Figure 2. Design of the nozzle and diffuser

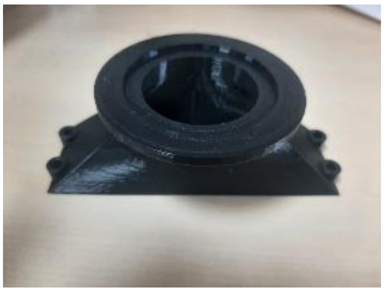


Figure 3. 3D printing of nozzle and diffuser

2.2 3D Printing of the Air Distributer

Firstly, the role of air distributer is to distribute or separate the indoor air flow and the outdoor air flow. As mentioned before, two air distributers are needed and they will have one input and one output for each air flow in order to process the heat transfer between them. The air distributer has six faces as shown (3) three are closed and the other three are opened to let the air enter or leave.
The air distributer has more details other than the other parts, due to its complex design.

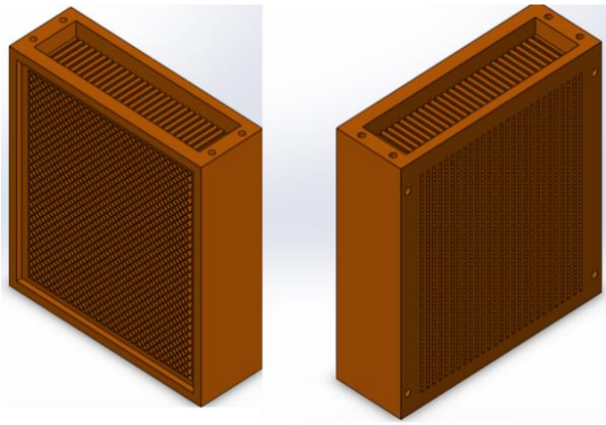


Figure 4. Design of Air Distributer

2.2.1 First 3D Printer

The first printer used is TEVO Tarantula Pro 3D Printer Kit with 235x235x250mm. the printing started with the following settings speed 120 mm/s, nozzle temperature 210 C°, bed 70 C°, wall settings were changed to 0.3 mm, layer 0.28mm, flow reduced to 70%. The result is in the following figure which is of bad quality and it took two days to print, the edges are not sharp that leads to air leakages. In addition, the air channels are open to each other that means the hot and cold air will mix, while heat transfer between them is needed.

Figure 5. 3D printing of (AD) using TEVO Tarantula Pro

2.2.2 Second 3D Printer

The second printer used is CREALITY 3D CR-3040 PRO. The printing started with the following settings: speed 160 mm/s, nozzle temperature 220 degrees, bed 50 degrees, wall settings were changed to 0.25 mm, layer 0.25 mm, flow 100%. After 18 hours of printing, we did not get the required result. There were cracks between the air channels and some channels were closed. In addition, there was an error in the dimensions of the air distributer.

Figure 6. 3D printing of (AD) CREALITY 3D CR-3040 PRO

2.2.3 Third 3D Printer

The third printer used is CREALITY 3D LD-006, i.e., a liquid 3d printer that takes about 13 hours to print the prototype. In the first trial, we started printing from the external side of the AD. This caused the liquid PLA to congregate in the middle of the printed AD due to the weight of the material, as shown in figure (6). In trial 2, we started printing from the internal side, which caused the air channels to partially close due to the weight as shown in figure (7).

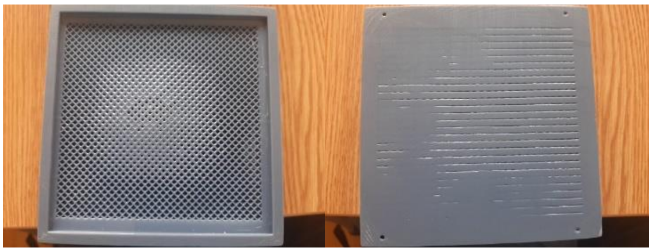


Figure 7. Printing start from first side of (AD) using CREALITY 3D LD-006 (left); Printing start from second side of (AD) using CREALITY 3D LD-006 (right)

2.2.4 Fourth 3D Printer

The fourth printer used is PRUSA MK4 that started printing with the following settings: speed 170 mm/s, nozzle temperature 230 degrees, bed 60 degrees, z height 0.2 mm, nozzle diameter 0.4 mm, flow 100%. The printing of the air distributer using this printing takes about 7 hours, while the result is the required one and it was perfect as shown in figure (8):

Figure 8. 3D printing of (AD) using PURSA MK4

2.3 3D printing of Heat Exchanger

The heat exchanger doesn’t have complex details of 106.0*104.4*300 mm dimensions, but it has a large height 300 mm that most 3d printer can’t print it. In this case a 200 mm from it will be printed. The cross section of (HX) shown in figure (9):

CREALITY 3d printer is used to print a few millimeters from the HX in order to have an idea about printing and if there are any errors. The result shown in the following figure (10). After changing some settings in order to have a good quality and the required result, the printing also failed. As seen in figure (10), there are cracks and the material doesn’t catch itself in order to print the air channels.

Then, the PURSA MK4 is used with last settings, 50 mm was printed in order to test the result. The result is also great as shown in figure (10).

After the good result of the 50 mm of HX printed. The printing of 200 mm of HX started those needs about 45 hours with same settings. The result is also the required one as shown in figure (11).

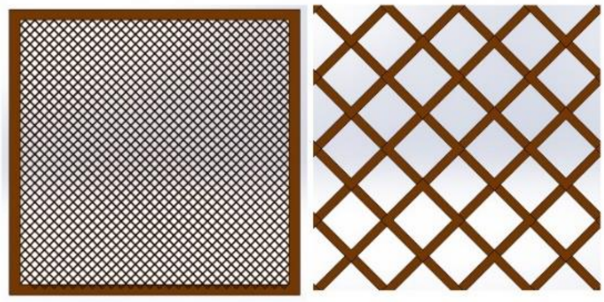


Figure 9. The cross section of (HX)

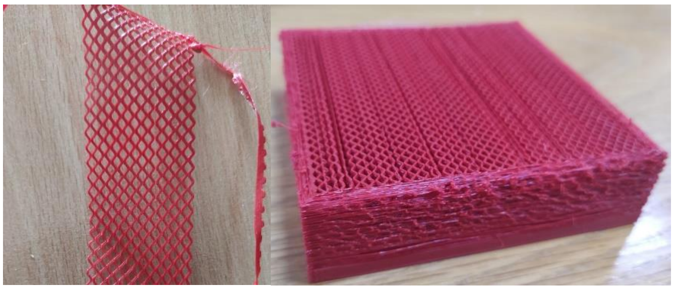


Figure 10. First 3D printing using CREALITY (left); Second 3D printing using CREALITY (right)

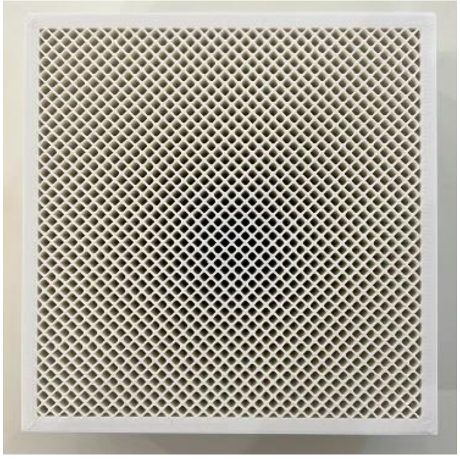


Figure 11. 50 mm of HX using PURSA MK4

After finishing 3D printing of all parts of the HRVS and starting the assembling and testing the system, the experiment showed that the cold and the hot flows are mixing in one of AD. The AD has a flaw in the design as shown in figure (12).

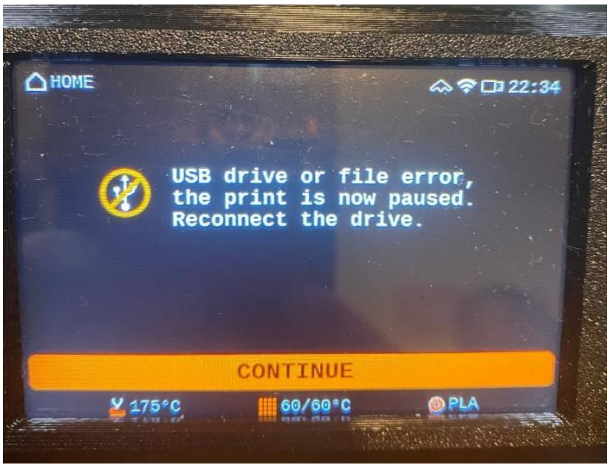
In addition, there are air leakage between the parts that will prevent the heat transfer between the two flows, this flaw is related to 3D printing as we can see in figure (14).

Figure 12. Flaw shown in the AD

Figure 13. 200 mm of HX using PURSA MK4

Figure 14. Printing error in the HX

After those errors were occurred now the HRVS will be printed in one piece (HX and the two AD) as one block in order to avoid air leakage and design errors in the system. In order to print it as one block we use the 3D printer PRUSA XL that can print large dimensions. The printing using this printer takes about 6 days, but after 5 days and printing about 75% of the model the PRUSA XL makes an error as shown in figure (15). In addition, after reading some reviews about, the printer makes an error while printing large files as the model we have.



USB drive or file error, the print is now paused. Reconnect the drive.

Figure 15. Error of PRUSA XL

Then the length of the HX minimized by 2 cm in order to have the ability to be printed in PRUSA MK4. Also, the printing takes about 5 days but the result was very good as shown in figure (16).

Figure 16. Model printed as one part

3. DISCUSSION

As seen before, there are many of 3D printers used, and each one the settings of printing changed in order to print the model of the HRVS. Thus, the 3D PRUSA MK4 proved that it is the best one regarding to the printed result that it is of high quality.

4. CONCLUSION

This paper aimed to prototype HRVS. The complex process which is the manufacturing showed the use of many 3D printers and printing settings. In conclusion, the 3D printer PURSA MK4 provides high-speed 3D printing with ease and is ever so reliable. In addition, prototyping any system that has air flow should be printed as one part to avoid air leakage.

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