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EDUCATING HISTORICALLY BLACK COLLEGES AND UNIVERSITIES INNOVATORS ABOUT THE COMMERCIALIZATION OF INNOVATION BY THE CUSTOMER DISCOVERY PROCESS

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ABSTRACT

Historically Black Colleges and Universities (HBCUs) innovators lag behind their non-HBCU counterparts in the commercialization of innovations as they were originally set up as teaching and blue-collar trade institutions. There exists a strong need for education and training to bridge this gap by promoting the commercialization of innovations in HBCUs and thus transform next-generation HBCU innovators into entrepreneurs. HBCUs are promoting entrepreneurial education and mindset via changes in engineering education programs and curriculums. Several federally funded programs like the National Science Foundation (NSF) Center of Research Excellence in Science and Technology (CREST) Center for Nanotechnology Research Excellence (CNRE) are promoting innovation and intellectual property generation at HBCUs. NSF I-Corps Program supports the education and training of innovators about the commercialization of mature or patented innovations at HBCUs. The NSF I-Corps Introduction to Customer Discovery explores strategies in identifying key customer segments through extensive customer interviews, which is a fundamental step in the commercialization process. This paper discusses our educational experience in the customer discovery process for Pumpless Solar Thermal Air Heater (Patent Number 10775058). To learn about prospective customers' attitudes and perceptions of the innovation, we conducted 30 interviews with potential customers (end users). Our innovation is focused on providing portable, cost-effective, healthy, and environmentally friendly space heating solutions. We tested several hypotheses about the value proposition of our innovation during interviews to explore the market segments for potential commercialization. During the Customer Discovery process, we came to know about new issues such as health issues caused by the dry air in winter. We also learned that mitigation of problems due to the current heating system required a humidifier to reduce health issues that added additional cost. Based on our interviews our innovation is suitable for customers needing: (i) Heating source mitigating health issues, (ii) add-on technology to reduce their heating bills. Our next step is to pursue market segments for our innovation. We plan to utilize the current experience of commercialization of intellectual property to develop training modules for the MECH 302 Undergraduate Research Experience and MECH 500 Research Methods and Technical Communication courses offered under the mechanical engineering program at the University of the District of Columbia (UDC).

Keywords: Historically Black Colleges and Universities (HBCUs), Commercialization of innovations; Customer Discovery; Engineering Teaching.

1. INTRODUCTION

Historically Black Colleges and Universities (HBCUs) are institutions that were established before 1964 expressly to educate African Americans [1]. HBCU is defined by The Higher Education Act of 1965, as amended, as: "…any historically black college or university that was established prior to 1964, whose principal mission was, and is, the education of black Americans, and that is accredited by a nationally recognized accrediting agency or association determined by the Secretary [of Education] to be a reliable authority as to the quality of training offered or is, according to such an agency or association, making reasonable progress toward accreditation." [2]. Over the years, though expressly established to educate people of African American descent, HBCUs have been providing all students regardless of background, race, ethnicity, a competitive way to develop their careers honing their innate talents and skills.

Additionally, HBCUs have been conducting cutting-edge research in many areas of national and global importance (see fig. 1) [3]

Figure 1: HBCUs Research Areas

Available research indicates that, before April 11, 1978, no HBCU had received a patent for an invention. The first HBCU to receive a patent was Shaw University with patent no. 4,083,841 A, received by Abha Pal Ghosh and Kalyan Kumar Ghosh that provided novel compounds that had a high level of activity as folic acid antagonists [3].

Since that time, HBCUs have been steadily increasing the number of utility (non-provisional) patent grants awarded and between 1969 and 2012, HBCUs received 100 utility (non-provisional) patents from the U.S. Patent and Trademark Office in various fields, including energy, advanced manufacturing technology, and breast cancer treatment [4]. Although this is a very small portion of patents issued by the USPTO during that period, the rate at which HBCUs have received patents has increased exponentially in recent years. In 2010, HBCUs received 10 patents; in 2011, 17 patents; and in 2012, 24 patents [4]. Available data shows that over the past decade HBCUs have seen a proliferation of new intellectual property, the visualization below details the total number of patents amassed by HBCUs since 1978 [5].

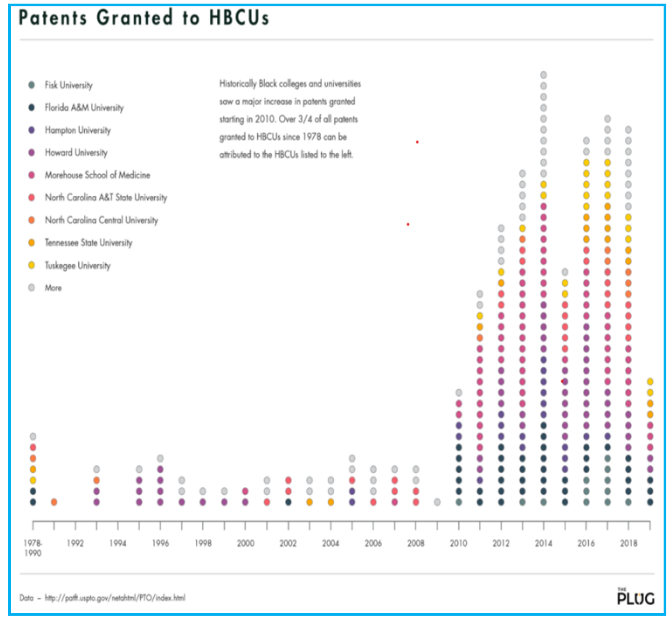

Figure 2: Patents Granted to HBCUs up to 2018.

HBCUs Impact

Since their establishment, the positive economic impact of HBCU's cannot be overemphasized as a study commissioned by United Negro College Fund (UNCF) makes clear, and the benefits also flow to the local and regional economies that are connected to HBCUs [6]. Key findings from the study (based on 2014 data) include:

- **HBCUs Spending:** Total initial spending by the nation's 100 HBCUs was $10.3 billion. This comprises three types of spending – spending by the institution for personnel services (wages, salaries, and benefits), spending by the institution for operating expenses, and spending by students.
- **Economic Impact:** The total economic impact on output (sales) is $14.8 billion. Conceptualized as the equivalent of business revenue, sales, or gross receipts, total output is the value of production by all industries, including intermediate inputs. Public HBCUs account for $9.6 billion of the output impact or 65 percent of the total amount. Private, non-profit, HBCUs account for $5.2 billion of the output impact or 35 percent of the total amount. Dividing the total output impact ($14.8 billion) by initial spending ($10.3 billion) yields a multiplier of 1.44. In other words, every dollar in initial spending generates an additional 44 cents for the regional economy. This measures the response of the regional economy to a change in spending.
- **Employment Impact:** Collectively, the employment impact of the nation's HBCUs on their regional economies was 134,090 jobs. Approximately 43 percent (57,868) were on-campus jobs at the HBCUs, and 57 percent (76,222) were off-campus jobs. In

terms of value-added (gross regional product), HBCUs generated $10.1 billion. Gross regional product, like output, is a measure of the value of production of all industries but does not include the value of intermediate inputs. Gross regional product equals output less intermediate purchases.

- **Labor Income:** The economic impact of the nation's HBCUs expressed in terms of labor income was $7.3 billion. Labor income includes all forms of employment income, such as wages, salaries, benefits, and proprietors' income. The $3.9 billion that HBCUs spent on wages, salaries, and benefits generated $7.9 billion in output, $6.3 billion in regional product, $5.2 billion in labor income, and 88,315 jobs. The $2.7 billion that HBCUs spent on operations generated $2.6 billion in output, $1.4 billion in regional product, $813 million in labor income, and 18,209 jobs. The $3.7 billion in spending by HBCU students generated $4.3 billion in output, $2.4 billion in regional product, $1.3 billion in labor income, and 27,566 jobs.
- **Economic Success of HBCU Graduates:** The economic success of the graduates of HBCUs can be measured in terms of higher earnings over a working lifetime. The 50,037 HBCU graduates in the Class of 2014 can expect work-life earnings of $130 billion; that is 56 percent ($46 billion) more than they could expect to earn without their 2014 certificates or degrees. That amounts to an additional $926,666 in work-life earnings per graduate [6].

However, with all these positive impacts, HBCUs lag behind their non-HBCUs counterparts in the commercialization of innovation because historically they have been under-served and were originally established largely as teaching and blue-collar trade institutions [7]. Promoting and supporting the commercialization of innovations in HBCUs will likely enable HBCUs to grow into new or stronger research-oriented institutions and ultimately have greater economic, employment, and lifetime impact.

There exists a strong need for education and training to bridge this gap by promoting the commercialization of innovation in HBCU and thus transform next-generation HBCU innovators into entrepreneurs. To this end, several federally funded programs like the National Science Foundation (NSF) Center of Research Excellence in Science and Technology (CREST) are promoting innovation and intellectual property generation at HBCUs. NSF I-Corps Program supports the education and training of innovators about the commercialization of mature or patented innovations at HBCUs. NSF I-Corps Program supports the education and training of innovators about the commercialization of mature or patented innovations at HBCUs.

2. CUSTOMER DISCOVERY PROCESS

Historically, "Customer Discovery" traces its roots back to two serial entrepreneurs: Steve Blank and Eric Ries, who are widely known for their contribution to the "Lean Startup" methodology. (Eric Ries authored "The Lean Startup (2010)" and Blank wrote "Why the Lean Startup Changes Everything" for the Harvard Business Review in 2013). The focus of "the Lean Startup" [8] and "Why the Lean Startup Changes Everything" [9] is the process of utilizing customers very early on in the business development process – and that is specifically what is behind the Customer Discovery process. However, Brant Cooper (author of "The Lean Entrepreneur) simplifies the meaning of Customer Discovery by indicating that it 'is all about questioning your core business assumptions." [10] Performed correctly, Customer Discovery is a customer-centric, scientific process that puts evidence behind an assumed product-market fit [11].

The NSF I-Corps Introduction to Customer Discovery explores strategies in identifying key customer segments through extensive customer interviews, which is a fundamental step in the commercialization process. This paper discusses our educational experience in the customer discovery process for Pumpless Solar Thermal Air Heater (Patent Number 10775058) developed by researchers in CNRE at the University of the District of Columbia.

The NSF I-Corps Introduction to Customer Discovery is a four-week course held online with 10 teams from different HBCUs during Spring 2021. Week 1 focused on the discussion of business models, customer segments and jobs, Pains/Gains, developing customer discovery action plan for interviews, evidence-based entrepreneurship, and hypothesis development (for customer and ecosystem). This was done within a two-hour online meeting for two days. After which, we conducted three (3) customer discovery interviews using developed questions based on our hypotheses and presented our findings in week two.

Week 2 had two sessions, with the first being a 30-minute office hours interaction with one of the commercialization experts aimed at discussing our hypotheses and interview findings. The second session was for two hours, where our interview findings were presented, and lessons learned were noted for subsequent interviews. We were requested to interview 7 potential customers (end users).

In week 3, we had a two-hour session for one day that focused on presenting the results of our 7 customer discovery interviews. The objectives of these presentations were to identify customers (end users), what problems they have, what our solution is, what we learned through our customer discovery relating to our initial hypotheses, and what our discovery plans were for the next customer discovery interview. We were to conduct additional 10 customer discovery interviews.

During week 4, we had a two-hour session for one day (the last day of the course). Within the first part of the session, we presented our findings from interviewing 10 customers in two groups with commercialization experts, who commented and gave their perspectives on our results. Also, we discussed value proposition development, which is our key solution to customers' problems (pain), and the next steps. In all we conducted 30 potential customers, 20 were done during the four-week course, and 10 were conducted after the course. We plan to conduct additional 20 potential interviews to target our identified market segment and strongly validate and support our tested hypotheses.

3. RESULTS AND DISCUSSION

The innovation we seek to commercialize, which was taken through the customer discovery process is the Pumpless Solar Thermal Air Heater (Patent # 10775058) and is briefly discussed below.

Pumpless Solar Thermal Heater (Patent # 10775058)

A pumpless solar energy-based air heater includes a body housing a chamber surrounded by a heat-conducting medium; an intake pipe to draw cool air into the chamber; and one or more exit pipes to push warm air out from the chamber, the one or more exit pipes having one or more structures within the interior of the one or more exit pipes to create a low friction factor for the air flowing upwards in the exit pipe while creating a high friction factor for the air attempting to move downward, thereby ensuring airflow in an upward direction; a pressure difference is created between an entry point of the intake pipe and an endpoint of the one or more exit pipes, thereby eliminating the need for a pump or a fan. A diagrammatic presentation of the heater is shown in figure 1.

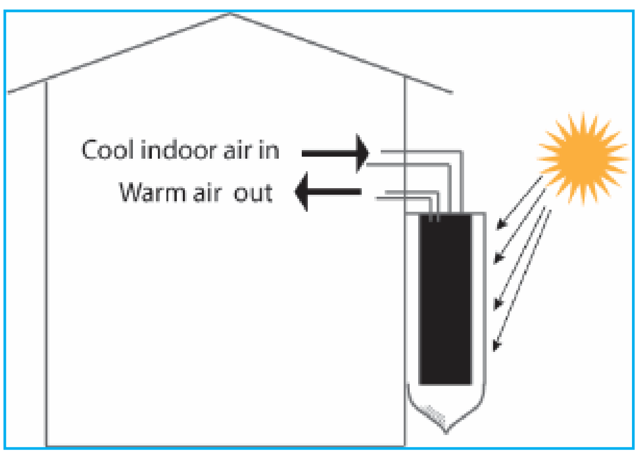

Figure 1: Pumpless Solar Thermal Heater (Patent # 10775058) placed at the window of a house with outside sunlight.

This innovative device focuses on a heat exchanger that creates net pressure to mobilize air heated by the sun radiation without utilizing any fan or mechanical pump. The heat exchanger is designed for a compact solar thermal air heater that is mounted in the exterior part near a sun-facing window. This heat exchanger is designed to three key steps (as detailed in figures 3 to 6 below):

a. Draw indoor cool air inside the solar thermal window collector,
b. Heat the air by utilizing heat from the solar absorber, and,
c. Push the heated air indoors.

The combined unit of the heat exchanger and solar thermal collector can be placed in windows in the exterior of a home. This combined unit uses a small section of the target window to draw cool indoor air and send the heated air back inside the home. Hence, this combined unit of the heat exchanger and solar thermal collector to do not block the window and it also does not require the creation of holes in the wall. The manufacturing of the heat exchanger is better accomplished with the help of metal 3D printing. To achieve the function of the mechanical pump, the pipes of the heat exchanger are designed to get differential friction - creating a high head loss in one direction and low head loss. A heat exchanger producing a pumpless solar thermal air heater can be designed to work with the vacuum tube solar thermal collector and flat plate solar thermal collector.

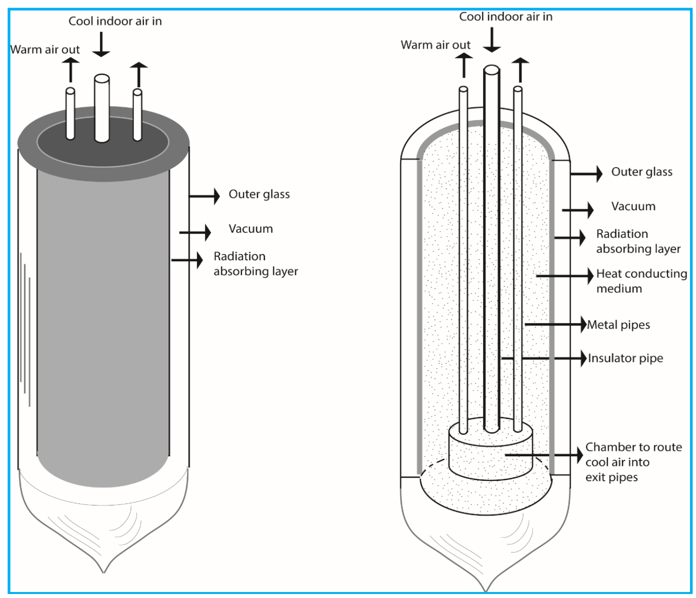

Figure 2: Heat Exchanger

In figure 2 above, a heater (on the left) is shown, having one or more intake pipes (cool indoor air in) and one or more exit pipes (warm air out). It should be noted that any number of pipes can be used as exit pipes based on the space available within the solar thermal collector body (on the left). As further shown in figure 2, the cool indoor air in and warm air out pipes are embedded within a heat-conducting medium, which is further enclosed within a radiation absorbing layer, a vacuum layer, and an outer glass layer. Insulation around intake cool indoor air in pipe ensures that air inside the intake pipe does not get heated to the same temperature as the air inside the metal exit pipes will get heated. As a result, the air inside the intake pipe will be cooler than the air inside the exit pipes. Cool air is denser than hot air and hence cool air inside the intake pipe will assist in creating a net pressure difference between intake and exit pipes. As a result, selecting insulating material for intake pipes and metallic materials for the exit pipes will enhance the heat exchanger's capability to create higher pressure difference.

It should be appreciated that the various shapes, materials, and sizes can be incorporated into the features discussed herein. The whole heat exchanger will be surrounded by the medium to transport heat from the solar collector inner glass wall to the heat exchanger. Further, the exit pipes are typically made of metallic materials, such as steel, aluminum, and copper. These pipes may also be 3D printed to create specific internal structures (as discussed herein) which are necessary to create a differential pressure between exit and intake points (thereby eliminating the need for a pump/fan).

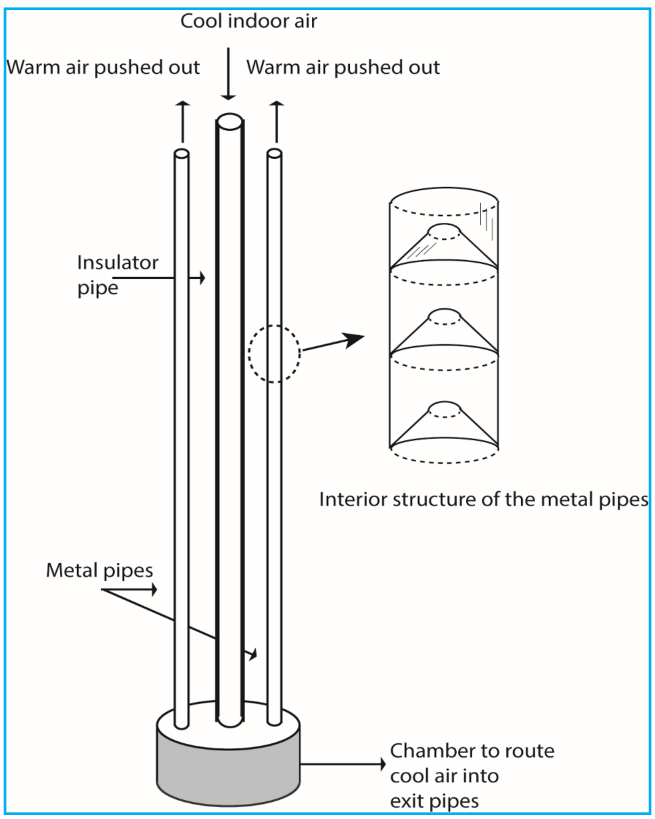

Figure 3: The metal pipes and their interior structure

The figure 3, the internal structure of the exit pipes is shown, wherein this structure allows for the creation of a net pressure difference between the entry point of the intake pipe and the endpoints of the exit pipes. As shown, the interior of the exit pipes can include a plurality of structures that create a low friction factor for the air flowing up the exit pipe and produce a high friction factor for any air attempting to move downward. This feature ensures that the preferential flow of air is always in the upward direction. As shown, in the preferred embodiment, the internal structures are conical in shape, however, as shown in figure 6 below, the structures can vary, include protrusions, or other features. These internal features of the pipes are designed to create high friction when air flows downward in the exit pipe, but a small amount of friction when air is flowing upward.

It should also be noted that one of the unique features believed characteristic of the present device is this difference in friction, which allows for the heater to push air back into a building without the use of a pump or fan. The internal features of the exit pipes are also helpful in providing a high surface area to heat the air in the exit pipes. Due to high heating air expands in the exit pipe and creates pressure. This pressure will now move the air upward and downward in the pipe. However, as discussed above airflow is mainly to happen upward in the exit pipes because internal features in the exit pipe only favor upward flow. As heated air moves upward, it will create space or a kind of vacuum to draw cool air from the intake pipe into the exit pipe. Cool air will get heated in the exit pipe and will move upward. This cycle will keep happening as long as sun radiation is heating the medium present around the heat exchanger pipes. Hence, the heat exchanger disclosed here will make cool air move through the air heater without requiring an additional pump or external fan. The intake pipe, which can be nonmetallic, may also have similar internal features. However, the role of such internal features will be mainly to promote the downward flow of air and restrict the upward flow of air within the intake pipe.

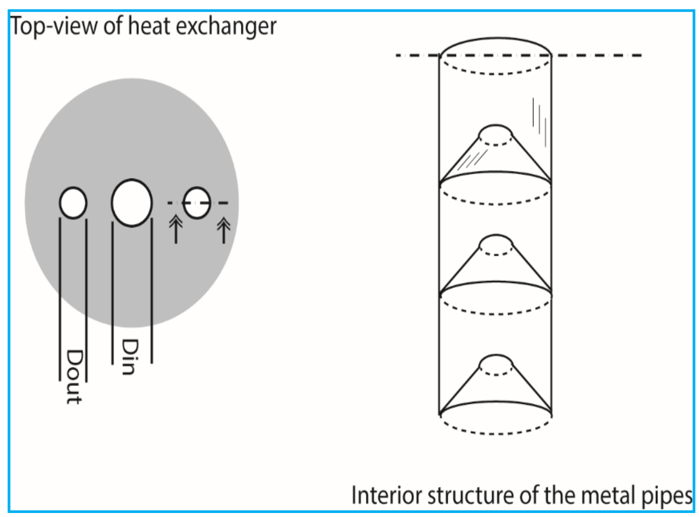

Figure 4: Top view of the Heat exchanger and interior view of the metal pipes

In figure 4 above, a top view of the heat exchanger and the interior structure of the pipes is further shown for clarity. In some embodiments, the intake pipe will have a larger diameter than the exit pipes.

Figure 5 overleaf shows a cross-sectional view of an intake pipe, and two exit pipes are shown for clarity. As shown, the intake pipe can have structures that allow for air to flow freely into the chamber, while preventing air from coming back up the intake pipe. As the air is heated, it is then pushed easily through the exit pipes, wherein the internal structures prevent backward movement of the air.

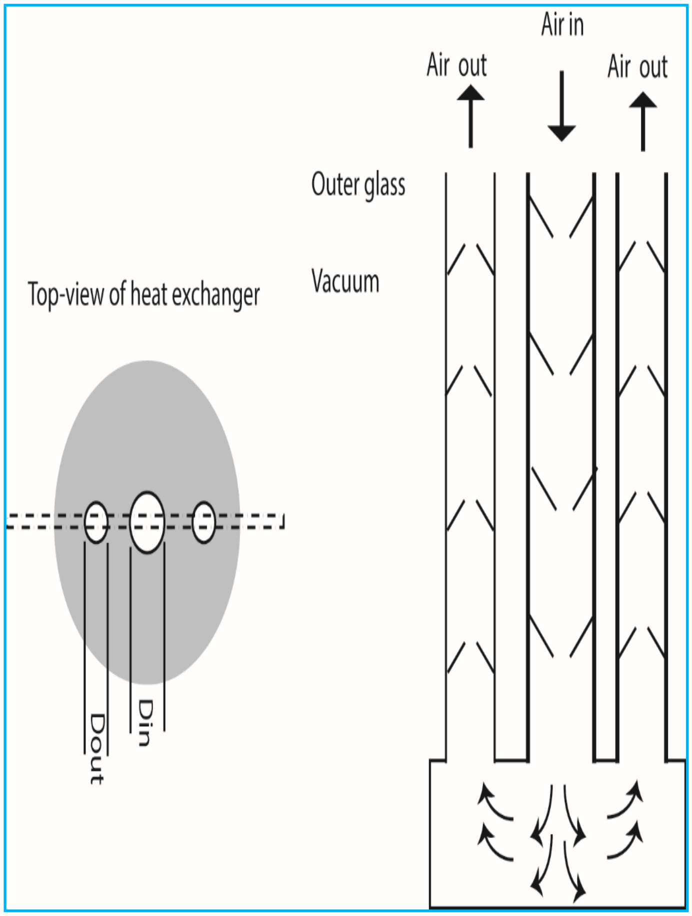

Figure 5: Top view of the Heat exchanger and interior view of metal pipes showing airflow.

In figure 6 below 6, alternative embodiments of the exit pipe are shown, wherein the exit pipe can vary in shape ((i) rectangular and (ii) circular). These pipes may have a variety of features to promote the net pressure difference between the entry point of the intake pipe and the endpoints of the exit pipes. (a-d) shows the cross-sectional view of various internal designs that may create preferential airflow in one direction and allow large surface area for effective heat transfer from pipe wall to flowing air. These features can be produced by metal additive manufacturing. Three-dimensional drawings or models of the disclosed heat exchangers can be directly produced in 3D printers or additive manufacturing machines. The laser sintering-based metal 3D printing may also produce very high surface roughness on the interior surface of the disclosed heat exchanger. The high surface roughness may significantly enhance the internal surface area to further increase the heat exchanger efficiency and the ability to create a high-pressure difference between the inlet and exit pipes of the disclosed heat exchanger.

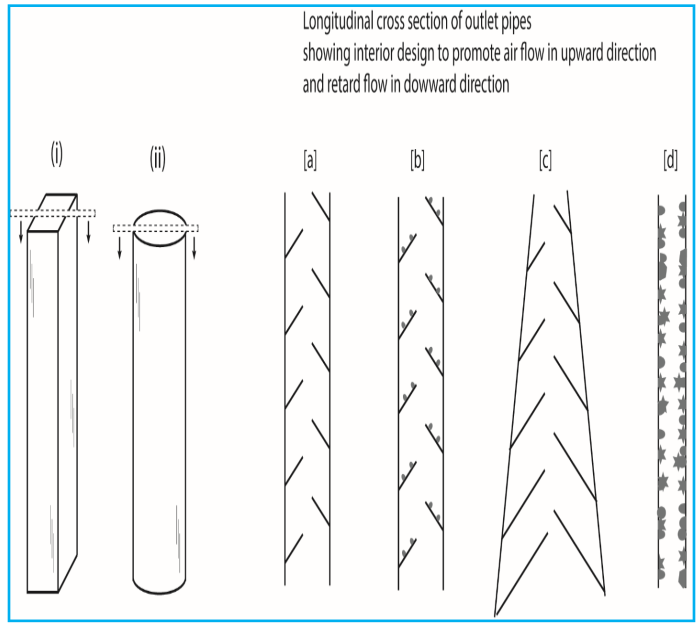

Figure 6: Top view of the Heat exchanger and interior view of the metal pipes

Advantages and Applications of Pumpless Solar Thermal Heater

As mentioned earlier this innovation relates generally to air heater systems, and more specifically to a heat exchanger for solar energy-based air heater that is configured to pull cool air from a room/building, warm the air via solar energy, and push the warm air back into the room/building without the use of any mechanical pump or fan.

Existing solar thermal air heaters require mechanical pumps and/or fans to circulate air through a solar thermal collector and push the air into a room. Some existing solar thermal air heaters are configured to be mounted within a window area, thereby blocking light and being aesthetically unpleasing. The need for a pump/fan, as well as the unappealing aesthetical appearance of these conventional solar thermal air heaters, are disadvantages and therefore, it is an object of the present invention to provide an aesthetically pleasing, pumpless solar energy-based air heater.

Conventional solar thermal air heaters have additional disadvantages, including:

(i) the need to make significant changes in the window or the point where these heaters will be employed;
(ii) fan/pump requirements to circulate air between the heater and interior air (hence, if electricity is not available then it may not be possible to heat the home effectively);
(iii) repair and replacement of these solar air heating units may be tricky and may be costly;
(iv) it may be unaesthetic for certain homeowners.

Accordingly, although great strides have been made in the development of solar thermal heaters, many shortcomings remain. The desirability of doing indoor air heating from the sun is highly popular and appears as a very straightforward and sensible concept. However, most homes, businesses, and buildings still do not take advantage of the free heating energy available from the sun. This is because of the high cost associated with the present solar systems, which is driven by their complexity in construction, installation, and operation. The operation of solar thermal air heaters is also dependent on the proper functioning of fans and the availability of a source of electricity. These days many solar air heaters embed a solar panel next to the solar thermal collector to supply electricity for circulating air between indoor and solar thermal collectors. However, on a cloudy day or a place where shade appears during the daytime solar cell may not generate enough power to mobilize the indoor air. It is noteworthy that a solar thermal collector may absorb almost full sun spectrum, but solar cells can only utilize partial sun spectrum to circulate fan for air circulation. Solar cells are made up of silicon-like semiconductors that require more than 1 eV of high-intensity sun radiation energy to function. Therefore, utilizing solar cells for running fans to exchange air between home and solar air heaters may reduce the usefulness of a solar air heater and increase the size of the overall solar thermal heater size and manufacturing cost significantly. Additionally, if a fan or any component of solar cells fails then a solar cell-dependent solar thermal air heater may stop working right away. Repairing solar cell-dependent solar thermal air heaters may be costly and time-consuming. Due to such potential issues, many potential customers of solar air heaters may not choose solar air heating.
In summary, this invention provides a solution to make solar thermal air heating cost-effective, maintenance-free (as no fan or solar cell is used), robust operation, retrofittable without drilling holes in the home structures.

The outcome of the Customer Discovery Process

To learn about the customers' attitudes and perceptions of the innovation, we conducted a total of 30 interviews with potential customers (end users). Our innovation as described above is focused on providing portable, cost-effective, healthy, and environmentally friendly space heating solutions. We tested several hypotheses about the value proposition of our innovation during interviews to explore the market segments for potential commercialization. The initial hypotheses tested are:

(a) End users can identify key issues related to their home heating systems as motivation to explore alternatives,
(b) Reducing heating bills is a priority for end-users,
(c) Reducing the level of noise from the heating system is a priority to end-users.

After the second week, when we had conducted 10 potential customer interviews, we learned about new value propositions that helped us to revise our initial hypotheses. We also realized that nose-bleeding and health issues caused by dry air from current heaters are a concern for several people. Originally, we did not think about this market segment. We, therefore, included a new hypothesis – minimizing health issues due to space heating is a priority to end-users.

During the interview process, we also learned that our hypothesis that reducing heating costs is a major motivation for the homeowner was correct. However, our interviews so far did not reveal that noise due to the heating system was any concern. To understand the implications of the results of the interview, we discussed the outcome of initial interviews and features of our innovation with a commercialization expert.

We conducted additional 10 interviews in the third week and discovered new value prepositions relating to portability and sustainability of our innovation and revised our initial hypotheses accordingly. The last 10 interviews conducted after the course, also validated our hypotheses. We present the results of our 30 interviews conducted below:

Table 1: Results of interviews conducted

Hypotheses Tested	**# Interested in New Solution**	**Percentage Interested**
Portable add-on technology on top of the existing HVAC system to reduce their heating bills	26	87%
Minimizing health issues due to space heating	17	57%
Low maintenance and >10 years lifetime heating systems for mobile home or recreational vehicles (RV)	19	63%

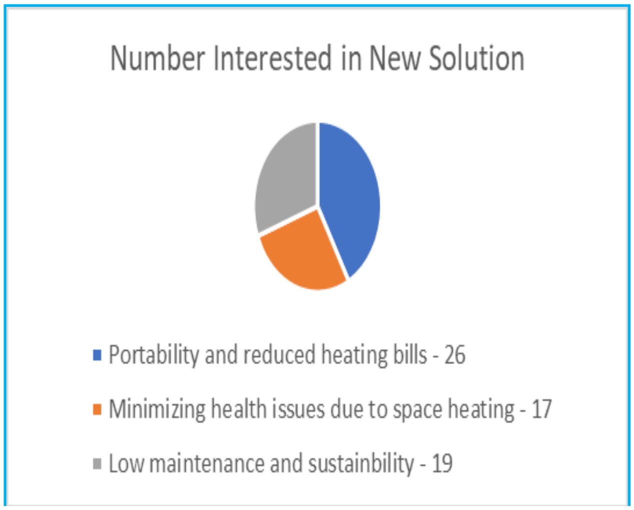

Figure 7: Chart showing number of interviewed potential customers interested in the new solution.

In all, four potential customers interviewed were not interested in the new solution mainly because they are living in newer houses, and they do not have any issues with their current heating system.

4. CONCLUSION

We have finally concluded that commercialization of our innovation is promising to focus the following value propositions: our innovation has the potential to serve the needs of customers;

(i) seeking ways to minimize health issues due to space heating,
(ii) seeking portable add on technology on top of the existing HVAC system to reduce their heating bills,
(iii) seeking low maintenance and >10 years lifetime heating system for mobile home or recreational vehicles (RV).

In future interviews, we also plan to test the hypothesis that a green supplementary heating system is a demand area in environmentally conscious homeowners. With this experience, we are geared up to look for suitable commercialization venues. Our next step is to target the different commercialization opportunities (market segments) for our innovation.

To promote commercialization of innovations in HBCUs and ultimately bridge the gap between HBCU innovators and their non-HBCU counterparts, we plan to utilize the current experience of commercialization of intellectual property to develop training modules for the MECH 302 Undergraduate Research Experience and MECH 500 Research Methods and Technical Communication courses offered under the mechanical engineering program at University of the District of Columbia (UDC).

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