Developing a Sustainable Air-Cooling Device

Problem Statement:

The opportunity for the project is twofold: Firstly, half of on-campus housing does not have central or pre-installed air conditioning, and as well as many of older academic buildings. Secondly, most air conditioning units out on the market are poor for the environment.

First, about half of on-campus housing does not have central air conditioning. Therefore, in hot weather, students choose between cooling themselves with fans or installing window air conditioning units, which are inefficient at best. In the past year, our college installed 18 window air-conditioning units for residents in non-CAC (Central Air Conditioned) apartments. Assuming the average unit had a 6,000 BTU capacity and the units were being run for six hours a day throughout the summer, the energy cost per year would be 22,809.6 kwh from the 18 units alone, accounting for a release of 34,675 lbs of CO2 in the atmosphere [I]. This number may appear small when compared to the over 1,000 trillion BTU consumed by the state of New York alone [II]. However, considering the fact that 53% of New York state households use individual wall or window air conditioning units, development of a freestanding device on that reduces energy usage while increasing cooling capacity could provide an opportunity for energy savings. Second, most of the products available on the market are created with a “cradle-to-grave” mentality, meaning that they are manufactured, used, and then disposed of such that the materials cannot be reclaimed. A “cradle-to-cradle” methodology has emerged recently in design and manufacturing, where a product is planned from the start with its complete lifecycle in mind. Currently, zero home cooling units/devices exist that can be disposed of in a zero-waste methodology; window air conditioning units in particular contain harmful refrigerants, which while they now have zero effect on the ozone layer, they can have anywhere between a GWP of 1300 and 1525 per pound of refrigerant [III]. These refrigerants make it highly unsafe for air-conditioning units to be disposed of in a traditional landfill. Therefore, an opportunity exists for the creation of a cooling device using a zero-waste philosophy.

Project Summary/Background:

Our team is seeking to address the problems through exploring an alternative, potentially greener method of air-conditioning. developed in a sophomore studio design class: an air-conditioning system that used a fan to cool air by blowing it through or over ice, intended for small homes. At the end of the class, the concept was untested, and it was unknown what method of ice presentation would be most effective, if any at all. NYSP2i provided an excellent opportunity to test out the feasibility of the device and compare it to cooling appliances on the market.
Potentially, our cooling system could reduce the amount of electricity used to cool the many non air conditioned rooms and housing locations on campus. What makes our design unique is that rather than waste energy in attempting to cool an entire space, we instead are focusing on cooling the surrounding area of the individual, which is only truly relevant, especially when one considers the amount of time an individual stays sitting in one place all day. Additionally, few methods of small-scale cooling using ice has been implemented in the context of a small residential space, outside of the small amount of DIY projects available online, and a product that became available on the market between the original NYSP2i proposal and the conclusion of the project. Therefore, we are utilizing ideas from the large scale ice-cooling processes, and testing to see if they can be scaled down. As very little scientific small-scale evidence is available for ice systems, we are using our testing approach to help us understand the limitations of cooling with ice, and how it might be best optimized, especially when considering the limits a user might have in terms of freezer space and ability to cycle the ice bricks when they are fully melted.

We are including the additional dimensionality of cradle-to-cradle design because of the need for the mentality to enter the product design process. Our concept seeks to build upon the existing materials and design approaches developed with the mindset of regenerative design and apply them to home cooling. Specifically, as taking into full consideration of the cradle-to-cradle ideology is beyond the scale of this project, we chose to focus on the materials reuse aspects of cradle-to-cradle design. Therefore, evaluating what material choices we might take is important to consider, but ensuring that the user can separate the parts of the appliance, and be able to dispose of them properly is just as imperative to the success of the design.

A variety of small appliances currently exist to address cooling needs in residential settings, each with their own advantages and disadvantages. The most common type of residential unit (after central air conditioning) is the “window” air conditioning unit, which requires very little technical installation, and relatively simple maintenance. The appliance relies on a refrigerant cycle that absorbs heat from inside air, and releases it outside [IV]. Recent models have seen an increase in their efficiency especially with the advent of Energy Star appliances, an initiative started by the U.S. government in 1992 [V].

Evaporative coolers (colloquially known as “swamp” coolers) are appliances that use water as a form of cooling. Unlike the ice model we have proposed, evaporative coolers rely on the relatively high enthalpy of vaporization of water, drawing heat from the surroundings to evaporate the water within the device, creating a cooling effect in the room. While effective, and more energy efficient than a window unit, the process increases the humidity of the inside environment, allowing for it to only be used effectively in dry climates [VI] (which is not feasible for the humid summers).

Ice as a method of cooling, used for many years before the introduction of air-conditioning units, has recently resurged in popularity, especially in use in large building complexes. In 2010, the Southern California Public Power Authority began retrofitting 1500
municipal buildings with 6000 rooftop units that freeze water at night when energy demand is low, and pipe a stream of cool water to an evaporator coil for cooling air during the day. These devices potentially cut power usage “by up to 95 percent” [VII]. Several skyscrapers in New York City have also begun to use ice to supplement their air conditioning systems, including the Bank of America Tower and Morgan Stanley [VIII]. Our project was directly influenced by the modern use ice as cooling, and is an attempt to see if it can be scaled down.

The closed life cycle concepts we integrate are derived from the book *Cradle to Cradle*: released in 2002. The authors, Michael Braungart and William Mcdonough (a material scientist and architect accordingly), argue that humans and the economy can exist with not only no negative impact but a positive impact on the environment. Specific to product design, the book details the integrated design process, appropriate differentiation and disposal of biological and technological nutrients, and ensuring the components of a product are not only safe, but beneficial to human health. Through the establishment of the Cradle to Cradle Products Innovation Institute they have cataloged and detailed 2,000 materials so that other producers may do the same [IX].

**Relationship to Sustainability:**

Developing a cheaper, more cost-efficient product could have implications in terms of environmental justice, especially for socioeconomic status. It is particularly important to pay attention to the prevalence and costs of cooling devices for people who rent homes as opposed to own; renters have an average yearly income that’s 47% less than the average income of a home-owner and yet spend 35% if that income on their housing, versus the 21% of homeowners. Additionally, 47% of rental housing does not have a central air conditioning system, versus 28% of owned housing units that do not [XII]. These numbers are important because renters generally have limited ability to install some of the more cost-effective cooling methods purported on websites such as energy.gov, such as better insulation, ventilation, or even ceiling fans, and must rely on the more expensive, energy inefficient integral units [XI]. Considering the fact that rentals represent two out of five occupied homes in the United States, developing a more effective cooling system that can be purchased without any additional installation could potentially affect the quality of life of many citizens [XII]

Additionally, demonstration of the creation of a cradle-to-cradle device, especially with a design that an uninformed user could easily repair or recycle would be a great promotional tool, especially for the relevance of industrial design in sustainability. Currently in certain programs at our college, sustainability is taught as more of a marketing consideration, and lifecycle development is not generally a part of curriculum. Demonstrating how design thinking most certainly comes into play when evaluating product lifecycles could promote and influence the current methods of teaching in the program.
As our cooling device would only be powered by a 120W fan, the energy savings versus a 6,000 BTU air conditioning unit would be about 1.75-.12 kw an hour. Additionally, our design would consume less materials in creation, and produce less waste than the average air conditioning unit. The impacts on the local environment are difficult to measure; however, 100% less greenhouse gas emissions from the fan itself would be a guarantee of our device.

Of course, a few trade-offs occur in the context of our cooling unit. Compromise of user comfort might occur; the device may not be as effective as an air conditioning unit, and the user must change out the ice at least every 3-4 hours. Additionally, the device could cause an increase in the consumption in water. Currently our model has it use a gallon of water in the ice bricks that can be reused for multiple cycles. However the user might want to clean out the ice bricks once every two months, causing an increase in water use at six gallons a year. Additionally, the energy used to freeze the ice blocks in the freezer might cause an additional hidden energy cost.

Materials and Methods:

The experiments occurred in three phases.

The first phase was used to establish benchmarks for the relative effectiveness of the three methods of ice containment our group decided to concentrate on: cubes made from ice trays, as well as recycled plastic bottles and aluminum soda cans, both filled with water and frozen. The three methods were chosen in particular because of the relative availability of materials, potential for upcycling, and ease of use for the user. Other methods were considered, including frozen ice blocks, and large frozen bowls of ice, but were ultimately dismissed for being too unwieldy for the average user to realistically be able to handle.

Each method of ice containment was placed in front of the fan (a 10 inch Honeywell desk fan we intended to use as part of our final design), and the temperature was recorded each second using a digital thermometer (an Arduino with an attachment programed to record temperature onto an SD card, designed by one of the team members) set 46 cm away. Each test took two hours: first, the thermometer would be turned on for 30 minutes to capture the a constant starting temperature of the room, then the fan would be turned on, and the ice placed in front of the fan. The thermometer would be run for another 90 minutes. Each set-up was tested three times.

The second phase of the experiment took the benchmarks from the different ice presentations and tested out different methods of containing and controlling the airflow. Many of the experiments involved creating rough cardboard box set-ups to see how that might affect the temperature difference produced by the ice. The most notable experiment in this phase was an alternative method of presenting ice cubes. In the initial phase, the ice cubes were presented in a plastic bowl, which did not give expose the majority of the mass to enough airflow. Instead, a set up was devised to increase the surface area that used aluminum cans with the ends removed and attached to form tubes. The ice cubes were then placed on and around the tubes and air was
circulated through the aluminum cans. During the majority of the second phase, the thermometer was still placed within 46 centimeters of the ice.

During both phases, notes were taken on the ease of use of each of the three methods of ice presentation, to better inform the final design. Additionally, all three phases of testing occurred within an apartment bedroom with little disturbance and stable temperature.

The third phase of the project involved the creation and testing of the final design of the model. Temperature differences as well as qualitative notes on use were used to from the first two phases were used to pick a preferred method of ice presentation. Initial concept sketches were then created, and evaluated. A 1:4 scale model was created, and edited so that it used wood the most efficiently. Rough full-scale cardboard mock-up models were also created and tested. After a few rounds of creation and tweaking, a final design was decided on, and constructed, using a piece of plywood and a ShopBot, with the help of a graduate student. The design was outfitted with the Honeywell fan, as well as environmentally-friendly(er) insulation, and then tested for effectiveness, at both close range, and from a distance.

The group leader was in charge of testing, evaluation, and design of the final type. The partner was involved in the design and programming of the Arduino thermometer, as well as assisting in experiment design, and result interpretation.

Overall: Professors gave design feedback. Partner took care of electronics and consulting; Team Leader ran experiments and constructed design.

**Results, Evaluation and Demonstration:**

The different methods of ice containment were evaluated both quantitatively and qualitatively to best inform the final design.

We evaluated the methods of ice containment on two parameters: water used and the cooling effect produced. Overall, we found the ice cubes to be the most effective, cooling the air by an average of 1.2 degrees Celsius with .71 liters of water for a cooled air:water volume ratio of 1.6, more than double the average cooling ratios of the bottles and cans. The cooling effect ratio of ice cubes was heightened to 2.3 when placed in the configuration that had increased the cold surface area exposure through passing air over empty aluminum cans surrounded by ice.

Despite the effectiveness of the ice cubes, the greatest change in temperature difference was seen in the plastic water bottles, where a cooldown of 1.9 degrees was achieved with just four water bottles, versus the 1.2 degrees produced by the ice cubes. Additionally, the cooling effect lasted longest with the plastic bottles versus the cans or the ice cubes. Doubling the bottles, however, only produced a cooling increase of 28% (as opposed to 50%), likely because it was difficult for the air to gain full surface exposure to the additional bottles beyond the four in front of the fan.
One of the unexpected results of the experiment was that when the fans and ice containers were enclosed in a box (meant to simulate the eventual box the items would be contained within), the difference in temperature decreased by typically .1-.2 degrees, usually by a factor of 7-10%. After consideration of the experimental set-ups, it was determined that a few changes in positioning of the containers to accommodate for the box; the information was used in the creation of the final design.

In addition to the change in air temperatures, qualitative, user-oriented measures for the three types of materials tested were also evaluated in the following categories: ease of use, relative time taken to cool, freezer space occupied, and sustainability. While taking these aspects into consideration may not initially seem important, our group did intend for the fan to be used in a household/dorm life environment, and the above use metrics are what overall informed our final design.

Of the three ice containment methods, frozen plastic bottles proved to be the easiest to use. Since less were needed to contain more water, less trips to the refrigerator (typically 2-3 on average) were required for each new experiment, versus the aluminum cans that could typically be carried only 2-3 at a time, and, because they had no top, were likely to spill after the end of a test. Ice trays were easier to use than aluminum cans because their stackable nature allowed for only one trip between the freezer and the fan; however, finding a balance between exposing the cubes to the fan while containing the melted aftermath proved to be challenging and at times, difficult to clean up.

Ice-filled aluminum cans proved to have the smallest footprint in terms of freezer space, followed closely by versatility of the plastic bottles. Unlike both the plastic bottles and the ice pans (which could not stack when water was freezing), the cans could stack, and thus occupy smaller amounts of space. Additionally, the cans were better able to fit into areas of the freezer that the bottles and pans could not, namely the door. The plastic bottles, while they did not fit into our particular freezer door, could be tossed anywhere within the freezer because they had a cap. Ice trays proved to take up the most footprint, and were the most difficult to deal with: they could not stack when water was freezing, and had to be kept level, which occupied gross amounts of space that could be better occupied by other needs for the freezer.

The relative sustainability of each method of ice containment was also evaluated, with a tie between the plastic bottles and the aluminum cans. Both the cans and the bottles were evidence of upcycling; all materials used in the tests were reclaimed from the trash. Additionally, the water used in both the bottles and the cans could be almost infinitely recycled between tests, with the bottles being slightly more water efficient, largely because they did not spill water or allow for the small amounts of evaporation that occurred in the cans. Sustainability-wise, the ice trays were the worst. Water used from each experiment, while it could be reclaimed, was more difficult and likely to spill than the cans or the bottles. Additionally, ice trays are produced with one purpose in mind: being an ice tray, which, while reusable, still has a finite shelf life. In fact,
over the course of testing, the trays themselves began to break (and leak), and needed to be replaced afterwards. And while it is true that ice cubes can be produced through other means (i.e. ice-makers), additional electricity is required to produce the ice, as well as the fact that the water produced from ice cubes not created through an ice tray cannot be reclaimed for any purpose beyond watering plants or housepets.

The information gathered in the first two phases of the experiments informed our design, which successfully incorporated a cradle-to-cradle approach. After considering our research, we decided to use eight plastic bottles arranged three lines contained within a diamond shaped box that better directed the air around the bottles. Our team decided to choose plastic bottles because of their sustainability and viability, combined with the fact that although they were not as efficient as ice cubes, they still produced a significant cooling effect. Mock-ups of our design showed a temperature difference of 3.5 degrees Celsius, for a water use ratio of .82, almost equivalent to the original water.

We revamped the original concept for the fan, as it was wasteful, overdone, and involved fasteners and paints that did not have eco-friendly substitutes. After looking back at the model, our group created a more tasteful and environmentally friendly design that better incorporated upcycled materials as a means of air cooling, and eliminated all needs for additional fasteners. The lack of fasteners and interlocking design of the piece also allows for a more sustainable product. For example, in the event that, say, one of the legs breaks, the user could easily replace the leg, rather than the whole furniture piece. Additionally, the design is easily flatpacked, allowing for it to be stored away when not in use, or easily transported and moved from place to place.

**Economic costs:**

The initial and running costs of our fan are fractions of what it costs to buy and run even the smallest window unit. The cost of wood for creating the fan was around $13.00, the insulation cost $5.00 while the fan itself cost $17.00, and the water bottles were free. The least expensive models for a 5000 BTU window unit (which will comfortably cool a bedroom) cost around $130. Our device initial costs are 27% of the window unit. On average, a 5000 BTU window unit uses 550 watts. Assuming the device is run 16 hours a day, and using the average of about 9 cents a kwh for our city, it would cost around $.79 a day or $23.70 a month. On the other hand, our device runs on 35 watts. Assuming the device is run 16 hours a day, using $.09 a kwh, it would cost $.05 a day, and $1.50 a month, 6% of the cost to run a window unit. The only aspect of the economic analysis we did not include (largely because of the difficulty in measuring) would be the potential increase in electricity used by the freezer in ice creation.

Of course, our device does not produce the total room cooling effect that a window unit would produce, and would not be as nearly as effective as the window unit, particularly in hotter climates. The highest temperature difference our unit was able to achieve in testing was a
difference of 4.5 degrees celsius, whereas window units are typically capable of differences of 15 degrees celsius or more. Even so, 30% of the cooling capacity of a window unit can be achieved for less than 27% of the price, with the margin increasing each month the device is used.

Our design has the potential to be scaled upwards into larger appliances for the home, or even office spaces; after all, we are using a 10-inch fan in the original design; Designs that incorporate larger fans could potentially be more powerful. Additionally, incorporating an ice-freezing system into the model (i.e. overnight the unit freezes its own ice, and during the day uses created ice) could be potentially more robust or user-friendly, although the sustainability of such a device would have to be established. As discussed before, self-freezing systems for mid-to-large size office buildings do exist; as our group has demonstrated here, there is potential for a piece designed for home to small business use.

The concept will be represented by a working model and a short video presentation.

**Conclusions:**

We learned that ice as a method of cooling can be more effective than expected, and might be beneficial to implement in limited needs climates such as New York state (which typically lacks the more energy-efficient CAC systems in most homes); however, even after testing and evaluating three different methods of ice containment and arrangements (and found frozen water bottles to be the best balance between effectiveness, user experience, and sustainability), our device does not come close to the total room cooling capabilities of a window unit and could use more investigation.

Many more experiments could be performed to both enhance our device and solidify our conclusions. For example, different materials and methods could potentially affect how the device performs; perhaps obtaining some different, more environmentally friendly insulations (such as mushroom foam insulation, not currently available on the market) could affect the cooling point of the device, or trying out the effect of larger-sized fans. Additionally, because of the time our group had to complete our research, and the diversity of tests that we had to complete, each test was limited to a 90 minute run, and each set-up was only tested three different times; further investigation into each could help strengthen our results. While controls were set in place to account for the differences from experiment to experiment (i.e. the variable temperature of the test site, as well as the differences in volume of water held by each container), better environments and more precise measurements could have been established. Greater scope in examining the area of effect of our device would be desired, as well as testing it in different settings (classroom, laboratory tests, etc.). Finally, a benchmark test against other cooling devices (which, due to restrictions, our group was not able to complete), and methods of ice cooling would help us compare and build upon our results.

Overall, the device has some potential for implementation. The construction is straightforward, useful, and non-imposing, and does produce a heightened cooling effect ideal
for students for the short periods of time in the school year where it would be wanted. Whether or not the device has a potential for non-students (such as city citizens) as whole would be up in the air, and would need some more research into the user needs of the area. However, we have shown that cooling with ice can have some beneficial impacts in the home, and is an area of possibility for future endeavors in sustainability.