AC Duct Research Overview

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Introduction

In countries with warm climates and a growing middle class[1], window mounted air conditioning units are often installed where it is convenient to do so, and not necessarily where they are the most needed. As a result, the primary room that the user wants cool is not the same room where the AC is, and thus the user has to run the AC on max in an attempt to cool the desired room via diffusion. In this scenario, the single AC is not filling the user's needs, and in an attempt to try and make it do so, the user accumulates a larger electric bill and racks up the environmental impacts of running an AC on high, and for longer periods of time. Our goal is to design and implement a solution to this problem that would allow ACs in such scenarios to be used more efficiently, and thus reduce environmental impacts.

We collaborated with colleagues in India and Pakistan to design an air conditioner 'duct' that could be implemented in those locations[2] to solve the stated problem. The basic idea of the duct is to re-route the air from the AC to where it is needed, allowing the AC to run for shorter amounts of time/on a lower setting, but still achieve the same level of cooling. In this way, the AC unit can be used in a less environmentally-impactful way, saving energy, and saving money.

We spent a semester doing roughly two credits' worth of work for this project (approx. 6-8 hours per week). We did our best to come up with as many solutions to the given problem statement as possible, and then spent a large portion of our time prototyping and testing out ideas in hopes of finding out which ones work and which ones do not. All of our work then cumulated in the construction of two prototypes that implement the best ideas/findings.

The next steps for the endeavor are to send out the two prototypes to the subcontinent for an initial round of testing over the2009/2010 winter. With the user feedback from these initial tests, we plan on making appropriate design changes to the duct system and sending out plans for a more finalized version of the duct, to be manufactured on a small scale and more vigorously tested in the 2010 summer. From those tests, we will hopefully have enough information to create a final design, and then we can begin marketing and selling the duct system in the subcontinent.

[1] By our definition, 'middle class' refers to anyone who can afford a window-mounted AC unit, but probably not two

[2] India and Pakistan both have very hot summers and a very large and growing middle class, and thus, we thought, are good candidates for the implementation of such a system.

Fig.1

One of the duct prototypes constructed as part of this project. This particular one is made from a blue lining, lined on the inside with 1mm plastic, mounts to the wall/ceiling, and is constructed of ~5m segments that clip together.

Summary of Design Factors and Decisions

In our research & prototyping, we explored a number of design factors related to the duct system: materials, aesthetics, durability, price, cleanability, suffocation dangers, air-tightness, modular length, attachment to the AC, and the duct-house interaction. What follows is an attempt to capture our findings, questions, and tentative decisions about the design factors.

Materials

(0 = bad, 5 = excellent) We're striving for as many 5's as possible in our choice!

	Aesthetics	Durability	Price	Cleaning	Suffocation	Air-Tightness	Weight	Flexibility
Rating Explained	5 = pretty	5 = durable	5 = cheap	5 = easy to clean	5 = no suffocation	5 = very air tight	5 = light	5 = flexible
Textile	5	5	0-4	5	5	0-5	0-5	5
Plastics	1	2	5	4	0	5	5	0-4

Aesthetics

- **Consideration**: Though we can see the possibility of using a material that is ugly for the duct (such as plastic), we figured something aesthetically pleasing would be more readily accepted by users, more welcomed in their homes, and would emanate more of an aura of permanence, which would lead to the duct being treated better and (hopefully) not thrown out as readily.
- **Our Findings**: Certain textiles look gorgeous, while every plastic we tried looked terrible. The plastics crinkled, bent, and looked cheap and disposable. The textiles were nice to touch, pretty to the eyes, and both of us agreed that we could put certain textiles up in our own houses.

Durability

- **Consideration:** The material will most likely be subjected to being stepped on, pulled, cleaned, and the stresses/strains of the duct's setup phase, and must not break. Pets may/may not be a factor to design for.
- **Our Findings:** There's a constant struggle and balance to be found between durability and weight. Heavier/thicker fabrics & plastics (like corduroy and 4mm plastic) are quite durable, but are so heavy that they can't inflate, while lighter/thinner fabrics & plastics (like linings and

.7mm) are more vulnerable to tears, and, as with the .7mm plastic, are so fragile that they aren't much good for anything.

Price

- **Consideration:** Though there is certainly the possibility of designing a high-end duct (possibly with more advanced features like temperature feedback to the AC), in our pursuits, we're trying to design something that is for the middle and lower classes; something that's functional, permanent, but affordable, and ultimately, would not only save energy and help the environment, but save the user some money. It has to cost little compared to a new AC unit, as we'd rather people buy a duct than a second AC.

Cleaning

- **Consideration:** The duct will be in a house environment, where it will be exposed to dirt, particles, and other assorted things. Thus it will most likely occasionally need to be cleaned, and a material that is easy to clean is desirable.
- **Our Findings:** Textiles have the benefit of having the ability to easily be thrown into a washing machine/hand washed. Likewise, plastics are easily cleaned (only manually though) by hand with a sponge.

Suffocation

- **Consideration**: Suffocation is a big consideration in our material choice; we don't want there to be any chance of any person – especially babies or small children – suffocating on the duct.
- **Our Findings**: We found that plastic easily stuck to the face, nose, and mouth, and could very easily cause suffocation. On the other hand, every textile we tested posed no risk of suffocation.

Air-Tightness

- **Consideration:** Having a duct that is air-tight is desirable, as more air gets to where it's supposed to go.
- **Our Findings:** Plastics performed terrifically here, having 100% air-tightness. Certain textiles (generally, linings and anything that was see-through) were not air tight, while tighter-woven polyester, polyester/nylon, acetate, polyester/cotton, and cotton/spandex materials worked fairly well (just a bit worse than the plastics). However, a hybrid of both – a textile tube lined with fabric on the inside – is a very compelling third option, combining the best of both worlds.

Weight

- **Consideration**: The lighter the material, the more easily the tube inflates, the less the AC unit has to work to inflate the tube, and the more air comes out of the end of the tube, and the better the duct functions. A more easily inflated tube is also desirable for rounding corners (such as in doorways to hallways), as air is restricted less.
- **Our Findings**: Most textiles were light enough to be used. The exceptions are corduroy, heavy canvases, and things like twill suiting. For plastics, the sweet spot is 1mm-2mm thick stuff, which is durable and light enough to easily inflate. For most of our final prototypes, we used 1mm.

Flexibility

- **Consideration**: A flexible material allows the duct to bend more freely, and thus work better around corners.
- **Our Findings**: Fabric (with the exception of really heavy ones like corduroy) worked great, and plastics <= 2mm thick worked well too. But heavier fabrics and thicker plastics had trouble bending well, and would create pinch-points when they bent, which restricted air flow and severely damaged the performance of the tube

Final Thoughts

- Though going for cheap, airtight plastics is a definite option, the suffocation risks, coupled with the poor aesthetics make this option unattractive.
- Therefore, we strongly recommend that textiles be used for the future of the duct. We believe that going with a material that definitely has no risk of suffocation, looks better, creates a sensation of quality, inflates easily, and is quite durable… well It's better. The air-tightness issues of fabric can be easily overcome by either selecting the correct fabric or by creating a hybrid textile-outside, plastic-inside duct that combines the best qualities of both materials, and is exceptionally air-tight, while still looking good. Though textiles can be quite expensive, even in the U.S., we found textiles that sold, on a commercial scale, for $1/yard, and we know that in India/Pakistan, textiles can be quite cheap (starting at 17c/yard). Furthermore, a duct made of fabric seems more like a product, and is less likely to be thrown away (we believe; especially when compared to a plastic tube).

Desired feedback from users

- Are aesthetics as important as we have made them out to be? (i.e. Do you care how pretty the duct is?)

Things we still need help with

- Identifying a cheap, aesthetically-pleasing, quite airtight fabric that could be used in future prototypes
    - With fabrics, the general rule of thumb we found was going for as light of a fabric as possible, and as tightly-woven as possible (should be near impossible to see through it).

Duct-House Interaction

The question here is – how permanent of an installation should the duct be in the house? Does the user want the duct out only when it's being used, or is ok with it being a more permanent fixture in the house? There are a lot of questions here, and so we'll start by splitting the issue into two broad categories: a 'permanent' and 'temporary' duct configuration.

There are two main use cases that we believe the duct has: to be installed as a relatively permanent fixture in the house (implying that it would be affixed somewhere out of the way, and very infrequently taken down), or be used as a temporary attachment when needed. Both have validity behind them, and we haven't figured out which one is best, but hopefully though feedback and user input, we can narrow down on one of them, or come up with some middle ground!

The 'Permanent' Configuration

- If the duct were to be 'permanently' affixed in the house, it would most likely be tacked up to the ceiling/ceiling-wall corner/high wall space, as to avoid obstructing doorways and passage through hallways. In this case, the duct has to be pre-fashioned with some sort of 'tabs' or rings that the user could use to secure the duct to the wall.
- **Benefits**:
    - This has a great 'set and forget' interaction, where a one-time installation is done, and then the duct can be used as needed whenever, no setup required again.
- **Drawbacks**:
    - The duct is always there. If the user isn't particularly fond of the way the duct looks, then that could be a problem…
    - Tacking the duct up will create permanent holes in the user's walls
    - May be difficult to put up that first time
- **Thoughts**:
    - The trick here would be to make the duct seem as a decoration or that it somehow fits in with the home.

The 'Temporary' Configuration

- In this configuration, the normal use case for the duct is to be taken out when it is needed, and put away when it is not. If a room needs to be cooled, the duct is taken out, run there, and then put away afterwards.
- Tentatively, this is simply done on the floor, but could conceivably be run along the walls as well (though this would require more setup)
- **Benefits**:
    - When the duct is not in use, it does not interfere with the ambiance of the house
- **Drawbacks:**
    - There's an unavoidable setup time each time the user wants to use the duct
    - If on the floor, the duct can get in the way of doors and people walking, and can be a general nuisance

Final thoughts

Based on our conversations with people, the primary use cases for the duct are either to cool a separate room (where the children are sleeping), or to cool the living room before guests arrive. In these

cases, the put-out and put-away temporary solution may work better, as other than those two use scenarios, the duct would not be in use, and thus wouldn't interfere. However, if guests are constantly coming over, or there is a desire to use the duct more frequently, taking it out/putting it away this often may prove to be a nuisance, and a more permanent installation would be more desirable.

This one is really up in the air. Both cases have a strong argument to them, and could be possibilities. It really all depends on the user and the specific family and living quarter configuration (some families are larger, and therefore have more guests coming over, while others simply like to keep to themselves more, and thus have visitors less frequently. Some might be ok having everyone sleep in the same room at night, while others have a desire to separate the generations).

The solution may lie in fusing the two solutions; putting 'tabs' on the duct no matter what, so that it has the option of being mounted to the wall/ceiling, but it can always be run along the floor as well.

Desired feedback from users

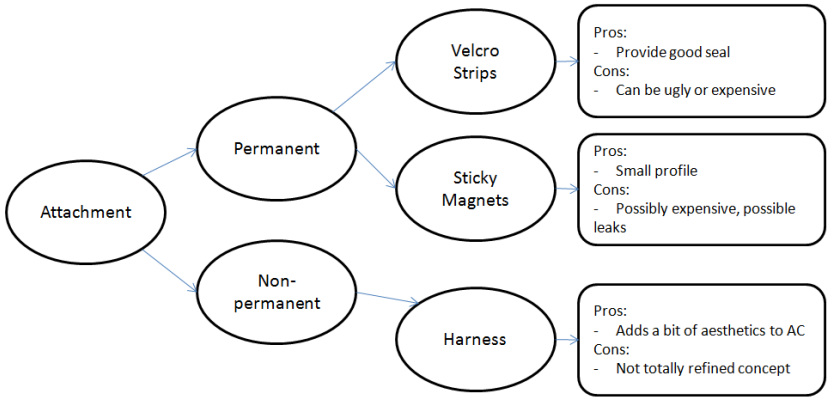
- How often are you in a situation where using the duct is beneficial?
- How often did you actually end up using the duct?
- Which configuration do you find more favorable?
    - Did you find yourself wanting to have the duct more on the floor, or on the walls/ceiling?
    - Do you like the idea of the duct as a temporary, or as a more permanent installment?
- (if applicable) Overall, how was the process of putting up the duct?
    - Who performed the installation? (Did you do it yourself, or hire someone to do it for you?)
    - Were there enough points of mounting to configure it as you desired?
- (if applicable) Do you mind putting holes in your walls to put the duct up?
- General impressions?

Things we still need help with

- Providing more examples of use-scenarios
- Feedback

Attachment

The duct needs to somehow attach to the window-mounted AC unit, and this attachment needs to be modular and fit a variety of AC exhaust vent sizes.



With the attachment, there are two main roads of thought: permanent attachments (which are affixed to the A/C via some sort of adhesive), or non-permanent attachments, which can be taken on/off of the AC. As we currently stand, we're not completely sure how users feel about attaching something sticky/permanent to their ACs, though preliminary explorations are indicating that users don't really care about attaching things to the AC, as the unit itself is often considered an eyesore already. In this regard, we actually have an opportunity to have our attachment method cover up the AC unit, or add some elements to it that not only aid the attachment of the duct, but also cover up the unsightly window mounted AC unit with nice fabric.

Talking specifically about the attachment methods, though we see great potential in the harness idea (some elastic 'harness' that is put on around the AC and can stretch and adjust to fit various AC and vent sizes), the design for it hasn't quite been solidified yet. However, the Velcro strips/sticky magnets concept is pretty simple and straightforward, and promising.

In order to have the attachment fit virtually any AC vent size, the initial attachment point must be designed in a modular method. Currently, this involves the construction of a 'funnel' that is permanently attached to the duct, and, on the other end, is of a larger size than the duct, allowing for attachment to most AC vent sizes. On the other side of the funnel, the attachment side, we made prototypes with either 8 embedded neodymium magnets, or 8 pieces of Velcro. The user then simply attaches the funnel to the AC unit via one of the methods described above. However, having the funnel attachment point be drastically larger than the vent size can lead to sealing issues. Because of this, we are considering implementing a drawstring on that end, so the user can adjust it to their specific AC unit specifications, and get a better seal.

But in all of these things, user testing will do a great deal in helping us see whether these methods are plausible, whether a non-permanent attachment method is desired, or if there is some other better method out there..

Final thoughts

- We don't have a definitive answer for this yet, but are looking forward to feedback and ideas from users/reviewers.

Desired feedback from users

- Is a 'permanent' attachment (where some adhesive ends up on the AC) permissible?
    - Is a non-permanent attachment more desirable?
- How well does the attachment fit your AC?
- How easy was it to install?
- Any suggestions/ideas for improvements or other attachment methods?

Things we still need help with

- More ideas and better methods for attaching the duct to the AC

Variable Length

The duct needs to be modular and adaptable to a variety of house/apartment configurations and sizes. Different users will have different needs for duct length, and it somehow needs to accommodate them.

Our Solution(s)

- We came up with two main methods of solving this problem: splitting the duct up into segments that can easily be combined, and embedding a drawstring to change the duct length. And an alternative that combines the best of those two methods.

Clip-on (magnetized) Segments

- The duct can be sold as a modular collection of long and short segments, and the user can buy as many as they need. (One sample amount is a long segment could be approx. 10m, and short segments are 5m each). This would allow the user to purchase as many segments as he/she needs for their particular living arrangements, and thus customize the duct system to suit their needs.
- We came up with two primary methods of connecting duct segments: clip-buttons and magnets. Then we built a prototype with each, and learned the following:
    - Embedding a set of magnets (4-6) in each tube side was not only seriously inconvenient to manufacture, but didn't work all that well. The magnets do not offer any sort of feedback about whether they've engaged or not. Also, despite using strong neodymium magnets, they lost much of their strength through several layers of fabric, and thus came apart quite easily

    - However, we found that using the clip-buttons worked fantastically! They have a clear outer visual indicator, are easy to manufacture and add into the tube, offer great physical and auditory feedback when clipped together, and are very strong (Have a high resistance to being pulled apart).
        - While prototyping with these buttons, we learned a couple of things. We used 4 per segment side, but we think 5-6 would be the ideal number (provide a better seal, balanced against ease of use and cost). Also, there needs to be a non-trivial amount of overlap between the segments (around 4 inches) for a minimal amount of air to escape. Furthermore, the place where the clip-buttons are attached must be reinforced with extra fabric (to prevent ripping).
    - Overall, the clip buttons worked quite well and, in our opinion, outperformed the magnets by a long short. There are still minor issues with the seal that need to be ironed out, but we believe they have great potential.

Drawstring

- The other plausible idea that we came up with for changing duct length is by embedding a drawstring inside of the duct (similar to those found in sweaters), which can be pulled on by the user to shorten the length of the duct.
    - In our prototyping, we learned that it is important to sew a pocket that's twice or three-times the size of the rope running through it, so that it can freely move and scrunch up.
- We believe this simple method has potential, and are looking forward to field tests to either validate or disprove it!

A combination

- Alternatively, the best aspects of both ideas can be combined into one:
- The duct can be sold as large (10m) segments that each have a drawstring and are thus more customizable on-the-fly, but can also snap together through magnets/buttons and form longer segments.

Final thoughts

- Though we have these ideas, and have implemented them in the prototype, we're really looking to the users here to tell us what works and what doesn't. We are also still trying to overcome sealing issues in the segment idea.

Desired feedback from users

- How do you feel about the interaction of the magnetized segments?
    - Would you be happy with/satisfied with clip-buttons instead?
- How do you feel about the interaction of the drawstring?

- Which part of the room do you prefer to have the duct terminate in? (the entry point, where you are, etc.)
- After the initial configuration, how often (if ever), do you have a need to change the length of the tube?
- What duct length(s) would be ideal for your configuration?

Things we still need help with

- More ideas of creating variable length
- Alternate solutions besides magnet/clip-button for the segments idea
- Thoughts on the various methods

Other Findings

Through our prototypes and experiments, we noted a couple of other things that we thought were important to share.

Duct Diameter

- In our explorations, we found the ideal duct diameter to be approximately 10.5 inches (33 inch circumference). Having a duct diameter that is too small will severely constrict air flow, while a size that is too large will be too cumbersome for the user to use. Thus, approximately 10.5 inches is the ideal size, which balances air flow against user considerations.

Aesthetics

- Though it is possible to not consider aesthetics in this duct system, and offer a cheap and low-quality product, we believe it is best to shy away from doing so. We strongly believe that a duct that looks good and feels good to the user will be used more frequently, will be repaired if broken, and will be treated better throughout its lifetime. Plus, it will be another selling point (or at least not a detractor) from user's decisions to purchase a duct.

Crimping the End

- One of the things we found was quite important in the good functioning/interaction of the duct was the 'crimping' of the end of the duct, reducing the final diameter by 1/3, ½, or ¾.
- Crimping the end creates a backpressure in the tube, which effectively inflates it.
- As a result, air flows at a much higher velocity out of the tube, and the tube is significantly more inflated throughout its length. A more inflated tube allows the duct to work better around corners (as it stays more inflated). Furthermore, a more inflated tube, alongside air coming out

faster increases the user-interaction, as the tube seems to be *doing more* to the user; more air is coming out, and because it's inflated, logically, air is flowing through.

Split-Unit ACs

- Especially in countries like Pakistan, split-unit ACs are gaining tremendous popularity for their efficiency over window-mounted AC units, and as their cost drops, more and more people are purchasing them. Thus, this is an important next step for this project, to consider and possibly design specifically for split-unit ACs as well.

Conclusion

All of this has cumulated in us creating two prototypes that explore many of the unknowns that we've pointed out in this summary (floor or ceiling, Velcro or magnets, segments or drawstring), as well as realizing the 'knowns' that we've decided (partially crimped end, textile material, etc.).

And now, onward to feedback and user testing! Through both of these processes, we hope to get answers to the ambiguities, have our assumptions challenged, decisions confirmed, and ultimately, re-build the prototypes into an actual product that is marketed and sold in India.

The future direction of this project will include a further exploration into design specifically for split-unit ACs, as well as for implementation in other countries like the Americas.

Yours truly,
- Boris Taratutin & James Regulinski