Energy and the Environment Capstone Design Project – Bass Connections 2019-2020

Exploring Hand Drying Alternatives to Paper Towels

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1. Abstract

Across Duke's campus, paper towels are widely used as the primary hand drying method in restrooms, and are expensive, messy, laborious to maintain, and unsustainable. We assessed the feasibility of replacing paper towel dispensers with electric hand dryers in Duke University's restrooms, examining the issue from social, environmental, and economic perspectives. Through a consumer research survey on consumer preferences for hand drying methods, we found that three out of four restroom visitors would be amenable to the idea of replacing paper towel dispensers with hand dryers. Using collected data as well as a literature review, we found that replacing paper towels in residential dorms could result in a removal of 339.62 metric tons of carbon dioxide equivalent over five years, or about 0.14% of Duke's 2017 emissions. Finally, after conducting a financial analysis, we found that over five years, the university would save about $96,000. Through the course of our study, we have concluded that this retrofit would be beneficial on both environmental and economic fronts, and would be agreeable to most restroom visitors.

2. Introduction

2.1 Problem Description

Duke University primarily uses paper towels for hand drying in restrooms across campus. Undergraduate residential dorms consume approximately 21,600 rolls of virgin Georgia Pacific paper towels annually (Smith, 2019), while other university buildings (academic, dining, offices, etc.) use 38,748 rolls of Scott paper towels of 60% recycled content (Eaton, 2019). Each year this hand drying method on campus produces 114 metric tons, or 629 football fields, of paper towel waste, and clutters restrooms as used towels overflow bins and litter the floor (Eaton, 2019; Smith, 2019). Ultimately the waste is shipped to and disposed of in landfills, the closest of which is located in Sampson County, NC, more than 92 miles from Durham (Norwood, 2020). Additionally, the university spends $581,653.68 per year on paper towel purchases alone (Eaton, 2019; Smith, 2019), with additional funds going towards paying custodial staff to clean paper towel-related waste, lining trash bins and removing and disposing of paper towel waste.

2.2 Literature Review

In addition to contributing to stress on landfills, paper towels have been identified to be a relatively carbon-intensive method of hand drying, largely due to the carbon- and land-intensive process of pulp production (Ingwersen et al., 2016). Comparative life cycle analysis (LCA) studies have calculated the relative global warming potential of paper towels and hand dryers, suggesting that high-speed hand dryers produce less lifetime emissions. However, many of these studies have been commissioned by electric hand dryer manufacturers suggesting conflicts of interest (Joseph et al. 2015; Gregory et al., 2013; Dettling et al., 2009).

Over the past decade, many college campuses have attempted to reduce paper towel usage for various reasons. The University of Sussex (“University to cut,” 2017), Temple University

(Furey, 2016), University of California Santa Cruz (Ravikumar, 2013), and UC Santa Barbara (Ravikumar, 2013), have all made efforts to replace paper towels to reduce the environmental impacts of physical waste streams. Additionally, undergraduate student researchers have generated comprehensive reports arguing for hand dryer retrofits on the basis of sustainability at the University of Colorado Boulder (Horn, 2011), Western University (Armstong and Kincaid, 2013), Dalhousie University (Ngo et al., 2019), and Stockton University (Alusik et al, 2016). Lastly, the University of Tennessee Knoxville installed 1,000 hand dryers to save costs and to allow "custodial staff to do professional custodial work (cleaning) in lieu of hauling trash" (Nelson, 2020).

2.3 Focus Statement

The focus of this study is to select a best fit hand drying alternative to paper towels for Duke University's restrooms, and to quantify its economic and environmental benefits. For the environmental benefit and economic analyses, calculations were performed at the scale of Wannamaker dorm. Qualitative data were also collected by a survey to understand student preferences relating to hand drying methods.

3. Choosing a Solution

We decided to narrow the scope of our study to investigate one alternative hand drying option in depth rather than skim the surface of several alternatives. The following section outlines the process we used to narrow our choices as well as our reasoning to determine what we ultimately feel is the best fit alternative to paper towels.

3.1 Creating and Using a Pugh Matrix

We used a Pugh matrix as a tool to help us narrow our list of feasible alternative hand drying options. To set up the matrix fully, we composed a list of hand drying methods to consider, some important qualities of the methods, clearly defined scales for each quality, and a proportional weight for each quality.

We began by brainstorming a list of feasible alternatives, which fell into three main categories: electric hand drying models, cloth towel dispensers, or a combination (paper towel dispensers alongside an alternative method). At face value, electric models seemed to hold the most promise as they do not produce physical paper waste. Cloth towel dispensers had potential but feasibility on a large scale was questionable. A blend of paper towels and an alternative method felt like a good compromise, one that could possibly yield the best results. However, we decided that this option was possibly more of a psychological study on human behavior (i.e. how and why people use certain methods to dry their hands). Also, it didn't lend itself well to the nature of this study because there were too many independent variables. Ultimately, the methods we decided to include in the matrix are the following: Dyson Airblade dB (an electric hand drying model), Xlerator (an electric hand drying model), and a cloth towel dispenser, in addition to the business-as-usual paper towel system as the control.

Next, the team picked five features or qualities we felt were important when considering hand drying methods: up-front cost, cost per dry, environmental impact, time to dry, and work to maintain. Up-front cost addresses the cost required to buy one hand drying unit; it is an initial one-time cost. Cost per dry encompasses the cost of the electricity or the cost of the paper used in one hand dry. Environmental impact considers the waste produced by the method and is a more qualitative feature because it is hard to measure precisely. Time to dry describes how long it takes to completely dry your hands. Work to maintain describes the level of maintenance and care required by the staff to keep the method working well (e.g. taking the trash out, replacing paper towel rolls, or repairing mechanical parts). There was much discussion about which qualities to include, but we feel that these five represent a comprehensive view of each method and reflect which qualities we feel are most relevant to our discussion here.

A scale from one to five was then created for each quality with each number being assigned a quantitative or qualitative value, whichever was most appropriate for the given characteristic. The quantitative values were created with data provided by the manufacturer or performance reports found online, and the qualitative values were reasonably assigned by us. These numbers, one through five, will be used to score each method on the Pugh matrix. The scales are presented below in Table 1. Additionally, each characteristic was assigned a weighted value to indicate their level of importance. From most to least important, they are environmental impact, up-front cost, cost per dry, work to maintain, and time to dry. Their numerical weightings are listed in the Pugh matrix in Table 2.

Table 1: Five-point scales describing qualities of the feasible hand drying alternatives.

Upfront Cost[1]	
1	>$1000
2	$551-$999
3	$101-$550
4	<$100
5	Free

Cost Per Dry[2]	
1	>$.015
2	$.01-$.015
3	$0.005-$.01
4	<$.005
5	Free

Environmental Impact[3]	
1	Strong negative
2	Negative
3	Neutral
4	Positive
5	Strong positive

Time to Dry[4]	
1	>20s
2	15-20s
3	10-15s
4	5-10s
5	<5s

Work to Maintain[5]	
1	a ton
2	a lot
3	some
4	a little
5	none

[1] Scale created around reference prices found online ("RestroomDirect").
[2] Calculated using values found on the manufacturers' page.
[3] Qualitative scale determined by team.
[4] Found on the manufacturers' page or estimated by us if not provided.
[5] Qualitative scale determined by team.

Looking at the specific data in Table 1, the prices of the various hand dryer models, the upfront cost, were taken from RestroomDirect, an online retail site that sells a variety of hand dryers ("RestroomDirect"). One note to consider is that these prices are retail, where Duke is likely to be able to purchase the hand dryers at a discount in bulk. To calculate the cost per dry for hand dryers, we multiplied the rated power of each hand dryer in watts as provided by the manufacturer by the advertised dry time, also provided by the manufacturer. We then used the average price for residential electricity for North Carolina, as reported by the EIA (2019), to find a final cost. For example, the Dyson Airblade dB is rated for 1,400W and has an advertised 12s dry time, yielding $1400W \cdot (12s) \cdot \frac{1\,hr}{3600\,s} = 4.67\,Wh = 0.00467\,kWh \cdot \frac{11.09\,cents}{1\,kWh} = 5\,cents.$ It is also important to note that this average electricity price is for residential customers, and Duke likely pays a lower price.

Once these preliminary decisions were made regarding matrix set-up, each of the four methods received a score between one and five for each characteristic. These scores were multiplied by the characteristic's respective weighting then summed to yield a total weighted sum for each method. The method with the highest sum is identified as the best; thus, helping us narrow down our focus to the best alternative method. As can be seen in the Pugh matrix in Table 2, the leading alternative was the Xlerator hand dryer followed by the Airblade dB.

However, for a couple reasons, not accounted for in the matrix, we ultimately chose the Airblade as the best alternative. First, Duke has installed the Airblades in most of the newly constructed buildings or recently renovated restrooms. Specifically, the Airblade can be found in buildings such as Grainger Hall, the Bryan Center, and Gross Hall. For convenience's sake then, it makes sense to continue with the model Duke has already shown preference to rather than suggest a new alternative. Second, the LCA literature we are utilizing in our research uses the

Airblade model. Therefore, it makes sense to be consistent if we are applying these studies to Duke's campus.

Overall, the Pugh matrix validated our initial assumption that electric hand dryers are the best alternative. Though the Pugh matrix showed the best method was the Xlerator model, we ultimately decided the Airblade dB was the most appropriate model to explore further because Duke has already installed a number of these units.

Table 2: Pugh scoring matrix for hand drying methods.

	Upfront Cost	Cost Per Dry	Environme-ntal Impact	Time to Dry	Work to Maintain	**TOTAL**
Dyson Airblade dB	1	5	5	3	5	**4**
Xlerator	2	5	5	4	5	**4.3**
Cloth Towel Dispenser	3	4	4	5	3	**3.7**
Paper Towel Dispenser	5	2	1	5	1	**2.4**
WEIGHT	**0.2**	**0.2**	**0.3**	**0.1**	**0.2**	**1**

3.2 Cloth Towel Dispenser Revisited

Out of curiosity, we returned briefly to considering cloth towels as an alternative method and did some research into the feasibility of implementation on campus. Nate Cole, a fellow researcher and student on campus, oversaw a pilot program for cloth towel dispensers installed in

Duke's Smart Home. At the time of our meeting, the program had only been in place for about a month, but he provided some insightful observations thus far. The cloth towel was working well in the Smart Home, but Cole attributed this to the nature of the environment there. Only 10 people live in the Smart Home, so it is used by only a small fraction of the number who would use it in a typical on-campus dorm -- thus making it easier to manage and maintain. The students were shown how to replace the cloth roll themselves, the dirty rolls were laundered externally by Laundrymen (a laundry service in the Durham area), and clean rolls were returned on a two-week cycle (based on the frequency of use). Taking this model to a larger scale, though, presents challenges. First, the facility's employees must be trained to maintain the dispensers, which is currently outside their legally required tasks. Second, there is uncertainty regarding when to change the roll. That is, should the roll be replaced at the end of a set timeframe even if the roll is unfinished? What happens when the roll is used up before the next scheduled replacement day? There are significant logistical challenges for dormitory housekeeping staff regarding replacement of rolls since students probably should not be trusted to change the rolls on their own. Additionally, the cloth needs to be laundered by a professional service to be considered sanitary, and hiring an external service requires additional costs and coordination as well. While the cloth towels are a unique idea with success on a small scale, here we judged it not feasible on campus at large because replacement and laundering of the towels presented significant logistical and financial challenges.

4. Consumer Research Analysis

A consumer survey was performed to gauge consumer preferences and their support for replacing paper towels with hand dryers. Through this survey, we wanted to assess when presented with the option of using either paper towels or hand dryer, which consumers used and why.

4.1 Survey Design

First, we started by identifying campus restrooms where both hand dryer and paper towel options were available. Next, we created a Qualtrics survey to ascertain the following: 1) which hand drying option the user chose, 2) which hand drying option the user prefers, 3) reasons why the user prefers that option, 4) whether the user would support a university initiative to replace paper towels with hand dryers, and 5) the user's primary affiliation at Duke (see Appendix for survey questions). To ensure a random sample, we stationed ourselves outside of restrooms, surveyed everyone who exited, allowed each person to respond to questions without the surveyor viewing their entries, and offered candy as incentive.

There are three locations on campus that we know of that offer hand dryers in restrooms: Grainger Hall, Gross Hall, and the Bryan Center (specifically the restrooms located between the elevator and the Duke Store). Out of these three, only the Gross Hall and Bryan Center locations offered both paper towels and hand dryers, since Grainger Hall has no paper towels. Ideally, we would have collected all of our data outside of these locations. However, these restrooms are not particularly highly trafficked and for the sake of time, we also gathered some responses from the Brodhead Center, which only has paper towels. Our goal was to collect 150 responses and get a wide variety of student, faculty, staff, and visitor responses. However, due to the campus shutdown

due to COVID-19, we were able to gather only 125 responses[6], almost all of which were student responses.

4.2 Survey Results

Of the 125 respondents, we surveyed, 63 of them used a restroom with both paper towels as well as a hand dryer. 47 used paper towels, 14 used the hand dryers, and 2 did not dry their hands, yielding approximately 75%, 22%, and 3% respectively. Although disappointing, this was not particularly surprising. Anecdotally, all of us had noticed that most people tend to use paper towels over hand dryers.

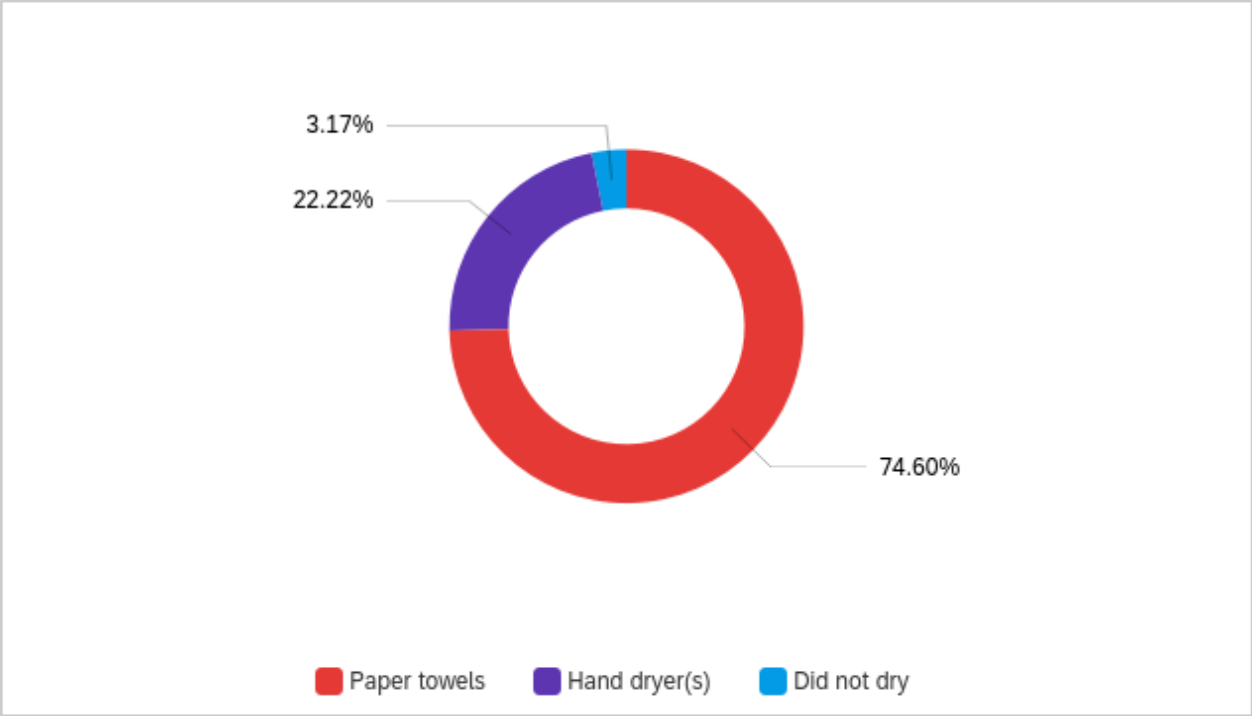

Figure 1: Hand drying method used.

Next, we surveyed respondents on their preferred hand drying method (if forced to pick one, ruling out the option of not drying hands). Unsurprisingly, this distribution was very similar

[6] We decided to leave the responses as-is, rather than attempt to solicit more responses remotely, out of fear that any outreach we could do in the limited time we had would be biased towards our friends, many of who tend to be more environmental than the general public.

to the distribution of hand drying methods actually used. 47 respondents stated that they preferred paper towels, and 16 stated that they preferred hand dryers. This makes approximately 74% and 26% respectively, which very closely resembles the distribution of method actually used. Although we expected this, it was disappointing to see that only 1 in 4 respondents preferred to use hand dryers.

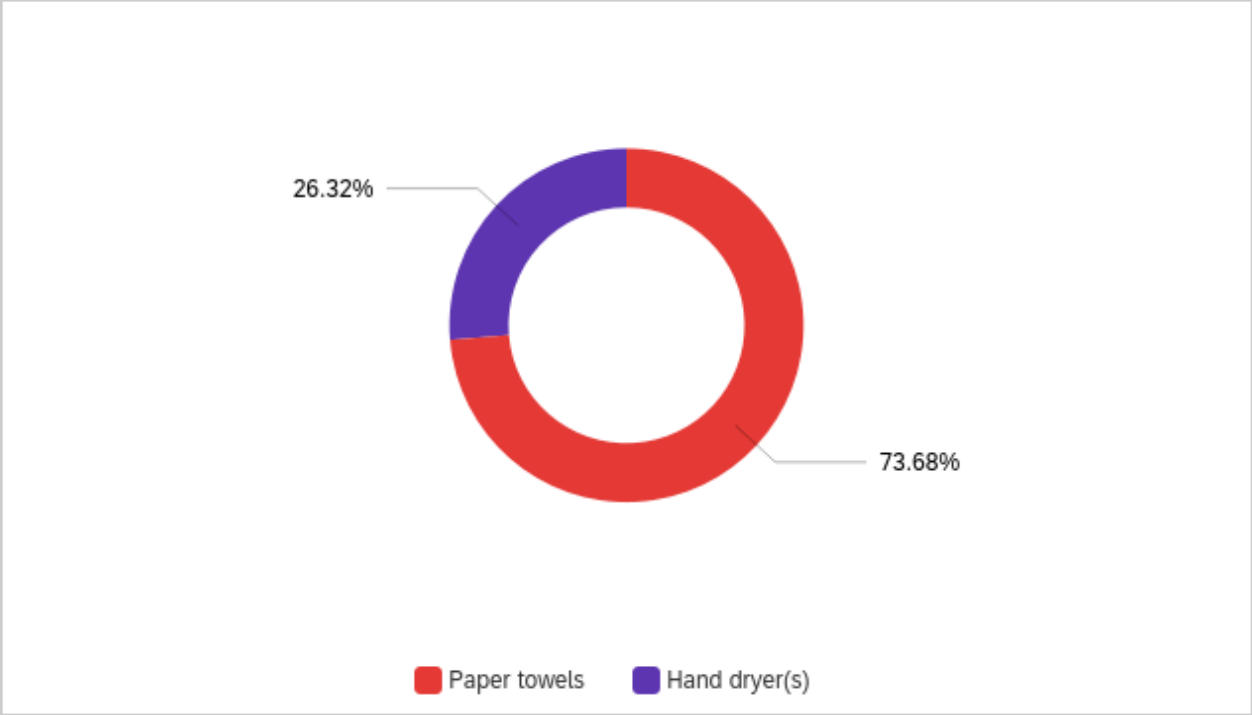

Figure 2: Preferred hand drying method.

To dig a little deeper into the rationale behind these preferences, we surveyed users on why they preferred hand dryers or paper towels. Rather than leave it open ended, we came up with five general categories: environmental awareness, effectiveness of drying, sanitation, time spent drying, and noise. We asked users to select as many as that applied. It was hypothesized that environmental awareness would be the main driver for usage of hand dryers, and sanitation, time spent drying, and noise would be the main drivers for usage of paper towels.

Looking at the data on respondents who indicated that they prefer hand dryers, we saw 24 answers for environmental awareness, 12 for effectiveness of drying, 8 for sanitation, and 3 for time spent drying. On the other hand, for respondents who indicated that they prefer paper towels, there were 60 answers for effectiveness of drying, 43 for time spent drying, 26 for sanitation, 10 for noise, and 2 for environmental awareness. As expected, environmental awareness was prevalent in reasons why respondents preferred hand dryers, and time spent drying, sanitation, and noise were all reasons why respondents preferred paper towels.

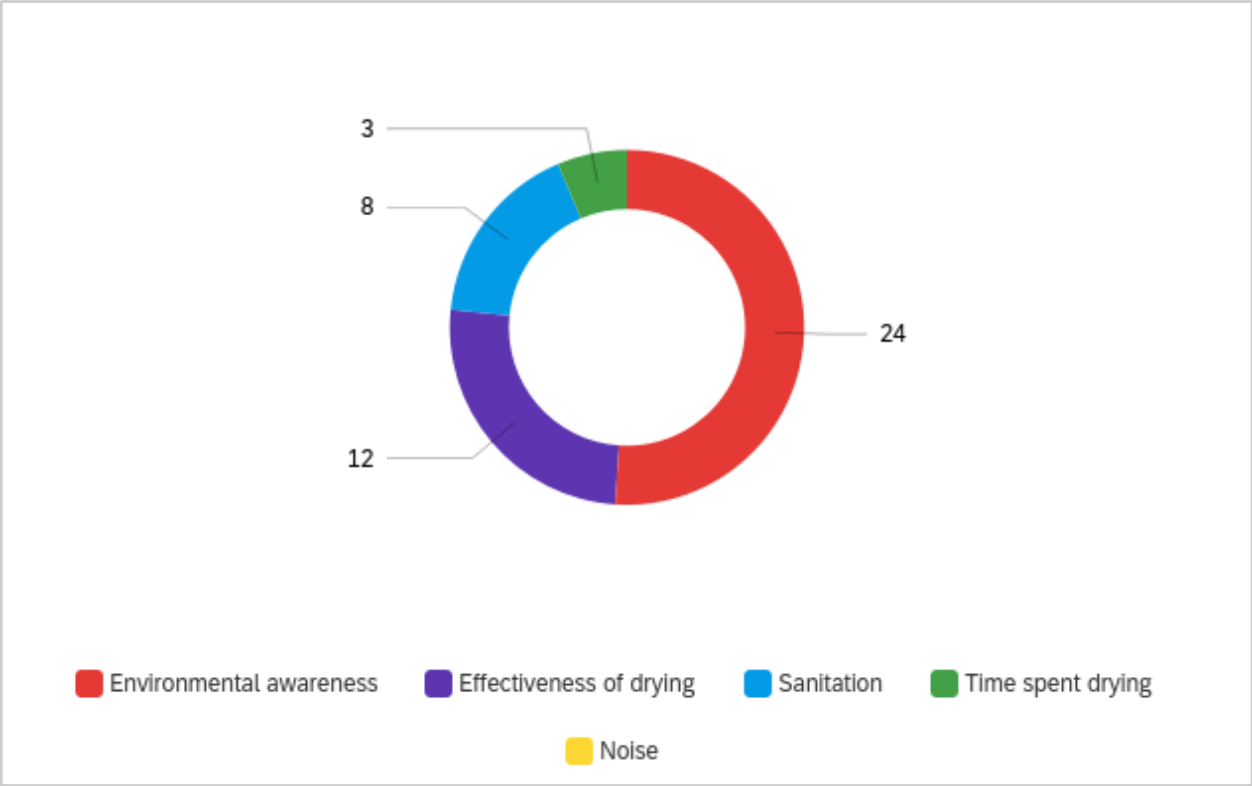

Figure 3: Reasons respondents preferred hand dryers.[7]

[7] Of those who selected that they prefer hand dryers.

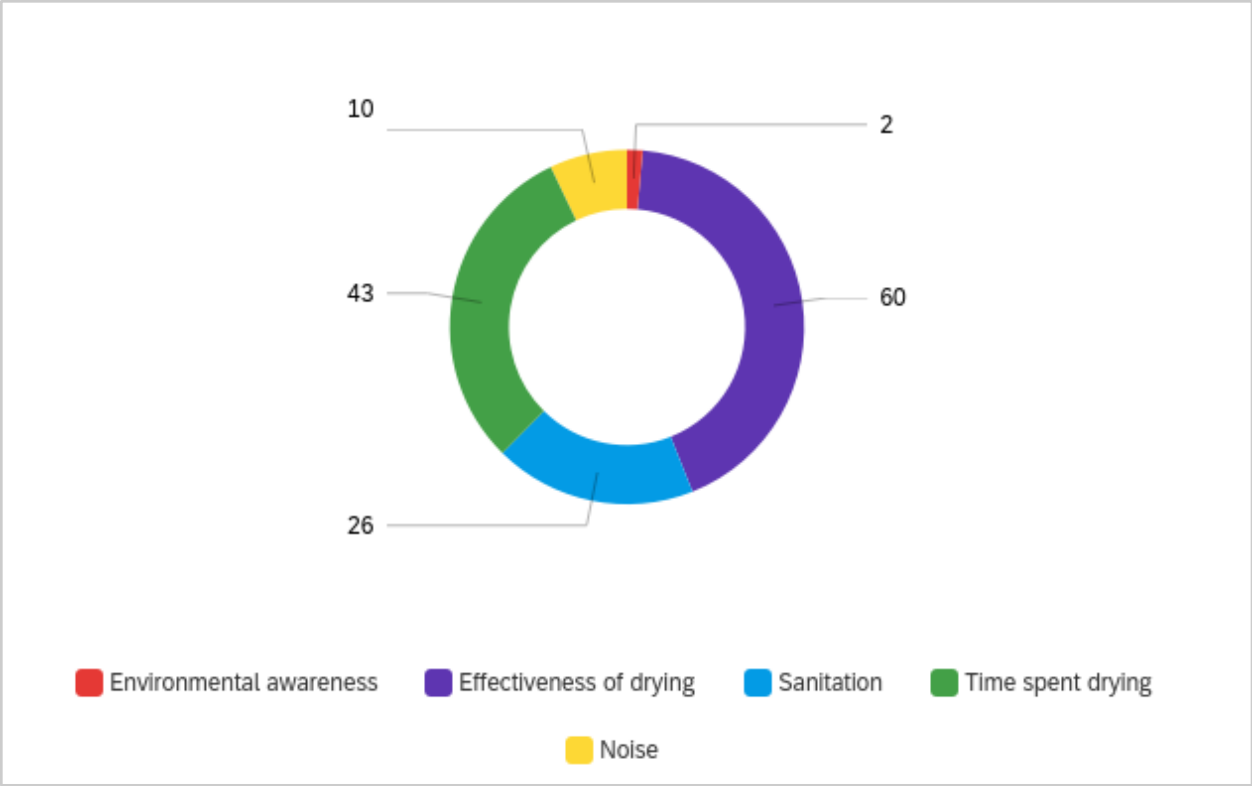

Figure 4: Reasons respondents preferred paper towels.[8]

Interestingly enough, we saw a fair amount of effectiveness of drying answers from both sides. When including this answer as an option, we figured it could go either way. Anecdotally, we knew many people often use more than one paper towel to completely dry their hands, and that people often leave the hand dryer before their hands are completely dry. The survey data seems to indicate the preference for drying method as far as effectiveness of dry goes is a mixed bag, although in proportion to total answers, we saw a higher percentage of this answer in reasons respondents preferred paper towels.

Finally, we asked whether respondents would support a Duke initiative to replace paper towel dispensers with hand dryers. The answers on this were surprising - after seeing that about 74% of respondents preferred hand paper towels, we saw 60 people (approximately 53% of

[8] Of those who selected that they prefer paper towels.

respondents) answer yes to this question. 33 (29%) answered maybe, and 21 (18%) answered no. Although we did not ask respondents to further explain why they would respond maybe, several points came up while speaking with respondents as they took the survey. We heard that paper towels were sometimes preferred for situations such as cleaning up a mess, blowing a nose, or opening a door by its handle.

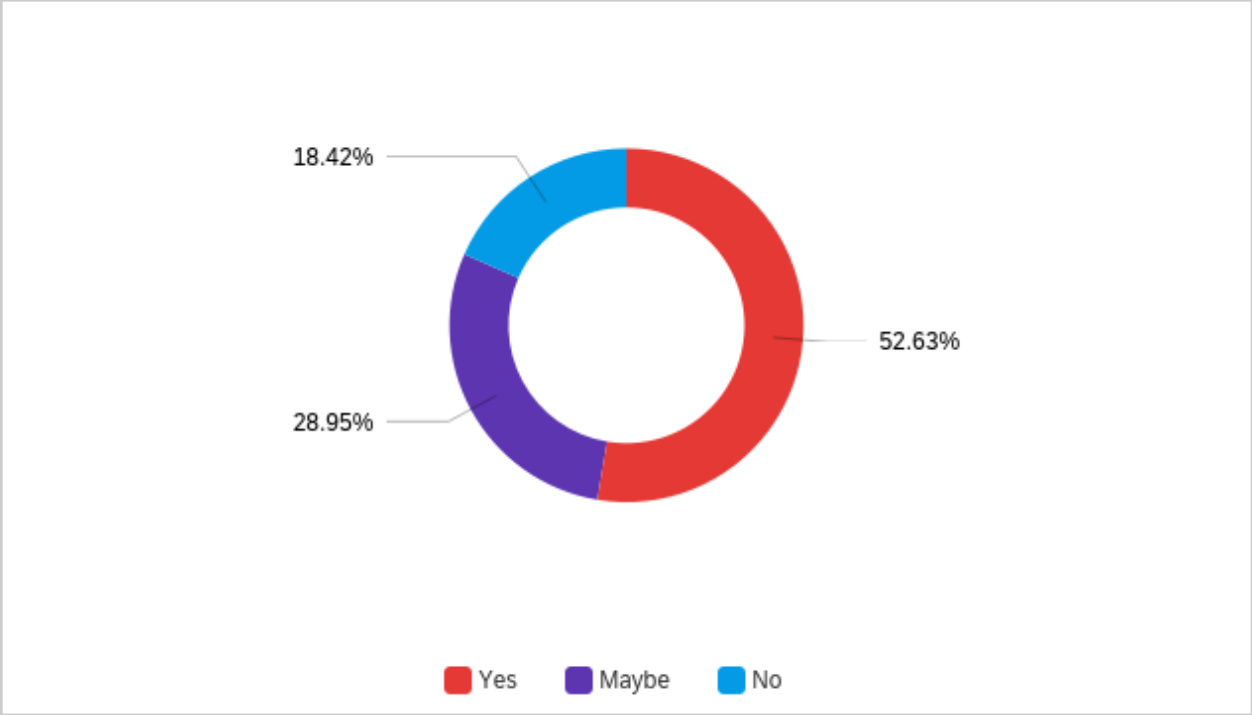

Figure 5: Whether respondents would support an initiative to install hand dryers.

4.3 Survey Analysis

One possible way to address preferences for both paper towels as well as hand dryers is to have both options installed in each location, but with the hand dryer closer to the sinks and to the exit. Looking at existing restrooms, there are many where multiple paper towel dispensers are already installed, especially in larger, public restrooms in classroom or academic buildings. We have noted anecdotally that in these restrooms, often the trash can near the exit will be overflowing whereas a trash can further away from the exit will be empty or close to empty. This is consistent

with user behavior looking for the “least effort”, so looking into installing combinations of hand dryers and paper towels may be a viable solution.

5. Environmental Benefit Analysis

5.1 Methods for Carbon Calculation

LCA calculations were performed to estimate the global warming impact (expressed in kg carbon dioxide equivalent) of transitioning Wannamaker dormitory from paper towel dispensers to Dyson Airblade dB electric hand dryers. Wannamaker was selected as a model dorm given its average size and layout. Whereas other dorms feature many independent "houses," or connected units, Wannamaker is a standalone dorm of moderate size (230 residents, four floors, and 20 restrooms) with well-defined boundaries. This layout rendered tracking usage paper towel consumption more clear by avoiding shared restrooms in a large connected dorm, such as Craven, and provided a useful, digestible scale for estimating the environmental impacts of transitioning from paper towels to electric hand dryers.

Duke Housing and Residence Life (HRL) and Duke Facilities provided data that allowed us to estimate the current paper towel usage of Wannamaker. Bernard Smith, Associate Director of Residence Hall Operations for HRL, communicated that annually residential buildings on campus use 21600 rolls of paper towels per year (Table 3). Bernard could not, however, provide dorm-specific statistics. To estimate Wannamaker's paper towel consumption, it was assumed that paper towel consumption of a dorm is proportional to its student population. Therefore, the number of students living in Wannamaker was divided by the total student population living in dorms served by paper towels and multiplied by the total annual residential paper towel use on campus to estimate the annual use of Wannamaker alone (Table 3). This assumption presumes that on average each student uses roughly the same amount of paper towels annually. Student population on West Campus was determined by summing Selective Living Group and independent housing statistics on HRL's website ("Duke Student Affairs," n.d.). Swift and the Hollows were identified

as the only on-campus dorms not served by paper towels and were thus excluded. The enrollment of the Class of 2023 was used to estimate the on-campus population of East Campus ("Duke 2023", n.d.).

Table 3: Wannamaker building and campus paper towel use data.

Wannamaker and Paper Towel Stats	Value
Students living in Wannamaker[9]	230
Students living in dorms served by paper towels[10]	4295
Number of current paper towel dispensers in Wannamaker[11]	20
Residential on-campus usage (rolls/year)[12]	21600
Length of roll (ft)[13]	700
Towels used per dry[14]	2
Wannamaker annual paper towel usage (rolls/year)	1157

It was assumed also that one high-speed hand dryer could adequately replace one paper dispenser to manage hand drying load. As a result, 20 hand dryers would be needed to transition Wannamaker from paper towels.

[9] HRL
[10] HRL
[11] HRL
[12] Bernard Smith
[13] Georgia Pacific
[14] Our assumption

To conduct our environmental analysis, we drew upon data points from Gregory et al. (2013), a comprehensive LCA study that assessed the global warming impacts of a variety of hand-drying options and the accompanying uncertainty of these estimates. While an in-house LCA would have been preferable, Gregory et al. (2013) was used extensively for a variety of reasons. Firstly, GaBi 9.1 LCA software was originally employed, but proved difficult to navigate, with limited applicable data sets available. Secondly, the Gregory et al. (2013) study clearly describes assumptions and methods so that it was possible to select appropriate data points and apply them to this study. Furthermore, the Gregory et al. study evaluated Airblade units; having been in extensive contact with Dyson, Gregory et al. had detailed information about the parts and performance of this model. This is also the exact model that had already been selected by our team as a replacement for paper towels. Additionally, the authors used Kimberly-Clark 100% virgin content paper towels in their analysis. Duke similarly uses 100% virgin paper towels, but they are manufactured by Georgia Pacific (Bernard Smith, 2019).

The key environmental data used are shown in Table 4. For the Airblade hand dryer, Gregory et al. (2013) assumed a 5-year lifespan given the 5-year warranty of the device with an estimated 350,000 uses over this period. As a result, the Airblade lifetime carbon without the use phase listed below is 1/350,000th of the machine's total lifetime. The use phase, which accounts for the machines' electricity consumption during use, was excluded because it is the largest contributor to carbon emissions for hand dryer and is very sensitive to the carbon intensity of the electricity at the point of use, according to a variety of sensitivity calculations (Gregory et al., 2013; Joseph et al., 2015). As a result, the lifetime use emissions were calculated using North Carolina's value for carbon intensity calculated by the Energy Information Administration (2018). Whereas the use phase emissions vary widely, the materials, manufacturing, transportation, and

end-of-life impacts incorporated in the Airblade lifetime carbon without use phase are more standard across locations and have a smaller impact on the overall carbon emissions, and were thus used in this analysis without North Carolina specific adjustments.

Table 4: Environmental data.

Environmental Data	Value	Source
Carbon intensity of electricity in NC (lb/MWh)[15]	814	Energy Information Administration (2018)
Paper towel lifetime carbon (g CO eq/pair of hands)[16]	15.5	Gregory et al. (2013)
Airblade lifetime carbon WITHOUT use phase (g CO eq/pair of hands)[17]	1.9	Gregory et al. (2013)

To calculate the carbon emissions of 20 hand dryers that would be added to Wannamaker, a 5-year timeframe was used given the warranty of the dryers and following the assumptions of Gregory et al. (2013). The use phase emissions, or those associated with electricity consumption, were first calculated. To do so, the energy consumed by the dryers was estimated. Based on a total consumption of 1157 rolls/year for the dorm (Table 3), the assumption that two 12 inch paper towels are used per dry, and that each roll is 700ft long it was determined that 404950 pairs of hands are dried annually in the dorm. Applying the Dyson Airblade data (Table 5), it was calculated that drying the same number of hands annually over 5 years would require 18.20 MW. Standby electricity consumption for the 20 dryers was assumed to be used when the blowers were not actively drying and accounts for powering sensors used to detect hands (Gregory et al. 2013).

[15] Energy Information Administration (2018)
[16] Gregory et al. (2013)
[17] Gregory et al. (2013)

This total 18.20 MW was multiplied by the energy intensity of NC power to get total use phase emissions (Table 6). The non-use phase emissions were then calculated by multiplying Airblade lifetime carbon WITHOUT use phase g CO eq/pair of hands by 350,000 for each dryer and then multiplying by 20 for the number of dryers. These two carbon values were then summed to get a total of 13300.03 kg CO2 eq for the hand dryers over their lifetime.

The paper towel lifetime emissions were calculated by multiplying the paper towel lifetime g CO2 eq/pair of hands carbon data point by the total number of hands dried in the dorm over 5 years. It is important to note that this is likely a slight underestimate. Unlike hand dryers, paper towels produce most of their emissions in the manufacturing phase. Because manufacturing is a variable input given usage of towels, it is more challenging to scale carbon estimates to the 404950 pairs of hands dried annually in Wannamaker. The 15.5 g CO eq/pair of hands estimated by Gregory et al. 2013 assumes that 350,000 pairs of hands are dried in the 5-year lifetime of a unit. In Wannamaker, however, only 101,237.5 pairs of hands are dried per unit over 5 years.

Table 5: Dyson Airblade data.[18]

Dyson Airblade Data	Value
Reported dry time (secs)	12
Power consumed by Airblade in use (W)	1,400
Power consumed by Airblade not in use (W)	1

[18] Data was obtained from (Gregory et al. 2013) who received this data directly from Dyson.

Table 6: Wannamaker hand-drying calculations.

Wannamaker Hand-drying Calculations	Value
Wannamaker pairs of dried hands per year	404950
Energy consumed by Airblade lifetime use (MW)	9.448833333
Energy consumed by Airblade lifetime standby (MW)	8.746501667
Total energy consumed by Airblade over lifetime (MW)	18.195335

5.2 Results of Carbon Calculation

The calculations reveal that retrofitting Wannamaker with 20 Dyson Airblades would reduce emissions by 18,083.6 kgs or around 18 metric tons of CO2 eq (Table 7). For scale, Duke's total 2017 emissions were around 250,000 metric tons ("2019 Duke Climate Action Plan"). Given Wannamaker houses 5.35% of total students living in dorms, a campus wide retrofit of all dorms assumed to yield similar results could reduce emissions by 339.62 metric tons over a five-year period. This would account for roughly 0.14% of Duke's 2017 emissions.

Table 7: Final carbon calculations over five-year lifetime.

Final Carbon Calculations over 5-year Lifetime	Value
Airblade (kg CO2 eq)	13300.03
Paper towels (kg CO2 eq)	31383.63
Difference	-18,083.6

5.3 Waste Reduction

Beyond offsetting carbon, retrofitting Wannamaker would divert 30.50 metric tons of physical waste from landfills over 5 years.[19] This reduction would significantly help Duke's efforts to reduce landfill-bound waste. The university has repeatedly aimed to limit how much waste it sends to landfills with "Duke Recycles" programs ("Duke Recycles," n.d.). For scale, one such major program, "Zero Waste Gameday", diverted 19 metric tons of physical waste in 2019 ("Duke Athletics Continues," 2020). Retrofitting Wannamaker, which accounts for only 5.35% of on campus housing served by paper towels, would thus result in waste reduction benefits on the same scale as major programs such as "Zero Waste Gameday". This comparison also highlights the high waste-saving potential of a campus wide retrofit. Aside from freeing space in landfills, diverting paper towel waste reduces methane emissions and leachate formation associated with paper towel decomposition in landfills, having important implications for water and air quality (Ingwersen et al., 2016).

[19] Given Georgia Pacific's reporting shipping weight of 25 pounds per 6 rolls. Assumes 1157 rolls used annually in Wannamaker and packaging is not recycled.

6. Economic Analysis

While there has been an underlying focus to assess environmental factors associated with hand-drying, we additionally investigated the relative economics of the two technologies to see if a switch to hand-dryers from paper-towels would be financially beneficial for the university. We chose to perform a side-by-side cost analysis of the two technologies, paper-towel dispensers and the Dyson AirBlade dB, in reference to the status-quo and a hypothetical retrofit of Wannamaker on Duke's West Campus. Wannamaker was chosen for the same reasons as for the environmental analysis: its standalone status, and its moderate size and layout served perfectly for making estimates regarding a hypothetical retrofit.

To ascertain the financial benefits of a hypothetical retrofit, estimates and projections for costs of both the status-quo paper towel system and a hypothetical scenario where paper towel dispensers were replaced by Dyson Airblade dB Hand Dryers were calculated. The costs were projected over a five-year period, the estimated lifespan of the Dyson Airblade as determined by Dyson's warranty and the assumptions followed from Gregory et al. (2013). Further, in order to account for the Time Value of Money, a discount rate of 1% (.01) was used to evaluate future costs in present dollars, and was based on current risk-free investment opportunities. Lastly, it was again assumed that each one of the twenty paper-towel dispensers in Wannamaker could be adequately replaced by one hand-dryer.

6.1 Cost of Paper Towels

Calculating the total cost of paper-towels for Wannamaker involved quantifying the total cost of the paper towels for HRL specifically on an annual basis, the cost of cleaning and maintaining the restrooms (particularly in terms of paper towel waste), the cost of lining the trash bins and the cost of removing and disposing the waste from the restrooms. While there was a cost

of buying and installing the paper towel dispensers, it was assumed that upfront capital cost would be equal to zero in this hypothetical retrofit, given that Duke already owns the machines and would not need to pay for them. When considering future construction, this line-item would merit further study and would be a significant source of cost if paper towels were to be chosen and new dispensers were needed.

The estimation of the cost of paper towels for Wannamaker is a function of total HRL annual spending on Paper Towels and the assumption that paper towel consumption is equal across all students living in paper-towel using housing offered through Duke HRL. This assumption allowed us to assume the cost attributed to Wannamaker could be equal to:

$$Wannamaker\ Cost\ =\ total\ HRL\ cost\ of\ paper\ towels \cdot \frac{\#\ of\ students\ in\ Wannamaker}{total\ \#\ of\ students\ using\ paper\ towels}$$

HRL's total cost of paper towels was drawn from information provided by Bernard Smith, who is an Associate Director of Residence Hall Operations for Duke HRL. Based on his estimates, HRL currently uses about 3600 cases of Georgia Pacific Product No. 2930 Paper Towels annually and each case costs approximately $45. Each case consists of six rolls, for a total cost per roll of approximately $7.50. The 3600 cases at $45/case gives a total annual cost of $163,800 for all of HRL. Next, using data provided by HRL, it was found that 230 students live in Wannamaker out of the total 4,295 students living in HRL dorms that use paper towels, equal to 5.36% of students. Based on this, it was calculated that Wannamaker annual paper towel usage is approximately 1157 rolls per year. Multiplying the total cost of paper towels annually ($163,800) by the proportion consumed by Wannamaker students (.0536) yielded a total annual cost estimate of approximately $8,772 for paper towels in Wannamaker.

The cost of cleaning associated with removal of paper towel waste was an additional factor considered for the total cost of paper towels used in Wannamaker. It was assumed that the hourly

cost of labor for Duke Cleaning was equal to $15.00/hour based on Duke's minimum wage (Grantham, 2017). While there was difficulty in obtaining absolutely exact estimates of time spent cleaning paper towel waste, as indicated by signs outside of each restroom in Wannamaker, each restroom is cleaned once daily, and each cleaning requires about ten minutes of housekeeping attention related to the picking up, bagging, lining, and removing of paper towels. Additionally, it was assumed the restrooms are cleaned 365 days/year. Thus, the following framework was used to estimate total annual cleaning costs of restrooms:

$$Annual\ Cleaning\ Cost\ = \frac{cleaning\ hours}{day} \cdot \frac{cost}{hour\ of\ labor} \cdot \frac{days\ cleaned}{year} \cdot (\#\ of\ restrooms\ serviced)$$

This format gave a total cost of $18,250 going directly towards cleaning of paper towel waste in Wannamaker restrooms annually. This excludes other necessary professional custodial work like cleaning toilets and showers that may be paid less attention to when custodial staff is forced to focus on exorbitant amounts of trash that must be hauled out of the dormitory for future disposal. Removing attention from plumbing and unclogging toilets full of paper towels can be another greatest time saving aspect of hand dryers, indicating further potential gains from removing paper towels from restrooms.

Another associated cost with paper towels is the cost of lining trash bins; in an initiative to replace paper towels with hand dryers at The University of Tennessee Knoxville, Housing representatives cited trash bin liners as the "most costly custodial supply item on campus" (Kennedy, 2018). Although no exact cost of liner was able to be obtained from HRL, public wholesalers of products highly similar to those used by HRL suggest a cost per liner of between $0.10 and $0.20. Sticking with the assumption each restroom is cleaned daily for 365 days a year, it can be inferred that around one liner is replaced every day as well. The following formula can be used to estimate total cost of liners annually:

$$Annual\ Cost\ of\ Liners\ = \frac{liners}{day} \cdot \frac{cost}{liner} \cdot \frac{days\ cleaned}{year} \cdot (\#\ of\ restrooms)$$

This yields a total annual spend of $1,095 / year on trash liners; with a modest assumption that trash bins would fill half as quickly without paper towel waste, this would equate to a annual saving of $547.50 resulting from a 50% decrease in the use of replacement of trash bin liners. This excludes environmental and waste disposal considerations, both of which would offer economic gains in this scenario. All in all, Duke currently spends around $28,117 annually on paper towels and other associated costs. This comes out to a total, undiscounted cost of approximately $140,600 over a five-year period (Table 8).

Table 8: Total annual cost of paper towels in Wannamaker.

Annual Cost of Paper Towels	$8,774
Annual Cleaning Cost specific to Paper Towels	$18,250
Annual Liner Cost	$1,095
Total Annual Cost	$28,117
Total 5-year Cost (undiscounted)	**$140,600**

6.2 Cost of Hand Dryers

The total cost of retrofitting Wannamaker with hand dryers involved putting values on the cost of the physical hand-dryers, the cost of installing the hand dryers, the annual cost of electricity required to run the hand dryers and the cost of maintaining the hand dryers.

The most obvious roadblock in the introduction of hand dryers across campus is the high upfront cost: most online retailers sell the Dyson Airblade dB for about $1,350, and we proceeded with the assumption that Duke would likely be able to receive a discount for purchasing wholesale and in bulk. We valued this wholesale discount at 10%, yielding a per-unit cost of $1,215. Again

assuming each paper towel can be replaced by one hand dryer, the total cost for 20 hand dryers in Wannamaker would be $24,300.

In addition to paying for the physical devices, there would be an additional cost of retrofitting the restrooms. The installation process would not require more than one full day of labor from a qualified electrician, as the process is notably straightforward. Duke University likely has contracted-staff members that are qualified for electrical work of this nature, and thus the labor cost is not considered. There is concern regarding whether the wiring of the restrooms in Wannamaker would allow for a straightforward installation; making such assumptions would require a large degree of guesswork without consultation from the individuals responsible for installation. A placeholder value of $1,215 (the cost of an individual Airblade dB) was used to indicate such a cost, and we acknowledge the variability in this estimate. It is of note, however, that in installations of new buildings this cost would be negligible given that the design of the building would account for this sort of wiring.

The main annual cost associated with hand dryers is the cost of electricity. This cost is a function of the number of hands dried annually, the dry time of the Airblade dB, the rated wattage of the hand dryer and the electricity price. We estimate that 404,95 hands are dried annually in Wannamaker, and again use a dry time of 12 seconds for the Airblade dB. Based on these two figures, it can be concluded that there are approximately 1350 use hours annually and 7410 standby hours annually. The Airblade dB has a rated wattage of 1400 W when in use, and it was estimated that in standby wattage is approximately 1 W. Using this, it was calculated that the total electric consumption of each hand dryer would be equal to approximately 1897 kWh per year, or 37,944 kWh in total for all twenty hand dryers. Based on EIA Data, the average commercial electricity rate in Durham, NC is equal to $0.0796/kWh, which was used as an estimate for what Duke pays

to provide electricity on campus. Multiplying the annual consumption and the price gives a total annual electricity cost of $3,020.

Table 9: Costs of hypothetical retrofit.

Upfront	
Cost of hand dryers	$24,300
Cost of installation	$1,250
Annual	
Cost of electricity	$3,020
Total five-year cost (undiscounted)	**$40,651**

In total, after discounting to the present value, Paper Towels came out to cost a little over $135,000 and hand dryers came out to cost just under $40,000, with an exact difference in cost of $96,216. The level of this difference speaks volumes to the price superiority of hand dryers: even with significant changes in assumptions, it is hard to hypothesize a scenario in which the two technologies were remotely close in terms of price.

6.3 Analysis of Costs

While it was not surprising that hand-dryers would be a more economical option than paper towels, it was truly shocking quite how large the price savings would be. Further, the most frequent roadblock to installing capital like hand dryers is the high upfront costs, yet it seems likely Duke and other top Institutions would be able to pay the $24,000 up front to save thousands more in the following years. When considering Duke currently pays employees nearly $20,000 annually to manage waste associated with paper towels, this investment seems even more reasonable.

Another main concern that could arise from this analysis is that it suggests Duke could save money by replacing people with technology. Rather, the gain to employees would be twofold: First, custodial staff would be able to focus on professional custodial work that ensures restrooms are as sanitary as possible rather than focus on hauling trash and unclogging toilets. This will not only improve the efficiency of the workers, but also improve the experience for students living in Duke Housing. Second, As Duke continues constructing new buildings and facilities, there is room for existing employees to take on new assignments without losing their jobs and benefits.

Table 10: Cost analysis of paper towels and hand dryers over five years.

Year	0	1	2	3	4	5	NPV
Hand Dryers							
Cost of hand dryers	$24,300.00	$0.00	$0.00	$0.00	$0.00	$0.00	($24,300.00)
Installation cost	$1,250.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Electricity cost	$0.00	$3,020.31	$3,020.31	$3,020.31	$3,020.31	$3,020.31	($14,658.85)
Total cost							**($38,958.85)**
Paper Towels							
Annual paper towel cost	$0.00	$8,773.92	$8,773.92	$8,773.92	$8,773.92	$8,773.92	($42,161.98)
Cleaning costs	$0.00	$18,250.00	$18,250.00	$18,250.00	$18,250.00	$18,250.00	($87,698.14)
Cost of liners		$1,095.00	$1,095.00	$1,095.00	$1,095.00	$1,095.00	($5,314.51)
Total cost							**($135,174.63)**

7. Conclusion

When reflecting on the two main lenses through which this study can be judged -- environmental and economic--it is revealing that hand dryers performed better in all aspects. The lower carbon intensity and lower waste revealed from the LCA study, though small in relation to Duke's total consumption, can help Duke reach their goal of carbon neutrality by 2024 ("2019 Duke Climate Action Plan"). Additionally, reducing the physical waste stream fits into "Duke Recycles" programs that includes "Zero Waste Gameday" as well as other initiatives ("Duke Recycles," n.d.). Further, the financial modeling evidenced how severe the price discrepancy is between paper towels and dryers, and highlighted the magnitude of unnecessary money being spent annually to use paper towels. While the savings would be small on an absolute basis if Duke were to update Wannamaker, there is potential for massive financial savings if changes were made on a campus wide level. Assuming HRL and Duke could find a way to effectively and equitably reassign custodial staff in new projects and understaffed areas, installing hand dryers would improve the working experience for custodial staff, the living experience for Duke students, all while easing the financial burden on Duke's budget.

All in all, there seems to be little reason to hesitate in making a switch to hand dryers on Duke's campus, especially when considering that nearly 75% of surveyed users of Duke restrooms would be open to an initiative that replaces paper towels with hand dryers. Next steps should involve presenting these benefits to relevant decision makers and possible advocates on campus, such as the Campus Sustainability Committee (CSC), Sustainability Office Staff, environmental student groups, and Duke Facilities. While hand-drying is often an overlooked topic, decision-makers may be drawn to action if made aware of the waste, financially and

environmentally, associated with current practices, and the likely positive reception from the Duke community were these changes to be made.

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Appendix

Restroom Exit Survey

Start of Block: Default Question Block

Q1 Which hand drying options were available in the restroom?

- Paper towels (1)
- Hand dryer(s) (2)
- Both paper towels and hand dryer(s) (3)

Display This Question:

If Which hand drying options were available in the restroom? = Both paper towels and hand dryer(s)

Q16 Which hand drying option did you use?

- Paper towels (1)
- Hand dryer(s) (2)
- Did not dry (3)

Page Break

Display This Question:

If Which hand drying options were available in the restroom? = Both paper towels and hand dryer(s)

Q19 Why did you choose to use ${Q16/ChoiceGroup/SelectedChoices} today? Check all that apply.

- [ ] Environmental awareness (1)
- [ ] Effectiveness of drying (2)
- [ ] Sanitation (3)
- [ ] Time spent drying (4)
- [ ] Noise (5)
- [ ] Convenience (6)

Q17 Which hand drying option do you prefer?

- ○ Paper towels (1)
- ○ Hand dryer(s) (2)

Q18 Why do you prefer this method? Check all that apply.

- [ ] Environmental awareness (1)
- [ ] Effectiveness of drying (2)
- [ ] Sanitation (3)
- [ ] Time spent drying (4)
- [ ] Noise (5)

Q20 Would you support a Duke University initiative to replace paper towel dispensers with hand dryers?

- Yes (1)
- Maybe (2)
- No (3)

Q21 What is your primary affiliation at Duke?

- Student (1)
- Staff (2)
- Faculty (3)
- Affiliate (4)
- Visitor (5)

End of Block: Default Question Block