

Developing a Sustainability Plan for Hammams in Morocco

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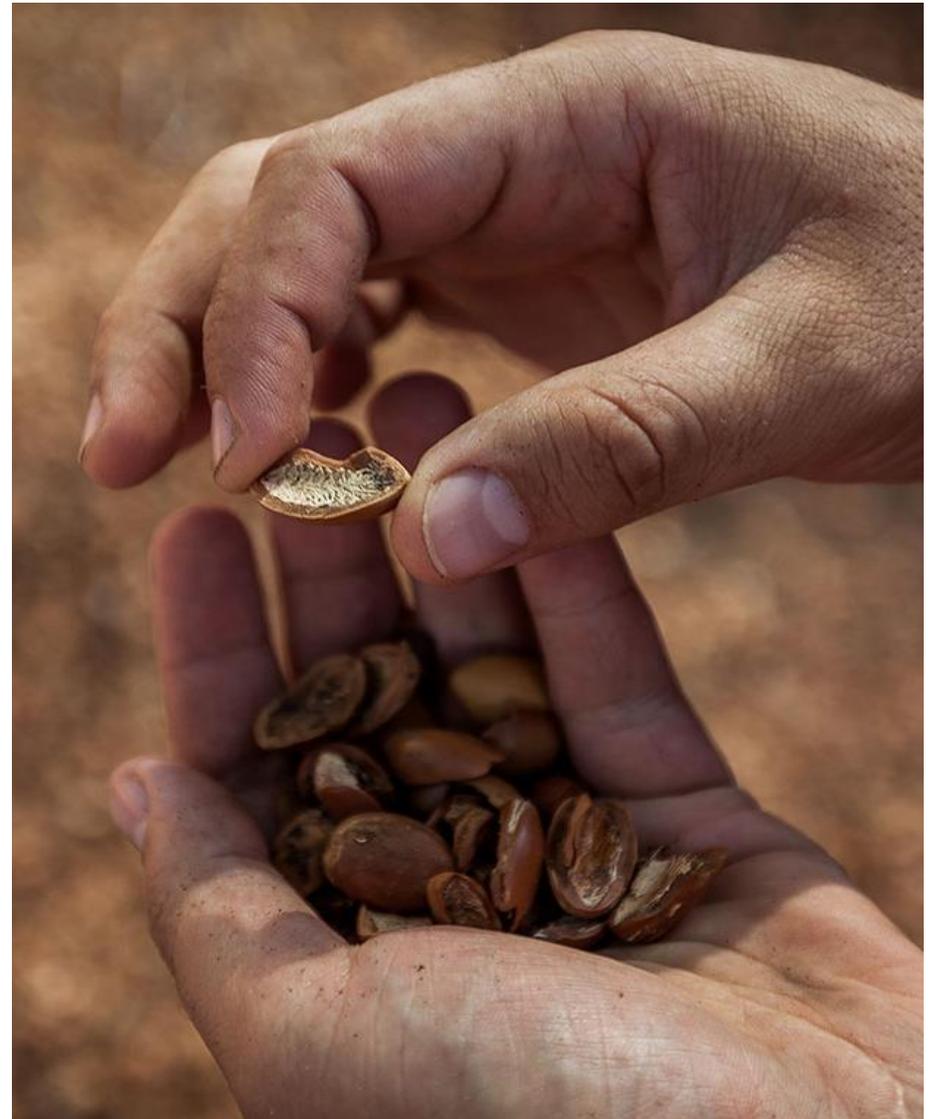
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Abstract

Morocco's unique geography contributes to varying environmental conditions throughout the country, including problems with water scarcity, deforestation, and desertification. Working with Association Ribat Al-Fath, our team outlined a sustainable improvement plan for Moroccan public bathhouses, known as Hammams, to combat these national issues on a local level. A cultural tenant, the bathing ritual will never change; however, the sustainability of the institution must. Through extensive modeling, our team analyzed the different resource management systems in Hammams to produce a set of recommendations that not only mitigates the environmental impacts of the industry but also bolsters the Moroccan economy through the creation of new jobs and market sectors.

Figure 1: Argan shells serve as a sustainable fuel option for Hammam fuel (Sebastian Caselier and Al Jazeera, 2016)



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Executive Summary

Since the implementation of the 2015 Paris Climate Agreement, the world has tirelessly worked to reverse the effects of climate change through the use of sustainable technologies and innovations, however, few countries are as determined as Morocco in lowering their carbon footprint (Kathir, 2016). The rise in global average temperature combined with a history of poor resource management has left Morocco with an abundance of issues including water scarcity, deforestation, and desertification. One of the major contributors to this problem is cultural institutions cemented in tradition, such as the Hammam, which continue to use outdated and inefficient water practices and heating methods.

Figure 2: Traditional male hammam (Rolling Stone Italia)



The Moroccan Hammam

The Hammam, or the public bathhouse, is a critical element of every Moroccan neighborhood. Traditionally, the Hammam existed as a religious necessity, allowing practicing Muslims to be in a state of major ritual cleansing, prior to reading from the Qu’ran on Friday, the day of prayer. Today the Hammam still holds an important religious function, however it has also gained a cultural and physical role, allowing Moroccans to both socialize and physically cleanse themselves. When visiting the Hammam, Moroccans are often unaware that the way in which they interact with space is detrimental to the environment. As such, to address the flaws of the traditional Hammam, we must reengineer the institution instead of its user.

Environmental Impacts of Hammams

The commitment to tradition in Hammams has led to outdated management styles that waste an excessive amount of resources and puts a strain on the environment. In order to heat the vast amounts of water and steam required for the bathing ritual, Hammams use a staggering amount of wood to fuel the furnaces. Wood harvested from the already scarce forests furthers deforestation, and in turn contributes to land degradation and desertification. When it comes to water, patrons average over one hundred liters per visit, partly because traditional Hammams heat water beyond a comfortable temperature, requiring bathers to cool the water themselves by mixing the over-heated water with cold water. Additionally, greywater waste from Hammams contaminates local groundwater supplies with chemicals found in soaps and shampoos. Finally, due to the

furnace setup used, those fueling the fire face dangerous conditions, including backfire and smoke inhalation, the latter of which directly affects the surrounding communities. With all these environmental impacts and health risks taken into consideration, it is apparent that a change to the current management methods of traditional Hammams is necessary. Even though the Hammam is still an essential aspect of Moroccan culture, there is rarely consideration amongst Hammam owners for resource management or the dangers this service poses to the environment. Luckily, there may be options for mitigating the detrimental effects of Hammams.

Figure 3: A truck filled with cedar to be used as fuel (Sebastian Castelier and Al Jazeera, 2016)



Sponsor - Association Ribat Al-Fath

Association Ribat Al-Fath is a non-government organization based in Rabat, Morocco with the goal of promoting sustainable living and environmental learning while fostering Moroccan culture and heritage. One of the Association's current projects, in conjunction with Dr. Khadija Kadiri and her cooperative, Istijmam Waraha, focuses on reengineering the Hammam into a more sustainable institution. The team assisted this project with the creation of a robust economic and environmental model to aid in the discovery of the best overall upgrade plan.

Sustainable Technologies in Hammams

A handful of Hammams owners have begun implementing sustainable innovations in their business, including alternative energy sources, improved water management systems, and modern lighting technologies. In collaboration with these pilot Hammams, our sponsors have not only been working to advocate the benefits of sustainable resource management systems, but also to further the existing research using more cutting-edge technologies. One such instance is the solar water heater Dr. Kadiri implemented in her Hammam, which reduced her fuel usage by over 90% in summer months. While these organizations and individual Hammam owners have taken an initiative to provide more sustainable options for Hammams, there has yet to be a single solution that addresses water management, heating efficiency, and lighting management.

Project Overview

The goal of this project was to make recommendations to Association Ribat Al-Fath to aid in the creation of more sustainable management methods for Hammams in Morocco. The following objectives were created to achieve this goal.

1. Understand the financials, heating methods, and resource management of Hammams throughout Morocco.
2. Model and quantify the sustainability of the heating systems in Hammams.
3. Prepare recommendations for guiding Hammams towards more sustainable operations based on our data analysis.

Having completed extensive archival research prior to arriving in Morocco, the team realized the missing information could only be obtained by visiting a diverse selection of Hammams and delving into their unique situations. Through collaboration with our sponsor, the team identified six Hammams in the Rabat-Sale-Kenitra region and two in Casablanca with varying combinations of boiler setups, fuel sources, and management strategies for an assorted collection of data. We then conducted semi-structured interviews with the owners of each Hammam selected to collect data on current heating methods, expenses, energy usage, lighting techniques and water usage.

In order to quantify the benefits of a sustainable Hammam, the team compiled the raw data collected from the semi-structured interviews with Hammam owners into two detailed models. These models used the data from the Hammam owners to calculate the energy and economic efficiency of different configurations and management styles. The calculations done by these models not only provided numerical justification for the benefits of modernizing Hammams but could also be used by Association Ribat Al-Fath to encourage change in the Hammam sector. The findings gathered from these comparison models and interview results were then used to produce a set of recommendations for the Association and for future research.

Project Deliverables

At the conclusion of this project, Association Ribat Al-Fath was presented with a comprehensive spreadsheet and a meta-analysis of economic and energy models that detailed the results of our research, along with a final presentation and written report. The purpose of these project deliverables was to summarize our work on the project and allow for the continuation of research on this topic.

Figure 4: The project team and sponsors during a site visit to a Hammam in Kenitra, Morocco



Heating Method Findings

During semi-structured interviews, many Hammam owners described wood as a dirty fuel that releases a considerable amount of ash and smoke, which not only leads to equipment deterioration but, also creates health risks for the employees that fuel the fire. The wood produces about a 10% ash yield per kilogram burned, which negatively impacts the heating system efficiency and adds another expense to dispose of the ash. In Morocco wood is sold at 0.8 MAD/Kg; however, the wood is wet and covered in dirt, adding to the weight and reducing the overall efficiency of the fuel by 40%. However, biomass fuels such as argan shells were observed to produce no carbon emissions and almost no ash when used in a proper heating system, meaning that as a fuel, argan shells burn more efficiently than wood. The energy balance model calculated that a traditional furnace fueled by biomass fuels is at worst 1.3 times more efficient than its wood counterpart, saving up to 60,000 MAD a year.

The benefits of switching to a biomass fuel can be increased by incorporating a modern boiler into the heating system. Anecdotal data from interviews with Hammam owners revealed that traditional clay furnaces lose over 30% of their energy to the environment, resulting in insufficient temperatures necessary to burn fuel to completion, thus wasting energy and money. Our models showed that upgrading to both a modern boiler and biomass fuel improves efficiency by 60% compared to a traditional system, saving at least 73,000 MAD a year.

The system can be further improved by implementing an automatic fuel delivery system in the boiler. The feeding system distributes fuel directly into the fire, concentrating the material in the center of the flame and allowing it to burn to completion. By removing the need to open the door to fuel the fire, a feeding system not only mitigates ambient heat loss from the boiler, but also

Figure 5: Traditional Hammam furnace made of clay and salt crystal



provides a safer working environment for Hammam employees by limiting their exposure to heat and smoke. Installing an automatic feeding system alongside a modern boiler fueled by argan shells is twice as efficient as the traditional wood-fired furnace, saving 85,000 MAD a year.

Implementing a solar heating array lowers fuel expenses by reducing the amount of energy required to maintain water temperature throughout a hot day. The system works by distributing water amongst a set of glass pipes, allowing solar radiation to heat it, then pumping the hot water into faucets inside the bathing rooms. Based on the anecdotal information from one of the Hammams interviewed, this method of heating saves an average of 30,000 MAD annually in fuel expenses. Due to the system's poor reliability and reliance on clear weather, the use of a solar heating array cannot be the only heating method used in the Hammam, but it serves as an excellent addition for both environmental and economic gain.

Figure 6: On average, Hammam patrons will use over 100 L of water per visit



Water Management Findings

Typically, in a traditional Hammam, the water heated by the boiler is distributed directly to the faucets for clientele use. This water leaves the faucets at an uncomfortably high temperature, forcing clients to recool it with additional water before using it to bathe. Two model sustainable Hammams successfully implemented a water mixing system that reduces water waste by mixing water directly off the boiler with cold water to an optimal temperature before distributing the water throughout the Hammam. Owners of both these Hammams stated that after implementing a mixing system, they noticed a decrease in wasted water, reducing expenses and environmental impact.

Lighting Technique Findings

Hammams use unique combinations of natural and artificial lights, depending on their location, roof access, and floor plan. When natural lighting is used, it often comes through flat square panel skylights. This method not only poorly diffuses light into the space, but also causes the skylights to easily fog over, preventing the entry of sunlight in the bath. The team's interview at one of the Rabat Hammams, revealed that switching from flat square panel skylights to the qamariyyat lights, or convex glass domes that diffuse light into the space, greatly increased the amount of light within the Hammam. Furthermore, at the same Hammam, solar panels located on the roof charged batteries during the day, which in turn powered LED lights at night. Through a combination of natural qamariyyat lighting and solar power, this Hammam eliminated electricity costs for lighting.

Recommendations

The following tables detail the team's recommendations for Association Ribat Al-Fath and Cooperative Istijmam Waraha based on the findings developed from our data analysis. The recommendations in this section include heating system upgrades, water saving techniques, lighting improvements, and general management recommendations.

Based on the team's economic and energy balance models, improving the heating systems in Hammams will reduce their expenses as well as their environmental impact.

Figure 7: Glass qamariyyat lights on the roof of a Hammam in Rabat, Morocco



Heating system upgrades	
Use biomass fuel in place of wood	Burning wood is inefficient, produces hazardous byproducts, and drives desertification. On the contrary, biomass is efficient, clean, and a sustainable resource in Morocco.
Implement a modern boiler	Traditional furnaces are inefficient due to high amounts of ambient heat loss. Switching to a modern boiler improves the system efficiency and thereby reduces fuel expenses.
Implement a feeding system	Using a feeding system improves worker safety and system efficiency by eliminating the need to open the furnace door to fuel the fire. This reduces the amount of heat loss and amount of fuel used.
Use proper fuel storage methods	Proper fuel storage assures that moisture and other unwanted substances do not contaminate the fuel, thereby lowering the efficiency and producing ash and smoke.

Based on data from semi-structured interviews the team recommends that Hammams implement the following water saving techniques to reduce the amount of wastewater.

Water saving techniques	
Install a water mixing system	Clients create waste trying to mix the hot and cold water to the perfect temperature. By implementing a water mixing system the water enters the Hammam at the ideal temperature eliminating the need to mix water.
Switch to automatic or metered faucets	By using automatic or metered faucets water usage can be measured and regulated minimizing wastewater.

Based on observations and anecdotal data the team recommends the following lighting improvements to reduce electricity usage in Hammams.

Lighting improvements	
Replace skylights with light diffusion domes	By replacing the standard flat skylights with qamariyyat lights, or dome diffusion lights, the lighting inside the Hammam will be drastically improved, as the dome geometry allows for natural light to cut through the steam of the Hammam.
Utilize solar-powered lights	Installing solar panels and attaching them to LED lights in the Hammam will reduce electricity costs. The solar panels power artificial lights when natural light is not accessible, cutting energy usage.

Based on findings from Hammam visits the team recommends the following general management improvements to streamline the operations of Hammams and allow for the implementation of other recommendations listed.

General management recommendations	
Implement a tracking system	Many Hammam owners are unaware of how their Hammams operate therefore, implementing a tracking system will allow them to track their financial data and utility usage to assist with future system upgrades.
Provide safety equipment for employees	Working in a boiler room poses many health risks for the employees, such as smoke inhalation and potential burns, making it important to provide them with the protection they need
Implement an educational program to train Hammam mechanics	Hammam owners have been hesitant to implement aspects of modern heating systems because of the lack of professionals to service these systems. By implementing educational programs to train professionals Hammam owners can receive the support they need to maintain their equipment while also creating new jobs.

Implement an artisan certification program	An artisan certification program will make it easy for Hammam owners to find skilled and trustworthy laborers who can not only install the complex systems required by a sustainable Hammam, but also innovate on the current technology.
Promote environmental awareness	By informing Hammam owners of the environmental issues their businesses pose and effects it can have in their communities they will be more likely to implement new technologies to mitigate their impact

Conclusion

Our project made recommendations to Association Ribat Al-Fath and Cooperative Istijmam Waraha that will lead to the implementation of more sustainable management methods in Hammams around Morocco. The realization of these recommendations will reduce both operating expenses and environmental impact of Hammams. However, it is important to maintain the cultural significance of the institution, such that tradition is not buried in modernization. Not only do Hammams play an essential religious role in Islam, but they also serve as a social outlet and physical service station for many Moroccans.

While conducting our research, the team identified many potential changes that can be implemented in Hammams throughout the country in order to mitigate their environmental impact. The recommended upgrades may be made implemented collectively or individually, depending on the current conditions of the Hammam, as each bath is unique in its setup and management methods. With the fulfillment of these recommendations, Hammam owners will not only contribute towards saving the environment but will also enjoy financial benefits. By modernizing Hammams, job availability in Morocco will increase, due to the creation of a new economic sector for Hammam equipment, and bolster pre-existing industries, such as the argan oil and olive oil industries, whose byproducts may now be sold as a fuel source.

Climate change is too large a problem for any individual, corporation, or nation to address. However, directed efforts by small groups like Association Ribat Al-Fath can work towards a greener future, and it is the sum of these changes that will have a lasting global impact.

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Executive Summary	All	All
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2.1 Global Climate Change	Vernon	Bielawski
2.2 Environmental Conditions in Morocco	Bielawski	Vernon
2.3 What is a Hammam?	Kaplan	Bielawski
2.4 Environmental Impacts of Hammams	Bielawski	Vernon & Kaplan
2.5 Emissions Reducing Technologies	Sousa & Preiss	Kaplan
2.6 Association Ribat Al-Fath	Preiss	Sousa
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3.5 Summary	Bielawski	Sousa & Vernon
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4.1 Heating Method Findings	Preiss	Bielawski & Kaplan
4.2 Water Management Findings	Bielawski	Preiss & Kaplan
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4.4 Summary	Preiss	Kaplan
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5.5 Summary	Preiss	All
6. Conclusion	Bielawski	All
Appendices	All	All

Table of Contents

Acknowledgements.....	ii
Executive Summary	iii
Authorship.....	xiii
Table of Contents	xv
List of Figures	xix
List of Tables	xx
1. Introduction.....	1
2. Background.....	2
2.1 Global Climate Change.....	2
2.2 Environmental Conditions in Morocco.....	2
2.3 What is a Hammam?.....	4
2.4 Environmental Impacts of Hammams	5
2.5 Association Ribat Al-Fath.....	7
2.6 Emissions Reducing Technologies	7
2.7 Summary	9
3. Methodology.....	10
3.1 OBJECTIVE 1: Understand the financials, heating methods, and resource management of Hammams throughout Morocco.	10
3.1.2 Semi-Structured Interviews	11
3.2 OBJECTIVE 2: Model and quantify the sustainability of the heating systems in Hammams	12
3.2.1 Organization of Data.....	12

3.3 OBJECTIVE 3: Prepare recommendations for guiding Hammams towards more sustainable operations based on our data analysis.....	13
3.3.1 Sustainable Upgrade Plan	14
3.3.2 Project Deliverables	14
3.5 Summary	15
4. Findings & Analysis	16
4.1 Heating Method Findings	16
4.1.1 Switching from wood to biomass fuel improves heating efficiency and reduces Hammam expenses.	16
4.1.2 Upgrading to a modern boiler and using biomass fuel improves energy efficiency and reduces fuel expenses.....	17
4.1.3 Using an automatic feeding system improves boiler efficiency by 50% and system efficiency by 10%.....	18
4.1.4 Utilizing a solar heating array saves up to 30,000 MAD a year in fuel costs.....	19
4.2 Water Management Findings.....	20
4.2.1 Mixing systems to optimize water temperature for the clients reduces the amount of water waste.....	20
4.3 Lighting Technique Findings.....	21
4.3.1 Using the qamariyyat lighting technique and solar powered LED lights effectively eliminates electricity costs for lighting	21
4.4 Summary	21
5.1 Heating System Upgrades.....	22
5.1.1 Switch to biomass fuel in place of wood.	22
5.1.2 Upgrade from a traditional furnace to a modern biomass boiler.	23
5.1.3 Implement an automatic feeder into the heating system.....	24
5.1.4 Use proper storage methods for fuel to increase efficiency.....	25
5.2 Water Saving Techniques	26
5.2.1 Install a water mixing system to reduce clientele water waste.	26

5.2.2 Switch to automatic or metered faucets	26
5.3 Lighting Improvements.....	27
5.3.1 Replace skylights with light diffusion domes to improve natural daylighting.	27
5.3.2 Utilize solar powered LED bulbs to reduce electricity usage.....	28
5.4 General Management Recommendations	29
5.4.1 Implement a tracking system to provide Hammam owners with accurate economic and utility usage data.	29
5.4.2 Provide safety equipment for Hammam employees.	29
5.4.3 Implement educational programs in local vocational schools to train professionals to provide boiler and solar system maintenance to specialized Hammam equipment.	30
5.4.4 Implement an artisan certification program for the Hammam industry.	30
5.4.5 Promote environmental awareness amongst Hammam owners and advocate for improvements with an informational video.	31
5.5 Summary	31
6. Conclusion	32
References.....	34
Appendices:.....	36
Appendix A: Sample Interview Script for Hammam Owners	36
Appendix B: Sample Interview Script for Cultural Experts	38
Appendix C: Hammam Classification System	39
Hammam Classification System.....	39
Appendix D: Sample Raw Data Table from Interview Results	40
Appendix E: Hammam Owner Interview Results	40
Temara Hammam 1.....	41

Rabat Hammam 1	44
Rabat Hammam 2	47
Hassan II Mosque Hammam.....	50
Casablanca Hammam 1.....	51
Kenitra Hammam 2.....	55
Rabat Hammam 3	57
Appendix F: Energy Balance Model.....	59
Appendix G: Economic Balance Model	60
Appendix H: Project timeline	61

List of Figures

Figure 1: Argan shells serve as a sustainable fuel option for Hammam fuel (Sebastian Caselier and Al Jazeera, 2016).....	i
Figure 2: Traditional male hammam (Rolling Stone Italia).....	iii
Figure 3: A truck filled with cedar to be used as fuel (Sebastian Castelier and Al Jazeera, 2016)	iv
Figure 4: The project team and sponsors during a site visit to a Hammam in Kenitra, Morocco	vi
Figure 5: Traditional Hammam furnace made of clay and salt crystal.....	vii
Figure 6: On average, Hammam patrons will use over 100 L of water per visit.....	viii
Figure 7: Glass qamariyyat lights on the roof of a Hammam in Rabat, Morocco	ix
Figure 8: Hammam hidden in the streets of Fez, Morocco.....	1
Figure 9: A field near Fez, Morocco that used to be covered in trees, but has since been cleared for firewood	3
Figure 10: Wood storage for a single Hammam in Fez, Morocco.....	6
Figure 11: Hammam employees must fuel the fire by hand, putting them at risk of burns and smoke inhalation (Sebastian Castelier and Al Jazeera, 2016)	7
Figure 12: Smoke emitted from a Hammam in Kenitra, Morocco contributes to air pollution	9
Figure 13: Argan shells being used as a biomass fuel in place of wood	17
Figure 14: An advanced boiler system fueled by argan shells.....	18
Figure 15: The solar heating array witnessed during an onsite interview in Rabat, Morocco	20
Figure 16: View of natural qamariyyat lighting from the inside of a Hammam	21
Figure 17: A feeding system directly connected to a modern boiler automatically directs fuel into the fire.....	24
Figure 18: Example of proper fuel storage for argan shells.....	25
Figure 19: Adjust water temperature or install metered faucets to reduce water waste	27
Figure 20: Qamariyyat glass dome skylights being utilized at one of the Hammams the team visited	28
Figure 21: Design for glass dome and solar powered LED lighting system (Sibley 2013).....	28
Figure 22: Hand drawn sketch to help visualize the layout of the Hammam	46
Figure 23: Project timeline from before arriving in Morocco to project completion	61

List of Tables

Table 1: The energy output of one kilogram of the three most common fuels in the two boiler types and the total heating system efficiency.....	18
Table 2: The weight of fuel in the possible heating system configurations to satisfy the Hammam energy requirement	19
Table 3: The weight of fuel to produce the required power for a day and the annual fuel expense for a traditional boiler fueled by the three most common fuel sources, wood, argan shells, and olive pomace	22
Table 4: Data table for quantitative interview results, completed for each Hammam visit.....	40
Table 5: Energy Balance Model	59
Table 6: Economic Balance Model.....	60

1. Introduction

Climate change is one of the most pressing issues in the modern global landscape. Not only does it present obvious extrinsic dangers in the form of extreme temperatures and weather events, but the increased global average temperature leads to rising sea-levels, lower agricultural yields, and a decrease in the world's biodiversity. In Morocco, the public bath house, known as a Hammam, often unknowingly wastes an excessive amount of energy and water. Currently, these traditional Hammams heat water and steam with wood as their main fuel source, releasing dangerous particles and carbon into the atmosphere and creating an unsafe environment for both the local communities and the employees fueling the boilers. Furthermore, the excess use of resources in Hammams introduces major concerns such as the desertification of the country. However, a few Hammams have begun experimenting with modern heating technologies, alternative fuel sources and solar lighting techniques. As such, a Moroccan NGO, Association Ribat Al-Fath, has prioritized reengineering the Hammams into a more sustainable institution. This project assisted the association with the creation of a robust economic and environmental model to aid in the discovery of the best

overall upgrade plan while advertising it to Hammam owners. The following chapters will detail the background information about Hammams and the shortcomings of the current systems, the methodology detailing the procedure followed to develop possible solutions, and the team's findings and recommendations to mitigate the environmental impact of Hammams.

Figure 8: Hammam hidden in the streets of Fez, Morocco



2. Background

This chapter provides the background information necessary to understand the problems posed by traditional Moroccan Hammams and the need for our project. The current environmental crisis is first explained as it relates to traditional heating methods, energy use, and water use. Next, the cultural significance of traditional Moroccan Hammams is discussed, as maintaining this significance is an important consideration in any potential solution. Environmental impacts of Hammams are then explained, as well as existing research and alternative heating methods that have a lesser impact on the environment. Finally, the need for our project in conjunction with the efforts of Association Ribat Al-Fath is explained, as we work towards the goal of analyzing more sustainable heating methods for traditional Hammams in Rabat, Morocco.

2.1 Global Climate Change

Global industrialization and modernization have resulted in changes in average air temperatures leading to rising sea levels, and an increase in the frequency of drastic weather events. The use of nonrenewable resources, such as

fossil fuels, contribute to air pollution, increased levels of CO₂, and ozone layer damage (Cooper, 2012). Deforestation compounds these effects by reducing the amount of trees that convert free CO₂ back into oxygen. Furthermore, deforestation leads to an increase in the amount of endangered species, a decrease in biodiversity, and heightened levels of soil degradation (IUCN, 2018). More sustainable practices are necessary to combat these issues, but many times it's difficult to enact change due to a lack of cost or resources. Although no single country, person, or institution is responsible for climate change, the crisis at hand requires immediate collective action, and there are many small changes that can be made by individuals in order to preserve the natural environment.

2.2 Environmental Conditions in Morocco

Morocco is located on the Northwest coast of Africa, bordered by the Atlantic Ocean and the Mediterranean Sea, as well as Algeria to the East and the Western Sahara Desert to the south (CIA, 2018). It has Mediterranean climate, and forests are plentiful in the northern region of the country and along the Atlas Mountains in the interior. In the south there is much less vegetation, as the country gradually fades into the Sahara Desert.

Currently, Morocco faces multiple environmental issues including land degradation, desertification, and water and soil pollution (CIA, 2018). Morocco is considered a water-scarce country due to dry climate conditions and dwindling water reserves, which have led to crippling droughts in recent years (US AID, 2019). Droughts in Morocco have been increasing in both frequency and intensity and are predicted to continue to increase for the next 20 years if preventative measures are not taken soon. (ICBA, 2018). This poses a problem for Moroccan society, as clean water resources are a necessity for many societal institutions. Due to a lack of government restrictions on industrial practices, industrial wastes are often dumped into the soil, the ocean, or inland water resources, which contributes to pollution of the water that is present (CIA, 2018). Finally, wood is the primary source of fuel for heating in Morocco, with almost every home, business, etc. using it for heat. As explained in the previous section, this reliance on wood contributes to increased atmospheric CO₂, and the climate change crisis. A study done at the Al Akhawayn University in Morocco showed that CO₂ emissions in Morocco had already reached about 60 million tons in 2014, while it was only about 15 million tons in 1980 (Soufiane, & Khaldoun, 2018).

Figure 9: A field near Fez, Morocco that used to be covered in trees, but has since been cleared for firewood



Furthermore, according to the Mongabay deforestation statistics, Morocco has about 102.3 million acres of forested area throughout the country, which is not nearly enough to power the entire country's fuel needs (Mongabay, 2018), and although many forests are being expanded, not much is being done to protect them. Due to this lack of energy resources, Morocco imports a large amount of its energy from foreign countries, but this is too expensive for many small businesses to afford.

Following the 2015 Paris Climate Agreement, Morocco has adopted plans for a more sustainable future in order to combat climate change and lower their carbon footprint.

Morocco was the first Arab nation to submit their intended nationally determined contribution and their aggressive plans for reducing emissions by 50% by 2025, which would make it the most progressive African country in the fight against the climate change crisis. While Morocco continues to prevent environmental degradation within its borders, the country's limited access to sustainable technologies mitigates these efforts. Environmental NGOs within the country work to combat climate change by taking small, but intelligent steps to improve the sustainability of various aspects of Moroccan daily life. One Moroccan institution whose sustainability can be improved is the public bath house, or the Hammam.

2.3 What is a Hammam?

Moroccan cities are characterized by their distinct neighborhoods, each containing institutions such as mosques or schools, and service stations such as bakeries and Hammams (Hehmeyer, 1998). These buildings synergize together to form a “system of service-nodes” (Golombek and Holod, 1979) that supply these neighborhoods with public services and cultural focal points as well. The Hammam, or the Moroccan public

bath house, serves three such roles: physical, spiritual, and social.

Before the Hammam can be examined as a cultural service node, it is critical to understand how someone physically interacts with the space. When a customer first arrives at a Hammam, they pay an entrance fee and then move into a reception and changing area where they can prepare themselves for the bathing experience (Sibley, 2007). Once undressed, they walk into the hottest of three rooms, where they will spend time sweating and rinsing themselves with hot water. Next, visitors move into the warm washing chamber, where they wash themselves down with soapy water and a studded glove. Finally, a customer will move into the coldest room and scrub themselves clean of dead skin cells, or alternatively, pay attendant to do this, along with a massage and stretch.

The Hammam's spiritual role comes in the form of ritual ablution. Friday, or *Al-Jumu'a*, is the day of congregation, when all Muslim men are required to go to Mosque for worship. As such, many Moroccans will visit the Hammam on Thursday night and Friday morning to clean themselves into a state of “ritual purity” so that they may read

from the Qur'an during *Jumu'a* (Hehmeyer, 1998; T. El Korchi, Personal Communication, November 8, 2019). There are two forms of such ritual impurity in Islam, minor and major, and cleansing oneself from the latter, as required after childbirth, intercourse, or prior to *Jumu'a* is only achievable in a Hammam (Hehmeyer, 1998). This spiritual connection between Hammam and mosque is most easily evident in the Hassan II Mosque in Casablanca, which features its own private Hammams that serve as ablution rooms (Eliason, 2019). Hammams are indubitably part of the religious culture in Islam and in Morocco and will likely remain that way despite the rise in the number of in-home bathrooms with functioning baths and showers.

The Hammam's third and final cultural pillar is its role as a social gathering place, specifically for women. Unlike their male counterparts, women tend to stay longer and use more water at Hammams. For them, the Hammam is not just a service station, but an institution where they can interact with friends, be entertained, and unwind (Sibley, 2007). Furthermore, it is common for women to bring in fruits and snacks to eat after bathing. The social function of the Hammam isn't limited to personal life either. Many traditional families

use it as a venue for pre-wedding bridal celebrations and circumcision parties for newborns. These traditions stem from the androcentric culture in Arab countries which made the Hammam one of the only public spaces for women to socialize. Nevertheless, be they physical service stations or religious and social institutions, Hammams play an essential role in Moroccan society, and it is critical to maintain this significance while bringing them into the 21st century.

2.4 Environmental Impacts of Hammams

Hammams are incredibly significant to Moroccan culture but they have many negative environmental impacts that must be considered as well. Traditional Hammams require an excessive amount of wood to fuel the boilers and heat the baths. As of 2016, the average annual energy consumption for Hammams in Morocco was 3323 KWh/m² for both hot water and space heating (Sahraoui, 2016). Wood is harvested from slowly diminishing forests in the Northern part of the country, and this contributes to land degradation and the potential for deforestation. The reliance on firewood as a fuel source for Hammams, as well as for residential woodstoves and farans, is a leading cause of forest loss in Morocco (Li, Boudreau &

Figure 10: Wood storage for a single Hammam in Fez, Morocco



Kociuk, 2000). The transport of logs also contributes to air pollution and climate change, as trucks and other transportation vehicles release greenhouse gases from fossil fuel consumption into the atmosphere.

Hammams additionally require large amounts of water. According to a study completed in 2011, traditional Hammams use an average of 8,480 cubic meters of water annually (Mahdavi & Orehounig, 2011). This water is used to heat pools and to produce steam in the different chambers of the building. Due to the water scarcity in Morocco, as discussed earlier in this chapter, there is not a large supply of water to draw from, so this poses a problem for Moroccan society (USAID, 2019). Furthermore, improper disposal of bathwater from the Hammams pollutes groundwater reserves. The wastewater from Hammams contains chemicals from soap and potential pathogens that, if dumped directly into the soil outside, can contaminate groundwater (Kallel, Amjad, 2018).

Workers' safety is another concern when concentrating on fueling the Hammam boilers. Currently, employees load wood into furnaces located in the boiler room which forces employees to live and work in dangerous conditions with limited training and no legal protection.

Due to lack of safety equipment, such as fireproof gloves, protective eyewear, etc. workers can easily be burned or suffer from inhalation of smoke emissions (A. Bennis, Personal Communication, January 16, 2020). Inhalation of

smoke can cause respiratory symptoms or infections and induce asthma symptoms because of the particulate matter it contains (Noonan, Ward, Navidi & Sheppard, 2012). This ambient particulate matter then does not only impact the Hammam workers, but also residents of the surrounding community (Noonan, Ward, Navidi & Sheppard, 2012).

Figure 11: Hammam employees must fuel the fire by hand, putting them at risk of burns and smoke inhalation (Sebastian Castelier and Al Jazeera, 2016)



With all these environmental impacts and health risks taken into consideration, it becomes apparent that a change to the current heating methods of traditional Hammams has the

potential to impact not only the owner and visitors, but the community at large. Luckily, there may be options for mitigating the detrimental effects of Hammams.

2.5 Association Ribat Al-Fath

Association Ribat Al-Fath is a non-government organization based in Rabat, Morocco with the goal of promoting sustainable living and environmental learning while fostering Moroccan culture and heritage. In the past few years, Ribat Al-Fath has sponsored multiple studies to promote sustainability, and currently they are looking to improve the sustainability of traditional Hammams. Our project will assist Ribat Al-Fath in developing recommendations for mitigating energy use, water use, and environmental impact of Hammams in Morocco.

2.6 Emissions Reducing Technologies

In Morocco, Dr. Khadija Kadiri and her cooperative, Istijmam Waraha, are working with Association Ribat Al-Fath to improve the sustainability of Hammams to promote sustainable practices in Morocco (Cooperative Istijmam Waraha, 2020). Modern advancements in alternative energy

sources such as biomass fuels or insulation provide opportunities to reduce the carbon footprint of Hammams.

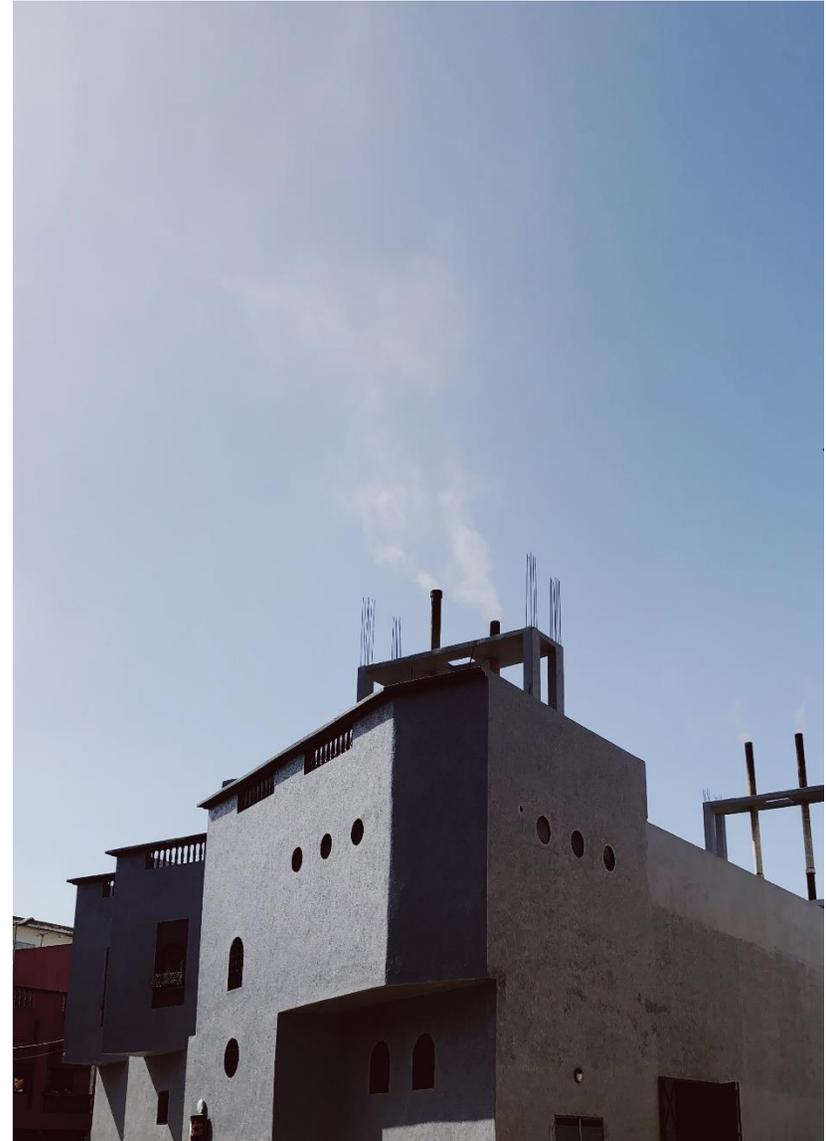
Biomass fuels are renewable and sustainable fuel sources made from organic materials. Olives can be turned into pomace, a biofuel that generates energy for Moroccan Hammams. Morocco is one of the biggest producers and exporters of olive oil. A study called “Water Heating in Moroccan Hammams Using Olive Pits”, by Ferdaouss Sahraoui analyzes the benefits of using olive pits and olive pomace as a biofuel to eliminate the need for wood furnaces in Hammams. The olive pits calorific value is greater than that of wood, meaning olive pits are efficient thermally. Olive pits are also cost-efficient fuel amounting to only 0.46 MAD/ kg (Sahraoui, 2016). Sahraoui’s study shows that using olive oil pits could save about 16.7 million dirhams annually as well as 146,250 tons of wood. The olive pits are pressed, to create the olive pomace, which must then be dried to be made into a biofuel (Sahraoui, 2016). Using this method and creating pomace can create a favorable waste management system for many production units of Moroccan olive oil. Olive pomace is an environmentally safe and sustainable substitute for burning wood.

A simple approach to improving the sustainability of Hammams would be to introduce an insulation system within the buildings. Improving the insulation in Hammams would help to mitigate heat loss, therefore reducing the amount of fuel required to maintain room temperature. A team of researchers used the life-cycle cost analysis method to determine the optimum insulation thickness, energy savings and payback periods for electricity tariff for three different insulation materials in six different regions in Morocco (Jraida, Farchi, Mounir, & Mounir, 2017). In all six regions extruded polystyrene provided the greatest energy savings with the smallest insulation thickness (Jraida, Farchi, Mounir, & Mounir, 2017). Depending on the region adding insulation can result in energy savings ranging from 5\$/m² to over 70\$/m² (Jraida, Farchi, Mounir, & Mounir, 2017). Although insulation can reduce the energy loss and save fuel the installation process can be difficult in existing buildings and may have little effect on the energy savings depending on the region. While there have been many possible solutions to reduce the carbon footprint of Hammams, none have addressed all the sustainable and cultural concerns.

2.7 Summary

In conclusion, traditional institutions are a threat to the global environmental crisis. In Morocco, Hammams negatively affect the surrounding environment and communities and deplete natural resources. While past attempts have been made to discover alternative heating methods, a solution has yet to be found that offers improvements in all areas of concern. Improvements are necessary to mitigate environmental impacts and health risks associated with Hammams, while still maintaining their cultural significance. Our project analyzes multiple solutions that consider all these constraints in order to recommend the best options for a more sustainable Moroccan future.

Figure 12: Smoke emitted from a Hammam in Kenitra, Morocco contributes to air pollution



3. Methodology

The goal of this project was to make recommendations to Association Ribat Al-Fath to aid in the creation of more sustainable management methods for Hammams in Morocco. Based on archival research completed prior to departure, the team discovered a critical gap in the data, one that could only be filled with on-site interviews with Hammam owners on their current heating and water management methods. Therefore, the following three objectives were created to achieve this goal:

Objective 1: Understand the financials, heating methods, and resource management of Hammams throughout Morocco.

Objective 2: Model and quantify the sustainability of the heating systems in Hammams.

Objective 3: Prepare recommendations for guiding Hammams towards more sustainable operations based on our data analysis.

The following sections explain the methods used by the team to accomplish the outlined objectives as well as the deliverables presented to our sponsor at the conclusion of our project. Samples of data collected during the interview process,

screenshots of the developed economic and environmental models, and the project timeline are included in the appendices.

3.1 OBJECTIVE 1: Understand the financials, heating methods, and resource management of Hammams throughout Morocco.

Before any recommendations could be made, the team had to first understand the environmental dangers posed by Hammams, their cultural significance, and the challenges that come with any potential change. The team completed archival research prior to departure, and continued research on site by interviewing Hammam owners and experts in our field of study, including members of our sponsoring organization. The information gathered was then used to analyze the feasibility of implementing changes into existing Hammams, and the potential economic and fuel efficiency outcomes of these changes.

3.1.1 Archival Research

To understand the current environmental state of Morocco the group conducted archival research on

environmental issues throughout the country. After gaining an understanding of the current issues facing Morocco, we completed research on how Hammams contribute to this problem by assessing threatening practices, such as production of smoke and water waste. We completed this assessment by online databases and past project reports relating to environmental sustainability and alternative heating methods for Hammams. This background research was later useful in defining our questions for Hammam owners during interviews.

3.1.2 Semi-Structured Interviews

Based on the methods described by both Dilley and IDEO, we gathered both qualitative and quantitative data through engaging in active conversations with experts in Moroccan politics and culture as well as Hammam owners. Prior to beginning the interviews, the team developed a standardized list of questions designed to steer the conversation in the correct direction and collect the necessary data. Both the sample question and the data collection form are outlined in Appendix A. It is important to note that many Hammam owners did not speak English; in these cases, translators were used to help facilitate the conversations.

Experts in Relevant Fields:

Prior to beginning the interview process with Hammam owners, it was necessary to have a fundamental understanding of the political and environmental issues in Morocco, such that we could approach Hammam owners with a respect and understanding of their field. For research on improvements to Hammam management, we defined “experts” as those who have completed past research on Hammam sustainability or are knowledgeable about Hammam boiler design and water management. Interviews with members of our sponsoring organization, specifically Mr. Abdelhadi Bennis and Ms. Khadija Kadiri, as well as Mr. Najib Motaoukkil provided insightful information into the cutting-edge of sustainable Hammams. For research on the cultural significance of Hammams in Moroccan society, we define “experts” as those who have been immersed in Moroccan culture and experienced the Hammam as a cultural institution. The pre-departure interview conducted with Prof. Tahar El Korchi, as documented in Appendix B, provided insight into what the Hammam experience is, and how we can preserve it.

Hamмам Owners:

In order to prove that the sustainable Hamмам is better both environmentally and financially, our team spoke with a diverse selection of Hamмам owners. Through collaboration with our sponsor we identified six Hammams in the Rabat-Sale-Kenitra region and two in Casablanca with varying combinations of boiler setups, carefully selected for an assorted collection of data. We initially categorized these Hammams into three distinct types: type one Hammams are traditional, with a clay fire pit that burns wood to heat the water inside the Hamмам, type two Hammams replace the fire pit with a boiler, however still burn wood, and finally, type three Hammams substitute wood for a biomass fuel such as argan shells or olive pomace. We then conducted semi-structured interviews with the owners of each Hamмам selected to collect data on current heating methods, expenses, energy usage, and water usage. The data collected from these interviews is available in Appendix E.

3.2 OBJECTIVE 2: Model and quantify the sustainability of the heating systems in Hammams

After compiling data acquired through archival research and semi-structured interviews, we compared the different Hamмам boiler setups, water management plans, and lighting configurations to create a generalized classification system see appendix C. This categorization system allowed us to develop models used to determine both the economic savings and energy efficiency of a sustainable Hamмам.

3.2.1 Organization of Data

We organized the quantitative data collected during semi-structured interviews with Hamмам owners into an extensive spreadsheet, providing us with a plethora of easily understandable information detailing how their businesses operate. The data provided insight into the type and amount of fuel each Hamмам uses, the origin and quantity of water, electricity used, what the financial obligations are associated with said fuel source, along with the management information. A preview of this spreadsheet is available in Appendix D.

3.2.2 Balance Comparisons

In order to quantify the benefits of a sustainable Hammam, the team compiled the raw data from our comprehensive spreadsheet into two detailed models. These models not only provided numerical justification for the benefits of modernizing Hammams but could also be used by association Ribat Al-Fath to encourage change in the Hammam sector.

Energy Balance Model

The team transferred relevant energy data from the extensive spreadsheet into the energy balance model. The model compared the current heating system in each Hammam by displaying possible energy savings through the selection of a fuel source and boiler classification. The energy balance achieved this by calculating the efficiency of all heating system configurations using the observed boiler data in each classification, anecdotal evidence from semi-structured interviews, and the calorific value of all the different potential fuel sources. A preview of the energy balance is available in Appendix F.

Balance Model

Based on anecdotal evidence from Hammam owners and experimentally determined data from the energy model, the team developed a thorough economic model for the Hammam sector. The model presents owners with expected revenues and profits for their Hammam given entry price and sustainability classification for each category. Furthermore, based on the current state of their Hammam, owners can see the expected capital investment needed to follow through with their chosen upgrade plan. A preview of the economic balance is available in Appendix G.

3.3 OBJECTIVE 3: Prepare recommendations for guiding Hammams towards more sustainable operations based on our data analysis

After compiling and analyzing the collected data, the team determined the most apt recommendation plan for improving the sustainability of heating systems, water management and lighting configurations in Hammams. We designed these recommendations to be applicable for the vast majority of Hammams throughout Morocco, as they identify

the most important aspects of modernized Hammams that can be implemented in other systems. These recommendations will be able to fit the needs of Hammam owners throughout the country, with explanations of how each option benefits the Hammam in terms of fuel, water and electricity savings, safety, and environmental impact.

3.3.1 Sustainable Upgrade Plan

With the models our team developed, we were able to quantify how much each element of a modernized Hammam contributed to overall environmental and economic gains. From there, we outlined a sustainable upgrade plan that used the most effective improvements for the average traditional Hammam in Morocco.

3.3.2 Project Deliverables

At the conclusion of this project Association Ribat Al-Fath was presented with a comprehensive spreadsheet, a meta-analysis of economic and energy models that detailed the results of our research, along with a final presentation and written report. The purpose of these project deliverables was to summarize our work on the project and allow for the continuation of research on this topic.

Comprehensive Spreadsheet

We presented the comprehensive spreadsheet used for compiling the data from Hammam interviews to Association Ribat Al-Fath at the conclusion of our project. This was done so that the association could compare our results with those of studies conducted in parallel. Furthermore, it provides a jumping off point for the association if they would wish to continue our research.

Meta-Analysis of Economic and Energy Models

An analysis of the economic and energy models was provided to detail the economic investments and savings as well as the energy savings associated with all potential upgrades detailed in our report for improving Hammam sustainability. The analysis includes data for the current cost effectiveness and energy efficiency of all Hammam classifications.

3.4 Challenges

Being foreign researchers in an unfamiliar country presented a variety of challenges. The biggest predicament we faced was the language barrier between our team and nearly everyone we talked too, including our sponsor. While this issue

was mitigated because one of our team members spoke French, a separate problem arose in that they would need to both actively engage in conversation and translate all pertinent information to the rest of the team. Although French is a common language in Morocco, a selection of those interviewed did not speak the language, resulting in the need for an Arabic translator and presenting the team with additional scheduling complications. While the language barrier did make conducting interviews challenging, it was not a limiting factor in our data collection. Furthermore, due to lack of technology and reluctance to provide data seen as a “trade secret”, some of our interviewees did not have access to the economic and environmental data we sought after. Data collection proved to be more difficult than expected as many Hammam owners did not have access to the necessary records we needed to complete our quantitative research. This posed the potential risk of collecting inaccurate information, thus skewing the results of the developed balance sheets. Next, due to the coastal location of the Rabat-Sale region, the Hammams our team investigated had easy access to both water and energy resources, creating a gap in our data for Hammams with limited water access or other environmental limitations. This national divide made it

difficult to explain the objective of our interviews, making it unlikely for our interviewees to see a need for change in their Hammam. Whether the problem was identified or not, unwillingness to alter the Hammams’ current methods of operation became an issue as the idea of change unsettled some of the Hammam owners. Finally, asking private and sometimes intrusive questions created awkward situations in interviews, as understandably, Hammam owners hesitated to speak openly about their electric and water usage along with the associated financial burdens to foreign students.

3.5 Summary

This project’s goal was to make recommendations to Association Ribat Al-Fath to aid in the creation of more sustainable management methods for Hammams in Morocco. The team accomplished this goal through archival research, semi-structured interviews, balance comparisons, and data analysis to meet each of the three objectives outlined. The next chapter will discuss the team’s analysis of the data gathered using the described methodology. These findings informed the recommendations presented to Association Ribat Al-Fath at the conclusion of this project.

4. Findings & Analysis

Based on data analysis and observations gathered from site visits and semi-structured interviews, the team developed the following findings concerning the sustainability of Moroccan Hammams, or public bathhouses, throughout the Rabat-Sale-Kenitra Region. Building from archival research completed prior to arrival, and the further input from Dr. Khadija Kadiri, the team identified key resource management styles that contribute towards sustainability. Using economic and energy balance models to regress the various components of a sustainable Hammam against its traditional counterpart, the team was able to quantify which of these management styles had the greatest environmental and economic impacts; these findings then became the basis for our project deliverables. The following chapter details the data analysis that led to our findings, beginning with fuel usage and heating, continuing with water management, and ending with lighting techniques.

4.1 Heating Method Findings

4.1.1 Switching from wood to biomass fuel improves heating efficiency and reduces Hammam expenses.

During semi-structured interviews, many Hammam owners described wood as a dirty fuel that releases a considerable amount of ash and smoke, creating not only health risks to those who fuel the fires, but also leading to equipment deterioration and the need for a stricter maintenance schedule. In Morocco, wood is sold at 0.8 MAD/Kg and it arrives into Hammams unprocessed, soaked with water and dirty with mud. After eliminating this water and dirt, only 60% of the wood Hammam owners pay for burns as fuel, raising the effective price to 1.3 MAD/Kg. Furthermore, wood has a 10% ash yield per kilogram burned, negatively impacting the efficiency of the heating system if unmonitored and adding the necessary overhead of disposing of the ash.

On the contrary, the biomass of choice, Argan shells, cost the same as wood and have an effective efficiency of 100%, burning with no residue. Two Hammams we investigated both noticed an immediate increase in the overall performance of their system after switching to a biomass fuel.

In addition, during our visits the team noticed that Hammams operating on biomass fuels produced little to no visible emissions and ash when used in a proper heating system. After comparing wood to biomass in our environmental model based from the amount of energy required to power a Hammam, it was evident that a traditional furnace fueled by biomass is at least 1.3 times more efficient than its wood counterpart. The higher efficiency of biomass results in an average savings of 60,000 MAD a year. As such, switching to biomass fuels is not only better for the environment, but returns immediate economic benefits as the change requires no capital investment from Hammam owners.

Figure 13: Argan shells being used as a biomass fuel in place of wood



4.1.2 Upgrading to a modern boiler and using biomass fuel improves energy efficiency and reduces fuel expenses.

Through interviews with Hammam owners in different stages of modernizing, we were able to compile a spectrum of data detailing the efficiency and cost effectiveness of each combination of boilers and fuel sources. Their anecdotal data revealed that the traditional wood fired clay and salt crystal furnaces are not only extremely inefficient, but also difficult to maintain, making them expensive to operate. The Hammam owners that had transitioned from a traditional heating method to a boiler fueled by biomass reported a notable reduction in both emissions and fuel costs. During interviews conducted at Hammams using both biomass and a modern boiler, the team noticed no visible emissions coming from the smokestacks, with both anecdotal and modeled evidence indicating a system efficiency of 90%. At Hammams operating a traditional boiler with biomass, we noted some smoke and ash from burning argan shells, which, while still less smoke and waste than that of a traditional wood burning Hammam, still indicated some inefficiency in the system, likely due to the 32.5% ambient heat loss of traditional furnaces, resulting in an inability to burn

argan shells to completion, leading to unnecessary waste and emissions.

Based on interview data on fuel usage inputted into the energy balance model, the team was able to calculate the weight of fuel in kilograms required to produce the desired energy output for the two types of boilers using each of the three most common fuel types. As seen in table 1, biomass fuels in both boilers have a much higher system energy output than that of a traditional wood fired furnace.

Table 1: The energy output of one kilogram of the three most common fuels in the two boiler types and the total heating system efficiency

Boiler Type	Traditional			Modern		
	Wood	Argan Shells	Olive Pomace	Wood	Argan Shells	Olive Pomace
System Energy Output (kJ/Kg)	9,320	13,925	12,150	11,049	16,504	14,400
System Efficiency	0.41	0.68	0.54	0.48	0.80	0.64

The calculations showed that upgrading to a modern boiler and switching fuels to a biomass fuel is over 1.6 times more efficient than the traditional wood fired furnace. Based on the table, argan shells are the most efficient fuel option for

Hammams and can reduce fuel by 76,000 MAD a year compared to a traditional furnace fueled by wood. Similarly, a modern boiler fueled by olive pomace is 1.64 times more efficient and saves 73,000 MAD a year in fuel expenses when compared to traditional wood furnaces.

Figure 14: An advanced boiler system fueled by argan shells



4.1.3 Using an automatic feeding system improves boiler efficiency by 50% and system efficiency by 10%

The anecdotal data received from interviews with Hammam owners revealed that the implementation of a feeding system had positive impacts on boiler and heating system efficiency. The feeding system distributes fuel directly into the

fire, concentrating the fuel in the center and allowing it to burn to completion. As seen in table 2, this system reduces the amount of fuel required because, the system mitigates heat loss from the boiler, by eliminating the need to open the door to fuel the fire.

Table 2: The weight of fuel in the possible heating system configurations to satisfy the Hammam energy requirement

Boiler Type	Traditional			Modern		
	Wood	Argan Shells	Olive Pomace	Wood	Argan Shells	Olive Pomace
Weight of fuel to supply energy (Kg)	1000.00	669.28	767.07	843.8	564.70	647.21
Weight of fuel to supply energy with feeder (Kg)	-	561.20	618.23	-	501.96	559.75

The concentration of the fuel and the reduction in heat loss improves boiler efficiency by 50%, increases overall system efficiency by 10%, and saves 9,000 dirhams in fuel costs per year. Furthermore, it provides a safer working environment for Hammam employees, because workers no longer need to fuel the fire by hand, minimizing exposure to the heat and smoke. Two Hammams were successful in implementing an argan shell feeding system with the traditional

boiler, lowering overall fuel usage and cost. Finally, anecdotal evidence revealed that return on investment for these systems was in the range of six to eight months.

4.1.4 Utilizing a solar heating array saves up to 30,000 MAD a year in fuel costs.

Solar heating arrays eliminate the need to constantly have the fire burning to maintain water temperature throughout the night. Water is distributed amongst a set of glass pipes, allowing solar radiation to heat it, and this hot water is then used to supply faucets inside the bathing rooms. Based on the anecdotal information from a Hammam which had implemented a solar heating array, this method of heating can save up to 7,000 MAD during summer months as the boiler is rarely required to be ignited, leading to savings of up to 30,000 MAD a year. It is important to note that the effectiveness of the array is directly correlated to sun exposure and the number of daylight hours, meaning that different Hammam owners will see different gains from the system in different months throughout the year. Due to this varying reliability, the use of a solar heating array cannot be the only heating method used in the Hammam, but it serves as an excellent addition for both environmental and economic gain.

Figure 15: The solar heating array witnessed during an onsite interview in Rabat, Morocco



Unfortunately, a solar heating array is difficult to install and maintain due to the current lack of skilled labor specific to sustainable mechanical systems in Morocco. The solar heating array referenced broke in the winter of 2018 due to rust buildup in the water pipes, and since then, the Hammam owner has not been able to find someone to fix the system, leaving it inoperable to date.

4.2 Water Management Findings

4.2.1 Mixing systems to optimize water temperature for the clients reduces the amount of water waste.

Based on anecdotal evidence gathered during site visits, the average bather will use anywhere between 100 to 200 liters of water during the Hammam ritual. While many factors contribute to this issue, the one which can be most easily remedied has to do with the overheating of water. Typically, in a traditional Hammam, the water heated by the boiler is distributed directly to the faucets for clientele use. This water arrives into the Hammam anywhere between 60°C and 80°C, significantly above the comfortable bathing temperature of approximately 43°C, in turn forcing clients to recool the hot water with cold water before using it to bathe. In both the Kenitra and Temara Hammam visits, a water piping system was installed which mixed hot and cold water together prior to distribution throughout the Hammam, such that the water would arrive at the faucet at the optimum temperature for most clients. The Hammam owners at both Hammams noted that after implementing a mixing system, they noticed a decrease in wasted water, providing both environmental and economic benefits.

4.3 Lighting Technique Findings

4.3.1 Using the qamariyyat lighting technique and solar powered LED lights effectively eliminates electricity costs for lighting

Hammams use a varying quantity of natural and artificial lights, depending on their location, availability to sunlight, and floor plan. When natural lighting is used, it often comes through flat square panel skylights. This method not only poorly diffuses light into the space, but also causes the skylights to easily fog over, preventing the entry of sunlight in the bath. The team's interview at one Hammam, revealed that switching from flat square panel skylights to the qamariyyat lights, or convex glass domes that diffuse light into the space, greatly increased the amount of light within the Hammam. Furthermore, at the same Hammam, solar panels located on the roof were used to charge batteries during the day which in turn powered LED lights located inside the bathhouse during the night. Through the combination of natural qamariyyat lighting and solar powered LED, this Hammam was able to eliminate its lighting costs.

Figure 16: View of natural qamariyyat lighting from the inside of a Hammam



4.4 Summary

This chapter presented an analysis of the data gathered throughout the course of our interviews. Based on raw anecdotal data, and thoroughly developed models, the team was able to quantify the sustainability of the resource management system in Hammams. We then used these conclusions to present Association Ribat Al-Fath with a set of recommendations on how to modernize the Hammam industry. In the next chapter, we will discuss these recommendations, as well as their benefits, limitations, and feasibility.

5. Recommendations

This chapter details the Team’s recommendations for Association Ribat Al-Fath based on the findings presented in the Findings & Analysis chapter. The recommendations in this section include heating system upgrades, water saving techniques, lighting improvements, and general management recommendations.

5.1 Heating System Upgrades

5.1.1 Switch to biomass fuel in place of wood.

Switching from wood to biomass fuel is one of the rare cases where making the environmentally sound decision carries economic incentives. Burning wood negatively impacts not only local communities and Hammam employees, but also the environment at large. On the contrary, biomass fuels, such as argan shells, olive pomace, and other agricultural byproducts, can be used as an excellent alternative fuel source, while producing little to no smoke and ash compared to their wood counterparts. Furthermore, in Morocco, biomass fuels are a plentiful resource that already exist as a byproduct of other

industries, unlike wood, which is cut from forests solely to be burned. Finally, and most importantly, biomass provides many economic incentives; table 3 shows a comparison between wood and two common biomass alternatives, argan shells and olive pomace, where it is clear to see that a smaller quantity of biomass is required for the same energy output, leading to immediate economic savings.

Table 3: The weight of fuel to produce the required power for a day and the annual fuel expense for a traditional boiler fueled by the three most common fuel sources, wood, argan shells, and olive pomace

Boiler Type	Traditional		
	Wood	Argan Shells	Olive Pomace
Weight of fuel to supply energy (Kg)	1000.0000	669.2778	767.0667
Yearly fuel expenses (MAD)	154,074.07	92,444.44	95,333.33
Yearly fuel cost savings (MAD)	-	61,629.63	58,740.74

By making the switch to biomass fuel, Hammam owners can decrease their fuel usage by 30% on average and save up to 60,000 MAD a year. Currently, Morocco’s most popular option for biomass fuel are argan shells as they are

ready to be cleanly burned the instant, they become a byproduct. Furthermore, their small size makes them easy to purchase in large quantities, transport, and store. While argan shells appear to be the best choice as a fuel alternative, we acknowledge there are not enough argan shells produced by the argan oil industry to supply every Hammam in Morocco. For this reason, we recommend switching to a variety of biomass fuels, distributed throughout the country to align with fuel availability in different regions. For instance, since the argan oil industry is most concentrated in the Southern region of Morocco, Hammams in this region and regions close by could make the switch to argan shell fuel, while the Northern Region, where the olive industry is concentrated, Hammam owners could make the switch to olive pomace. Other Moroccan byproducts that could potentially be used for biomass fuel include dates, almonds and recycled wood. Regardless of the type, switching to a biomass fuel is extremely advantageous for the environment, while presenting tremendous financial benefits to Hammam owners.

5.1.2 Upgrade from a traditional furnace to a modern biomass boiler.

The upgrade from traditional clay furnaces to modern boilers provides numerous benefits for Hammam owners, employees, and the environment. Firstly, modern boilers are 33% more efficient than their traditional counterparts, therefore requiring one third less fuel to produce the same energy output, and thereby reducing operating costs. Secondly, modern boilers are cleaner and safer for employees to operate and load as their modern insulation design lowers the amount of exposure to heat and smoke that Hammam employee will face on the daily. While upgrading to a modern boiler does require a large initial investment, evidence from interviews with Hammams who've made the switch show that on average, the return on investment is three to five years.

While upgrading to a modern boiler is both environmentally beneficial and cost efficient, prior analysis of the system is required to ensure the ideal boiler for each individual system. One Hammam owner shared that although he has fully upgraded to a modern boiler and water management system, he still experiences major problems with system inefficiencies. This was because the boiler was

mistakenly over dimensioned for the Hammam, meaning a disproportionate amount of energy went to heating water that was never used. From this anecdote, we realized that there is more to going green than implementing a modern boiler and biomass fuel; boilers must be sized correctly to meet the water usage and energy needs of each specific Hammam. In order to do this, a Hammam must first implement a tracking system to log resource usage, then use the collected data to select the proper boiler for the system. Without this data, the risk for incorrectly dimensioning a boiler, and therefore installing a system that is too powerful or too weak, increases dramatically. In the former case, a boiler too powerful for the system will create excess heated water, which will then go to waste as there aren't enough customers in the bath to use said water. On the contrary, if the system is not powerful enough, the boiler will not be able to heat water to the necessary temperatures required by patrons, thereby losing the Hammam customers.

5.1.3 Implement an automatic feeder into the heating system.

A biomass feeding system, known as a burner in the Hammam industry, is a screw conveyor-based delivery method for fuel. When implemented, it is one of the most important

Figure 17: A feeding system directly connected to a modern boiler automatically directs fuel into the fire



aspects of a modern heating system, providing enormous economic and energy savings. This is because a feeding system eliminates all ambient heat loss that occurs when opening the boiler door to add fuel. Furthermore, by concentrating added fuel to the center of the fire, it makes sure the fuel is burned to completion further reducing emissions. Based on our data analysis, the feeding system increases the overall efficiency of

the Hammam by 10% leading to fuel savings of up to 15,000 MAD a year with an ROI in six to eight months. Based on these findings we strongly recommend that all Hammams install a feeding system in conjunction with the switch to biomass fuels. If possible, we also recommend the installation of a modern boiler to maximize system efficiency.

While installing a feeder system offers many benefits, there are still some limitations. Since feeding systems are not widely used throughout the industry, there is a lack of professionals capable of maintaining these systems. This lack of available mechanics creates issues when components break, either forcing Hammams to buy a new unit, or operate without a feeding system for an extended period.

5.1.4 Use proper storage methods for fuel to increase efficiency.

Putting care into proper fuel storage is an important aspect of maintaining fuel efficiency, regardless of the combustible material. When dirt, dust, water, and other impurities are mixed in with the fuel, the efficiency of the material is lowered. In order to burn most effectively, fire requires dry conditions and direct access between fuel and air, thus, when a combustible becomes contaminated with

Figure 18: Example of proper fuel storage for argan shells



moisture, it won't be able to burn to completion, thus leaving behind residue in the form of ash. Small bits of plastic, which can come from trash or storage bags left on the ground near the boiler, can mix in with wood or argan shells and when burned, release chemical contaminants into the atmosphere. In the case of one Hammam with a traditional furnace fueled by argan, improper fuel storage created ash and smoke during the burning process. In this case, the combustible was stored on the ground around the furnace, mixing with dust, ash, and other particles, making the complete combustion of the shells impossible. In this case, we recommend storing the argan shells in waterproof bags or buckets, preferably in a dry section of the

boiler room or an enclosed space to protect them from contaminants. If traditional wood is still being used, we recommend storing the logs in a dry, ventilated area to prevent mold and rotting. It is also important to note that Hammam owners should avoid storing either type of fuel too close to the furnace or boiler to reduce fire hazard in the event of open flame or high temperatures.

5.2 Water Saving Techniques

5.2.1 Install a water mixing system to reduce clientele water waste.

Based on our research, one of the simplest and most effective ways to conserve water is to regulate the temperature of the water being delivered into the Hammam. The comfortable human bathing temperature is approximately 43°C, significantly below the 60°C to 80°C at which water arrives typically arrives into the faucets. This leads to situations where Hammam patrons must manually mix the scalding hot water with cold water to regulate it down to a temperature they are comfortable bathing at. This practice of water mixing is not often done in a conservative manner, wasting notable amounts

of both hot and cold water before the optimal temperature is achieved.

To avoid this, we recommend implementing a control system like the ones implemented at the Kenitra and Temara Hammams. In these systems, hot water from the boiler was mixed with cold water from the well prior to distribution. While still inefficient due to necessary recooling of water, taking the mixing out of patron's hands resulted in a notable decrease in the amount of wasted water. Another option is to implement a control system for the boiler, where it will automatically shut off once the water hits the desired temperature. With either option, the water will be prematurely monitored such that the customers will not get access to the water until it is at an ideal temperature, mitigating water waste, and creating a more pleasant bathing experience as well.

5.2.2 Switch to automatic or metered faucets.

Installing automatic faucets that shut off water flow after a predetermined amount will limit water waste and encourage clients to use water more sparingly. With the implementation of metered faucets, Hammam owners could charge money for how much water each individual client uses.

Visitors could pay for how much water they needed before bathing, and water usage could be easily tracked and recorded so that Hammam owners know how much water is being used each day.

Figure 19: Adjust water temperature or install metered faucets to reduce water waste



One of the problems noted by Hammam owners interviewed is that faucets tend to get easily broken inside the Hammam. The concern with implementing automatic or metered faucets is then the fact that they may be damaged too often and too expensive to replace. Limiting water available to clients also poses the danger of negatively changing the bathing experience. Our team recommends implementing these faucets on a trial basis, to at least track water usage in different Hammams as a result of the switch.

5.3 Lighting Improvements

5.3.1 Replace skylights with light diffusion domes to improve natural daylighting.

By removing skylights and adopting traditional qamariyyat lights, or handcrafted glass light diffusion domes, electricity costs can be eliminated. Many of the Hammams visited are currently using electric lighting during daylight hours because they either have inadequate access to natural daylighting through windows or skylights, or the skylights they have are not properly positioned or maintained, causing them to fog over and obstruct light. The traditional Moroccan skylights are small, flat glass panels that do not provide enough light on their own. The alternative glass qamariyyat light's oculus structure allows for "sunlight to filter through the thick steam of the bathing spaces," providing more light in the interior room with the same opening to the outside (Sibley, 2013). Therefore, in Hammams that already utilize skylights for natural lighting, our team recommends replacing these flat skylights with domed qamariyyat lights, shown in Figure 3. To optimize the reflection of the daylight entering through these qamariyyat lights, white paint can be applied to the buildings'

roof surrounding the dome, as well as the interior walls of the skylight and ceiling (Sibley, 2013).

Figure 20: Qamariyyat glass dome skylights being utilized at one of the Hammams the team visited



5.3.2 Utilize solar powered LED bulbs to reduce electricity usage.

Another way for Hammam owners to reduce electricity usage is by implementing a solar panel system to power LED light bulbs. The Hammam discussed in the previous section also experimented with small solar panels on the roof designed to power electric lights in conjunction with the implementation of the qamariyyat domes. By using these qamariyyat domes during the day, and the solar powered LED bulbs at night, the owner of the Hammam, effectively eliminated the need for

electricity to light the Hammam. In a study conducted by Dr. Magda Sibley in Fez, Morocco, solar energy powered lighting was implemented into a Hammam, and it was found that the lighting quality of the solar powered LED bulbs surpassed that of the lighting quality of preexisting fluorescent tubes. Sibley's design for the glass dome and solar powered bulb lighting system is shown in Figure 4. With this information, we recommend that Hammam owners invest in small solar panels to power any electric lighting they require.

Figure 21: Design for glass dome and solar powered LED lighting system (Sibley 2013)



The team acknowledges that there is limited production of affordable solar panels, as well as qamariyyat lights throughout Morocco, which complicates the implementation of this new lighting technique.

5.4 General Management Recommendations

5.4.1 Implement a tracking system to provide Hammam owners with accurate economic and utility usage data.

While conducting our research on heating systems, water management, and lighting techniques, the team discovered a sizable gap in the knowledge that, if filled, would greatly assist in the implementation of the recommendations on this list. In order to accomplish the maximum efficiency or revenue possible, Hammam owners must first be able to track and record their current usage and financial data. For example, prior to making the switch to an improved boiler system, a Hammam owner must first know what size boiler is required for their specific Hammam. Similarly, data detailing the daily hourly traffic rate allows owners to prepare for the fluctuation in clientele allowing them to adjust the temperature of the

boiler, accordingly, mitigating water and energy waste. In many interviews with Hammam owners, we found that the majority do not track data, either because it seems unnecessary, or they do not have the ability to do so. However, our team views the tracking system as one of our top recommendations to be applied in every Hammam.

A tracking system could consist of a written sign-in book, tracking how many people come into the Hammam at what time each day, and how long they stay for. This could be expanded to include how much water each person uses, and total money made each day. The tracking system could also be implemented on a computer, with a spreadsheet or a simple user interface that allowed employees to input numbers when prompted. The challenge with this, as we have noticed through interviews, is the lack of technology in most traditional Hammams, and the lack of technical training for employees to be able to operate a computer.

5.4.2 Provide safety equipment for Hammam employees.

To improve the safety of Hammam employees, and effectively lower the risk of injury, we recommend the use of safety equipment for people working in the boiler room.

Employees can easily be burned by the open and often erratic flame in a traditional furnace and risk dangerous smoke inhalation from the constant need to access the fire. Access to protective gear, such as heat protectant gloves and safety goggles, reduces the chance of burn injury for Hammam workers. In addition, a face shield that covers the nose and mouth can protect workers from dangerous smoke inhalation. A feeding system can also help to mitigate the risk of burns and smoke inhalation for workers, but even if this is the case, protective equipment must still be used when workers open the boiler door or operate equipment.

5.4.3 Implement educational programs in local vocational schools to train professionals to provide boiler and solar system maintenance to specialized Hammam equipment.

A large limitation for implementing more sustainable energy practices is concern for how to maintain and service them. While it may be easy to switch from an old system to a newer one, at some point even modern technologies will need service to ensure the longevity of the system. Many Hammam owners hesitate to make the sustainable switch as they worry that there is not a service technician available for the newer

system when maintenance is needed. Therefore, our team recommends the implementation of educational programs in local vocational schools to train professionals that could specialize in modern Hammam maintenance. With funding from the government, vocational schools could install educational programs focused around maintenance of mechanical systems, including modern boilers, automatic feeding systems and solar heating systems. These technicians would be able to create a new vocation specific to modern sustainable energy systems, and this could be groundbreaking for the future of green energy throughout Morocco. Students would also have an increased awareness of the issue and be able to help develop new solutions. If there were mechanics trained to install and maintain the advanced systems available, it would be easier and more reasonable for Hammam owners to make the change.

5.4.4 Implement an artisan certification program for the Hammam industry.

Currently, there are no restrictions on who can design, assemble, and install the sustainable innovations in the Hammam industry. An artisan certification program will make it easy for Hammam owners to find skilled and trustworthy

laborers who can not only install the complex systems required by a sustainable Hammam, but also innovate on the current technology. In partnership with the vocational schools, artisans possessing proper certification can assist with the growth of the industry by undertaking apprentices and training the next generation of craftsmen.

5.4.5 Promote environmental awareness amongst Hammam owners and advocate for improvements with an informational video.

Our final recommendation is to advocate for all these ideas, and the Sustainable Hammam Project as a whole, with an informational video. The video could be presented to Hammam owners at conferences, or during visits, to provide an overview of the problem and potential solutions to consider. It outlines the different options for improving sustainability within a standard Hammam, as well as average costs and potential savings, and directions for implementation. The use of this video by Association Ribat Al-Fath will further the goals of the project by promoting environmental awareness and educating Hammams owners on how they can achieve these goals in Hammams throughout Morocco.

5.5 Summary

This chapter outlined the team's recommendations for Hammam owners throughout Morocco, including heating system upgrades, water saving techniques, lighting improvements, and general management recommendations. These recommendations were presented to Association Ribat Al-Fath at the conclusion of this project to assist in the implementation of more sustainable Hammam management methods. The implementation of these recommendations will reduce the environmental impact of Hammams while still maintaining their cultural significance, while providing economic benefits for the people of Morocco. Our recommendations can also help to further inspire research and future efforts towards a more sustainable Hammam industry. The next chapter will discuss the final outcomes of this project and the team's concluding observations.

6. Conclusion

Our project made recommendations to Association Ribat Al-Fath and Cooperative Istijmam Waraha that will lead to the implementation of more sustainable management methods in Hammams around Morocco. In the first phase of the project, the team completed extensive archival research to gain a basic understanding of the Hammam industry. Once in Morocco, we began interviewing Hammam owners and other experts in the field of Hammam sustainability to gather the necessary data about financials, resource management, and operations. Using this data, we created environmental and



economic models to quantify the sustainability and cost effectiveness of the various components found in the heating, water distribution, and lighting systems. Finally, we prepared and presented a list of recommendations based on our findings to our sponsors with the goal of guiding the Hammam industry towards a more sustainable future.

The implementation of these recommendations will reduce both operating expenses and the environmental impact of Hammams. However, it is important to maintain the cultural significance of this institution, such that tradition is not buried in modernization. Not only do Hammams play an essential religious role in Islam, but they also serve as a social outlet and physical service station for many Moroccans. These cultural pillars are why the Hammam has remained virtually unchanged for hundreds of years. Now, in the context of modern society and the current environmental crisis, we must consider the environmental impacts of the traditional Hammam and the technological advancements that can be made to preserve an institution so deeply rooted in the Moroccan way of life.

While conducting our research, the team identified many potential changes that can be implemented in Hammams

throughout the country in order to mitigate their environmental impact. Options to improve energy efficiency include switching from wood to biomass, upgrading from a traditional furnace to a modern boiler, implementing an automatic feeding system, and improving fuel storage to prevent contamination. In order to mitigate water usage, our team recommends the installation of a water mixing system, or automatic and metered faucets. To nearly eliminate electricity costs, we recommend the installation of light diffusion domes and solar powered LED lights. Finally, by implementing a resource tracking system, Hammam owners will be able to collect accurate financial data as well as the necessary information for making informed upgrade decisions in their Hammam. Additionally, we recommend the creation of educational programs to train professionals on how to service and innovate the new systems being implemented into Hammams. The recommended upgrades may be made put into practice collectively or individually, depending on the current conditions of the Hammam, as each individual Hammam is unique in its setup and management methods. With the implementation of these recommendations, Hammam owners will not only contribute towards saving the environment but will also enjoy financial

benefits. By modernizing Hammams, job availability in Morocco will increase as well, due to the creation of a new economic sector for Hammam equipment, and bolster pre-existing industries, such as the argan oil and olive oil industries, whose byproducts may now be sold as a fuel source.

Climate change is too large a problem for any single person, corporation, or nation to solve. There is no all-encompassing option to tackle the issue, just as there is no one solution for modernizing Hammams, because everyone, corporation, and nation has its own unique set of needs and capabilities for approaching the problem. However, there are many small steps that can be made to work towards a greener future, and it is the sum of these changes that will have a lasting global impact.



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Appendices:

Appendix A: Sample Interview Script for Hammam Owners

Oral Consent Form

We are the Ribat Al-Fath Sustainable Hammams team from Worcester Polytechnic Institute in Massachusetts. We are conducting a survey of Hammam owners in Morocco to collect information about Hammam heating systems and water usage to develop a more sustainable management method. We strongly believe this kind of research will ultimately improve environmental sustainability, as well as the user experience and cost to Hammam owners and workers in Morocco.

Your participation in this interview is completely voluntary and you may withdraw at any time. Please remember that your answers will remain anonymous. Your name and business address will only be used for our records. No names or identifying information will appear on the questionnaires or in any of the project reports or publications.

This is a collaborative project between Association Ribat Al-Fath and Worcester Polytechnic Institute, and your participation is greatly appreciated. If interested, a copy of our results will be provided via email.

If you have any questions regarding our research, you can contact our team at gr-ribat-al-fath-c20@wpi.edu. If you have any questions regarding your rights as a research subject, please contact Worcester Polytechnic Institute's Institutional Review Board at irb@wpi.edu

Thank you for your help!

Introduction

Salamu 3alaykum! We are engineering students from the United States who are completing research on environmental sustainability in Morocco. One area of Moroccan culture that we think can be improved to be more sustainable are the Hammams, because currently many Hammams in Morocco use a lot of wood and water. We are not looking to change the user experience of the Hammam, nor the way the Hammam looks or functions. Instead, we want to find ways to reduce fuel and water usage, in order to mitigate the Hammam's impact on the environment. We'd like to ask you a couple questions regarding the heating system and water usage of this Hammam and compare the answers to data from other Hammams we are interviewing, in order to make the best recommendations for improvements that can be made. Do you have any questions for us before we begin?

Semi-Structured Interview Questions for Hammam owners:

1. Can you tell us your name and a little bit about yourself? How did you become a Hammam owner?
2. How large is your Hammam?
 1. How many rooms are there?
 2. Can you give us an estimate of the square footage?
 3. What are your hours of operation?
 4. How many customers visit the Hammam each year?
 - i. How many women visit?
 - ii. How many men visit?
3. How is the water and interior space currently heated in your Hammam? What fuel sources do you use? Wood, Olive pits, or Solar Power?
 1. Is this how you've always heated the water?
 2. Can we see the boiler room?
4. How much fuel do you use for the heating system each year?
5. Where does the water come from? Is there a water well, or does the water come from a water treatment plant (ONEP)?
6. How much water is used in the Hammam each year?
7. What type of lighting is used in the Hammam?
8. What energy source is used to power the lights?
9. If you don't mind us asking, how much do you pay each month for fuel?
 1. How much do you pay each month for electricity and for water?
 2. How much does the customer pay to use the Hammam?
10. Who tends to the fire / who maintains the heating system?

1. Are there any difficulties in that job?
11. Have you noticed any environmental impacts or health risks from your Hammam?
12. Do you see any benefits in making changes to the heating system or water usage of your Hammam? How would you improve your Hammam to make it more sustainable?
13. Do you know anyone else we can talk to that may be able to help us with our research?

Note: Interview questions and data collection sheets are presented here in English but were translated into French or Darija during interviews for the purpose of communication with Hammam owners.

Appendix B: Sample Interview Script for Cultural Experts

Interviewee: Tahar El-Korchi

Date of Interview: 11/12/2019

Time of Interview: 10 am

Location: Worcester Polytechnic Institute - Kaven Hall

Interview Facilitator: Rebekah Vernon

Interview Scribe(s): Payton Bielawski

1. How are you today?
2. Where are you from?
3. Can you tell us a little bit about growing up in Morocco?
4. How is your experience different from America?
5. What is your personal experience with Hammams?
 1. How often do you go?
 2. How old were you when you first went?
 3. What is the process or structure of going to the Hammam?
 4. How many people normally visit?
 5. How clean are they?
 6. How expensive is a typical visit?
 7. How long do you stay?
6. Can you talk some more about the general use and influence of Hammams in Moroccan culture?
 1. What is the difference between tourist Hammams and resident Hammams?
 2. How do you find a Hammam?
 3. What does the Hammam do wrong? What can be improved?
7. Can you tell us about the structure and design of Hammams, and how these aspects contribute to the overall experience?
 1. What is the general Hammam structure and orientation?
 2. What things are essential to the Hammam experience?
 3. What are the normal heating methods?
 4. Do you know of any Hammams that use sustainable energy?
8. Solar Decathlon Project:
 1. What were some aspects the team used to achieve net-zero for the solar decathlon project?
 2. What were the most abundant resources / materials available for Oculus?
 3. Were there sustainability methods used in that building that were specific to Morocco?
9. Do you know of anyone else we could talk to that may be able to help us with our research?

Appendix C: Hammam Classification System

Hammam Classification System

The Hammams we have visited have been classified based on three categories: heating methods, water management, and lighting technique.

Heating Methods

Heating methods were classified into three types based on the energy efficiency of the system.

Type 1: Hammam that utilizes a traditional clay and salt crystal furnace and wood to heat the Hammam, often with holes or other sources for major heat loss.

Type 2: Hammam that has made select upgrades to a boiler system but has not yet implemented all aspects of a modern sustainable boiler setup.

Type 3: Hammam that utilizes a variety of available technologies and biomass fuels to improve boiler efficiency and safety, minimal heat loss and maximum efficiency of fuel being burned.

Water Management

Water management methods were classified into three types based on the amount of water saved.

Type 1: Hammam that distributes water heated by the furnace directly into the bathing rooms at a high temperature.

Type 2: Hammam that utilizes mixing techniques to distribute water at the optimal temperature and minimize clientele use.

Type 3: Hammam that utilizes available technologies and controls to mix the water and has implemented a recapture system to mitigate waste.

Lighting Technique

Finally lighting techniques were classified into three types based on the Hammam's reliance on electricity for interior lighting fixtures.

Type 1: Hammam that is reliant on grid powered electricity to power non-LED light bulbs.

Type 2: Hammam that utilizes both natural light and LED bulbs powered by city power in order to cut down on electricity usage.

Type 3: Hammam that utilizes natural lighting techniques and solar powered bulbs to avoid relying on electricity at all.

Appendix D: Sample Raw Data Table from Interview Results

Table 4: Data table for quantitative interview results, completed for each Hammam visit

Hammmam Name						
Hammmam Details	Traditional	Modern	Traditional	Modern	Traditional	Modern
Location	Temara	Temara	Rabat	Rabat	Rabat	Rabat
Heating Method Classification	1	3	1	2	X	3
Water Management Classification	1	3	X	X	X	3
Lighting technique Classification	X	X	1	1	X	3
Number of rooms	3+ changing rooms each	3+ changing rooms each	3+changing room	3+changing room	3+ changing room	3+ changing room
Total Area (m^2)	500	500	146	146	X	X
Hours of operation	10 am - 6 pm	10 am - 6 pm	7:30am-11:30pm	7:30am-11:30pm	X	X
Average number of clients per year	70,000	70,000	31,000	31,000	30,160	30,160
Men per year	24,000 (1/3 clients)	24,000 (1/3 clients)	X	X	X	X
Women per year	47,800 (2/3 clients)	47,800 (2/3 clients)	X	X	X	X
Entrance Fee	dh12.00	dh12.00	dh16.00	dh16.00	dh14.00	dh14.00
Fuel Method						
Fuel Type	Wood	Argan shells	Wood	Argan shells	Wood	Argan shells
Quantity of fuel used per year (Tons)	365	200	243	87.6	X	X
Cost of Fuel per Year	dh365,000.00	dh200,000.00	dh243,000.00	dh87,600.00	X	X
Water Usage						
Origin of Water	Groundwater well	Groundwater well	Bought from Government	Bought from Government	Groundwater well	Groundwater well
Quantity of water used per year (Liters)	16,500	16,500	X	X	X	X
Cost of Water per year	dh0.00	dh0.00	X	X	dh0.00	dh0.00
Lighting Method						
Type of Lighting	X	X	Natural & LED	Natural & LED	X	Sunlight / LEDs
Source of Electricity for Lights	X	X	Grid	Grid	X	Solar power
Cost of Electricity per Year	dh24,000.00	dh24,000.00	X	X	X	dh3,000.00
Special notes	Utilizing the irradiator to heat water and maintain the temperature of the steam to heat the hot room floor has also allowed for the boiler to be shut off during the night saving fuel		The furnace was designed by an artisan not an engineer so it is not an efficient system. They have looked into a new boiler but have not switched because they can not service the new system			

Note: Hammam names have been omitted from this report for the privacy of those Hammam owners interviewed.

Appendix E: Hammam Owner Interview Results

Temara Type 3 Hammam

Hammam details

Hammam Location: Temara, Morocco

Date of visit: 22/1/2020

Classification (Type 1,2,3):

Heating Methods: Type 3

Water management: Type 3

Lighting Technique: N/A

Number of Rooms: 3 for both men and women & 2 changing rooms

Total Area (m²): 500 m²

Hours of Operation: 10 am - 6 pm

Average Number of Clients per year:

Women: 47,800 (2/3 total)

Men: 24,000 (1/3 total)

Total: 70,000

Entrance Fee for customers: 12 MAD

Description of Equipment

Upgraded boiler system with automatic Argan Shell feeder, insulated room beneath hottest chamber with reflective heat stones, mixing of cool water with hot water from boiler in piping system to regulate temperature, Radiator in hot room fed with cold water to cool steam and heat water that can be fed into Hammam, fire suppression system in boiler room

Fuel Method

Fuel Type Used: Argan shells

Quantity of Fuel used per year: 200 tons per year

Cost of fuel per year: 200,000 MAD

Water Usage

Origin of water (Well, ONEP, etc.): Groundwater well

Quantity of Water used per year: 16,500 tons per year

Cost of water per year / per month: 0 expense

Lighting Method

Cost of electricity per year: 24,000 MAD

Heating System maintenance

Boiler room attendant to fill Argan shells, Maintenance 15 days a year

Environmental Impacts / Health Risks

No smoke from argan shells, reduced water waste, less ashes produced from argan shells than from wood, feeder system reduces risk of injury for worker

Further notes

Building

- Building codes say:
 - Must have at least 3 perimeter walls
 - Specific perimeter required (500m)
 - Grates / ventilation is required from exterior wall to boiler room
- Accompanied by a cosmetic store and corner store for convenience
 - Type I will most likely not have this

- Wood storage room must be vented to the outside (grates in exterior wall) to allow wood to dry and reduce fire risk
- Water storage tank is on the roof (stores 12 tons of water)
- Boiler ignited at 10am and put out at 6 pm daily
- All pumping systems and boiler are located on backside of building
- Mr. Motaoukkil built the entire building with the Hammam on the lower floor and 4 floors of apartments above
- Fire suppression system (sprinkler piping) throughout boiler room, and fire extinguishers → Most traditional Hammams will not have a fire suppression system

Fuel

- Argan shells as fuel, used to use wood but recently switched to biomass fuel
- Argan shells were initially an unused byproduct of the argan oil business (just 5 years ago, they were being thrown away) but, now the farmers can make more money selling them as a biomass fuel instead of disposing of them.
 - Center in used to make oil for cosmetics & food so instead of disposing the shell of the nut, these ready to use shells can be used as a heating source
- Both wood and argon cost 0.8 MAD/Kg → Need less Argan shells to produce the same amount of heat so shells have a better profit

- Wood requires labor
 - Must be chopped
 - Paid by kilo and wood is often wet and has dirt so less efficient to buy (40% lost due to wetness / dirt)
 - Carrying the heavy wood can lead to back problems for the employees (~25kg per log)
 - Harder to store the wood
 - 10% ash yield per kilo of wood (20 tons of wood creates about 2 tons of ashes)
 - Costs money to dispose of that ash
- Significantly more profit using argon shells over wood
 - Argon produces next to no ash (minimized ash disposal costs as well as hours lost when the Hammam closes for cleaning)
 - Argon is immediately ready to use and easier to work with
 - Shells cracked, dry, and easily accessible
 - Calorimetric value much higher than wood (will test this with sample given to us)

Mechanics / Advancements

- 2003: used 1 ton of wood a day in a 3m x 3m x 2m heating room
- Upgraded the boiler used 750 Kg a day
- 2007: biomass burner uses 500 Kg of argon a day for same energy output
- Has a sprinkler system and fire extinguishers for safety

- Type I Hammams typically will not have these safety investments
- Water is heated by the boiler to 80-90 C and is run through the pipes
- Comes through the pipes at 65 C, then mixes with cold water in the pipes to lower the temperature to 50 C
 - This creates a system that already saves water as customers will not have to mix the water themselves to get it to a tolerable temperature
- Ambient hot stones (made of clay) and a 20 cm layer of sand to insulate and reflect the heat from the hot room and maintain the temperature
 - This originally kept the room at 110 C which was too hot and created a heat loss
 - Reworked system to have a water tank stored in the hot room pumping cold water
 - The result: cold water cooled the room while the heat from the room warmed the cold water without using the boiler ***recycled heat***
- 12 tons of water is heated by the boiler (the boiler has 2 chambers: men's section other section for women)
- Automatic thermometer stops feeding argon shells once the water has reached 80 C
- Heat lost through the door of the boiler, rest of the boiler is insulated with panels
- Boiler ignited at 10am and put out at 6 pm daily
 - Immediate access to warm water by the radiator
- Insulation maintains the temperature so that the fire does not need to constantly be burning

- Traditional Hammams need flame burning continuously
- Insulation also keeps water warm overnight even when boiler is not running
- Once a year Hammam closes for 15 days to give the boiler a deep cleaning
 - Dispose of calcium deposits and whatever ashes have accumulated
 - The only cleaning maintenance done all year
- Upgrades cost:
 - 100,000 MAD for biomass boiler
 - 5,000 MAD for the shell feeding system
 - Irradiator made of scrap so relatively cheap
 - Looking to patent the design
 - Had to close Hammam for a month to replace the boiler after damage caused by loading wood
 - Years of throwing the wood into the boiler thinned the insulation so it needed to be replaced
 - Now that they are using argan nuts the boiler should have better upkeep
- Water usage
 - Average man 102 liters
 - Average women 208 liters
- Irradiator
 - Steam below the hot room to maintain the temperature and heat the floor
 - Uses cold water to keep the steam from reaches temperatures too high

- The water is then heated by the steam and stored in the irradiator so there is always hot water immediately ready to use in the Hammam
- Electric system controls the rate of the argan shells being fed into the boiler by a level of how busy the Hammam is
 - Less busy, set to a lower feed level
 - Busier, set to a higher feed level

Rabat Type 2 Hammam

Hammam Details

Hammam Location: Rabat, Morocco

Date of visit: 30/1/2020

Classification (Type 1,2,3):

Heating Method: Type 2

Water Management: N/A - No Data Gathered

Lighting Technique: Type 1

Number of Rooms: 3 + reception / changing room

Total Area (m²): approximately 146 m² [estimation based off tile count and calculations in changing room]

Hours of Operation: women during the day men at night 7:30am-11:30pm

Average Number of Clients per year: mostly women because of more favorable hours

Numbers from 27/1/2020-30/1/2020

Women: 366

Young people: 101

Kids: 65

Total: 532 (in one day)

Entrance Fee for customers: 16 MAD women, 15 MAD men, 8 MAD kids<9, 5 MAD kids<6

Two floors of living units above the Hammam

Description of Equipment

Still using a traditional furnace designed by an artisan to heat the water and, the back of the furnace is below the hot room to heat the floor of the hot room.

Fuel Method

Fuel Type Used: Argan Shells

Quantity of Fuel used per year: 17 tons every 50 days (worker)

18 tons every 75 days (owner)

Cost of fuel per year: 87,600 MAD

Notes: No containment or organization of argan shell storage, most were scattered on the floor and dusty. This Hammam has more coal and ash from the argan shells than anticipated and we hypothesize this was because they were not stored properly, not burned to completion, or not burned at an ideal temperature. The owner reported that there was a 50kg bag of ash accumulated for every 1 ton of argon shells burned.

Water Usage

Origin of water (Well, ONEP, etc.): bought from the government

Quantity of Water used per year: No Data Gathered

Cost of water per year / per month: No Data Gathered

Lighting Method

Lighting Fixtures: 8 ceiling mounted LED lights, and 2 wall mounted LED lights throughout space, 1 small skylight in cool room, 2 skylights in medium room and 1 skylight in hottest room

Origin of electricity: city grid

Cost of electricity per year: No Data Gathered

Heating System maintenance

Every summer for about 15 days

Environmental Impacts / Health Risks

Smoke and ash from the chimney. To mitigate these effects a water basin was installed to filter out the particulates and lessen the pollution in the area

Recommendations

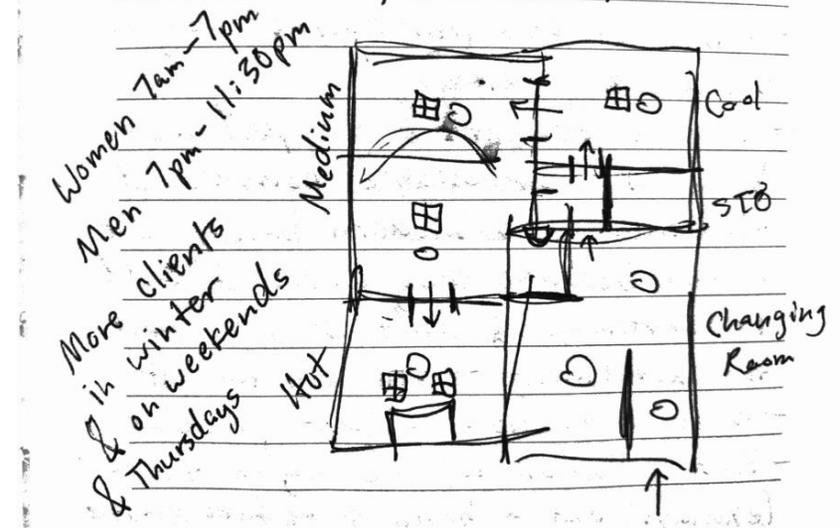
- Business management systems to track the amount of fuel, water, and electricity being used and the amount of customers
- Use the tracking system to calculate Hammam energy requirement and investigate modern boilers that can fit the
- Proper fuel storage to keep undesired particulates and moisture from mixing with fuel
- Increasing insulation on the furnace and concentrating the fuel in a smaller area to burn the fuel to completion
- Replacement of skylights with glass domes to diffuse more light into the space and reduce electricity usage and electricity costs during the day

Further notes:

- Used to burn tree trunks because they burned longer but were too expensive. Wood was three times more expensive than argan
- 600 MAD per trip to have the argan shipped in it is a 4-hour trip
- “It wasn’t built by engineers, it was built by artisans” - referring to the Hammam boiler room and furnace
- Had a feeder for the furnace but it kept breaking and was difficult to find someone to fix it and so they have stopped using it.
- Considered switching to a modern boiler but do not feel comfortable finding people to service it and it being worthwhile / money
- Argan is creating one bag of ash for every ton burned

- 4 water tanks above the furnace and one behind the hot room the ones above the furnace are 6 tons each and the one in the hot room is 8 tons
- Peak times are during the winter, weekends, and Thursdays
- Has skylights in each of the washing chambers but they are small square windows, and they are very recessed into the ceiling, so they don't provide a lot of light
- There was also a window in the changing room, but it was covered with a shade and providing very dim light
- 2 floors of apartments above the Hammam
- Faucets were in the hottest room, coming directly from the wall that faces the boiler room
- Boiler room is located below ground and has space that extends underneath part of the hot room to radiate heat up
- Argan shells were stored in bags stacked on the floor underneath the stairs to the boiler room, but large amounts of shells were spilled all over the floor and mixed up with dirt, and moisture from the outside and some plastic
- Boiler room is open to the outside by a hole in the wall → potential water runoff into storage space

Figure 22: Hand drawn sketch to help visualize the layout of the Hammam



Rabat Type 3 Hammam

Hammmam Details

Hammmam Location: Rabat, Morocco

Date of visit: 31/1/2020

Classification (Type 1,2,3):

Heating Method: Type 3

Water Management: Type 2

Lighting Technique: Type 3

Number of Rooms: 3+changing room one changing room and one chamber for men

Total Area (m²): m²

Hours of Operation: 8am-8pm

Average Number of Clients per year:

Total: ~30,160 women only Hammam

Entrance Fee for customers: 14MAD

Description of Equipment

Top of the line boiler designed for efficiency (roughly 6x4x10ft), with an argan shell feeding system, and heat distributed directly from the boiler into the hottest bathing room. Water mixing system for optimum water output temperature. Utilization of skylights and solar powered bulbs to eliminate electricity usage. Past experimentation with a greywater recapture system, and solar water piping array on the roof.

Fuel Method

Fuel Type Used: Argan Shells

Quantity of Fuel used per year: No Data Gathered

Cost of fuel per year: MAD

Water Usage

Origin of water (Well, ONEP, etc.): Well on site

Quantity of Water used per year: No Data Gathered

Cost of water per year / per month: No Data Gathered

Lighting Method

Origin of electricity: No Data Gathered

Cost of electricity per year: No Data Gathered

Heating System maintenance

Every summer for about 15 days

Environmental Impacts / Health Risks

Reduction of smoke since switching to the new boiler and argan shell fuel, reduction of water waste since implementing a water mixing system

Further notes:

- Located in a poor neighborhood where most homes still have no hot water, so they visit the Hammams in this area at least once a week
- Lots of renovations happening in the neighborhood to try to make it better
- Typical traditional Hammam layout with very large changing room and 3 bathing rooms that get hotter as you go back
- Since switching to argan shells there's been no smoke
- Boiler is a 3rd generation, most modern boiler there is, burns completely clean so that no smoke is produced, argan feeding system in front of the boiler

- Hot water tank in the boiler room stores water at 70 C, automatically shuts off heating if water reaches 80 C to reduce waste
- Another storage tank holds water at 60 C, and this is used to fuel the Hammam faucets
- Boiler is much more insulated than other boiler's we've seen - you can touch the outside and it feels cool, and the door is screwed shut and tightly sealed to mitigate heat loss
- Excess heat comes out of boiler and directly through wall into the hottest bathing room because boiler room is located right next to hot room
- We were given a schematic diagram of the whole water heating system
- Well for water is located right next to the Hammam and has 2 pumps to bring water up - the pumps alternate turning on and off to prevent overheating
- There's also an aeration system for the well, the air gets rid of toxic gas buildup in the well underground, because if they didn't aerate it a spark could make the well explode
- Water storage tank and solar heating pipes on the roof
- The piping system on the roof had water running through it, and the water was heated by solar radiation to be used inside the Hammam, this worked really well but the system broke because the pipes got clogged with rust buildup, and she hasn't been able to get the system fixed so she doesn't use it anymore
- Range of electricity cost = 15 MAD / day at best - 3,000 MAD / day other times
- Natural daylighting from glass domed skylights (Qamariyyat lights), which she installed recently to replace old flat skylights
- Domed skylights are inspired by traditional Hammam lighting - using small skylights all over the ceiling to create a dimly lit interior - and the domes diffuse light into the room to fill the space during the day
- Domes were imported from Poland because the only place you can get them in Morocco is Marrakech and the man who makes them charged more than it was to import them from Poland
- Sometimes domes are made from colored glass in Hammams / other buildings in other countries to change the lighting inside
- Professor Sibley has been working with Khadija on these lights as well as other research in Hammam sustainability, and she can give us Sibley's contact information
- There are also solar panels on the roof - not normal photovoltaic cells we're used to seeing, they look like flat donut shaped metal disks - and these are used to power LED bulbs hanging below the skylights at night
- Khadija says she installed a heat recapture system inside the Hammam, but customers didn't like it because they thought it looked like a greywater recapture system, and so some customers stopped coming and she had to recover the heat recapture

- Hammam is women only, but she has a separate washing room that's much smaller on the other side that men can use
- Khadija has been tracking data on her Hammam since 2015
- She's also set up a Hammam sustainability program to have ideal, environmentally friendly Hammams built as an example for other Hammam owners in different areas around the country
- Inside the bath they have both 15 L and 30 L buckets for clients to use to reduce waste
- Women use 100-120 L of water on average when they bathe, but it does vary from person to person - some people use very little water and some stay at the Hammam all day and use 500 L of water
- Average number of clients: Mon-Thurs = 80 people, Fri-Sun = 120 people
- Now there are 15 Hammams in the neighborhood so she gets less clients than she used to, she also lost some clients when the government relocated homeless people in the area into housing projects
- She rents the Hammam building for 9,000 MAD / month
- She also pays her employees and insurance
- She shuts down once a week in the summer for maintenance, or she can do 15 days to a month for bigger upgrades
- Future improvements she wants to make include metered faucets and tracking a lot more data (she says

there are some inaccuracies in her data with people coming in and using the Hammam for free)

- Most Hammam owners don't keep track of data, and even if they do, they keep it as a trade secret, so a lot of people kind of despise her for coming out and publicly stating all her cost and usage numbers

Hassan II Mosque Hammam

Disclaimer:

The Hassan II Mosque Hammam is a special case as it was a large government funded project designed with the purpose of being a luxury spa. This is a strong contrast to the other Hammams we've visited: small service stations designed for the community.

Hammam Details

Hammam Location: Casablanca, Morocco

Date of visit: 3/2/2020

Classification (Type 1,2,3): N/A- No Data Gathered

Number of Rooms: 3 + changing room for each side and 2 saltwater pools

Total Area (m²): 6,000 m²

Hours of Operation: 8 am - 11 pm

Average Number of Clients per day:

Women: 200

Men: 200

Total: 400

Entrance Fee for customers: 50 MAD for adults and 40 MAD for children age 3-10 - more for treatments and accessories

Description of Equipment

Unable to view any of the equipment

Fuel Method

Fuel Type Used: Electricity - Power comes from offsite renewable energy farms

Quantity of Fuel used per year: No Data Gathered

Cost of fuel per year: No Data Gathered

Water Usage

Origin of water (Well, ONEP, etc.): purified ocean water and water treatment plants

Quantity of Water used per year: No Data Gathered

Cost of water per year / per month: No Data Gathered

Lighting Method

Origin of electricity: City Grid

Cost of electricity per year: No Data Gathered

Heating System maintenance

No Data Gathered

Environmental Impacts / Health Risks

No Data Gathered

Further notes:

- Hammams are located underground and connected by tunnels that run under the mosque
- Electricity for lighting and heating comes from renewable energy farms off site such as solar and wind
- Heated Saltwater bathing pools for both men and women
- Handicapped accessibility everywhere
- Turkish inspiration for washing stations - individual stations with faucets, basins, and seats for personal washing
- Individual scrubbing rooms with heated tables
- Copper piping under the washing rooms to radiate heat

Casablanca Type 1 Hammam

Hammam Details

Hammam Location: Casablanca, Morocco

Date of Visit: 4/2/2020

Classification (Type 1,2,3):

Heating Method: Type 1

Water Management: N/A - No Data Gathered

Lighting Technique: Type 1

Number of Rooms: 20 separate washing stalls, a hot room, and changing rooms on both men's and women's sides

Total Area (m²): Not Data Gathered

Hours of Operation: 6 am - 10 pm

Average Number of Clients per day:

Women:

Men:

Total: approximately 100

Entrance Fee for customers: 13 MAD

Description of Equipment

Old brick and mortar furnace accessed through a narrow hallway full of wood. Furnace had holes and in need of repairs

Fuel Method

Fuel Type Used: wood

Quantity of Fuel used per year: 1 ton a day so ~365 tons a year

Cost of fuel per year: ~365,000MAD

Water Usage

Origin of water (Well, ONEP, etc.): well

Quantity of Water used per year: No data gathered

Cost of water per year / per month: No data gathered

Lighting Method

Origin of electricity: Grid

Lighting Method: LEDs - about 8 throughout washing rooms and 3 in changing rooms [X2]

Cost of electricity per year: No data gathered

Heating System maintenance

Unknown

Environmental Impacts / Health Risks

- To use the boiler only one narrow hallway filled with wood to access the room and there is no ventilation or lighting
- Buildup of mold and algae inside the Hammam

Recommendations

- Business management systems to track the amount of fuel, water, and electricity being used and the amount of customers
- Proper fuel storage to keep undesired particulates and moisture away from fuel
- Switching from wood to biomass fuel and implementation of an improved boiler system
- Better access to and ventilation in boiler room, as well as a light source in the boiler room

Further notes:

- Boiler splits steam for men and women
- Washrooms are divided into many smaller stalls instead of the normal three heat gradient rooms, stalls are approximately 6'X6' chambers each with their own faucet

- Hot room all the way inside - on women's side there was an upper changing room that was much warmer than the entrance changing room, and we think this may have been located directly above the hottest chamber
- Hammam uses a serpentine system of copper pipes carrying steam to heat the Hammam
- ~100L of water/person /day
- Olive and date pits are too dirty to use for fuel they lead to a lot of waste so the pits must go through a secondary process to be transformed into pomace which can be used as fuel. This process causes these fuels to be more expensive
- Argan is the cleanest and most efficient fuel source

Kenitra Type 3 Hammam

Hammam Details

Hammam Location: Kenitra, Morocco

Date of visit: 2/7/2020

Classification (Type 1,2,3):

Heating Method: Type 3

Water Management: Type 3

Lighting Technique: Type 2

Number of Rooms: 3 + reception / changing room

Total Area (m²): 1200 m²

Hours of Operation: 6am-11:30pm (11:30 is when the last clients are let in)

Average Number of Clients per year: approximately 24,000/year

Entrance Fee for customers: 13 MAD traditional experience, 70 MAD Turkish experience, 100 MAD massage, 250 fancy Hammam

Description of Equipment

The current boiler has poor insulation which is losing heat to the environment. This meant that the boiler needed to produce more heat to make up for the percentage lost to the environment and so it was retrofitted with a system to increase air flow.

Fuel Method

Fuel Type Used: Argan Shells

Quantity of Fuel used per year: 240 tons

Cost of fuel per year: 240,000 MAD

Notes: The boiler output is more than required to heat the Hammam and so not all energy is being used and this leads to ash and smoke

Water Usage

Origin of water (Well, ONEP, etc.): well

Quantity of Water used per year: No Data Gathered

Cost of water per year / per month: No Data Gathered

Lighting Method

Lighting Fixtures: uses natural lighting during the day and LEDs at night

Origin of electricity: city grid

Cost of electricity per year: No Data Gathered

Note: Thought about installing a solar panel to power lights but has no reliable location to do so on the roof because of the water storage tank.

Heating System maintenance

No data provided

Environmental Impacts / Health Risks

Smoke and ash from the chimney. To mitigate these effects a water basin was installed to filter out the particulates and lessen the pollution in the area

Recommendations

- Business management systems to track the amount of fuel, water, and electricity being used and the amount of customers
- Resizing the boiler based on energy requirements after third floor is constructed

Further notes:

- 2 neighborhood Hammams with same name

- Male Hammam might be above female Hammam (higher level)
- Electric board separated from hot room for safety reasons
- Argan shells (cleanest bioproduct he says) stored in a silo close to the boiler
- Primary boiler w/10-ton tank about $5+5+5+5 = 25$ total tons of water STO
- Smokey in the boiler room
- Serpentine system (15,000m of plumbing pipes heating the Hammam)
- Can feel the heat coming off the boiler 35% heat loss (he estimated)
- Fit or fix? issues & high pressure from pumping air in + deforestation from wood
- Feeding system into boiler
- 3rd boiler produces steam (hottest room filled with steam), mixes steam with eucalyptus & other herbs to create aroma inside (helps w breathing- respiratory) * all byproduct (recycled)
- Traditional well (very large) pumped up to a water tower above the Hammam and then gravity brings it down into the Hammam faucets
- Pumps buried 70 m down (1 submerged, 2 above) use a Floater? To measure when the water level gets too low (regulate system)
- Old serpentines are copper pipes new are polyethylene (here poly)

- Smells like fire in the boiler room -- very warm & smoky
- 3 hot water tanks, a little bit of hot and cold water mixing to moderate pressure & more to make water below 70 C
- All temps in the system are tracked on a meter
- Hot water in a bag = 43 C
- 43 C = a good bathing temp & least water waste (sweet spot)
- Water from the boilers is 70 C
- About 10 degrees Celsius of heat loss between the three tanks
- Monitors temp in the last tank but sets temp for water coming into the 1st tank
- System cost 50,000 dollars
- 50,000 DH per tank
- Turnaround investment for the system is 4-5 years
- Wood: 30,000 Dhs energy/month
- Now: 20,000 Dhs fuel/month
- Electricity went up 20% but with a 30% efficiency gain for fuel
- Saves \$1,000 worth of energy cost but pays extra \$100 for electric
- Saves \$900 a month with new system
- He was the 1st Moroccan to switch to argan shells & did it 3 years ago (Kadiri = 1yr)
- No tracking system for usage, he thought about it, but employees don't have enough technical skill to use computers (no data tracking)

- Natural lighting in Hammam during day night = LEDs from electric grid
- Switch for 3 reasons
 - Inefficiency
 - Economic
 - Environmental group he's involved in
 - Right now the owner is working on a green power station in Casablanca
- Water tank in middle of roof prevents reliable solar energy
- Hours 6:30am-20:30pm -21:00pm
- 1200m² w all three floors
- Currently building new, modern Hammam rooms on the top floor with separate massage rooms, and washrooms and saunas will be 250/person instead of lower price on lower levels
- Greywater recapture system on the top floor (filtered down)
- There's going to be a large hot water tank on the roof to feed the baths w gravity
- Smoke on the roof-> mostly because his boiler is old and wasn't designed to do what it's doing (too powerful and retrofitted) smoke is filtered through the water basins
- No environmental certification (like LEED) is very popular/ used in Morocco (might not exist) he tried to get a certification)

Kenitra Type 2 Hammam

Hammmam Details

Hammmam Location: Kenitra, Morocco

Date of visit: 7/2/2020

Classification (Type 1,2,3):

Heating Method: Type 1

Water Management: No Data Gathered

Lighting Technique: Type 2

Number of Rooms: 3 + reception / changing room

Total Area (m²): No Data Gathered

Hours of Operation: No Data Gathered

Average Number of Clients per year:

Women: No Data Gathered

Men: No Data Gathered

Total: No Data Gathered

Entrance Fee for customers:

Description of Equipment

Still using a traditional clay and salt crystal furnace that is fueled by scrap wood and sawdust. There are circular holes in the furnace to increase oxygen flow to the fire. Fuel is thrown through a large hole in the furnace which can shoot out huge flames out of the holes creating a very unsafe work environment.

Fuel Method

Fuel Type Used: scrap wood and sawdust

Quantity of Fuel used per year:

Cost of fuel per year: 0.4 MAD/ Kg they make deals with factories

Notes: No containment or organization of fuel storage, most were scattered on the floor and dusty. Worker also reported that flames often shoot out of the furnace during fueling and it is quite hazardous for him.

Water Usage

Origin of water (Well, ONEP, etc.): No Data Gathered

Quantity of Water used per year: No Data Gathered

Cost of water per year / per month: No Data Gathered

Lighting Method

Lighting Fixtures: windows for some natural lighting but mostly relies on electrical lights which are most likely LEDs

Origin of electricity: city grid

Cost of electricity per year: No Data Gathered

Notes: all lighting and electrical data was collected from observations

Heating System maintenance

No Data Gathered

Environmental Impacts / Health Risks

Smoke and ash from the chimney. To mitigate these effects a water basin was installed to filter out the particulates and lessen the pollution in the area

Recommendations

- Business management systems to track the amount of fuel, water, and electricity being used and the amount of customers
- Proper fuel storage to keep undesired particulates and moisture from mixing with fuel
- Changing fuel sources to a biomass fuel to increase fuel efficiency

- Adding a feeding system to the furnace to improve worker safety and boiler efficiency
- Replacement of skylights with glass domes to diffuse more light into the space and reduce electricity usage and electricity costs during the day

Further notes:

- Fuel storage all over the floor and mixed with dirt and moisture and other particles
- Door of the furnace has a loose fit and results in a lot of heat loss
- They pay for the scrap wood (40-50 cents per kilo) from furniture stores
- 2 tanks of water
- Scrap wood harder to use than logs
 - Constantly refueling
- Smoke passes through shipka (space between floors) to heat the floor of the hot room

Rabat Type 2 Hammam

Hammmam Details

Hammmam Location: Rabat, Morocco

Date of visit: 18/2/2020

Classification (Type 1,2,3):

Heating Method: Type 2

Water Management: Type 1

Lighting Technique: Type 1

Number of Rooms: 3+ changing room each

Total Area (m²): No Data Gathered

Hours of Operation: No Data Gathered

Average Number of Clients per year: No Data

Gathered

Women: No Data Gathered

Men: No Data Gathered

Total: No Data Gathered

Entrance Fee for customers: 15 MAD

Description of Equipment

Still using a traditional clay and salt crystal furnace that has been retrofitted with a new feeding system that has a blower attached to it to help stoke the fire

Fuel Method

Fuel Type Used: argan shells

Quantity of Fuel used per year: 84 tons

Cost of fuel per year: 1 MAD/ Kg they believe about 0.2 MAD is for transportation

Water Usage

Origin of water (Well, ONEP, etc.): Well but on high days they must use water utilities from the city to keep up with the demand

Quantity of Water used per year: No Data Gathered

Cost of water per year / per month: No Data Gathered

Notes: Only one water tank is used at a time and when that temperature gets too cold, they switch to use the hottest tank

Lighting Method

Lighting Fixtures: all lighting is LED

Origin of electricity: city grid

Cost of electricity per year: No Data Gathered

Heating System maintenance

Has only been a year since the new feeder has been installed but, they have shut down for once for a day to service the feeder and clean out the boiler

Environmental Impacts / Health Risks

With wood there was a lot of black dirty smoke and ash that had affected the neighborhood but since switching to argan it is much cleaner. There is still some smoke, but it is much less and much cleaner than before. When he was using wood, he would have to clean out the boiler often and empty out all the ash but now with argan it is much cleaner and there's about a handful of ash a day

Recommendations

- Business management systems to track the amount of fuel, water, and electricity being used and the amount of customers
- Fixing gaps near the door of the furnace to help prevent heat loss

- Upgrading to a modern boiler to increase efficiency
- Implementing natural lighting or using solar power to charge LEDs

Further notes:

- Smoke coming out of the feeding system
- Clay walls lose about 30% heat
- Furnace door has gaps in it
- Replaced water tanks two years ago and is still working on paying those off and so that's why he is putting off switching to a modern boiler
- 4 water tanks with temperatures being monitored
- Water is stored at about 40C
- Uses a 220-watt pump to get water out of the well
- Argan is much easier to store than wood and everything about it is cleaner
- First tried almonds as a biomass fuel and they were great for heating the water but not the bath
- Next tried olives but they were too sticky and got stuck in the feeder and so they weren't worth the trouble
- Once they fixed the heating system and were able to heat their floor, they got a lot more customers
- Smoke passes through shipka (space between floors) to heat the floor of the hot room.

Appendix F: Energy Balance Model

Table 5: Energy Balance Model

Boiler Type	Traditional	Modern	Fuel type	Holm Oak	Argan Shells	Olive Pomace
% Energy Captured	0.675	0.8	Caloric Value (kJ/Kg)	23012	20630	22500
% Energy lost	0.325	0.2	% Energy Potential	0.6	1	0.8
			% Energy Lost	0.4	0	0.2

Boiler Type	Traditional			Modern		
Fuel	Holm Oak	Argan Shells	Olive Pomace	Holm Oak	Argan Shells	Olive Pomace
Usuable energy from fuel (kJ/Kg)	13807.2	20630	18000	13807.2	20630	18000
Energy lost from fuel (kJ/Kg)	9204.8	0	4500	9204.8	0	4500
Energy lost by boiler (kJ/Kg)	4487.34	6704.75	5850	2761.44	4126	3600
System Energy Output (kJ/Kg)	9319.86	13925.25	12150	11045.76	16504	14400
System Efficiency %	0.405	0.675	0.54	0.48	0.8	0.64
System Efficiency with feeding system %		0.805	0.67		0.9	0.74
System Energy Output with feeding system (kJ/Kg)		16607.15	15075		18567	16650

Hammam Energy Requirement (kJ) 9319860

Boiler Type	Traditional			Modern		
Fuel	Holm Oak	Argan Shells	Olive Pomace	Holm Oak	Argan Shells	Olive Pomace
Weight of fuel to supply energy (Kg)	1000.0000	669.2778	767.0667	843.7500	564.7031	647.2125
Weight of fuel to supply energy with feeder (Kg)		561.1956	618.2328		501.9583	559.7513514

Boiler Type	Traditional			Modern		
Fuel	Holm Oak	Argan Shells	Olive Pomace	Holm Oak	Argan Shells	Olive Pomace
Weight for 1000 kJ (Kg)	0.1073	0.0718	0.082304527	0.0905	0.0606	0.0694
Weight for 1000 kJ with feeder (Kg)		0.0602	0.0663		0.0539	0.0601

Boiler Type
Fuel Type
efficiency vs Traditional wood no feeder
efficiency with a feeder vs Traditional wood no feeder

Traditional	
Argan Shells	Olive Pomace
1.494147981	1.303667652
1.781909814	1.617513568

Modern	
Argan Shells	Olive Pomace
1.770842051	1.545087587
1.992197308	1.786507523

Appendix G: Economic Balance Model

Table 6: Economic Balance Model

Clientelle Per Year	
	30,000

Cost of Wood + Traditional Boiler (MAD/Kg)	Source Efficiency	Daily Energy Use	Daily Energy Cost	Monthly Energy Cost	Yearly Energy Cost	Yearly fuel cost savings
MAD 0.80	41%	527.6509386	MAD 422.12	MAD 12,663.62	MAD 154,074.07	

Cost of Argan + Traditional Boiler (MAD/Kg)	Source Efficiency	Daily Energy Use	Daily Energy Cost	Monthly Energy Cost	Yearly Energy Cost	Yearly fuel cost savings
MAD 0.80	68%	316.5905632	MAD 253.27	MAD 7,598.17	MAD 92,444.44	MAD 61,629.63

Cost of Argan + Traditional Boiler + FS (MAD/Kg)	Source Efficiency	Daily Energy Use	Daily Energy Cost	Monthly Energy Cost	Yearly Energy Cost	Yearly fuel cost savings
MAD 0.80	81%	265.4641368	MAD 212.37	MAD 6,371.14	MAD 77,515.53	MAD 76,558.55

Cost of Olive + Traditional Boiler (MAD/Kg)	Source Efficiency	Daily Energy Use	Daily Energy Cost	Monthly Energy Cost	Yearly Energy Cost	Yearly fuel cost savings
MAD 0.66	54%	395.738204	MAD 261.19	MAD 7,835.62	MAD 95,333.33	MAD 58,740.74

Cost of Olive + Traditional Boiler + FS (MAD/Kg)	Source Efficiency	Daily Energy Use	Daily Energy Cost	Monthly Energy Cost	Yearly Energy Cost	Yearly fuel cost savings
MAD 0.66	67%	318.9531793	MAD 210.51	MAD 6,315.27	MAD 76,835.82	MAD 77,238.25

Cost of Wood + Modern Boiler (MAD/Kg)	Source Efficiency	Daily Energy Use	Daily Energy Cost	Monthly Energy Cost	Yearly Energy Cost	Yearly fuel cost savings
MAD 0.80	48%	445.2054795	MAD 356.16	MAD 10,684.93	MAD 130,000.00	MAD 24,074.07

Cost of Argan + Modern Boiler (MAD/Kg)	Source Efficiency	Daily Energy Use	Daily Energy Cost	Monthly Energy Cost	Yearly Energy Cost	Yearly fuel cost savings
MAD 0.80	80%	267.1232877	MAD 213.70	MAD 6,410.96	MAD 78,000.00	MAD 76,074.07

Cost of Argan + Modern Boiler + FS (MAD/Kg)	Source Efficiency	Daily Energy Use	Daily Energy Cost	Monthly Energy Cost	Yearly Energy Cost	Yearly fuel cost savings
MAD 0.80	90%	237.4429224	MAD 189.95	MAD 5,698.63	MAD 69,333.33	MAD 84,740.74

Cost of Olive + Modern Boiler (MAD/Kg)	Source Efficiency	Daily Energy Use	Daily Energy Cost	Monthly Energy Cost	Yearly Energy Cost	Yearly fuel cost savings
MAD 0.66	64%	333.9041096	MAD 220.38	MAD 6,611.30	MAD 80,437.50	MAD 73,636.57

Cost of Olive + Modern Boiler + FS (MAD/Kg)	Source Efficiency	Daily Energy Use	Daily Energy Cost	Monthly Energy Cost	Yearly Energy Cost	Yearly fuel cost savings
MAD 0.66	74%	288.7819326	MAD 190.60	MAD 5,717.88	MAD 69,567.57	MAD 84,506.51

Appendix H: Project timeline

Figure 23: Project timeline from before arriving in Morocco to project completion

Task	Week								
	PQP	1	2	3	4	5	6	7	8
Archival Research	■	■							
Orientation Presentations		■	■						
Hamмам Visits			■	■	■	■	■		
Compile data into spreadsheet			■	■	■	■	■		
Create balance sheets			■	■	■	■	■		
make recommendations						■	■		
Compile recommendations & data for RAF							■	■	■