Automated germination and seedling growth system

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BREE 495 - Senior Design

McGill University – MacDonald Campus

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Executive Summary

The automated germination and seedling growth system project consists of providing Urban Barns, Canadian food producer, with a solution for their future increasing output requirements specifically for the germination phase of production, which is currently inefficient. A design was created that maximizes growing space while at the same time minimizing human involvement. The analysis of the structure, watering, lifting and lighting systems components was done in order to have a completely autonomous system. The functionality of the system was analyzed by prototyping a ⅙th scale model to test and improve the theoretical components of the design. Several improvements were implemented and the design was optimized based on the experimental results. With the final design proposed, their new production could be sustained using only 2 of these systems, therefore producing 144 germinating trays on a square foot area of about 40 ft^2.

1. INTRODUCTION

1.1. Problem statement

Vertical farming is an innovative form of agriculture, which consists of growing plants in controlled indoor environments using artificial lighting within a vertical system. This type of agriculture implemented near cities will have the goal and the potential to sustain its nearby population without consuming any agricultural land as well as minimizing the transportation distance between the produce and the consumer. Vertical farming has the advantage of growing crops vertically meaning that producers can maximize production on smaller surface areas. Furthermore, this kind of practice may become very interesting in areas where the soil and climate are not viable for conventional agriculture.

Urban Barns Foods is a Canadian food production company based in Mirabel, Quebec, that uses an indoor LED-lighted vertical farming technology to grow consistent, fresh and healthy vegetables year-round. Their vegetables are grown in a totally controlled environment, meaning that they have no contact with the outside world hence eliminating the use of pesticide use and the possibility of the plants being contaminated or infected.

The current growing-phase of the process receives plants that are 3-weeks old into a mechanized vertical loop system, which comprises an automated watering method. The company is in the process of acquiring new growing production units, which will increase dramatically their production potential. Currently, Urban Barns is working mainly with lettuce, basil and a variety of micro-greens, but expects to expand its production varieties to include small berries and vine-vegetables in the near future.

The germination process preceding the entry of the plants into the growing system is currently inefficient and does not yield the production requirements that are expected to augment in the coming years. The labour work is at the moment extremely time consuming mainly because of the lack of proper installations and the specific needs of the plants. Based in a reaffected manufacturing plant, there is an important vertical space available that is currently not exploited at its potential by Urban Barns. Therefore, an important retrofit of the germinating system is required to automatize part of the labor work and maximize the production in a vertical manner while maintaining a safe environment for the workers.

1.2. Objectives

Maximization of outputs and vertical space

Due to recent retrofits, the current room utilized in the facility for the germination and first stages of the seedling growth will be decommissioned in order to increase the room's capacity. Maximizing the use of the warehouse's available vertical space is critical to the future retrofits in order to meet the outputs entering the growing machineries while minimizing the horizontal space consumption. Urban Barns' production is expected to increase by 5 times, requiring an output volume of more than 33 000 seedlings, or equivalently 140 standard trays of germination containing 240 seeds each, per week.

Minimizing human involvement

An essential aspect of the design is to minimize the amount of human involvement by integrating an automated watering system. At the moment, the installations require the immersion of the styrofoam trays containing the seeds into water baths one by one every day, which is time consuming and inadequate for a high production process. The idea is to mimic the other operations of Urban Barn while also providing a fluid operation that does not require a large workforce hence reducing at the same time the labor expenses.

Sustainability

Urban Barns' concept has the objective of bringing clean, pesticide free produce to local markets. Their loop process also allows them to recapture and treat the water used in order to reduce their water waste. Sustainability is part of their identity and the design proposed should integrate this important criterion.

Safe and simple operation

While minimizing human involvement, the system should also be simple to use and easily operated by one person. The management of the seedling growth should be made without the involvement of actions that could be dangerous or cause injuries to the workers.

2. DESIGN ANALYSIS

2.1. Overall view of the design

The proposed design finds its greatest strengths in the flexibility and simplicity of the arrangement of its different components.

Structure

The design is mainly constituted of two identical rolling carts each containing 36 standard germination trays divided within 6 horizontal levels. The two carts are placed one above the other using a lifting system. Each cart has a total height of 6 ft. The two carts together generate a production of 72 germinating trays in total or 17 280 seedlings. The total height of the germination system is of 14 ft. within when the carts are put one above the other. The structure is made of aluminum while the tray levels containing the germination trays are made out of steel. Each level is removable from its unit for the cleaning and maintenance of the containers.

Lighting

Each horizontal level is lighted by its own light roofing which can be moved as desired to create a distance between the lights and the plants of 4" or 6". The lights used are low generating heat, white, LED strips shining uniformly on all germination trays. At the greatest distance, the light intensity emitted is 75µmol.

Lifting

One of the two carts is lifted above the other using a acme screw system. The motor used is a 1Hp motor and will lift the cart in approximately 1.22 minutes.

Watering

The watering system comes and exits the system as a main single stream but is split between each level providing to each tray its individual watering system. The waters fills from the side of the tray and exits from the bottom and the side overflow holes. The amount of water is regulated in each level to provide a ¾" layer of water at the bottom, which is the minimal amount for the substrate to uptake water from the bottom. The use of quick-coupler allows one level to be easily separated from the piping system for its removal. The water is recaptured at the end of the watering cycle to be treated. One watering cycle requires the use of 400L for the watering of the 12 levels.

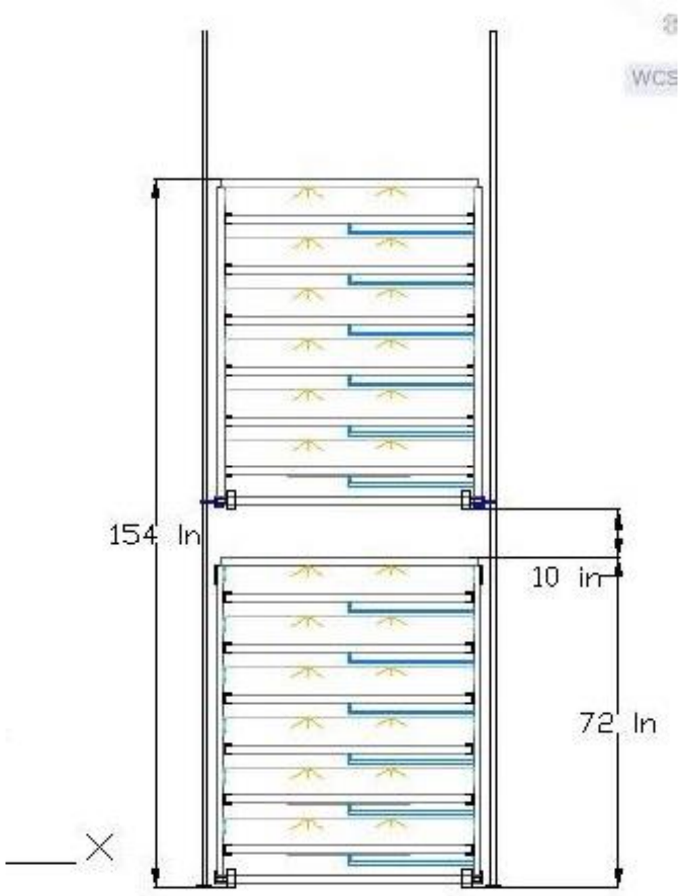

Figure 1: Overview of the design

3. DESIGN DEVELOPMENT: REQUIREMENTS & DESIGN SPECIFICATIONS

3.1. Structure containing the germinating trays

3.1.1. Requirements

The main attributes desired in the structural component of the design are first and foremost a simple operation method to be managed by a single operator. The structural sizes have to be adequate for a person of normal height and range to assess the health of all the seedlings in a quick look and manage with ease the germination trays in and out of the system. It also has to be easily cleaned and ensure the safety of the person operating it at all times.

3.1.2. Design specifications

The structure was designed with the first and main objective of using the vertical space available in the facility; it is therefore build in height. It mainly consists of twelve horizontal containers, referred to as levels, placed one on top of the other, in which are disposed the germination trays. These twelve levels are divided within two identical carts that are placed one above the other using an acme screw lifting system. Each of the carts therefore contains 6 levels. The carts are standing on rolling wheels and therefore can be moved in and out of the lifting mechanism for the management of the plants. The structure was designed to accommodate the styrofoam germination trays presently used by Urban Barns to grow the seedlings. Therefore, the design was build around the dimensions of a standard tray of germination.

Figure 2: 3D view of one cart

3.1.2.1. Tray container

Each level is designed as a rectangular stainless steel container, which holds 6 germination trays. Each of these germination trays has side dimensions of 15.5” by 26” and contains 240 seedlings. The germination trays will be disposed in rows of 2x3 with the tray’s largest side facing the front of the design. Each container was created with dimensions of 54” by 50” with a height of ½”, also placing the largest of the two dimensions at the front of the design. This was performed to allow one to have the widest view on all the trays, and the smallest distance to observe the plants from the first tray through the last tray at the back. The number of trays was chosen in order to optimize the number of plants being germinated on one level at a time, while also providing the worker a good view on all the plants in a quick look.

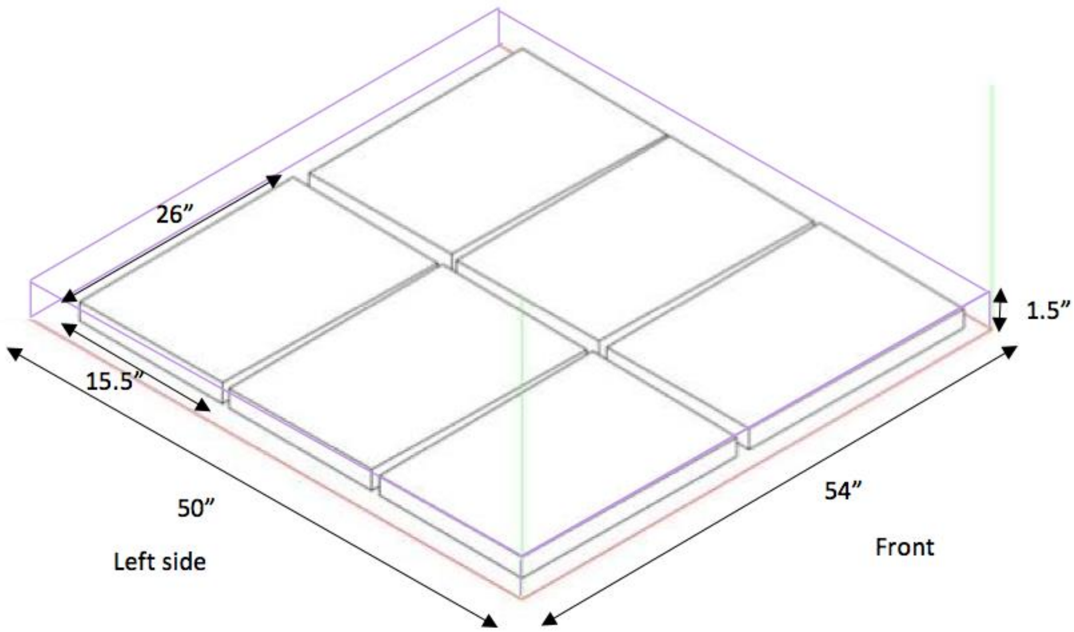

Figure 3: Tray container layout and dimensions

Every container is installed in the cart using C-brackets attached to the main cart structure on each side, allowing for the containers to be easily removed from the cart. This special feature was included in the design in order to allow firstly the easy management of the germination trays in and out of the levels, and secondly, the removal of the containers to be completely cleaned in the case of a microbial infection generated by the light contact with the nutrient water.

Each of these levels, also referred throughout the report as tray containers or tray level, is provided with its individual watering and lighting system.

Integrated individual watering and lighting systems

The containers are provided with a 1% slope finding its lowest point at the bottom center of the tray level. This slope is created to ensure the proper drainage downwards of the water during the watering cycles. The piping system relating the watering system to each of the tray levels are attached using quick couplers, which are easily attached and detached from the overall watering piping system. This allows the simple removal of one stainless steel tray out of the cart.

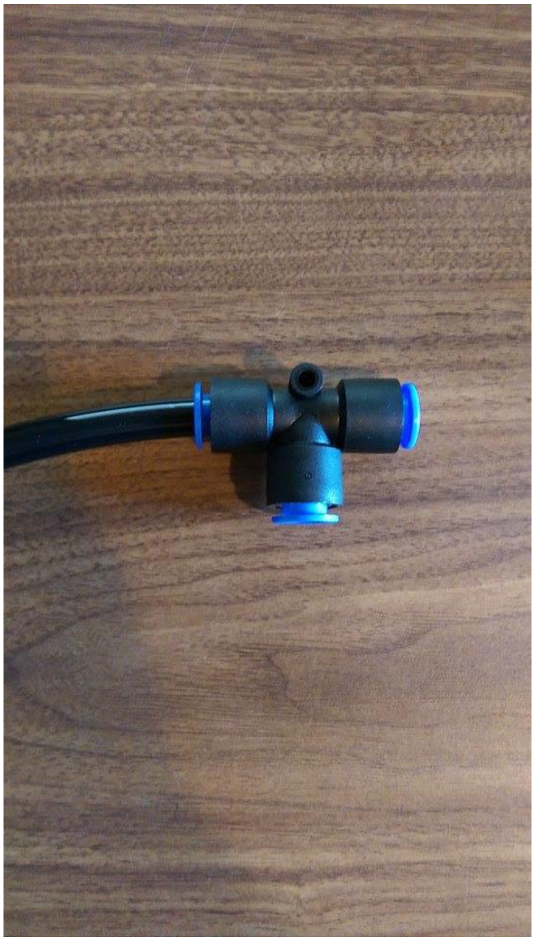

Figure 4: Quick coupler to integrated on each watering level

An individual light roofing is placed above each tray level. This small roofing provides a flat surface on which are disposed the LED lights. This roofing is attached to the cart structure with a movable screw that can generate a distance between 4” and 6” above the stainless tray. Therefore, this special component of the design allows the system to integrate plant varieties with different light and height requirements. Hence, a plant requiring lower light intensities or greater space to grow its biomass will be well accommodated into the tray levels using the higher roofing distance.

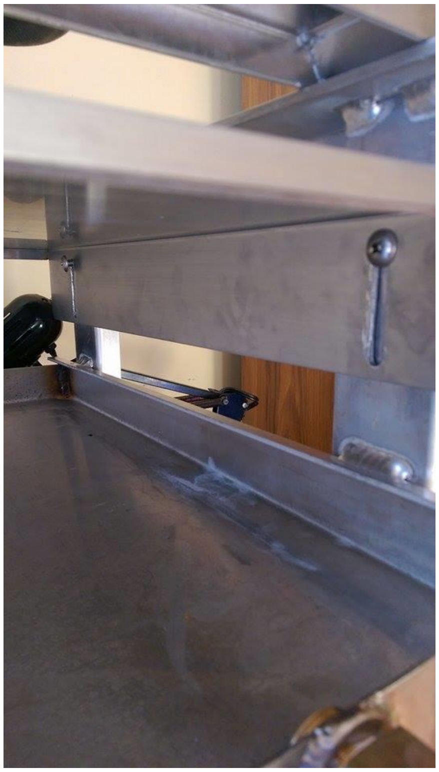
Figure 5: Roofing with moving screw for different distances

The overall distance allowed between each tray level was consequently determined to be 11” in total, from the bottom of one level to the bottom of the succeeding level, which allocates a decent space for the piping system found under the tray and the plant’s growing space above. Independent watering and lighting systems allow to save energy if some levels are not used.

3.1.2.2. Carts

Cart dimensions

One cart contains exactly 6 levels. This number of level per carts was determined by the maximum distance allowable between two levels. From this distance, which was found at 11in, the number of levels per cart was determined in order for one person of normal height to be able to observe any level with ease. It was an important criterion that the total height of the cart would not exceed of much the average human height, and especially that the last level of germinating trays be easily inspected by any operator. Considering that the average height of between the average male and female is 5’5”, the mixal tray level was not to exceed this height.

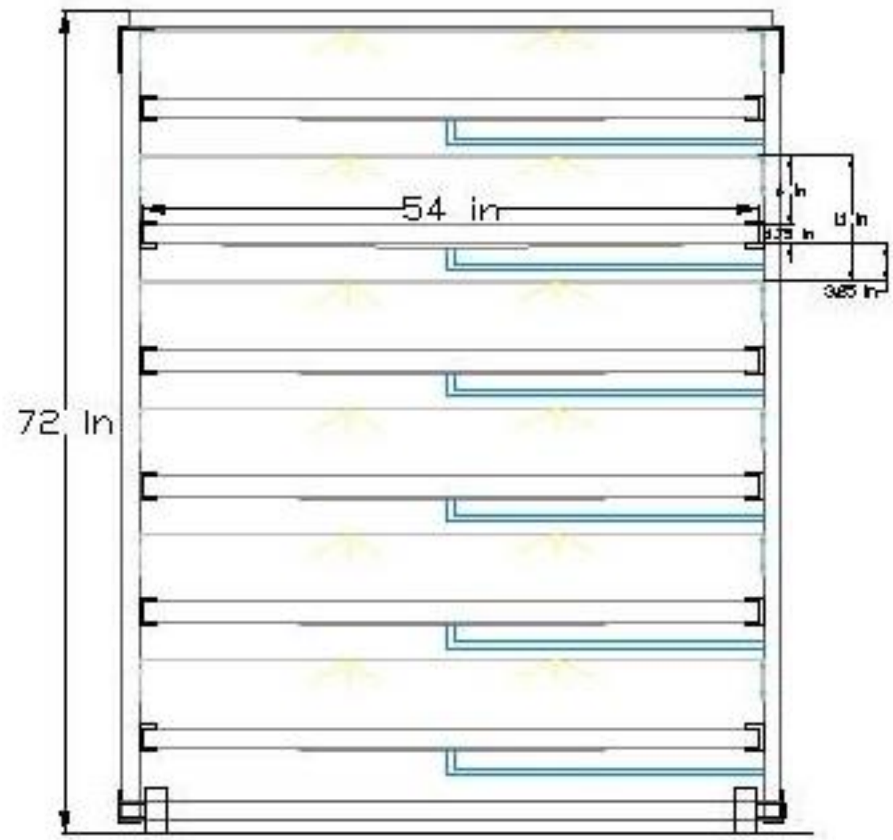

Figure 6: Dimensions of one cart

From this analysis, it was determined that the total height of one cart would be of 6 feet, which is equivalent to 1.83m. With this height, the first level will be found at 9½” (25cm) from the ground and therefore the last level will be held at a maximum height of 5”4’ (1.63m).

A number of factors helped determine the maximum allowable distance that could be assigned between two levels. Based on experimentations, it was determined that a distance of 11in was an acceptable distance to leave between each level to allow adequate space for the plants to grow in height without being burned by the lights and sufficient space for the piping system. This distance would allow a proper spacing between the lights and the plants, while also providing clearance below the container to include the required tubing for the watering system.

The carts are also placed on four small wheels allowing them to enter in and out of the lifting systems. They can also be manoeuvred around the germination room or any place in the facility. This feature also allows the operator to access an side of the levels of germinating plant with ease, allowing for a comfortable management and assessment of the seedlings.

Cart structure

The structure of the carts is mainly composed of aluminum C-brackets which holds the stainless steel tray levels from all sides. The detailed dimensions of the structural pieces are found in the following table. The structure consists of three aluminum U-bars on which are welded the c-brackets that maintain the stainless steel containers. Two u-bars are also placed at the bottom and the top of the structure, attaching both sides together. These side, top and bottom bars are joined together on each corner by an L-shape bar going through the whole side of the structure. According to the calculations made in the lifting system, the use of 2 U-bars would not be required, the use of only one of those would sustain the whole weight however, two bars were disposed to increase the solidity between all structure components.

Figure 7: Dimensions of aluminum pieces forming the cart frame

Material	Piece	Length (in)	Width-flat (in)	Thickness (in)	Number of units	Volume	
						in^3	ft^3
Aluminum	C-brackets for trays (1.5”, 2.25”, 1.5”)	50	5.25	1/8	12	393.75	
	U-bars side (1.5”, 2.25”, 1.5”)	69	5.25	1/8	6	271.69	
	U-bars top (1.5”, 2.25”, 1.5”)	56	5.25	1/8	2	73.5	
	U-bars bottom (1.5”,	57.5	5.25	1/8	2	75.5	

	2.25”, 1.5”)						
	L-bottom (1.75”, 4”)	50	5.75	1/8	2	71.9	
	L-top (1.75”, 4”)	50	7	1/8	2	87.5	
	Roof (3.5”, 54.5”, 3.5”)	50	61.5	1/32	6	576.56	
Total						1551	0.9

At the bottom of the cart’s structure, stainless steel wheels of 4” diameter and 2” width will be placed using a press-fit built-in bearing. The wheels will be covered with hard rubber of ensure a proper gripping between the floor and the system while in movement.

The carts being identical, they are interchangeable into the lifting system. By the removal of the bottom cart, the cart standing above is easily brought to the ground where the management of the trays can be done, while the other tray is lifted back into the air. The carts are easily aligned into lifting system and an L-shaped stainless steel structure grips the cart on its L-sides from under.

3.2. Lifting system

3.2.1. Requirements

Based on calculations performed to determine the total amount of material used to build the design, it was found that one cart has a total weight of 290Kg when all its levels are filled with the germination trays containing saturated plugs, and weights 490Kg when the carts are filled with water during the water cycle (see appendix 6). Therefore, the lifting system is required to maintain in the air an approximated maximal weight of 490Kg.

3.2.2. Design specifications

One of the two carts is lifted above the other using a acme screw system. The motor used is a 1Hp motor and will lift the cart in approximately 1.22 minutes, (see appendix 8 for calculations).

3.2.3. Mechanical analysis of the rolling resistance

Since the carts are extremely heavy when containing saturated plugs, it was mandatory to determine the force that would be required to move the carts in and out of the lifting system by one person. This was performed using the rolling resistance equation.

Rolling resistance

$$F = c * \frac{N}{r} = 0.01 * \frac{290Kg * 9.81 \, {}^{m}/_{s^2}}{0.0508m} = 560N$$

Where F = the force required to roll the object

c = rolling coefficient=0.015 between hardrubber and concrete

N = normal force

r = radius of wheel

In this calculation, it was assumed that the floor and Urban Barns is made out of concrete. From this calculation, it was found that the required force to move one cart of the germination system containing the maximum amount of germination trays and saturated plugs would require a force a 560N to be moved, which is equivalent to 57Kg. It might be expected that the force to put the cart in movement be twice as much (Beardmore, 2013). This is an issue in the design since the design is supposed to be safe to use on a daily basis. Therefore, it will be addressed in the optimization section of this report.

3.3. Lighting

3.3.1. Requirements

The most important criteria to keep in mind during germination and seedling growth is the temperature generated by the lighting system. High temperatures can cause the plants to burn, mainly on the tips and margins of the leaves. Consequently it is of fundamental importance to use a lighting system that does not generate too much heat. Two important criteria to take into account when germinating and growing seedlings are the photoperiod as well as the light intensity required for their optimal growth and development.

3.3.1.1. Photoperiod

The photoperiod is the daily period of light to which an organism is exposed. In both, the dark and the light phase of germination, seeds do not require the same amount of light.

Dark Phase

Germination highly depends on the type of plant being grown. Many seeds are impervious to light however, numerous species need to be stimulated or inhibited by continuous or short periods of light to be able to germinate properly (Dr. Robert William, McGill University, personal communication, January 2015).

Light phase

The optimal photoperiod for leafy greens during the seedling growth is of 16 hours. However longer periods, such as 24 hours, are acceptable if the light intensity is decreased to provide the same total daily amount of light accumulated as the optimal photoperiod would supply the plants (Dr. Robert William, Mcgill University, personal communication, January 2015).

3.3.1.2. Light intensity

The lighting system should be configured for an optimal uniform distribution of light over the entire growing area.

Dark phase

As mentioned above, in the dark phase, plants only need light to stimulate or inhibit their germination hence why in the case of leafy greens, the light intensity should be around 50μmol/m2/s of photosynthetically active radiation (PAR) (Brechner, N.D; Dr. Valerie Gravel, Department of Plant Science, McGill University, personal communication, January 2015). This level of illumination prevents the seedlings from stretching while minimizing the tendency of supplemental lighting to dry out the surface of the medium.

Light phase

For the seedling growth of mainly leafy greens, the seeds require a higher light input in order to properly grow hence the light intensity should be increased up to 75 μmol/m2/s of PAR (Valerie Gravel, Department of Plant Science, McGill University, personal communication, January 2015).

3.3.2. Design specifications

This design consists of low heat emission and energy consumption LED strips that are fixed on separate levels from the trays. This constitutes the advantage of separating the electrical and water components of the system for safety purposes even if the LEDs used are waterproof. The LEDs needed are required to produce at least 22W of energy, however from an experimentation conducted with the prototype, the use of LEDs generating between 30W and 50W of energy would result in optimal growing conditions without generating excess heat. The light spectrum generated by the LEDs is white seeing that it stimulates seeds and seedling germination. Furthermore, the lighting system has the benefit of having an adjustable light spectrum that can either be dimmed at 0%, 25%, 50%, 75% or 100%. Moreover, depending on the distance between the trays and the lighting system, it is important the LEDs used trigger at least 75μmol/m2/s when at a 100% light intensity. In addition, since the lighting system is independent for each level, different lighting requirements can be satisfied according to the needs of the plant variety as well as the different growing stages of the seed.

3.4. Watering

3.4.1. Requirements

The seedlings require to be watered and their rockwool to be completely moisturized by the function of an automated watering system everyday in order to grow healthy and strong plants. The seedlings are contained in the standard germination trays, which require a water level of roughly ¾" at its bottom in order for the substrate to absorb the water up to the top of the substrate by capillary diffusion. The watering of the plants can be required to be performed once or twice per day, in the case of the seed germination, while requiring more frequently as the seedlings grow. It was found that the seedling growth would require a 15 minutes watering every 6 hours (Brechner N.D)

The system requires that the same amount of water be provided to all levels throughout the carts when a complete watering of the system is performed. The water inflow should be closely monitored in order to reduce the possibility of over overspilling, which could become very dangerous since the system design also involves an electrical system for the lights. Therefore, the inflow and outflow rate require to be closely monitored in order for the germination trays to be provided with the necessary amount of water at each watering.

3.4.1.1. Water required at bottom of the germination tray

This was determined by a simple observation experiment when analyzing the plant flats, as when put into water, the styrofoam trays float. However, when the plant plugs are saturated already, which is the case since all plugs must be submerged into water before the sowing, the styrofoam trays sink. To achieve contact of the water with the plant, plugs require a water level that ensures some flotation of the plant trays as well as enough to fill in all the crevices on the bottom of the tray since there is a small gap between the bottom of the tray and the bottom of the plugs.

3.4.1.2. Nutrient solution

A nutrient solution should be used to lower the pH of the rockwool, which is of initially of 7.5 or greater to an optimal pH for lettuce growth between 5.5 and 5.8 (Resh, 2006). Furthermore, the nutrient solution is also utilized as a high nutrient source, mostly of potassium, nitrogen and phosphorus, for the optimal development of the seeds and growth of the seedlings. Depending on the type of plant, the nutrient solution should be blended with different quantities of water and addition of other micro-nutrients in order to provide the seeds with solution meeting their specific needs.

3.4.2. Design specifications

3.4.2.1. Water requirements per level

As mentioned above, due to the design of the bottom of the styrofoam flats, the tray geometry requires a minimum height of water of roughly ¾" at its bottom in order to reach an optimal water uptake. This number, multiplied with the length and depth dimensions of the trays, allowed us to approximate a maximum water volume of 33.15 L per level. This in turn allowed for calculation of the total weight and mechanics of the lifting system required to lift a maximum weight cart.

3.4.2.2. Pump sizing and flow breakdown

Based on the required amount of water to be filled for each level at every watering, an adequate pump size could be determined. The sizing of the pump depends on multiple criteria, namely the capability for an adequate fill rate of the trays, the capability to reach the full height of the germination system, and an affordable price. For this design, the Mondi Utility 1585 gph pump was chosen (Mondi, N.D.). This particular pump can fill the entire system in roughly 4 minutes assuming no outflow, and can pump to a maximum height of 27 feet assuming no partitions. Based on these specific prerequisites, this pump ideal for the watering system, however it is important to note several points regarding water entry into this germination system. The schematic below demonstrate the flow breakdown:

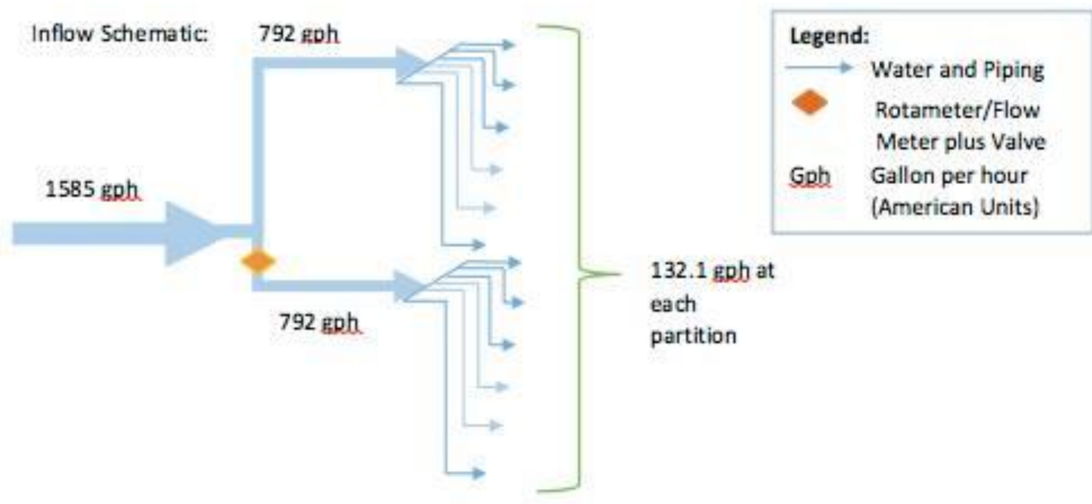

Figure 8: Flow breakdown

From the schematic, it can be observed that the Mondi pump will move water at 1585 gph until the first division for each cart. This is an area of focus since the pressure heads on pumping water up vertically after a division of the flow can cause an unequal distribution of water, as observed in the prototype. A particular concern must therefore be put into the regulation of the flow moving down to the lower cart as this is a path of least resistance for travelling water.

After this first partition, the water enters 6 flow divisions to reach each tray, of which all should each experience roughly 132.1 gph. This division occurs at the top of each cart, and piping carrying the water to its respective trays completes the entry of nutrient water into the germination system. The water will enter the side of the level container and fills the germination trays with their required amount of water.

Regulation of flow

The difference in pressure heads induced by the partition of water to different heights requires the addition of a device to control the distribution of the water. It is recommended to integrate a rotameter or flow meter, along with a valve to monitor and control the flow. The more expensive flow meter and rotameter setups come with the benefits of higher accuracy and precision, however for this project an economical option is preferred. The FL-30002 on Omega Canada's website would be a good choice for the purpose of the design. This tube may lack in the high degree of precision of the more accurate industrial type rotameters, yet the simplicity of the watering system design implemented only requires an instrument that can offer close and approximate readings for flow management. Nevertheless, Omega Canada also offers digital flow meters that also record analog data, which provides the ability for live data recording and observations of ideal flow restriction. Specifically, the FLR7330D flow meter can serve a flow range between 180 and 1800 gph which satisfies the needs of this design (OMEGA Engineering Inc., N.D.)**.** The downside of this technology is its cost, which is potentially excessive for the sakes and purposes of this design (OMEGA Engineering Inc., N.D.). Therefore, the choice of the FL-30002 is more adequate for the design presented.

Optimized ebb & flow system

The original idea was to integrate a complete ebb & flow system in the design that would pump the water up into the tray containers from the bottom and also drain from the same hole, while keeping the right amount of water into the containers using an overflow hole on the side of the tray that would drain the excess of water. This technique however, as observed in the prototype, requires that this pump and the catching container collecting the used water be at a lower height than the lowest level. It also involves the use of a pump that can perform a backflow, which was not desired to be used in our final design since all the used water needs to be recaptured after each watering cycle in order to be treated between each cycle.

Therefore, the watering inlet was moved to the side of the tray containers, and the outflow drainage hole and its assigned piping system remained at the center bottom of the container. Much like the inflow design, the outflow of each tray will subsequently connect to a secondary-main pipe for each cart and then connect to the main pipe out. This main pipe directly leads the water towards the bottom of the entire system. This design thus uses a passive gravitationally initiated drainage to outflow the water to the recycling tank. For this reason, the bottom most drainage hole must be higher than that of the entry into the collection tank for recycled water. A switch-activated component is added to the collector tank to detect when the container has reached a height close to the height of the bottom most level. This device is incorporated in order to prevent the inflow rate of overly filling the bottom containers.

Overflow component & outflow rate

In the possible event of a blockage of a bottom drain hole, a supplementary overflow design is integrated to ensure no full flooding can occur and minimizing the exposure of the electrical light system to water. The overflow catchments would transfer possible water spillage directly to the same main pipeline on either respective cart. It is important to recognize that connections at partitions and jointures in the piping networks are achieved with quick-connect coupler pieces, and require that largest inflow and outflow pipes be separate of the integrated piping on the cart.

The desired outflow rate is dependent on a preference of technology. If the germination system were fitted with a computer interface that could control and monitor all that is functioning, the outflow rate bears little influence on the system relative to the fill time per tray container. This specifically refers to the theoretical time of 3 minutes and 52 seconds to fill a tray, and an automated computer system as such would ideally be able to control the pump based on the required fill time. The use of a computer interface to control every aspect of the germination process would be an ideal set-up, and offer many benefits when fitting an appropriate watering system. However, as seen in the prototype design, a specific outflow of water was necessary since the pump was overqualified for the amount of water needed. Also, the prototype depended on a 15 minutes increment automatic timer to turn the pump on and off, meaning the time to fill the container was fixed. The outflow requirements were imperative and strict as otherwise this watering system would overflow and flood the premises. For these reasons, in either situation, the combination of a bottom drain hole and overflow catchment is desirable.

Active component sensor

The next phase regarding full functionality and holistic integration of the watering system depends on an active component to ensure full drainage. As observed in the prototype testing, for water to flow passively flow downwards there must be a necessary change in potential energy. More specifically, if the water needs to completely drain from this system, the maximum height of the outflow-collection tank must be below the bottom most drain hole. Otherwise, the risk of overflowing the bottom levels of the bottom cart increases and nullifies the entire design. Therefore, the collection tank must be equipped with a submersible pump that can be activated when that maximum water height is reached. This can be achieved by an in tank sensor that is connected to the outflow-pump, and would trigger this pump into action when the water reaches its allowable height. This can also be done with an in tank flotation device. The apparatus would rise until the desired water height is reached; meanwhile moving a lever attached to the top of the tank which functions as a mechanical switch. Both options are valid methods, however the electrical sensor may prove to be more reliable, which also comes with a higher price.

Watering cycle

With this particular watering system, a single cycle watering the twelve levels would require approximately 400 liters of nutrient water, which could be collected at the bottom of the germinating system and refiltered before re-entering a second cycle. This design therefore allows for the recycling of the water and reduction in water waste, which are two important values of the Urban Barns systems.

3.5. Growing environment of plants

3.5.1. Requirements

Multiple environment conditions are to be taken into account while growing seedlings in a closed place such a the temperature, the relative humidity and the aeration. The goal is to induce the environment with the most favourable conditions that will encourage the seed germination (refer to Design 490 proposal). Depending on the type of plants, the temperature in which seeds are grown can easily inhibit the germination and growing processes. For example, lettuce grow at an ideal temperature around 21°C, however, if found in a room temperature higher than 30°C, their germination could be highly inhibited (Borthwick, 1954). For lettuce and basil, the ideal temperatures at which they are grown is commonly found to be between 21°C and 23°C (Valerie Gravel, Department of Plant Science, McGill University, personal communication, January 2015). According to Mortensen, a higher relative humidity environment also induces a greater biomass production in plants. It is also very important. Moreover, plants grown in higher relative humidity are found to have higher growing rates compared to ones grown in drier conditions (Mortensen, 1986). It is often suggested that the relative humidity to grow seedlings be above 75%, and even better, close to 100% (Mortensen, 1986; Valerie Gravel, Department of Plant Science, McGill University, personal communication, January 2015). The temperature of the substrate used should also remain relatively high, but not as much as the ambient temperature; it should be around 18C (Resh, 2006). It is also important maintain the seedlings in conditions where their growing medium is well aerated (Mortensen, 1986) to enhance the development of seedling growth.

In Urban Barns' current facility, the germination room will be decommissioned; therefore, no physical constraints are actually restraining the system.

3.5.2. Design specifications

Two possibilities are currently available for the company. First, the facility could reallocate a separate growing room specifically for the germination growth in which the adequate ventilation, relative humidity and temperature would be controlled.

The second option would be the covering of the system by a growing tent. While the latter has the advantage of being much cheaper, it also restrains the access to the plants. In such a restrained space, the temperature and ventilation would have to be greatly monitored in order for the temperatures not to increase too drastically and therefore inhibit the plant growth.

At the light of these requirements, it is proposed to Urban Barns that the germination system be placed in a new germination room, separated from the growing phase of their systems. This would allow adequate ventilation and maintain of the ideal relative humidity and temperature. It would also add a greater physical separation between the germination system and the growing systems in case of possible infection.

3.6. Materials

3.6.1. Requirements

In choosing the materials for this design, it is necessary to consider the strength properties, resistance to corrosion through exposure to water, overall effect on total weight, and costs of materials. For each section of the design, careful analysis of materials chosen is necessary, especially because the reliability and durability of the system are major criteria for making this successful. For simplicity's sake, dividing the system into its components will facilitate understanding on the underlying focuses for material selection.

3.6.2. Design specifications

3.6.2.1. Tray containers

The tray containers are designed out of stainless steel. In the prototype, 16 gauge stainless steel sheets were chosen mainly because of the desired qualities, but also due to availability of supplies when constructing the prototype. Stainless steel is ideal for this design because of its durability, high strength capabilities, and high resistance to corrosion (ASSDA, 2013). It also is a much more affordable metal type, however has a downside of being a heavy alloy. This detail is seen to be a large reason why the carts in this design are as heavy as they are; the largest components, the trays, make up about 66% of the weight alone. However, because this design stipulates the germination trays are to hold and come into contact with water on a frequent daily occurrence, stainless steel is a top option.

3.6.2.2. Cart structure

The cart frame is designed out of aluminum, another alloy that has high strength capabilities as well as solid corrosion resistance. The lightness of aluminum was another key feature, as the structure of the cart comprises a large percentage of the rest of the carts weight. Specifically in the prototype development, T-6 Aluminum was used because it was made available to us, and was subsequently used in the weight calculations and cost estimates. The drawback of using aluminum is the cost of the material, however it is a small price to pay when compared to the convenience and effectiveness of its implementation.

4. TESTING: METHODS, RESULTS AND ANALYSIS

4.1. Prototype

4.1.1. Construction of the prototype

A prototype was built in order to test the feasibility as well as the basic concept of the theoretical design parameters. It was built at Adanac Air Tube System's shop, in St-Lambert, due to the opportunity of free materials and professional help regarding welding, bending and the overall construction of the prototype.

4.1.1.1. Frame structure

Weight is an important factor of the design. Most of the maximum weight is be constituted of water mass however minimizing the overall weight was an aspect we wanted to show in our prototype. The frame was built out of Aluminum due to its strength to weight ratio. It is important to note that Aluminum will eventually oxidize however there is a point of diminishing returns where by the time the frame rusts the benefits of the material will outweigh its retrofit. Aluminum corrosion resistance is very good in untreated aluminum. It has a superior corrosion resistance in most environments. This is primarily because aluminum spontaneously forms a thin but effective oxide layer that prevents further oxidation. Aluminum oxide is impermeable and, unlike the oxide layers on many other metals, it adheres strongly to the parent metal. If damaged mechanically, aluminum's oxide layer repairs itself immediately. This oxide layer is one of the main reasons for aluminum's good corrosion properties. The layer is stable in the general pH range 4–9. (Sapa,2015).

In the prototype, T6 2mm thick sheets of aluminum were cut and then bent using a brake machine to form U shaped members. These members were then fusion welded together creating the outer frame.

Figure 9: Prototype

4.1.1.2. Tray container design and sizing

In order to produce a prototype that would reflect the design proposal, an appropriate scale needed to be determined so realistically building something could be accomplished all while staying true to the final design. An approximate prototype of 1/6th of the final design size was built. It was composed of two trays stacked on top of each other. that contained one germinating tray each. It was conveniently chosen to use the same white foam growing trays and plugs that are currently being used by Urban Barns in order to incorporate current functional germinating practises while automating them. The first designed component was the stainless steel tray containers that had to accommodate the styrofoam trays containing the rockwool plugs. Stainless Steel was chosen to not only be strong enough to endure the mass of water it needed to hold, but to also be resistant to rust as the material would constantly be wet. The stainless steel trays were slightly over designed to allow the easy removal of the styrofoam trays due to their heavier weight when wet. The stainless steel trays measure 16"x28" with a height of $1^{1/4}$ inch. A slope of 1% was incorporated at the base of the tray to promote draining and limiting water to light exposure hence minimising algae growth. With the trays sized appropriately, the inflow and outflow was calculated. A ½ inch national pipe thread (NPT) fitting was implemented at the base of the tray. Using a plasma cutter, a ¾ inch hole was cut on the front side of the tray and a ¾ inch NPT fitting was socketed to have an overflow. Since the flow of water into the tray is smaller than the potential outflow, overflowing cannot happen hence leaving a steady water table in the tray of around 3/4' inches. Due to capillary water movement in the rockwool plugs the seedling have their water replenished according to a schedule dictated by a timer controlling the water pump. The trays are watered once a day for a period of 15 minutes.

4.1.2. Watering system

Designing and Optimizing the water delivery components

The pump used in the prototype is a 290 GPH donated to us by Ardanac Air Tubing. The pump was mildly too strong for the scale of the prototype, which means that the pump would fill up the trays within a matter of seconds. . This was mitigated by using a ''master flow'' valve that allowed calibration for the total flow of water entering the system. Another aspect to be considered is the height differential of the two levels and how this will affect the amount of water delivered to each tray. During the trials of free flowing tubes to both stacked trays, a differential of water flowing to each tray was observed where the bottom would receive a higher proportion on the total pumped water than to top one making it fill up in half the time. To mitigate this issue a ''split-flow'' valve was implemented on the bottom tube to add more resistance on that flow path balancing both flows and making them equal. The implementation of these two calibration valves allows the advantage of having different pressure heads linked to one pump as well as having different size pumps.

4.1.3. Lighting

The lighting system is fixed on the prototype on a separate level than the trays mainly for convenience purposes. This adds the benefit of not having to ever remove the lights with the trays and also adds a level of separation between electrical and water components for safety. Lights can also be adjusted at the same rate that the germinating plants are growing in order to keep a uniform height at all times during germination. This also has the advantage of enabling the company to grow different varieties of plants that might require different lighting requirements.

Three LED strips, one white LED strip and two blue/red/white LED strips, have been placed using an optimal light dispersion pattern. The pattern is shown in figure 10. The white LED strip produces about 22W of energy. When comparing the red/blue/white LED strips with what is currently on the market as well as with the white LED strip, it is estimated that these lights can generate between 30 and 50W of energy. Both types of LED are dimmable and can be set to different light intensities such as 25%, 50%, 75% and 100%.

Figure 10: Light distribution on prototype

4.2. Experimentation

An experimentation on the growth of Breen lettuce and Dolly basil was lead in the prototype system to compare the impact of the seedling development under two different distances, 4" and 5.5", from the LED lighting arrangement to the germination tray. The plants were grown in the basement of the McGill Macdonald campus greenhouse, which already serves as a laboratory for testing on Urban Barns systems.

As mentioned previously, the temperature of the substrate in which plants are grown has a great impact on the seed development. The ambient air temperature as well as the relative humidity also influence the growth of plants. Therefore, the temperatures of one substrate on each level were evaluated in addition to the relative humidity and the temperature in the room. The relative humidity and room temperature sensor was placed on the prototype frame, close the de air between the levels. The other two sensors were placed in the middle of the germination trays. The data logger registered the information every 5 minutes for 13 days.

The germination trays on each level had the same composition. On one level, half of the seeds, 120 seeds (60 basil and 60 lettuce), had been germinated out of the system following the same method as currently used at Urban Barns and integrated into the system at day 9. The other half of the seeds, also 120 seeds (60 basil and 60 lettuce), were germinated directly within the prototype. The seeds and seedlings were watered once a day for 15 minutes with a Hoagland solution diluted in water with a ratio 1:1. The lights were kept on 24 hours per day for an easier analysis of the data.

For the sake of the experiment on the effect of different distances between the light system and the germinating trays on the seedling growth, all three LED strips were set at 100% light intensity. The upper lighting level has been set at the lowest germination tray to lighting system distance possible, which results in a 4” spacing. The highest light intensity is of 67.88 μmol and is found mostly at the middle of the tray. On the other hand the lower lighting level has been set at the highest germination tray to lighting system distance possible, which results in a 51/2” spacing. The highest light intensity is of 49.22 μmol and is found mostly at the middle of the tray. Figure F and G represent the light distribution on the upper and lower level of the prototype, respectively. A similar pattern can be observed, where the highest light intensities are found mostly at the middle on the trays. This is mainly due to the fact that despite our greatest intent the light pattern was not entirely consistent throughout the roofing. Using straight LED strips would remove this important varying in light intensity.

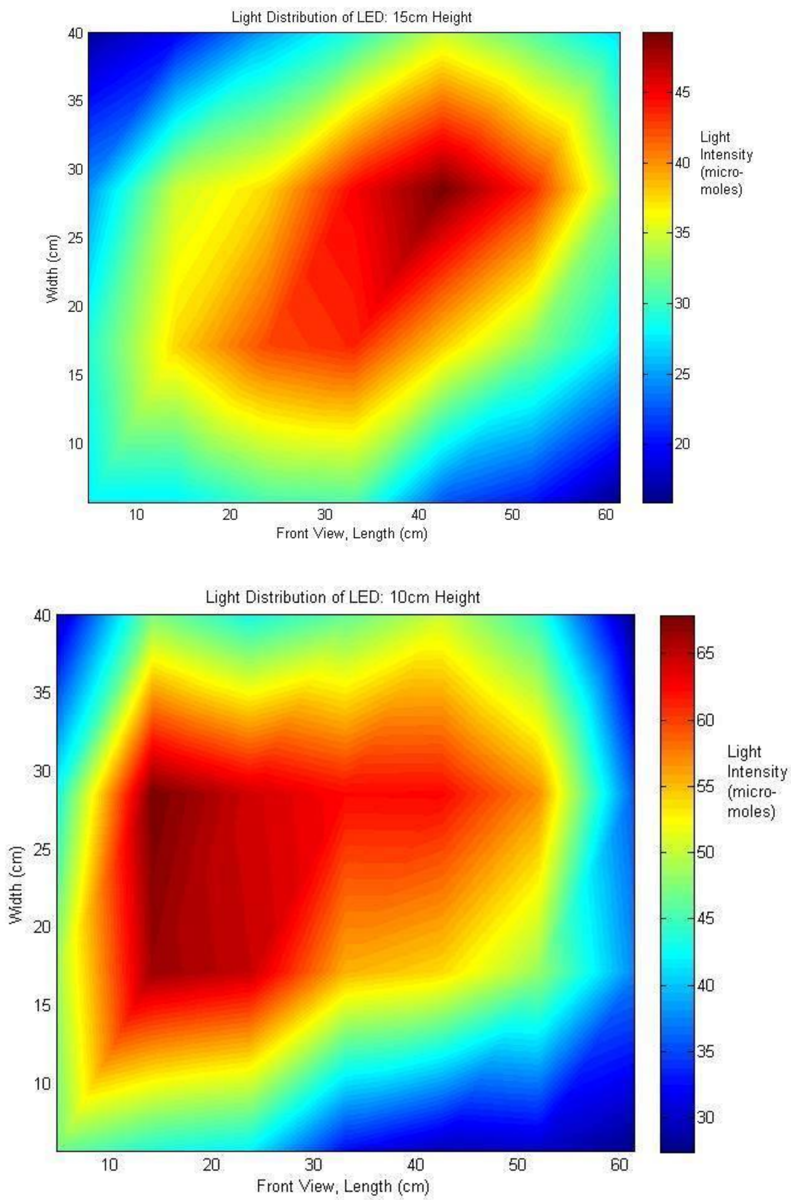

Figure 11: Light distribution on different levels

The two temperature sensors were placed in a rockwool on the middle of each level more or less where the highest light intensity was found. This was done in order to evaluate if the different distances, and consequent light intensities, would affect the temperature of the rockwool.

4.3. Results

From the data gathered by the data logger, it was found that rockwool placed in the higher level, which had a smaller distance between the germination trays and the roofing, had a constantly greater temperature than the rockwool placed at a greater distance from its light roof (as can be seen on the graph in appendix 7). The difference between the two temperature varied between approximately 1C and 4C, ranging between 21C and 26C. This indicates that although the LED's are of very low force, they have a direct impact on the rockwool temperature because of the great proximity of the materials.

On the graph, straight lines of temperature and relative humidity can be observed. These lines indicate when the watering of the plants occurred since during each of these moment, which happened once a day, the relative humidity increased while the three other temperatures decreased. Moreover, the temperature within the rockwool were always lower than the ones registered in the ambient air.

Observations on the plants

Some observations were made on the health of plants throughout the experiment. The plants that were put immediately after the sowing stage into the growing system were found much healthier than the ones germinated outside, especially the lettuce. This can be explained by the fact that plants germinated outside the prototype lacked of light intensity at some point before entering the system.

Overall, lettuce plants germinated in the level at 4" distance were found healthier than the ones germinated at 5.5". The ones with the smallest distance between the light and the plants were found in general with larger stems, bigger leaves and a darker green color. On the other hand, the lettuce seeds germinated in at the lower level with a lower light intensity were found with fragile and elongated stems presenting a more green-yellow leaf color.

In comparison, the basil germinated well at both levels and there were no apparent distinction between the two. The two trays generated healthy, green and strong basil seedlings.

As a general comment, plant growing in areas where the light intensity was lower did not grow the appropriately in order to be then integrated into a growing system. The ones on the side where the lighting was lacking tend to grow long and fragile stem, reaching towards the greater light intensity areas.

4.4. Conclusion of the experiment

Lights have an impact on the temperature of the rockwool, it is therefore very important to analyse the heat generation of the LED lights use. The temperature and amount of light received by the plants can greatly influence the seedling growth based on the specific requirements of the variety of the plant. The amount of light received by a seedling should be close to 75umol or more.

5. SAFETY AND COST ASSESSMENT

5.1. Cost Analysis

Urban Barns is presently planning on investing a large amount of capital into a specially designed germination chamber system that would be much more expensive than anything our design could cost. For that reason, the design is not limited by the potential cost since our proposal would ultimately be a fraction of what Urban Barns' alternative choice would be.

As can be noticed on the materials price breakdown, the most expensive components of the system are the materials used to build the trays and the frame, the 22 W LED strips as well as the lifting system. There are also a few other materials not directly included in the materials price breakdown such as the rubber parts of the wheels and the valves since, at this time, it is hard to estimate the quantities and dimensions needed for those materials. The price for those components has been roughly estimated and can be found under the category "others".

Material	Amount	Unit Price (CAD)	Price ($CAD)
Aluminum (1/8" thick) (4X8 ft. sheet)	9	$230.20	$2071.8
Aluminum (1/4" thick) (4X8 ft. sheet)	2	$450.13	$900.26
Aluminum (2" thick) (1X1 ft. plate)	8	$203.69	$1 629.52
Stainless Steel (16 GA) (4X8 ft. sheet)	12	$323.85	$3 886.08
LED strips (22W, 12V)(10ft long)	72	$74.96	$5 397.12
Sump pump (1585 GPH)	1	$124.95	$124.95
⅝ pipe	50	$0.59/ft.	$29.5
½ pipe	50	$0.42/ft.	$21
Screw-Jack system	1	$3000	$3 000
Quick coupler	24	$5.60	$134.4
Labour	160 hours	$25/hour	$4 000
Other			$1 000
Price before taxes			**$22 194.63**
TPS		5%	$1109.73
TVQ		9.975%	$2213.91
Total Price			**$25 518.28**

Figure 12: Cost analysis

If the company decides to go towards more efficient LED lights, which produce more energy, the cost could be increased however if the design is to be implemented and multiple units are to be built, a decrease in unit price could be observed hence balancing out.

5.2. Safety

The number one concern when developing any type of design or feat of engineering is safety. This alone had a great amount of influence on features in this project, especially when electrical and hydroponic equipment operate together. The LED light fixtures fixed on an independent level from the watering system and are waterproof which ensure that occasional exposure will not provoke an electrical danger. This is also aided by the more docile movement of water in the ebb & flow system, again minimizing risk of an electrical threat. This particular watering system, however, also offers its technical difficulties when continuous flow is to fill trays simultaneously in a vertical array. The overflow catchments mentioned in the watering system section describes how potential overflow and spillage is kept in the system without loss, and again avoiding the instigation of an electrical danger. Even the collection tank is fitted with a sensor to activate a pump for more active drainage, ensuring that effective circulation of water is possible while reducing spillage.

The individual carts in design are rather robust, and their weight were of some concern in regards of safety. However, the lifting mechanism for this design offers a great deal of stability, and the addition of grips reduce risks of the cart slipping while being lifted. The implantation of a sensory system also would be effective for automatically stopping the lifting system, however the calculations provided in the mechanical analysis are just as effective for timing the motor to shut off. This would avoid damaging the cart and possibly tipping of the system, as well as salvaging the motor from irreparable damage if left running for too long. Another feature integrated in the lifting system is a backstop to avoid pushing the cart too far. These design choices were particularly important, as the goal of this automated germination system is to be a fully functional and convenient tool. If safety is compromised, the design is rendered useless and a large liability.

6. OPTIMIZATION

Currently, the weight of a cart is an important concern regarding the design. Most of the weight is caused by the tremendous amount of water absorbed by the rockwool therefore the making it strenuous to move. There are several ways this issue could be addressed which would make this system more efficient

6.1. Changes in dimensions

A simple way of cutting down some weight would be to simply build smaller carts. For example, the system could consist of 3 carts of 4 level each, which would each weigh approximately 193 kg. Furthermore, smaller carts in height would not only be lighter but would also allow for a better view of the upper tray trays.

Moreover, reducing the amount of germinating trays within 1 level would also greatly decrease the cart's weight since most of the weight is present in the water absorbed by the rockwool. This optimization would however diminish the production of 1 unit.

6.2. Change in materials

Another way the weight could be diminished would be by changing the tray container's material. The massive weight of stainless steel can pose issues regarding the functionality of this system. In fact, the structural strength of the steel may even be unnecessarily strong for this design. This inspired the research of lighter materials. High-impact acrylic may serve a better role for tray material since it is much lighter than stainless steel, and has strength properties that make it still a valid candidate. Acrylite Resist ™ by Degussa has 3 different grades of available acrylic, each with a tensile and flexural strength to withstand the 2.60 kPa load that a tray would experience (Cyro, 2006).

The total weight reduction by switching from stainless steel to the Acrylite material would be of 101 kg with one acrylic tray weighing roughly 6.9 kg. This change of material would render the cart more useful and increase the its maneuverability. If purchasing is to be done by the provided supplier, it is recommended with their grades of acrylic to choose either the Acrylite Resist™ 65 sheet or the Acrylite Resist™ FF because of their forming capabilities (Cyro, 2006).

6.3. Robotic system

The idea of completely automating the management of the system is of high interest mainly due to todays growing technology industry. Presently one unit consists of two 6 level carts stacked one on top of the other. The idea of two moving carts would be dismissed in the robotic system, which would consist of 12 independent levels, similar to the ones we have currently however they would be fixed in the unit. Each level would be supplied with a small camera that would allow for the continuous scrutiny of the germination and seedling process of the plants. If ever a level needs particular attention, a robotic system will bring down the level in question, hence making it easier for the operator to manage the germinating plant. The watering system would remain similar to the one used it the current design however the pump size might need to be resized.

In the case of a robotic system, weight would not be of an issue anymore. While this is a potentially beneficial recommendation, further brainstorming would be needed to conceptualize how the robotic system would function.

7. Concluding Remarks

In conclusion, the primary findings of this report suggest that the automated germination and seed growth system was a successful proof of concept. The seeds germinated within the system and grew into strong seedlings. Even though the prototype showed successful results, there are still some aspects of the design that need improvement such as the weight of the cart. Moreover, this project has demonstrated that seeds can in fact germinate and grow to satisfactory levels using LEDs as source of lighting and that the spacing between the germinating trays and the lighting source can be reduced to as much as 4” for an optimal germination.

8. References

ASSDA, 2013. Stainless steel. Available at: http://www.assda.asn.au/benefits-of-stainless-steel Accessed: April 5th, 2015.

Beardmore, R. 2013. Friction Factors. *Roymech.* Available at: http://www.roymech.co.uk/Useful_Tables/Tribology/co_of_frict.htm Accessed: April 13th, 2015.

Bewley, J. D. 1997. Seed Germination and Dormancy. *The Plant Cell*. 9:1055-1066.

Borthwick, H. A., S. B. Hendricks, E. H. Toole and V. K. Toole. 1954. Action of light on lettuce-seed germination. *Botanical Gazette.* 115(3):205-225.

Brechner, M., A.J. Both. N.D. Hydroponic Lettuce Handbook. *Cornell Controlled Environment Agriculture*. Available at: http://www.cornellcea.com/attachments/Cornell%20CEA%20Lettuce%20Handbook%20.pdf Accessed: March 14th, 2015

Cyro, 2006. Acrylite Resist. *Degussa.* Available at: http://www.tapplastics.com/uploads/pdf/Acrylite_Resist_Tech_Data.pdf Accessed: April 13th, 2015.

Dietrich F. Fischer, G. A. G. Harry and W. Janes. 1990. A System of Intensive Tomato Production Using Ebb-Flood Benches. *Professional Horticulture*. 4:99-106.

Domingues, D. S., H. W. Takahashi, C. A. P. Camara, S. L. Nixdorf. 2012. Automated system developed to control pH and concentration of nutrient solution evaluated in hydroponic lettuce production. *Computers and Electronics in Agriculture Computers and Electronics in Agriculture*. 84:53-61.

Kratky, B. 1996. Lettuce production guidelines for Hawaii. University of Hawaii CTAHR. Available at www.ctahr.hawaii.edu. Accessed March 14th, 2015.

Mondi, N.D. Mondi owner's manual: utility and sump pump. Available at: http://www.mondiproducts.com/pdf/Mondi-Utility-Sump-Pump-1585x-Gold-Series-Manual.pdf Accessed: March 27th, 2015

Mortensen, L.M. 1986. Effect of relative humidity on growth and flowering of some greenhouse plants. *Seientia Horticulturae*. 29:301-307.

Murali, R., M. Soundaria, V. Maheswari, P. Santhakumari, and V. Gopal. 2011. "Hydroponics"-A novel alternative for geoponic cultivation of medicinal plants and food crops. *International Journal of Pharma and Bio Sciences*. 2(2):286-296.

OMEGA Engineering Inc., N.D. Flow meter process control information system. Available at: http://www.omega.com/Green/pdf/FLR-D.pdf Accessed: March 27th, 2015.

Pantanella, E., M. Cardarelli, G. Colla, E. Rea, and A. Marcucci. 2012. Aquaponics vs. Hydroponics: Production and Quality of Lettuce Crop. *Acta Horticulturae*, 2(927):887-896.

Park, M. H. and Y. B. Lee. 1999. Effects of CO2 concentration, light intensity and nutrient level on growth of leaf lettuce in a plant factory. Acta Horticulturae. 548:377-383.

Percival Scientific. 2014. Seed Germination. Percival. Available at: www.percival-scientific.com. Accessed March 17th, 2015.

Resh, H. 2006. Hydroponic culture of Lettuce I. *Hobby Hydroponics*: *Second edition.* Available at: http://www.howardresh.com/Hydroponic-Lettuce-Production1.html Accessed: March 10th, 2015

Resh, H. M. 2013. *Hobby Hydroponics*, *Second edition*. Boca Raton Fl.: CRC Press

RSC. N.D. Nutrient Solution. Reckitt Benckiser. Available at: http://www.rsc.org/learn-chemistry/content/filerepository/CMP/00/001/134/Nutrient%20Solutions.pdf Accessed: April 13th, 2014

Sapa, 2015. Aluminum Corrosion Resistance. *Aluminum Design*. Available at: http://www.aluminiumdesign.net/design-support/aluminium-corrosion-resistance/ Accessed: April 11th, 2015.

Titouna, D., S. Bougoul. 2013. Simulation model of water and solute transport in two types of rockwool. *Journal of plant nutrition.* 36(3):429-442.
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APPENDIX 1 – Watering system

Watering system design calculations
Assumed pump strength/flowrate: 1585 gph (0.55 Hp)
<u>Flow partition</u>

- Initial flow rate 1585 gph at first partition,
- 2-way split 792.5 gph each way
- 6 way split with 132.1 gph per split

Therefore, each tray gets approximately 132.1 gph
<u>Time to fill one tray</u>
Inflow water: 132.1 gph x (3.89 L/gal)x(1 hr/ 60 min) = 8.56 L/min for each tray
Volume of water per tray: VT = (0.0381 m)x(1.27 m)x(1.37 m) x ½ = 66.3 L/2 = 33.15 L water per tray
Assuming no outflow
time to fill tray, t = VT/QT = (33.15 L) / (8.56 L/min) = 3.87 min = 3 minutes 52 sec.

APPENDIX 2 – Weight calculations

Final Cart Design Weight Calculations:
Tray dimensions (SI units):

- Height, H= 3.81 cm (1 ½")
- Depth, D=127 cm (50")
- Length, L=137 cm (54")

Weight rating lb per ft^2 (16 gauge stainless steel sheet metal) = 2.5 lb/ ft^2
Weight rating kg per m^2 = 2.5 lb/ ft^2 x (4.88 $^{kg/m^2}/_{lb/ft^2}$) = 12.2 kg/m^2
<u>Area and Weight Calculations for 1 tray</u>:

- 16 gauge stainless steel sheet metal used for weight analysis and prototype

Area of Stainless Steel for Tray = (2 x H x D) + (2 x H x L) + (D x L)
= 2(0.0381 m)(1.27 m) + 2(0.381 m)(1.37 m) + (1.27 m)(1.37 m)
= 0.0968 m^2 + 0.1045 m^2 + 1.742 m^2 = 1.944 m^2

Mass of 1 tray = Total Area Stainless Steel x Mass per Area Rating
= (1.944 m^2)(12.2 kg/m^2) = 23.7 kg
<u>Volume and Weight Calculations for Supporting Structure:</u>

- T6-Aluminum: density, ρ = 2.70 g/cm^3 = 2700 kg/ m^3
- Assume metal is initially flat sheet

- Thickness, $t = 4$ mm = 0.004m
- Width, $w = 0.1016$m (4”)
- Total Height, TH= 1.83 m (6 ft)
- Depth, D=127 cm (50”)
- Length, L=137 cm (54”)

Vertical U-Bar Volume = t x w x TH = (0.004 m)(0.1016 m)(1.83 m) = 0.000744 m^3 per bar

Total Volume = (0.000744 m^3/bar)(6 bars)= 0.00446 m^3

Horizontal L-Bar Volume = t x w x D = (0.004 m)(0.1016 m)(1.27 m) = 0.000186 m^3 per bar

Total Volume = (0.000186 m^3/bar)(4 bars) = 0.000743 m^3

Horizontal U-Bar Volume = t x w x L= (0.004 m)(0.1016 m)(1.37 m)= 0.000268 m^3 per bar

Total Volume = (0.000268 m^3/ bar)(5 bars) = .00134 m^3

Total Mass of T6 Aluminum = ∑ Total Volumes x ρ = (0.00654 m^3)(2700 kg/ m^3) = 17.7 kg

<u>Maximum Weights With and Without Water</u>:

- Mass of saturated 1 plug= 1 gram dry wt., = 9 grams saturated
- 6 trays per cart, 6 plant flats per tray, 240 plants per flat
- Assume weight of Styrofoam negligible
- Mass of Plugs, M_p = 77.8 kg
- Mass of Stainless Steel, M_{SS} = 6(23.7 kg) = 142.2 kg
- Mass of T6- Aluminum, $M_{T6\text{-}Al}$ = 17.7 kg
- Mass of total Water, M_{water} = 33.15 L/tray (1L/kg)(6 trays) = 199 kg

Total Mass (with max water) = $\sum M = M_p + M_{T6\text{-}Al} + M_{water} + M_{SS}$ = (77.8+17.7+199+142.2) kg = 436.7 kg

Total Mass (no water) = $M_p + M_{T6\text{-}Al} + M_{SS}$ = (77.8+17.7+142.2) kg = 237.7 kg

APPENDIX 3 – Light Distribution M-file

%% Micromole of Light graphs
% Nicholas Busque
% 260429206
% BREE 495-Senior Design

```
clear
clc

%% Variables 10cm Set-up:
v=[0,70,0,50];
x=[4.72, 14.15, 23.58, 33.02, 42.44, 51.87, 61.3];
y=[5.72, 17.15, 28.58, 40];
z_u=[46.63 43.44 41.9 32.30 29.12 29.84 27.52;
   48.72 66.51 64.75 55.43 53.83 48.41 37.56;
   42.91 67.88 64.38 62.29 62.40 56.90 35.71;
   29.41 47.49 43.15 46.31 50.43 44.36 27.45];

surfc(x,y,z_u)
axis(v);
title('Light Distribution of LED: 10cm Height')
xlabel('Front View, Length (cm)')
ylabel('Width (cm)')
zlabel('Light Intensity (micromoles)')
shading interp
colormap(jet)

pcolor(x,y,z_u)
title('Light Distribution of LED: 10cm Height')
xlabel('Front View, Length (cm)')
ylabel('Width (cm)')
shading interp

%% Variables 15cm Set-up:
v=[0,70,0,50];
x=[4.72, 14.15, 23.58, 33.02, 42.44, 51.87, 61.3];
y=[5.72, 17.15, 28.58, 40];

z_d=[27.66 27.60 30.35 30.70 22.43 20.22 15.80;
   29.17 37.70 42.37 43.59 37.90 32.58 27.22;
   24.60 34.82 37.56 44.84 49.22 43.64 32.61;
   16.62 19.56 25.27 29.32 34.70 31.10 27.04];

surfc(x,y,z_d)
axis(v);
title('Light Distribution of LED: 15cm Height')
```

```
xlabel('Front View, Length (cm)')
ylabel('Width (cm)')
zlabel('Light Intensity (micromoles)')
shading interp
colormap(jet)

pcolor(x,y,z_d)
title('Light Distribution of LED: 15cm Height')
xlabel('Front View, Length (cm)')
ylabel('Width (cm)')
shading interp
```

APPENDIX 5 –Details of Hoagland solution

The Hoagland solution is a hydroponic solution that provides all possible nutrients necessary for plant growth. It has the benefit of being suitable for the growth of a large variety of plants. Since it is extremely rich in Nitrogen and Potassium, the solution is appropriate for the development of large plants such as tomato plants and bell pepper plants. Moreover, with additional dilution, the hoagland solution becomes well suited for the growth of plants with lesser nutrient demands, such as lettuce and aquatic plants. The following table indicates the different macronutrients, micronutrients and iron chelates as well as their stock solution (RSC, N.D.).

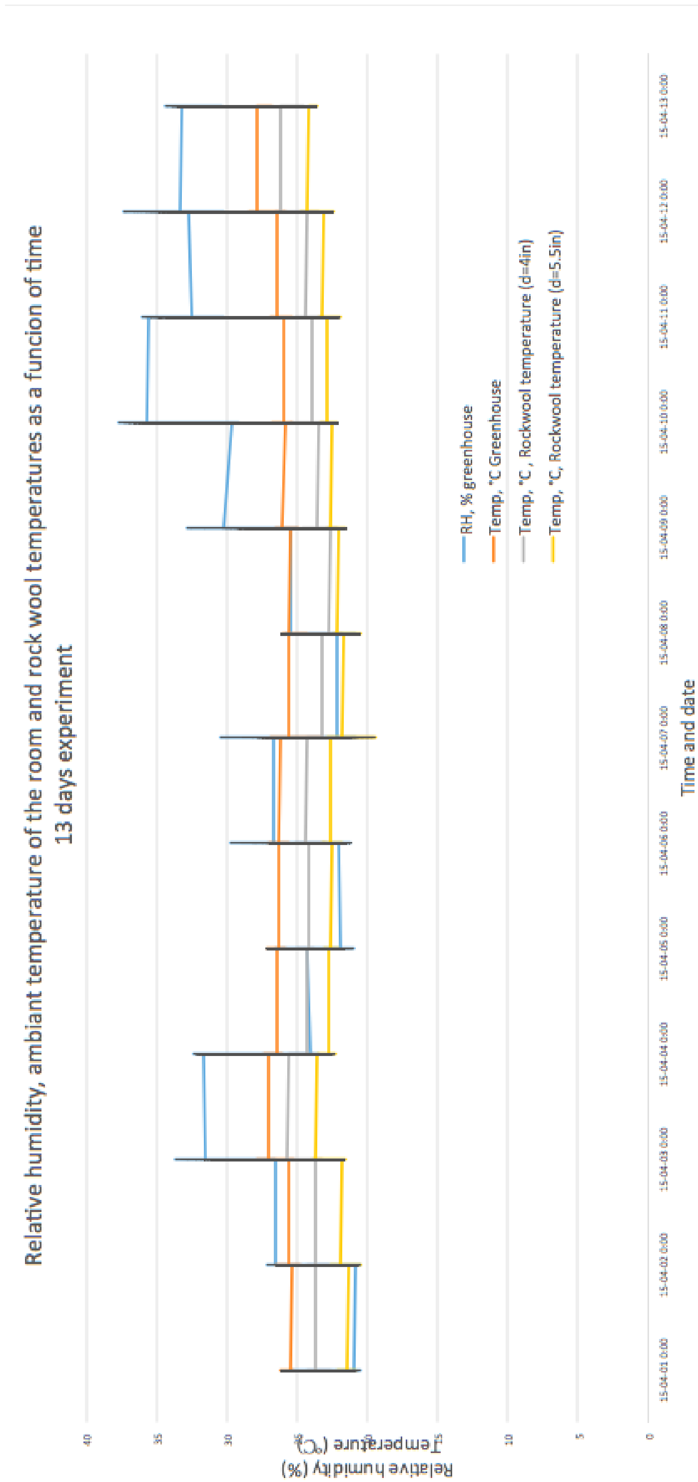
Components	Stock Solution (g/L)
Macronutrients	
1M KNO_3	101.1
1M $Ca(NO_3)_2 \bullet 4H_2O$	236.25
1M $MgSO_4 \bullet 7H_2O$	246.5
1M KH_2PO_4 (pH to 6.0)	136.09
Micronutrients	
H_3BO_3	2.86
$MnCl_2 \bullet 4H_2O$	1.81
$ZnSO_4 \bullet 7H_2O$	0.22
$CuSO_4 \bullet 5H_2O$	0.051
$Na_2MoO_4 \bullet 2H_2O$	0.12
Iron chelate	
NaEDTA	7.45
$FeSO_4 \bullet 7H_2O$	5.57

APPENDIX 6 - Competition

In the scope of Design 2 and 3, we were asked to enroll our design in an engineering competition. On January 29th, our automated germination and seedling growth system was presented in the innovative design category of the Quebec's Engineering Competition. This competition is instigated to test the contestants to become more creative and innovative engineers and to develop products while bearing in mind their environmental, economical and social impacts. In the innovative design category, the competitors are asked to present a product that they have developed that isn't presently on the market and has the opportunity to be commercialized and sold.

This was a very enriching opportunity for our team since we got the chance to have inputs on our design from engineers of different fields such as mechanical engineers and electrical engineers. This contributed to the development of new ideas regarding our system.

APPENDIX 7 – Temperature data from experimentation

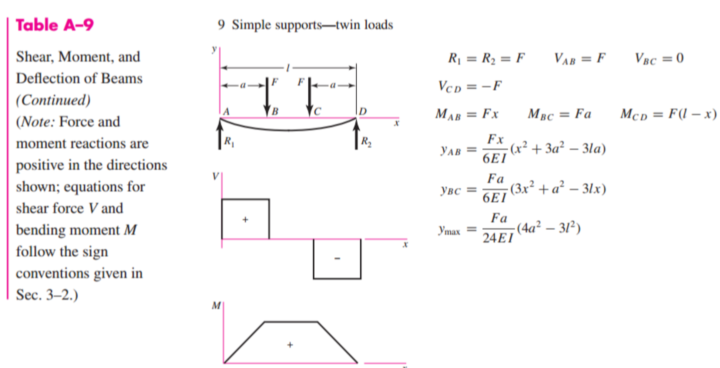


APPENDIX 8- Lifting calculations

Lifting system:
Buckling:
1)
490Kg*9.8N/Kg=4802N High strength Steel =>
Sy=690Mpa
4802N/4 Screw Jacks=1200.5N/Screw Jack
Su=760Mpa
SF are 1.2 for material 2 for Buckling
E=190Gpa
690Mpa/1.2=575Mpa=σall
L=4.26m
2)
I= (SF*Pdes*L^2 eff)/ (E*pi^2) = (2*1200N* 4.26m^2)/ (190*10^9N/m^2 *pi^2) = 2.3*10^{-8} m^4
3)
Pi*d^4 /32 = I =2.3*10^{-8} m^4 d = 0.022m = 0.86614173 inch
⇨ 1 inch (Standard) = 0.0254m

4)
Pdes/A = 1200N/ (pi*d^2/4) = 2.3 Mpa <<< 575Mpa/2
This massive overdesign maybe indicates that a round bar may not be the best shape for the bar. A hollow bar might be better.
5)
Pcr= pi^2 * E* I/ L^2 eff = pi2 * (190*10^9N/m^2) * (pi*0.0254^4 m/32)/ 4.26m^2 = 4221.9 N
Pcr/SF = 4221.9/2 = 2110.9N > 1200.5N OK.

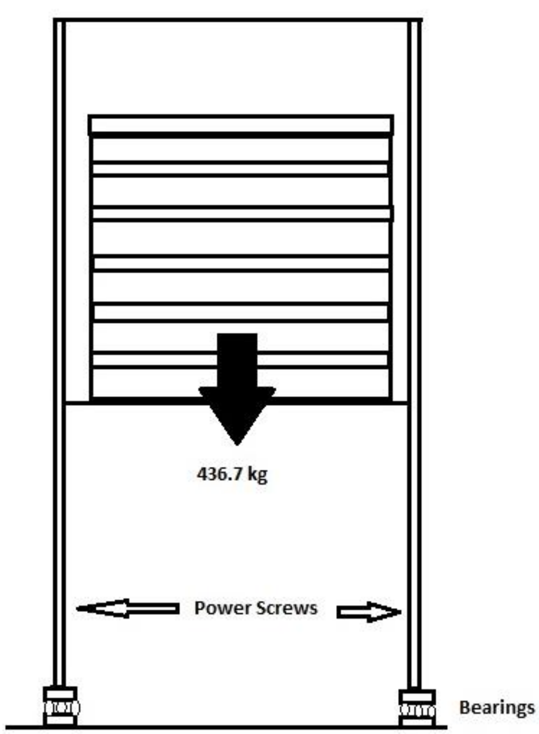
2)
Beam support-Twin loads



(490Kg*9.8N/Kg)=4802N
4802N/2sides=2401N =F
L= 54"= 1.3716m
a = 1inch = 0.0254m (Distance between screw jacks and vertical structural beams)
Small a due to all force carried comes down on vertical structural components on the side of carts and is very close to supports
Vab=2401N Vbc=0 Vcd=-2401N
Mab=2401N*x Mbc=2401N*0.0254m= 61Nm
Mcd=2401N*(1.3716m-x)
Yab=((2401N*x)/6EI)* (x^2+3a^2+3La)
Ybc=((2401N*0.0254m)/6EI)*$(3x^2+a^2-3Lx)$
E=69Gpa (Aluminum)
I= H3b/12 + 2[h3B/12 + hB(h+H)2/4]
= $4.5188*10^{-7}$m4 (C beam) (h=b=1/8'', B=1.5'',H=2")
(Source:http://www.amesweb.info/SectionalPropertiesTabs/SectionalPropertiesCbeam.aspx)
Ymax = ((2401N*0.0254m)/24*E*I)*($4*0.0254^2$m -$3*1.3716^2$ m) = 0.4mm of deflection max
The reason that deflection is so small is due to the fact that the vertical structural components on the side of carts are very close to supports

Torque and Power Screw Analysis of Cart Lift:

- High strength steel
    - Yield strength = 300-690 MPa
    - Minimum in diameter, dr, 25.4
- Torque and calculations is determined per power screw
- Square Threads



Step 1: Find All Necessary Dimensions and Known Information:
<u>From Table 8-1 (TEXT BOOK REFERENCE):</u>
d = 30 mm
P = 3.5 mm
d_r = d – P = 26.5 mm
d_m = d – P/2 = 28.25 mm
L = 2P = 7 mm
Force per Power Screw, F = (490 kg x 9.81 m/s^2)/4= 4,807 N/4= 1.2 kN

From Table 8-5 (TEXT BOOK REFERENCE):

- our material- steel
- nut material – steel with machine oil
- Friction factor, f = 0.11

Step 2: Find Torque to Raise and Lower Load:

$T_r = \frac{Fd_m}{2}\left[\frac{L+\pi f d_m}{\pi d_m - fL}\right]$

$T_r = \frac{(1.2\ kN)(28.25\ mm)}{2}\left[\frac{7\ mm+\pi(0.11)(28.25\ mm)}{\pi(28.25\ mm)-(0.11)(7\ mm)}\right]$

$T_r = 3.23\ kNmm$

$T_L = \frac{Fd_m}{2}\left[\frac{\pi f d_m - L}{\pi d_m + fL}\right] = \frac{(1.2\ kN)(28.25\ mm)}{2}\left[\frac{\pi(0.11)(28.25\ mm)-7\ mm}{\pi(28.25\ mm)+(0.11)(7\ mm)}\right]$

$T_L = 0.523\ kNmm$ → Positive torque for lowering, indicates that the load can hold up on its own.

Step 3: Determine the Efficiency:

$e = \frac{FL}{2\pi T_r} = \frac{(1.2\ kN)(7\ mm)}{2\pi(3.23\ kNmm)}$ = 41.4 % Efficient

Step 4: Body Stresses (per bar):

a. Normal stress: $\sigma = \frac{F}{A} = \frac{1.2\ kN}{\pi(\frac{d_r}{2})^2} = 0.0021\ GPa = 2.1\ MPa$

b. Shear Stress (due to Torque): $\tau = \frac{T*r}{J}$, where is polar moment of inertia $J = \frac{\pi d^4}{32} =$ $48{,}415.4\ mm^4$ $\tau = \frac{3.23\ kNmm\frac{26.5\ mm}{2}}{48415.4\ mm^4} = 0.000888\ GPa = 0.888\ MPa$

c. Bearing Stress on thread (1st): $\sigma_B = \frac{F}{A_B} = \frac{0.38F}{\pi d_m(\frac{p}{2})} = 0.00294\ GPa = 2.94\ MPa$

d. Bending Stress at Root: $\sigma_{bending} = \frac{6(0.38)F}{\pi d_r P} = \frac{2.74}{291.4} = 0.00939\ GPa = 9.39MPa$

e. Transverse Shear: $\tau_{max,rectangle} = \frac{3F_{shear}}{2A_B} = \frac{3(0.38)(1.2\ kN)}{2(\pi d_r\left(\frac{p}{2}\right))} = 0.0047\ GPa =$ $4.7\ MPa$

Step 5: Find the Equivalent Stress: $\sigma_{xx} = -2.1\ MPa, \sigma_{yy} = 9.39\ MPa, \tau_{xy} = -0.888\ MPa$

$\sigma_e = \sqrt{\sigma_{xx}{}^2 + \sigma_{yy}{}^2 - \sigma_{xx}\sigma_{yy} + 3\tau_{xy}{}^2} = \sqrt{4.41 + 88.2 + 19.7 + 2.37} = 10.71\ MPa$

Step 6: Safety Factor: $SF = \frac{Strength}{Load} = \frac{\delta_{yield}}{\sigma_e} = \frac{690}{10.71} MPa = 64.43$ → Very Strong

$SF = 1.2 = \frac{690\ (Yield\ Strength)}{X} \rightarrow Max\ Target\ Load = 575\ MPa = 0.575\ GPa$

$$0.575\ GPa = \sqrt{\sigma_{xx}{}^2 + \sigma_{yy}{}^2 - \sigma_{xx}\sigma_{yy} + 3\tau_{xy}{}^2}$$

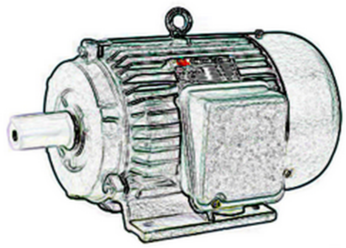
$$= \sqrt{(0.00181F)^2 + (0.0072F)^2 + (0.00181F)(0.0072F) + 3(0.00074F)^2}$$

$0 = 7.86 \times 10^{-5}F^2 + 0.00222F \quad + 0.119 \rightarrow F =$
$54.71\ kN, -86.43\ kN\ (not\ appropriate)$

Max load per bar, F = 54.71 kN, mass =5577 kg

Max total load, F = 218.8 kN, mass = 22308 kg

Required Torque for motor (minimum): 12.92 Nm



Power versus torque and motor velocity in electric motors are indicated below:

Power		Motor Velocity (rpm)											
		3450			2000			1000			500		
		Torque											
hp	kW	(in lb_f)	(ft lb_f)	(Nm)	(in lb_f)	(ft lb_f)	(Nm)	(in lb_f)	(ft lb_f)	(Nm)	(in lb_f)	(ft lb_f)	(Nm)
1	0.75	18	1.5	2.1	32	2.6	3.6	63	5.3	7.1	126	10.5	14.2
1.5	1.1	27	2.3	3.1	47	3.9	5.3	95	7.9	10.7	189	15.8	[illegible]
2	1.5	37	3.0	4.1	63	5.3	7.1	126	10.5	14.2	252	21.0	28.5
3	2.2	55	4.6	6.2	95	7.9	10.7	189	15.8	21.4	378	31.5	42.7
5	3.7	91	7.6	10	158	13.1	18	315	26.3	36	630	52.5	71
7.5	5.6	137	11	15	236	20	27	473	39	53	945	79	107
10	7.5	183	15	21	315	26	36	630	53	71	1260	105	142
15	11	274	23	31	473	39	53	945	79	107	1891	158	214

P=3.5mm = 0.133779inch

Source: http://www.engineeringtoolbox.com/electrical-motors-hp-torque-rpm-d_1503.html

Lifting height= 96 inches

96inches/0.133779inches= 690 rotations **It will take 1min22 sec to lift with 500rpm

A 1HP electric motor running at 500rpm can produce 14.2Nm

The three main components analysed were designing an acme screw lifting system that would resist buckling, an analysis of deflection of the bottom beam holding up the cart connecting the acme screws together and finally an analysis of torque and power Screw of cart lift.

Results show that our lifting system will have four 1inch diameter acme screws attached to a 1 hp motor in order to provide at least 12Nm of torque to lift our cart. It will take approximately 1.22min for the lifting to be done assuming 1:1 ratio gears boxes. It is also important to mention that there is a necessary torque to lower the cart requiring a motor that can run in reverse. These attachments will be at all four corners of the cart. The beam holding up the cart will have a negligible deflection due to the distance between application of force and reactionary forces is very small. One beam would be sufficient to hold up the maximum weight of the cart however for practical purposes the cart will have two bottom beam attaching both front screws and back screws in order to have uniform lifting.