Urban Rooftop Garden

BREE 495: Design III

Alexandre Cournoyer, Marcela Rojas, Amélie Sirois-Leclerc, Trevor Stanhope, Sara Tawil, Mei Xiao

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Executive Summary

For the 2013 - 2014 Engineering Design Capstone Project our team, in a joint venture with the Société Environnementale de Côte-des-Neiges (SOCENV), proposes a design for a sustainable rooftop garden to supplement MultiCaf, a community kitchen in the Côte-des-Neiges borough of Montreal.

Rather than an expensive overhaul of the roof, a permanent deck structure was developed as both a community space and a platform for the volunteers and other members of the building. As the garden will mainly be run by volunteers, two low-tech and easy to use growth systems were developed which can be sourced mainly from recyclable materials. The deck structure will also feature modular sections for an easy access to the roof membrane for maintenance.

To achieve high plant yield and to ensure the growth systems are adequate for a rooftop environment, both an ebb-and-flow hydroponic system and different designs of self-watering planters were studied and tested. An attached coldframe on the hydroponics table would transform it into a nursery table to provide early season growth for selected plants, while planters would bring them to maturity and allow the growth of plants with larger root systems. Usages of the two systems are independent from each other. A modified ebb-and-flow watering system was selected for the hydroponic table due to its simple and low cost maintenance and initial investment. A cascading system was also designed for tables to minimize cost of plumbing and other related equipment.

After analyzing the results, green leafy plants are highly suggested for early seasonal growth, due to their resistance to weather fluctuation. On the other hand, solanaceous crop production in self-watering planters is encouraged for the regular season. The total cost for the project is estimated to be around $80,000, which represents a major investment and leads to important considerations such as risk analysis for both the growth systems and the project as a whole, along with establishing a comprehensive funding plan.

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Introduction and Objectives

Montréal is a city with important economic, social, and cultural development, yet food security is still a problem on the island. High transition areas, such as the Côte-des-Neiges-et-Notre-Dame-de-Grâce borough, are particularly vulnerable to food and nutrition insecurity and depend on food assistance programs to meet their daily needs.

Our clients are Multicaf, a community cafeteria that serves up to 260 lunches a day along with free breakfast, located at the corner of Chemin de la Côte-des-Neiges and Avenue Appleton, and SOCENV (Société Environmental de Côte-des-Neiges), an Éco-quartier and a non-profit organization dedicated to improving the local environment and the quality of life in the community. They wish to convert the rooftop space of MultiCaf's four story building into a vegetable garden in order to supplement their needs for fresh produce while reducing the gap between people and their source of food. A team of architects from Atelier Cropas + Klopp was invited to join the project as technical specialists.

For the 2013-2014 Engineering Design Capstone Project, our team proposed to design a modular rooftop garden with two growth systems: a self-watering passive soil planter and a soil-less hydroponics system run on a modified ebb and flow system. The goal is to ensure that the garden, run mainly by volunteers, would be easy to construct and maintain on a yearly basis. Furthermore, the designs will strive to be sustainable both environmentally and economically. This report will detail the design and testing of the two growth systems along with an overview of the required rooftop structures and funding plans.

Analysis and Specifications

Rooftop Structure

After consulting with the structural engineer jointly working on the project, it was concluded that the current roof slab could not resist additional load beyond snow accumulation during the winter. The maximum load allowable on the roof suggested by the engineer's analysis is 48 lb ft^{-2} (285 kg m^{-2}), which is inadequate for implementing a garden on the roof. Therefore, a deck structure was designed to redistribute the load onto the existing columns o the building to avoid placing any additional load on the roof slab.

Specifications and Constraints

Prior to the deck design, several specifications and constraints were considered to ensure that the deck meets certain expectations. Since roof membranes deteriorate over time, the deck would have to allow access to the roof for maintenance and inspection. Therefore modules would have to be easily pre-assembled and lifted up in the shortest time. The deck would also need to support sufficient loads, such as garden accessories (e.g. pots, nursery tables and windbreaks) throughout the year, as well as the weight of volunteers and visitors during gardening season and snow loads during the winter season.

Design

To adhere to the specifications, it was decided that the deck would have to be made of modular sections. Referring to figure 1, section A shows the initial rooftop without the deck. Points (3) show where local demolition of concrete membranes would be required to give access to the structural slab above the eight indicated columns. Roof units (1) would be relocated and the door frame (2) has to be replaced. Section B will be directly installed on the roof, but would have to be cleared of furniture (4,5,7) during winter. A water reservoir would also be installed on the elevator shed. Lastly, section C demonstrates the principal modular part of the roof. Structural galvanized I-beam and secondary (8, removable) wooden beams would be the core of the structure. Eight support points are centered on the columns. 20 pre-assembled cedar modules (9) for an easy access to the roof and finally windbreaks (10) attached to railings.

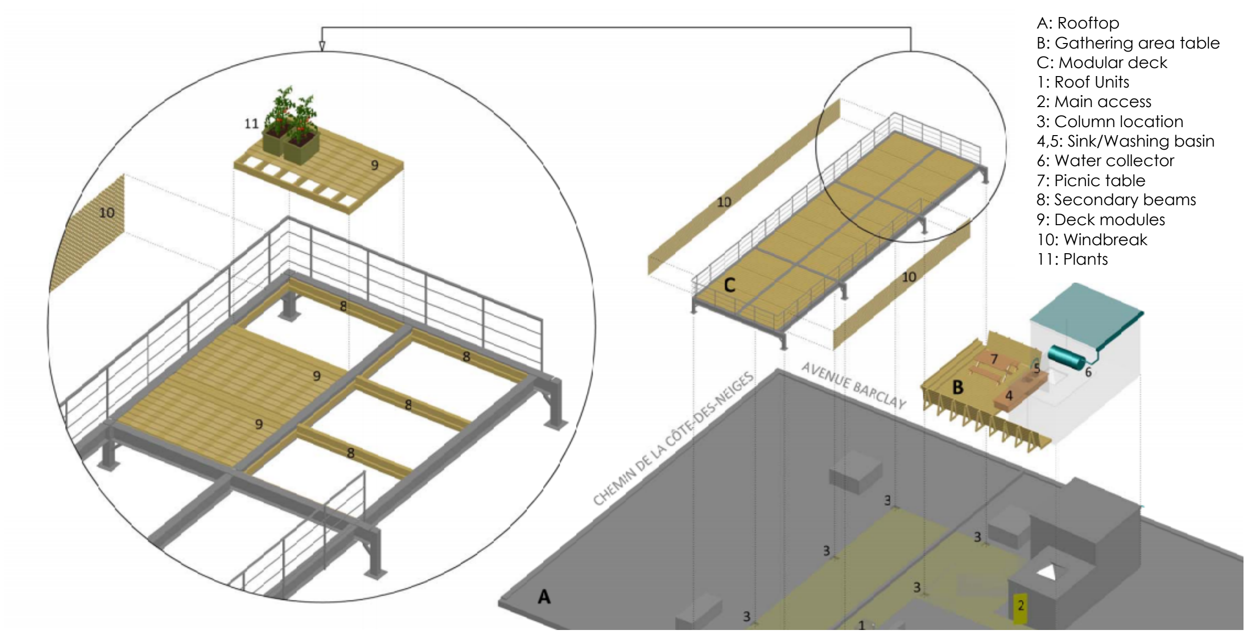


Figure 1: Aerial view of modular garden

As shown in figure 2, cedar modules would have a width of 69 in. (1.75 m) and the distance between columns would be of 94 in. (5.44 m). The middle part of section C would have a width of 280 in. (7.11 m). Depth (not shown in figure) would be about 206 in. (5.23 m). For any other dimensions and structural details, refer to appendix A.

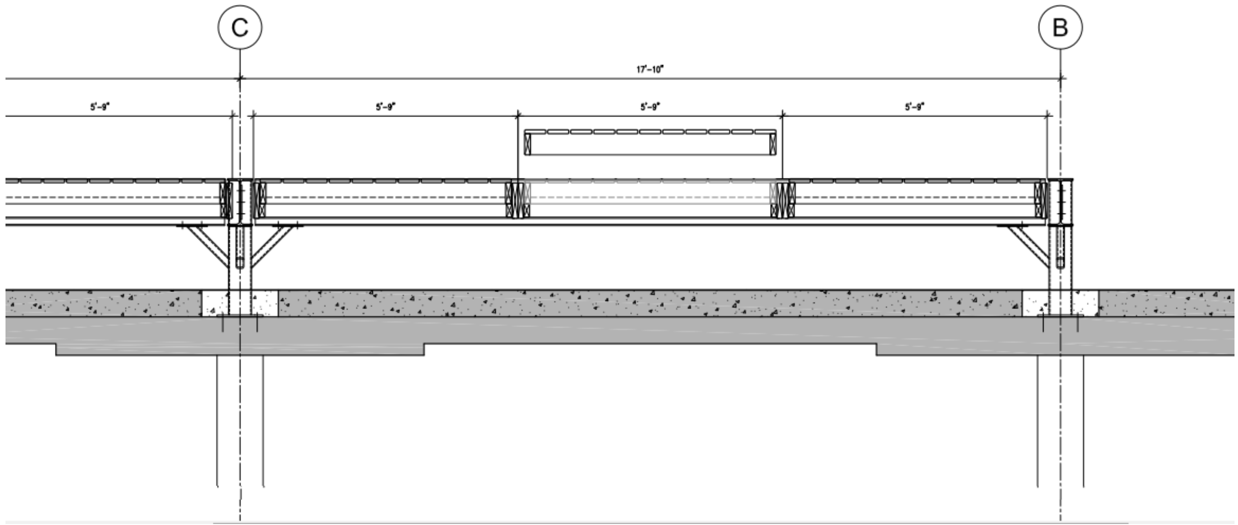


Figure 2: Cross sectional view of deck module (Fig. 1, Section C)

Nursery Table

Season extension is an important method of increasing productivity for an urban garden. Many flowering crops cannot grow to full maturity during the growing season in Montreal, which is relatively short due to the high latitude at which the city is located. To address this issue, a portable nursery was developed with a goal of allowing the garden to start its own seedlings in the cold climate of early April. This nursery is composed of a coldframe mounted on a hydroponics table. This system is versatile because the coldframe can be dismounted from the hydroponics table when nightly temperatures are warm enough for plants to survive without the coldframe's protection. For solanaceous crops like tomatoes and peppers, protection from cold temperatures is crucial to survival. However, for leafy greens like kale and spinach, cold temperatures do not have as much of an effect; these plants would thus be able to grow more easily in the nursery table in early spring.

Coldframe Design

Coldframes are made up of four walls, forming a frame, and a sash, usually made of a recycled window. When designing a coldframe, one often depends on the dimensions of the recycled window that is to be used as a sash. There is, however, one design aspect of the coldframe that is up to the designer: the sash angle.

Sunlight penetration is a very important aspect to consider in coldframe design because, in the rooftop garden situation, the sun is the only heat source provided to the seedlings. As a result, calculations and modeling were used to determine the optimal sash angle for sunlight penetration, which can be found in appendix B. This would be equivalent to an angle of 5° from the horizontal. Entering our data in our model, it was found that the optimal sash angle was 16°.

However, there was only three percent increase of heat produced at 16° sash angle than at 0°. The University of Missouri's Extension website (Schrock, 1998) discusses coldframe design and their suggested sash angle is a one-inch of elevation (2.54 cm) per foot of length (30.5 cm). As a result, it was concluded that the sash angle did not have an overly significant effect. Furthermore, including a sash angle in the design would only complicate the building of the coldframe. This contravenes with one of our constraints which is the ease of manufacturability.

Table Design

The nursery table was developed to include a re-circulating ebb-and-flow hydroponic system. Using an aquarium pump and a programmable timer, nutrient solution is supplied to the plants on regular intervals throughout the day. Between flooding cycles, dry periods provide oxygenation to the plants and encourage root development.

The outer frame (fig. 3) itself was designed to be deep enough for leafy greens to be grown to full maturity, and thick enough to provide adequate insulation to the plants. For the material, 10 in. x 2 in. (25.4 mm x 50.8 mm) pine planks were selected due to their wide availability and relatively low cost. For the quarter-scale prototype, the design objective was to accommodate ten fully-grown lettuce heads at a spacing of 6 in. (152.4 mm), whereas the full-scale model can accommodate 40 fully-grown plants. The sizing of the full-scale model was selected such that a single table can be cut from just two 96 in. (243.84 cm) planks and can be found in table 1.

Model	Dimensions (nominal)
Full-Scale (40 lettuce heads)	32 in x 64 in (81.28 cm x 162.56 cm)
Prototype (10 lettuce heads)	16 in x 32 in (40.64 cm x 81.28 cm)

Table 1: Nominal dimensions of nursery table frame

For the flood zone, a depth of 2 in. (50.8 mm) was desired to accommodate 2 in. (50.8 mm) deep circular mesh pots, which given a tray thickness of 0.5 in. (12.7 mm) would be suspended 0.5 in. (12.7 mm) above the 2 in. (50.8 mm) flood zone. Given a maximum water depth of 2 in. (50.8 mm) and assuming 1000 kg m^{-3} density of water, the base of the table would need to support a minimal load of 500 N m^{-2} (eq. 1). Therefore, 0.5 in. (12.7 mm) Grade B plywood was selected to act as the base for the flood zone because it is relatively light and more than capable of supporting such a load.

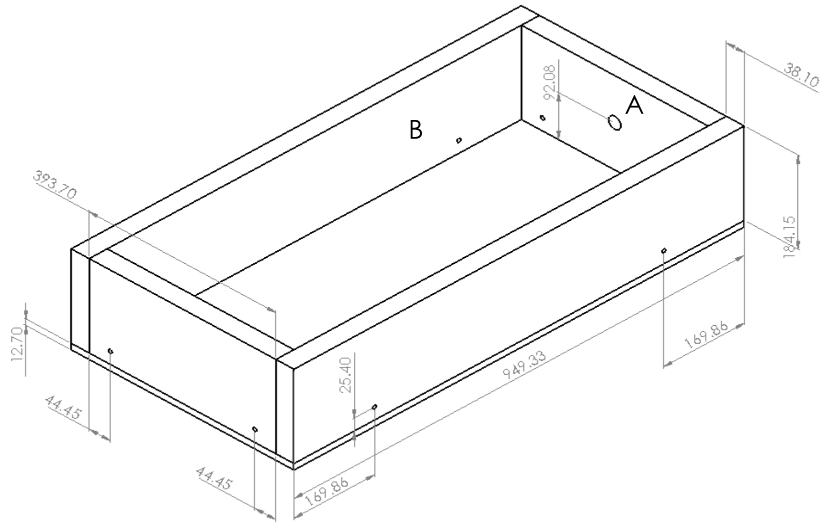


Figure 3: Outer frame of nursery table. Dimensions refer to the size of the prototype. Frame includes holes that will be used to run the water pipes (A) and to mount the bracket used to hold the waterproof lining (B).

The pressure on the base of the growth table can be calculated as follows:

$$P = \frac{V\rho g}{A} = h\rho g \tag{1}$$

$$\begin{aligned}
&where \\
&P = Pressur\ due\ to\ the\ water\ in\ the\ flood\ zone\ (N\ m^{-2}) \\
&\rho = density\ of\ water\ (kg\ m^{-3}) \\
&g = Gravitational\ acceleration\ (m\ s^{-2}) \\
&A = Area\ of\ flood\ zone\ (m^2) \\
&h = height\ of\ flood\ zone\ (m)
\end{aligned}$$

$$P = 50.8{\times}10^{-3}\ \mathrm{m} * 1000\ \mathrm{kg\ m^{-3}} * 9.8\ m\ s^{-2} = \frac{497N}{m^2} = 0.072psi$$

To suspend the plants above the flood zone, a tray was constructed as in figure 4 from 0.5 in. (12.7mm) plywood for holding 2 in. (50.8 mm) mesh pots. Each of the holes can be drilled using a 2 in. circular-hole saw.

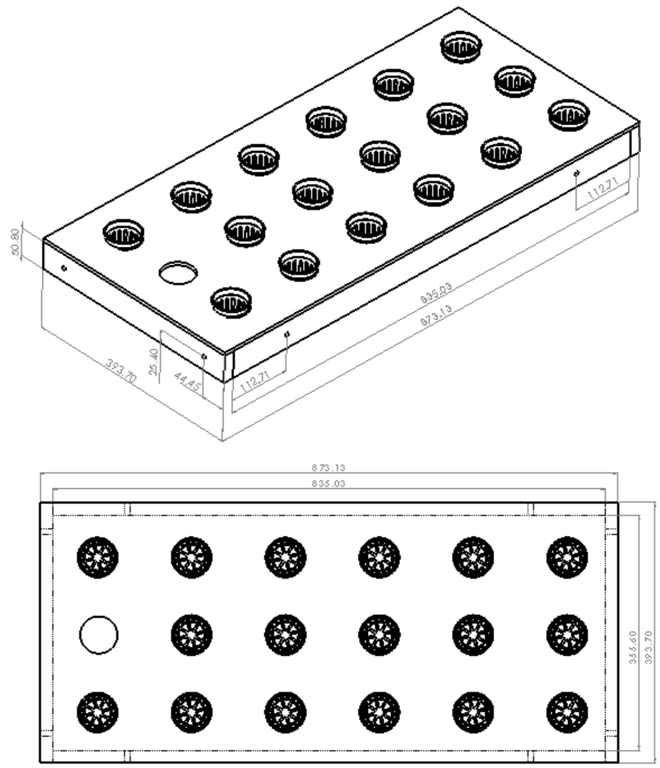


Figure 4: Suspended mesh pot tray. Up to 18 pots can be used for seedling growth

In order to create a watertight flood zone for the plant roots, the table was designed to accommodate a replaceable waterproof liner, such as woven polyethylene tarpaulin. To secure the lining, four 2 in. (50.8 mm) bracing bars are used which are tightened to the outer frame by 5/16 in. (7.9 mm) galvanized steel bolts. The bracing bars serve a double purpose by both securing the tarpaulin and supporting the plant tray. Woven polyethylene was selected as the lining because it is readily available at recycling facilities. However, the design can easily accommodate other linings if available, such as the single sheet polyethylene often used in temporary greenhouses.

Altogether, the flood zone has a maximum volume of approximately 15 Liters (eq. 2), so an opaque 37.9 L low density polyethylene (LDPE) bin with dimensions of 24 x 16 x 8¾ in. (6 x 41 x 22.2 cm) was selected for the quarter-scale prototype. The opaqueness is a very important quality, as light penetration into the nutrient solution can quickly lead to the development of algae. For the full-scale model, a 60 Liter flood zone, a 140 L reservoir would be used with dimensions of 32.4 x 20.4 x 18.6 in. (82 x 53 x 48 cm). By sizing the reservoirs to hold slightly more than double the required volume of the tray, the interval between refills can be extended, as well as allowing for each bin to serve as a reservoir for up to two separate grow tables. A model of the proposed prototype can be seen in figure 5. Instruction manuals detailing the construction and usage of the table and coldframe attachment will be included for our clients in appendix I.

$$V = Ah \tag{2}$$

$where$
$V = Volume\ (mm^3)$
$A = Area\ (mm^2)$
$h = height\ (mm)$
$from\ figure\ 4,$

$$V = 835\ mm \times 356\ mm \times 50.8\ mm \times \frac{1\ L}{1\times10^6\ mm^3} = 15.1\ L \sim 15\ L$$

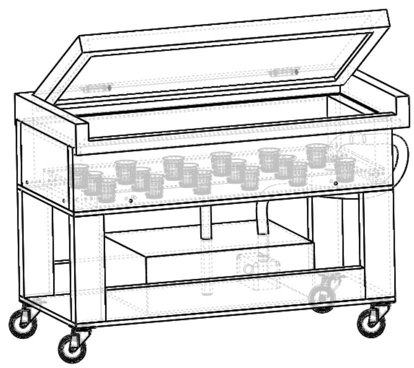


Figure 5: Quarter-scale prototype with flow system, reservoir trolley, and coldframe

Heat Transfer Analysis

Since our clients considered starting their gardening season during the month of April to achieve a higher production yield and to avoid the need of buying seedlings, the use of coldframes would be required. A heat transfer model was used to find out if proceeding with further research would be of worth. Coldframes would be of use in early gardening season so that heat within the nursery table would be higher than the surrounding temperature. The average temperature in April is about 10.7°C (Climat-Québec, 2014) and MultiCaf would be aiming for an internal ambient temperature of 15°C overnight to grow crops inside the closed tables. Additionally, the model would consider worst case scenario type concerning the wind with a speed of 2 m/s on rooftop (four storey building). Average hourly radiation transmittance for April 21st was determined using equations found in appendix C, and was found to be 368.14W.

Using the following dimensions from the nursery table prototype:

$$h = height = 8\ in = 20.32\ cm$$
$$w = width = 15.5\ in = 39.37\ cm$$
$$L = length = 37.375\ in = 94.93\ cm$$

The model used assumes a short cylinder rather than a rectangular shape to allow simplifications for the heat transfer model. Radius is defined as the average of the width and the height of the nursery table.

The Nusselt number for a short cylinder in gas for Nusselt number is defined as: (Kreith Principles Heat Transfer 7th. 2011)

$$Nu_D = 0.123 \cdot {Re_D}^{0.651} + 0.00416 \left(\frac{D}{h}\right)^{0.85} \cdot {Re_D}^{0.792} \tag{3}$$

$$\begin{aligned}
&where \\
&Nu_D = Nusselt\ Number \\
&Re_D = Reynolds\ Number = \frac{u_\infty D}{v} \\
&D = Diamter\ of\ cylinder\ (m) \\
&u_\infty = Average\ fluid\ speed\ (m\ s^{-1}) \\
&v = Kinematic\ viscosity\ (m^2 s^{-1})
\end{aligned}$$

Model restrictions:

$$\begin{aligned}
&7\times10^4 < Re_D < 2.2\times10^5 \\
&\frac{L}{D} < 4
\end{aligned}$$

$$\begin{aligned}
&R = \frac{15\ ½ + 8}{2}\ in = 11.75\ in = 0.29846\ m \\
&D = 2R = 0.5969\ m\ \frac{L}{D} = \frac{0.9493\ m}{0.5969\ m} = 1.59 \\
&1.59 < 4 \therefore within\ model\ restrictions
\end{aligned}$$

$$\begin{aligned}
&Re_D = \frac{2\frac{m}{s} \cdot 0.5969\ m}{14.205 \cdot 10^{-6}\frac{m^2}{s}} = 84040 \\
&7\times10^4 < 8.4\times10^4 < 2.2\times10^5 \therefore within\ model\ restrictions
\end{aligned}$$

$$Nu_D = 0.123 \cdot 84040^{0.651} + 0.00416 \left(\frac{0.5969}{0.2032}\right)^{0.85} \cdot 84040^{0.792} = 280.2$$

Having a Nusselt number of 280.2 (eq. 3), it is obvious that the heat loss through convection is not negligible. The heat transfer coefficient selected refers to the one for softwood materials (EngineeringToolBox). If the table were to be imagined as a cylinder, both circular end surfaces would be placed so that they would not be affected by the wind.

The rate of heat flow can be determined from equation 4.

$$q = h_c A(T_{in} - T_{out}) \tag{4}$$

$$\begin{aligned}
&where \\
&q = Rate\ of\ heat\ flow\ (W) \\
&h_c = Heat\ transfer\ coefficient\ (W\ m^{-2}\ K^{-1}) = \frac{Nu \cdot k}{D} \\
&k = Thermal\ conductivity\ (W\ m^{-1}\ K^{-1}) \\
&A = Surface\ area\ affected\ by\ the\ wind\ (m^2) \\
&T_{in} = Temperature\ inside\ de\ nusery\ table\ (K) \\
&T_{out} = Temperature\ surrounding\ the\ nursery\ table\ (K)
\end{aligned}$$

$$\begin{aligned}
&h_c\ = \frac{280.2 \cdot 0.12}{0.5969} = 56.33\ W\ m^{-2}\ K^{-1} \\
&q = 56.33 \cdot [2\pi(0.29846)(0.9493)] \cdot (9.3) = 932.12\ W. \\
&\Delta q = 368.14\ W - 932.12\ W = \ -562.98\ W
\end{aligned}$$

According to the conditions defined previously, coldframes would not be able to sustain a high enough temperature inside the nursery table. However, this model is wanted to be a simplified scientific approach and only aims to have an order of scale for the heat loss. Moreover, the model doesn’t take into account the thickness of the material which could have a high index ratio of heat transfer resistance between the inside and the outside surface of the frame and neglects the air bulk, which has a low heat transfer coefficient. The interior space of the table is also probably too small to let a natural convection process occur. Hence, heat transfer from air to the walls of the frame should be tested as conduction heat transfer between a fluid bulk (air) and solid material (wood). Therefore, the construction of a table and tests were ran to determine the real properties of such garden appliance.

Water Supply Design

Typical operations employing ebb and flow hydroponics suggest flooding at four equally spaced cycles per day, with each flood lasting for one hour with still water. However, implementing a conventional ebb and flow system into the table design would require additional control valves and increase the difficulty in connecting multiple tables in series on a shared reservoir. Therefore, the water supply system was designed such that the rate of inflow during the flood cycle is slightly greater than the rate of outflow, resulting in accumulation within the flood zone.

Due to the availability of pumps used in aquariums, a standard sized pump capable of 2000 Liters per hour (LPH) was selected with an outlet diameter of 0.5 in. (12.7 mm). For the outlet diameter, the initial assumption was to use a matching 0.5 in. (12.7 mm) diameter to fit that of the inlet. However, to verify that this diameter would be effective for obtaining the desired accumulation rate, testing needed to be conducted to verify this assumption. An alternative consideration was the use of 0.75 in. (19.05 mm) fixtures, which is also a common diameter of plumbing parts available at most hardware stores and would provide similar outflow rates. Therefore, to achieve the proper accumulation rate resulting in a flood cycle of 1 hour, the height of the table must be sized according to the desired drainage rate of the selected outlet diameter.

To meet the goal of a one hour flood cycle for the full-scale model, a fifteen minute flood cycle was the target for the quarter scale prototype with flood zone capacity. A target pumping time of 7.5 minutes to reach maximum capacity was assumed as the latter half of the flood cycle would be for draining the flood zone, resulting the desired 15 minute ebb-and-flow flood cycle. For the 2000 LPH pump, a 7.5 minute pump time would translate to an accumulation rate of 120 LPH (eq. 5). For the 2000 LPH pump and a 120 LPH accumulation rate, a drainage rate of 1880 LPH is required (eq. 6). The conditions at the outlet were assumed to be laminar due to the very low pressure (i.e. gravitational flow) as there would be at greatest only 2 in. (50.8 mm) of water depth in the flood zone. According to our calculations for a ¾ in. (19.05 mm) outlet, the table should be raised such that there is a height differential of 6.7 in. (17 cm) between the outlet and the reservoir level (eq. 7).

For the full-scale implementation, a cascading system connecting two tables in series can be used to reduce the fixed costs of plumbing equipment. However, as the first table reduces the initial flow rate from 2000 LPH to 1880 LPH, the rate of accumulation in the second table would be insufficient to flood if the second outlet has the same flow rate of 1880 LPH. Therefore, when installing a cascading system, the outflow rate of the second table can be adjusted by reducing necessary height difference between the outlet and the reservoir (eq. 6, eq. 7). This results in a slightly lower height difference between the second table and the reservoir of 5.9 in (15 cm). Taking into consideration the required height for storing the reservoir under the tables of 18.6 in (47.25 cm), the complete cascading system is a user-friendly 31.5 in (80 cm) in height with sufficient space under either table for storing the 140 L reservoir (fig. 6). This low height differential also guarantees that head losses at the pump should be near negligible.

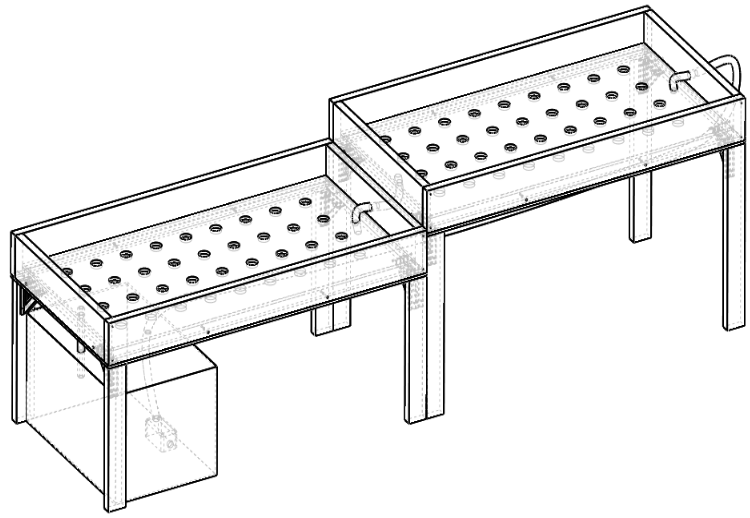


Figure 6: Two table cascading system

The height differential required between water reservoir and the inlet can be determined by the following equations:

$$Q_{acc} = V_{quater} * t_{flood} \tag{5}$$

$where$
$Q_{acc} = Rate\ of\ water\ accumulation\ (L\ hr^{-1})$
$V_{quarter} = Volume\ of\ prototype\ flood\ zone\ (L)$
$t_{flood} = time\ to\ fill\ flood\ zone\ (hr)$

$$Q_{acc} = \frac{15\ L}{0.125\ hr} = 120\ L\ hr^{-1}$$

$$Q_{drain} = Q - Q_{acc} \tag{6}$$

$where$
$Q_{drain} = Rate\ of\ water\ drainage\ (L\ hr^{-1})$
$Q = Rate\ of\ water\ in\ (L\ hr^{-1})$

$$Q_{drain} = (2000 - 120)L\ h^{-1} = 1880\ L\ hr^{-1}$$

$$Q_{drain} = vA = \sqrt{2gh}\left(\frac{D}{2}\right)^2 \pi$$

$$h = \left(\frac{Q_{drain}}{\left(\frac{D}{2}\right)^2 \pi}\right)^2 \frac{1}{2g} \tag{7}$$

$$\begin{aligned}
&where \\
&Q_{drain} = Rate\ of\ water\ drainage\ (L\ hr^{-1}) \\
&v = Outlet\ velocity\ (m\ s^{-1}) \\
&A = Outlet\ Area\ (m^2) \\
&D = Outlet\ diameter\ (m) \\
&g = Gravitational\ acceleration\ (m\ s^{-2}) \\
&h = height\ differential\ (m)
\end{aligned}$$

$$h = \left(\frac{1880\frac{L}{hr} \times \frac{1m^3}{1000L} \times \frac{1hr}{3600s}}{\pi\left(\frac{19.05\times10^{-3}m}{2}\right)^2}\right)^2 \frac{1}{2 * \frac{9.81m}{s^2}} = 0.17m$$

For the second table in the cascading system, the height can be similarly determined:

$$Q_{drain} = Q - Q_{acc}$$

$$Q_{drain} = (1880 - 120)L\ h^{-1} = 1760\ L\ hr^{-1} \tag{6}$$

$$h = \left(\frac{Q_{drain}}{\left(\frac{D}{2}\right)^2 \pi}\right)^2 \frac{1}{2g} \tag{7}$$

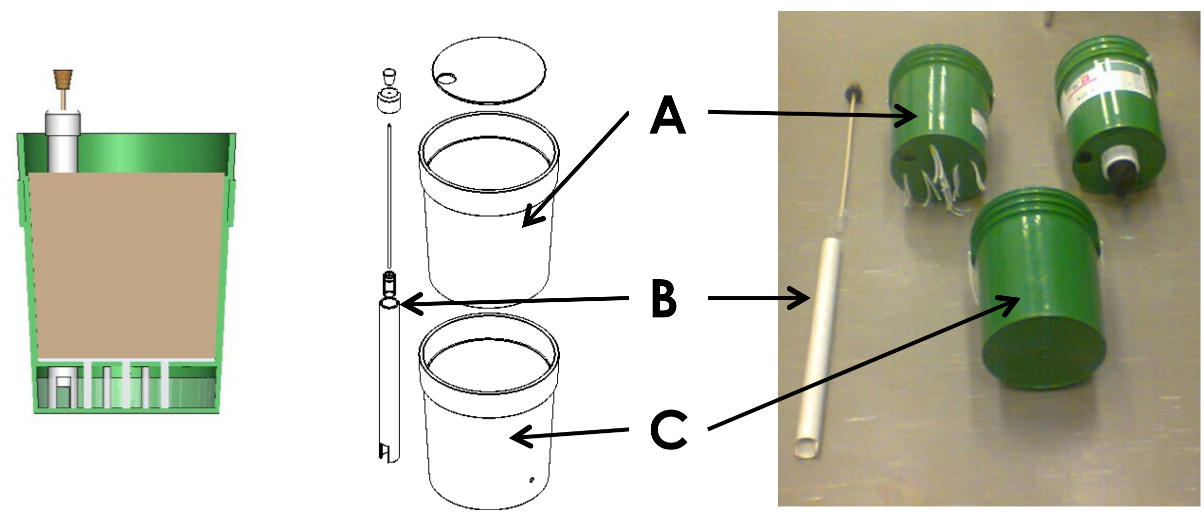
$$h = \left(\frac{1760\frac{L}{hr} \times \frac{1m^3}{1000L} \times \frac{1hr}{3600s}}{\pi\left(\frac{19.05\times10^{-3}m}{2}\right)^2}\right)^2 \frac{1}{2 * \frac{9.81m}{s^2}} = 0.15m$$

To account for non-ideal conditions, additional factors that must be considered are fluctuations of the level of water in the reservoir along with turbulence at the inlets before flow is fully developed. However, each of these considerations would have a counteracting effect, where lower than expected drainage rate would reduce time to accumulation by increasing outflow rate, but turbulence would increase it. As the effect of the reservoir depth would be likely to have a greater impact on the outlet rate, the system is likely to require a greater time to fully flood. This is an inconsequential result, as a full 2 in. (50.8 mm) flood is not necessary to provide the plants with sufficient water. The only major issue is the possibility of too high of an accumulation rate, resulting in over-flooding. In the event of overflow, reducing the pumping time would immediately resolve the issue. Additionally, because the plants are suspended in mesh pots filled with porous growth media (e.g. expanded clay pellets), even if the flooding period is too short the absorbed water will act as a buffer.

Planters

Planter Design

Taking into consideration the environment of the roof, a self-watering planter was chosen as the soil-based growing system, which uses irrigation by capillarity action. The roof environment is characterized to be windy and sunny, increasing evapotranspiration rates that allow the top layers of the soil to dry out faster. It is hypothesised that the moisture content difference between the top layers and the bottom ones will create a driving gradient for capillary action to occur at a faster rate. Hence, the self-watering system was adapted for this project. Two prototypes were built, both using two cylindrical containers sitting one within each other. The design shown in figure 7 consisted of two compartments; the top compartment (section A) contained the soil and the bottom one (section C) retained the water. A pipe (section B) was introduced in the planter to allow direct access to the water reservoir. The first prototype (P1) shown on left of figure 7c used wicks to transport water from the reservoir to the soil. The second



(a) (b) (c)

Figure 7: Self-watering planter design showing (a) the solid works design assembly, and (b) its exploded view. The design consists of two containers offset by 0.3 m. The top container (A) is filled with soil and the bottom one (C) contains the water reservoir; the pipe (B) allows for direct access to the water reservoir. The picture (c) shows the two prototypes built; prototype 1 (P1) on the left uses a wicking system to transport the water from the reservoir into the soil and prototype 2 (P2) on the right has a geotextile in direct contact with both the water and the soil.

prototype (P2) shown on the right side of the same picture had a container filled with soil and made of geotextile that was allowed to be immersed in the water reservoir. The performance of both prototypes in distributing water throughout the soil profile was tested. The details of the testing can be found in the section prototyping, testing and optimisation. The overall dimensions of the system were a height of 9 in. (228 mm) and a diameter of 14 in. (359 mm).

Plant Recommendations

We recommend buying seedlings of solanaceous crops like cherry tomatoes, tomatoes, and peppers as these crops are very popular and many rooftop gardens are growing them. They are also very versatile and fruit for a long period of time. Climbing plant such as peas and squash, like solanaceous crops, are also suitable for rooftop applications. These plants are useful to implement because they are able to use space efficiently by wrapping themselves on the structures provided like a porous windbreak.

Leafy greens, including kale, spinach, and lettuces, can be started as seeds in coldframe and are able to resist colder temperatures. By starting these plants in the coldframe, we are able to get two harvests during the growing season since they typically have a growing season of 40 to 50 days (MU, 2000). Another advantage of using greens is that most of the plant mass can be used as food and, if grown using hydroponics system, do not need to be washed of soil.

Prototyping, Testing, and Optimization

Coldframe

The prototype was built to suit specific requirements and did not reflect exactly the final design that would be used as part of the rooftop garden. In order to promote the Rooftop Garden Project, Multicaf wants to display the hydroponics table along with the coldframe prototypes in front of their establishment during summer 2014. The setup would include lettuce seedlings being grown in the hydroponics table. These are a few specifications that need to be included if the setup is displayed and accessible to the public:

1. Coldframe needs to be locked to the table
2. Seedlings must be visible but inaccessible to public
3. Coldframe cannot be open to allow ventilation

The first issue is easily remediable by adding a hinge hasp that is attached to the coldframe at one end and to the table at the other. The second and third specifications are met by the same solution. Since our clients wish to restrict access to the seedlings, we need to design for a window replacement that permits ventilation. The ideal solution for this was to use a second frame made from poultry mesh (or chicken wire). This option is inexpensive (2.70$/ m^2) (Rona, 2014) compared to buying mosquito screens. Also, the thin wire and wide spacing in the mesh make it easy to see the seedlings through the frame, as well as letting air circulate through the wire. Finally, the window frame and the chicken wire frame are interchangeable by the means of disassembling the hinges. As such, if the daily weather predictions are too warm to keep the window closed, then staff can easily remove the window frame to replace it by the chicken wire frame.

Air proofing

The coldframe prototype had a gap along the back wall and the window frame during hinge assembly. This gap proved to be detrimental to the heat retention of the coldframe. As a result, the instruction manual will specify the user to pay close attention when attaching the hinges, making sure that there is no gap between the window frame and the back wall.

Ease of Manufacturability

There are definite improvements that could be made to increase ease of manufacturability of the coldframe. As it is, the bottom of the coldframe is grooved all along the edges so as to fit snugly on to the hydroponics table using a table saw, which our clients have access. There are two methods to installing the coldframe: creating a groove on the inside of the frame or adding side bars to the table. The prototype used the groove method, which proved to be complicated and inconsistent. As a result, the design was changed to include side bars on the outside of table walls on which the coldframe can rest.

Hydroponics Table

Table Support Tests

Though the initial design of the system did not feature a trolley to support the reservoir, this feature was requested by the client. The initial design consisted of only four 2 in. x 4 in. (50.8 mm x 101.6 mm) legs mounted directly to the 0.5 in. (12.7 mm) plywood base. However with the additional weight of the filled reservoir, significant bowing and cracking occurred. To remedy this, two additional sections of 2 in. x 4 in. (50.8 mm x 101.6 mm) were mounted to the base to provide lateral support against bending. Additionally, the trolley was initially going to feature 5/16 in. (7.94 mm) pegs at the top of each leg to fit into corresponding holes on the underside of the table for easy removal. This proved to be difficult to manufacture and the pegs were replaced by 2 in. (50.8 mm) right-angle brackets (fig. 8)

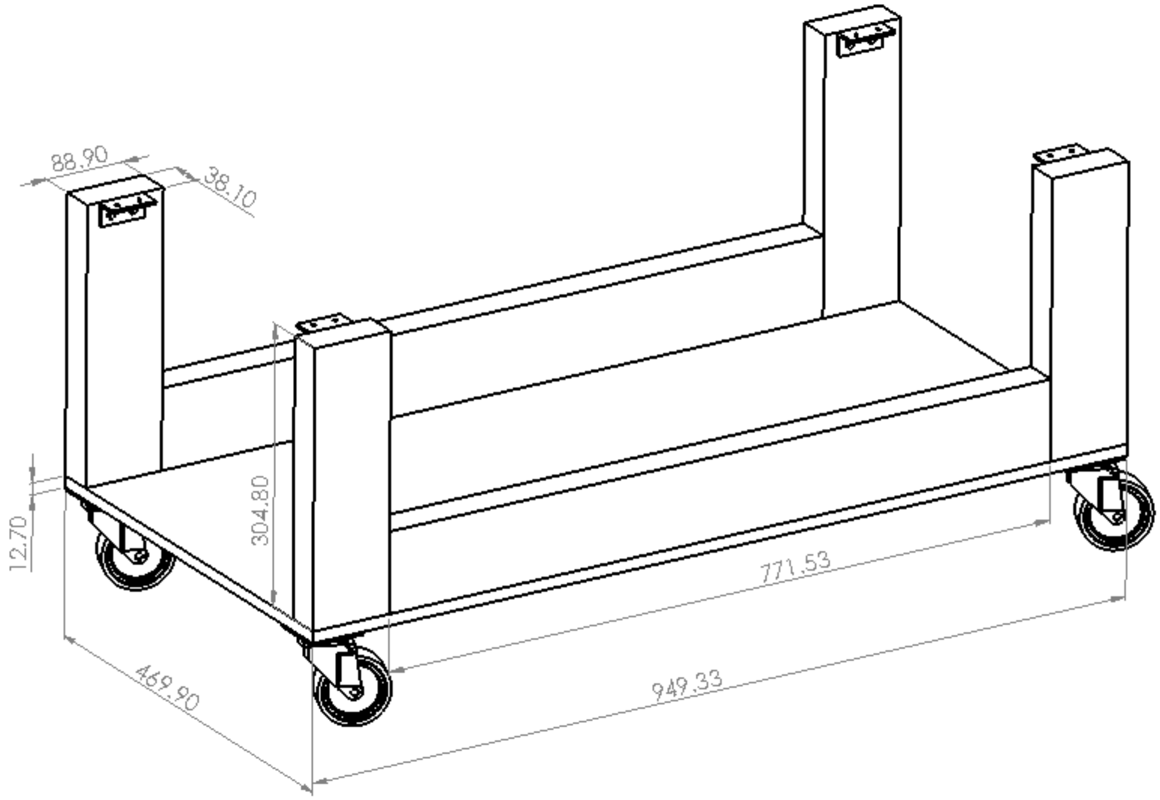


Figure 8: Modified reservoir trolley with lateral beams and right-angle brackets

Waterproofing Tests

To verify the water retention of the woven polyethylene tarpaulin, the nursery table's outlet was plugged and the floodplain was filled with water. The woven polyethylene showed no signs of leakages as evidenced by the lack of any bubbles. This test was conducted on a section of unused tarpaulin, therefore when replacing the lining with heavily-used, recycled tarpaulin, a similar visual inspection should be conducted by the gardeners. Unfortunately, after the conducting waterproof testing over a one week period, the ½ in. (12.7 mm) plywood used as the plant tray began to exhibit signs of warping. To address this, a new tray was built, replacing the ½ in. (12.7 mm) plywood with ¾ in (19.1 mm) plywood and painting the tray with a layer of water-resistant, oil-based green paint. Water-proof testing was then re-conducted over several weeks, and neither tray nor table frame showed any further signs of warping.

Flow Tests

To test the operation of the flood cycle, the nursery was fully assembled, including the pump, inlet/outlet hoses, and solution reservoir. For testing, ½ in. (12.7 mm) rubber tubing was used to verify if the smaller gauge could be used throughout the system to reduce cost and to improve upon the interchangeable nature of the parts, as compared to using ¾ in. (19.05 mm) for the outlet hoses. The flood cycle was initiated and the time until the water level completely filled the flood zone was measured. It was found that the calculated accumulation rate of around 120 LPH was within the acceptable range, resulting in required pumping times slightly shorter than 7.5 minutes. The shorter fill-time was likely due to a few compounding factors, such as the pump providing greater than 2000 LPH, inaccuracies in the height calculation, or turbulence at the outlet due to under-estimation of the effect of friction. However, the required height difference corresponding to ½ in. (12.7 mm) outlets was significantly greater than practical if used in a cascading system, with a necessary height difference approximately 0.85 m from outlet to reservoir level (eq. 7). This differential would be excessive if used in a cascading system, as the total height of the table would be approximately 81 in. (2.05 m) including the depth of the table. Therefore, for the final design, the recommended outlet size of should be ¾ in. (19.05 mm) which allows for a smaller height differential and a more practical overall height of the system.

$$h = \left(\frac{Q_{drain}}{\left(\frac{D}{2}\right)^2 \pi}\right)^2 \frac{1}{2g}$$

$$h = \left(\frac{1880\frac{L}{hr} \times \frac{1m^3}{1000L} \times \frac{1hr}{3600s}}{\pi\left(\frac{19.68\times10^{-3}m}{2}\right)^2}\right)^2 \frac{1}{2 * \frac{9.81m}{s^2}} = 0.85m \tag{7}$$

Temperature and Humidity Tests

To verify the heat retention capabilities of the nursery table, an Arduino data logging program was developed in C++ for recording internal vs. external temperature and relative humidity (Appendix D). The monitoring system (fig. 9) consisted of a 7.5 Ah Sealed lead-acid battery (SLA), an Arduino UNO with a SD card shield, and two DHT22 capacitive-type sensors capable of monitoring temperature and relative humidity to one decimal precision. With a low power consumption of around 100mA, the data logger could be used continuously for 75 hours. Three separate tests were conducted, the first on the weekend of March 25th to March 28th, the second from April 1st to April 3rd, and a third from April 11th to April 14th, with results shown in figure 10.

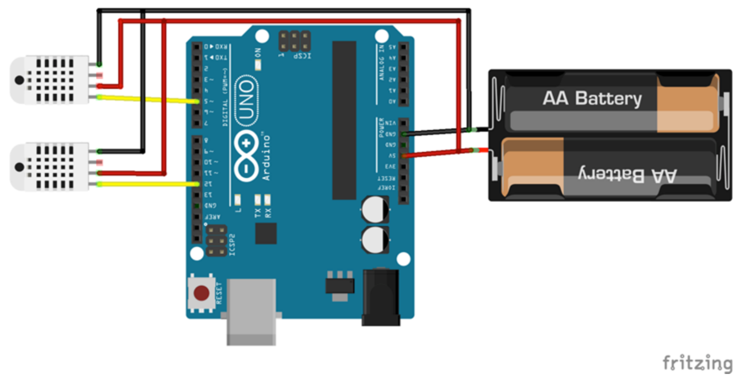
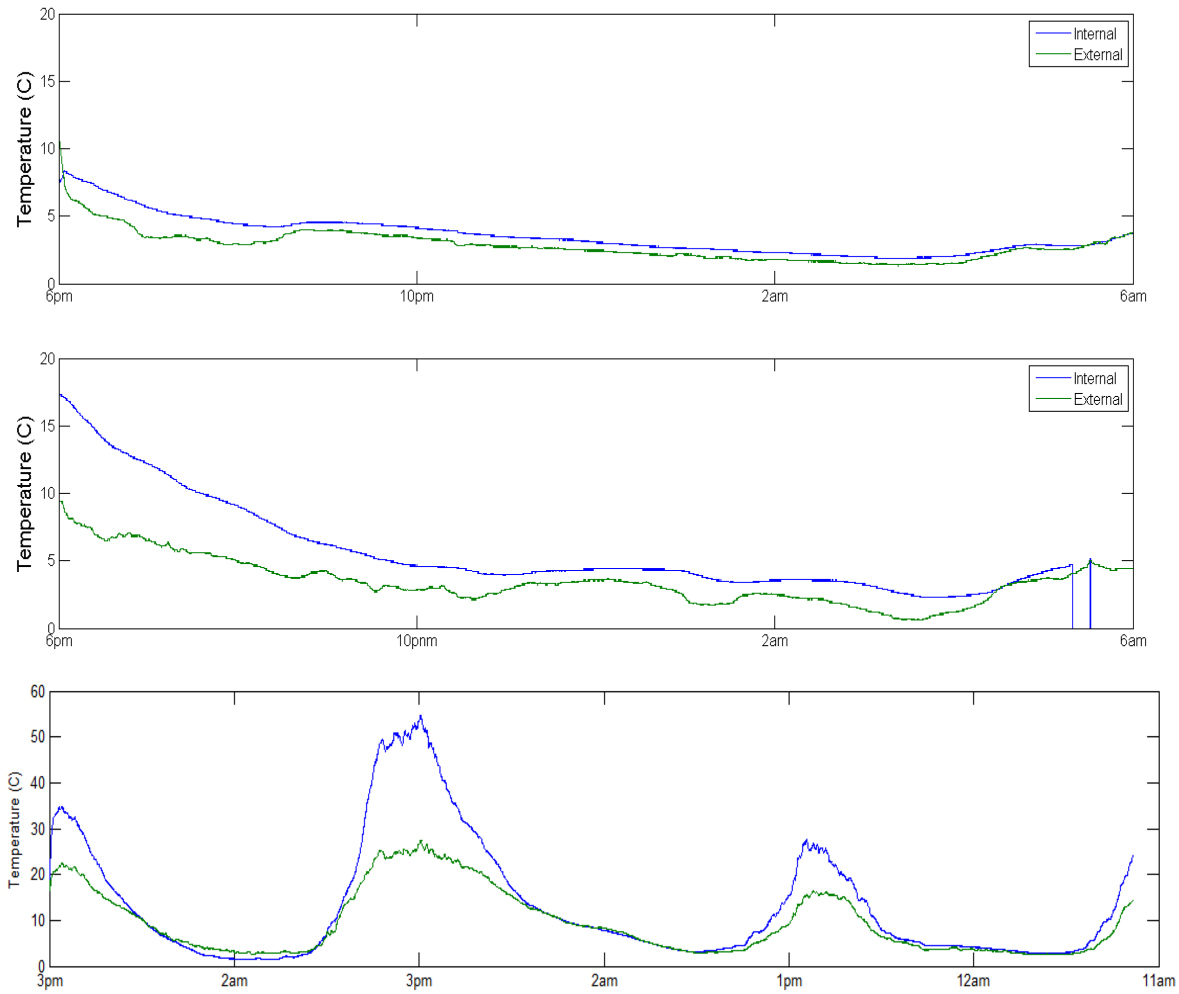


Figure 9: Temperature and humidity data logger

Figure 10: Temperature Tests. (a) Test 1, 6pm March 28th to 6am March 29th. (b) Test 2, 6pm April 1st to



6am April 2nd. (c) Test 3, 3pm April 11th to 11 am April 14th

The first test (fig. 10a) was the initial evaluation of the prototype and the timing was selected to gauge the effectiveness of the nursery in the worst possible conditions that could be present in the beginning of the season. Heavy rainfall lasted throughout Friday the 25th to Saturday the 26th, and a sudden blizzard took place on the morning of Sunday the 27th.

After the first test, revisions were made to the design to improve the heat retention of the system. Fixes included properly sealing gaps between the coldframe and the table with rubber, as well as adding thermal mass. The purpose of the second test (fig. 10b) was to evaluate design revisions taken after the first test. The weather of the second test was similar to that of the first test, however no snow-fall event occurred. A third and final test was conducted to demonstrate the coldframe during warmer weather (fig. 10c).

The results of the first two tests show that after proper insulation, the cold-frame was capable of maintaining an internal temperature 2-3°C greater than the external, even at the coldest part of the night. Additionally, the overall variability of temperature was significantly lower inside the cold-frame, which is another important factor during the early stages of plant growth. This amount of heat retention is more than sufficient for leafy greens and would allow increasing production by two additional harvests, one in spring and one late fall. Unfortunately, higher value crops such as tomatoes would likely be stressed at these temperatures. However, it is important to note that this year the weather during late March and early April was exceptionally colder than normal (Climat-Québec, 2014).

The relevance of the coldframe implementation is arguable. Results show that a relatively few heat was saved at night time, while the temperature inside the table drastically increased in sunny and warm weather to a level that would definitely be detrimental for crops. Even though with an optimal average temperature of about 10°C for early gardening season, there is no assurance that sudden heat fluctuation would not happen and lead as an example to chilling injury of plants. As mentioned previously, rubber tape was used to improve deficient insulation, which showed improvement in the overall heat retention in the second test. If the coldframes are to be implemented, they should only be of used during mild weather. Additionally, their construction price being relatively small compared to the whole project scope, coldframes should still be implemented and tested for further improvement over time.

Self-Watering Planters

An experiment and a simulation were conducted in order to predict the performance of the customized self-watering planter. The experiment consisted of testing the ability of the system to bring water from the reservoir to the upper layers of soil in the container; the simulation helped predicting whether or not the water flow would be sufficient for plants to growth. Two prototypes P1 and P2 were tested (fig. 7). Their main difference was in the mode in which the soil had access to the water from the bottom compartment.

Gravimetric moisture content experiment

The experiment consisted of filling the water reservoir of the two prototypes to full capacity. P1 had the water transferred by capillarity to the soil above the reservoir; P2 had a geotextile layer in direct contact with the water and the soil. In addition to the two prototypes, a control planter was set up in such a way that the water table was in direct contact with the soil. After monitoring the change of the water table every 24 hours for three days, two samples were taken from six different layers within each planter for a total of 36 samples. The layers were two inches in depth.

A visual analysis of the samples can be done by observing figure 11; it can be noted that the color of the soil gets darker as it is taken from the deeper layers. The samples had their water content determined by gravimetry with oven drying technique. Two extra samples were taken; one to determine the initial water content of the soil used and the second one was determine the water content of the soil within the geotextile container. Each sample had about 3 g of soil weighted on a balance (precision ±0.001 g) and placed on open aluminium containers (tare). The oven was set at 100-110^{o}C and after 18 hours the samples were weighted twice (with a one hour waiting time in between) to determine if the weight was constant.

The water content was computed using the following formula:

$$\theta_g = \frac{\big((weight\ of\ wet\ soil + tare) - (weight\ of\ dry\ soil + tare)\big)}{(weight\ of\ dry\ soil + tare) - (tare)}$$

(8)

$$where$$
$$\theta_g = gravimetric\ moisture\ content$$

The gravimetric moisture content was then converted to the volumetric moisture content by means of the following formula (Bilskie, 2001):

(9)

$$\theta_v = \frac{\theta_g \times \rho_{soil}}{\rho_{water}}$$

(9)

$$where$$
$$\theta_v = volumetric\ moisture\ content$$
$$\rho_{soil} = particle\ density\ of\ soil$$
$$\rho_{water} = density\ of\ water$$

The particle soil density was of 0.42 g/ cm^3 (Holycow).

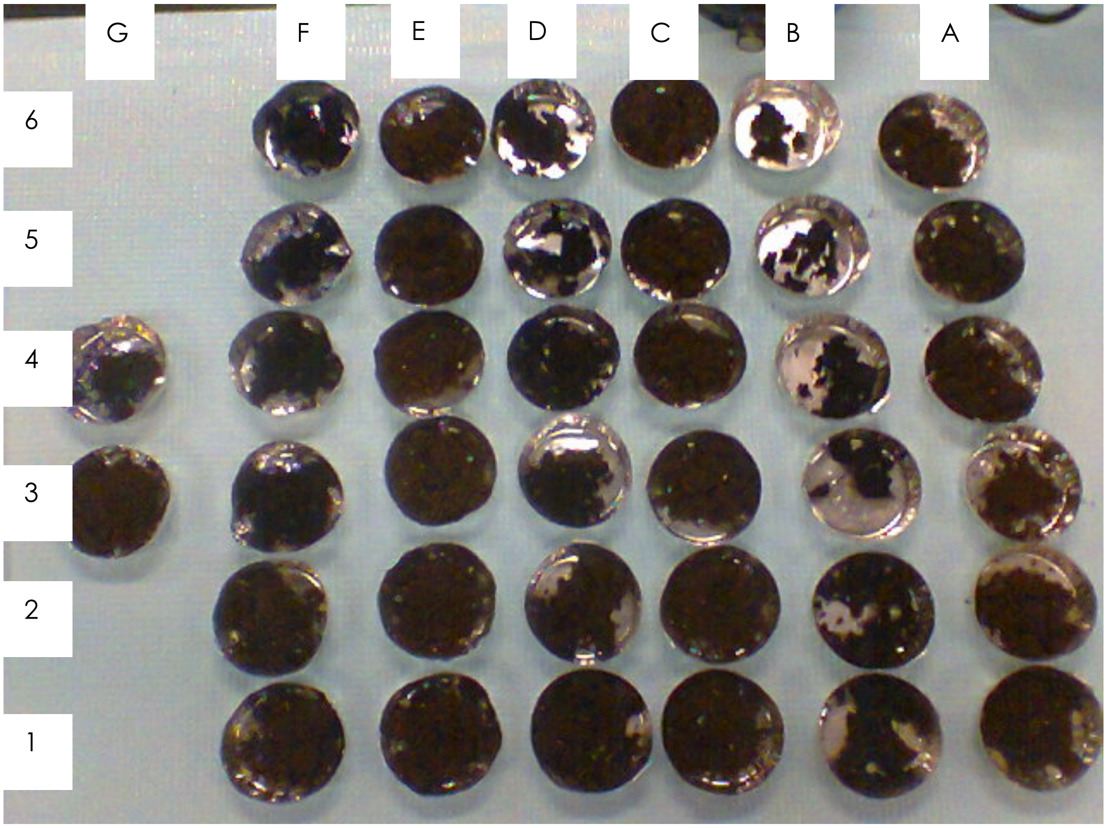


Figure 11: Soil samples before drying. Columns A and B had samples taken from the control container; columns C and D had the samples taken from P1, and columns E and F had the samples taken from P2. The samples were placed one replicate after the other (i.e. A1 and A2 are two replicates) with samples taken from deeper layers in the container going from row 1 to 6 and from column right to left (i.e., A1/A2 = layer 1 in-3 in; A3/A4= layer 3 in-5 in; A5/A6= layer 5 in-7 in; B1/B2=layer 7 in-9 in; B3/B4=layer 9 in-11 in, and B5/B6= layer 11 in-13 in all taken from the control container). Sample G3 represented the initial moisture content and sample G4 was taken from the soil within the geotextile container in P2.

UPFLOW simulation

Coupled with this experiment, the simulation UPFLOW developed by Raes (2002) was run to approximate the expected upward water movement from the water reservoir to the top soil. The software used a modified and adjusted version of Darcy's equation developed by DeLaat, 1980:

$$z = \int_0^h \frac{K(h)}{q + K(h)} dh \tag{10}$$

$where$
$z = Vertical\ coordinate\ (m)$
$q = Constrant\ upward\ movement\ of\ water\ (m^3\ m^{-2}\ day^{-1})$

$h = soil\ matrix\ potential\ (hydraulic\ head)(m)$
$K(h) = hydraulic\ conductivity\ as\ a\ function\ of\ hydraulic\ head\ (m\ day^{-1})$

DeLaat's equation describes the relationship between the elevation and the hydraulic head most commonly known as the pressure profile. From the soil water retention curve (i.e., the relation between soil water content, θ, and the hydraulic head, h), pressure profiles can be transformed into moisture profiles. The soil water retention curve was characterised by the Van Genuchten parameters developed in 1991. It used the equation:

$$\theta(h) = \theta_r + (\theta_s - \theta_r)\frac{1}{1 + [\alpha h^n]^m} \tag{11}$$

$where$
$\theta(h) = is\ the\ soil\ water\ content$
$\theta_r = residual\ water\ content$
$\theta_s = saturated\ water\ content$
$\alpha, n, m = empirical\ parameters$

UPFLOW estimated the value of m by assuming $m = 1 - 1/n$. In addition to the soil water retention curve, the soil saturated hydraulic conductivity (K_{sat}) was another physical soil property that needed to be input in the software. The parameters for Van Genuchten equation and the saturated hydraulic conductivity were taken from an experiment done on weakly decomposed sphagnum peat from Ireland and they are shown in table 2. This peat was chosen as its organic matter content was high (930 g kg^{-1}), which was similar to the one, used in the experiment (68% OM) (Cannavo et al., 2011; Holycow, n.a.).

θ_s	0.931
θ_r	0.263
α	17.965 kPa^{-1} (1.76 m^{-1})
n	2.060
K_{sat}	4.8 x 10^{-5} $m.s^{-1}$

Table 2: ***Van Genuchten parameters and saturated hydraulic conductivity for peat (Cannavo et al., 2011)***

Given the K-h and θ-h relation for the various soil layers of the profile above the water table, UPFLOW calculated for various fluxes the corresponding pressure and soil moisture profiles. Moisture profiles where the soil water content in the topsoil dropped below the specified mean water content were rejected. Finally, the software assumed steady state for the water balance of the soil which meant that the maximum upward flow of water was determined by the evapotranspiration of the soil surface. Evapotranspiration can be predicted based on the environmental conditions and the amount of water that plant roots can extract from a given soil volume per unit of time (S_{max}). Since hard environments characterize rooftops, it was assumed that evapotranspiration was at its maximum (4.7 mm day^{-1} for the default crop the values for an average crop). S_{max} was taken from the default crop, which was 3.5 mm day^{-1} at the surface, 1.0 mm day^{-1} at 0.17 m, and 0.2 mm day^{-1} at 0.33 m below the surface.

The simulation was also able to compute the volumetric moisture content of the given soil at field capacity, wilting point and anaerobiosis point. Field capacity is defined as the moisture content of the soil at a hydraulic head of -33kPa; wilting point is determine by the moisture content of soil at a hydraulic head of -1.5 MPa. Both points determine the ideal range of moisture in the soil for plants to grow. The anaerobiosis point determines the upper boundary where water content is too high and roots start dying from a lack of oxygen. It is a property of the crop planted; in the simulation, the default crop had an anaerobiosis point of 7 vol% below the saturated water content.

Results and optimization

The results from the gravimetric water content experiment are shown in figure 12. From the graph it can be deduced that both systems were able to transport water from the reservoir to the lower layer of soil. Moreover, the wick system had its moisture content very close to the control at the bottom of the soil container, which proved that the system was highly effective in transporting water from the reservoir.

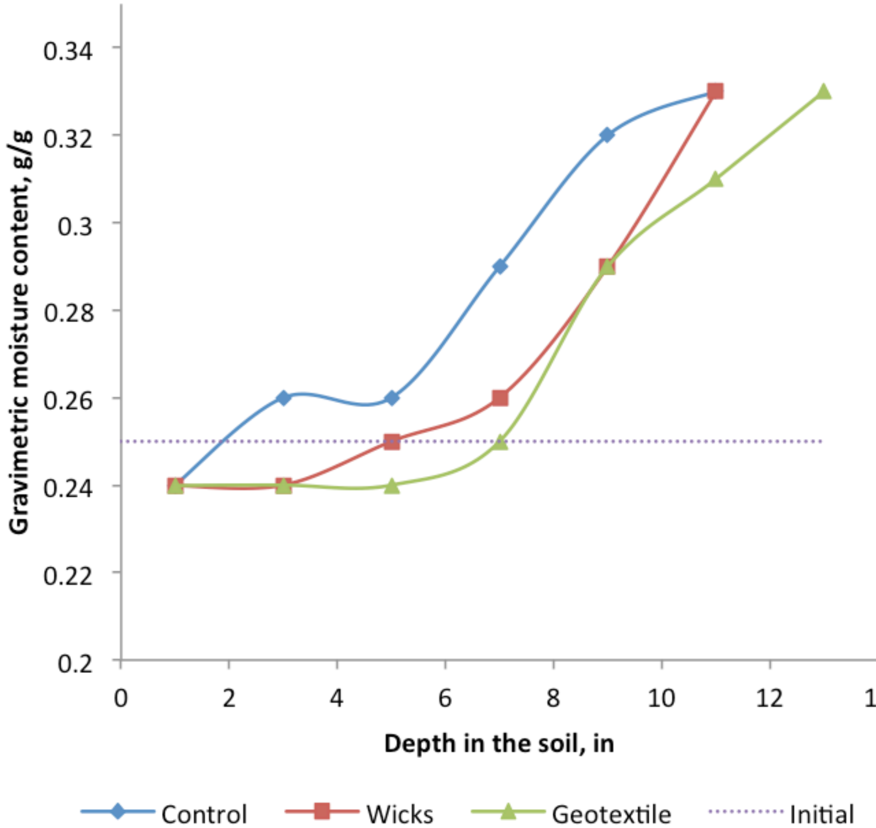


Figure 12: Results from graviometry water content experiment

The results from the simulation are shown in table 3. Note that the ideal range of volumetric water content in the soil is 28.4-33.9 vol%. By comparing it to figure 12, it is possible to estimate that P1 and P2 were able to reach that range at soil depth of 8-13 in. (20-33 cm). This shows that root development will be directly towards the bottom of the planter. In addition, there was no sludge created in such a way that oxygen depletion was rotting the roots (i.e., the anaerobiosis point of 86.1 vol% was not reached anywhere within the planters). Moreover, figure 13 showed that the plant leaving a capillary rise of zero at the soil surface takes all water. It can be concluded that there is no accumulation of water in the soil in such a way that stagnation and root rotting occurs; however, another experiment measuring the productivity of plants has to be performed in order to determine if irrigation by capillarity is sufficient.

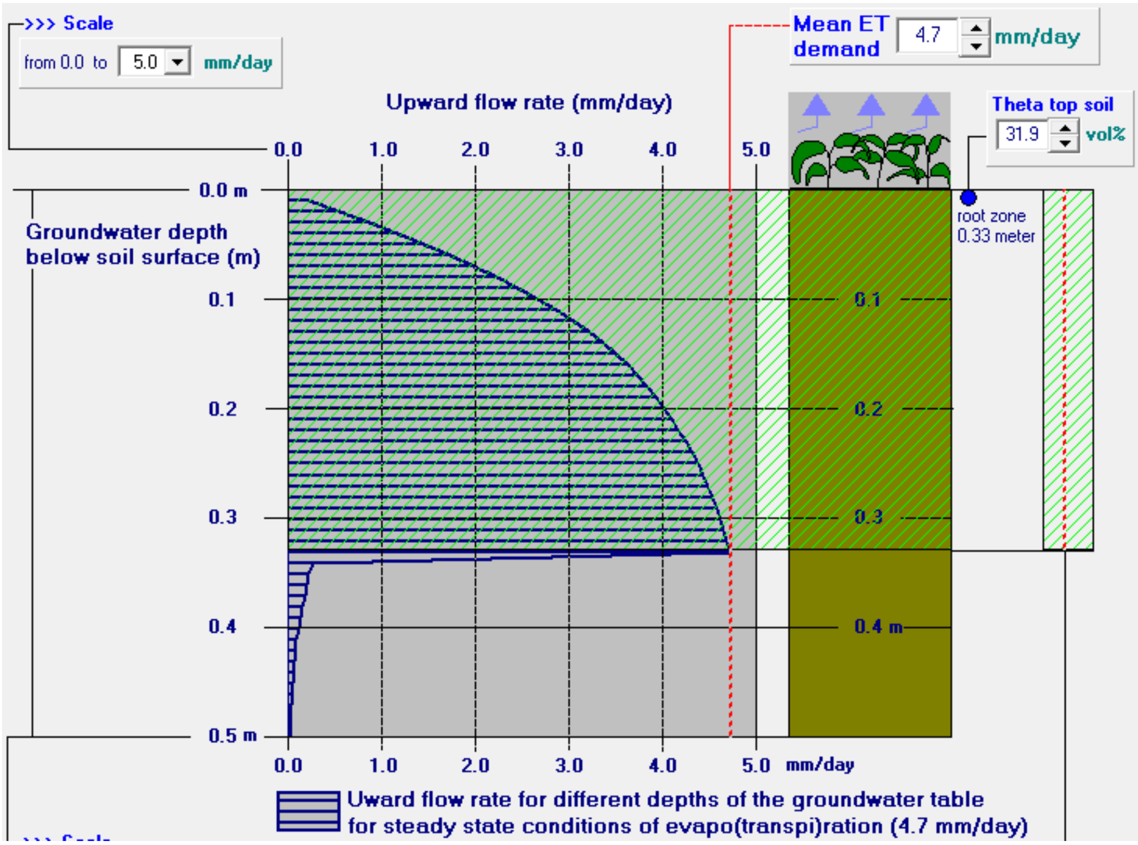


Figure 13: Upward flow rate for default plants using UPFLOW simulation. The estimated evapotranspiration demands was 4.7 mm.day-1.

	Volumetric water content (%)
Saturation point	93.1
Field Capacity	33.9
Wilting point	28.4
Anaerobiosis	86.1

Table 3: Result from the UPFLOW simulation

Comparison of existing planting systems with the proposed design

A list of criteria and constraint for this project were determined in the first phase of the project to compare the proposed self-watering planter with existing planting systems. Although the Bac Altenatives system is being used in community gardens managed by SOCENV and has shown good productivity over the past four years, it still has certain disadvantages. For instance, the water storage space is not well isolated from the soil which creates a sludge mixture at the bottom of the planter causing disease to spread and soil compaction. These two disadvantages decrease the ease of use of the Bac Alternatives (table 4) since soil has to be changed in case of a disease or soil compaction.

The Smart Pot is another planting system that has been widely used in urban agriculture in Montreal. The Smart Pot is UV resistant, can come in different shapes, and has a lifespan of 10-15 years. A pot with a growing area of 0.2 m^2 costs around 15$. The major disadvantage of Smart Pots is the high rate of evapotranspiration especially in sunny and windy environments such as the roofs. Since the system is surrounded by the aerated geotextile, the water evaporates from all the sides of the container. This defect increases the watering requirements and thus management time; hence, affecting its easiness to use and decreasing its resistance to the sun and wind. Another problem related to the Smart Pot is the fact that it cannot be washed in case of a disease; therefore, it has to be discarded increasing the produced waste.

Finally, customized self-watering planters can be used as a planting system. They can be optimized to reduce the water and soil contact at the reservoir level; hence, minimizing disease development and soil compaction. However, the time to build it and the availability of UV resistant materials may cause a problem in the implementation of such system. In fact, most of the information related to a customized self-watering planter is not available (productivity, material durability and sun and wind resistance).

Criteria and Constraints	Bac Alternatives	Smart Pot	Customized Self-watering planter
Ease of Use	-	-	+
Productivity	+	+	n/a
Waste Management	+	-	+
Educational value	0	0	+
Material durability	+	-	n/a
Aesthetics	+	+	-
Low Cost	-	+	++
Dead load	0	+	-
Sun and Wind resistance	+	-	n/a

Table 4: List of criteria and constraints related to the project MultiCaf's roof-top garden. Each criteria and constraint is used to compare three planting systems. A negative sign (-) means that the design alternative does not meet the specific criteria or constrain; a positive sign (+) means that the design meets the specific criteria or constrain zero (o) means the design is neutral for that specific constrain/criteria; finally, n/a means that there is not enough information

Cost Analysis

The cost for the entire project was estimated to be around 80,000$ (table 5), and a breakdown can be found in Appendix F.

Roof Modifications	$ 0
Steel and Wood Terrace	$ 36,000
Other Installations	$ 15,000
Garden Equipment	$ 8000
Subtotal	*$ 59500*
Contingencies (15%)	$ 8925
Professional Costs	$ 11,000
Total Costs (before tax)	**$ 79,425**

Table 5: Cost summary of rooftop garden project.
*** Modifications will be performed during roof renovations, paid for by the building's owner**

The garden, along with necessary tools and equipment, were estimated to be $80,000 for a 350-plant garden, using existing Bac Alternatives as passive growth systems. These planters are sold for $40 per box and can hold around two plants with larger roots. Disadvantages of these planters include the inability to easily wash the system of the mix of soil and water at the bottom of the box. However, the Bac Alternatives is a system that has been tested in similar situations and has been known to work well, so additional testing is required from the proposed self-watering planter to ensure similar plant productivity.

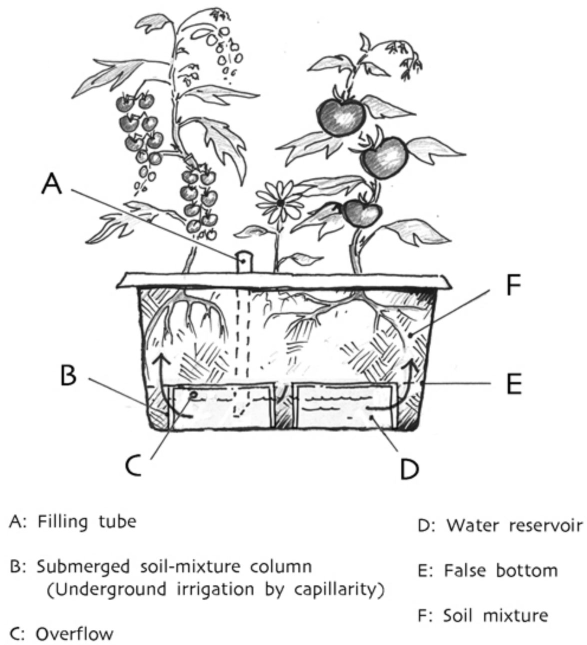


Figure 14: Bac Alternatives (The Rooftop Garden Project, 2009)

When comparing the proposed passive soil systems and the Bac Alternatives, the two systems that can be used for plants with larger root system, it can be seen that the Bac Alternatives is more expensive to purchase. The cost per plant for a hydroponics table (without coldframe attachment) decreases with increasing table size as the design can be scaled up with minimal additional cost, as can be seen in table 6. Bill of materials for both the hydroponic system, the passive soil planters, along with the coldframe can be found in appendix G.

GROWTH SYSTEM	Number of Plants	Cost	Cost per unit
Hydroponic	10	130	$13.00
Hydroponic	20	160	$8.00
Hydroponic	40	190	$4.75
Passive Soil Planter	1	12	$12.00
Bac Alternatives	2	40	$20.00

Table 6: Cost per unit plant for hydroponic systems of different sizes, passive soil planters, and Bac Alternatives

Direct comparison between the hydroponics system and passive soil system is not recommended due to the restriction of plants that can be grown successfully in a soilless medium. Furthermore, a soilless system also increases the risk of disease or contaminant transmission through the water as there is no soil to act as buffer for the plant. The lack of soil also makes the plants more vulnerable to sudden changes of temperatures which can cause stress and affect productivity.

Final Design Specifications

For the soil based growth systems the self-watering planter with wicks was selected (fig. 15). The planter can hold up to 5 gallons (18.9 L) of soil with a water reservoir capacity of 0.9 gallons (3.4 L).

For the final specifications of the hydroponics table, the full-scale table (32 in. x 64 in or 813 mm x 1626 mm) was selected (fig. 16). A 2000 LPH pump, electric timer, 140 Liter low-density polyethylene reservoir, and 0.75 in. drainage outlet will serve as the water supply system. When used with a second table in series (i.e. cascading tables), the same water supply system can be easily adapted by channeling the outlet of the higher table to the inlet of the lower table.

A coldframe attachment can be added onto the hydroponic table to allow for a second harvest of leafy greens, such as kale and lettuce, but is not recommended for the use of seed germination on a rooftop environment. Structural details of the roof can be viewed in appendix A.

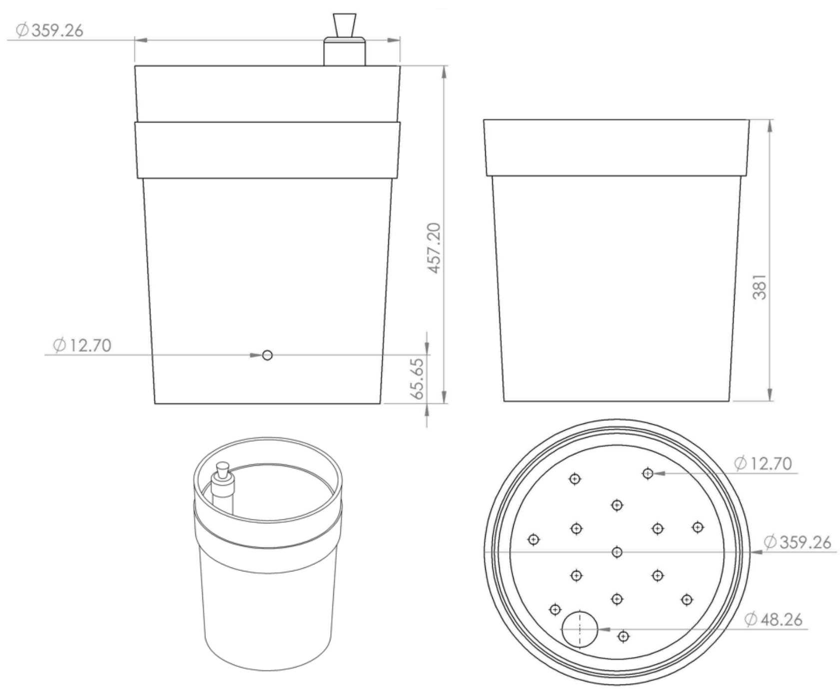


Figure 15: Self-watering planter design

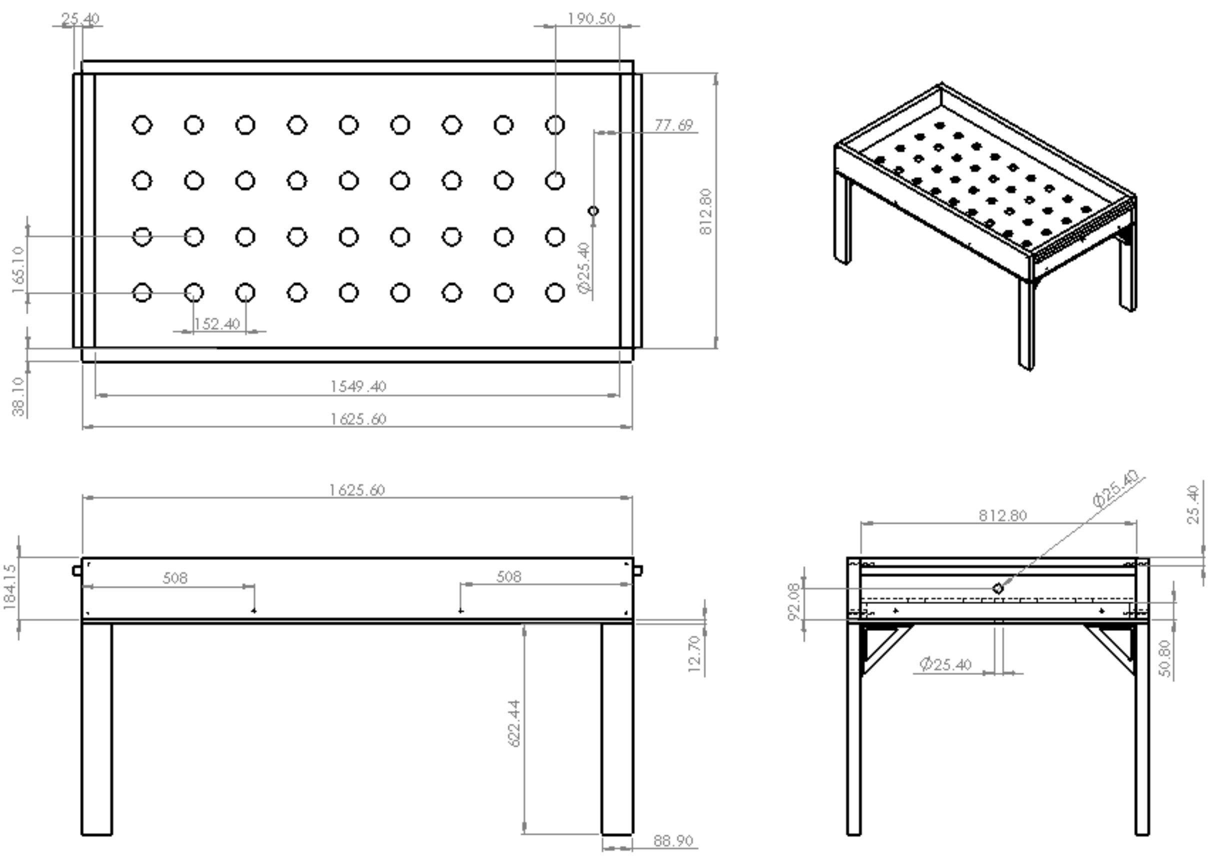


Figure 16: Full scale hydroponics table design

Other Considerations and Future Perspective

Risk Management

Coldframe

As the coldframes cannot insulate plants in a soilless medium effectively, only hardy leafy greens would be able to withstand the chilly spring days while flowering and fruiting plants would be vulnerable to dips in temperature. As such, the coldframe attachment is not recommended for seedling application in a rooftop situation due to the high risk of temperature variability. However, they are suitable for season extension of leafy green plants, allowing two additional harvests (in the spring and in the fall). If the coldframe is left closed during warm weather, overheating would most likely occur and damage/kill the plants.

Pump Operation

Despite the flooding cycles being fully automated with an electrical timer, there is still the chance of failure. Maintaining sufficient water level in the reservoir is extremely important to prevent burning the pump, as it is the most likely cause of pump failure. The ebb-and-flow watering cycle will naturally increase the resistance of the plants to sustained periods without water, but within only a few days the prolonged drought stress to the plants will result in losses. To aid identifying a failed pump, the flood cycles should be timed such that garden managers are present during their operation to check that water is flowing properly to the plants. Additionally, a low-cost float meter can be installed, consisting of a PVC pipe leading to the reservoir with a small floatation device (such as a foam block) connected to a metered stick protruding from the PVC pipe. Alternative electronic methods are also available, but are unnecessary if basic daily inspections of water level and pump functionality are performed.

Nutrient and Disease Management

To meet the nutrient requirements of the plants, the reservoir should be checked daily to ensure there is adequate volume of nutrient solution. If the solution is low (i.e. less than the volume required to fill the flood zone) then new solution should be prepared and can combined with the existing solution. For leafy greens, organic nutrient solution can be easily purchased on the island of Montreal and simply requires following the proper mixing ratio. If the plants begin to exhibit discoloration (e.g. yellowing or browning), this is indicative of excess nutrients and the solution within the system should be diluted. To achieve an exact nutrient balance, pH testing strips can be used. In the event of disease symptoms (e.g. rot, algae, mildew), the reservoir and lining should be cleaned, and then the system should be flushed with fresh water.

Planters

To ensure the plant nutrient requirements are met, watering instructions of the fertilizer being used should be followed. There are three main ways of fertilizing soil-based systems: water soluble fertilizer, liquid nutrient mix, and granular fertilizer. If the client prefers less management on the long run, a granular fertilizer can be mixed into the potting soil mix before the plants are transferred to the containers. This eliminates the need to fertilize for at least the first half of the season.

Security

No real testing has been done for the structural aspect of the design, but a structural engineer will validate the final proposal. There are safety concerns with volunteers working on the rooftop if they were not to stay on the deck structure and access sections of the roof that are not equipped with rail guards.

Achievability

Funding is also a crucial aspect of the project achievability. There is no guarantee at this step that funding will be granted. If, however, funds received are sufficient for the completion of the project, it is not assured that enough funds would be collected, since the total amount required can't be given by only one interested party, group or individual. So far, all stakeholders have kept interest in the project, with a small if none return of benefit. If the project takes too much time to see significant advancement, some members of the project team might lose interest and abandon the project. Additionally, volunteers will be needed for garden maintenance and to assure decent yield from plants. They will have to follow pre-established instructions and be under relative supervision.

Funding

In every project at a certain moment, whether it is at the very beginning or once launched, the funding question will have to be analyzed and solved. Since this project is an initiative led by a team of non-profit organisations and McGill Bioresource Engineering students, neither the government nor the university provided initial funding. Thus, members had to do research and approach various organisations for financial support. To do so, a methodical four step approach was carried out to select the organisations that would most likely be interested in sponsoring the project.

Step 1 - Preliminary listing

Identify all known organisations working in the field of environment and community improvement, local elected officials on the municipal, provincial and federal levels, financial establishments and special public/private funds for specific area of projects. Most of the potential sponsors were either found by looking at similar project reports or by visiting government environment and community websites listing other not-for-profit organisations specialized in funds distribution.

Step 2 - Preliminary skim

Once the potential sponsors were listed with their program description, admissibility criteria, open submission dates and deadlines, some of the programs and organisations were eliminated from the list since the project was either not fitting their admission criteria or were simply closed for admission. In this second case, these programs were kept in a separate list for eventual approach.

Step 3 - First contact

After a more credible list was established, team members contacted the selected groups to confirm the project eligibility and target key representatives within the organisation. Doing so would simplify further communication and assure that the funding request would directly go to the correct individual responsible for funds distribution.

Step 4 - Funding document

Even though contact has been made with the right people and organisations, no funds would be attributed without proper financial documentation. Therefore, our team working directly with MultiCaf, SOCENV, and Atelier Cropas + Klopp created a document for this purpose. This document is principally aimed at convincing sponsors to finance the project. To do so, it exposes the different aspects of the project, the level of expertise behind it, the already impressive support from various stakeholders and social impacts resulting in the implementation of an urban garden in Côte-Des-Neiges.

Conclusion

Being a community project, the roof-top garden has a quite large number of stakeholders involved in the design phase. SOCENV and MultiCaf are the two clients and they are in charge of approving the design in order to meet with the needs of the community; they also contribute to the achievability of the project by contacting other important stakeholders such as the owner of the building. In the future, they will be in charge of obtaining the sources of funding and permits from the city of Montreal in order to start the construction phase. Ateliers Cropas+Klopp and the McGill Bioresource students are in charge of the technical aspects of the design. The technical aspects included the design of the deck and the growing systems.

Since the rooftop will not be able to withstand the load of the garden, a modular deck was proposed. The modular system was chosen to allow easy access to the roof for repairs, inspection and maintenance. The two growing systems are an adapted version of an ebb and flow hydroponic table and a customized self-watering planter. The ebb and flow system can be used to grow leafy greens and it can be coupled to a coldframe to allow season extension. Table support, waterproofing and flow were tested to ensure the good functionality of the hydroponic table. The final design can be seen in figure 15. In order to minimize operation costs, a cascade arrangement was proposed to reduce pump requirements. Concerning the cold frame, multiple temperature and humidity tests were performed. The results show that the coldframe was able to keep the inside temperature warm enough to allow greens to be planted in the spring and potentially during the fall; however, to avoid temperature peaks, it is important to open the coldframe during sunny days. The self-watering planters can be used to grow plants with deep root systems such as tomatoes. Two alternate prototypes were tested in order to determine their ability to distribute the water through the soil. Prototype one with the wick system was found to be more effective (fig. 16). For future implementations, both growing systems have to be tested for their productivity. For the self-watering planters, this future test will also include the comparison of yield production with the planters that are available in the market (e.g. Bac Alternatives and Smart Pot).

Since the overall cost of the project is around $80,000 a funding plan has been implemented. The first steps of identifying and contacting potential sources have already been completed. The owner of the building has proposed to time repairs of the roof with the project's implementation as well as helping with minor costs such as moving mechanical units to give the space necessary to the garden. The TD Friends of the Environment Foundation has shown its interest in donating 10,000$. Moreover, a funding document is being finalised which includes a description and the objective of the project, the stakeholders involved, a clear budget, and letters of support from sponsors to ease the task of finding the amount of funding necessary for the project. The funding phase of the project should be done by Fall 2014 in order to start the building phase by the Spring 2015.

Acknowledgements

We would like to give a special thanks to SOCENV and MultiCaf for giving us the opportunity to be part of this inspiring project as well as Ateliers Cropas+Klopp for all their support. In addition, we would like to thank Dr. Grant Clark, Dr. Mark Lefsrud, Robert Williams, Dr. Shiv Prasher, Kathy Zarayan, and Mark Rogers for their mentoring and contribution to this project.

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Appendix A: Structural Specifications

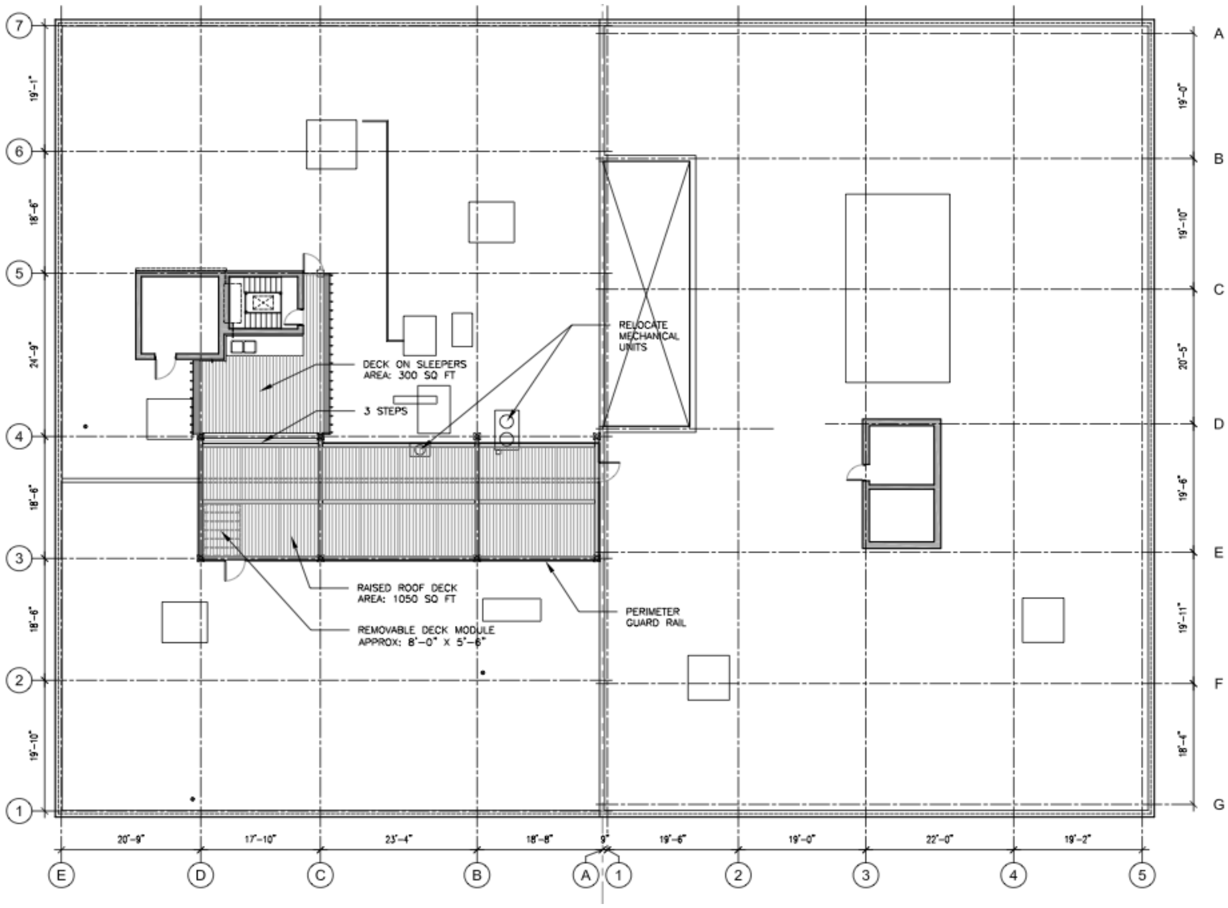

Figure A1: Architectural specification of rooftop garden

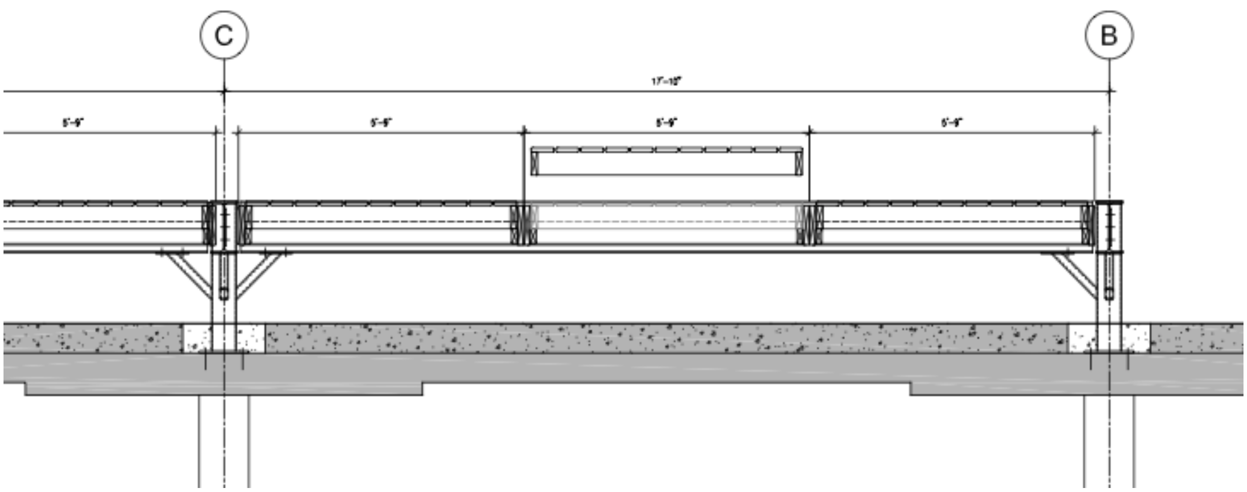

Figure A2: Typical deck module

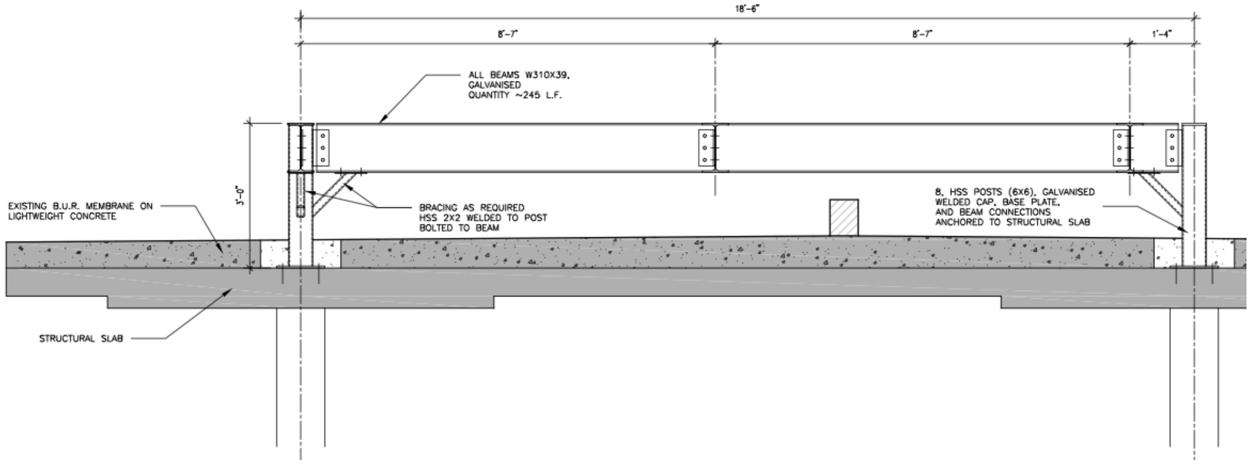

Figure A3: Deck attachment to roof

Appendix B: Angle of Glazing

The angle of the glazing has a direct effect on the amount of solar radiation transmitted into the coldframe.

Method

The Clear Sky Calculator was used to gather Solar radiation data in W/m^2 in increments of an hour. Solar elevation and azimuth data were similarly obtained. To determine the amount of solar radiation transmitted through the glazing, the angle of incidence of the direct beam irradiance was calculated.

$$\cos(\theta_{tilt}) = -\cos(\gamma_s)\sin(\gamma_t)\cos(\alpha_s - \alpha_t) + \sin(\gamma_s)\cos(\gamma_t)$$

$\theta_{tilt}: angle\ between\ the\ incident\ beam\ and\ the\ normal\ vector\ perpendicular\ to\ the\ surface$

$\gamma_s: solar\ height\ angle$

$\gamma_t: glazing\ angle\ with\ the\ horizontal$

$\alpha_s: solar\ azimuth\ angle\ cw\ from\ North$

$\alpha_t: glazing\ deviation\ from\ south$ (Quaschning, 2005)

Angle of incidence	Normalized Transmittance
<40	1
[40,50[	0.98
[50,60[	0.95
[60,70[	0.80
[70,80[	0.65
[80,90[	0.25
90	0

Table B1 - Solar Transmittance of typical 3mm glass with 92% transmittance (Adapted from Fig.5, Furler, 1991)

* Note: The intervals and their corresponding values were read from a continuous curve

The direct radiation intercepted by a tilted surface is related to the direct irradiation on a horizontal surface as follows.

$$E_{dir,tilt} = E_{dir,hor} * \frac{\cos(\theta_{tilt})}{\sin(\gamma_s)}$$ (Quaschning, 2005)

$E_{dir,tilt} = direct\ irradiation\ on\ a\ tilted\ surface\ (W/m^2)$

$E_{dir,tilt} = direct\ irradiation\ on\ horizontal\ surface\ surface\ (W/m^2)$

$\theta_{tilt}: angle\ between\ the\ incident\ beam\ and\ the\ normal\ vector\ perpendicular\ to\ the\ surface$

$\gamma_s: solar\ height\ angle$

As diffused radiation is very variable, it was assumed to be 10% of the total radiation.

$$E_{diff,tilt} = E_{diff,hor} * \frac{1}{2} * (1 + cos\gamma_t)$$

$E_{diff,tilt} = Diffused\ irradiance\ on\ a\ tilted\ surface$

$E_{diff,hor} = Diffused\ irraciance\ on\ a\ horizontal\ surface$

$\gamma_t = surface\ tilt\ angle$ (Quaschning, 2005)

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Appendix C: Solar Transmission on April 21, 2013

NOAA Solar Calculations - Change any of the highlighted cells to get solar position data for that location and date.

Latitude (+ to N)	45.5
Longitude (+ to E)	-73.64
Time Zone (+ to E)	-4
Date	4/21/2013

Date	Time (past local midnight)	Julian Day	Julian Century	Geom Mean Long Sun (deg)	Geom Mean Anom Sun (deg)	Eccent Earth Orbit	Sun Eq of Ctr	Sun True Long (deg)	Sun True Anom (deg)	Sun Rad Vector (AUs)	Sun App Long (deg)
4/21/2013	1:00:00	2456403.71	0.13302418	29.439508	5146.2734	0.016703	1.8263399	31.265848	5148.0997	1.0049368	31.263696
4/21/2013	2:00:00	2456403.75	0.13302533	29.480577	5146.3145	0.016703	1.8259314	31.306508	5148.1404	1.0049482	31.304356
4/21/2013	3:00:00	2456403.79	0.13302647	29.521645	5146.3555	0.016703	1.8255219	31.347167	5148.1811	1.0049596	31.345015
4/21/2013	4:00:00	2456403.83	0.13302761	29.562714	5146.3966	0.016703	1.8251115	31.387825	5148.2217	1.0049709	31.385673
4/21/2013	5:00:00	2456403.88	0.13302875	29.603782	5146.4377	0.016703	1.8247002	31.428483	5148.2624	1.0049823	31.426331
4/21/2013	6:00:00	2456403.92	0.13302989	29.644851	5146.4787	0.016703	1.8242879	31.469139	5148.303	1.0049937	31.466987
4/21/2013	7:00:00	2456403.96	0.13303103	29.68592	5146.5198	0.016703	1.8238748	31.509795	5148.3437	1.0050051	31.507642
4/21/2013	8:00:00	2456404.00	0.13303217	29.726988	5146.5609	0.016703	1.8234607	31.550449	5148.3843	1.0050164	31.548297
4/21/2013	9:00:00	2456404.04	0.13303331	29.768057	5146.6019	0.016703	1.8230457	31.591103	5148.425	1.0050278	31.58895
4/21/2013	10:00:00	2456404.08	0.13303445	29.809126	5146.643	0.016703	1.8226298	31.631755	5148.4656	1.0050391	31.629603
4/21/2013	11:00:00	2456404.13	0.13303559	29.850194	5146.6841	0.016703	1.822213	31.672407	5148.5063	1.0050505	31.670254
4/21/2013	12:00:00	2456404.17	0.13303673	29.891263	5146.7251	0.016703	1.8217952	31.713058	5148.5469	1.0050618	31.710905
4/21/2013	13:00:00	2456404.21	0.13303787	29.932332	5146.7662	0.016703	1.8213765	31.753708	5148.5876	1.0050732	31.751555
4/21/2013	14:00:00	2456404.25	0.13303901	29.9734	5146.8073	0.016703	1.8209569	31.794357	5148.6282	1.0050845	31.792204
4/21/2013	15:00:00	2456404.29	0.13304016	30.014469	5146.8483	0.016703	1.8205364	31.835005	5148.6689	1.0050959	31.832852
4/21/2013	16:00:00	2456404.33	0.13304130	30.055538	5146.8894	0.016703	1.820115	31.875653	5148.7095	1.0051072	31.873499
4/21/2013	17:00:00	2456404.38	0.13304244	30.096606	5146.9305	0.016703	1.8196927	31.916299	5148.7502	1.0051186	31.914145
4/21/2013	18:00:00	2456404.42	0.13304358	30.137675	5146.9715	0.016703	1.8192694	31.956944	5148.7908	1.0051299	31.954791
4/21/2013	19:00:00	2456404.46	0.13304472	30.178743	5147.0126	0.016703	1.8188452	31.997589	5148.8315	1.0051412	31.995435
4/21/2013	20:00:00	2456404.50	0.13304586	30.219812	5147.0537	0.016703	1.8184202	32.038232	5148.8721	1.0051526	32.036078
4/21/2013	21:00:00	2456404.54	0.13304700	30.260881	5147.0947	0.016703	1.8179941	32.078875	5148.9127	1.0051639	32.076721
4/21/2013	22:00:00	2456404.58	0.13304814	30.301949	5147.1358	0.016703	1.8175672	32.119517	5148.9534	1.0051752	32.117362
4/21/2013	23:00:00	2456404.63	0.13304928	30.343018	5147.1769	0.016703	1.8171394	32.160157	5148.994	1.0051865	32.158003
4/21/2013	0:00:00	2456404.67	0.13305042	30.384087	5147.2179	0.016703	1.8167106	32.200797	5149.0347	1.0051979	32.198643

Mean Obliq Ecliptic (deg)	Obliq Corr (deg)	Sun Rt Ascen (deg)	Sun Declin (deg)	var y	Eq of Time (minutes)	HA Sunrise (deg)	Solar Noon (LST)	Sunrise Time (LST)	Sunset Time (LST)	Sunlight Duration (minutes)	True Solar Time (min)
23.437561	23.43584	29.120275	11.911979	0.0430215	1.27353479	103.64256	12:53:17	5:58:43	19:47:51	829.140441	6.7135348
23.437561	23.43584	29.159243	11.926103	0.0430215	1.28190696	103.65807	12:53:17	5:58:39	19:47:55	829.264562	66.721907
23.437561	23.43584	29.198214	11.940222	0.0430215	1.29026647	103.67358	12:53:16	5:58:35	19:47:58	829.388654	126.73027
23.437561	23.43584	29.237189	11.954335	0.0430215	1.29861333	103.68909	12:53:16	5:58:30	19:48:01	829.512719	186.73861
23.437561	23.43584	29.276166	11.968443	0.0430215	1.3069475	103.70459	12:53:15	5:58:26	19:48:04	829.636755	246.74695
23.437561	23.43584	29.315147	11.982545	0.0430215	1.31526899	103.7201	12:53:15	5:58:22	19:48:08	829.760762	306.75527
23.437561	23.43584	29.354131	11.996641	0.0430215	1.32357777	103.73559	12:53:14	5:58:18	19:48:11	829.884742	366.76358
23.437561	23.435839	29.393118	12.010731	0.0430215	1.33187382	103.75109	12:53:14	5:58:13	19:48:14	830.008693	426.77187
23.437561	23.435839	29.432108	12.024816	0.0430215	1.34015715	103.76658	12:53:13	5:58:09	19:48:17	830.132615	486.78016
23.437561	23.435839	29.471101	12.038895	0.0430215	1.34842771	103.78206	12:53:13	5:58:05	19:48:20	830.256509	546.78843
23.437561	23.435839	29.510098	12.052968	0.0430215	1.35668552	103.79755	12:53:12	5:58:01	19:48:24	830.380374	606.79669
23.437561	23.435839	29.549098	12.067036	0.0430215	1.36493054	103.81303	12:53:12	5:57:57	19:48:27	830.50421	666.80493
23.437561	23.435839	29.588101	12.081097	0.0430215	1.37316276	103.8285	12:53:11	5:57:52	19:48:30	830.628018	726.81316
23.437561	23.435839	29.627107	12.095153	0.0430215	1.38138218	103.84397	12:53:11	5:57:48	19:48:33	830.751796	786.82138
23.437561	23.435839	29.666117	12.109204	0.0430215	1.38958877	103.85944	12:53:10	5:57:44	19:48:36	830.875546	846.82959
23.437561	23.435839	29.705129	12.123248	0.0430215	1.39778252	103.87491	12:53:10	5:57:40	19:48:40	830.999267	906.83778
23.437561	23.435839	29.744145	12.137287	0.0430215	1.40596341	103.89037	12:53:09	5:57:36	19:48:43	831.122959	966.84596
23.437561	23.435839	29.783164	12.15132	0.0430215	1.41413143	103.90583	12:53:09	5:57:31	19:48:46	831.246622	1026.8541
23.437561	23.435839	29.822187	12.165347	0.0430215	1.42228657	103.92128	12:53:08	5:57:27	19:48:49	831.370256	1086.8623
23.437561	23.435838	29.861212	12.179368	0.0430215	1.43042881	103.93673	12:53:08	5:57:23	19:48:53	831.493861	1146.8704
23.437561	23.435838	29.900241	12.193384	0.0430215	1.43855814	103.95218	12:53:07	5:57:19	19:48:56	831.617436	1206.8786
23.437561	23.435838	29.939273	12.207393	0.0430215	1.44667453	103.96762	12:53:07	5:57:15	19:48:59	831.740983	1266.8867
23.437561	23.435838	29.978309	12.221397	0.0430215	1.45477799	103.98306	12:53:06	5:57:10	19:49:02	831.8645	1326.8948
23.437561	23.435838	30.017348	12.235396	0.0430215	1.46286848	103.9985	12:53:06	5:57:06	19:49:05	831.987987	1386.9029

Hour Angle (deg)	Solar Zenith Angle (deg)	Solar Elevation Angle (deg)	Approx Atmospheric Refraction (deg)	Solar Elevation corrected for atm refraction (deg)	Solar Azimuth Angle (deg cw from N)	Solar irradiance W/m2	angle of incidence	Solar Transmittance	Solar irradiance transmitted on inclined surface J per day
-178.3216	122.56802	-32.56802	0.0090334	-32.55898	1.9487594	0	124	0	0
-163.3195	120.6325	-30.6325	0.0097439	-30.62275	19.049469	0	122	0	0
-148.3174	115.84789	-25.84789	0.0119104	-25.83598	34.818058	0	117	0	0
-133.3153	108.82436	-18.82436	0.0169257	-18.80744	48.766923	0	109	0	0
-118.3133	100.21255	-10.21255	0.0320281	-10.18052	61.056153	0	101	0	0
-103.3112	90.560379	-0.560379	0.572272	0.0118931	72.171229	0	91	0	0
-88.30911	80.300399	9.6996006	0.0906903	9.7902909	82.708652	61	80	0.9016	5923256.227
-73.30703	69.796983	20.203017	0.0434704	20.246488	93.33138	179	70	0.9016	17658128.97
-58.30496	59.417992	30.582008	0.0272151	30.609223	104.83991	310	59	0.9016	30727757.34
-43.30289	49.63711	40.36289	0.0189564	40.381847	118.31841	434	49	0.9016	43111817.86
-28.30083	41.195791	48.804209	0.0141134	48.818322	135.25475	539	40	0.9016	53600928.03
-13.29877	35.298708	54.701292	0.0114195	54.712712	157.08978	616	34	0.92	62541265.96
1.7032907	33.450394	56.549606	0.0106564	56.560263	183.02259	659	32	0.92	66915708.78
16.705346	36.305004	53.694996	0.0118497	53.706846	208.34056	665	35	0.92	67509720.47
31.707397	42.891104	47.108896	0.0149769	47.123873	229.02905	633	42	0.874	61008515.16
46.709446	51.706699	38.293301	0.0204009	38.313702	245.05844	565	51	0.874	54384123.36
61.711491	61.659641	28.340359	0.0297992	28.370158	257.99333	467	61	0.736	37756437.29
76.713533	72.084805	17.915195	0.049353	17.964548	269.23469	347	72	0.598	22658233.53
91.715572	82.542351	7.4576486	0.1152437	7.5728923	279.78881	217	83	0.23	5322438.125
106.71761	92.671261	-2.671261	0.1236708	-2.54759	290.41417	92	93	0	0
121.71964	102.09609	-12.09609	0.0269236	-12.06916	301.75349	4	103	0	0
136.72167	110.36068	-20.36068	0.0155477	-20.34513	314.38175	0	111	0	0
151.72369	116.89102	-26.89102	0.0113777	-26.87964	328.72666	0	118	0	0
166.72572	121.03279	-31.03279	0.0095905	-31.0232	344.81839	0	122	0	0
							Total transmittance per day		529118331

Appendix D: Code for Temperature and Humidity Sensor

```
/* --- Libraries --- */
#include "stdio.h"
#include <DHT.h>
#include <SD.h>
/* --- Pins --- */
#define SD_PIN 10
#define DHT_INTERNAL_PIN A0
#define DHT_EXTERNAL_PIN A1
/* --- Values --- */
#define DHT_TYPE DHT22
#define BAUD 9600
#define CHARS 8
#define BUFFER 128
#define DIGITS 4
#define PRECISION 2
#define INTERVAL 1000
#define TIMEOUT 1
/* --- Functions --- */
float get_int_temp(void);
float get_int_humidity(void);
float get_ext_temp(void);
float get_ext_humidity(void);
/* --- Objects --- */
DHT INT_DHT(DHT_INTERNAL_PIN, DHT_TYPE);
DHT EXT_DHT(DHT_EXTERNAL_PIN, DHT_TYPE);
/* --- Strings --- */
char INT_T[CHARS];
char INT_H[CHARS];
char EXT_T[CHARS];
char EXT_H[CHARS];
/* --- Line Buffers --- */
char CSV[BUFFER];
/* --- State --- */
int TIME = 0; // seconds on
/* --- Setup --- */
void setup() {
 Serial.begin(BAUD);
 Serial.setTimeout(TIMEOUT);
 pinMode(SD_PIN, OUTPUT);
 if (!SD.begin(SD_PIN)) {
   return;
 }
 INT_DHT.begin();
 EXT_DHT.begin();
}
/* --- Loop --- */
void loop() {
 TIME++;
 dtostrf(get_ext_temp(), DIGITS, PRECISION, EXT_T);
 dtostrf(get_ext_humidity(), DIGITS, PRECISION, EXT_H);
 dtostrf(get_int_temp(), DIGITS, PRECISION, INT_T);
 dtostrf(get_int_humidity(), DIGITS, PRECISION, INT_H);
 sprintf(CSV, "%d,%s,%s,%s,%s",TIME, INT_T, EXT_T, INT_H, EXT_H);
 Serial.println(CSV);
 File datafile = SD.open("datalog.txt", FILE_WRITE);
 if (datafile) {
```

```
  datafile.println(CSV);
  datafile.close();
 }
 delay(INTERVAL);
}
/* --- Sensor Functions --- */
// Internal Humidity
float get_int_humidity() {
 float val = INT_DHT.readHumidity();
 if (isnan(val)) {
  return 0;
 }
 else {
  return val;
 }
}
// Internal Temperature
float get_int_temp() {
 float val = INT_DHT.readTemperature();
 if (isnan(val)) {
  return 0;
 }
 else {
  return val;
 }
}
// Get External Humidity
float get_ext_humidity() {
 float val = EXT_DHT.readHumidity();
 if (isnan(val)) {
  return 0;
 }
 else {
  return val;
 }
}
// Get External Temperature
float get_ext_temp() {
 float val = EXT_DHT.readTemperature();
 if (isnan(val)) {
  return 0;
 }
 else {
  return val;
 }
```

Appendix E: Preliminary Heat Transfer Model

```
%% Presentation
% Heat transfer model for cold frame in urban roof garden

%% Codes
clc
clear

default = 368.14;
q_in = input('Enter radiation power intake (W): '); % Daily intake of energy
(1.98797 x 10^7 J)

%% Dimensions
h = 1.8288; % 72 inches
w = 0.766;  % 30 inches
l = 0.3048; % 12 inches

%% Finding r
side1 = h*w;
side2 = h*l;
side3 = w*l;

area = 2*side1 + 2*side2 + 2*side3;
radius = (-h + sqrt(h^2 + 4*1*(area/(2*pi))))/2;

%% Conditions
D = (2*radius);
k = 0.0250; % W/m k
h_over_D = h/D;
Ts = 20;
Ti = 10;

Re = 2*D/(14.205*10^(-6));
Nu = 0.123*Re^(0.651) + (0.00416)*(D/h)^(0.85)*(Re^(0.792));

disp('Restrictions: h/D < 4 and 7*10^4 < Re < 2.2*10^5')
fprintf('Values dor h/D and Re are respectively %4.2f and %4.2f', h_over_D,
Re)
disp(' ')

hc = Nu*k/D;
q = hc*area*(Ts - Ti);
Q = q_in - q;

fprintf('The heat transfer loss is %4.2f W for a constant forced convection',
q);
disp(' ')
disp('of 2m/s air flow having a temperature of 10 Celcius degrees')

if q_in < q
    fprintf('The cold frame has a loss of %4.2f W', Q)
elseif q_in > q
    fprintf('The cold frame gains %4.2f W', Q)
end

     disp(' ')
```

Appendix F: Total Cost Estimate

ROOF MODIFICATIONS		
Roof Repairs		
Relocation of rooftop units		
Replacement of doors		
Plumbing modifications with stop valve addition		
Installation of two outlets exposed to rooftop		
SUBTOTAL	**$**	**-**
STEEL STRUCTURE		
Local demolition, materials, shipping, installation	$	20,000
Professional service to locate columns	$	1,000
SUBTOTAL	**$**	**21,000**
WOODEN TERRACE		
Floating terrace (Prefabrication of modules)	$	5,750
Installation of terrace on roof	$	2,250
Carpenters	$	6,000
Crane (Also used for steel structure)	$	1,000
SUBTOTAL	**$**	**15,000**
OTHER INSTALLATIONS		
Safety Railings (incl. installation)	$	12,000
Windbreaks	$	800
Sink and storage unit	$	1,500
Water collection system for roof of shed	$	800
Picnic table	$	400
SUBTOTAL	**$**	**15,500**
GARDEN EQUIPMENT		
Growth Systems	$	6,750
Fertilizer	$	300
Water reservoirs	$	320
Tools	$	630
SUBTOTAL	**$**	**8,000**
COST ESTIMATE OF CONSTRUCTION (Before Taxes)	**$**	**59,500**
CONTINGENCIES (15%)	$	8,925
OTHER PROFESSIONAL SERVICES	$	11,000
TOTAL COSTS	***$***	***79,425***

Appendix G: Bill of Materials

PASSIVE SOIL SYSTEM

ITEM	AMT	COST PER UNIT	TOTAL COST
Bucket (5-gallon)	2	$3.97	$7.94
1.5in PVC pipe (19" long)	1	$0.78	$0.78
1/4" Wood dowel (17.5" long)	1	$0.39	$0.39
Cork stopper	1	$1.11	$1.11
PVC Cap	1	$1.56	$1.56
TOTAL COST			*$11.78*

HYDROPONICS TABLE

ITEM	AMT	COST PER UNIT	TOTAL COST
2" x 8" x 8' Plank	2	$5.20	$10.40
1" x 2" x 8' Furring Bar	2	$0.96	$1.92
5/16"-18 x 4" Carriage Bolt	8	$2.80	$22.40
5/16"-18 Hex Nut	8	$0.10	$0.79
5/16" Washer	8	$0.11	$0.86
8' x 10' Tarpaulin	1	$10.97	$10.97
8' x 4' x 7/16" Plywood	1	$7.35	$7.35
37.9L Rubbermaid Tote	1	$7.49	$7.49
1/2" Pump	1	$40.00	$40.00
1/2" x 3/8" Pex Compression, Straight, Ball Valve	1	$4.28	$4.28
1/2" Hosing (4')	4	$0.48	$1.94
Swivel Castors	4	$2.49	$9.96
2" Net Pots	18	$0.25	$4.50
2" Flat Bracket	4	$2.00	$8.00
24" x 36" Twinwall Sheet	1	$8.36	$8.36
TOTAL COST			*$129.25*

COLDFRAME ATTACHMENT

ITEM	AMT	COST PER UNIT	TOTAL COST
Lexan sheet 36" x18"	1	$22.64	$22.64
2" x 4" x 10" Cedar Lumber	2	$12.35	$24.70
Pack of 2x 3" hinges	1	$6.09	$6.09
Wooden deck screws 2"	24	$0.06	$1.49
1 " finishing nails	20	¢0.43	$0.09
TOTAL COST			*$54.22*

Appendix H: Potential list of sponsors (French)

Liste personnes à joindre pour financement
1. Russel Copeman – Maire de l'arrondissement de Côte-Des-Neiges
Faire parvenir document par courriel : russell.copeman@ville.montreal.qc.ca
Adresse de bureau : 5160, boul. Décarie, bureau 710, Montréal (Québec), H3X 2H9

2. Isabelle Morin – Député Fédéral arrondissement Côte-des-Neige/Lachine
Faire parvenir document par courriel : Isabelle.morin@parl.gc.ca
Adresse du bureau : 735, rue Notre-Dame, Bureau 104, Lachine (Québec), H8S 2B5

3. Pierre Arcand – Député Provincial arrondissement Mont-Royal
Faire parvenir document par courriel et/ou papier: ccomeau@assnat.qc.ca
Adresse du bureau : 5005 rue Jean-Talon Ouest, poste 326, Montréal, H4T 1W7
Note : Document envoyé à Christine Comeau, attachée politique

4. Denis Coderre – Maire de Ville de Montréal
Faire parvenir document par courriel et/ou papier : maire@ville.montreal.qc.ca
Adresse du bureau : 275 Notre-Dame Est, Bureau du Greffe – 1.134, Montréal, H2Y 1C6
Note : Envoyer à l'intention du maire M. Denis Coderre

Liste des organismes à joindre pour financement
1. Mouvement des Caisses Desjardins
Faire parvenir document par courriel : michele.f.garneau@desjardins.com
Adresse du bureau : 100 avenue des Commandeurs, Lévis (Québec), G6V 7N5
Note : Document envoyé à Michèle Garneau, Direction Relations publiques, Commandites et dons, Mouvement des caisses Desjardins du Québec.

2. Fonds d'action québécois pour le développement durable (FAQDD)
Faire parvenir document par courriel : infos@faqdd.qc.ca
Adresse du bureau : 840 rue Raoul-Jobin, bureau 200, Québec (Québec) G1K 6T3
Note : Suggère d'envoyer la version électronique étant donné qu'aucun contact n'a été fait précédemment.

3. Jour de la Terre
Faire parvenir document par courriel et/ou papier : info@jourdelaterre.org
Adresse du bureau : 460 Ste-Catherine Ouest, bureau 504, Montréal, H3B 1A7
Note : Une soumission officielle devra être faite via le site web www.jourdelaterre.org entre les mois de Décembre 2014 et Janvier 2015.

4. Fondation du Grand Montréal
Faire parvenir document par courriel et/ou papier : diane.bertrand@fgmtl.org
Adresse du bureau : 1 Place Ville-Marie, Bureau 1918, Montréal (Québec), H3B 2C3
Note : Document doit absolument être présenté par Multicaf à Mme. Diane Bertrand, Directrice du Programme des Subventions.

5. Soutient Action Bénévole
Faire parvenir document par courriel : sacais@mess.gouv.qc.ca
Adresse du bureau : 425, rue Saint-Amable, 1er étage, Québec (Québec) G1R 4Z1
Note : Date limite pour application le 14 Mars 2014.

6. Centre Local de Développement Côte-Des-Neiges
Faire parvenir document par courriel et/ou papier : helene.bordeleau@cdeccdnndg.org
Adresse du bureau : 155, boulevard Charest Est, bureau 160, Québec (Québec) G1K 3G6
Note : Document présenté à Hélène Bordeleau, Agente de développement économique/concertation avec le milieu

7. Ministère des Finances - Plan d'Action et Développement Durable
Faire parvenir document par courriel : info@finances.gouv.qc.ca
Adresse du bureau : 12, rue Saint-Louis, Québec (Québec) G1R 5L3
Note : Document présenté à M. Jean Lefebvre

Appendix I: User manuals and Instruction Manuals

Hydroponic Grow Table User Manual

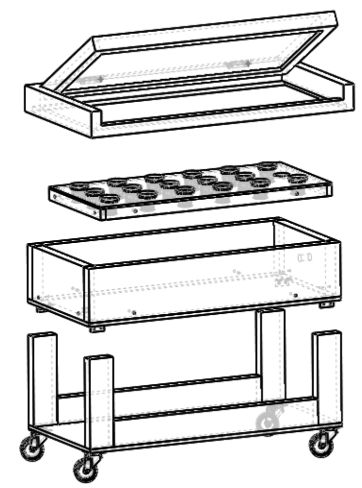
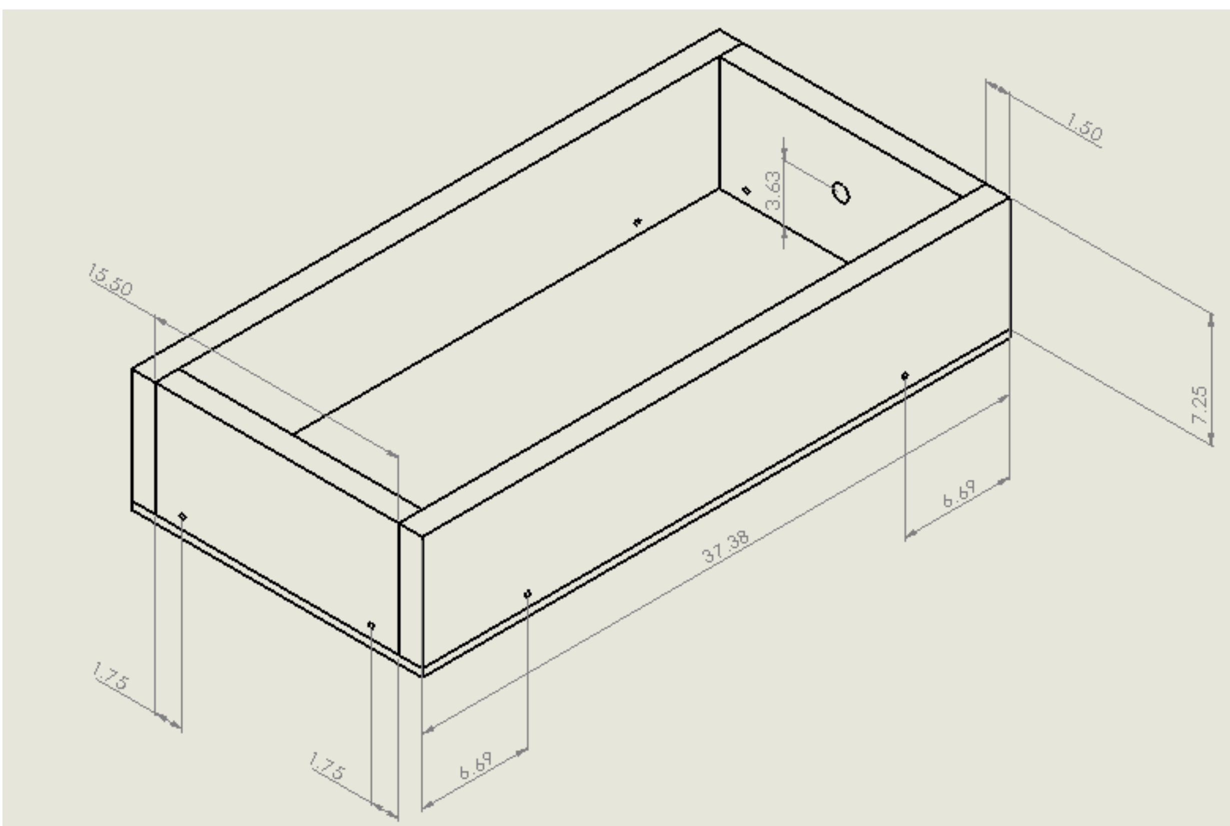


Table Frame



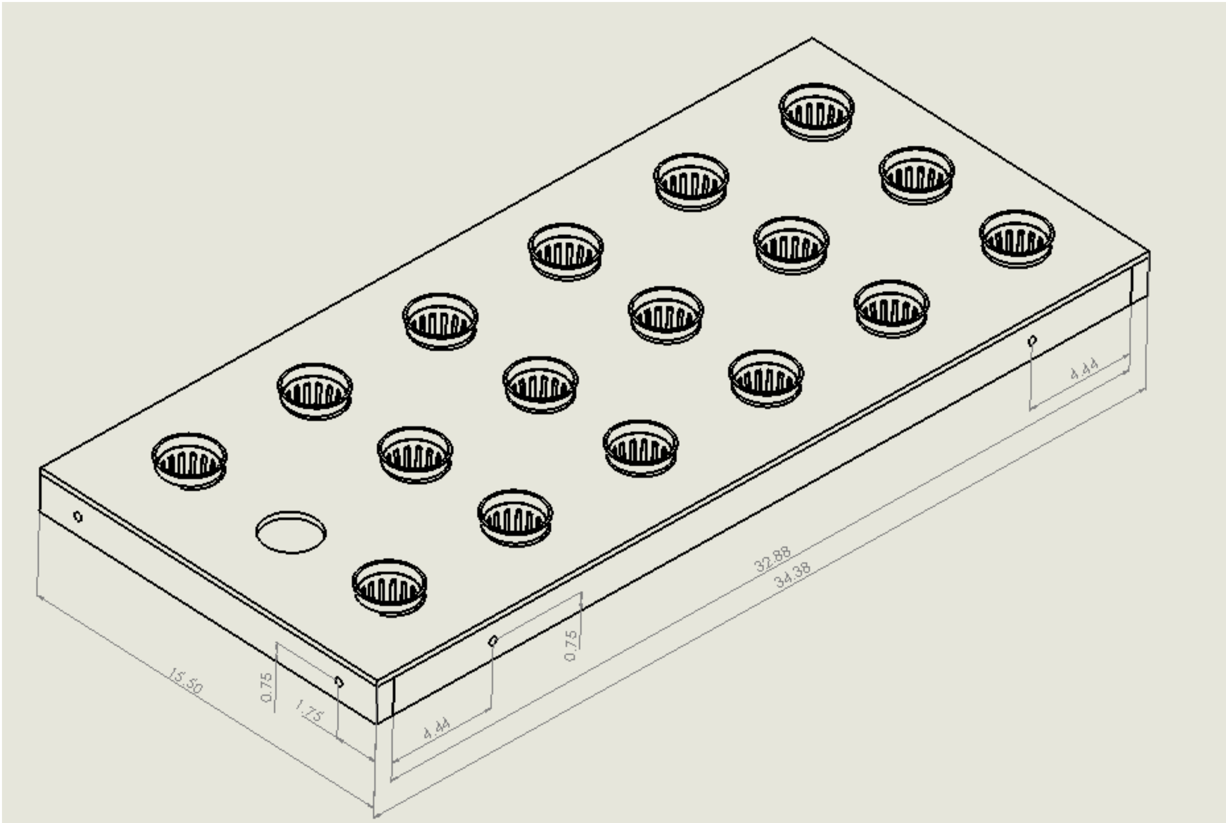
Materials and Tools

Table Saw
Power Drill with 1-in. Hole Saw and 5/16-in. Drill Bit
1x 4-ft. by 4-ft. ½-in. Plywood
2x 8-ft. by 2-in. by 10-in. Pine Plank
1x 8-ft. by 1-in. by 2-in. Pine Bar
8x 5/16-in.-18 by 4-in. Galvanized Steel Carriage Bolts
8x 5/16-in-18 Galvanized Steel Hex Nuts
8x 5/16-in. Galvanized Steel Washers
50x 2-in. Outdoor Wood Screws

Assembly

1. With the **table saw,** cut **two pieces 37⅜-in. long** from the **2-in. by 10-in. pine planks**.
2. With the **table saw,** cut **two pieces 15½-in. long** from the **2-in. by 10-in. pine planks**.
3. With the **table saw,** cut **one 37⅜ -in. by 18-in. rectangular section** from the **½-in. plywood**.
4. With the **power drill**, drill **two 5/16-in. bolt holes,** ¾-in. from the bottom edge and 6-in from the side edges, into each of the **37⅜-in. pin planks**.
5. With the **power drill**, drill **two 5/16-in. bolt holes**, ¾-in. from the bottom edge and 4.45-in from the side edges, into each of the **15½-in. pine planks**.
6. With the **power drill**, drill **one 1-in. hose hole,** 3⅝-in. from the bottom edge, into one of the **15½-in. pine planks**.
7. With the **power drill**, drill **one 1-in. hose hole** into the **37⅜-in. by 18-in. section of plywood**.
8. Attach the **37⅜-in. by 18-in. section of plywood** to the underside of the frame with **2-in. wood screws.** .
9. Assemble as shown with **2-in. wood screws**.

Grow Tray



Materials and Tools

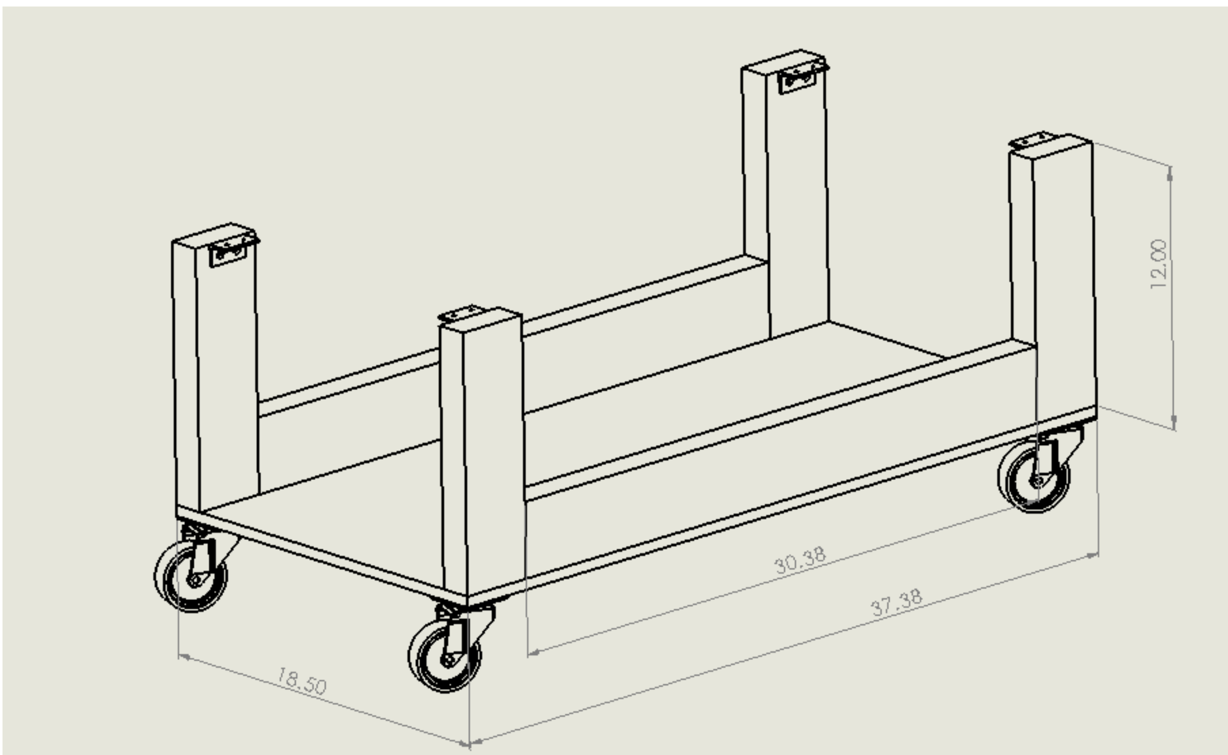
Table Saw
Power Drill with 2-in. Hole Saw and 5/16-in. Drill Bit
1x 4-ft. by 4-ft. ½-in Plywood Board
1x 8-ft. by 4-ft. Woven Polyethylene Canvas
18x 2-in. Circular Net Pots
1 Pint Outdoor Paint

Assembly

1. With the **band saw**, cut **two 32⅞-in. long pieces** from the the **1-in by 2-in. pine bar**.
2. With the **band saw**, cut **two 15½-in. long pieces** from the **1-in by 2-in. pine bar**.
3. With the **band saw**, cut **one 34⅜-in. by 15½-in. section** out of the **½-in plywood sheet**.
4. With **scissors**, **one 41-in. by 21-in. section** out of the **8-ft. by 12-ft. polyethylene canvas**.
5. With the **power drill**, drill **two 5/16-in. bolt holes** into each of the **1-in by 2-in. by 35-in pine bars**. To align the holes with the corresponding holes in the table frame, clamp the bars to the frame and drill through the existing holes in the frame.

6. With the **power drill,** drill **two 5/16-in. bolt holes** into each of the **1-in by 2-in. by 15-in. pine bars**. To align the holes with the corresponding holes in the table frame, clamp the bars to the frame and drill through the existing holes in the frame.
7. With the **power drill and 2-in. hole saw**, drill net-pot holes into the **34⅜-in. by 15½-in. section of plywood.** For plants to be grown to maturity, two evenly spaced rows of 5 holes is ideal. For seedlings only, three evenly spaced rows of 6 holes is ideal.
8. Paint the **34⅜-in. by 15½-in. plywood section** with **two coats of outdoor paint.**
9. Assemble as shown. The tray is fully disassemblable and does not require screws.

Reservoir Trolley



Materials and Tools

Table Saw
Power Drill with
1x 4-ft. by 4-ft. ½-in Plywood Board
1x 4-ft. by 2-in. by 4-in. Pine Plank
24x 2-in. Outdoor Wood Screws
4x 2-in. Right Angle Brackets

Assembly

1. With the **table saw**, cut **four 12-in. long pieces** from the **2-in. by 4-in. pine plank**.

2. With the **table saw**, cut **two 30⅜ -in. long pieces** from the **2-in. by 4-in. pine plank**.
3. With the **table saw**, cut **one 37⅜-in. by 18½ -in. section** from the **½-in. thick plywood**.
4. Assemble as shown.

Water Supply

Materials and Tools

Power Drill with 1-in. hole saw attachment
1x ¾-in Barbed Bulkhead Fitting
1x 2000 L/hr Water Pump with ½-in. barbed outlet
1x Uberhaus Electric Timer
1x 3-ft. Section of ½-in. Garden Hose
1x 1-ft. Section of ¾-in. Garden Hose
1x 37.9 L Rubbermaid Low Density Polyethylene Bin (opaque)

Assembly

1. Mount the **¾-in. bulkhead fitting** into the **1-in. outlet hole** of the tray.
2. With the **power drill and the 1-in. hole saw**, drill **two 1-in. holes** into the cover of the bin.
3. Place the pump in the bin, and fix the ½-in garden hose to the outlet of the pump.
4. Run the hose to the inlet hole of the table through one of the openings cut into the bin cover. Cut hose to desired length.
5. Fix the ¾" hose to the barbed bulkhead fitting of the outlet into the second opening of the bin cover. Cut hose to desired length.
6. Plug pump into the controlled outlet of the electrical timer.

Cahier d'instruction pour l'assemblage du coldframe

Matériaux nécessaires

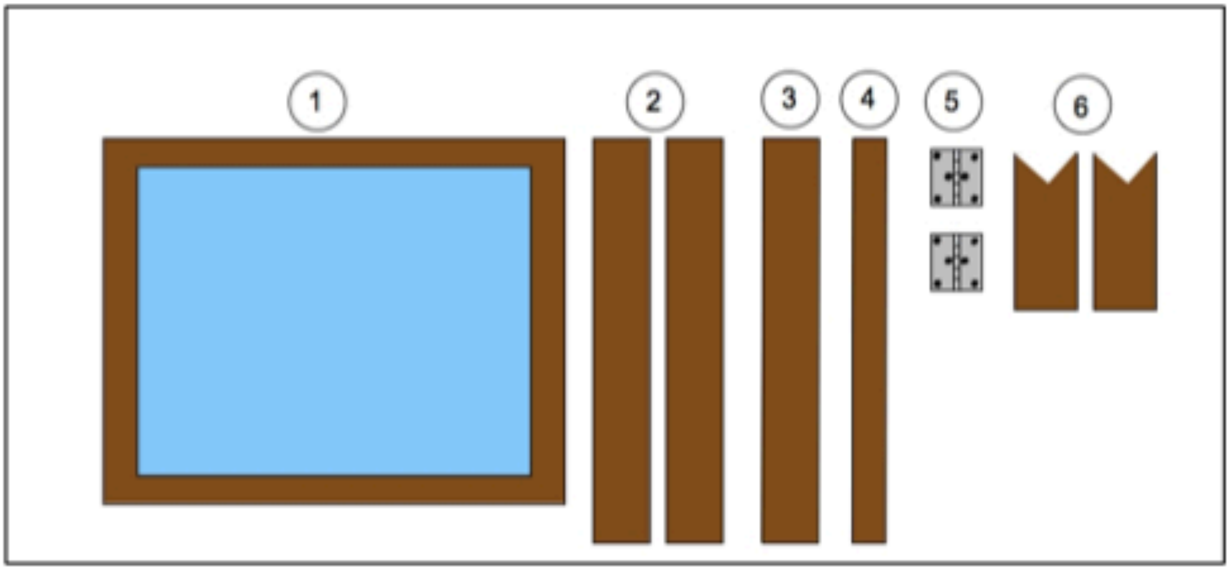
- Cadre de fenêtre (peut être recyclé) avec une fenêtre en verre ou en lexan.
- Morceaux de bois. Préférablement du « deux par quatre ».
- Pentures d'au moins 3 " de largeur.
- Vis d'une longueur de 2 ".

Outils nécessaires

- Perceuse électrique
- Banc de scie
- Scie à ruban

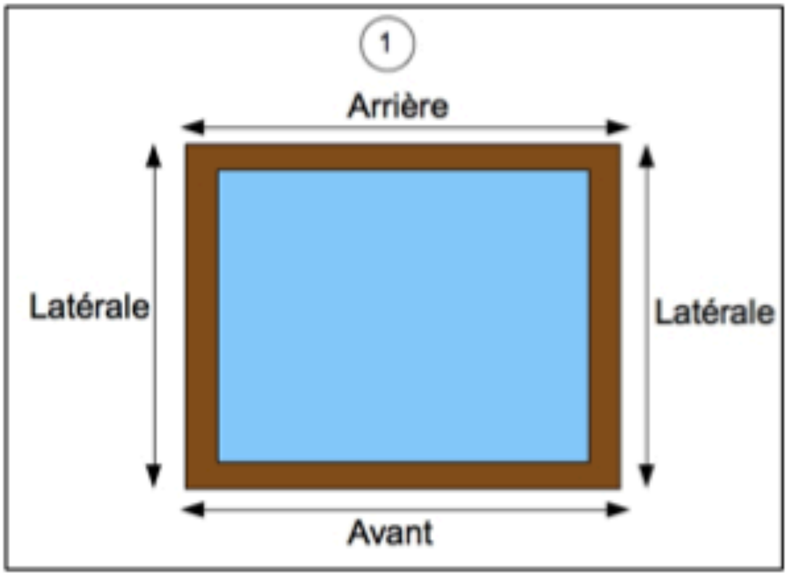
Diagramme des pièces

Notez bien : les dimensions 1.5 " x 3.5" se réfèrent à ce qui est courrament appellé un « deux par quatre ».



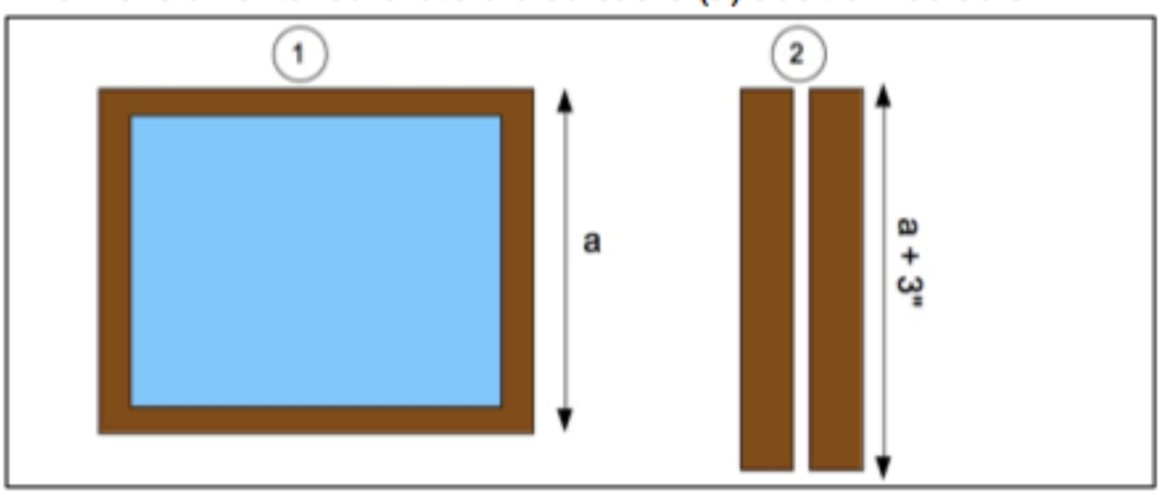
1) Cadre de fenêtre : Cadre en bois entourant la vitre ou le lexan.
2) Pièce de boîte arrière : Morceau de 1.5 " x 3.5" se situant à l'arrière qui fait partie de la boîte entourant le cadre de fenêtre.
3) Pièce de boîte avant : Morceau de 1.5 " x 3.5" se situant à l'avant qui fait partie de la boîte entourant le cadre de fenêtre.
4) Pièces de boîte latéraux: Morceaux de 1.5 " x 3.5" se situant sur les côtés qui font partie de la boîte entourant le cadre de fenêtre.
5) Pentures: Permettent au cadre de fenêtre de s'ouvrir.
6) Batonnets de support: Permettent au cadre de demeurer ouvert.

Préparation à l’assemblage

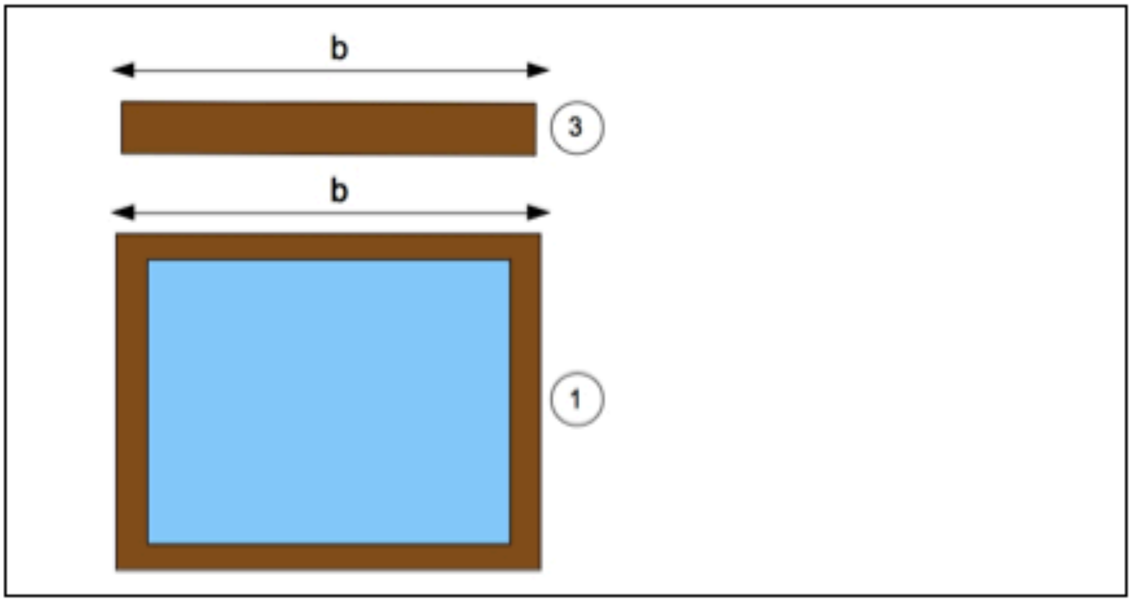


Le diagramme ci-joint représente les emplacements des différentes dimensions.

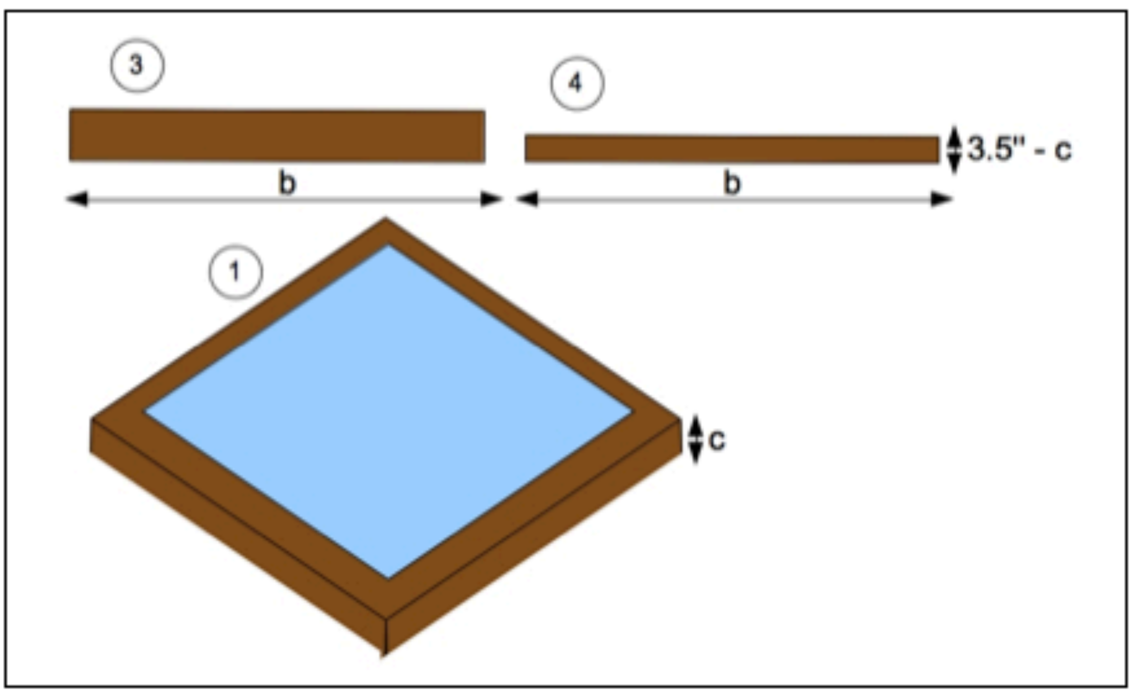
1. Mesurer et noter les dimensions extérieures arrières, avant et latérales du cadre de fenêtre.
2. Avec le banc de scie, couper deux morceaux de bois qui vont devenir les pièces #2. La longueur de ces pièces est égale à la dimension extérieure latérale du cadre (a) additionnée de 3 “.



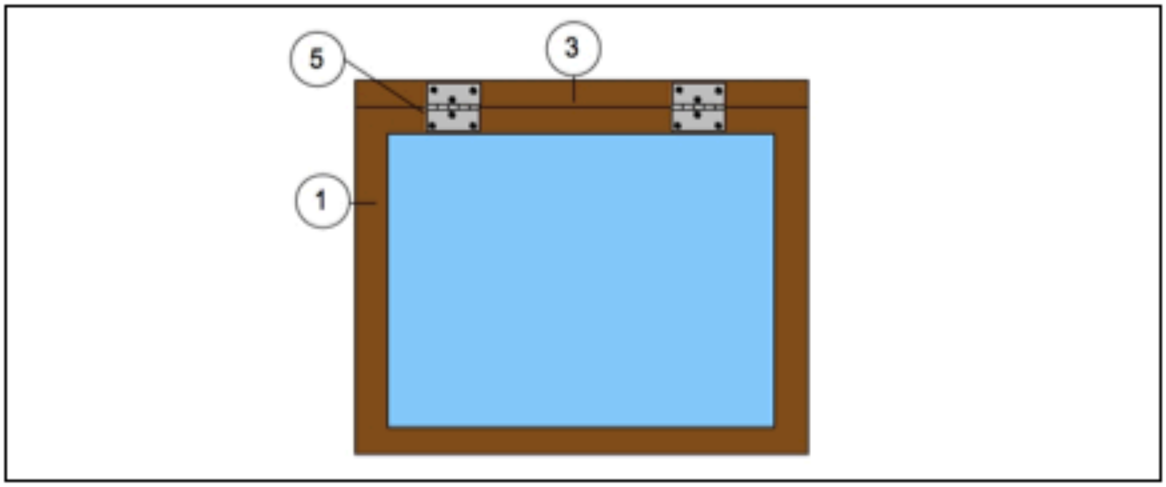
3. Avec le banc de scie couper un morceau de bois qui va devenir la pièce #3. La longueur de cette pièce est égale à la dimension extérieure arrière du cadre (b).



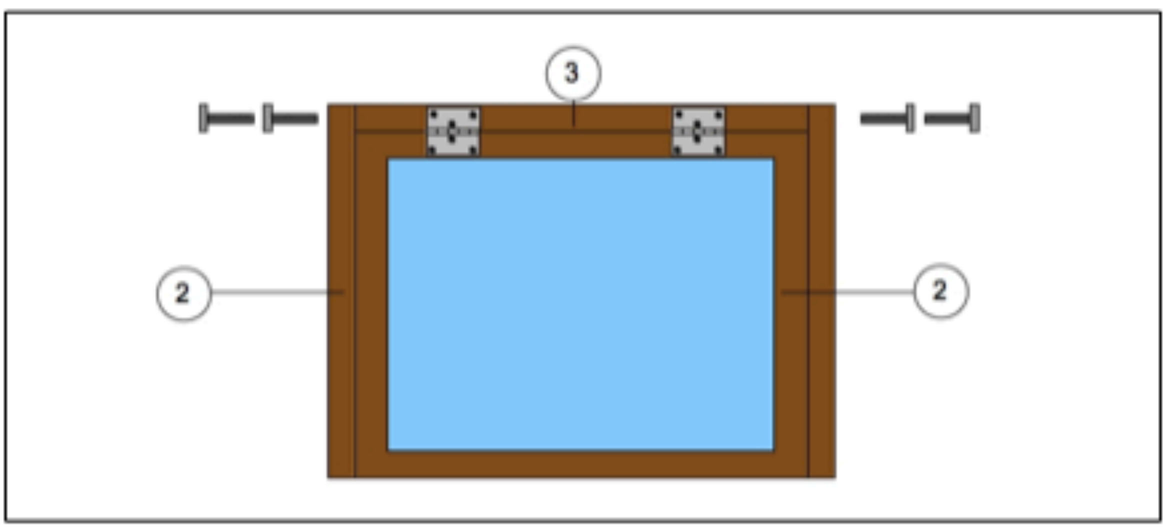
4. Répéter l'étape 3 pour faire la pièce # 4. Avec le banc de scie, couper la pièce #4 dans le sens de sa longuer afin que sa hauteur soit égale à 3.5" - l'épaisseur du cadre (c).



5. Aligner le coté arrière du cadre avec le côté de 1.5“ de la pièce #3. Poser les pentures tel qu'indiqué dans le diagramme ci-dessous.



6. Avec la perceuse électrique, visser les pentures en place avec les vis de 2 “.
7. Avec la perceuse électrique, attacher les pièces #2 à la pièce #3 à l'aide de 2 vis de 2 “ à chaque extrémité, tel qu’indiqué ci-dessous



8. Avec la perceuse électrique, attacher la pièce #4 aux pièces #2 à l'aide de 2 vis de 2" à chaque extrémité tel qu'indiqué ci-dessous.