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# Design and plan of a modified hydroponic shipping container for research

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# DESIGN AND PLAN OF A MODIFIED HYDROPONIC SHIPPING CONTAINER FOR RESEARCH

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# ABSTRACT

Houtman, John, A. M.S., Purdue University, December 2016. Optimal Design and Plan of a Modified Hydroponic Shipping Container. Major Professor: Robert M. Stwalley III.

As the world's population continues to increase, food production will need to increase in order to meet the predicted rise in food demand. However, with increased pressure on cropland available from environmental effects and urbanization, new innovative methods of crop production need to be researched in order to increase agricultural production with limited land. This research focuses on the design of a single form of urban agriculture that is considered Zfarming and has the potential to produce quality urban agricultural produce through ground-based measures. This project produced detailed step-by-step analysis of the design process, develop variability within the modified hydroponic shipping container (MHSC) for research potential, create AutoCAD drawings of the different MHSC systems and components, and lastly identify which design areas can be improved with suggestions to commercial manufacturers for increasing productivity. The research oriented MHSC will contain four growing areas, each consisting of a growing, irrigation, environmental control system. The main purpose of this MHSC system is as a research module to compare to commercial products available. Throughout the design process, there has been a focus on variability in experimental execution in order to find the most optimal MHSC growing conditions. The MHSC can produce numerous crops, has adjustable supporting units to vary the growing tray slope up to 5.5%, allows different lighting sources, adjustable distance from plants to lights (from 2" to 54"), has an adjustable drain to vary water height from ½" to 2" within the growing trays, contains variable pump to vary the flow rate (0.75 to 3 gpm), and potential for range of 3 to 60 air change per hour in the ventilation system. Four individual growing areas facilitate research experiments within one shipping container. To improve production based on observations from the bench tests conducted, a water cooling method was installed and the drain was re-designed.  To improve the production potential of MHSCs, a focus increasing the environmental control accuracy, integration of harvesting automation, and improved energy efficiency are suggested.  By designing this hydroponic shipping container to contain variable methods of production, further research will allow for optimization of production and an advantage in reaching the expected increase in food demand.

# CHAPTER 1. INTRODUCTION

Over the past decades, global demand for food has been met by increasing yields through intensification and increasing inputs to improve the yield, rather than expanding or increasing land area for higher output of crop production. However, this intensive method of production has contributed the largest source of pollution of any industrial sector, and current estimations show yield growth rates are slowing down (Tilman, 2002). These, have caused an increased uncertainty regarding our ability to meet future demands for agriculture production.

With the predicted continual rise in population, the spreading of urban environments, the growth of local food markets, and consequences of a changing climate, the demand for agricultural commodities are expected to increase, especially near urban areas as the population continues to migrate from rural communities to cities. Around half of the current population lives within an urban setting, and 35 years from now, the amount of people living in urban areas will increase by 2.5 billion people; two-thirds of the estimated population (GAP, 2015). There will be an increased need for innovative crop production systems within urban centers aiming to increase the sustainability of food production, provide income to urban citizens, and decrease environmental impacts from commercial farming methods. Factors influencing environmental impacts include transportation and potential deforestation when non-cropland is converted into crop land as a method of increasing potential agricultural production in order to meet future global food demand.

In recent times, municipal entities have begun integrating crop production in and near urban centers with goals of providing a local, year-round source of fresh produce as a means of improving food and nutritional security, community development (Armstrong, 2000), and environmental quality through self-provisioning and the shortening of supply chains (Albov, 2015). This urban agriculture (UA) is defined as a food production industry located within or on the fringe of a town, city, or metropolis capable of distributing food and non-food products while re-using human and non-human waste and delivering those agricultural products to people located within the urban environment. The main factor that differentiates UA from rural agriculture is the integration into the urban economic and ecological system (Mougeot, 2000).

There are many different forms of UA. These include, but are not limited to:

- Institutional Farms;
- Community Gardens;
- City and Urban Farms; and
- Rooftop Farms;

Institutional farms, community gardens, city farms, urban farms and rooftop farms are all forms of UA in which crops are produced within cities and are typically owned and operated by nonprofit organizations or the public. Aquaponics and hydroponics, intended for UA, are normally integrated within environmentally controlled buildings or structures, allowing crop production on a year-round basis. These types of UA production modes are typically owned and operated by for-profit entities.

One of the most interesting and under-researched urban agriculture methods of crop production is the process of modifying a recycled shipping container into controlled environmental chamber using hydroponic systems for crop production. This modified hydroponic shipping container (MHSC) is capable of being located nearly anywhere within a city or urban environment due to the high mobility and stack ability characteristics of a shipping container. However, this method of UA is a relatively new idea, compared to the other forms and

UA systems, and there is little research detailing their viability and efficiency. This research project will focus on designing and constructing a modified hydroponic shipping container for the purpose of conducting multidisciplinary agricultural research projects. A longer term goal is to improve efficiency and viability of the shipping container as a crop production system while establishing a baseline production metric. It is also hoped that this research will have broader commercial applications in addition to the basic and applied research goals that it will satisfy.

## 1.1 Problem Statement

As demand for agricultural commodities within urban environments continues to increase and the environmental hazards that arise from modern farming grow, recycled shipping containers modified with crop producing hydroponic systems have been implemented in urban centers as a form of Urban Agriculture. However, data regarding the design and optimization of this type of urban agricultural production system is limited in research literature. It is necessary to have an extremely generalized shipping container to further investigate claims within this new area to provide a base design to be further developed and investigated. The goal of this project was to design a generalized hydroponic shipping container unit to investigate productivity potential and energy use efficiency regarding this form of UA crop production.

## 1.2 Specific Research Questions

When introducing shipping containers retrofitted with hydroponic systems into urban centers:

1. What are the components, systems, and optimal conditions needed in order to efficiently produce hydroponic crops within, specifically, a shipping container?
2. Which areas of the constructed system have the most potential for improvement in order to increase productivity?

## 1.3 Research Goals

This program has had the following specific goals:

1. Specify design constraints for envisioned modified hydroponic shipping container;
2. Produce detailed step-by-step analysis of designing and building generalized, research MHSC;
3. Develop flexibility within the different MHSC systems for future research and experimentations to be conducted;
4. Complete a complete set of AutoCAD dimensioned drawings scaling the MHSC systems and components; and
5. Identify areas of design where improvements can be made regarding the increase of productivity and feasibility of a MHSC and each system (growing, irrigation, and environmental control systems);

## 1.4 Scope

The scope of the project includes identifying necessary materials and components needed to operate a research MHSC and how the MHSC should be designed in order to further understand the potential growing capacity of a modified hydroponic shipping container. This involves the growing trays, lighting, water storage and delivery systems, environmental control, and the varying types of plants and concentrations of nutrients required for agricultural growth. Although the successful completion of this work will produce a workable and usable MHSC unit, an actual operational test of a specific investigative variable is beyond the scope of this work.

## 1.5 Significance

The author's research analysis will eventually have impact on companies and individuals involved in using MHSCs as a method to feed local populations within urban environments by providing a tool to increase the knowledge and information regarding this new and unique Urban Agriculture technique. Globally, the author's project will provide quality research on a method of crop production that has potential to reduce transportation costs of food commodities, improve food security and water scarcity concerns and reduce environmental concerns while increasing quantity of available food to meet consumer demands.

## 1.6 Assumptions

Certain assumptions were made prior to conducting this research project in order to focus on the stated goals and complete the construction within the given timeframe. The initial general assumptions for this project were:

- Intended for research purposes and flexible for future design changes
- 40’ x 8’ x 9’ standard shipping container
- Need for varied styles of growing trays
- Need for adjustable and tailored lighting
- A drain capable of adjusting the height of water during plant growth cycles
- Four independent growth units designed for unique treatment combinations
- Each of 4 individual unit runs as a closed system
- Intended for food crops such as vegetables and leafy greens

## 1.7 Plan of Development

This thesis will justify and explain the need for this research project by first introducing how the global demand for Urban Agriculture has increased due to different trends and conditions increasing food security concerns, a growth in the local food market, effects of modern farming, new technology in crop production, the surplus of unused shipping containers and a profile of the MHSC manufacturers currently producing units. Secondly, Urban Agricultural systems will be defined, as well as describing pros and cons and the methods of crop production for different types of UA. After that, the state of the UA market will be explained by providing information and status on the multiple municipalities currently involved in producing urban agricultural goods.

The design methodology will follow and it will include the planning and designing of the MHSC along with the materials used and steps taken in constructing the experimental unit. Finally, the preliminary design will be observed based on a bench test, three cycles of Butterhead lettuce growth, to find certain areas of improvement for the design. Future improvements on how this form of UA can be more effectively utilized and made more efficient will be discussed.

# CHAPTER 2. LITERATURE REVIEW

## 2.1 Increased Demand for Urban Agriculture

The ability to produce agricultural commodities in quantities sufficient for the global population has become an increased concern. The predicted increase in global population will require a higher rate of crop production to meet the rise in food demand (Hertel and Baldos, 2016). Agriculture in rural environments, especially those located near cities, will need to increase production while the effects from environmental change and increased urbanization rate result in greater pressure on the amount of cropland available. This leads to a higher demand for methods of agricultural production near cities which utilize sustainable methods.

### 2.1.1 Population and Income Growth

Researchers suggest the two most important drivers in global demand for agricultural commodities are population and per capita income (Hertel and Baldos, 2016). Simply put, more mouths to feed and "each mouth" having more money available to spend on agriculturally produced goods results in the demand for these goods increasing beyond the level of simply providing more food needed to satisfy the population. Food quality and production techniques become additional factors in consumer decisions.

Even though the global population growth rate has been declining over the past forty years (Trostle, 2008), the global population is expected to increase from 7.3 billion in 2015 to 9.7 billion by 2050 (GAP, 2015). This vast population growth can be attributed to the highly improved health and nutrition levels resulting from both the industrial revolution, which spawned modern medicine and improved sanitation. Also, the agricultural revolution (Hertel and Baldos, 2016), where genetically advanced crops and livestock, along with precise practices from improved technology and increased input utilization efficiency, have dramatically improved results (GAP, 2015).

The majority of this anticipated population growth will occur in developing countries, fifty % of growth occurring in Africa alone (GAP, 2015). This will sharply increase the demand for agricultural produced goods in cities where urban citizens have low incomes along with high food and nutrition security risks.  This combination will make these economies extremely sensitive to the rise of food prices (Satterthwaite *et al*., 2010).  Of the total increase in global crop demand and crop land use, 68% is predicted to occur in the regions of Sub-Saharan Agrica, South Asia, Southeast Asia and China/Mongolia (Hertel and Baldos, 2016).

Global economic growth has been increasing since the 1990's (Trostle, 2008), most importantly in developing countries, which has allowed these countries to increase their wealth and help contribute to the ongoing increase in average global income. Per capita income is considered one of the key determining factors in food consumption pattern which can lead to an estimate of global food demand (Hertel and Baldos, 2016) based on the amount of capital each population is capable of spending on certain food commodities.  Per capita income increases are predicted at a rate of 1.7% in developed countries and 4.4% in developing countries (GAP, 2015). Demand for agriculturally produced commodities increases in response to the directly correlated rise in food consumption (Hertel and Baldos, 2016), and the introduction of meats, dairy products, and vegetable oils into diets (Trostle, 2008) requires an increased demand on agriculture resources compared to consumption of crops (Hertel and Baldos, 2016). According to the FAO, if the current rate of agricultural production is assumed, there will be a 60% increase in demand within developed countries and 100% increase in developing countries (Hertel and Baldos, 2016).

### 2.1.2 Environmental Effects

Throughout the past 50 years, agricultural productivity has been able to meet the consumer demands by increasing productivity through improved genetic variety, improved management, and the increasingly efficient use of inputs (Karl, 2009). However, there is recent indication of a decrease in the rate of growth in yields of important crops, including research detailing yield plateaus in rich crop productive areas such as California, Korea, and Northern Europe (Hertel and Baldos, 2016). In order to meet the future global food demand from an increased population, an increase in agricultural productivity will need to occur, and this is dependent on Earth’s climate and land resources (Karl, 2009).

The Earth maintains its climate due to the natural greenhouse effect, which warms the surface to a livable temperature by trapping greenhouse gases (GHG), such as ozone, carbon dioxide, water vapor and methane. These gases absorb radiated heat from the Earth’s surface and then re-radiate that energy back to the surface (Karl, 2009), slowing the overall heat loss into our atmosphere and beyond. The GHG act as ‘insulation’ for the planet. It is widely accepted that elevated GHG emissions, most importantly carbon dioxide, have led to the increase of surface temperatures over the past 50 years (Karl, 2009). The carbon dioxide emission rate into the atmosphere has increased from 4.06 metric tons per capita in 2000 to 4.95 metric tons per capita in 2011 (World Bank, 2016). At this GHG emission rate, some models predict a temperature increase of 0.3 to 0.4 degree Celsius per decade is expected by 2050 (Hertel and Baldos, 2016). The effects resulting from global climate change have the potential to reduce agricultural productivity and increase global food demand by threatening the growing environment for important crops (Hertel and Baldos, 2016).

Agriculture and all biological activities are influenced by temperature (Hertel and Baldos, 2016) and can negatively or positively affect crop's productivity and growth. Most crops show a positive response to higher carbon dioxide concentrations in the atmosphere, which will allow more efficient use of water and eventually production (Karl, 2009). However, this higher level of $CO_2$ also benefits weed growth. Sixty-four percent of the loss of soybeans is to weeds in southern U.S. farms, and in northern U.S., it is 22%. In conjunction with increased temperatures, an increased number of pests and diseases can occur, further hindering the productivity of certain crops (Karl, 2009). Many of the natural consequences of the increased temperature, 2 degrees Fahrenheit over the past 50 years in the U.S., include increased frequency of heavy downpours, droughts, floods and extreme weather events (Karl, 2009). These events will cause a crop's productivity to be limited due to saturation or deprivation of water (Karl, 2009). Another important factor to consider with regard to how the intensive production of agriculture in rural areas affects the environment is the emission of carbon dioxide from the burning of fossil fuels during the process of transporting goods to urban areas, as well as resulting from field operations throughout the growing season (Edwards-Jones *et. al.*, 2008). As most agriculturally produced food is imported from rural environments into urban areas, climate change reducing agricultural productivity in rural regions will have an indirect effect on the food security in urban environments (Frayne *et al.*, 2011).

In order for agriculture commodities produced in rural areas to reach urban citizens, complex transport infrastructures, storage and distribution systems are needed (Tacoli *et al.*, 2013), which in conjunction with the increased extreme weather events due to change in climate

(Frayne *et al*., 2011), can further impact urban food security, increasing the need for locally produced agricultural goods. Researchers have estimated 10 to 30% of food losses between production and retail occur on-farm, transport, distribution, and from spoilage (Armar-Klemesu, 2000). One study estimated a 150 g pot of strawberry yogurt travels 1500 km from point of production to supermarket in Southern Germany (Böge, 1995).

To meet future global food demand and reduce the risk of food insecurity, future agricultural output will need to be doubled (GAP, 2015). Past production levels have mostly been set by improving genetic varieties, improved management, and the increased use and efficiency of agricultural inputs including water and fertilizer (O'Neill and Dobrowolski, 2011). Achieving expected future food demand will require either increased intensification or further expansion of crop land to meet the future consumer demand, both of which have environmental consequences including increased greenhouse gas emissions, growing need for irrigated water, reduction of forested land capable of sequestering carbon, and increased risk or soil erosion Hertel and Baldos, 2016; GAP, 2015).

Agriculture contributes 13.5 % of greenhouse gas emissions from human sources, including 80 % of all nitrous oxide emissions which can be traced to certain agricultural management practices such as fertilizer application (EPA, 2016; Karl, 2009). In the United Kingdom, researchers have estimated 1.5 % of the total carbon dioxide emissions are derived from the energy used in the industrial production of fertilizers and pesticides (Howe *et al.*, 2012). In the United Kingdom, the consumption of food, which takes into account the multistage process from agriculture production to consumer consumption, accounts for 19% of the GHG emissions in all of the goods and services consumed (Audsley, 2010).

According to Dubbeling and de Zeeuw (2011), the Asian Cities Climate Change Resilience Network concluded one method of improving cities capability to respond, resist, and recover from changing climate conditions is implementing urban agriculture (UA). In addition, NIFA determined a major theme in improving agricultural water security was, “exploring new technologies and systems for the use of recycled/reuse water in agricultural, rural, and urbanizing watersheds” (O’Neil and Dobrowolski, 2011).

UA can contribute to food securing in growing cities, where this form of crop production is available. It can provide resiliency to climate change (Dubbeling and de Zeeuw, 2011), and when managed correctly, it will be important in improving and maintaining the sustainability of agriculture (Horrigan *et al.*, 2002). Environmental benefits resulting from UA implementation stem mainly from the reduction of energy use and GHG emissions by reducing the distance from agriculture production to consumer by increasing the amount of locally produced food (De Zeeuw *et al*., 2011). This reduction in city’s ecological footprint can be attributed to limiting the amount of energy required in feeding urban dwellers by reducing the amount of transportation, cooling, and storage involved (Howe *et al*., 2012), each of which are dependent on the burning of fossil fuels and result in emissions of carbon dioxide (Skjolden, 2014). Other sources of environmental benefit from the adoption of UA methods include increasing open green spaces and vegetative cover, reducing the heat island effect, reducing rapid storm runoff through increased water infiltration, and increasing carbon dioxide capture (Dubbeling and de Zeeuw, 2011).

A study regarding the environmental benefit of partially substituting an urban agriculturally produced food supply system into a consumer's normal food supply system in Sutton, South London found a reduction in greenhouse gas emissions (Kulak *et al.*, 2013). Researchers have determined that reducing the amount of carbon dioxide emitted into our atmosphere would significantly reduce the rate of climate change and is more effective than carbon dioxide reductions of the same size later on (Karl, 2009; Levy II, 2009). The resulting effects of climate change can increase the rate of rural populations migrating into urban centers such as is expected in Africa due to the expected increased flood frequencies. This has the potential to displace the rural population, increasing the rate of urbanization (De Zeeuw *et al*., 2011).

### 2.1.3 Urbanization

As the global population continues to increase, a necessary factor to consider regarding the impact of implementing urban agriculture is the distribution of this growth. The majority of population growth is estimated to occur within urban areas in the next 30-50 years (De Haen *et al*., 2003), where population is expected to double to 6.4 billion by 2050 (De Zeeuw *et al.*, 2011). In 2008, for the first time ever, the population residing within urban defined areas surpassed those dwelling in rural environments (Satterthwaite *et al*., 2010). A common misconception is the majority of the world's urban population exists in North America and Europe. However, over half of the world's population currently resides in Asia, and Africa alone has a greater number of urban dwellers than North America and Western Europe put together (Satterthwaite, 2007). This trend of increasing population shift from rural environments to urban environments is one form of urbanization, and it can be determined by the net transfer of rural-to-urban populations. Other types of urbanization include the growth of an urban population from within, the expansion of urban environments into rural areas (Satterthwaite *et al*., 2010), and changes in overall population densities (Brown *et. al*., 2005). In order for urban areas to be defined, certain criteria are required which differentiate certain environments between rural and urban. Unfortunately, each country has its own criteria for determining urban environments, which include population size, density, concentration of non-agricultural employment, administrative status, or a combination of each (Satterthwaite and Tacoli, 2003).

An urban population increases due to three basic reasons:

1. Natural increase; a higher amount of births than deaths within the urban environment.
2. Migration of rural population into urban environments.
3. Reclassifying area to urban due to the expansion of urban boundaries of which were previously deemed rural.

When nations, such as those in sub-Saharan Africa, are faced with limited economic growth and show signs of high levels of natural increase, the growth in urban population is mostly from a higher birth to death ratio. On the other hand, nations like China have high economic growth, and when coupled with low rates of natural increase, these conditions result in urbanization through the process of rural populations migrating into urban environments (Satterthwaite, 2007). The migration of rural to urban populations is most often the case for an increase in a nations urban population (Satterthwaite *et al*., 2010), mainly due to the potential for economic success and investment opportunities from the many industries and services that are more abundant within urban than rural areas (Satterthwaite, 2007). This growth in urban environments has created an important relationship between the amount of agriculture production and its location relative to the urbanization area (Heimlich and Anderson, 2001).

These economic factors are capable of shepherding populations into urban environments, but certain factors can also act to expel populations from rural areas, forcing a move to urban settings (Fay and Opal, 2000). These authors state that income potential and higher wages within urban environments, when compared to rural income opportunities are an economic incentive attracting migration from rural-to-urban populations. Factors contributing to urbanization through "pushing" rural populations out of an area include decreased agricultural commodity prices and limited amounts of available land (Fay and Opal, 2000). Researchers have found a direct correlation between economic growth and urbanization, as 97 % of the world's gross domestic product (GDP) is generated within urban areas. Nearly 65 % of the world's population work within these urban industries (Satterthwaite *et al*., 2010).

Economic growth is not the sole reason that rural populations migrate to urban regions. A survey was conducted in 1988 (Fuguitt and Brown, 1990) which concluded that the majority of Americans favor settling within 30 miles of a city with a population over 50,000 (Heimlich and Anderson, 2001). Rural populations may seek urban areas for greater social status or a safer environment due to the increased diversity of urban populations and enhanced police protection (Fay and Opal, 2000). Technological advancements, including the automobile, divided highway systems, improved telecommunications, and the ability to provide utilities remotely from urban centers, have also allowed for the expansion of urban environments (Heimlich and Anderson, 2001). Rural landowners, located on or near an urban fringe, are under significant pressure to seek superior returns on their land, through selling less productive land, such as woodlands and pastures, and non-agricultural ground for future development. The increased obstacles in maintaining profitable agriculture productions in areas close to urban zones contributes to this pressure. From 1950 to 2000, there was an 11% decrease in amount of cropland area in the U.S. The majority of this decline occurred in the East, with more than half within non-metropolitan areas as the percent of ex-urban, region outside the urban fringe, growth increased by 90% through the same time period (Brown *et al*., 2005).

As urbanization is the ratio of urban to rural populations and can be related to urban land expansion, urban sprawl is considered the low-density development near the urban and rural intersection point responsible for requiring relatively large amounts of land (Heimlich and Anderson, 2001). From 1999 to 2000, there was a 2.1% average decrease in population per year within the core of Mexico City, while the suburban areas surrounding showed a 2.8% average increase per year (Tacoli *et al*., 2013). This development results in a rural areas undergoing conversion to urban environments, leading to major impacts on the environmental landscape and the agricultural community from the resulting fragmented developmental pattern created (Heimlich and Anderson, 2001). One aspect concerning the transformation of available cropland to urban environments is the unlikelihood that this urban development can or will ever be reversed, forever reducing the potential for agriculture productivity (Thompson and Prokopy, 2009). The loss of available agriculture production land and resulting environmental concerns due to the expansion of urban areas has led to concerns regarding humanity's ability to meet food demand by continuing current methods of crop production (Heimlich and Anderson, 2001).

Farm operations close to urban housing and settlements result in adverse impacts on farmer's ability to efficiently produce crops and maintain profitability. As urban environments continue to expand, the land prices on the city's fringes are increased as the pressure for nonfarm development becomes greater. Citizens within close distances to agricultural production and operations may become affected by strong odors, chemical spray drift, and noise. In order to please neighbors, farmers may be forced to use different methods of operation which may result in an increased cost of operations and lower the potential for profits. Transportation of farm machinery, which is required in order to conduct the several daily, in-field operations, is also negatively impacted by urbanization, as it becomes extremely difficult and inefficient to move the equipment due to the increased traffic and fragmented crop land areas near urban growth boundaries. Additionally, agricultural producers near urban zones are undergoing increased restrictions on water use and other important production inputs, introducing further constraints on their capability for production (Heimlich and Anderson, 2001).

Finally, as noted above, cropland located within an expanding edge of an urban environment will have a heightened potential to be converted into urban development (Heimlich and Anderson, 2001), resulting in a reduction in the amount of farmland available for crop production, including ground based urban agriculture (Thompson and Prokopy, 2009). One important example regarding the impact urbanization has on the agricultural community's ability to produce crops is the production of vegetables in the U.S. The soil and environmental characteristics necessary for productive vegetable growth include warmer temperatures, sufficient water supply, and well-drained soil. These conditions happen to occur in the states of California, Florida, Texas, and Arizona (Heimlich and Anderson, 2005). However, these same characteristics also favor urban development due to the fertile soils and fresh water supply (Tacoli *et al*., 2013). This is cause for an extreme concern, due to the high future projections of population increase in California, which contains seven of the top ten counties where vegetables are produced (Heimlich and Anderson, 2005). *Figure 2.1* illustrates urbanizations impact on different forms of agricultural farms and various adaptations farmers can undergo based on farm size (Heimlich and Anderson, 2005)

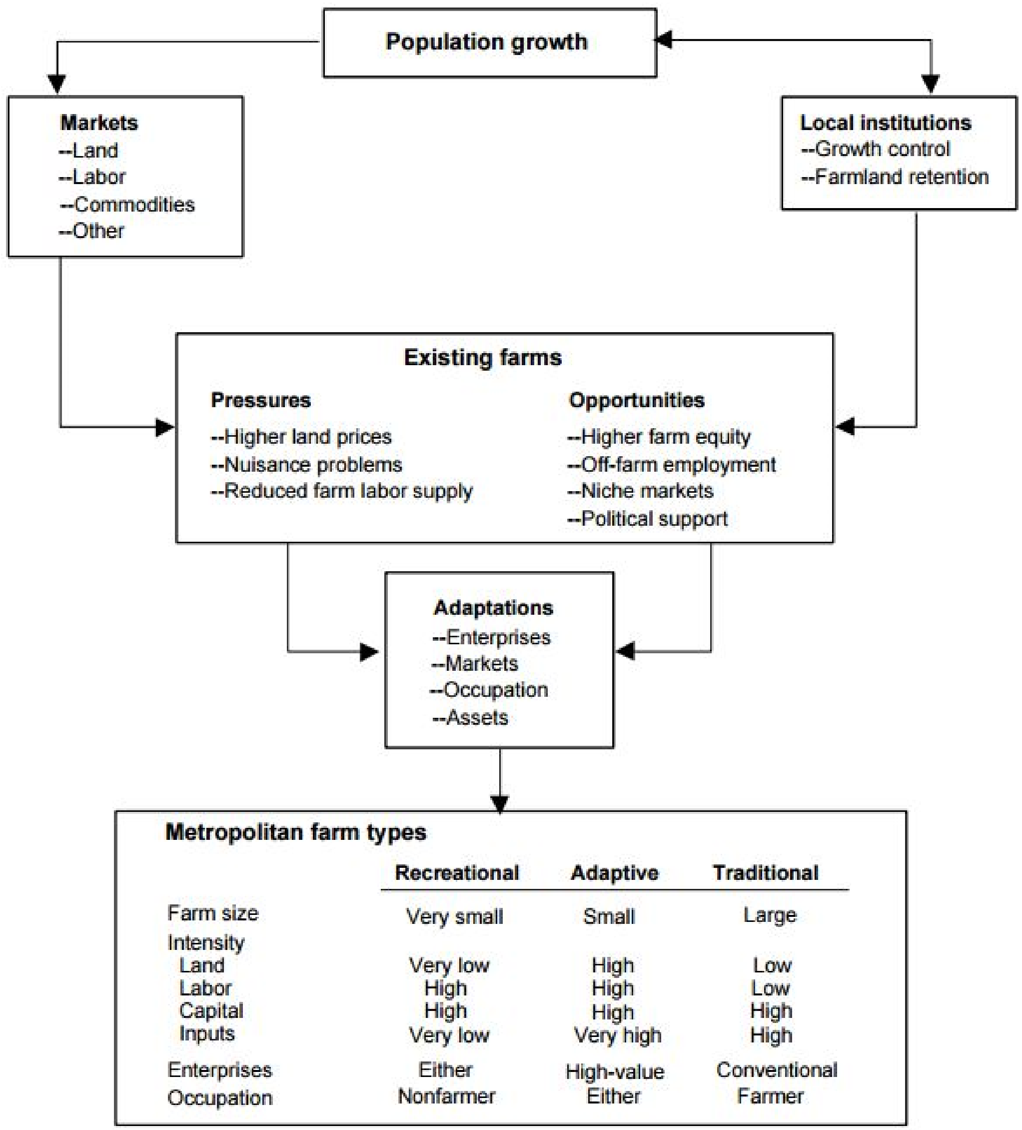


*Figure 2.1.* Adaptation methods for agricultural farm (Heimlich and Anderson, 2005).

Additional harmful effects resulting from the continuous expansion of urban development, which has potential in limiting agricultural productivity and degrading land, are the environmental impacts. As previously mentioned, urbanization and the effect of urban sprawl create areas of low-density development where the rural and urban settings meet (Heimlich and Anderson, 2001). This type of development can be attributed to inadequate land use planning and relatively little control regarding sustainable measures of urban expansion (Satterthwaite *et al*., 2010). Poor land use planning can lead to loss of open space and extreme land fragmentation, thus limiting the spatial potential for diverse agricultural production. As urban environments continue to grow, the amount of automobile based traffic will likely contribute an increasing burden on the urban core and surrounding environments. This has potential for adversely affecting environmental quality especially air and water quality (Kjellstrom *et al*., 2006).

Inefficient urban expansion can lead to soil erosion, water runoff, stream and river pollution, and simultaneously affect and reduce aquifer recharge rate and quality. Increased urban sprawl and greater distances between municipal services and residential areas developed on the sprawling urban periphery can further challenge on-site septic systems, which have increased risks of contaminating water supplies (Heimlich and Andreson, 2001). Agriculture is one of the largest users of fresh water in the United States (Schaible and Aillery, 2011). Uneven development of urban centers raises concern about society's ability to integrate innovative solutions involving ground based methods of urban agriculture in and near cities to meet future food demand. As a result, creative methods of utilizing space and reducing transportation distances for agricultural production are needed in order to provide food supplies to rapidly increasing urban markets (De Zeeuw *et al.*, 2011).

Access to arable land in urban environments remains an issue for potential growers (Schmelzkopf 1995; Kaufman and Bailkey 2000; Midmore and Jansen 2003; Mougeot 2006). Increasing urban food demand provides opportunities for local, hydroponically grown produce within a controlled environment structure.

## 2.2 Growth of Local Food Market

During the past decades, an increased amount of the population has migrated to urban environments resulting in further distances from points of agricultural production to the consumer. From 1980 to 2000, the average distance from farm to consumer increased by 25 % in the United States and 50 % in the United Kingdom. *Figures 2.2 and 2.3* illustrates the different distances certain commodities travel from their production source, to consumers in both the United Kingdom and Iowa, U.S. Technology advancements in transportation efficiency and food storage have allowed food to maintain its freshness longer and thus over greater distances traveled. Even though an increase in technology and distance comes with an increased cost, the fact that many large scale producers are selling into a complex marketing chain results in consumers being able to buy goods at the lowest cost. These farmers and farm communities, often have produce exported to foreign nations. Because of this free agricultural trade, some communities have suffered from malnourishment and reduced serving size amounts (Halweil, 2002).

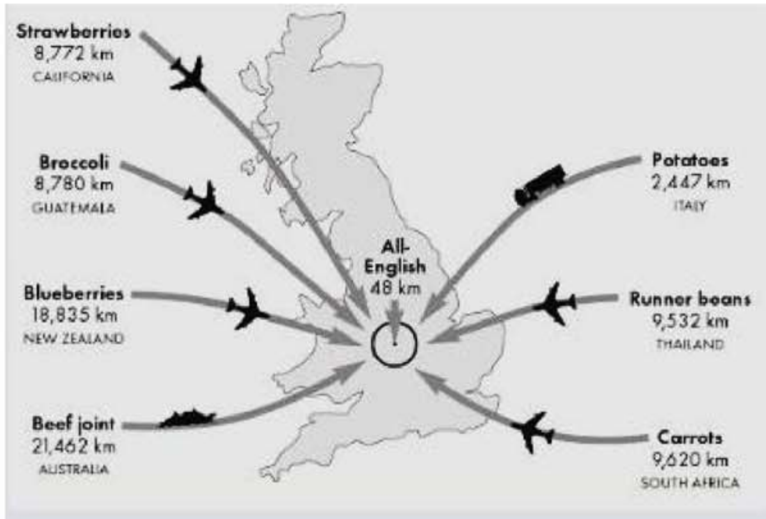


*Figure 2.2.* Distances traveled for commodities in UK (Halweil, 2002).

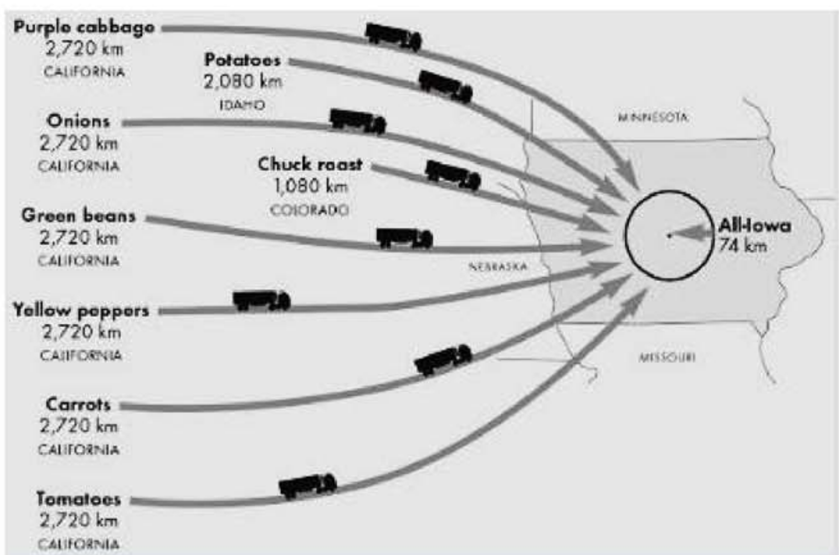


*Figure 2.3.* Distances traveled for commodities in U.S. (Halweil, 2002).

The recent emphasis on transporting food great distances has been slowing, as consumers begin to favor fresh, local production with low carbon footprint and closer involvement within the food production chain goods (APA, 2007). Consumers have been found to pay double for food goods that were produced locally, compared to food produced throughout the U.S. Also, there has been a 111 % increase in the number of farmers' markets in the U.S., where most locally grown food is sold (Darby *et al*., 2008). The rise in the number of farmers' markets and community supported agriculture is one of the main drivers in the growth of local food systems (Halweil, 2002).

In a survey completed by Oberholtzer and Grow (2003), market managers detailed benefits of farmers' markets:

- Creating a hub of social activity or bring life to a public space;
- Bringing freshly grown produce into the community;
- Fostering a sense of a community;
- Improving economic state of local businesses; and
- Increasing awareness regarding where produce comes from by consumers.

In addition to an increasing number of consumers preferring locally grown produce, the government has begun to promote local food as well. In the U.S., programs have been established in forty-four states which label locally grown produce or foods grown within the U.S. (Darby *et al*., 2008). Additionally, $22 million was granted to support 166 local food systems projects from 1999 to 2003 by the U.S. Department of Agriculture (USDA) through the Community Food Security Act (Tauber and Fisher, 2002).

## 2.3 New Engineered Solutions Needed

The idea of producing agricultural goods within cities is not necessarily a new concept. King Nebuchadnezzar built the Hanging Gardens of Babylon around 600 B.C. (Krystek, 2010). However, the motives and techniques for developing and integrating urban agriculture into cities are much different than ever before. Increased urban settlements compete with agricultural land and water resources, resulting in the demand for food produce rising (FAO, 2014). With less available land and more production needed, new urban agriculture production technologies and methods that take advantage of pre-existing urban resources have become more and more interesting. One example of such technologies is retrofitting a hydroponic system inside a highly mobile shipping container.

As these new technologies become increasingly integrated within urban environments, more research is needed in order to completely understand the overall urban agriculture impact and potential. Due to lack of published literature, additional research is needed to further understand solutions to recycle necessary resources, $CO_2$ footprint of each system, sustainability potential, feasibility, and economic possibilities (Specht *et al.*, 2014). With regards to a modified hydroponic shipping container (MHSC), further research is needed as to the amount of energy input required, optimal design orientation for maximum production, essential components, environmental control techniques, and yield/production potential. This project aims to design and construct a MHSC for research purposes to provide an opportunity to further investigate and close the knowledge gap regarding this type of UA production.

## 2.4 Urban Agricultural Systems

Urban agriculture (UA) is a term with varying definitions due to the vastly different forms of UA systems. The most general definition explains UA being a method of fuel and food production within a city or peri-urban area which is consumed through a local market or household uses (Smit *et al.*, 1996). When introducing the notion of implementing urban agricultural methods within cities, it needs to be mentioned that this form of food production is not intended to replace rural agricultural production. UA aims to complement and supplement rural production (Mougeot, 2000), in order to increase a city's resiliency to climate change, while reducing dependency on imported foods (Dubbeling and de Zeeuw, 2011). UA takes advantage of underutilized urban resources to generate local agricultural produce through methods including shallow-bed gardening, hydroponic systems, aquaponic systems, aeroponic, building integration, vertical farming, greenhouses, and mobile containers (Smit *et al.*, 1996; Specht *et al.*, 2014; Ackerman *et al.*, 2013; Hodgson *et al.*, 2011). Fruits and vegetables are the most common and profitable produce supplied by UA, due to the advantages provided by locality: freshness and quality (Thomaier *et al.*, 2015). Some UA systems include animal production (Smit *et al.*, 1996), but these are less common. Cities that integrate UA production systems into the urban environment benefit from the many advantages UA offers.

UA has a positive impact on urban economies by generating economic activities in an important area, while being a relatively easy industry to enter (Smit *et al.*, 1996). Previously unproductive land, generating no economic output, is being placed into service (Kaufman and Bailkey, 2000; De Zeeuw *et al.*, 2011). As households and companies begin to generate produce through UA, eventually they may begin producing more than is necessary for their own consumptions, thus resulting in net incomes from their surpluses (De Zeeuw *et al.,* 2003). Of course, total entity income depends on the crop choice and its scale of operation (Ackerman *et al.*, 2014). Even when a specific UA site is not highly productive, the food produced will supplement a family's food and income (Smit *et al.*, 1996), allowing greater funds for the purchase of other essential items (De Zeeuw *et al.*, 2011). Other advantages of UA include an increased nutritious diet from fresher produce and greater food security and sustainability through enhanced food availability (De Zeeuw *et al*, 2011), along with educational opportunities for inhabitants in cooking, nutrition, and small scale agricultural production (Ackerman *et al.*, 2014).

Even with all the advantages that integrating UA into a city offers, there are some distinct disadvantages that may occur if UA is not managed and designed properly. Most of these issues are due to UA's similarity to conventional rural agriculture (Ackerman *et al.*, 2013; De Zeeuw *et al*., 2011). Water from rivers or canals, recycled through UA, may become contaminated through mixing with industrial or household wastewater. In more intensive UA methods, agrochemicals that are used may lead to groundwater and environmental contamination. When livestock are being managed in urban environments, health risks increase from improper regulation of feed lots, slaughterhouses, manure, and urine (De Zeeuw *et al*, 2011). These disadvantages depend on the type of urban agriculture technique being applied and how each specific system is managed.

The different forms of UA have been categorized based on various characteristics, depending on which literature is being researched. The following are the different methods of classifying UA systems based upon the features being classified:

- Building integration and ground based, space conditioning (non-conditioned or conditioned) (Goldstein *et al.*, 2016);
- Commercial and non-commercial (Weissman, 2012);
- Type and description (Aerts *et al.*, 2016; Hodgson *et al.*, 2011);
- Intended function and self-identity (Neilson and Rickard, 2016);
- General land use, different UA forms and products (Specht *et al.*, 2016); and

- Ecosystem services and biodiversity types (Lin *et al.*, 2015).

In a response to continuous urbanization and the reduction of available land, urban agriculture has become an important center of research for the production local, fresh agricultural products. In an attempt to categorize the different UA methods, this research project will address two main types of urban agriculture that have been generalized by system design. Each of these are capable of overlapping with regard to certain practices (Ackerman *et al*., 2013). The first is considered "ground-based" urban agriculture, which requires some form of open space or land for food production and can be typically found on vacant, underused, or undeveloped lots (Ackerman *et al*., 2013). The second form of urban agriculture can be categorized as "non-ground-based" or "Zero-acreage farming" (Zfarming), where the focus is on intensive agricultural production, integrated within pre-existing buildings or structures requiring increased technological challenges without the use of farmland or open space (Specht *et al.*, 2016).

Ground-based methods of UA usually involve either raised beds or the use of natural soil on the surface, and they can be found on multiple, varying sites (Ackerman *et al*., 2013). Examples of ground-based UA, shown in Table 2.1, include allotment gardens, community gardens, floating farms, pavement gardens, private/backyard gardens, guerilla gardens, demonstration gardens, and large-scale farms. Most of these examples are small-scale farms, likely to be managed privately or communally, and not intended for market production (Aerts *et al.*, 2016; Weissman, 2012; Hogdson, 2011). Even though each of these UA forms have specific definitions, in some instances their characteristics may be shared with others. On the other hand, large-scale farms are mainly designed for high production (Napawan, 2015). Excluding large-scale farms which normally use conventional farming techniques and are located near the urban fringe, most produce generated through ground-based UA methods are consumed by the grower or sold in local farmers' markets (Napawan, 2015; Ackerman *et al*., 2013).

Land used for ground-based UA is normally difficult to obtain control due to the expensive prices and short leases for highly competitive land (Ackerman *et al.*, 2013). Urban agriculture food production through ground-based methods is an effective technique for locally feeding an urban population when land availability is not a limiting factor within a less densely populated area. However, a greater number of cities are encountering high population densities and reduced open spaces and most vacant area remain vacant due to soil contamination (Specht *et al*, 2014).

The second main type of urban agriculture is non-ground-based and this has been termed by Specht *et al*. (2014) as Zero-acreage Farming or Zfarming. Zfarming has become increasingly important in urban food production due to land constraints within urban areas (Ackerman *et al*, 2013). Zfarming involves a higher degree of technological challenges due to its integration within pre-existing buildings and challenges with water, energy, and waste recycling. Other terms created to describe this form of UA are vertical farming and building-integrated agriculture. The primary focus of Zfarming is food production within an urban environment through the non-use of farmland or open space (Specht *et al*., 2014). Methods of production for Zfarming, shown in Table 2.1, include rooftop farms, windowsill farming, indoor farms, and greenhouse farming. Similar to ground-based UA, different forms of Zfarming can be intertwined with each other, possible sharing characteristics. Excluding windowsill farming, Zfarming utilizes either soil-based or aquaponic production and can include some ground based measures of urban food production as well (Thomaier *et al.*, 2015).

Due to the fact that these forms of UA are operated within buildings, most production involves the use of a controlled environment in order to mimic the natural environment and control each environmental variable. This integration of food production within urban buildings provides potential to reduce food insecurity in environments where cropland is limited. However, the potential contamination from air pollution, high investments, and increased operating costs raises significant concerns regarding Zfarming's feasibility (Thomaier *et al.*, 2015; Specht *et al*., 2014). This project will focus on a single form UA that is considered Zfarming and has the potential to produce quality urban agricultural produce through ground-based measures.

Table 2.1. List and Description of Urban Agriculture (UA) Methods

| Form of UA | Type of UA | Descriptions |
|---|---|---|
| *(Aerts et al., 2016)* | | |
| **Allotment Garden** | ground-based | Plot of land subdivided in small parcels that are assigned to and cultivated by individuals or families, usually peri-urban; in the USA also known as community garden |
| **Community Garden** | ground-based | Plot of land cultivated collectively by a group of people |
| **Container Garden** | both | An array of containers, usually plastic or geo-textile, in which vegetables are grown |
| **Edible Green Roof** | Zfarming | Roof of building partially or completely covered with substrate in which vegetables are grown; also applies to container gardens or hydroponic systems placed on roofs |
| **Floating Farm** | ground-based | Container garden or hydroponic system placed on barge |
| **Private Garden** | ground-based | Private plot of land partially or completely cultivated by an individual or family, known as backyard (or frontyard) when attached to private house |
| **Aquaponic** | both | Soil-free greenhouse agriculture in which irrigation water and nutrients are intensively re-used, includes both aquaculture and hydroponic |
| **Pavement Garden** | ground-based | Very small and extensively or intensively planted vegetable garden replacing impervious surfaces on public terrain |
| **Rooftop Farm** | Zfarming | Vegetable farm using containers, raised beds, hydroponic systems or engineered soil placed on roof of a building, |
| **Square Foot Garden** | both | Small but intensively planted, often multi-layered vegetable garden, often in raised beds or in containers |
| **Windowsill Farm** | Zfarming | Growing vegetables in containers on the windowsill or balcony |
| | | |
| *(Weissman, 2012; Hogdson, 2011)* | | |
| **Private/Backyard Gardens** | ground-based | Food production on private property for personal consumtion, locations in backyards, rooftops, balconies, windows |
| **Guerilla Gardens** | ground-based | Unauthorized food production on untended, vacant, private or public land, by individual or group, products for consumption |
| **Demonstration Gardens** | both | Food produced on private or public property, for education, training, and demonstration |

## 2.5 Modified Hydroponic Shipping Container

This project will focus on a form of UA with the potential of providing food in urban areas on varying scales, depending on operating goals, while reducing concerns regarding food quality. This system was termed a modified hydroponic shipping container (MHSC) by Rachel Sparks (2016), who initially studied these units in the Purdue University Agricultural and Biological Engineering Department. A MHSC can be defined as a system for generating high-yield production comprised of at least one container of which contains a growing system and a monitoring system (Mcnamara and Friedman, 2013). MHSC is primarily considered a form of Zfarming, through the use of containers to produce hydroponic leafy vegetables on rooftops. However, it has potential to be ground-based, if placed in a vacant lot and "integrated with a plurality of other modular containers to expand the system horizontally or vertically to fit a space" (Mcnamara and Freidman, 2013). The use of a shipping container for food production results in the need for modification of that device to improve conditions and allow produce to thrive. This modification involves incorporating multiple growth systems or components into a single, efficient operating module. The general components of a MHSC required for food production include (Mcnamara and Freidman, 2013):

- Growing trays;
- A lighting system;
- An irrigation system;
- An environmental control system;
- A monitoring system for the conditions within the MHSC.

Urban agricultural production by a MHSC takes advantage of controlled environment agriculture (CEA) (Specht *et al*., 2014) and can be highly mobile, due to the characteristics of a shipping container in general. Producers or managers can place this form of agricultural production almost anywhere within a city, and can be completely self-sustained, with the main inputs required, for hydroponic operation, being water and electricity.

A CEA is an engineered building or structure capable of maintaining an optimal growing environment throughout the entire year by controlling each environmental variable within the vessel (Ackerman *et al*., 2013; Jensen, 2001). Due to a lack of research on MHSC production, greenhouses are the type of production that is most often compared and used to understand the design and needed components for a MHSC because of the similar characteristic of requiring a controlled environment to enhance indoor production. The systems include the installation of a heating, ventilating, and air-conditioning (HVAC) control system (Schwenk and Chamberlin, 1996), used to maintain an optimal environment for crop production (Brown-Paul, 2015). The main difference between a MHCS and a greenhouse is the material and size of the structure. Greenhouses utilize the sun through a transparent roof, unlike a MHSC, where energy for plant growth is input through utility connections, since it is completely cut-off from the natural environment. This difference will affect the design and needed HVAC components for a MHSC, a major area where research is lacking. The entire climate within the modified shipping containers needs to be optimized, based upon the type of produce and the region where the MHSC is located.

The most common method of food production in CEA systems utilize soilless, hydroponic technology, which allows for higher yields per square foot compared to a conventional rural crop production system (Ackerman *et al*., 2013). Hydroponics is a form of food production which grows plants through water enriched with fertilizers, creating a nutrient solution taken in directly through the roots of the plants. By using hydroponics within controlled environment systems, soil-borne diseases are reduced (Jensen, 2001), growing seasons are extended, and the ability to completely control environmental variables is greater than in other methods of urban food production (Ackerman *et al*., 2013). Negatives with CEA using hydroponic systems are the high initial construction costs and energy requirements, the intensive nature of managing the crop production (Jensen, 2001), and the low acceptance of food produced with soil-less measures (Specht *et al.,* 2016). A model created by Sparks (2016) showed 80% of the total energy consumption for MHSCs are by heating and cooling, totaling 54,200 kWh per year. Continued research regarding the positive aspects of controlling the environment within these structures will further decrease the energy and input costs required.

## 2.6 State of MHSC Production Market

In response to the food insecurities and challenges the world faces in providing food to highly dense and populated cities, multiple companies have commercialized the MHSC method. The market for local produce within urban environments is more apparent than ever before. Several companies have designed and produced their own vision of a modified shipping container for food production. Each have many similarities with regard to the general components, however, each specific design layout, features, and innovations in each offering vary. Four different companies, Freight Farms, Growtainer, Vertical Harvest Hydroponics (VHH), and Cropbox, are selling a type of MHSC. These will be analyzed based on their respective backgrounds, system design and innovations, available potential crops, associated costs, and expected production.

Each of these companies has similar features regarding the design and operation of their respective shipping container crop production systems. In order to produce crops within a shipping container, each company has integrated a climate control system consisting of a HVAC and computer controllers. These computer controllers are used to maintain the environmental settings, along with the ability for remote control to ensure proper growing temperatures and climate. Included within the environmental control system are sensors to measure different variables for feedback into the controller. Also, due to the general design of shipping containers, each company provides a modular capability for their units by stacking multiple containers on top of each other. Another similar characteristic each company provides is production through a hydroponic technology. These products are meant to be “turn-key” systems, meaning they are ready for production instantly upon placement. Even though the main components of a MHSC are shared between each company, each has a specific innovation that is intended to separate themselves from their competition.

Freight Farms was founded in 2010 by Brad McNamara and Jon Friedman and is located in Boston, Massachusetts. Their primary product is called the Leafy Green Machine (LGM), shown in *Figure 2.4*. They have a small-scale version not yet on the market called a Leafy Green Cube (LGC), pictured in *Figure 2.5*. The LGM is a 40’ x 8’ x 9’ shipping container that weighs 7.5 tons and is “outfitted with all the tools needed for high-volume, consistent harvests” (Freight Farms, 2016). The LGM comes in two choices, a LGM Base and a LGM Premium. The LGM Premium comes with more harvesting work space, a dehumidifier, an electric box heater, a sound system, and a more advanced filtration system.

The LGM will require a 60 amp, 120/240-volt single phase connection or a 120/208 three phase connection to supply the 80 KwH of daily electrical use. For the water needed, a garden hose feed or a pre-built LGM water tank capable of providing 10 gallons per day is suggested. These units, and the seeds, nutrients, and some additional gardening equipment, are the only components that the farmer will need to begin operation. Freight Farms uses a hydroponic production system oriented in a vertical fashion, consisting of 265 vertical towers. The nutrient solution is inputted at the top and travels down, through the vertical tower through a drip irrigation system. The company has a patent on their lighting system which consists of vertical LED lights using different red and blue lights to optimize growth.


*Figure 2.4.* Freight Farms' Leafy Green Machine (LGM) (Freight Farms, 2016).


*Figure 2.5.* Freight Farms' Leafy Green Cube (LGC) (Freight Farms, 2016).

Produce available for production through Freight Farm's product includes:

- Lettuce –romaine, butterhead, lola rosa;
- Brassicas – kale, swiss chard, arugula; and
- Herbs – basil, oregano, mint.

Freight Farms has provided yield information and operating costs for their LGM producing mini-head lettuce. Based on the number of farmers already producing mini-head lettuce in LGM's, they average 40-70 pounds per week production, approximately 88 cases. Operating costs consist of water, electricity, plant growth needs, site expense and their "farmhand connect", integrated monitoring system, which totals an average of $10,400 per year. With regard to other business costs, the average per year is $7,200 for insurance payments, packaging requirements, safety equipment, and delivery expenses. The Freight Farm prospectus report states mini-head lettuce sell for $12.50 a case, totaling $57,000 in revenue annually. Taking into account the operating and business expenses, they predict each farmer averages $39,000 in profit per year for a single LGM (Freight Farms, 2016). The LGM Base model retails for $82,000, and the LGM Premium is $85,000. In order to increase the usability of their products, Freight Farms offers a mobile application connecting the farmer to the status of the environment and nutrient conditions. The app also includes a "Farmhand Shop", which contains all the products and equipment a farmer may need for production. Additionally, Freight Farms offers a training session called 'Farm Camp', which teaches the farmer about operations, maintenance, and how to optimize crop growth for that specific location.

Growtainer is a company that focuses on a MHSC capable of providing research opportunities for students to learn more about this form of crop production along with the potential for local, fresh food production. They currently have two "Growtainer containers" located at The Texas A&M Agrilife Research Center in Dallas (Growtainers, 2016). Their MHSC is the usual 40' x 8' x 9' shipping container capable of full environmental control. The hydroponic production design within their device is horizontal with four sections, as shown in *Figure 2.6*. Growtainer has two innovations specific to their design, "Growracks" and "Growtroller". Growracks is a lightweight aluminum rack where the crops are produced. Each Growrack is capable of varying propagation levels to allow for various crops, based on each crop's height requirements, to be produced. The lighting used for plant growth is integrated into the Growracks. The Growtroller is Growtainer's environmental control and sensor system. One advantage the Growtroller provides is the "HydroCurve", changing the ebb and flow system of the nutrient supply, based on the varying environment surrounding the plant (Growtainers, 2016). There is no specific crop information provided by the firm, but Glenn Behrman (Nijs, 2014), one of the co-founders of Growtainer, states the Growtainer can produce "vegetables, leafy greens, and many other specialty crops". Due to the research orientation of their product, there are no production metrics published. Growtainers are for sale at $75,000 (Nishihara, 2015).


*Figure 2.6.* Shipping container and hydroponic system design available by Growtainer (Growtainers, 2016).

Another company currently producing MHSCs is Vertical Harvest Hydroponics (VHH), founded in 2013. VHH is located in Anchorage, Alaska, and their product is called a Containerized Growing System (CGS), pictured in *Figure 2.7*. The focus region for VHH is in remote areas where crop production is highly variable and not year-round. Similar to the MHSCs produced by other companies, the CGS is a standard 40', total environmental control unit with a control and sensing system that can be remotely controlled. The production method is, again consistent with the majority of indoor farming, hydroponics. The six hydroponic racks contain horizontally positioned trays and are shown in *Figure 2.8*. These are capable of holding 300 to 450+ plants and being stacked on top of one another and adjusted per type of plant. One of the innovative design aspects the CGS has compared to other companies is the multiple heating options for the highly rural locations VHH's consumers live. CGS owners can supply heat to their unit by: fuel oil, kerosene, diesel, natural gas, or liquid propane furnaces; biomass burners; electric resistance or direct; natural gas convection (VHH, 2016). According to their website, the CGS is capable of producing "23,000 to 46,000 heads of greens per year", depending on the type of crop and rack configuration (VHH, 2016). Crops capable of being produced with the CGS include lettuce varieties, kale, arugula, mint, cilantro, dill, thyme and basil. A single CGS is for sale at $100,000, and the company reports two units have been placed commercially (DeMarban, 2016).


*Figure 2.7.* Containerized Growing System (CGS) from VHH (VHH, 2016).

*Figure 2.8.* Hydroponic growing system within Containerized Growing System (CGS) (VHH, 2016).

The last company to be evaluated is CropBox. These agricultural producing shipping containers are developed by Williamson Greenhouses, who have contributed to the tobacco industry by developing hydroponic techniques to grow tobacco products in greenhouses. The CropBox grows its produce through a horizontally oriented hydroponic system. The racks where the plants are located are stacked on top of each other with a walkway running in between each set of racks, as shown in *Figure 2.9.* The lights are located under the racks, creating a single unit. The main concept behind CropBox is to create the most affordable product. The company uses a normal 40’ shipping container, but their modifications, to allow for food production, are with cheaper materials, which in turn allows their unit to be sold for $54,000, much less than their competitors

*Figure 2.9.* Hydroponic set-up for CropBox (Cropbox, 2016).

There are three different CropBox products, each capable of growing different produce. The first is for herbs, greens, and lettuce, capable of growing "up to 12,000 pounds each year". Cropbox claims that a one acre of field lettuce is required to match a single crop cycle within the 320 square foot CropBox. The second type of CropBox is not yet available, but it will have the potential to grow 7,000 pounds of strawberries per year. The last type is for microgreens and fodder, and it yields 140 tons of fodder or 84 tons of microgreens each year, capable of feeding 17 horses per CropBox (Cropbox, 2016). Farmers using the CropBox will be able to manage their operations completely through a smartphone. According to their website, the "CropBox uses 90% less water and 80% less fertilizer than conventional production". This conventional agriculture can be defined as the production of crops in large-scale operations. They offer an expected business model based on different crop production. When producing arugula, the company estimates around 8,000 pounds yield per year. This is then projected to provide an income of $40,560 per year for a single CropBox. This results in an overall net income of $17,522 per year, making the payback period about 35 months to get the initial investment returned (Cropbox, 2016).

# CHAPTER 3. PLAN AND DESIGN OF MHSC (PRELIMINARY DESIGN)

## 3.1 Introduction

As the world's population continues to rise, urbanization is placing pressure on our current available crop land. As a result, urban agriculture has become an increasingly important research area in helping meet the expected upturn of food insecurity. The majority of today's crop production, within urban agriculture, is by community farms. however, with limited land in cities, technological advancement is needed in order to produce more local food with less land. One of these new potential technologies is crop production within shipping containers. Commercially available shipping containers are outfitted with a hydroponic system capable of producing various crops and are modified to have complete environmental control for an optimal plant growing climate. However, due to the recent development of this technology, there are many unknowns regarding how efficient and sustainable these modified hydroponic shipping containers (MHSC) can be. The main goal of this project is to design a MHSC in such a way to allow further research to be conducted and increase our knowledge on how to optimize and improve this method of urban agriculture. This planning and design section will detail the different systems and equipment used, how equipment fits with the design (why a particular design/part was chosen), explain the importance of each component with respect to reaching the design goal, and include AutoCAD drawings of the different systems and components. The different systems and components to be detailed in the MHSC include: shipping container, growing system, irrigation system, and environmental control system.

## 3.2 Key Concepts and Ideas

In the initial stage of the design process, specific aspects of this MHSC were established in order to determine the design goals. The concept of producing crops within a shipping container for a local, urban community is relatively new compared to the existing technology and research regarding conventional rural agriculture. For this reason, there is little to no research published detailing the necessary components, optimal design, and production potential. Some companies with either established or potential MHSC products have published information regarding operation costs and yield estimates, but these have yet to be investigated extensively and stand as merely projections crafted by the manufacturers of these units. This project aimed to design and construct a research oriented MHSC that will allow for future experiments and various experimentations to be implemented to further investigate the numerous unknowns involved in urban crop production through MHSCs.

For the MHSC to be a viable research device, the design will consist of four separate hydroponic growth areas. Each growth area will be designed identically and will operate on a closed loop system, allowing precise crop production and nutrient uptake in each. This will allow for individual treatment combinations to test different experiments on growing process within, while maintaining a common set of environmental conditions. In order to provide the needed requirements for these different treatments and experiments, the entire MHSC is designed to be highly adjustable in many aspects. This flexibility characteristic of the MHSC will entail different production designs by adjusting certain components to better understand the most efficient and optimal production design. Crop production through controlled environments and hydroponic systems involves many different needed components and equipment of which need to be interacting in specific ways for optimal production to occur. The MHSC is designed to offer the ability to change certain variables of each component and conduct experiments to analyze the results. In addition to the design goal of being research oriented, the MHCS will be designed to allow educational programs to take advantage of its operation.

## 3.3 Constraints

There were certain constraints for this project instrumental in determining the design of the MHSC and equipment used to complete the final build. This project did not have a definite budget. However, the funds were limited, influencing the quality and type of equipment purchased. Time was also a constraint, affecting the amount of work capable of being accomplished and scale of the project. The shipping container that was used as the overall structure and housing component was donated, resulting in the module used to design a research, hydroponic crop production system within. Similar with the characteristics of the different versions of a crop producing shipping container companies are developing, the final product of this project needed to be a “turn-key” system, which meant it would need to have most of the necessary systems and modifications required for crop production. As stated previously, the design of this MHSC was developed behind the need for research oriented module and not for production measures. The final MHSC product needed to be able to have educational potential, which also meant there needed to be adequate space dedicated for movement and working areas.

## 3.4 Proposed Preliminary Design

The shipping container used for the MHSC was a standard, 40’ x 8’ x 9’ recycled cargo container, (*Figures A.1* and *A.2*, refer to AutoCAD drawings of each component and system design, found in Appendix A), previously used for transportation of goods. The shipping container is an important component behind this form of urban agriculture. It provides a high mobility factor, by the original intended nature of a shipping container, allowing crop production in numerous locations and environments throughout a city or urban environment. The rectangular shape, fairly large size, and modular, stackable design, offer the potential for multiple MHSCs to be used to produce crops in a small land area, dramatically increasing crop production with minimal land area. Additionally, shipping containers are designed structurally capable of storing an assortment of products, providing the strength needed to handle the modifications necessary for hydroponic crop production.

### 3.4.1 Layout of Shipping Container

The design of the layout within the shipping container (*Figure A.3*) focused on the ability to move around and host multiple people at one time. The four growing chambers, containing the necessary systems for crop production, are located in the four different corners of the container, with a 2’ walkway in between them. Each growth chamber was 15’ long, length of the PVC pipes, and 2.5’ wide. A 3’ area in the middle of each growth chamber is designated as the location for the different components of the irrigation system, including the reservoir. The 3’ area, where the irrigation system drained to, was necessary because a high percent of operations is expected to occur in monitoring and adjusting the concentration of nutrients of the irrigation system, cleaning pumps and varying the drain height. The original doors to the container were designated the entrance, shown in *Figure 3.1*, rather than fabricating a door into a wall. On the opposite end of the door, labeled “REAR”, is a 4’ area that will serve as a storage area for extra equipment. In the nursery location (*Figure A.3*) a designated bench will provide an area to plant the seedlings and the different operations involved in maintaining initial growth until transplantation occurs. For this project, the shipping container is located on a chassis, requiring the construction of a deck, pictured in *Figure 3.1*, (*Figures A.4* and *A.5*), and stairs on the door end for easy access into the container. Everything within the shipping container was designed to allow easy mobility, including access to all plants in each growing tray.


*Figure 3.1*. Existing doors of the shipping container will serve as the entrance.

There were modifications to the structure of the shipping container in the design which instrumental in developing a MHSC with experimentation potential. Access to the water and electrical inputs were placed near the door. This ensures the inputs would not interfere with other components, and it also increases ease of access eliminating the need to walk through the container to maintain the connections. Another modification was the installation of 1.5” deep B-line strut channel, shown in *Figure 3.2*. Seven sections were welded on the two 40’ walls (*Figure B.1*, refers to respective AutoCAD drawings of design, found in Appendix B), pictured in *Figure 3.3*, respectively 5.5’ apart from each other, and two welded 4’ apart on the rear wall (*Figure B.2*). These conduits, located on the wall, were 7’ long as to provide attachment channels throughout the container. Strut channel that was also welded to the ceiling (*Figure B.3*), designed to mirror the four different PVC pipes of the growing trays. The strut channels provide universal placement connectivity for plumbing, electrical, ductwork, and data acquisition lines. *Figures F.1, F.2, and F.3* (refers to respective AutoCAD drawings of design, found in Appendix F) show electrical and plumbing schematics, taking advantage of the strut channels to provide the necessary energy and water to each component.

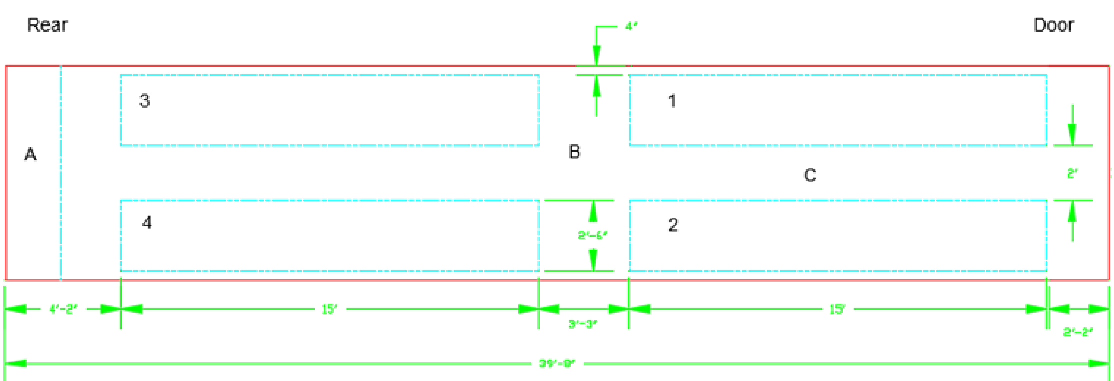


*Figure A.3.* Overhead Full MHSC Layout

The pieces of strut channel on the ceiling were 15' long and 8" apart, shown in *Figure 3.4*, designed for different design set-ups of the hydroponic growing systems, including the potential for different crops to be produced. These sections will hold the water pipes and electrical wiring, removing them from the working and operating areas. Those welded to the ceiling will house the lighting units, material separating the different chambers and possibly plant vines. The strut channel integration was designed to provide the possibility of different lighting combinations, plant varieties, and growing system designs to occur, further improving the ability to conduct different experiments testing certain variables. The main idea behind designing and constructing the interior wall strut channel was to provide a high number of attachment points for any future change in design or additional modifications. One-quarter of the shipping container floor is constructed out of wood and to limit the potential for wood rotting, the floor had two coats of clear, waterproofing wood protector applied prior to the start of interior construction.

*Figure 3.2.* Close up of the 1.5" B-line strut channel used for universal attachment points.

*Figure 3.3.* Strut channel pieces welded to walls of shipping container.

*Figure 3.4.* Strut channel pieces welded to ceiling of shipping container.

### 3.4.2 Growing System

There are two primary designs of the orientation of hydroponic growing systems, horizontally or vertically. Companies producing MHSCs have implemented both. Horizontal designs increase their potential for production by stacking multiple “growing trays” or racks on top of one another or in multiple rows. For this project, and the fact this MHSC is not intended for intensive production, each of the four growing systems will consist of a single growing tray and the lighting components. A growing tray is considered the physical unit that will house the plants and growing mediums, provide a structure for nutrient solution to flow through, variable leg components, and includes the lighting components; all of which can be seen in *Figure 3.5*. There will be four growing trays within the MHSC, one in each growth area. When designing the layout of the growing system, it was important to maximize the amount of plants capable of being produced while maintaining space for movement and operations to occur.

*Figure 3.5.* Growing system: PVC pipes, leg components, and lights.

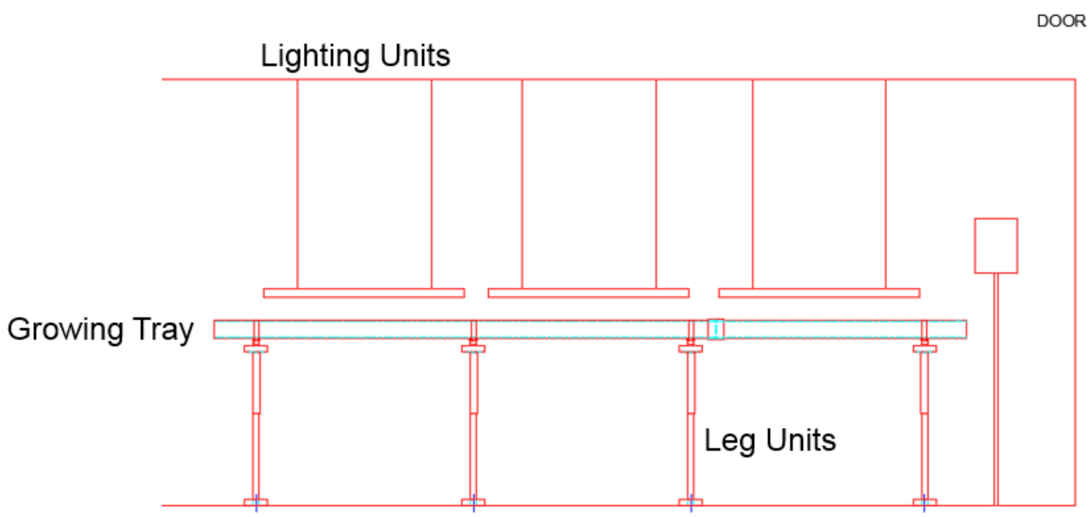


*Figure C.9.* Rightside Full Growing System

The first main component of the growing system was the growing tray. This plant housing component was made of 4” diameter PVC piping (*Figure C.5*). PVC was chosen as the material due to its relatively lower cost and ease of machining, which was necessary in this project. This size of PVC also allows varying hydroponic methods to be conducted, improving the experimentation potential of the system. As noted earlier, this research oriented MHSC was not intended to reach maximum crop production, however, there was a need for uniform growth to ensure the design offered precise experimental results. After the orientation and layout of the four growing trays were finalized, it was determined each tray would be 15’ long and 2.5’ wide, consisting of 4 PVC pipes (*Figures C.1* and *C.2*, refers to respective AutoCAD drawings of design, found in Appendix C). A single PVC pipe was only available in 10’ increments, resulting in unifying a 10’ pipe with a 5’ segment to produce growth tubes (*Figure C.6*). Twenty-two, 2” holes were drilled into each PVC pipe (*Figure C.4*), resulting in the potential for 88 plants per growing tray. A distance of 8” in between each hole and 7.25” separating the PVC pipes (*Figure C.3*) was designed to allow for proper growth area, ensuring no limitations from neighboring plants, (*Figure C.7*). The 2” holes were sized to hold the net cups containing the growing medium and plant. On each of the PVC pipes, a Flexible PVC Cap Fitting, shown in *Figure 3.6*, was included in the design to hold the nutrient solution within the pipes, but also, allowed access to the inside of the pipes for cleaning and maintenance.


*Figure 3.6.* Plastic end caps on each end of growing trays.

The next major component of the growing system was the support for the growing trays. The support component consisted of five parts, designed to allow for varying heights of the growing tray and numerous different slopes. The ability to adjust the slope, at which the growth tubes function and the plants grow, was intended to provide experimental opportunities with the height of solution, ratio of aeration, and flow rate of the nutrient solution within the growing trays to determine the most optimal set of variables for plant growth. The four PVC pipes, were attached to 1.5" B-line strut channel by PVC clamps, four per pipe (*Figure C.3*), pictured in *Figure 3.7*. Then, each B-line strut channel piece was bolted to 2" x 4" wood boards, providing increased support strength to stabilize the growing trays. The wood boards were covered in waterproofing wood protector to reduce the potential for wood rot and increase its longevity. Two legs were attached on either side (totaling eight leg per growing tray) of the wood board, providing the necessary support for the entire growing system (*Figures C.2* and *C.3*). Each one of these legs were intended to be adjustable, providing different height options of the growing trays and varied slopes during growth periods.

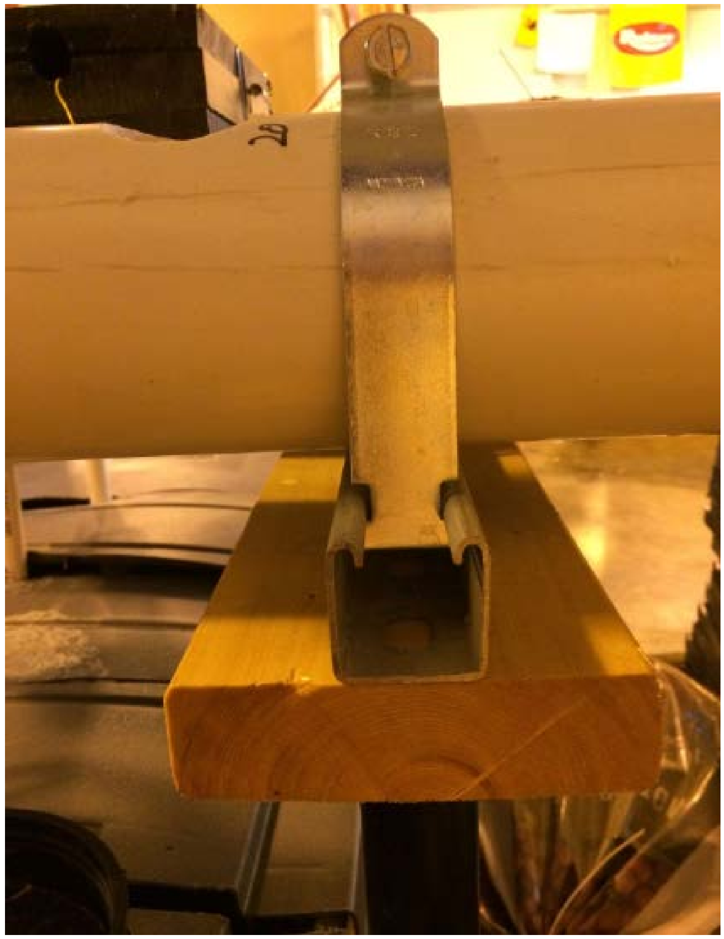

*Figure 3.7.* Attachment of PVC pipes to support system using PVC clamps, strut channel, and wood board.

The lighting is the last component of the growing system. In most commercial MHSC designs, the lighting component is attached to the growing rack, creating a single unit. However, for this project's MHSC, the lighting design will take advantage of the 1.5" B-line strut channel sections that were welded to the ceiling. This was designed to allow different types of lighting units and various lighting sources to be implemented for experimentation. There will be a total of six lights per growing tray, although this can be adjusted in future designs. The fluorescent lighting units were found to consume 12,300 kWh per year (18% of total energy consumption) in producing lettuce in a 36-day cycle (Sparks, 2016).

For this research project and the budget given, the lights were designed to use 120-volts bulbs in T8 American Fluorescent High Performance ballasts. The lights were positioned in two rows, 5.5” away from the grow tray surface, shown in *Figure 3.8* (*Figures C.8* and *C.9*) this design allows each of the intended plants to receive adequate and equal amounts of light energy for proper growth. By suspending the lighting ballast from the B-line strut channel with adjustable wires, experimental tests can be conducted to further understand the optimal light source and light distance from plants. Additional lights will be fabricated at the rear of the shipping container, to B-line conduits on the ceiling, to ensure proper lighting occurs for working and different operations.

Lastly, there will be lights for the nursery area, also located at the rear of the shipping container, consisting of the same type of lights as the growing trays, and designed with the same potential for adjustability. Each light unit in the MHSC was intended to be automatically cycled on and off based on the necessary time period each needs to be operating. This was designed to provide the needed light for plant growth, imitating the natural environment, and improve efficiency by limiting wasted time and electricity. The electrical input required for the lighting units will need to be outsourced, brought into the shipping container near the door entrance through a fabricated entrance. The wires from the outside electrical source will enter through this hole, connect to the distribution point, and then run along the walls and ceiling via the welded conduits, and finally will be fixed to each lighting unit.

*Figure 3.8.* View of lights above growing trays.

### 3.4.3 Irrigation System

Hydroponic growing systems grow plants without the use of soil. The substitute for soil is de-ionized water, from reverse osmosis or distillation, with nutrients matched to the needs of plants, to create the nutrient solution necessary. Each growing chamber consists of a single, closed circuit irrigation system, further increasing the quality of potential experiments. The irrigation system was designed to limit the amount of light exposed to the nutrient solution, reducing the potential for bacteria growth. In the preliminary design, the irrigation system consisted of (per growth chamber) a reservoir, a pump, hoses, a distribution mechanism, and a drain for each PCV pipe (*Figure D.1*, refers to respective AutoCAD drawings of design, found in

Appendix D). The reservoirs would be located near the center of the shipping container, in the 3' designated area between the growth chambers, and the pumps will return the nutrient solution to the opposite end of the growing trays (*Figure D.1*).

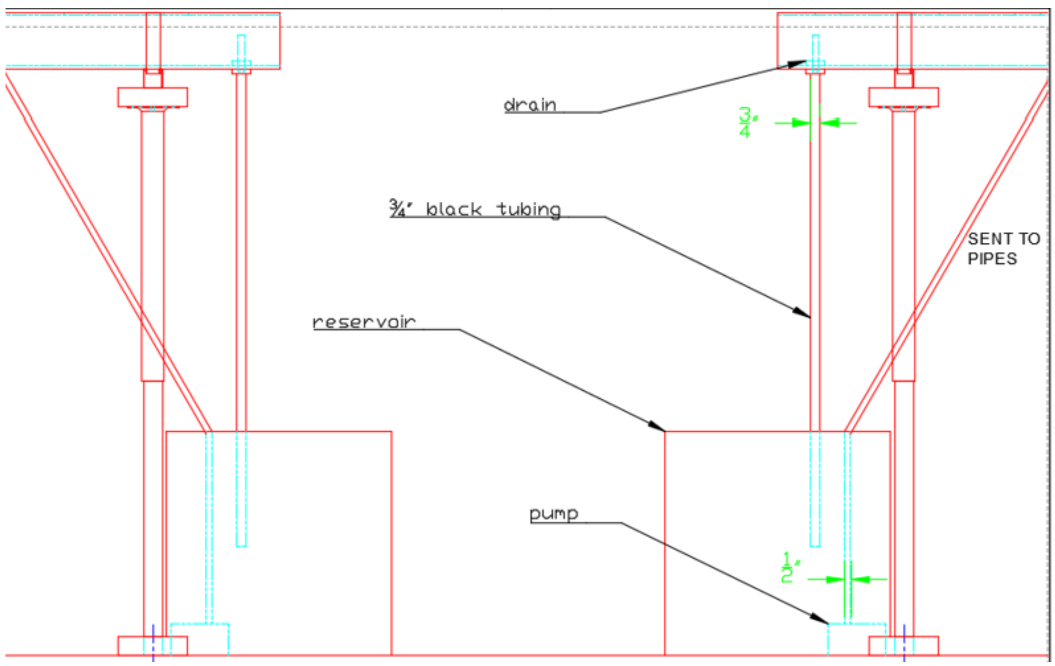


*Figure D.1.* Rightside Reservoir Drain and Pump

The main requirement in designing the irrigation system, except for the drain, was to adequately size the different components. Each PVC pipe drained into a single reservoir, which was a 50-gallon plastic Sterilite tote, pictured in *Figure 3.9*. The 50-gallons were required due to the volume of water potentially held in each PVC pipe. The reservoir needed to be able to hold the maximum amount of nutrient solution running through the growing system. In the preliminary design, the single pump was placed inside the reservoir, returning the nutrient solutions back to the beginning of the growing trays via ½" diameter, black tubing. The pump, located in the reservoir, is shown in *Figure 3.10*. The solid black color of the tubing was intended to limit the amount of light exposure to the nutrient solution. In order to maintain the design goal, the pump, shown in *Figure 3.10,* was an adjustable flow pump, capable of varying flow rates with a maximum rate of approximately 3 gallons per minute (gpm). Using a single pump for each growth chamber was found to require 1,330 kWh per year (2% of total energy consumption) when producing lettuce on a 36-day cycle. Similar to the lighting units, the pumps were designed to allow for automatic control. To provide equal flow and volume of nutrient solution to each pipe, a delivery manifold, which can be seen in *Figure 3.11,* was designed at the front of the growing trays, equally distributing water to each PVC pipe through four separate ¼" drip irrigation tubes, one for each PVC pipe.

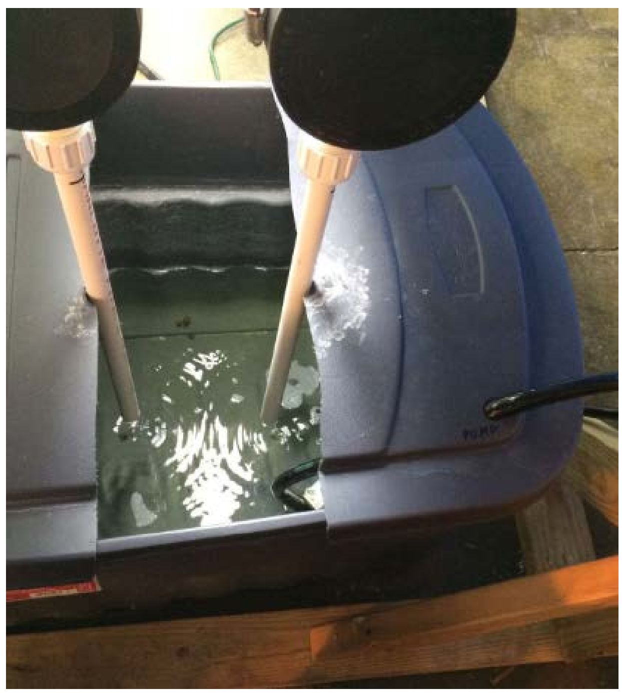

*Figure 3.9.* Growing tray draining into reservoir.

*Figure 3.10.* Pump and black tubing of irrigation system.


*Figure 3.11.* Delivery manifold with tubing delivering water to each PVC pipe.

A challenge in the irrigation system design was adjustment of the volume of nutrient solution, and thus the amount of air, within the growing trays while a growth cycle is in progress. Optimal plant growth requires a specific water to air ratio, especially in hydroponic systems because these, and light source, are the only material inputs. To allow future experiments comparing this ratio, a variable drain was designed. Another advantage of this variable drain was due to the large sized PVC pipes used in this research project. In the early stages of plant growth, the roots are very small in length, growing over the length of the growth period.

To provide nutrients via water to these roots at all stages of growth, different heights of the nutrient solution were required. The variable standpipe drain used a ¾" double ended slip joint and a ¾" PVC pipe, capable of adjusting the PVC pipe to the height of water desired, shown in *Figure 3.12*. Each growing tray, will contain four drains, one for each 4" PVC pipe, each delivering the nutrient solution directly to the reservoir with no exposure to light as seen in *Figure 3.9*. The preliminary design included the slope of the growing trays to be 1%, or a 1.8" drop from beginning to end. This of course can be adjusted due to the variable leg designed as part of the growing tray based on the desired flow rate and volume of nutrient solution needed.

*Figure 3.12.* Preliminary drain for irrigation system.

### 3.4.4 Environmental Control System

The control of the various environmental factors within the shipping container is arguably the most important feature of the MHSC. In conventional agriculture, farmers are limited to a specific period of the year where the temperature, soil conditions, and weather allow optimal growing conditions. The same optimal growing conditions are needed for crop production within a shipping container. However, modifying the shipping container with certain environmental control components, constant optimal growth climate, results in a greater growth period for crop production. The central method for controlling the climate conditions within both a shipping container and buildings is through a HVAC system: heating, cooling and ventilation. In this project, the modifications were intended to further improve the ability to control the different growing factors within the shipping container. The preliminary design for controlling the growing conditions within the MHSC for this project was minimalistic and included paint, insulation, and ventilation. Future intentions of increasing the amount of environmentally controlling components were outside the scope of this project. Each modification was designed with future experimentation in mind, ensuring each of the four growth chambers would have equal environmental control. In the winter months (Jan., Feb, and Dec.), 60% of the heat loss is from the shipping container walls and ceiling (Sparks, 2016). The heat loss and gain percentages can be found in Table 3.1.

The first step in improving the growing conditions within the shipping container was to improve the loss and gain of heat through conduction from the walls. In the summer months, the sun beats down and heats up the metal container, increasing the temperature within. On the other hand, in the winter months, a large amount of heat is lost, without any modifications, due to the thin walls with little insulation qualities (Sparks, 2016). The exterior surfaces of the shipping container were covered in two coats of an oil-based, white paint intended for steel surfaces, shown in *Figure 3.13*. The white paint was designed to reflect the sunshine, reducing the amount of heat gain in the summer months. The interior surfaces of the shipping container were also painted white, pictured in *Figure 3.14*. However, the paint had non-toxic qualities so as to not expose future plants to potential environmental harm. The interior white paint was intended to help reflect the interior lights back to the plants, improving their efficiencies, but also, increase visibility within the shipping container.

*Figure 3.13.* Exterior painted shipping container.

*Figure 3.14.* Interior painted container.

Next, 1” thick, R-5.0 insulation, seen in *Figure 3.15*, with moisture resistant qualities, was installed on each of the interior walls. Each insulation section was 4’ x 8’, when glued to the walls of the shipping container, there was, roughly, a 10” gap in between the top of the insulation panel and the ceiling, leaving room where the ventilation ducts would be installed (*Figures E.1* and *E.2*, refers to respective AutoCAD drawings of design, found in Appendix E). The insulation will act as a thermal resistance barrier for the shipping container, limiting the amount of heat lost in the winter months, as well as reducing temperatures during summer months. The walls were considered the largest source of heat loss and gain due to the highest square footage of the shipping container, and unlike the roof had more severe solar inclination angles during the summer months (Sparks, 2016). Lastly, white, fiberglass reinforced plastic (FRP) wall paneling, with the same 4’ x 8’ dimensions, were installed, covering the exposed insulation. Insulation is extremely flammable, so the FRP paneling is a safety precaution. Looking at Table 3.1 (Sparks, 2016), the greatest percentage of heat loss is during winter months. By providing insulation and paint, the growing period can be extended significantly during these months.

*Figure 3.15*. Insulation on all walls of container.

Table 3.1. Monthly Heat Loss and Gain by Different Components (Sparks, 2016)

| Month | Contribution to Monthly Heat Loss or Storage (%) | | | Contribution to Monthly Heat Gain or Storage (%) | | |
|---|---|---|---|---|---|---|
| | Structural | Ventilation | ET | Structural | Ventilation | Lighting |
| Jan | 68.7 | 30.0 | 1.3 | 0.0 | 0.0 | 100.0 |
| Feb | 66.6 | 32.0 | 1.3 | 0.0 | 0.0 | 100.0 |
| Mar | 46.5 | 52.1 | 1.4 | 0.0 | 0.0 | 100.0 |
| Apr | 27.0 | 71.1 | 1.8 | 0.0 | 0.4 | 99.6 |
| May | 15.3 | 80.7 | 3.9 | 9.3 | 49.9 | 40.8 |
| June | 1.9 | 82.2 | 15.9 | 13.1 | 71.2 | 15.7 |
| July | 0.3 | 77.1 | 22.7 | 13.3 | 73.1 | 13.6 |
| Aug | 1.6 | 83.6 | 14.8 | 12.8 | 71.7 | 15.5 |
| Sept | 13.0 | 81.5 | 5.5 | 9.5 | 59.3 | 31.2 |
| Oct | 29.2 | 68.8 | 1.9 | 0.4 | 8.0 | 91.7 |
| Nov | 45.2 | 53.4 | 1.4 | 0.0 | 0.0 | 100.0 |
| Dec | 64.0 | 34.7 | 1.3 | 0.0 | 0.0 | 100.0 |

The implementation of a ventilation system was the final step in environmental control system for the MHSC (*Figure E.7*). Ventilation was designed to allow the movement of air throughout the shipping container. The movement of air was intended to cool the plants, through higher evapotranspiration rates, during summer months and remove stale air during winter months. The intake of outside air increases the carbon dioxide levels within the shipping container, required for plant growth.

The ventilation system will consist of a fan, exterior exhaust mount (*Figure E.3*), set of ducting, holes in the floor, and two dampers. There were two initial designs for the ventilation setup. In both designs, the components were the same, the fan was to be located at the top center of the rear wall, where the exhaust penetration was found (*Figure E.8*). Outside air will enter the container through 3” holes drilled along the bottom of the container, with a mesh filter to keep animals out, located near the door and 3’ area in the middle of the container (*Figure E.9*). The ventilation fan (*Figure E.4*) for the MHSC was sized based on the maximum amount of air changes per hour during the summer months. At exterior temperatures above 70 degrees Fahrenheit, 60 air changes per hour would be required to maintain adequate temperatures (Sparks, 2016). To reach 60 air changes per hour, a fan capable of 600 cubic feet per minute (cfm) was needed. A Dayton High Volume Direct Drive Forward Curve Blower was to be installed, consisting of a single-speed fan, 1/3 hp motor, 1725 rpm and capable of moving air at 985 cfm, shown in *Figure 3.16*. Ventilation requires the least amount of energy input, 1% of the total energy consumption per year, because it will be in operation during the summer months. The ventilation fan required 8” ducting based on the intake diameter. The ductwork desired was Easy Flow, black-inside foil ducting, capable of reducing fan noise and containing perforations to increase air movement throughout the ventilation system. A 9” x 6” rectangle was cut into the shipping container rear wall for the exhaust. Shown in *Figure 3.17,* on the exterior side of the exhaust hole would have the exhaust mount, protecting the fan from any outside harm (*Figures E.5* and *E.6*).

*Figure 3.16.* Ventilation fan mounted to rear wall.

*Figure 3.17.* Exhaust mount on exterior of shipping container.

*Figure 3.18.* Ventilation ductwork and fan on rear wall.

In the first design, a central single duct was connected to the ceiling, via the B-line strut channel pieces, and meeting the ventilation fan at the rear of the container. This design added simplicity to the ventilation system from the single duct configuration. However, the design did not provide equal environmental control to all growth chambers. The second, and final, design consisted of two sets of ducts, on each side of the shipping container ceiling. Shown in *Figure 3.18*, at the rear corner of each side of the shipping container, the ducts would be fastened to a 90-degree elbow, then another set of ducting connected to a tee joint, which then completed the ventilation system by reaching the ventilation fan (*Figures E.7* and *E.8*).

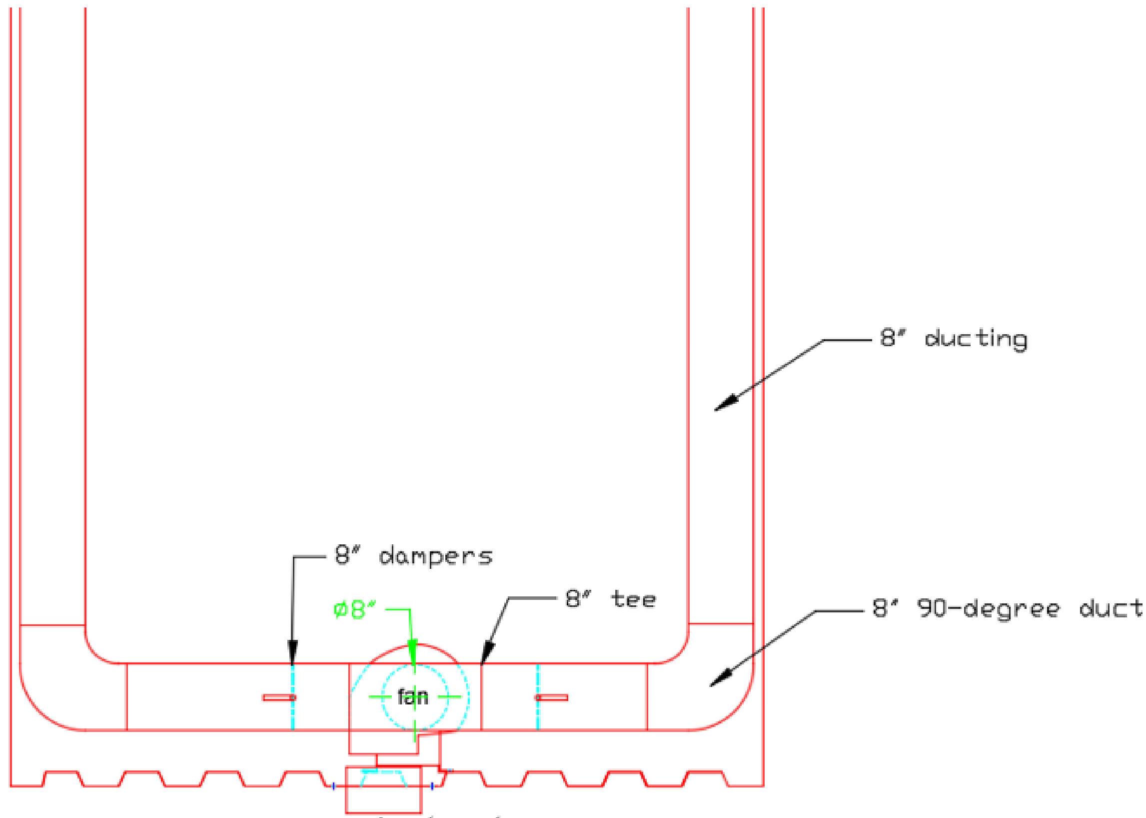


*Figure E.6.* Overhead Ventilation Assembly

From the results in Sparks' (2016) research, it was determined variable ventilation rates were needed. During summer months, the majority of heat entering the shipping container is from the intake of air through ventilation. By reducing the ventilation rate of air changes per hour during this period to a minimum, the change in temperature can be controlled more efficiently. On the other hand, during winter months, a relatively higher ventilation rate is needed to reduce the potential for high humidity and low carbon dioxide levels. To provide this variable ventilation rate, two dampers, one for each set of ducts, have been installed (*Figures E.7* and *E.8*). The dampers can be adjusted to limit the amount of air capable of traveling through the ducts, thus increasing or decreasing the air changes per hour.

## 3.5 Additional Obligations

The final MHSC design and build for this project has current intention of being placed just north of the Imagination Station, located in Lafayette, Indiana. The MHSC will serve as an educational tool for those involved within Imagination Station as well as an experimentation tool for researchers. To further improve the education experience and marketing for this project, certain requirements will need to be met. A sign indicating the research team, Purdue, Imagination Station, and sponsors is being placed on both sides of the shipping container, shown in *Figure 3.18*. A hands-on model of the growing system will need to be created, including a poster regarding the process of crop production within a shipping container.


*Figure 3.19.* Sign design for each side of shipping container.

## 3.6 Design Assessment

Crop production within a shipping container requires numerous different systems and components, operating together in order for optimal growth. For each system and component, there can be varying methods of designs and settings, further complicating the overall production system. The MHSC designed in this research project provides a device to experiment and test those variables in an easily replicate able manner.

The layout of the different systems within the shipping container were designed with usability and sustainability in mind. Providing enough room, for multiple people, to walk and perform operations as easily as possible. This includes placing the electric and water input locations near the doors, the 2' walkway in between the growth chambers, designing each growing system to drain towards the center where a 3' space is located, and constructing 1.5" B-line strut channel throughout the container. The growing system was designed to be the main location of crop production with capabilities of varying each different component to experiment optimal growing conditions. In conjunction with the irrigation system, different plant types, varying light sources, flow rate of nutrient solution, distance between lights and plants, and concentration of air within the pipes are able to undergo variation, facilitating a variety of potential experiments. Simple modifications were made to improve the environmental control within the shipping container, impacting the growing system and irrigation by creating increasingly favorable conditions for plant growth. To further comprehend how well this design operates, a bench test was undertaken, replicating the different MHSC systems in a test of the production of Butterhead lettuce with one of the growth units.

# CHAPTER 4. BENCH TEST

## 4.1 Test Unit Design

Once the design process was completed, an experimental test was conducted consisting of three cycles of growing Butterhead lettuce. This bench test was intended to provide a further understanding of the feasibility and usability of the MHSC design, on a small scale scope, before implementing the design full scale. For the purposes of this project, the goal was to observe each system and how they integrate with each other in order to find any problems with the design and where certain improvements needed to be made. The test replicated each component and system within a single growth chamber. This test unit was placed in the Agricultural & Biological Engineering building, Room #106 work shop at Purdue University, where the bench test growth trials took place.

In order to simulate the environmental conditions of crop production in a shipping container, a wooden frame, 5’ x 20’, was constructed, surrounding the growing trays, pictured in *Figure 4.1.* To rid light from entering the experiment from outside sources, a dark colored tarp was draped over the wooden frame, covering the entire growing system, shown in *Figure 4.1*. Fluorescent lights were attached to the wooden frame by adjustable wires, *Figure 4.2*, granting the capability to vary their distance from the plants. The irrigation system was constructed on par with the preliminary design, which included a single pump, plastic tote for a reservoir, a mechanism to distribute equal nutrient solution to each pipe, and the drain component, as seen in *Figures 3.9, 3.10 and 3.11*.

*Figure 4.1*. Growth unit during bench test.

*Figure 4.2*. Lighting units in experimental test.

## 4.2 Experimental Process

The experimental test consisted of three growing cycles of Burpee Butter Bowl lettuce over the period of three months. For each cycle, lettuce plants were planted, by hand, into Rapid Rooter grow plugs (growth medium), shown in *Figure 4.3* with Butterhead lettuce sprouting, which were soaked in water. The Rapid Rooter plugs containing lettuce seeds were then placed in a nursery growing tray where germination and root growth first occurred. During the nursery stage, lights were placed at three inches above the plugs. After seedlings emerged,0.25 to 0.50 gallons of nutrient solution was added each day until root growth was mature enough for transplantation to the PVC growing trays (Sparks, 2016). Prior to planting in the PVC growing trays, the Rapid Rooters were placed into net cups containing aeration rocks (Hydroton pebbles), pictured in *Figure 4.4*. For each cycle, water within the hydroponic system was introduced with a concentration of General Hydroponic FloraSeries nutrients to match the needs of the lettuce plants. Details on the contents in each of the FloraSeries nutrient concentrations are located at General Hydroponics website. The different nutrient amounts for each growth cycle, amount of days each cycle had in the nursery stage and irrigation information can be found in Table 4.1 (Sparks, 2016). After 36 days of growth in the growing system, the lettuce plants were harvested, process shown in *Figure 4.5*, and each respective plant was weighed. These results were reported in detail by Sparks (2016).

Table 4.1. Nutrient and Growing Needs for Each Growth Cycle (Sparks, 2016)

| System Condition | Cycle 1 | Cycle 2 | Cycle 3 |
|---|---|---|---|
| Nutrient Formula (Nursery Stage) | 1 tsp FloraGro per 1 gal water | 1 tsp FloraGro per 1 gal water | 0.5 tsp FloraMicro + 0.5 tsp FloraGro + 0.5 tsp FloraBloom per 1 gal water |
| Nutrient Formula (NFT Trays) | 3 Tbsp FloraGro per 1 gal water | 1.5 tsp FloraMicro + 2 tsp FloraGro + 0.5 tsp FloraBloom per 1 gal water | 1.5 tsp FloraMicro + 2 tsp FloraGro + 0.5 tsp FloraBloom per 1 gal water |
| Days in Nursery | 21 | 20 | 20 |
| Water Source | Tap water | Reverse Osmosis (RO) | Reverse Osmosis (RO) |
| NFT Pumping System | One 172 gallon/hour pump, delivery manifold, four ¼ inch drip irrigation tubes | Four 172 gallon/hour pumps, four ½ inch irrigation tubes | Four 172 gallon/hour pumps, four ½ inch irrigation tubes |

*Figure 4.3.* Rapid Rooters with lettuce germination.


*Figure 4.4.* Plants in net cups with aeration rocks. (Courtesy of Sparks, R.).

*Figure 4.5.* Harvesting lettuce plants at end of growth cycle.

## 4.3 Problems with Design

Throughout these growing cycles, observations regarding how the design of each system and the entire unit as a whole were assessed. Different issues, relating to the construction and system design, came to light as plant growth and usability were below industry standards. The first obstacle, to improve the usability aspect in the design, was the drainage system. The original variability goal of the drain design was not operating effectively, because it was unable to be adjusted mid-growth cycle without leaking large volumes of water. The installation of the drain to the PVC pipes, which used commercial grade caulk to seal the connection, shown in *Figure 3.12,* resulted in the drain leaking water throughout growing periods.

During the second cycle of lettuce production, the plants were infected with root rot and needed to be harvested prior to the intended 36 days of growth. It was determined the growing trays were not properly cleaned following the first growth cycle, but additionally the temperature of the nutrient solution was measure, and was above the level intended, favoring an environment for bacterial growth. The flow rate within the pipes was too low, also allowing bacterial growth to accumulate. Lastly, during the first two cycles, there was a noticeable non-uniform growth pattern. The plants near the beginning of the growing trays, the inlet of irrigation system, grew at a much higher rate compared to those near the drain end of the trays. Also, there was a difference in plant maturity from pipe to pipe. Increasing the flow rate, decreasing the solution temperature, and re-designing the drain were implemented with intentions to improve the production of the system, which resulted in a final design for the full-scale MHSC.

# CHAPTER 5. FINAL DESIGN

The preliminary design was created based on the necessities of a MHSC, the goals intended to be reached, and the constraints of this research project. Before full-scale construction of the MHSC, the components and systems of the design were bench tested to find which components would need to be re-designed for proper operations to occur. Once the flaws in the design were identified, including why each problem area became an issue, the preliminary design was modified before implementing the final design into a MHSC (*Figure G.1*, refers to fully assembled MHSC design, found in Appendix F).

## 5.1 Drain Re-Design

The drain was a key component that needed a re-design with aims to maintain the variability of the drain, while being able to stop the flow of water while adjusting the drain. There were three new designs for the drain, while the last option would be to keep the current design. The first design was called the "thru-hull" drain (*Figure D.3*), and it took advantage of the components of a boat drain. A thru-hull boat drain would be installed to the PVC pipe with rubber washers in between the threaded plastic, providing the water seal without complex measures, shown in *Figure 5.1*. A ½" PVC pipe piece would be inserted into the top on the thru-hull fittings, which would be the adjustable component of the design. It would drain into the reservoir similar to drain in the preliminary MHSC design, which flows directly into the reservoir via PVC piping.

The second design for the new drain was termed “multiple nozzles”. This design consisted of three nozzles constructed down each side of the 4” PVC pipe, totaling six nozzles per pipe (*Figure D.4*). The nozzles would have a hose attachment on the outside portion and be water sealed through caulk. Each nozzle would have a valve to stop the flow of water, allowing the height of water to be adjusted by shutting off the lower nozzles, forcing the water to drain out the top nozzles. The two nozzles switched “on”, one on each side of the PVC pipe, would attach to black, vinyl tubing, eventually draining to the reservoir.

The third and final re-design of the drain was called the “flow stopper” (*Figure D.5*). The main component of this design was a plastic piece, cut into a semi-circle to match the bottom curve of the PVC pipe. This plastic piece would be a ½’ thick with rubber glued to its edge. This rubber stopper would slide through a slit at the top of the 4” PVC pipe and act as a dam to block the flow of water, creating a variable flow rate. The actual draining component would be the same as the preliminary design.

To determine the best design for the MHSC and goals established, a design matrix for all three was created, shown in Table 5.1. The criteria for the matrix was cost, leakage potential, ease of assembly, ease of changing water height, availability of parts, reduction in water loss during adjustment. The cost, leakage potential, and ease of changing water height were given higher weights, because each were essential for our goal.

Table 5.1. Design Matrix of Final Drain Design

| **Criteria** | **Weight** | **Drain Type (1-5) 5=Excellent** | | |
|---|---|---|---|---|
| | | Thru_Hull | Multiple Nozzles | Flow Stopper |
| Cost | 4 | 4 | 2 | 3 |
| Leakage potential | 5 | 3 | 4 | 2 |
| Ease of assembly | 2 | 3 | 2 | 4 |
| Ease of changing water height | 4 | 4 | 4 | 1 |
| Availabiliy of parts | 3 | 5 | 2 | 3 |
| Reduction in water loss | 3 | 3 | 5 | 4 |
| | | **77** | **69** | **55** |

It was determined the thru-hull design was the best option to adjust the height of water during growth cycles and prevent leakage. The “multiple nozzle” provided precise water height with limited leakage potential. However, it would have been expensive and would have required a high amount of modifications to each PVC pipe. The “flow stopper” design showed a relatively low cost, but it would operate with a high amount of water leakage and be difficult to change the water height, because it would have used the same to drain hardware as the preliminary design.

The thru-hull design was a simplistic design where each part could be found at local stores. It was determined this drain design would allow minimal water leakage, but the build-up of organic material, throughout each growing cycle, would seal the connection completely. Changing the height of water within the growing trays was easy by simply lowering the O-ring around the ½” PVC pipe which inserted into the thru-hull fitting. There was water loss during adjustment, but it was much improved from the original drain design. The constructed thru-hull design, without the ½” PVC pipe, is shown in *Figure 5.1*.

*Figure 5.1.* Constructed thru-hull drain design.

## 5.2 Additional Design Adjustments

When observing the production of the test unit, there were many instances where growth was non-uniform throughout the growing tray, and in cycle two, disease caused the growth period to end sooner than intended. It was decided the nutrient solution needed to have a higher flow rate. The nutrient solution was also determined to be too warm and the quality of the water might have been an issue.

The majority of these issues where solved by adjusting the components in the irrigation system. To improve the flow rate, four pumps were used, one pump for each PVC pipe of the growing tray, instead of the original single pump per growing system. In addition, the mechanism that equally distributed the pumped solution was no longer needed since each pump delivered water directly to each growth tube. By removing the ¼" drip tubing, from the distribution mechanism (*Figure* 3.11), and replacing them with ½" tubing, this increased the rate at which water was delivered to the growing system.

The next issue was to reduce the amount of bacteria growth by reducing the water temperature. This was accomplished by implementing a cooling mechanism into the reservoir, pictured in *Figure 5.2,* which consisted of a copper coil with tap water flowing through. This increased the amount of water used during the growing cycle, however is not intended to be included in the final design of the MHSC. This, along with thoroughly cleaning the entire system with low-concentrations of bleach, prevented the potential of diseases to occur. Lastly, after the first cycle, when the observations of non-uniform plant growth occurred, the water used in the irrigation system was switched from tap water to reverse osmosis water.

*Figure 5.2.* Cooling coil placed in reservoir to lower water temperature.

# CHAPTER 6. CONCLUSIONS AND DISCUSSION

## 6.1 Conclusion

The primary driving concept behind this project was to improve the means to perform research on urban agriculture (UA), specifically in regard to crop production within shipping containers. To increase the amount of research conducted on the potential for modified hydroponic shipping containers (MHSC), this project designed and planned a research oriented MHSC. The research aspect would allow future experimentation to be conducted varying certain key components in each MHSC system to determine the most optimal productive measures.

Design goals were determined during the initial stage of this project. Project constraints were developed to focus the scope of the project. A step-by-step analysis, with regard to the design and construction of the research MHSC, was detailed to explain the methods and reasons for the specific design. To provide experimentation potential, flexibility needed to be integrated within the different MHSC systems. Additionally, AutoCAD drawings were created, detailing each component and its integration within the shipping container, providing the potential for replicating the MHSC design. Lastly, areas within the design were identified where improvements could be made to increase the productivity and feasibility of the MHSC.

This project was limited mainly by the time to be completed and the budget. These factors influenced the type of materials used for each component and the creation of a non-production oriented MHSC. With regard to the design constraints, commercial MHSCs are "turn-key" systems, ready for crop production upon consumer's receiving the system. This required the design of the research MHSC to include every component necessary for crop production. Based on the concept of designing a research and educational vessel, it was determined the layout within the MHSC would allow for multiple persons to move around inside. Lastly, the water and electrical requirements for the system were to be input from external sources.

Throughout the duration of this research project, the design process of each key system was detailed. There are three main systems integrated into MHSCs, growing, irrigation, and environmental control systems. These provide the necessary conditions for optimal plant growth. Each system contains numerous components, resulting in a complex design that has been minimally reported within the technical literature. For this project, each different component and equipment selection was described, including the rationale for the selection of each based on the constraints and research goals.

Within this MHSC, four identical growth areas were designed, each containing the necessary components for plant growth. Each different component within the growth areas were designed with certain variable characteristics, allowing independent experimentations to be conducted to determine the most optimal and efficient method of growth within shipping containers.

The growing system, where the plants will be produced during each cycle, consists of a growing tray, multiple table legs, and the lighting fixtures. The number of plants capable of being produced within each growing area is 352, 1,408 for the entire four growth areas. However, the growing tray was designed to allow any number of plants to be grown and in any location along the trays. The type of plant capable of being grown within each different growing area varies as well. The 8" separating the PVC pipes and each 2" hole were designed to allow proper growth area for leafy vegetables and herbs. Strut channels were welded to the ceiling, mirroring the 15' long PVC pipes of the growing trays. This was to provide an attachment location for vegetation requiring vines, such as tomatoes. The table legs, providing support to each growing system, are adjustable based on the desired slope needed during growth periods. Each leg can be 23.5” to 33.5” in height, resulting in a slope range up to 5.5%. For the lighting components, each are hung from the strut channels located on the ceiling, providing the potential for multiple different types, Light Emitting Diode (LED), Fluorescent, and Incandescent. Lighting system choices are maximized by not limiting the space containing the light units. The distance between each light and the plants can be 2” to 54” by adjusting the length each light hangs from the ceiling, limited only by the ventilation system above.

When designing the irrigation system, the main areas of variability determined to be of high importance were the nutrient flow rate, amount of air within the PVC pipes, and height of water during growth cycles. The flow rate was adjustable with variable rate pumps. In the final design, each growing area contained four pumps, one for each growth tube. The potential volumetric flow rate of nutrient solution ranged from 0.75 gpm to 3 gpm. The flow velocity within the growth tubes can be adjusted slightly based on the percent slope of the growing tray. To vary the water height and amount of air within each growth tube, allowing proper nutrient uptake throughout the growing process, an adjustable drain was designed. The final drain design can provide 0.5” to 2” of water height and equally varying the amount of air within the growth tubes.

The variability aspect within the environmental control system design was in the air change rate by the ventilation system. The ability to vary the air removal rate was accomplished by integrating 8” dampers into the ductwork, adjusting the amount of air able to flow through each duct. By adjusting the damper, the number of air changes per hour can vary from 3 to 60. There are also capabilities for introducing more environmental control factors in the future from the strut channels placed throughout the shipping container.

For each of the different systems within the project’s MHSC, AutoCAD drawings were developed detailing the design of each component within. Each drawing further provided the necessary measures to replicate the design for this project, allowing future research oriented MHSC to be produced. Additionally, the areas where improvements in the design which could increase productivity will be detailed in the following discussion section.

## 6.2 Discussion

When considering the potential changes or additions to the design to improve the production potential, the improvements are will increase the efficiency and quality of experimental potential from consistent plant growth. There are certain components, preliminarily observed during the bench testing, which could increase the feasibility and productivity of the MHSC.

The integration of the cooling coil in the reservoir was not considered for the final MHSC design, because it was needed due to the non-optimal growing environment where the bench tests were conducted. The reason for its need should not exist in the MHSC, but the cooling coil proved to be a successful addition to combat the specific problem of warm nutrient solution. Future additions to the environmental control system should be considered to provide proper growing conditions, for more of the Midwestern annual environmental cycle. The suggested components to improve the climate within the shipping container are a heating system, cooling system, and $CO_2$ generator. In addition, each of these components would further provide accurate environmental conditions, if a remote monitoring and sensing system was integrated into the MHSC. A remote monitoring system would provide a method to view and potentially adjust settings within each system. This, along with an automatic sensor system, would allow accurate growing conditions to improving the quality and reduce the loss of each crop.

Another area of concern is the labor and logistics involved in producing crops in MHSCs. During each growing cycle in the bench tests, the management required during plant development was intensive. The conditions of the plants, solution temperature, pH, nutrient concentration, and bacterial growth needed to be continuously monitored to ensure proper growing conditions. This was found to be a daily process, even with the environmental control being minimalistic. In commercial MHSCs, the ability to develop a highly detailed operational manual would improve the efficiency in production. Additionally, the harvesting process was extremely labor intensive with little room to operate. In a production oriented MHSC, the operating area is even less spacious, limiting the number of workers able to harvest in a single unit. One of the characteristics of using shipping containers for UA is the ability to stack each unit, increasing production with limited land. However, this could increase the difficulty and intensiveness in harvesting the crops within. Designing some type of automation harvesting system, similar to the advancement in rural farming machinery, would reduce the amount of labor required, improving crop production by MHSC's sustainability commercially.

The last aspect of growing produce within MHSCs is the use and disposal of necessary external inputs. From the three bench tests, Sparks (2016) developed a model and calculated the energy requirements in maintaining environmental conditions in the MHSC. It was found this form of UA involved a high use of energy, mainly from the heating and cooling methods, necessary in providing optimal growing conditions within the shipping container. The amount of water used in the irrigation system, containing necessary nutrients, was also observed to be used at a high rate. The integration of a method to capture natural water would improve the efficiency of commercial MHSCs.

Crop production in shipping containers is a new method of agricultural production compared to conventional farming methods. Ground-based farming has been highly researched and studied resulting in advanced technology increasing productivity and reducing labor intensiveness. This project designed a MHSC with aims in allowing experimentation to be conducted in regard to optimal growing conditions. The method in designing and planning the MHSC was detailed and illustrated to provide the opportunity for replication by other universities and investors to further investigate this method of UA. Currently, commercial manufacturers, including Freight Farms, Growtainer, Cropbox, and VHH, are producing their own form of MHSCs. However, the data available regarding production and operation potential has yet to be challenged and proven. The research oriented MHSC designed in this project will begin the process in determining the potential of MHSC crop production impact on humanity’s concern in providing enough food for a growing population.

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APPENDICES

# Appendix A. Shipping Container Layout

A.1 shows the overhead exterior view of the shipping container and illustrates the door side verses the rear end. The length of the shipping container is 40’, and the width is 8’. A.2 provides a side exterior view of the shipping container, showing it sitting on the chassis. The height of the shipping container is 9’. A.3 illustrates the overhead interior design layout of the growing areas in the MHSC. There are four growth areas, labeled 1-4, a storage and nursery operational area (A), a 3’ area in the middle of the growth areas where irrigation will be located (B), and the 2’ walkway. The focus in designing the layout was to provide adequate room for movement and the ability for multiple persons to operate at a time. A.4 is an overhead view of the deck, showing the necessary wood materials and arrangement. This deck was required due to the shipping container still located on its chassis. A.5 provides a side view of the deck assembly with the shipping container in the background. The shipping container was 4.5’ above the ground, so the deck allowed easier access.

*Figure A.1*. Overhead Container

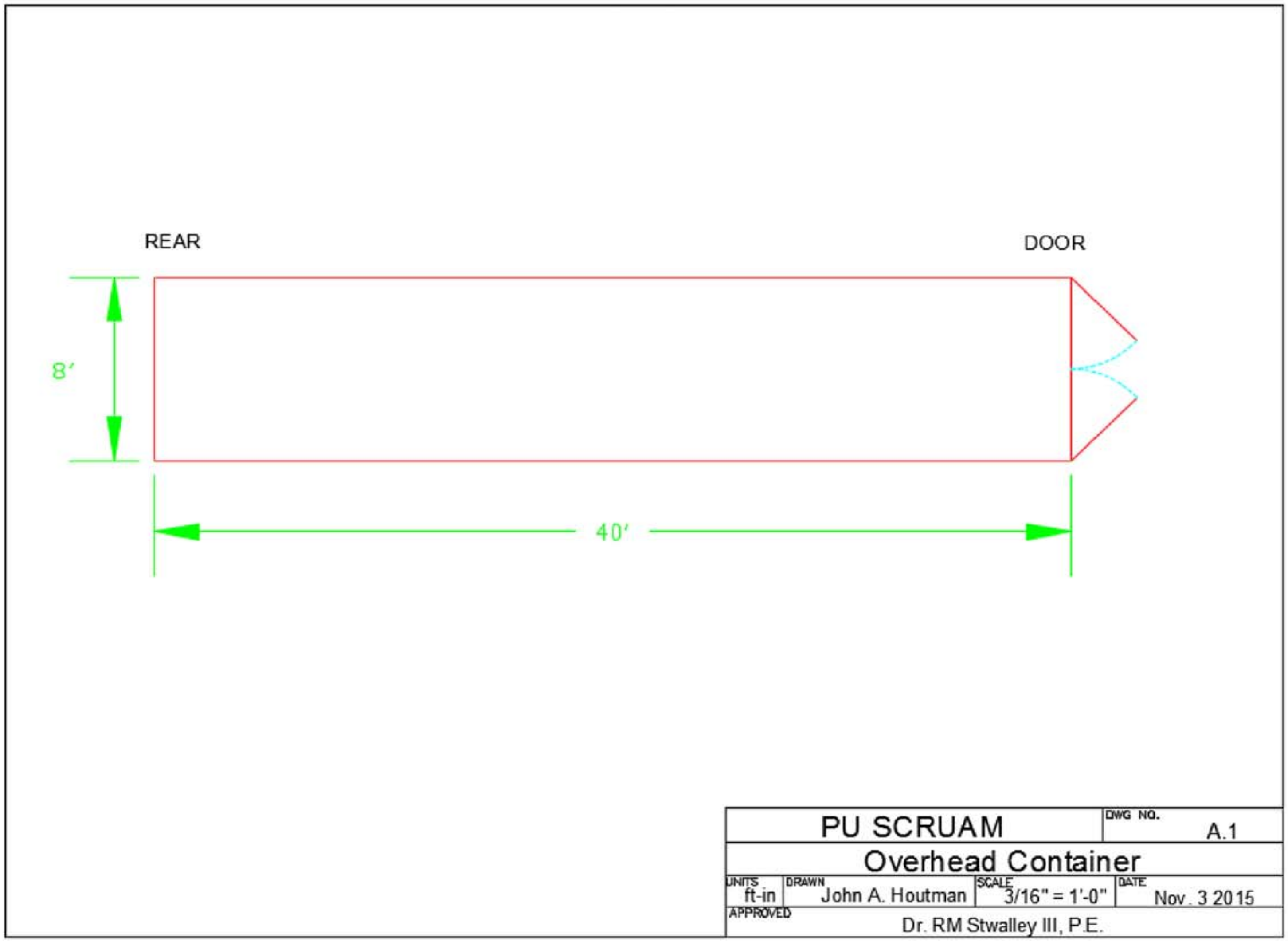


*Figure A.2*. Rightside Container

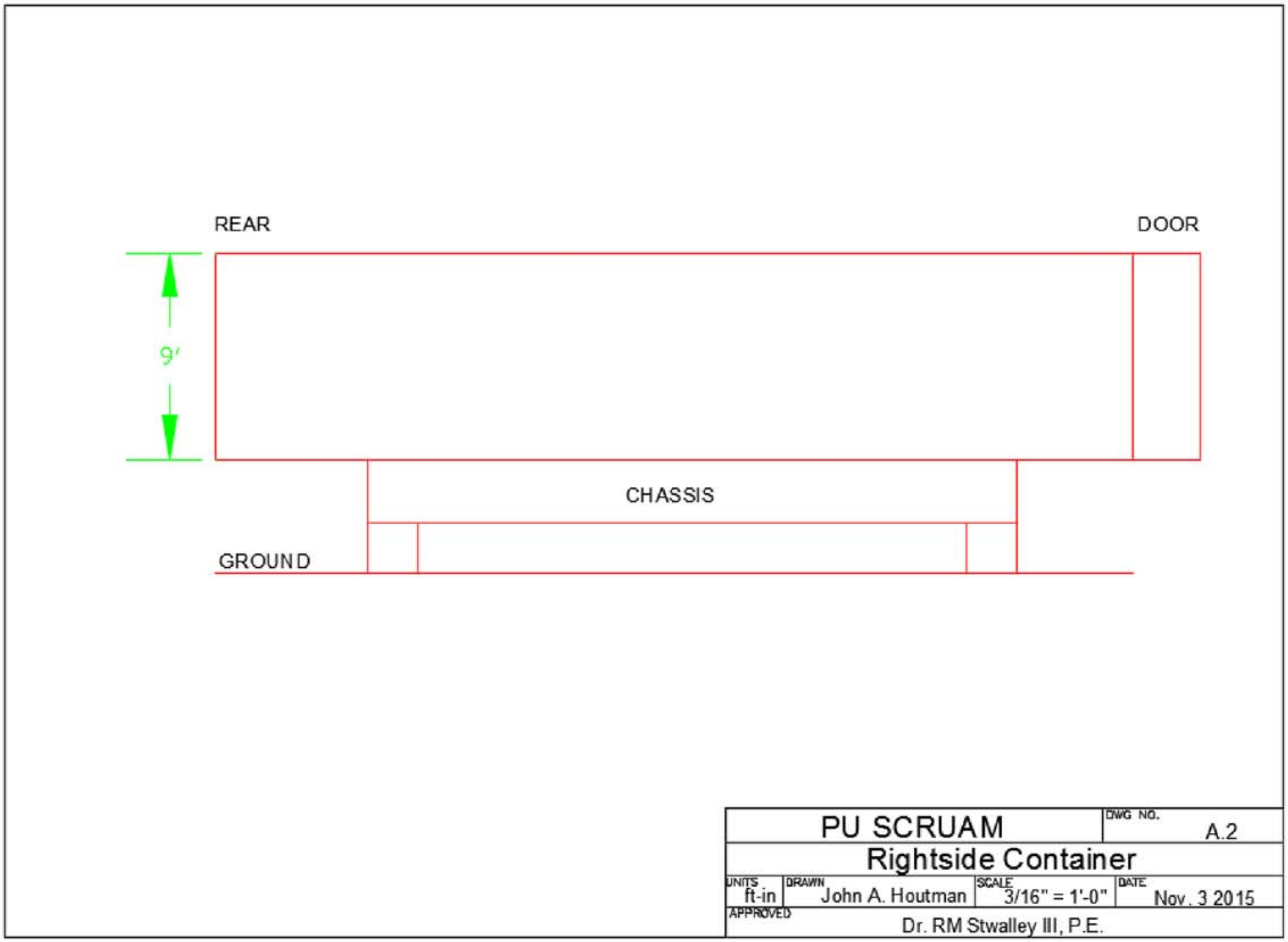


*Figure A.3*. Overhead Full MHSC Layout

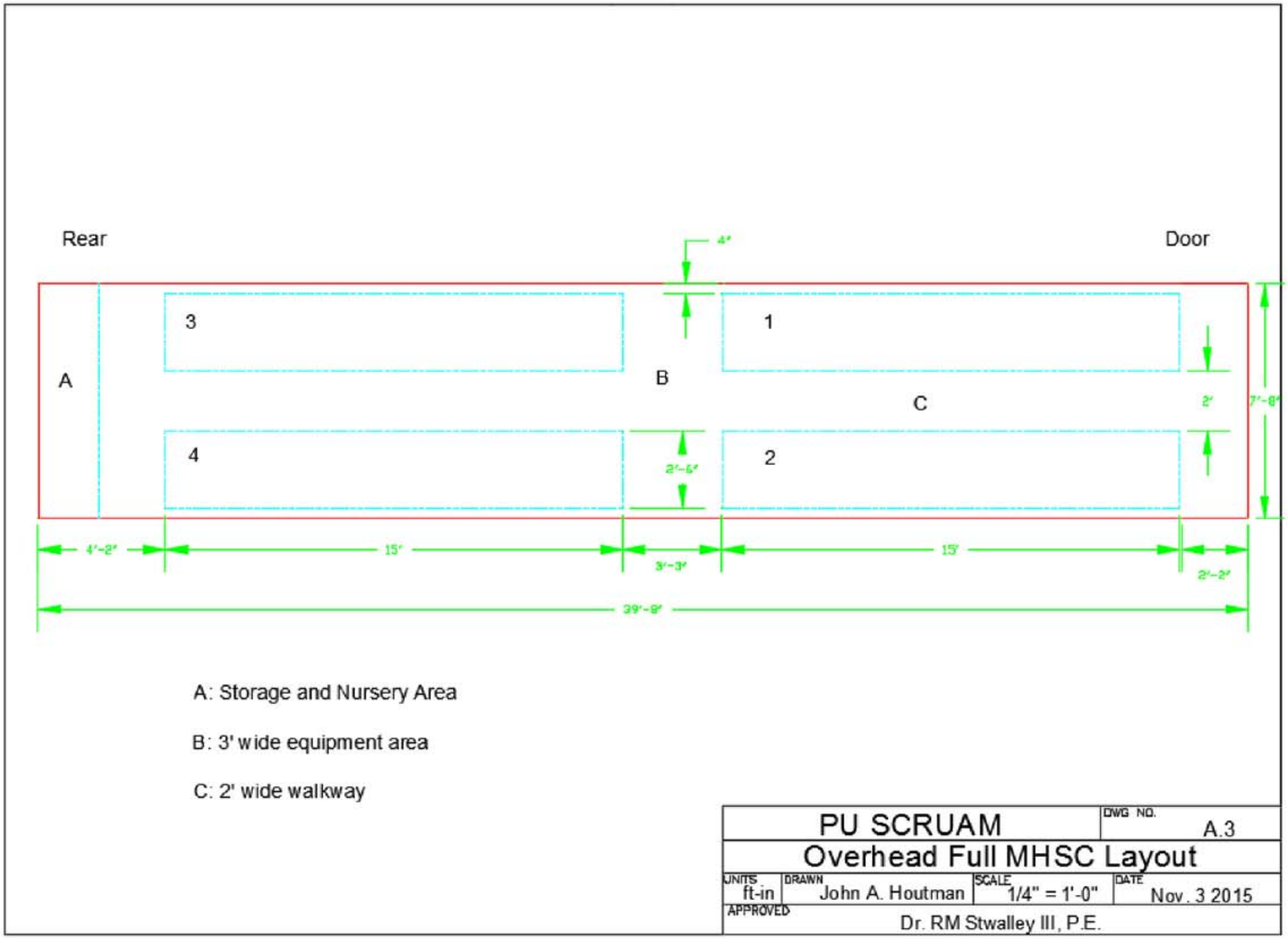


*Figure A.4*. Overhead Deck Assembly

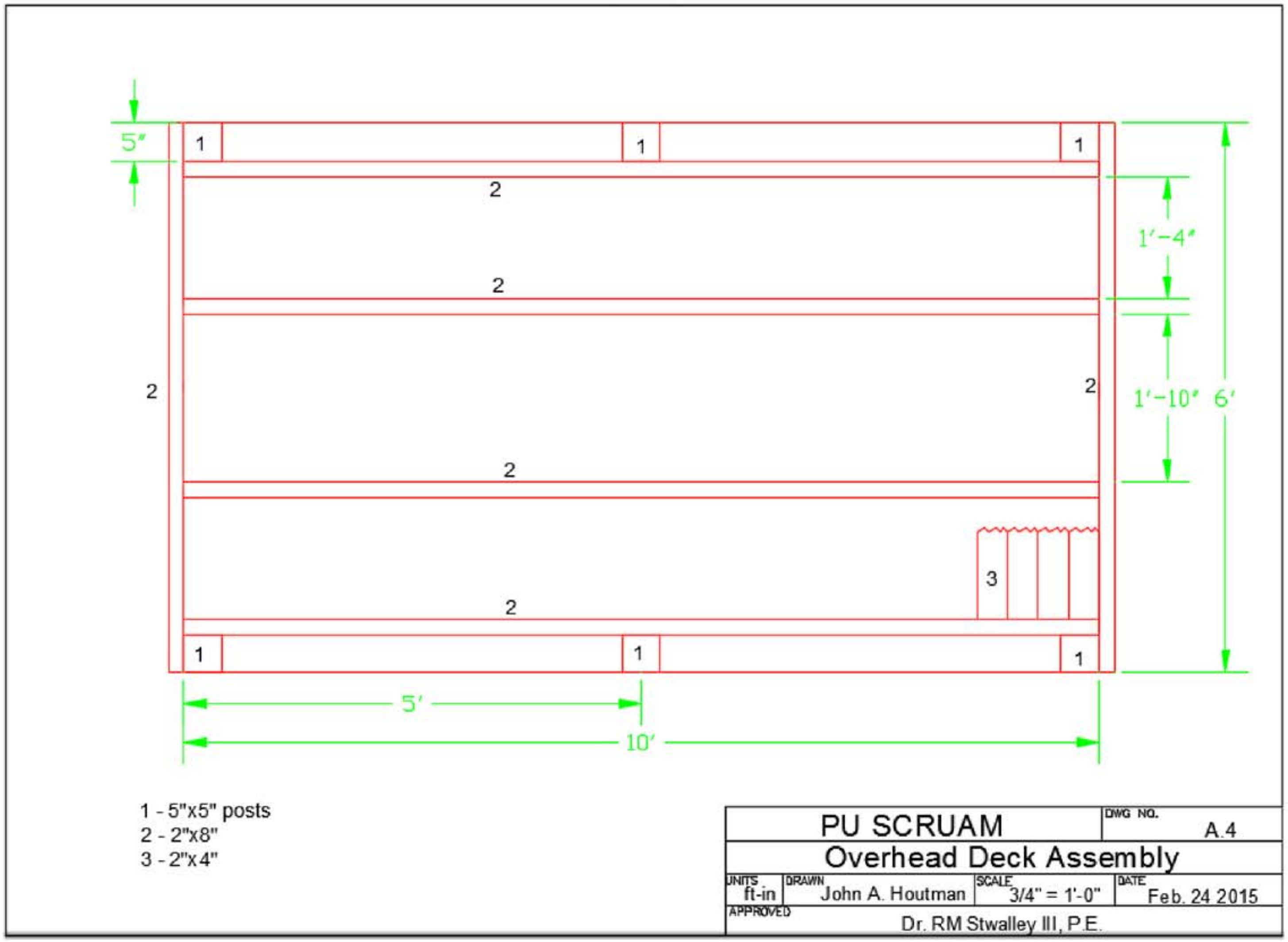
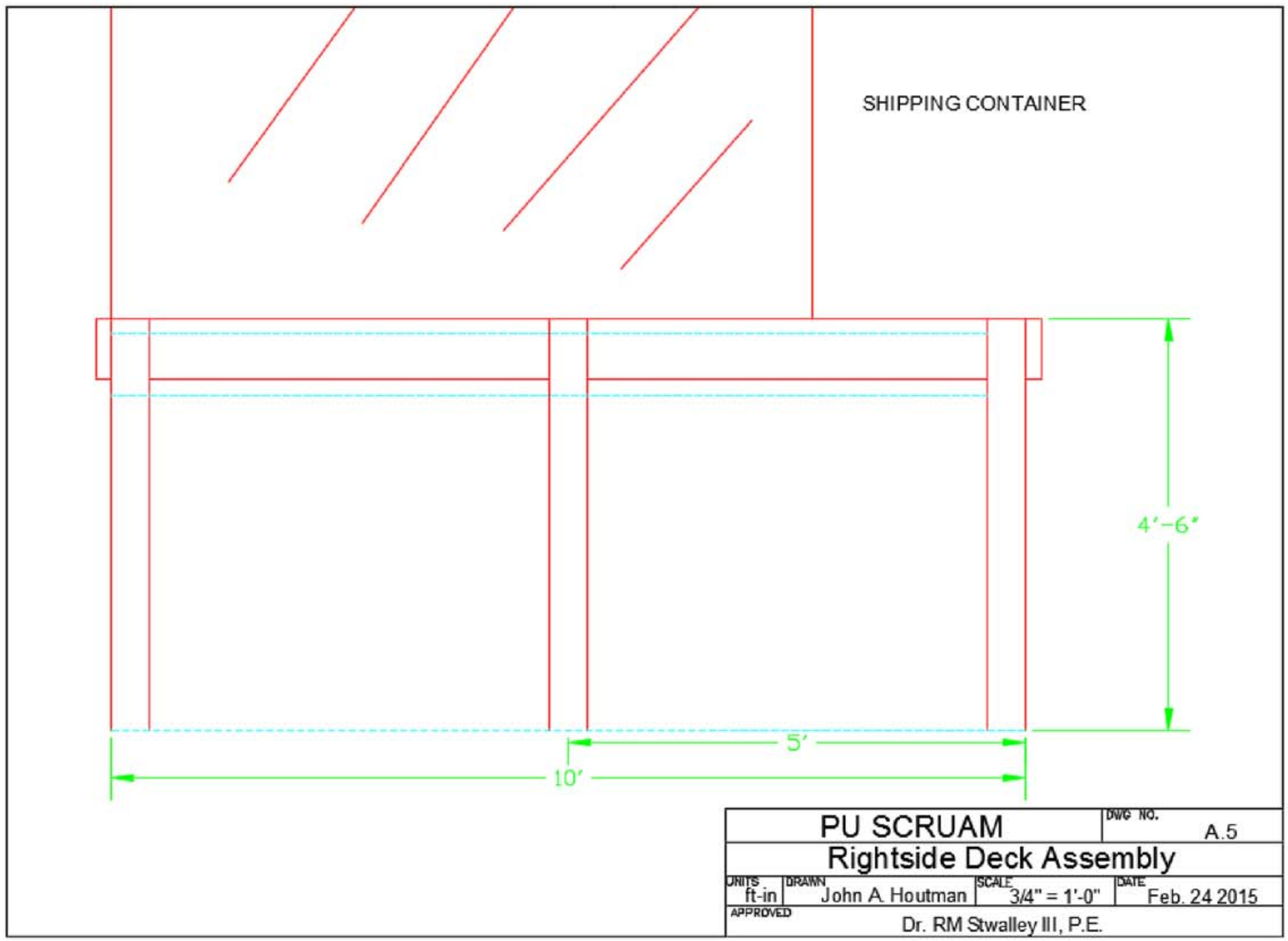


*Figure A.5*. Rightside Deck Assembly



# APPENDIX B. Strut Channel Modifications

B.1 provides a side view of locations where strut channels were placed along the side walls inside the shipping container. Each strut channel section is 7' long and placed in the middle of each wall, roughly 5.5' apart. Fourteen strut channels on the side walls provide attachment points for any future modifications or changes in the design of the hydroponic system, plumbing, and data acquisition lines. B.2 is a front interior view of the strut channels located on the rear wall (opposite of the door). Two channels were welded to the rear wall, 4' apart to increase the variable aspect in changing future designs. B.3 is an overhead interior view of the strut channels located on the ceiling of the shipping container. Each strut channel is 15' long, consisting of two sections per row. The strut channels on the ceiling mirror the growth tubes, providing attachment locations for electrical, ductwork, lighting units, and any future modifications necessary.

*Figure B.1*. Rightside Walls Strut Channel Sections

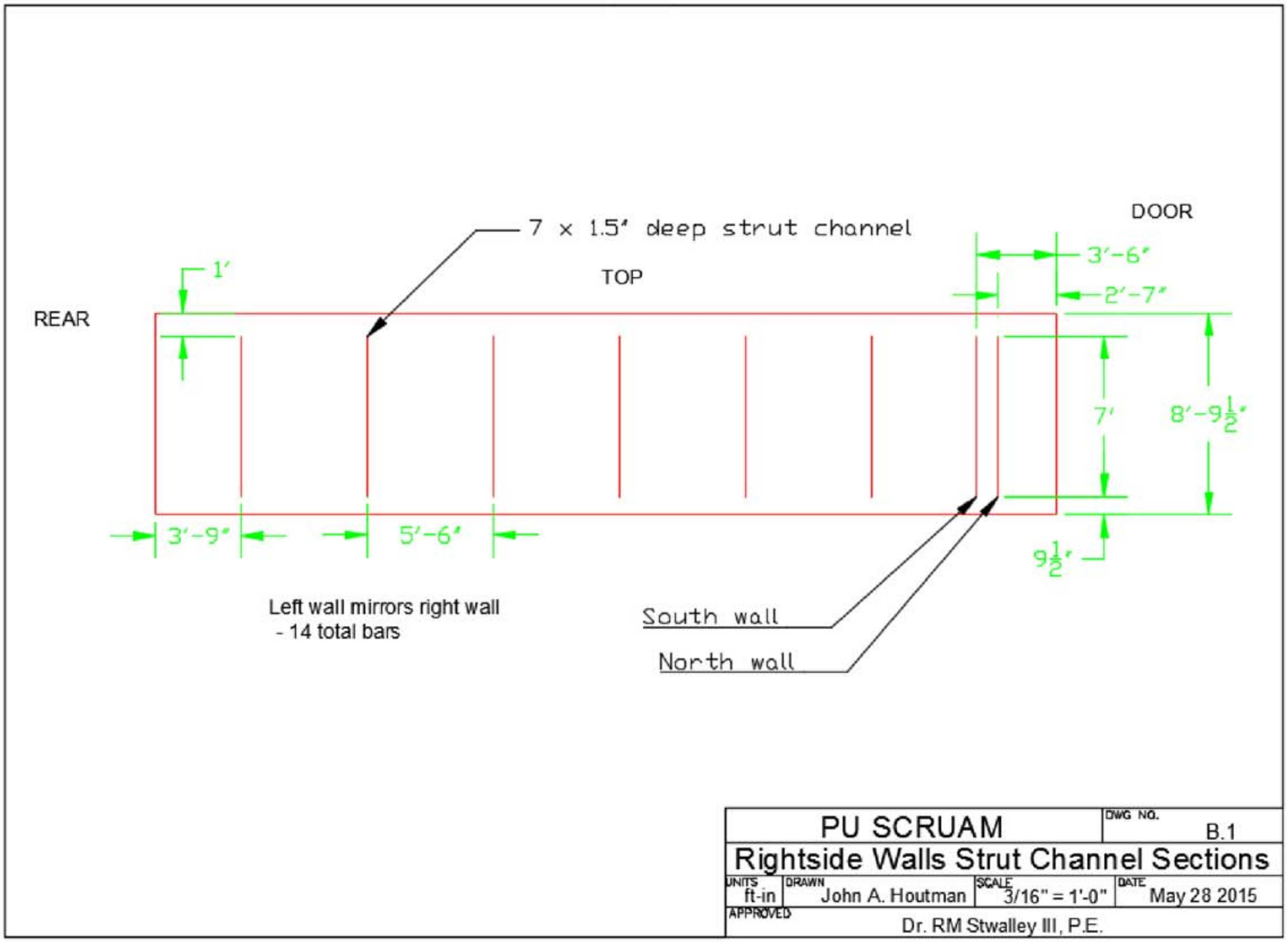


*Figure B.2*. Rear Wall Strut Channel Sections

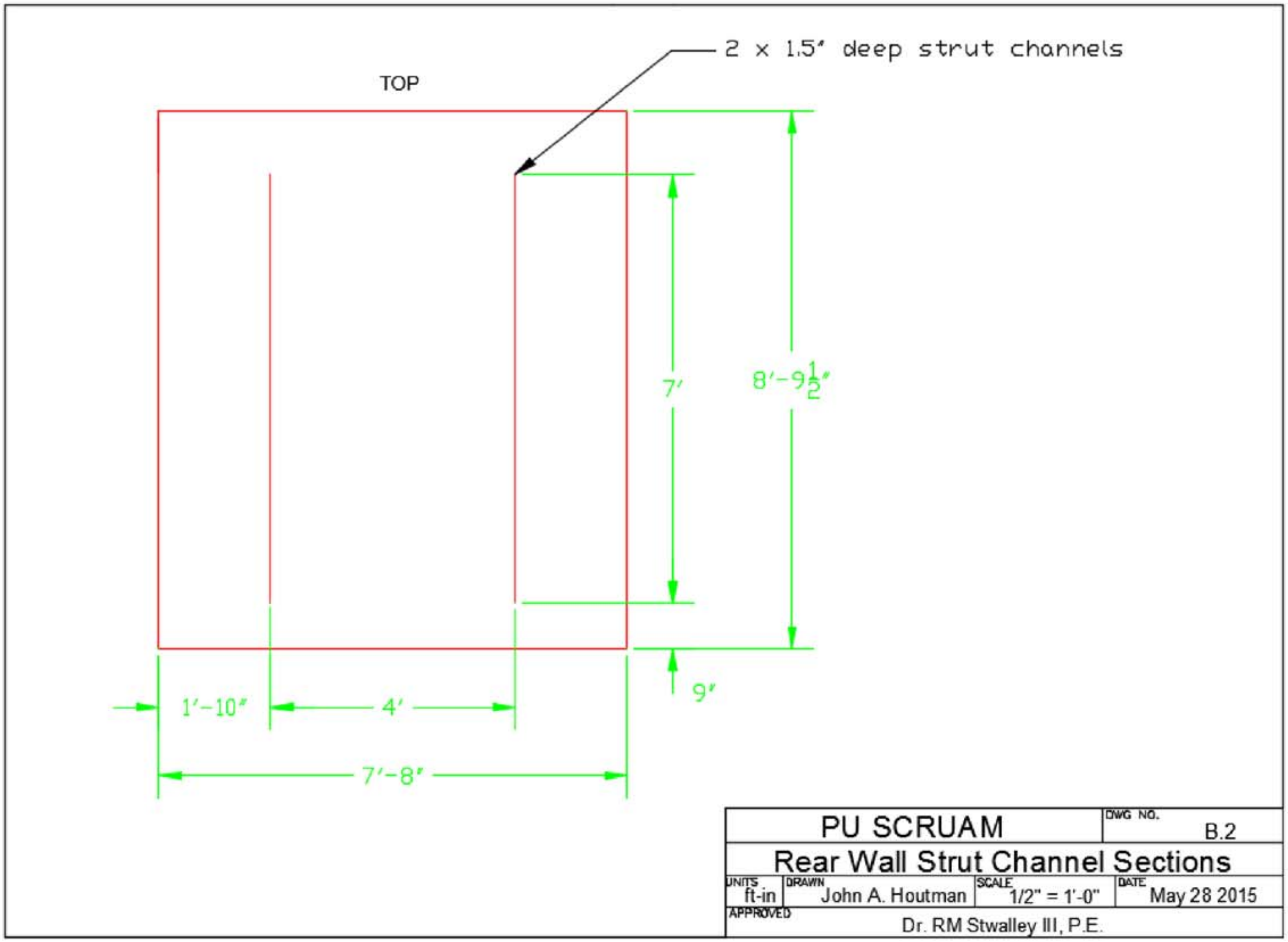
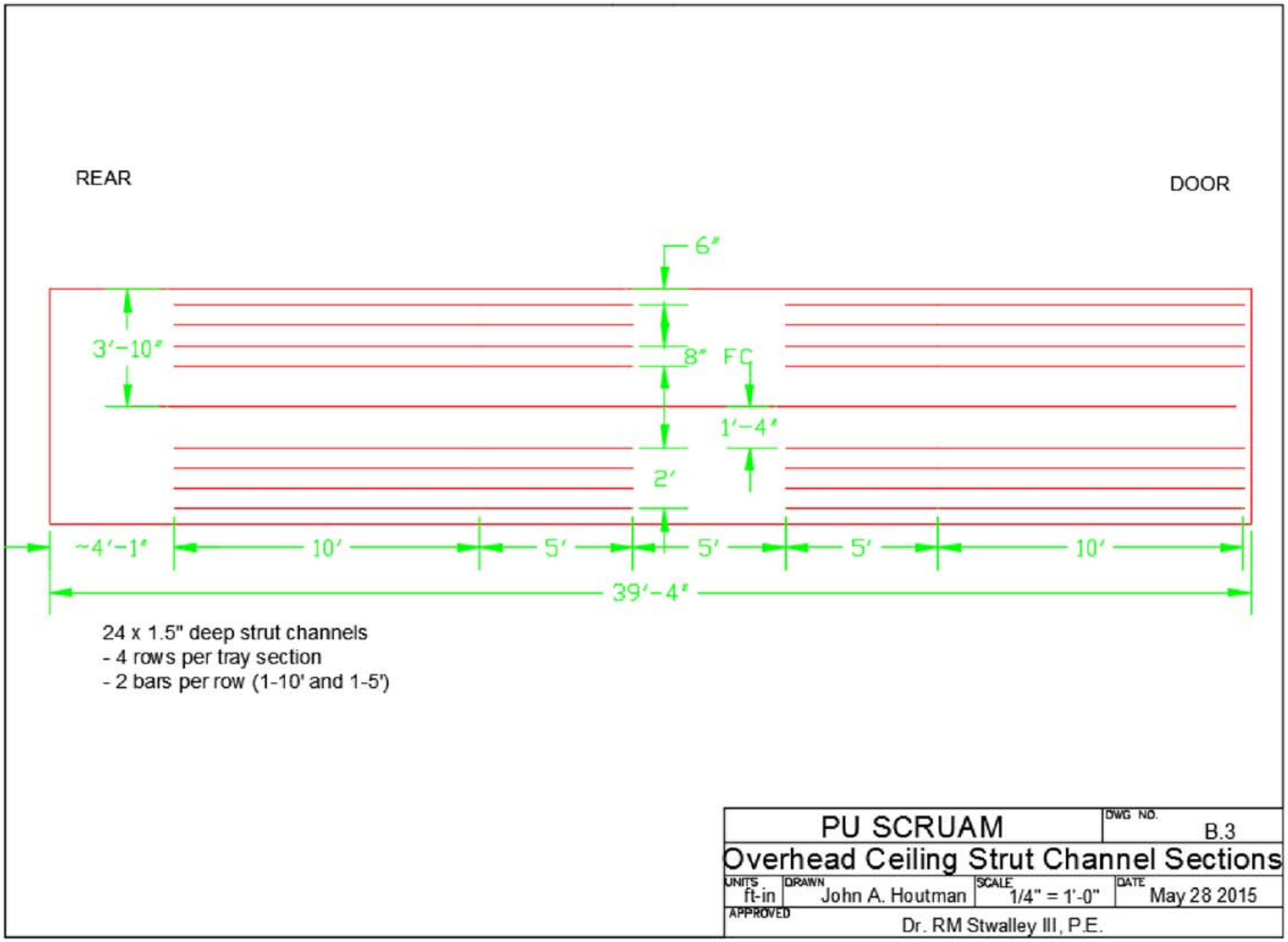


*Figure B.3*. Overhead Ceiling Strut Channel Sections



# Appendix C. Growing System

C.1 is an overhead view of the growing trays and legs, part of the growing system. Each growing tray consists of four, 4” PVC pipes which are 15’ long. There are 88-2” holes in each growth tube, totaling 352 holes for each growing tray. The holes alternate to provide adequate growing area for different types of crops. C.2 provides a side view of the growing trays and leg support components. Each growing system contains four sets of legs, eight total. The legs are adjustable, providing varying heights and slope of the growing tray during growth cycles. C.3 is a front view of the growing tray and supporting legs. Each leg height ranges from 23.5” to 33.5”. The components of the leg unit consist of, from top to bottom, a 2.5’ long strut channel bolted to a 2” x 4” plank of wood, connected to the adjustable table legs. C.4 is an overhead view of the single 4” PVC pipe used in the growing trays. Each hole, where plants will be located, are 8” apart to provide proper room for mature growth. C.5 provides a front view of the single 4” PVC pipe. PVC was used as the growing tray material for its low cost and ability to be modified easily. C.6 shows a close-up, overhead view of the coupling joint used to create the 15’ long growth tubes. C.7 is a zoomed-in, overhead view of the drain end of the growing tray and table legs. The growing trays are 2.5’ wide, designed to allow access to entire tray during planting and harvesting. C.8 is a front view of the lighting units in the growing system. The lights can range from 2” to 54”, providing potential for experimentation on proper lighting arrangement. C.9 is a side view of the entire growing system within the MHSC. Each lighting unit is attached to the strut channels located on the ceiling, designed to allow various types of lighting fixtures to be used during growing cycles.

*Figure C.1*. Overhead Growing Trays and Legs

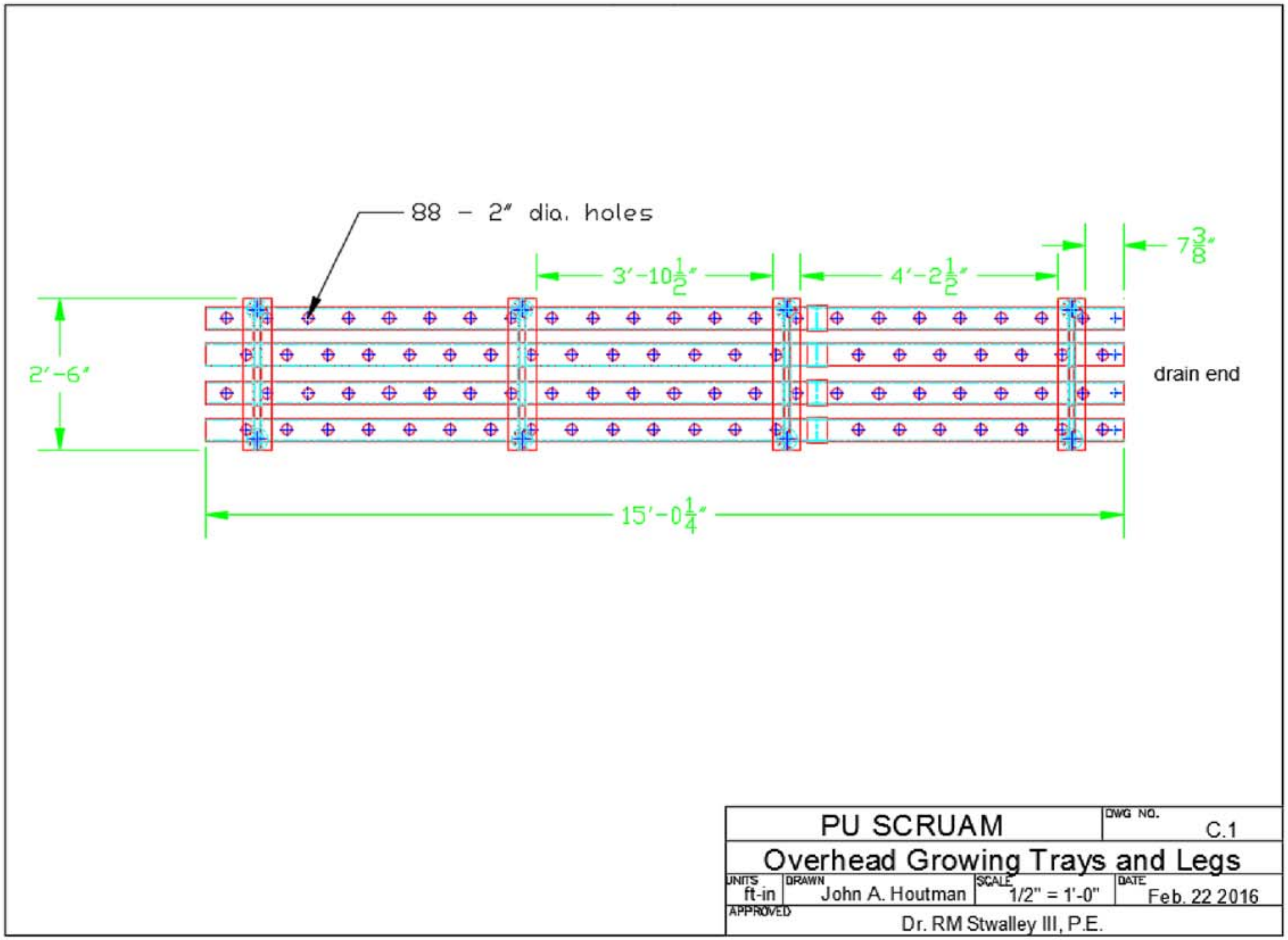


*Figure C.2*. Rightside Growing Trays and Legs

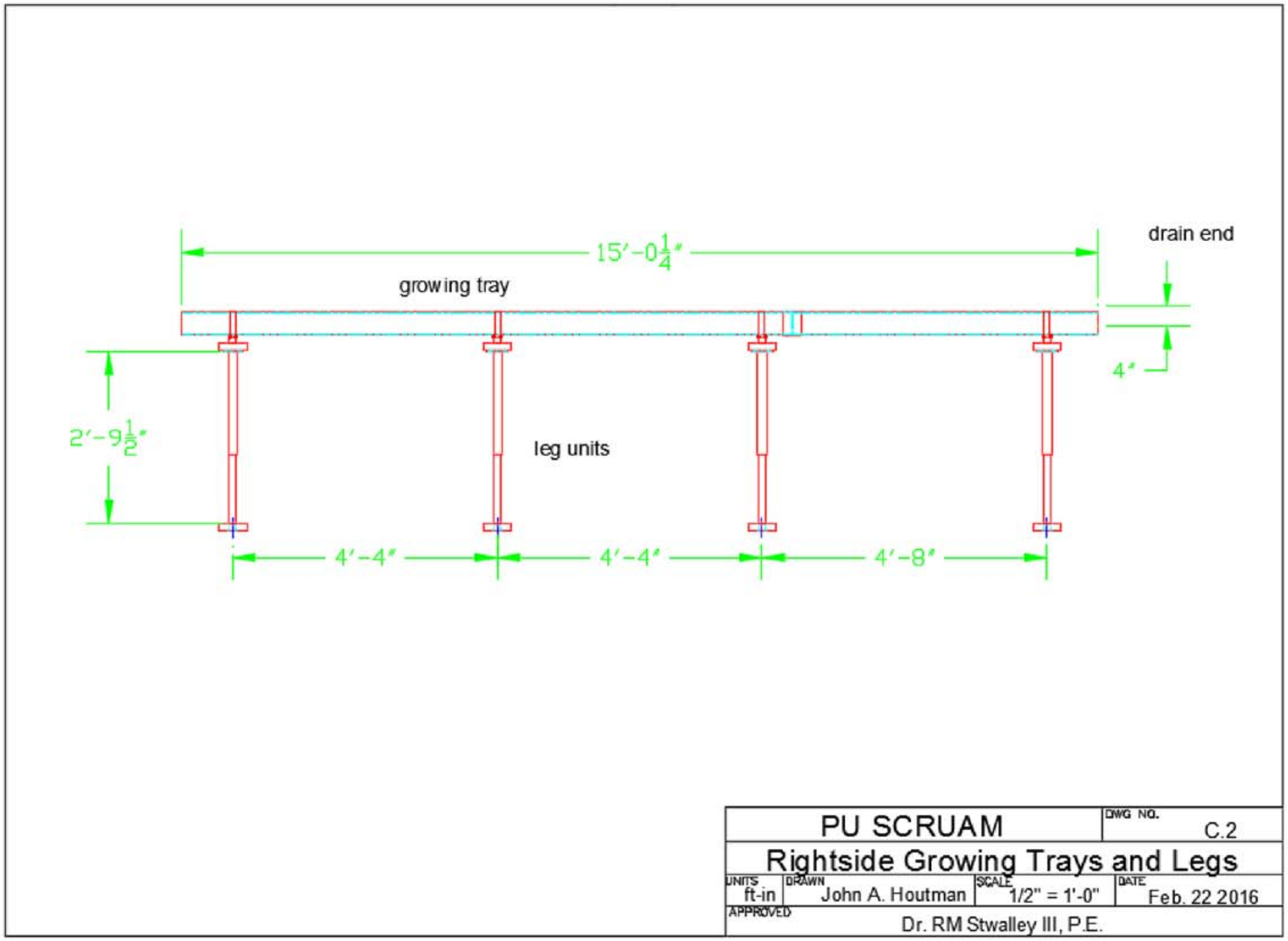


*Figure C.3*. Front Growing Trays and Legs

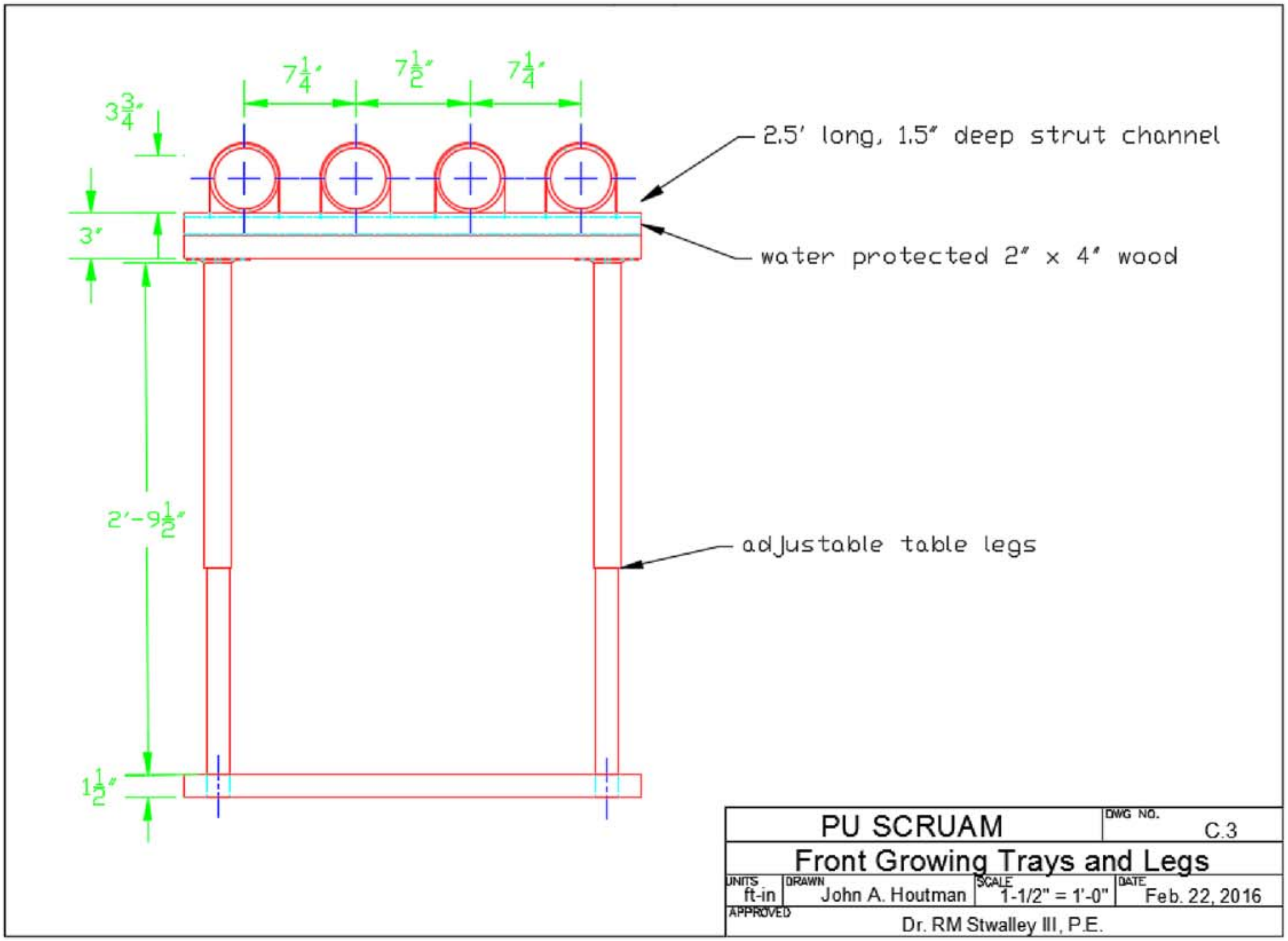


*Figure C.4*. Overhead Growing Pipe

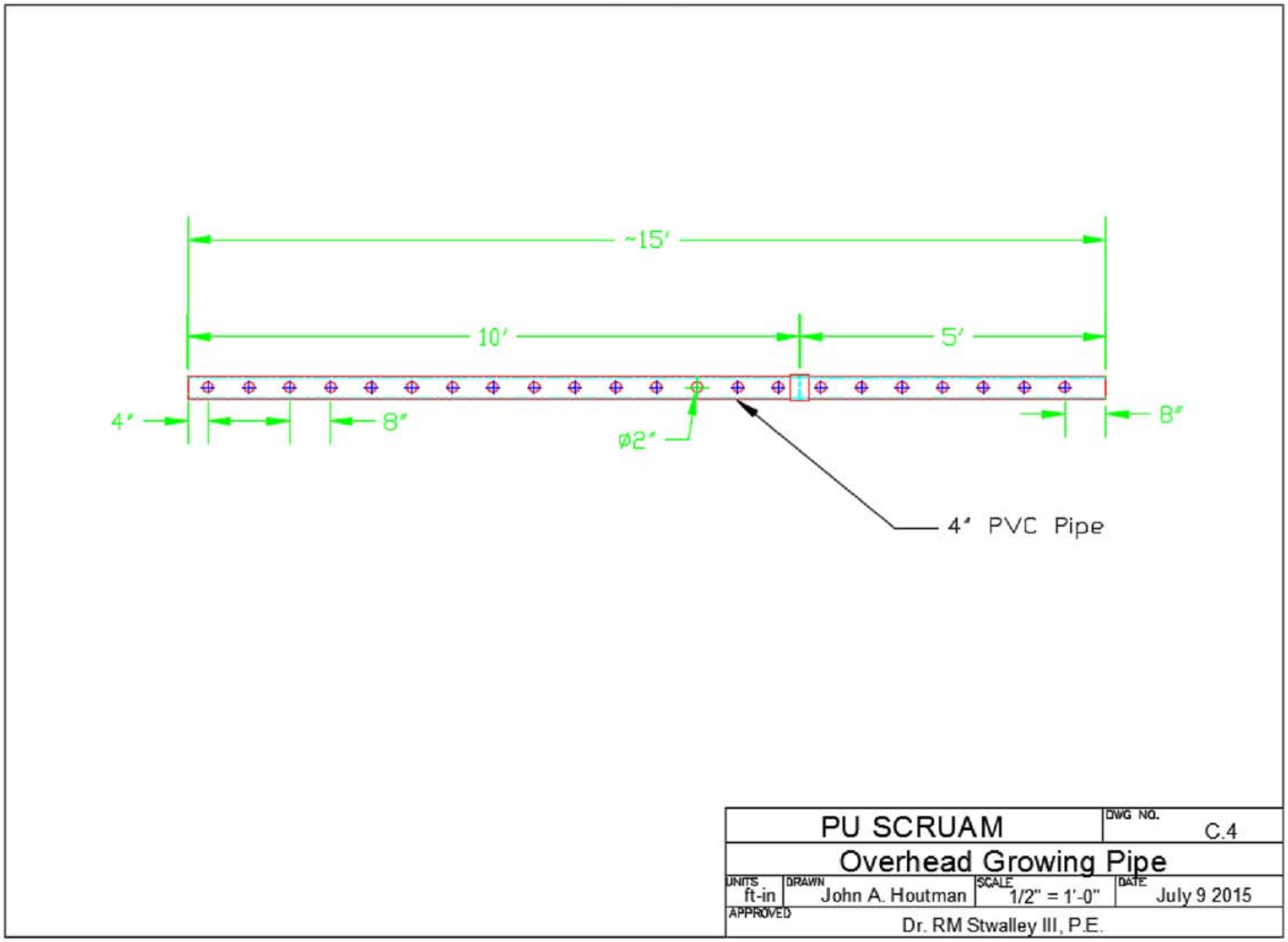


*Figure C.5*. Front Growing Pipe

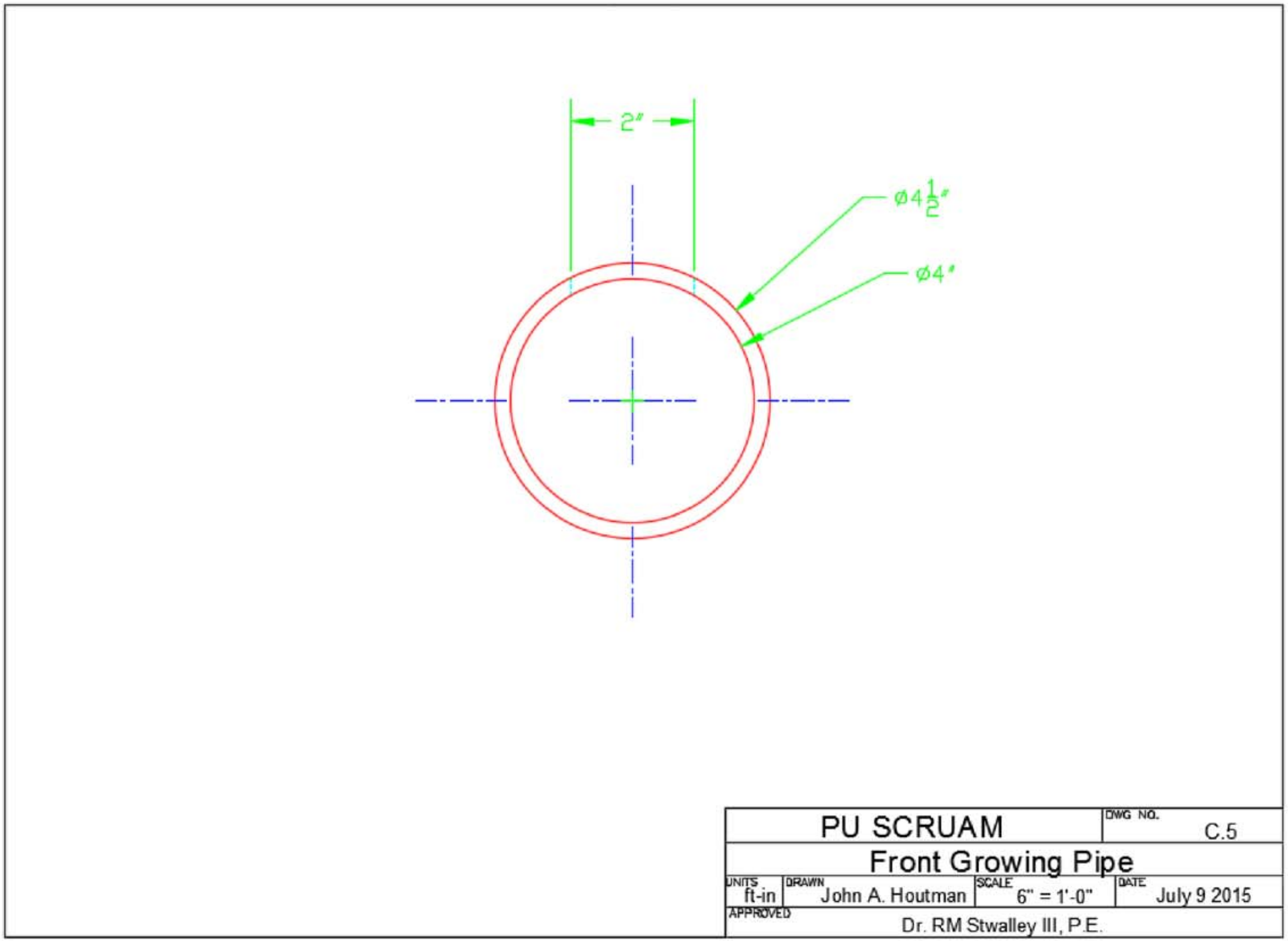


*Figure C.6.* Overhead Coupling Growing Pipe

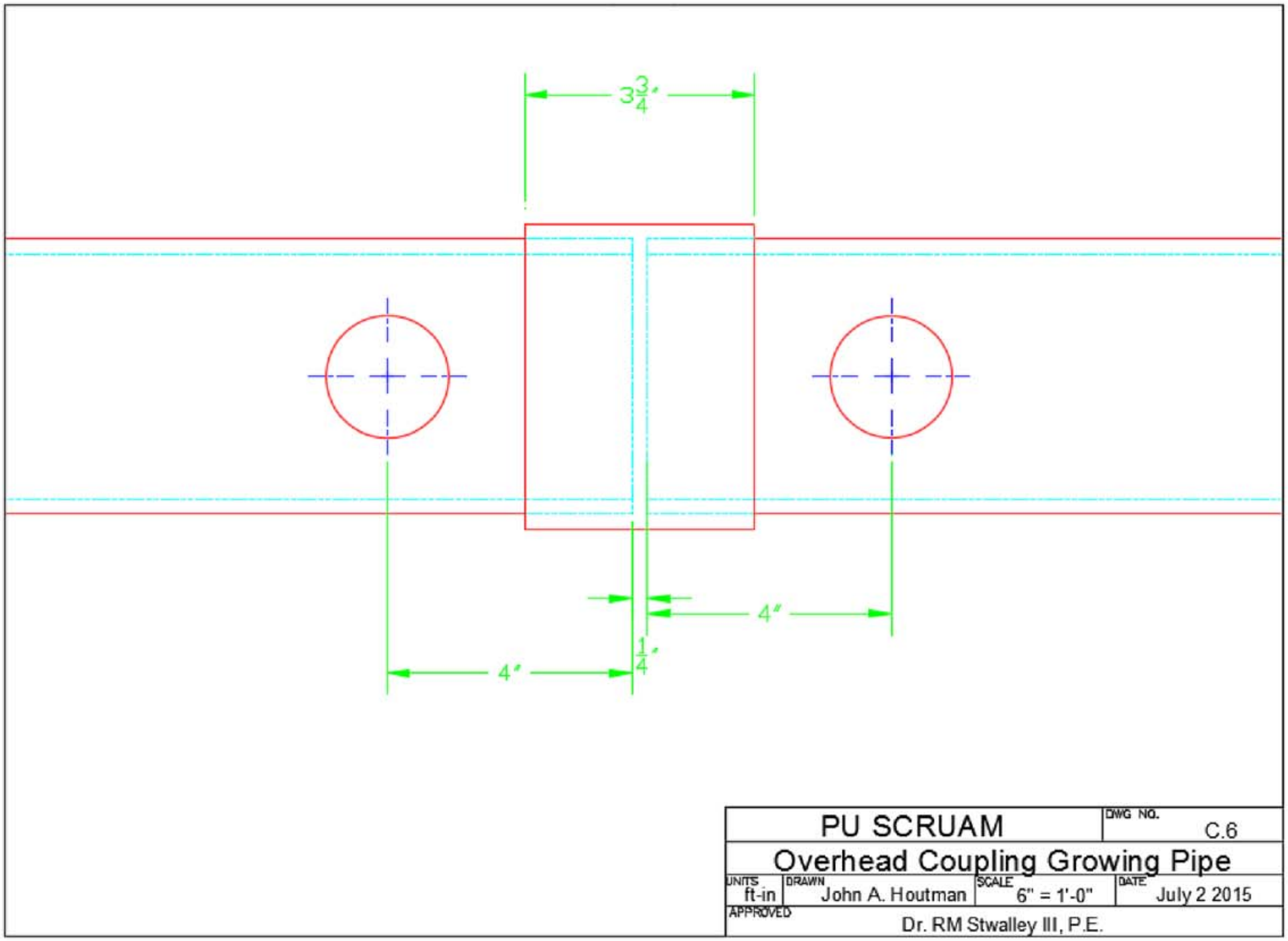


*Figure C.7.* Overhead Alternating Holes Growing Tray

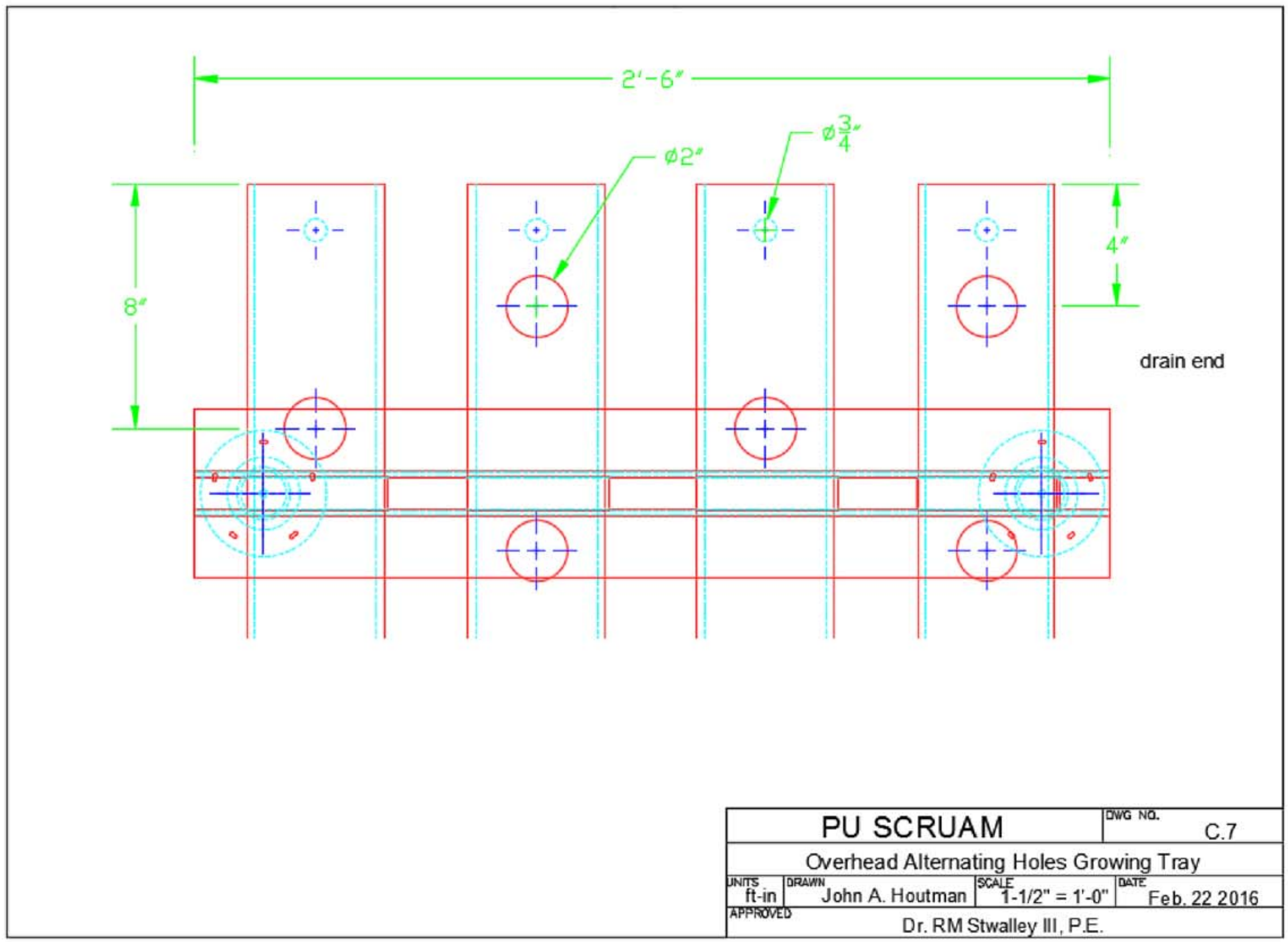


*Figure C.8*. Front Lights Above Growing Tray

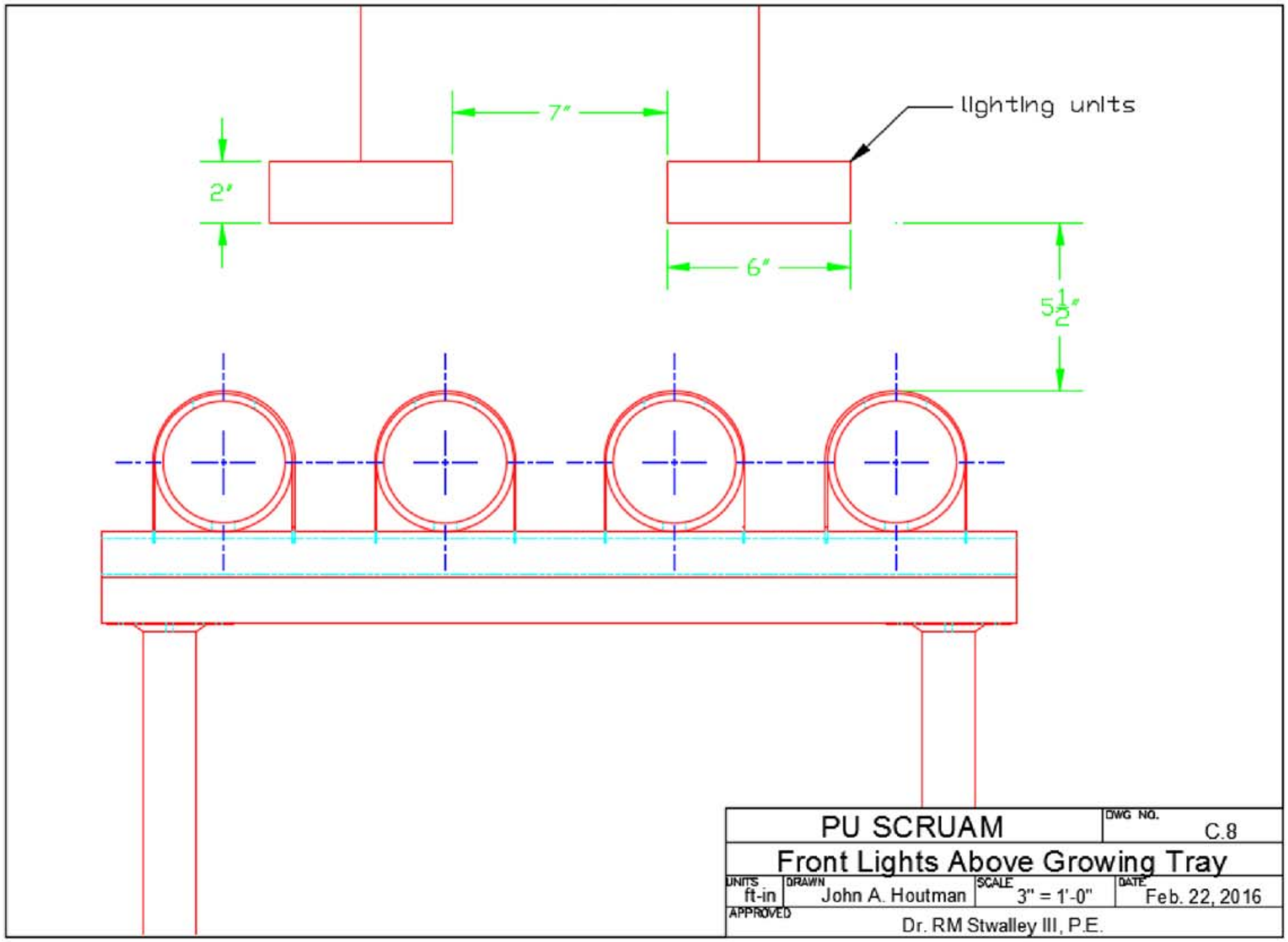
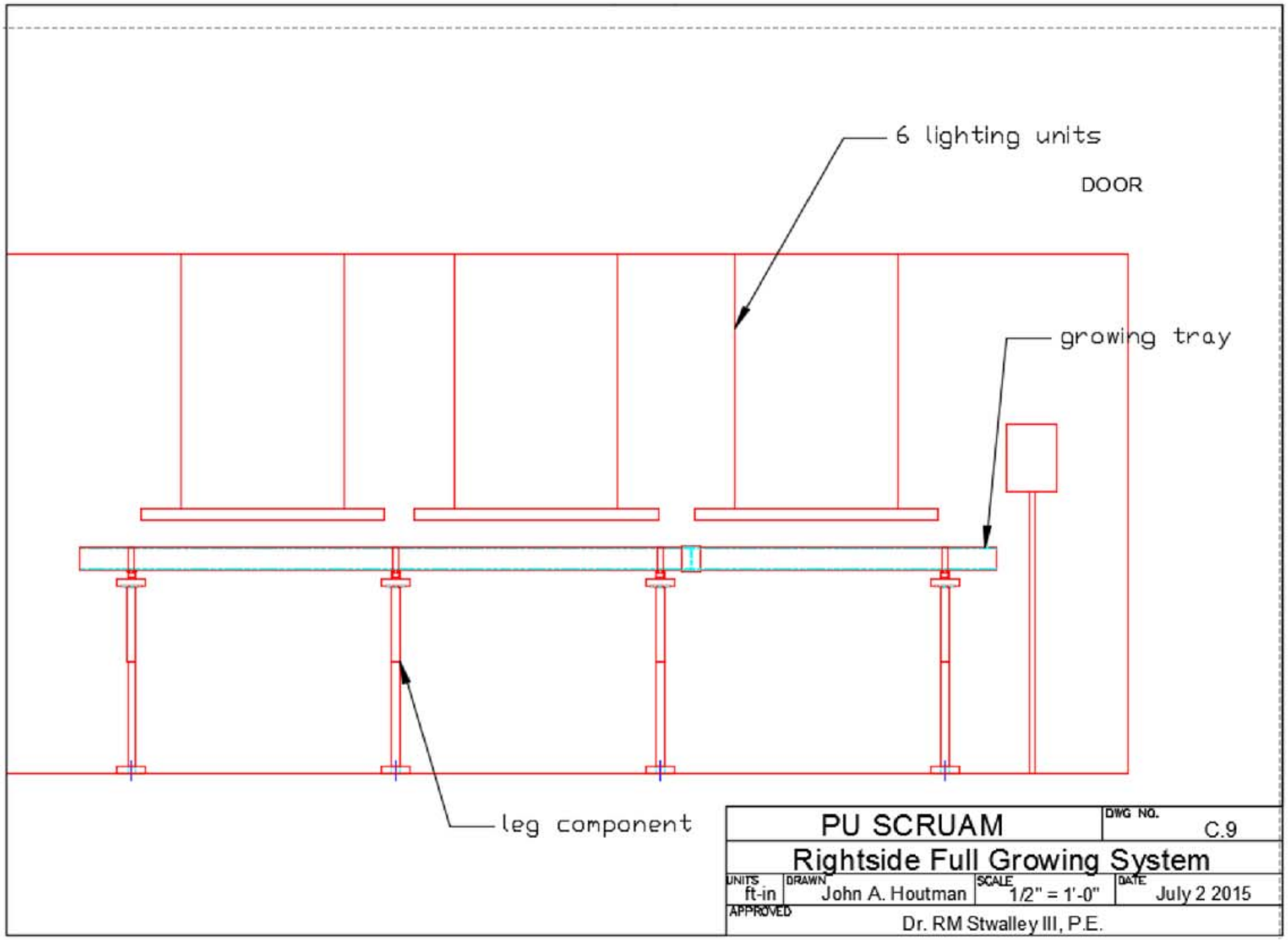


*Figure C.9*. Rightside Full Growing System



# Appendix D. Irrigation System

D.1 provides a side view of the components in the irrigation system: drain, delivery system, reservoir, and the pump. The drain is located on the bottom of the PVC pipe with a ¾” drain tube. The drain is adjustable, designed to provide varying heights of water during growing periods. The pump is located inside the reservoir, also variable to adjust the nutrient flow rate. D.2 is a side view of the black tubing entering the growth tube. Each PVC pipe has a single pump delivering nutrient solution to the growing system. The ¾” black tubing is attached to the growing system to limit hazards. D.3 is a front view of the thru-hull drain design. A boat drain was installed into the bottom of the growth tube, sealed with an O-ring. An adjustable ½” PVC pipe is inserted into the thru-hull drain, allowing varying heights of water in the growth tubes. D.4 shows a front view of the multiple nozzle drain design. Every nozzle was designed to contain a switch that will stop the flow of nutrient solution to the respective nozzle. Depending on the desired height of nutrient solution within the growth tube, the matching nozzle would be switched to “open”, each draining to the reservoir. D.5 is a front view of the flow stopper drain design. A “plastic stopper” was designed to slide into a ¼” slit in the top of the PVC pipe. The rubber attached to the bottom of the “plastic stopper” would seal to the bottom of the growth tube, stopping the flow of nutrient solution, providing time to adjust the drain to the desired water height.

*Figure D.1*. Rightside Reservoir Drain and Pump

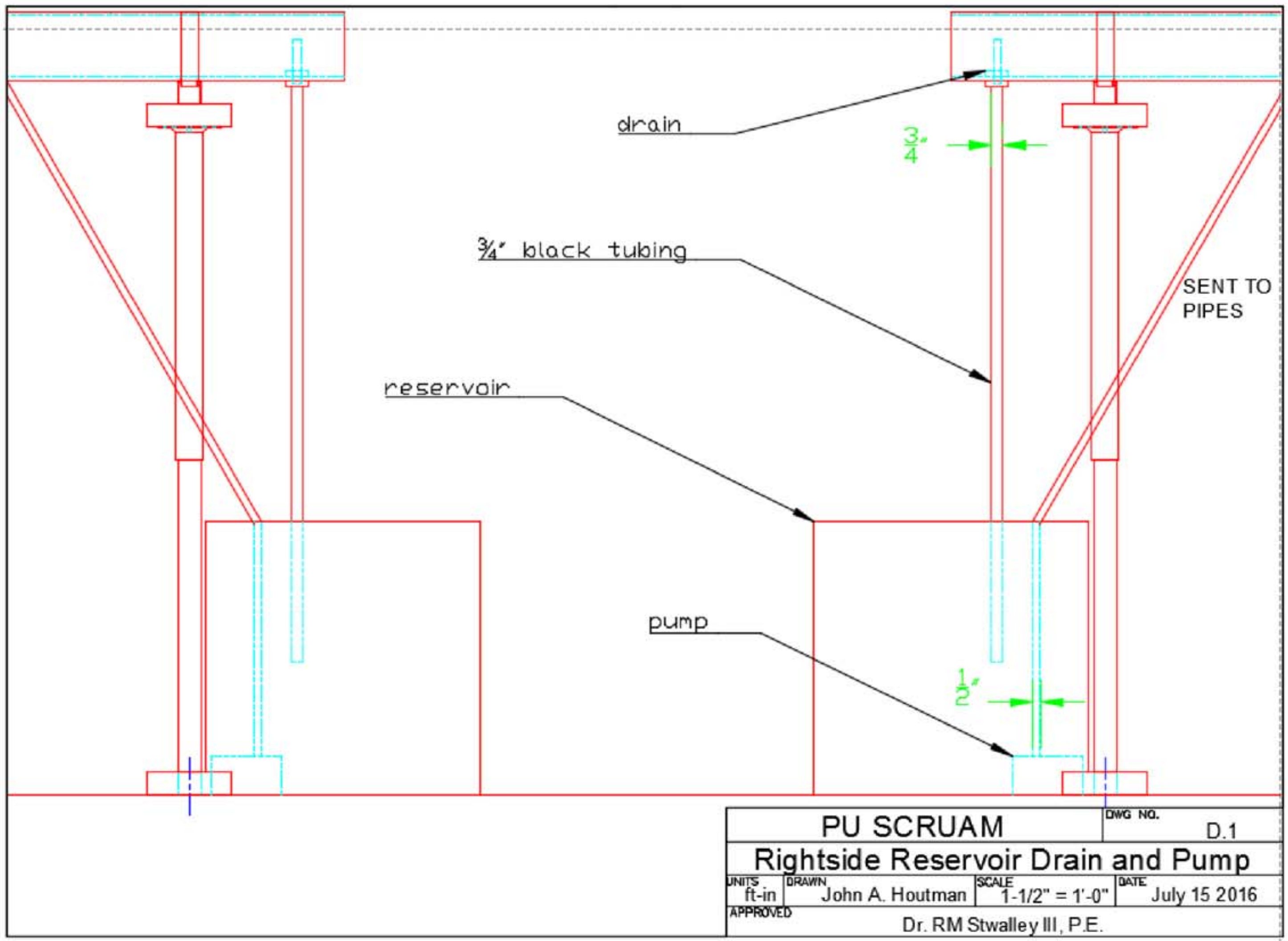


*Figure D.2*. Rightside Tubing Water Deliver

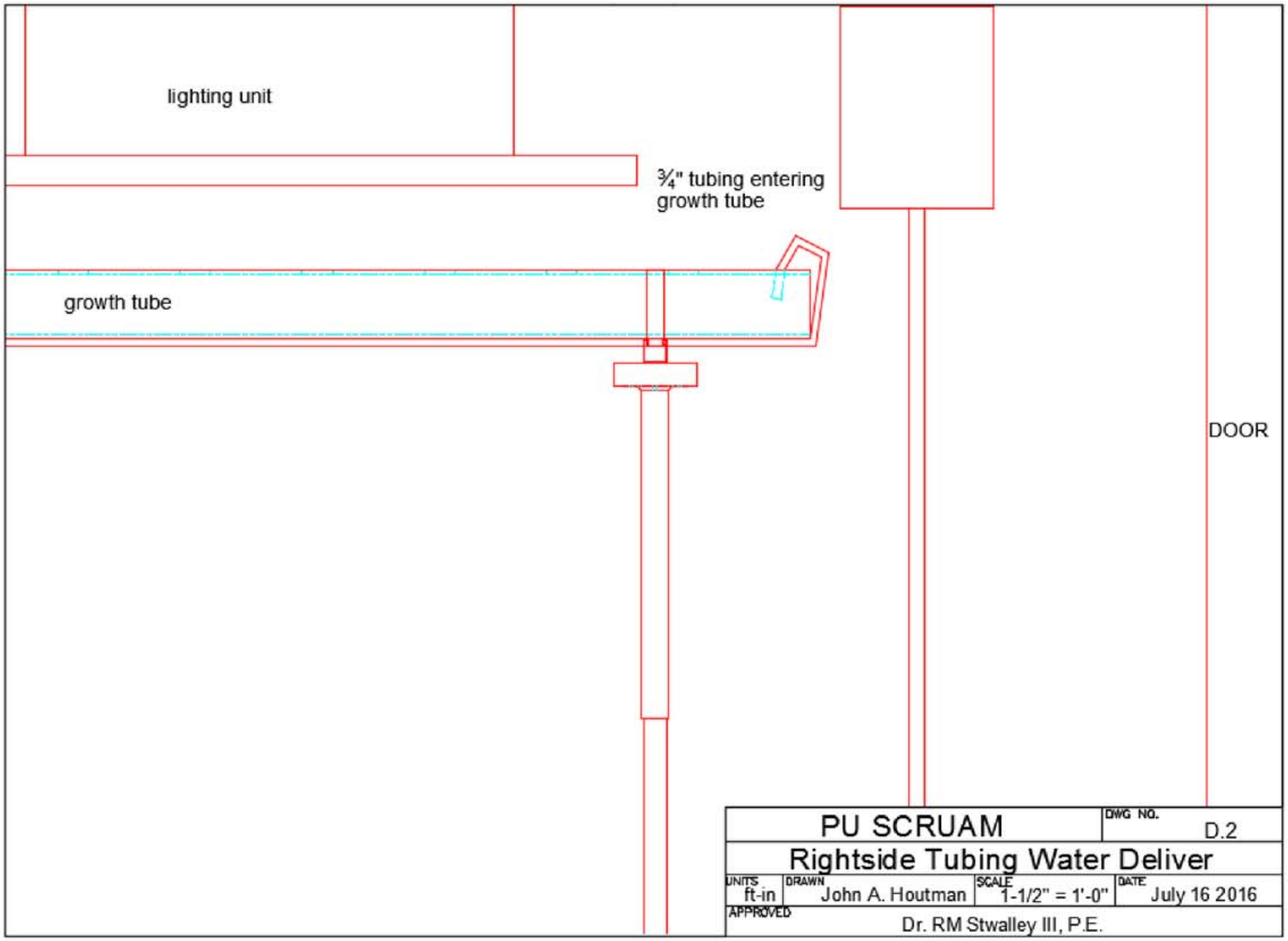


*Figure D.3*. Front Thru-Hull Drain Design

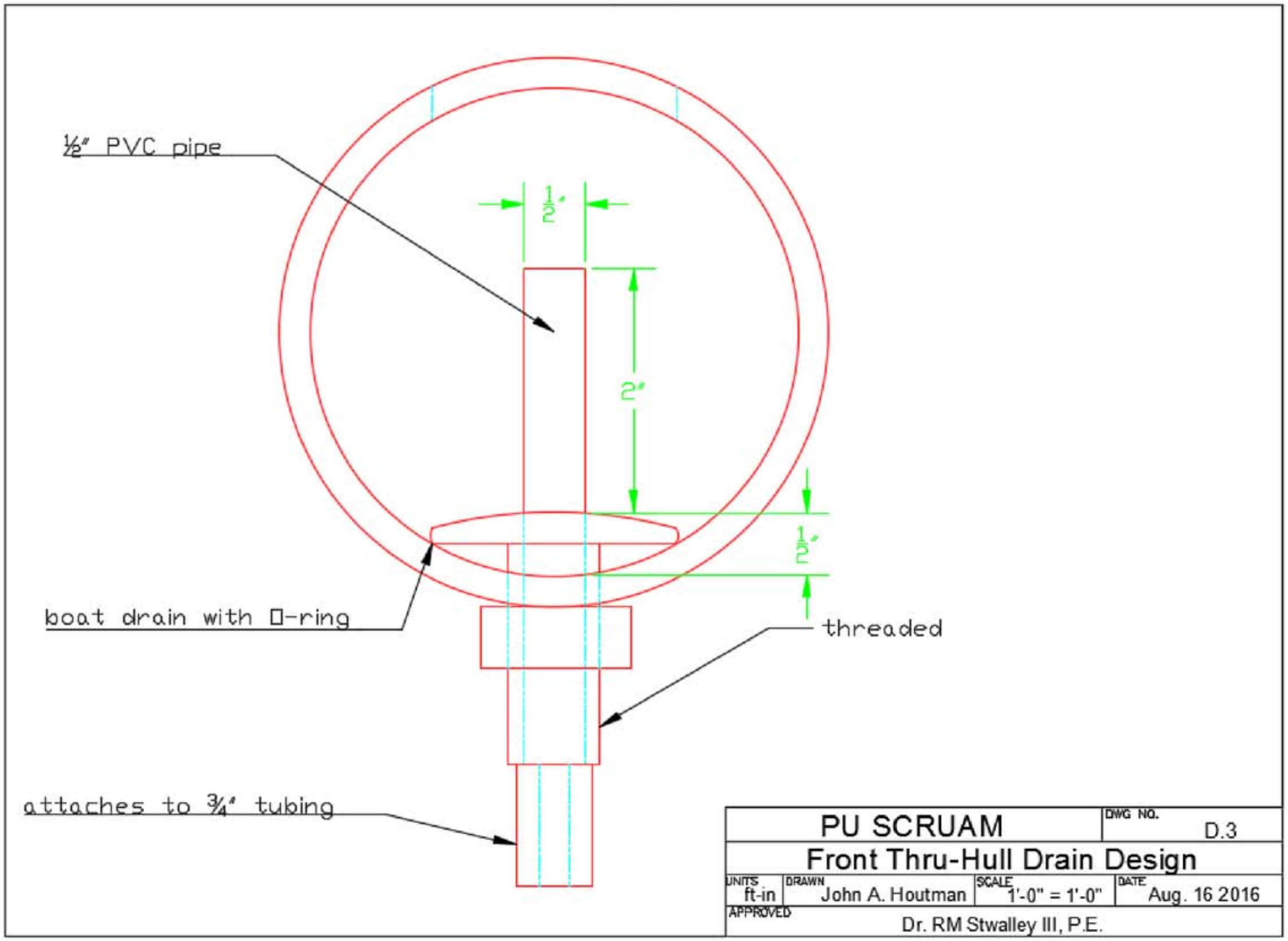


*Figure D.4*. Front Multiple Nozzle Drain Design

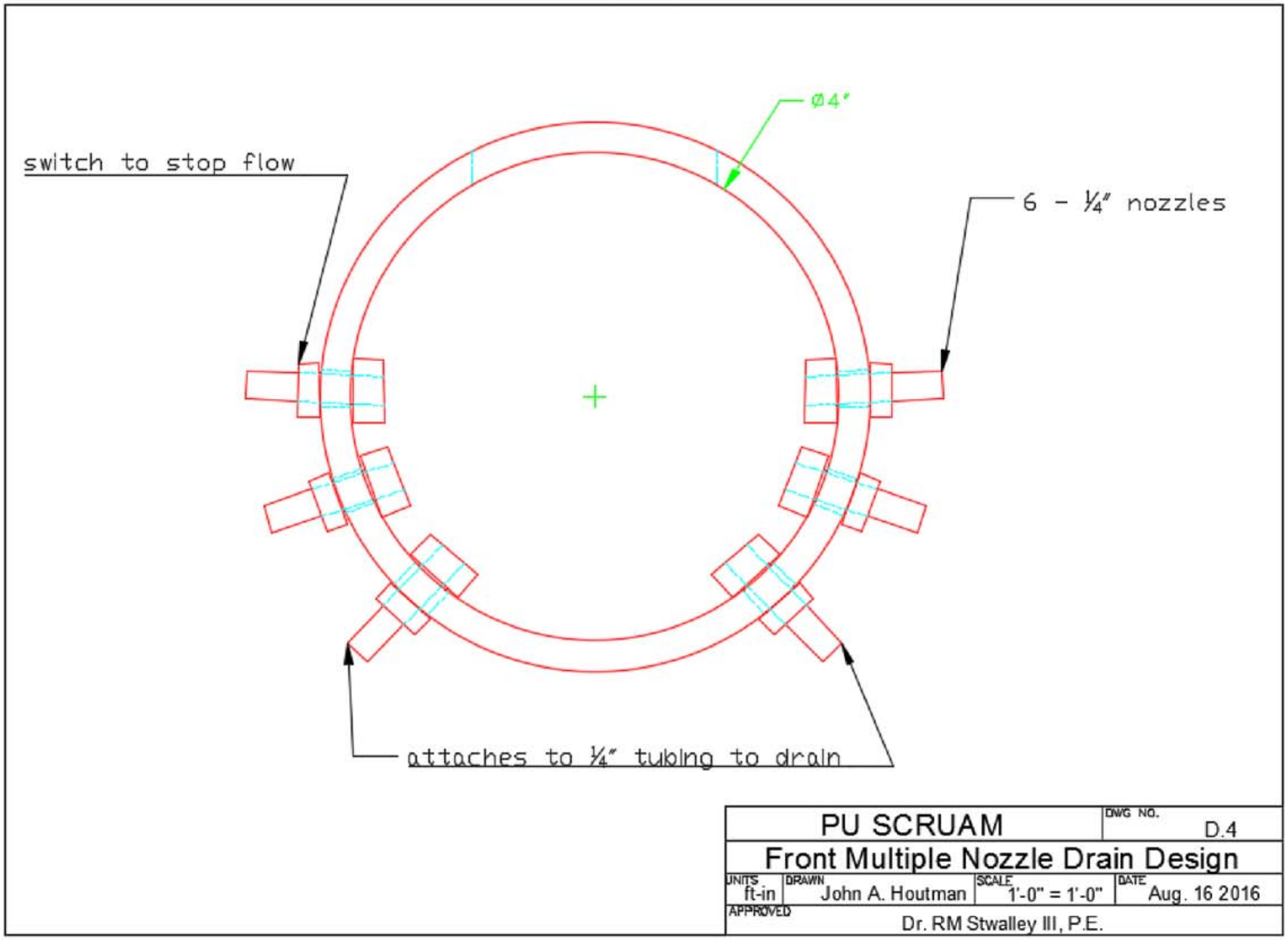
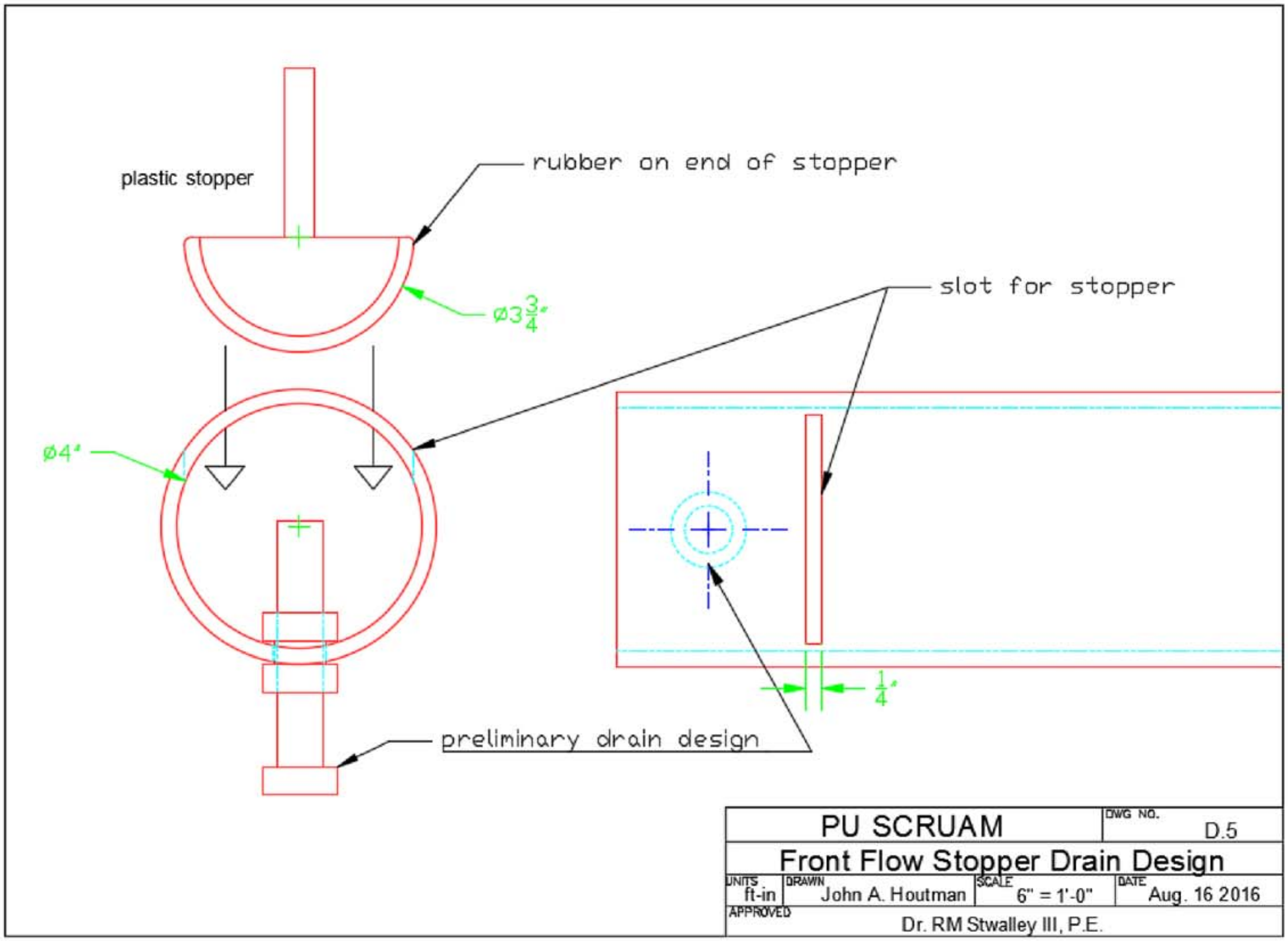


*Figure D.5*. Front Flow Stopper Drain Design



# Appendix E. Environmental Control System

E.1 is a side view of insulation and FRP panels installed to the side walls on the interior of the shipping container. The panels were 8' in height and were placed approximately 1" away from the strut channels. Insulation was included in the environmental control design to reduce heat loss during winter months and heat gain in summer months. E.2 provides a front view of insulation and FRP panels installed on the rear wall. FRP was attached on top of the insulation panels to prevent fire hazards from occurring within the shipping container. Approximately 9.5" of space was not covered at the top of each wall for proper area for ventilation components. E.3 is a front view of the exhaust mount located on the exterior of the shipping container. The exhaust mount has a mesh screen and shield to prevent objects and animals from entering the ventilation system. E.4 is a front view of the ventilation fan and motor located inside the shipping container, at the top, center of the rear wall. The motor is located on the motor housing unit. Air enters through the top of the fan, 8" intake, and exits through the exhaust. E.5 provides a front view of the exhaust mount, ventilation fan, and motor assembly. E.6 is an overhead view of the exhaust mount and ventilation fan assembly. The exhaust mount is attached to the outside of the rear wall, and the ventilation fan is located on the inside of the rear wall. E.7 is an overhead view of the ventilation fan, exhaust mount, and ductwork. The 8" ducting located on both sides of the shipping container connect to a 90-degree piece, which delivers air to the fan through an 8" tee. Ventilation was needed in the environmental control system to improve the $CO_2$ concentration and removal of warm or cool air within the shipping container. This improves the growing conditions within. E.8 provides a front view of the fan and ductwork mounted at the top center of the rear wall inside the shipping container. The air removal rate is able to be varied due to adjusting the 8" damper, located within the ducting just before intake of the fan. E.9 is an overhead, interior view of the air inlet holes drilled into the floor of the shipping container.

*Figure E.1*. Rightside Insulation and FRP Side Wall

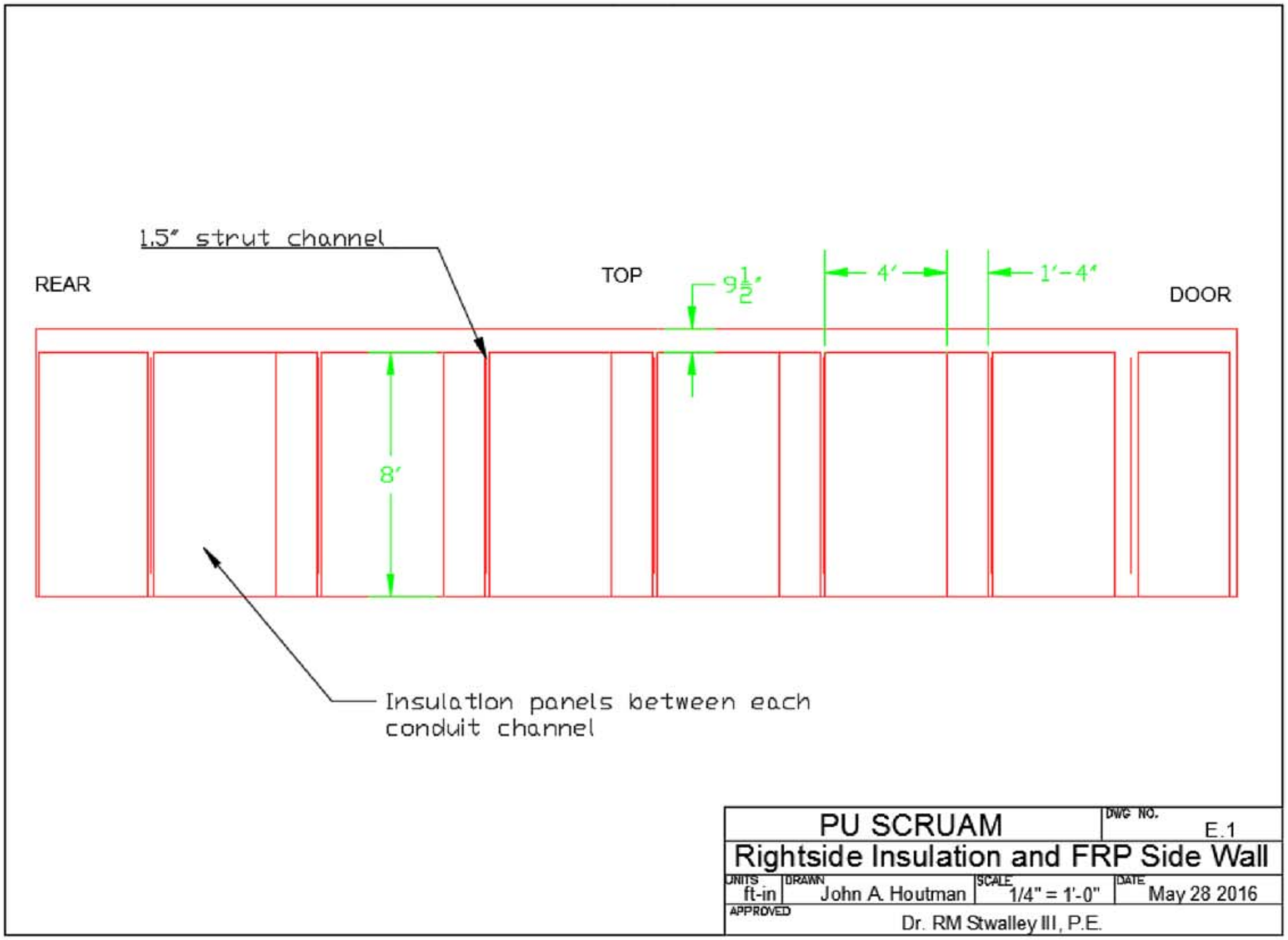


*Figure E.2*. Front Insulation and FRP Rear Wall

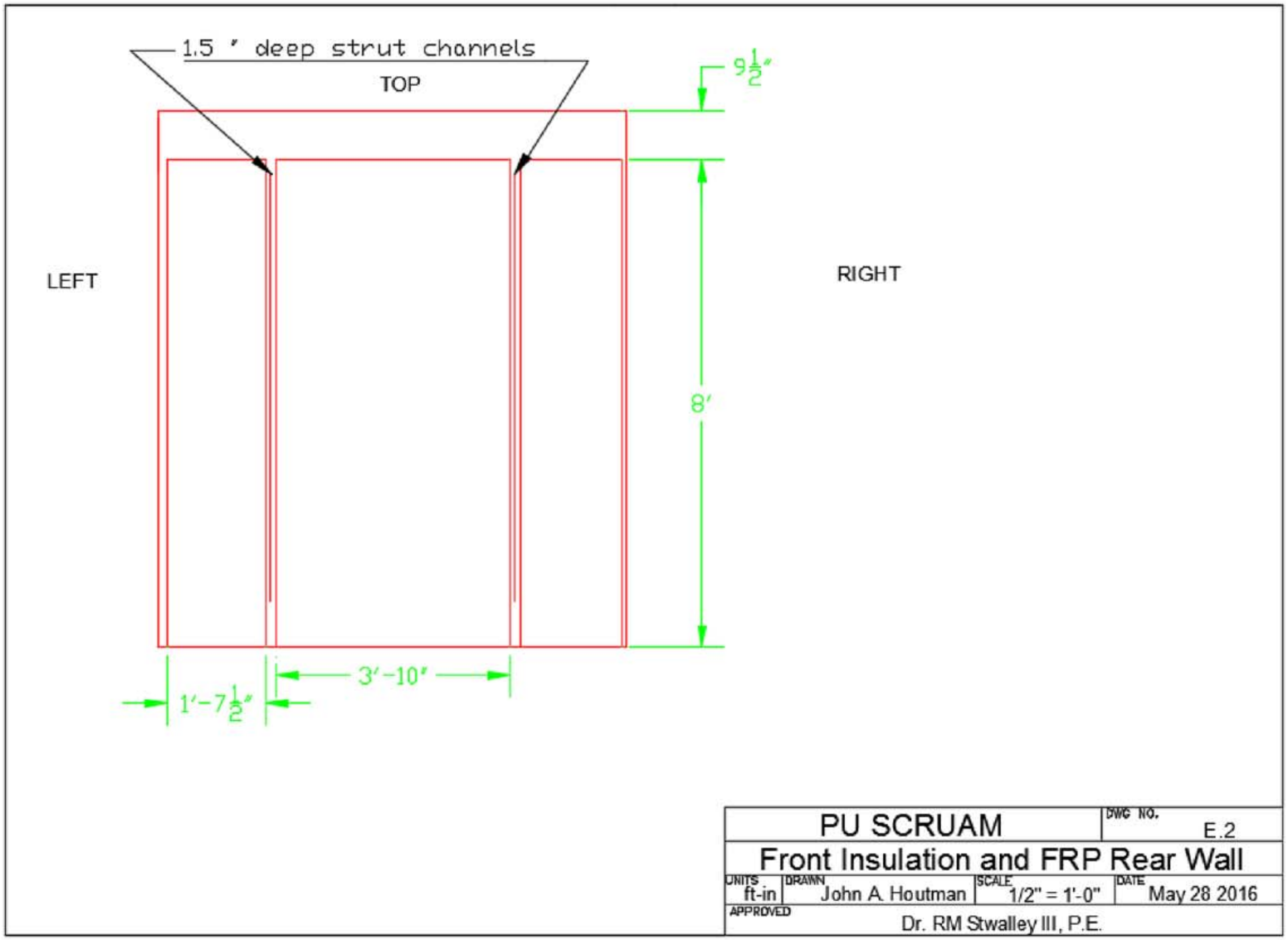


*Figure E.3*. Front Ventilation Exhaust Mount

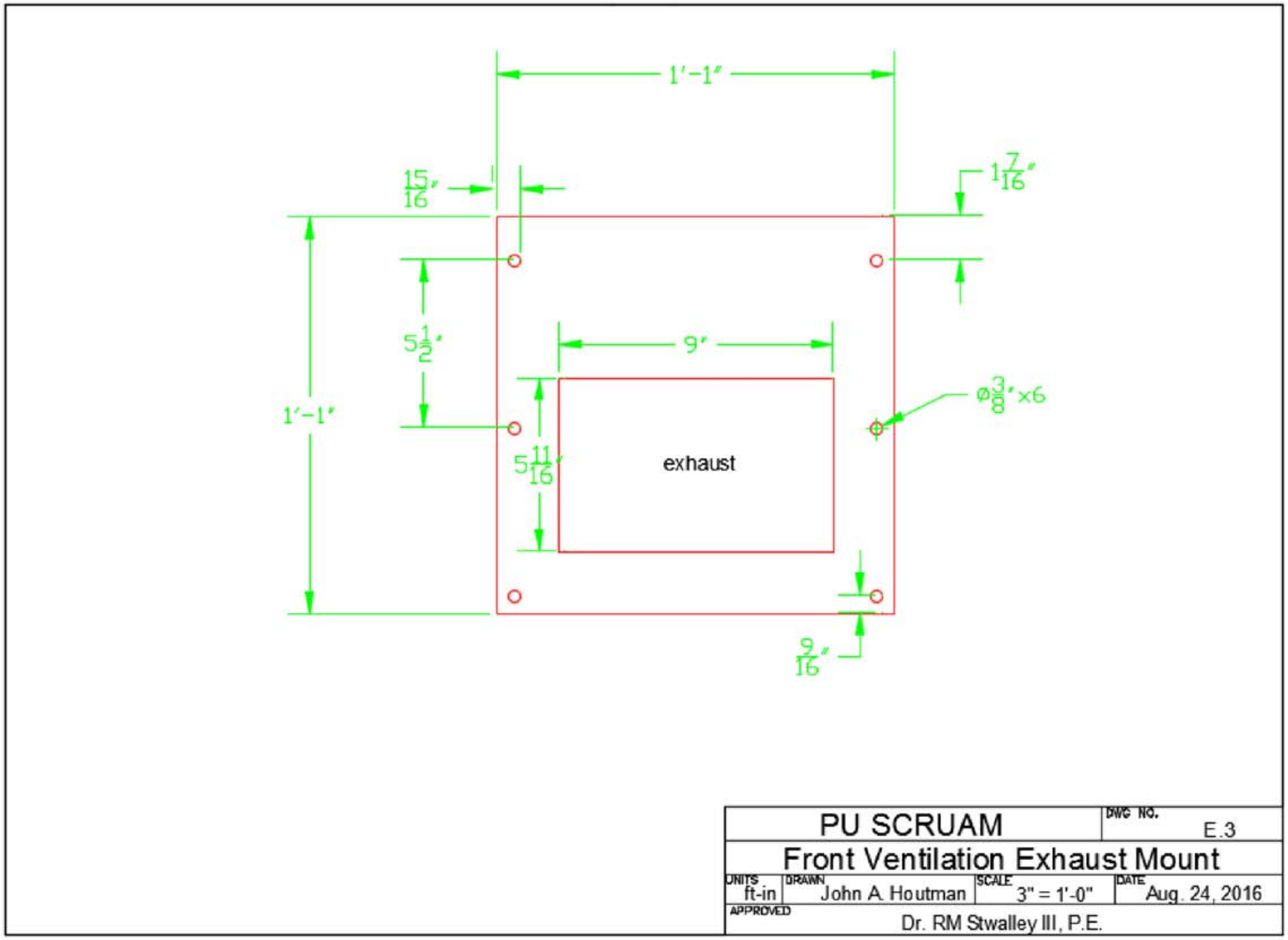


*Figure E.4*. Front Ventilation Fan and Motor

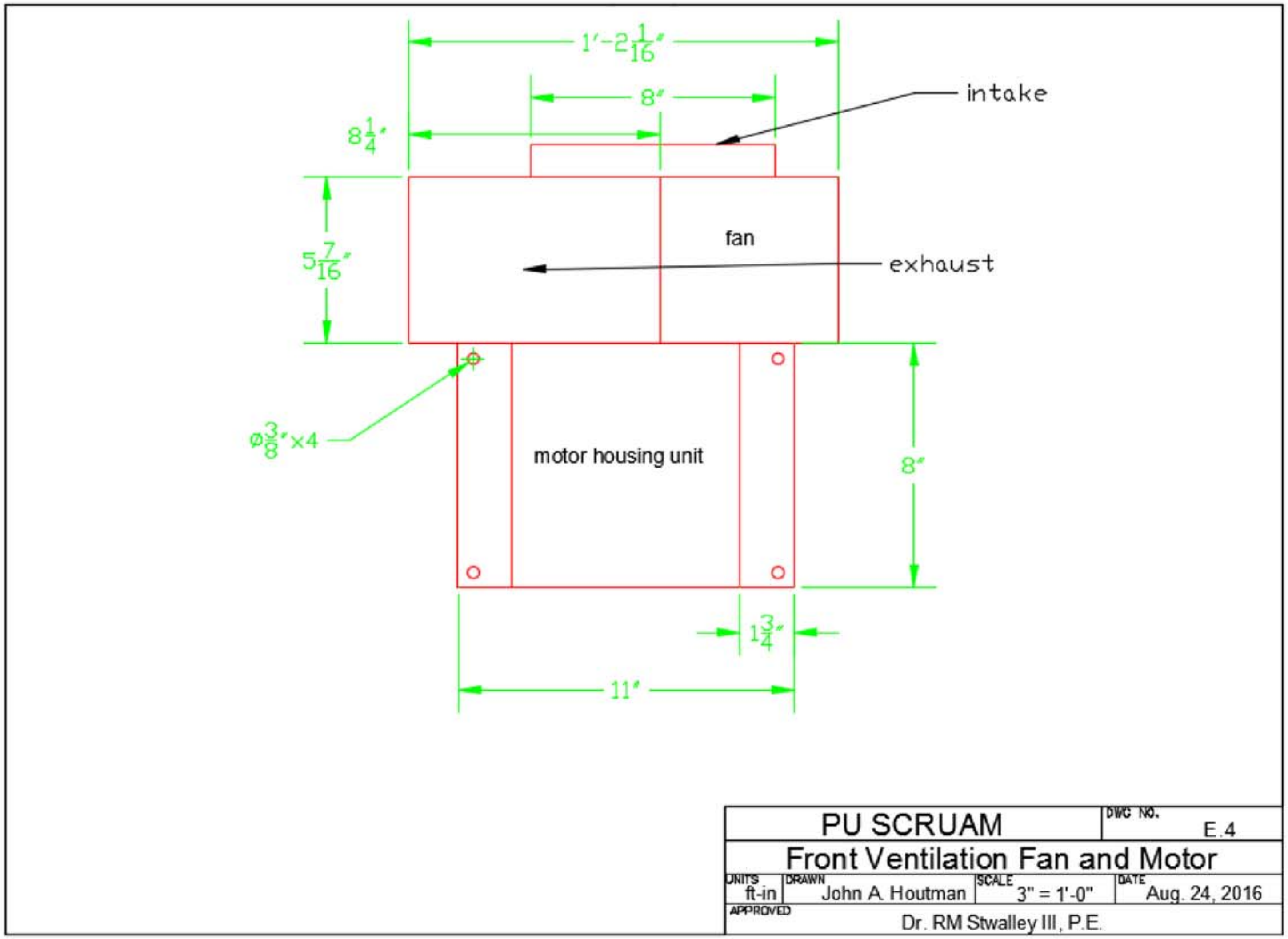


*Figure E.5*. Front Ventilation Assembly

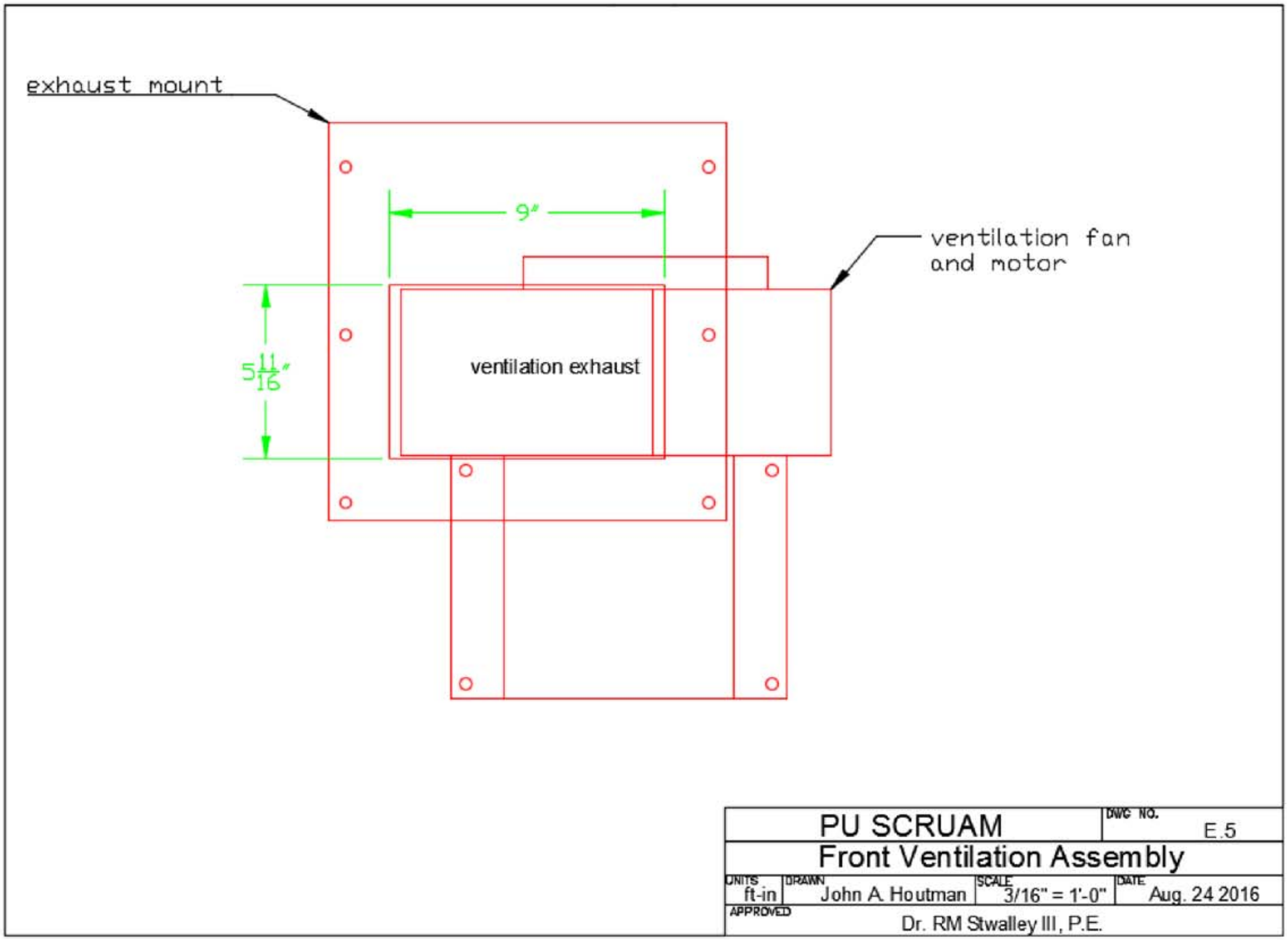


*Figure E.6.* Overhead Ventilation Assembly

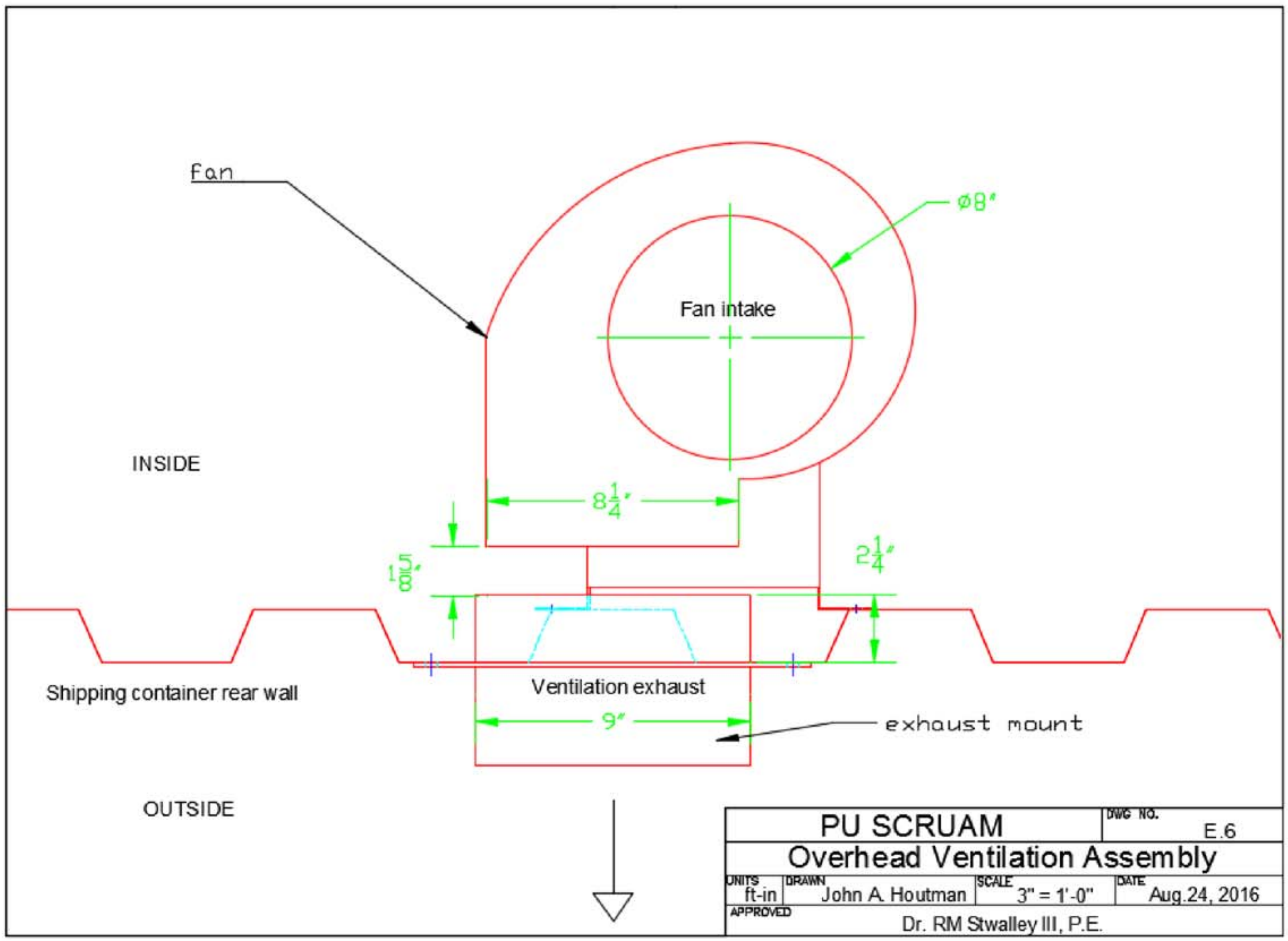


*Figure E.7*. Overhead Ventilation Ducting

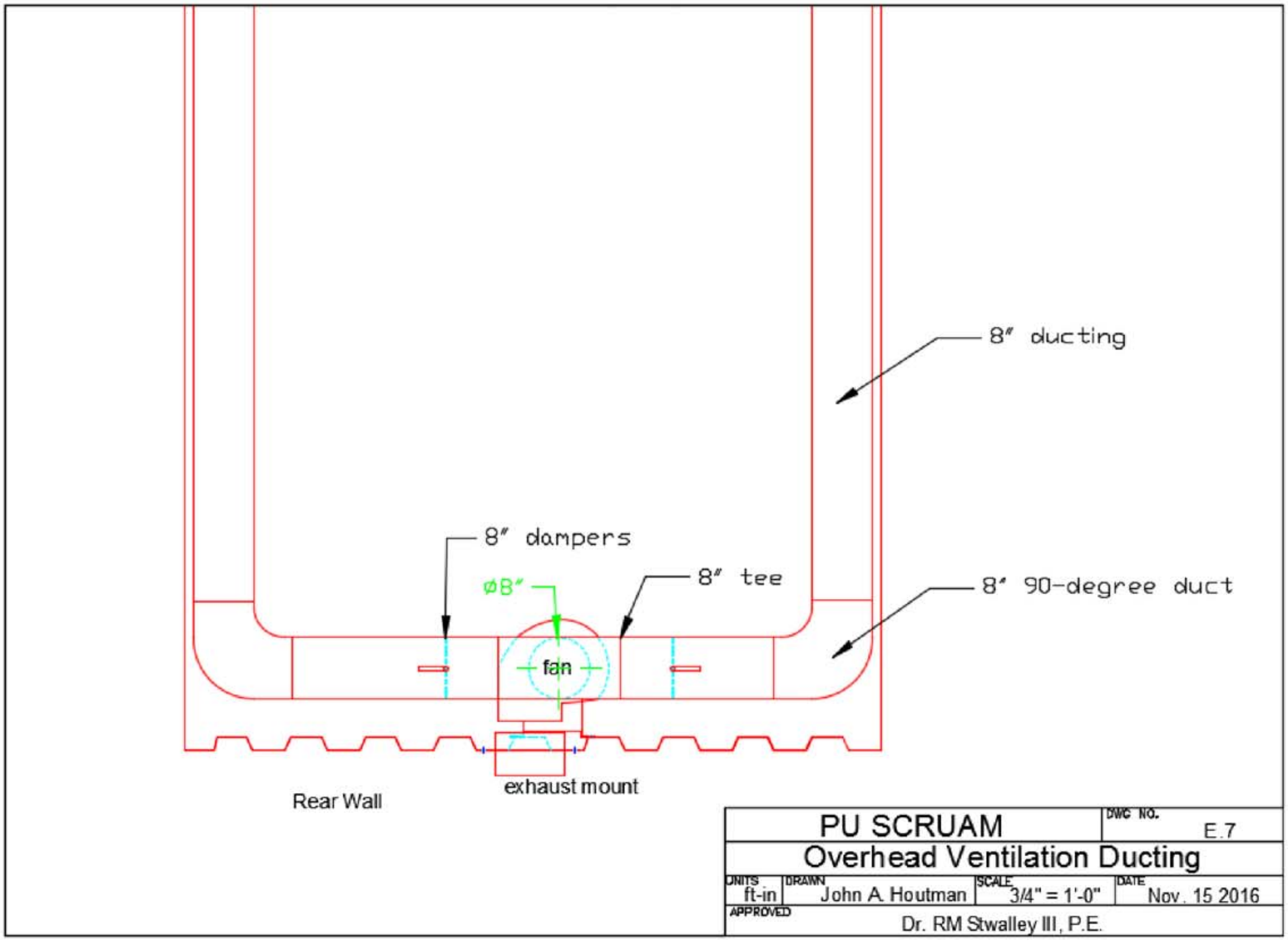


*Figure E.8*. Front Ventilation Fan and Duct

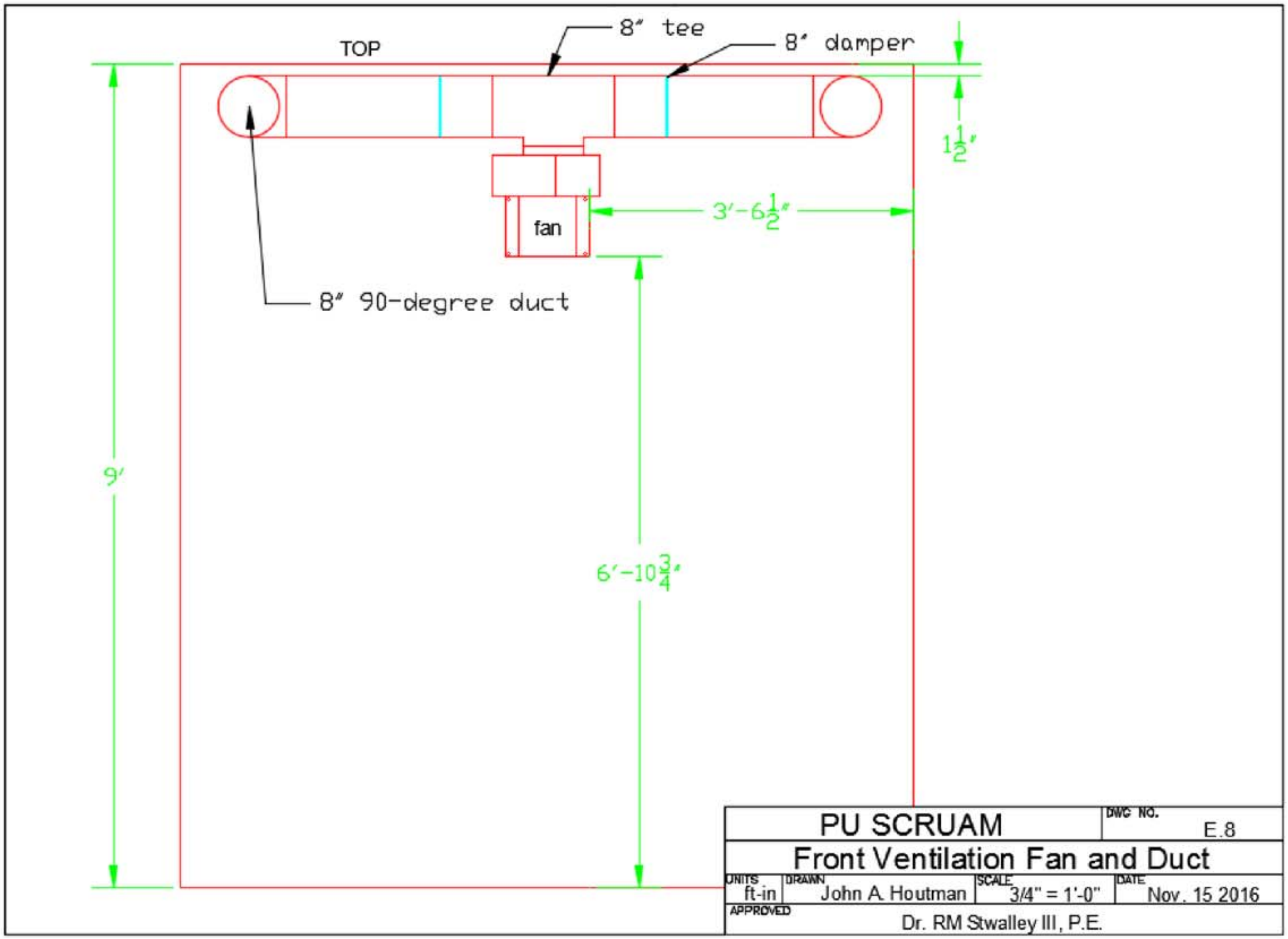
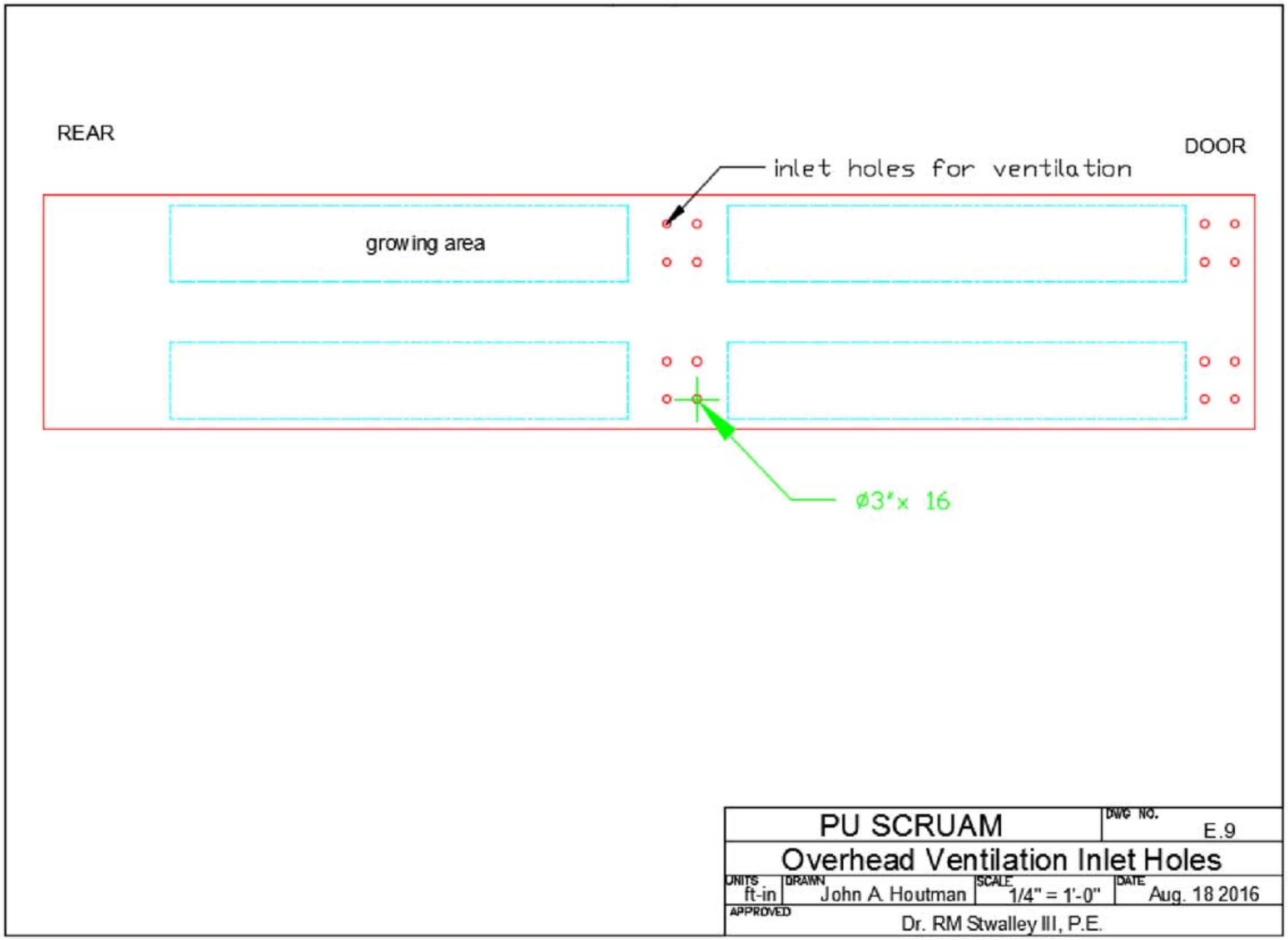


*Figure E.9*. Overhead Ventilation Inlet Holes



# Appendix F. Electrical Schematic and Plumbing

F.1 shows the side view of the schematic for the electrical wiring inside the shipping container. The components needing electricity in this design are the work lights, grow lights, ventilation fan, and irrigation pumps. The wires will travel through the shipping container via the strut channels. F.2 is an overhead view of the wiring and where each component, needing energy, is located. The wiring necessary for the lights will be attached to the ceiling strut channels. F.3 is a side view of the plumping necessary for the supply of water to the irrigation system. A valve is located near the door, where the outside water source will enter the MHSC. F.4 is an overhead view of the irrigation plumping schematic. The plumping will be attached to the strut channels located on the side wall.

*Figure F.1.* Rightside Electrical Schematic

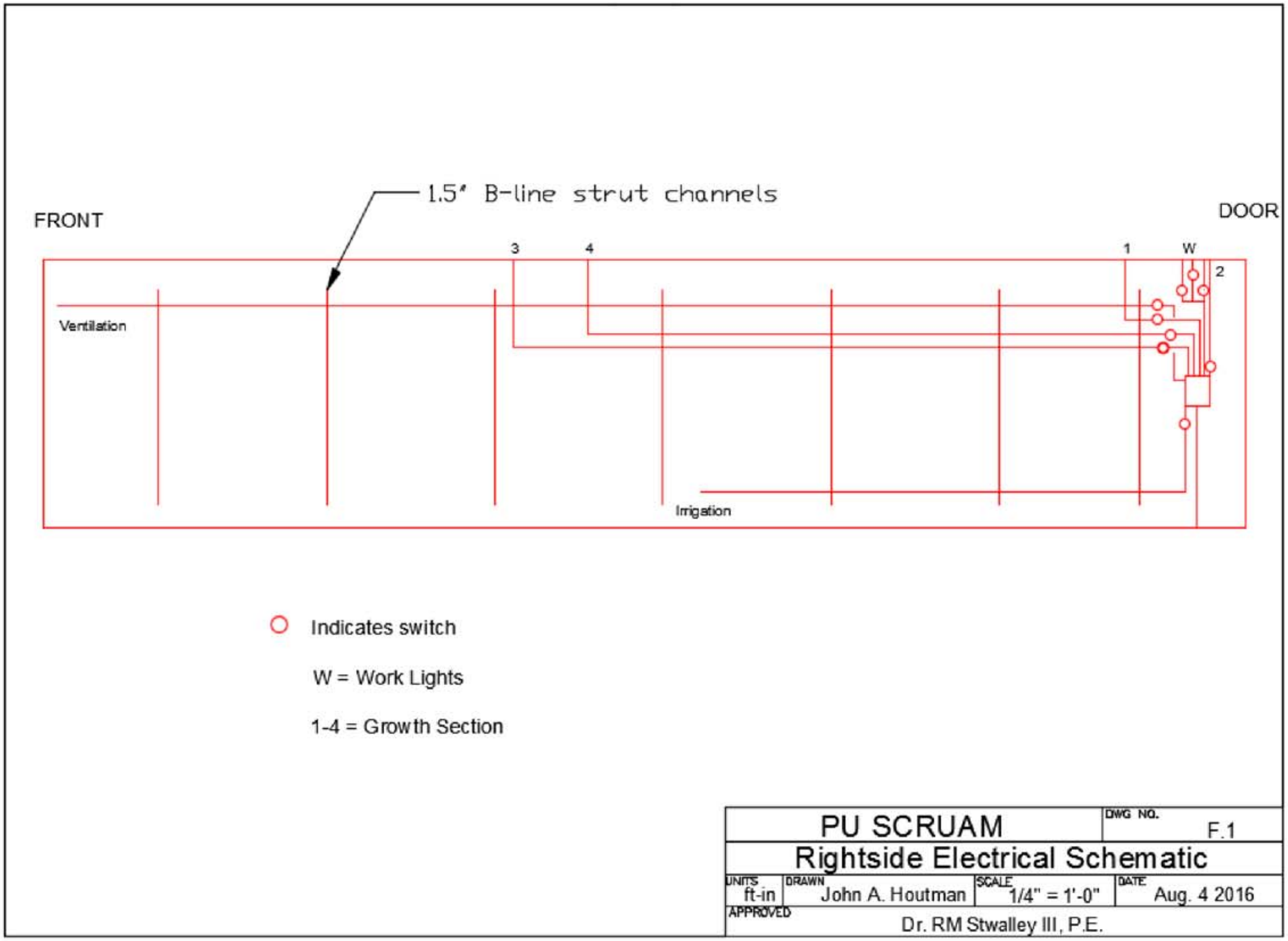


*Figure F.2.* Overhead Electrical Schematic

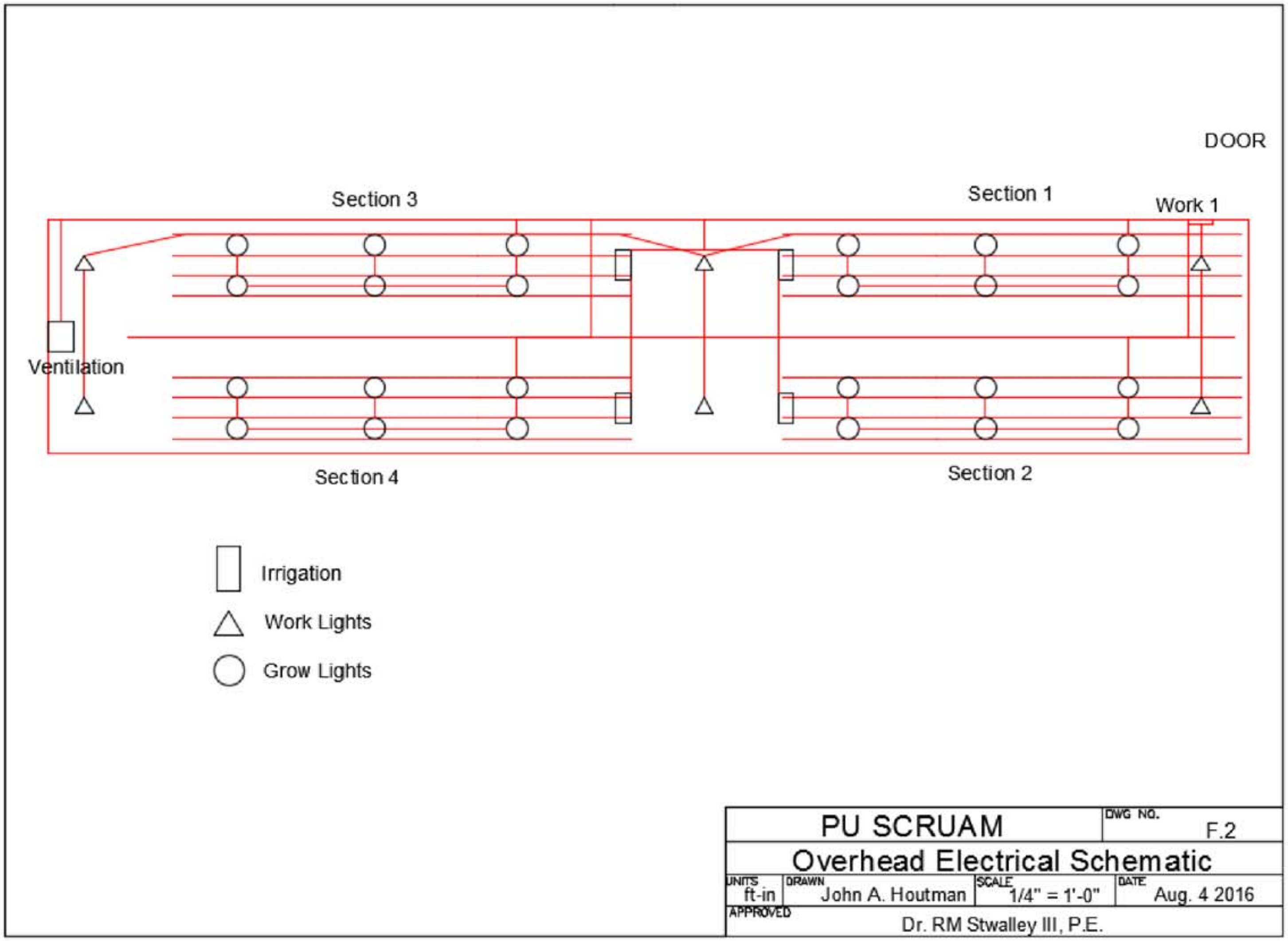


*Figure F.3.* Rightside Irrigation Plumbing

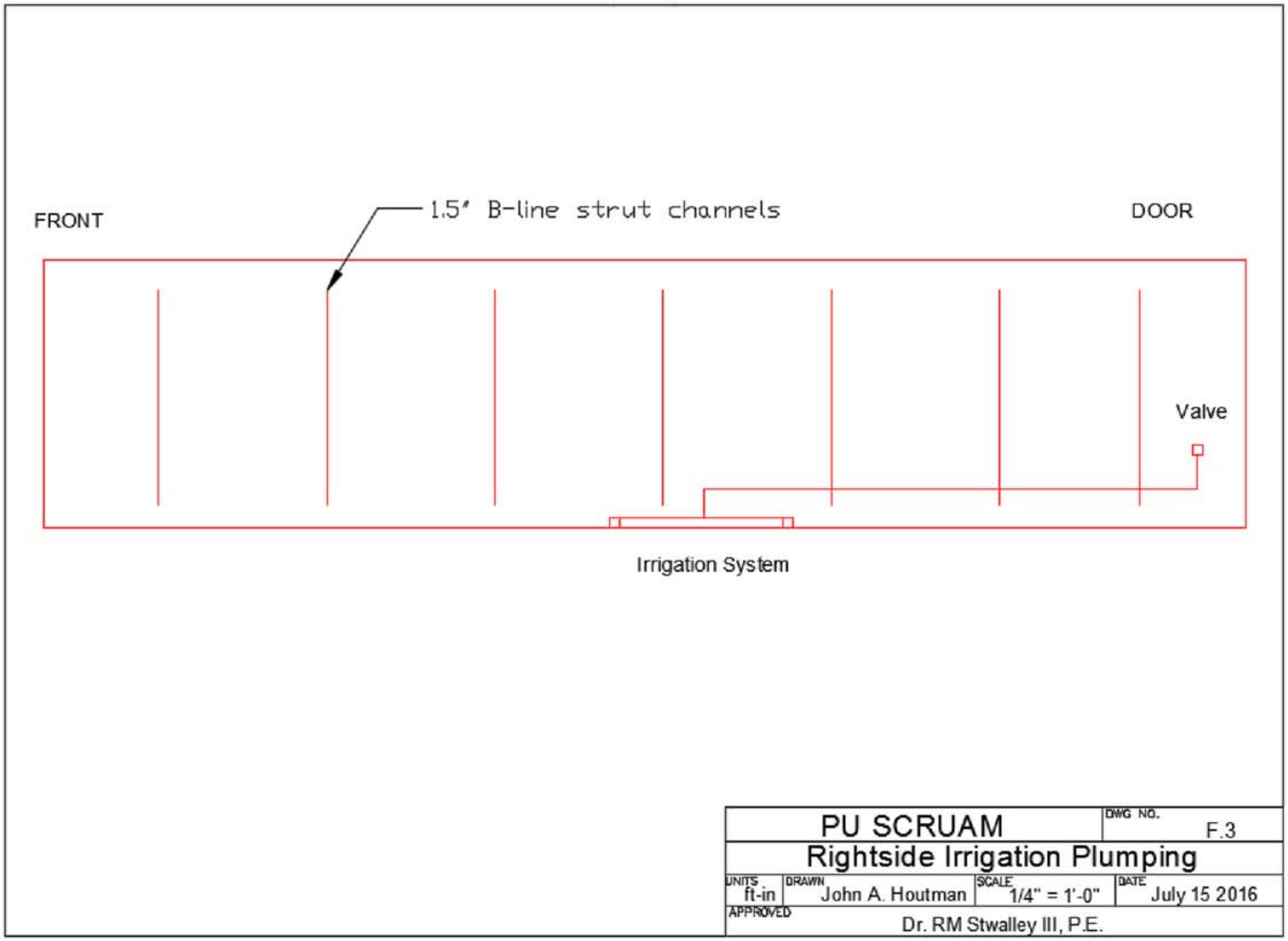
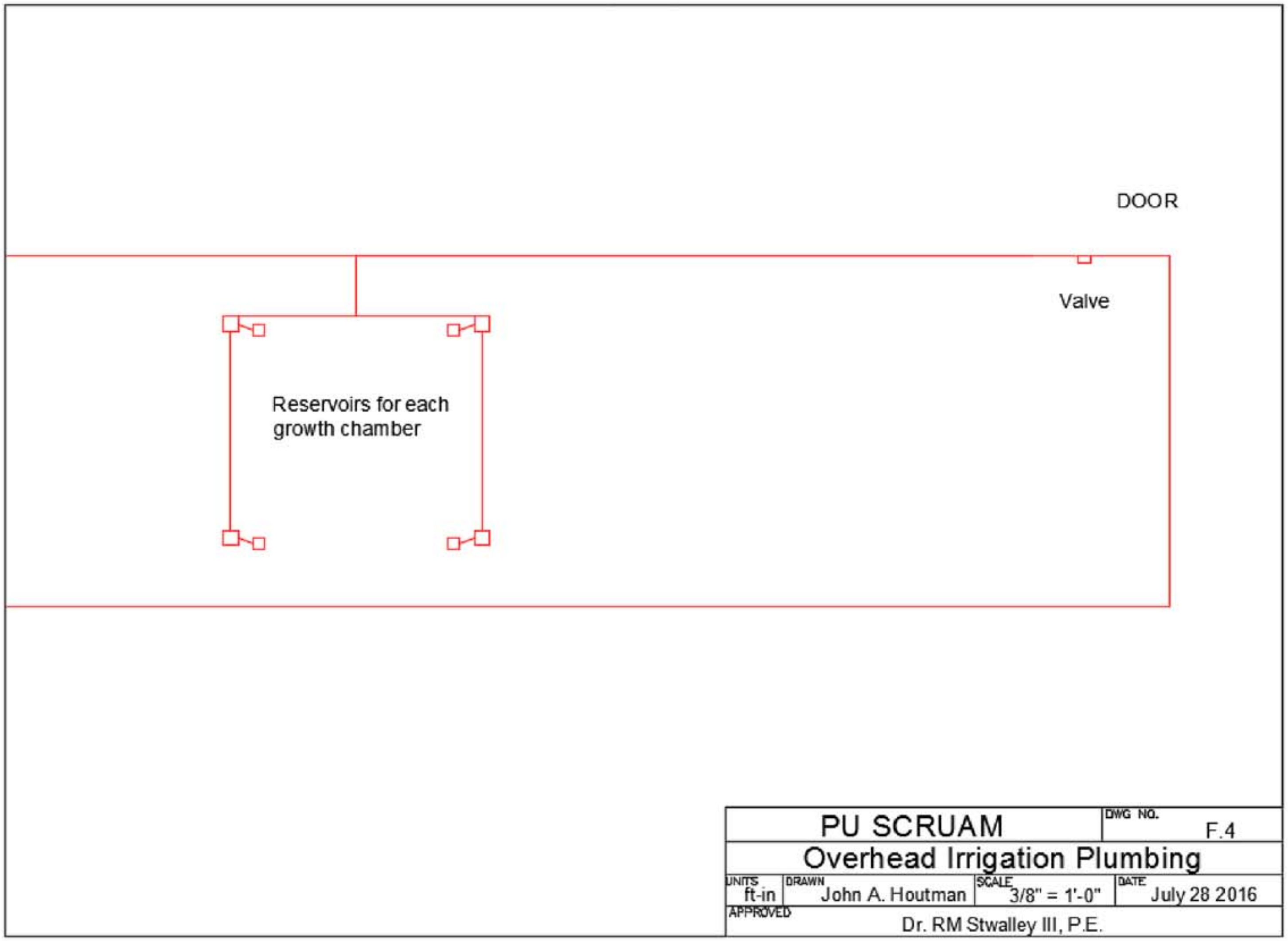


*Figure F.4.* Overhead Irrigation Plumbing



# Appendix G. MHSC Full Assembly

G.1 is a side, interior view of each system and component designed in the MHSC. (A) is the growing system, consisting of the growing lights, trays and leg units. The lights are located just above each tray, attached to the conduits on the ceiling. There are four growing systems within the MHSC. (B) is the irrigation system, consisting of the pump, nutrient delivery system, drain, and reservoir. The reservoirs hold the nutrient solution and are located in the middle of each growing system. There are four pumps per growing area, each delivering nutrient solution to its respective growth tube via ¾" black tubing. (C) is the ventilation system, consisting of a fan, exhaust mount, ductwork, and damper. Air enters the shipping container through holes drilled into the floor, arrows in the drawing, and travels through the ducting located along each side of the MHSC. The fan is attached to the rear wall, where it meets the exhaust mount, which protects harmful substances from entering through the exhaust hole. (D) is the electrical and water input location. This is where the plumbing and electrical wire will enter the MHSC. They will then travel to the desired component by attaching to the strut channels placed along the walls and ceiling.

*Figure G.1*. Rightside MHSC Components