D-Lab I Report: Potato Storage and Agricultural Education Facility in Bareti, Georgia

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Table of Contents

Executive Summary

Our client (Bediani Children's Center) in the Kvemo Kartli region of the Republic of Georgia is pursuing a holistic, multi-faceted approach to increase the economic capacity of the village of Bareti. The potato farmers in this village lack sufficient capital to access or utilize information that is necessary to improve agricultural practices and production, and are uninclined to use new methods unless proven effective due to their economic vulnerability. Additionally, there is a lack of education and resources available to prevent potato seed degeneration, which has been caused by a lack of temperature and humidity-controlled storage environments, as well as poor seed-saving practices. Because of this, the Bediani Children's Center has proposed to build a climate and humidity-controlled potato storage facility to support local farmers and their potato harvest and seed crop. This space will also be used for agricultural education classes and programs during the summers.

Introduction

Potatoes are a crucial crop in the Republic of Georgia. This is very much the case in Bareti, Georgia (our client's community), where it is their staple crop. The community is economically and nutritionally dependant on the crop year round, but its location (a two hour drive away from the nearest city) is separated from the bulk of available farming expertise in the country. As a result, there is little accessible education for the farmers to improve agricultural production methods. Traditional methods result in high seed degeneration and crop waste, but farmers are reluctant to change their production practices.

Community needs assessments have concluded that there is a large need for both a centrally located postharvest facility, as well as an education space for producers to increase their capacity and improve their farming methods. The construction of this center is aimed to sustainably improve nutritional and economic security in the region through communal storage availability, profit retention, and capacity development.

Methodology

We approached this project by assessing the largest barriers to the successful completion and operation of this storage facility. We quickly understood that the lack of information regarding potato storage facilities was a weakness, and that we could contribute research in multiple fields over the course of the quarter. Our client agreed, citing a lack of relevant and accessible expertise as a main problem of the project. The bulk of our efforts was then directed towards answering questions that our client had about specific components, offering recommendations so that our client could narrow down his final design, and researching different sectors that were relevant to the successful use of the storage/education facility. These sectors ultimately ended up being: architecture, insulation, HVAC systems, layout, and maintenance. The results of our research can be seen below.

In addition to the above research, we used two methodological tools to crystallize the needs, strengths and weak spots of this project. Our SWOT analysis (figure 1.1) and Life-Cycle Analysis (figure 1.2), which highlights the cyclical life of the facility instead of a single linear timeline, were helpful in defining big picture issues.

Results and Discussion

Sector One: Architecture

Goals

To have a climate controlled storage facility that can house over 900 tons of potatoes over the winter. During summer months, the space should be able to accommodate educational workshops in order to improve local farming practices.

Prospective Facility

This structure that the client provided to us (figure 2.1) has over 500 square meters of floor space, but given the drive-thru lane for a truck (efficient for delivery and pick-up), over 200 square meters of space is sacrificed for the convenience. Furthermore, doors are the most porous insulators in a building; this layout would act as a potential corridor for cool air to flow through the building, potentially devastating the HVAC controlled climate. Additionally, windows (figure 2.2) are not recommended as sunlight can negatively affect potatoes in storage.

Architecture Findings and Recommendations

Building Type

Hakan Kibar, in his article, *Design and Management of Postharvest Potato Storage Structures*, writes that most structure-types are satisfactory for storing potatoes, some of these are buildings of “concrete, wood stud and pole frame, and metal quonset” (Kibar, 40). Kibar mentions that “commercial rigid frame steel buildings are not normally used because the exposed steel beams and columns are difficult to insulate” (Kibar, 40), which we would highlight for the designers of the potato storage facility. Furthermore, this structure requires pillars that supports the roof frame, which can interfere with “stock management procedures” (Kibar, 44), the loading and unloading of potatoes. Given these difficulties, it will be very important to insulate/wrap a vapor barrier around these exposed columns. Additionally, the distance between the pillars and the dimensions of the wooden potato storage boxes ought to be considered simultaneously. There are 6 different approved sizes of potato box, so choosing the dimension that best efficiently fits within the columns will maximize the effectiveness of the space.

Drop-down Ceiling

Consistent temperature and condensation levels crucial to a potato storage facility. These are often controlled by an HVAC system, but adding permanent drop-down ceiling can reduce the burden on this system. A ceiling underneath the trusses has many benefits: Roger Brook writes that,

> "A ceiling is important in any potato storage, especially those with a truss roof. Space above the ceiling will provide good venting for the ceiling insulation. The reduced space between the potatoes and the ceiling will result in less temperature stratification. The ceiling surface will remain warmer to reduce the likelihood of moisture condensation" (Brook, 468).

An image and a bullet-pointed summary of these benefits can be found in the appendices (figure 2.3).

Windowless Potato Storage

While windows make for an improved space for human habitation, sunlight does not have a positive impact on stored potatoes. This is one potential conflict between the needs of storing potatoes and the needs of an educational workspace. The latter would be positively impacted by sunlight, but for potatoes:

> "A potato tuber accumulates chlorophyll when exposed to light, which turns the tuber green. The longer the tuber is exposed to light, the more greening will occur. The process will not reverse--the green color will not go away if you then store the potato in a dark place...green potatoes can form compounds called glycoalkaloids that develop along with chlorophyll formation. Glycoalkaloids may make the potatoes taste bitter" (Kibar, 29).

Given this, it appears that windows, while helpful for a workspace, will have a negative effect on the crop. Thus, it is best to not have windows in the storage facility.

Footing or Insulation below the Frost-Line

An important consideration for a facility in cold climates is its foundation. If the foundation doesn't go underneath the frost line of the soil, it could allow the winter cold to seep in from underneath the building. There are two primary ways of protecting a facility from frost penetration: to dig a deep foundation with footings that are deeper than the frost line (figure 2.4), or use "enough exterior perimeter insulation to prevent frost penetration under edge of a shallow wall footing" (Roberts, 11). (figure 2.5)

Double-Sliding Doors

While it might not seem important, doors are an integral part of any climate-controlled building. They are the weakest link in terms of air leakage both when open and closed. Hakan Kibar recommends double-sliding doors that are "preferably made of steel, or at least reinforced along their lower edges with metal plate at protection against rodents, they should be sufficiently large and close fitting" (Kibar, 45). Additionally, double-sliding doors open only to the needed size of an entering object, whereas roll-top doors must open all the way regardless of it, ie. a human versus a tractor. Thus, a sliding door minimizes airflow between exterior and interior spaces, which is crucial in maintaining a controlled inside environment.

Anteroom

This last recommendation is the most important and impactful: an anteroom or entry structure that separates the actual storage space from the outside environment. Hakan Kibar recommends this "attached second building...so that it acts as an airlock" (Kibar, 45). This recommendation requires dropping the prospective drive-thru floor plan that has an entry and egress door. While convenient, it would upset the climate controlled environment inside the store. An anteroom (figure 2.6), on the other, with an exterior door (to the outside) and an interior door (into the store), would serve as an airlock that would maintain the temperature, condensation and humidity levels provided by the HVAC system. Preserving that control would reduce the workload of the HVAC system, perhaps lengthening the time between HVAC servicing.

The system for unloading the store would work as follows: the exterior anteroom door would open during farmer unloading, but the interior door would remain closed to keep the cold, wet winter air out. After this process is complete, the exterior door would close. Then, the interior door could be opened and the stock moved into the controlled environment. Given the sporadic and multiple times potatoes might be loaded into the store--given the collective nature of this facility--a plan to minimize airflow into the space is crucial. This architectural addition will help significantly in protecting the store and its tons of potatoes.

There are other benefits as well. As mentioned above, during unloading, it would serve as a space for farmers to unload out of any inclimate weather while not interfering with the storage area. It could also be used as a space for grading and sorting potatoes. Even more, it could function as an extra storage space for any equipment, machines or tools (a forklift for instance) at the facility, instead of using the precious potato storage space for non-stock items.

In this smaller and distinct space where no potatoes will be stored, windows and skylights could be installed. In the summer months any tools or machines could be moved into the primary hold and the anteroom could be turned into a classroom. South-facing windows and skylights would blanket the room with sunlight, which would promote a pleasing environment for any workshop or educational classes.

Sector Two: Climate Control System

Sector Goals

Controlling the interior climate of a potato storage facility is important primarily because it reduces the degradation of the potato crop over time. It is important to note that proper storage conditions is not a 'cure-all' for potato storage as it can not increase the quality of potatoes in the storage. The quality of potato being placed in the storage can only decrease as time passes.

With this being said, the client's application to the Japanese embassy has requested a climate system that solves the problems of "temperature, humidity range, CO2 level, air circulation and light" as the current root cellar method does not account for these factors.

Figure 3.1 in the Appendix shows a System Map of the different variables that influence the quality of the stored potatoes. It is broken down into 4 categories: storage design, environmental properties, potato properties, and quality of potato. This figure can be consulted during the HVAC discussion as it provides a visual breakdown of the various topics. The storage design considerations influence various environmental properties within the storage which cause the potatoes to undergo certain processes and ultimately influence the end quality of the potato.

Environmental Properties

This portion of the sector is designed to give a brief overview of the different environmental properties in the facility in order to understand why certain storage design recommendations are made. These properties are temperature, humidity, and oxygen.

Temperature

The first environmental property, and arguably the most important, is temperature. It controls the respiration rate of the potatoes, the relative humidity in the air, whether condensation will form, the rate diseases can propagate, and whether or not the potatoes will freeze. Temperature determines the respiration rate of the potato, which is a measure of its metabolism rate (Storage of Potatoes). A potato's metabolism and dormancy period are inversely related so a higher respiration rate will result in a shorter dormancy period. This means that if a potato is stored at the improper temperature, it may begin to sprout before it is taken out of the storage.

Potatoes should be stored at different temperatures depending on what their end destination is. Generally speaking, seed potatoes are held at 3 to 4 ℃ while table and market potatoes are held at 4.5 to 5 ℃ (Storage of Potatoes). The purpose of changing the holding temperature is to adjust the dormancy period and the development of sugars in the potato. If potatoes are stored below ~ 4 ℃ they will begin to develop sugars that may give a sweet taste. Since seed potatoes will not be eaten it is preferable to opt for the longer dormancy period but table potatoes may use a shorter period. The seed potato temperature can delay sprouting for 7-8 months while the table potato temperature can delay sprouting for around 4 months (Bulk Potato Storage). While it is recommended to store seed and table potatoes separately due to their different temperature requirements, a mixed storage can operate at 4.5 ℃.

Temperature influences both the possibility of potatoes freezing and the spread of disease. Since this facility is to be constructed in areas that report frozen potatoes during storage, it is important to note that the inclusion of proper insulation and ventilation should protect against freezing (Edgar, 37). However, this will introduce the issue of condensation which can provide a medium for disease to flourish. Typically, diseases increase greatly after ~4.5 ℃ (Voss) so a storage should keep temperatures low to limit their growth rate.

Humidity

The humidity in a storage is directly influenced by the temperature of the air. Warm air can hold much more water when compared to cold air and effects the water content in the potatoes (Kibar, 28). If the relative humidity (RH%) of the ambient air is too low, water from the potatoes will evaporate into the air in order to reach an equilibrium. The end result of this is water loss of the potato. While this makes the potato lighter and thus easier to transport, it is more susceptible to bruising and is overall a net loss (Wustman). To prevent this, a RH of 95% is recommended as it is high enough to slow evaporation but not 100% (Wustman). At 100% RH, the air has reached its carrying capacity of water vapor and water can begin to condense on surfaces in the storage facility. If the newly condensed water droplets form on the potatoes or fall on the potatoes, it can lead to mold and begin to rot.

Oxygen

Adequate amounts of Oxygen in the storage are needed to maintain an adequate respiration rate. The potatoes' respiration consumes the local oxygen in the storage and outputs carbon dioxide. If there is not enough oxygen available, a condition called blackheart develops. This is when the inside of a potato starts to die because there is not enough oxygen available to keep it alive. It begins to die from the inside out and thus severely reduces the quality of the potato.

Recommendations

Insulation

Insulation in a storage serves to make the internal temperature operate independently of the external temperature. In general, a R value of 30-40 is recommended for cold climate storages (Potato Storage Design & Management pg. 466). This roughly corresponds to a thickness of 250mm fiberglass or 150mm polyurethane (Kibar). Insulation needs to be applied in a manner that there are no gaps between panels. If a wall consists of insulating material, a wooden column, and additional insulating material, the heat from inside the storage will transmit through the column better than the insulation. This will lead to a localized cold spot within the structure which leads to disparity in storage conditions. If part of the wall of the storage is colder than the rest, condensation can occur which leads to rot.

Part of the insulation of a facility is a vapor barrier. The vapor barrier is primarily for preventing water from condensing on the insulation and thereby decreasing their effectiveness. Adrian Cunnington, head of research at the Sutton Bridge Crop Storage Research writes that,

> "Nearly all insulation materials have their performance reduced significantly by small increases in their moisture content. The use of vapour barriers to protect insulation is only effective in the high humidity conditions found in potato stores where composite metal/polyisocyanurate (PIR) sandwich panels are used. These are commonly used for newly built stores at thicknesses of up to 120mm" (Cunnington, 4).

An effective vapor barrier is 6mm thick polyethylene sheets (Potato Storage Design & Management). These sheets should be placed on the interior wall so that the highest vapor resistant material is in the inside. If a high vapor resistant material is in between panels, moisture can build up and slowly degrade the building. Spray on foam is not recommended as it mainly seals cracks but does not block vapor (Potato Storage Design & Management).

Preventing a temperature gradient in the storage is also important in social equity terms as well. Since temperature is a main determinant of the end quality of the potato, different storage temperatures will result in the potatoes resulting in different qualities. If one single organization was using the facility it could just be written off as a loss, but since multiple farmers are using the storage, it is important to ensure everyone has the same storage conditions. Since the quality of the potatoes are economically important to them, a farmer with a poor storage location in the facility would be worse off than a farmer who has a better spot. This disparity in storage conditions could drive inequality and the insulation should be planned carefully to mitigate this.

Ventilation

The second recommendation area is ventilation. This topic is very important because it influences the interior temperature, humidity, and oxygen content. The air within the storage tends to be warm, carbon dioxide rich, and a high RH% while the atmosphere tends to be cool, oxygen rich, and with a low RH%. The ventilation systems controls how much the exterior air is mixed with the interior air and thus influences those three main environmental properties. Typically, storages containing less than 160 tons of potatoes can use only natural ventilation but since the storage is projected to hold around 900 tons, a forced ventilation system should be used (Rastovski, 430). A proper ventilation system should be able to monitor quantities such as temperature, humidity, and oxygen content at various points within a storage, be able to mix the proper quantities of interior and exterior air, and distribute the air evenly to prevent localized hot or cold spots.

HVAC monitors can be used to create a temperature map of the storage system. This shows where there are hot and cold spots so the ventilation can be adjusted to equalize these spots. Figure 3.2 in the appendix lists various types of measurements and what the corresponding effect may be.

Ventilation systems primarily consist of inlet vents, a blending chamber, ducts, fans, and an outlet vent. The arrangement of the ventilation system depends on whether the potatoes are stored in boxes or in a large pile so this sector will focus on the box approach as they are recommended for storage. Figure 3.3 shows a side view of a typical ventilation system. Intake vents should be positioned so the rain does not get inside and ruin the fans. The air moves from the intake vents into a recirculation chamber to mix interior and exterior air. This is meant to prevent a direct vent from the outside to inside which would result in cold air being blasted into a single area of potatoes. The intake and recirculation vents can be opened slightly to adjust the ratio of exterior to interior air. Figure 3.4 shows various dampening arrangements of the vents and their effects on the storage interior. The fan and vent controls can be setup in cooperation with the facility sensors so that ventilation occurs when an environmental value reaches a certain threshold (Bulk Potato Storage pg. 21). The facility manager should monitor the facility as the sensor feedback systems are difficult to perfect and unforeseen circumstances can disrupt the system.

Vents should be arranged in a manner that ensures even distribution of air to ensure a uniform temperature. Figure 3.5 displays an air duct system that can be used to distribute air in the facility.

Stacking Methods

The way that the potato boxes are stacked influences the airflow around them and thus the temperature inside of them. A storage facility can have an excellent ventilation system but if the boxes are not arranged to promote good airflow it will not yield the expected results. Both this section and the layout section cover potato box arrangement, but this section will discuss it from the point of view of airflow, while layout will discuss the best way to efficiently pack them.

Figure 3.6 shows various ways that potato boxes should be stored to optimize the airflow around them. The stacks of boxes should alternate so that air can flow around them and cool their exteriors. If they are flush with one another, the inside potatoes will be much warmer than the outside potatoes and there will not be uniform ventilation. Boxes should also be a uniform height as a variance in height can create differences in airflow. Lastly, a spacing of 600mm is recommended for boxes near the intake vents to allow to enter.

Sector Three: Layout

Proper storage layout considers the holding containers of the potatoes, the quantity stored per container, and the method of placement within and removal from the storage facilities.

Stacked Boxes and Floor Plan

For a well-functioning facility layout, it is crucial to consider and design for many variables, these include: potato box sizes, stack height, forklift reach and forklift maneuverability. These and their impacts are detailed below.

Potato Boxes

Well-designed and well-made potato storages boxes are crucial in a potato store. Each box must not only withstand the weight of its own potatoes, it also must be strong enough to hold the cumulative weight of any boxes stacked on top of it. This design then, is not to be taken lightly. Fortunately, there is a standard construction for 1000 kg potato boxes: BS 7611: *Potato Storage Boxes for Mechanical Handling*. This is a published research paper out of the United Kingdom from 1992--it remains the yardstick for boxes constructed in the U.K. and the European Union. The paper details the construction design, woodtype (softwoods), fasteners, dimensions etc. It costs approximately 200 USD, it is recommended to purchase this paper and to share it with local woodworkers/contractors in the area and D-Lab 2 participants.

While the very specific details of construction are not known, some information is, which will have impacts on floor plan and layout. Specifically, there are six different box sizes (A-F), though they all hold 1000 kg. A has the largest footprint, F the smallest--a difference in height, increasing from A to F, allows for the equivalent weight load. A chart of the dimensions and other important links to BS 7611 can be found in the appendix (figure 4.1).

It is important to consider box size early on in the planning stages of this facility. Given that columns will be present, picking a size that will neatly and efficiently fit into the spaces between the columns is crucial. Planning a floor plan in tandem with a box size will help minimize unusable space, while improving efficiency and ease of storing around the needed obstructions.

Box Height

A further consideration is box height. BS 7611 boxes (figure 4.2 and 4.3) are designed for stacking--they are approved to stack eight boxes high. Eight boxes of type A will yield a total height of 8,560 mm, while eight boxes of type F will be 10,160 mm tall. Currently, both stacks are taller than the proposed facility height. Designing a facility to one of the above heights would minimize the needed floor plan size. Alternatively, a larger floor plan and a lower stack height might be preferable.

If it takes time to construct and acquire the storage boxes, it is essential that the potatoes are not stacked more than three meters high in the same box or pile, so that the pressure of the pile does not damage the potatoes at the bottom of the container (Eltawil, 2006).

Forklifts

To stack boxes, a forklift is needed; and there are many types of forklifts. Picking the right one will be based on the the desired stack height of the boxes. Alternatively, the type of forklift purchased will dictate the stack height (and stack height will affect the required size of the floor plan).

A standard forklift (figure 4.4) has a reach of 3000-4500 mm. At best, this can stack 5 boxes of A and 4 boxes of F. If this is the only affordable or accessible kind of forklift for this project, the limited stack height requires a more expansive floor plan. However, there are specialized tall reach forklifts (figure 4.5) that can lift at a maximum height of 9000 mm. This forklift could stack BS 7611 boxes between 7 or 8 high, which would accommodate a smaller overall floor plan.

One final issue: given the use of a forklift in loading and unloading, an appropriate aisle width for forklift maneuverability is necessary. A formula to determine the needed space for a forklift to function in an area is:

(Length of forklift) + (Length of Potato Box) + 460mm = Optimal Aisle Width

The architect should consider all aforementioned variables (forklift type, potato box size, aisle width) when designing the floor plan, column layout and ceiling height. A little bit of forethought will pay considerable returns in decreasing storage layout problems prior to the operation of the facility

Sector Four: Maintenance

Logging Information

A store diary is essential to track an organize each client's storage, and ensure accountability. Walkways and ladders should be available so that potatoes are easily checked from the tops of the containers. A procedure for an employee to regularly check and log potato conditions in the warehouse should be planned. During the storage period, this diary may also be used in order to log temperature changes and comments on the stored potatoes.

Pre-Storage Activities

To ensure the responsible and effective storage of the client's crop, it is necessary to complete several pre-storage activities. For accountability, organization, and improvement of storage practices, it is essential to log the occurrences of these practices. A store diary that is kept in an accessible and nearby office can be used for this purpose. Before potato storage occurs, it is essential to screen the stored harvest so that diseased potatoes are thrown out and unable to damage more of the crop. It is recommended to have a workshop for growers to learn how to grade and screen their own crop to add profit to their portion of the value chain and to expedite the on-site screening process. Recording disease levels per bin and harvest temperatures is also recommended to assure due diligence. Potatoes are best placed in storage before temperatures hit below 5°C in order to prevent shatter damage (Cunnington).

Mechanical systems and repair ducts must be cleaned and operational. A thermometer must be used to check all temperature control sensors and ensure the accuracy of the HVAC system. Containers must be cleaned of all dirt and debris from the prior season and then sanitized before storage with an appropriate disinfectant, so that bacterial and fungal disease vulnerability is reduced prior to the potatoes' curing stage. Equipment should be cleaned regularly and serviced annually, and these activities should be logged in the store diary (Small, Potato Storage Management).

Stages of Potato Storage

There are five stages of potato storage, and storage managers need to oversee appropriate activities to ensure proper storage conditions. Firstly, right after putting potatoes in storage, the pile needs to be allowed to equilibrate the temperature. If precipitation has moistened the produce, this moisture must be dried before the potatoes are placed into storage. During this phase, ventilation must be used so that each potato pile is within 2°C of the average pile temperature. If potatoes are harvested while chilled or frozen, ventilation and temperature with low humidity must be applied during this stage.

Secondly, after the equilibration stage the potatoes must be cured so that the skin is thickened and any inflicted damage or wound to the potatoes is healed. This is achieved at a temperature between 8-20°C and a relative humidity of 8% for 7 to seventeen days, meaning that ventilation and temperature controls must be used and strictly managed during this period, in order to keep bacteria and fungal diseases from destroying the crop. Thirdly, an optional phase is introduced where the potatoes are kept at curing temperature so that reducing sugars (mainly found in potatoes harvested early) do not pool.

Fourthly, a holding phase is necessary. This is the bulk of the storage process, and because of Bareti's cold winter climate, the temperature control system must keep the temperatures of the potatoes below freezing in order to prevent seed degeneration. Optimally, this storage temperature would be between 2-4°C for seed potatoes and 3-5°C for market potatoes. Lastly, before the potatoes are taken out of storage, they must be warmed in order to prevent any damage that may subsequently occur during handling and unloading. No excessive handling or force should be applied during this transport in order to minimize physical damage of the potatoes (Small, Potato Storage Management).

Throughout this process, it is imperative for management to keep watch on the potato quality, regularly checking the humidity levels of the potato containers and observing and logging the physical changes of the potatoes. If changes in the potatoes occur during regular inspection (sprouting, spots), it is important to note this in a storage diary and contact the farmer using the bin (Walsh, 2005).

Safety

Any jobs maintaining and monitoring the storage facility must comply with safety standards. Ladders should be checked annually to ensure the safety of workers. Box edges should be marked so that access to them is deterred. The inspection and proper stacking of boxes is crucial to ensure worker safety as well. To promote visitor and inspector safety, it is crucial to make sure that individuals in the storage area walkways are easily visible, and adequate lighting is provided to avoid accidents and injuries. Walkways should be marked and clear of equipment, debris, and other obstructions (Cunnington, 2001). Managers should be trained in safety procedures, and log any accidents to ensure due diligence.

D-Lab II Recommendations

BS 7611 Potato Box and Layout

Given the above research, we recommend that D-Lab II use the BS 7611 paper to construct a prototype wooden box. Using a wood shop here on campus, students will be able to study the design and make the box based on the given plans. It is recommended that D-Lab II learn about woodworking facilities in Georgia --specifically, what tools, machines, and wood types are available to builders there--so that D-Lab II students build to their constraints.

It would be helpful to receive a floor plan from the architect as soon as possible, so that D-Lab II could pick an appropriate box size to make. Close communication should occur between the architect and D-Lab II given the variables related to floor plan, ceiling height, column layout, box dimensions, stack height, forklift reach, forklift maneuverability and aisle width. These should all be considered simultaneously to maximize storage effectiveness and D-Lab II can assist in this process.

HVAC Control System

An additional project that can take place in D-Lab II is the prototyping of an HVAC control system. This project would entail the use of a computer such as the Raspberry Pi to collect sensor data from various points in the storage, record this data, and control fans/vents based on various user-defined thresholds.

If installed HVAC system does not come with a sensor system, then the D-Lab II prototype can be used as a workaround to record data. While it is best to have the manufacturer of the HVAC system either install of recommend a sensor system, having a basic one is better than having no data collection.

Note: this recommendation will be harder to implement than the potato box because it requires the prototype to be scaled to the actual facility size. The potato box would be built to specification which could transfer directly over to the facility and be built in the same manner in Bareti.

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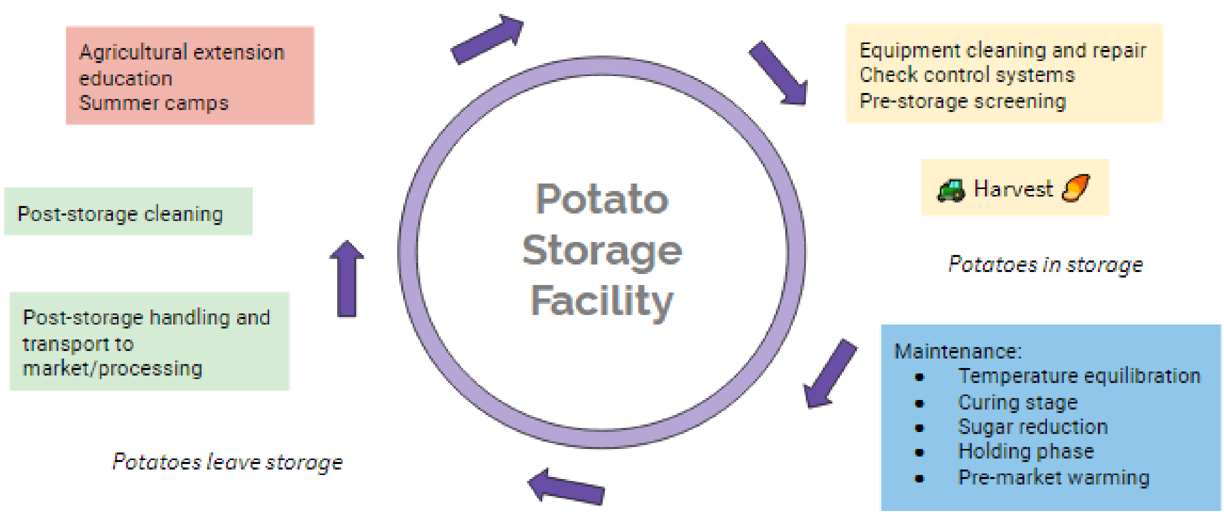
Appendix

1. Methodology

Figure 1.1 SWOT Analysis

Figure 1.2 Storage Facility Life Cycle Analysis



2. Architecture

Figure 2.1

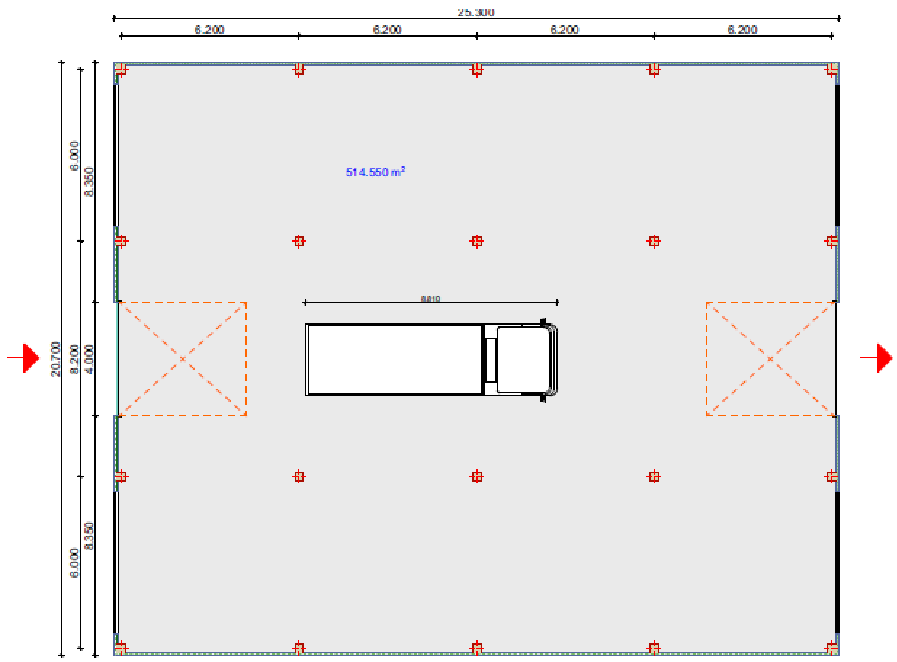


Figure 2.2

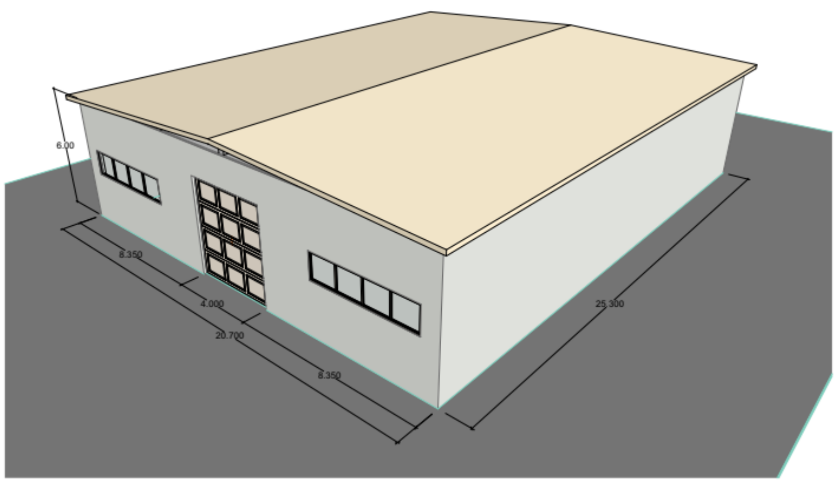


Figure 2.3: Robert Brook, 469.

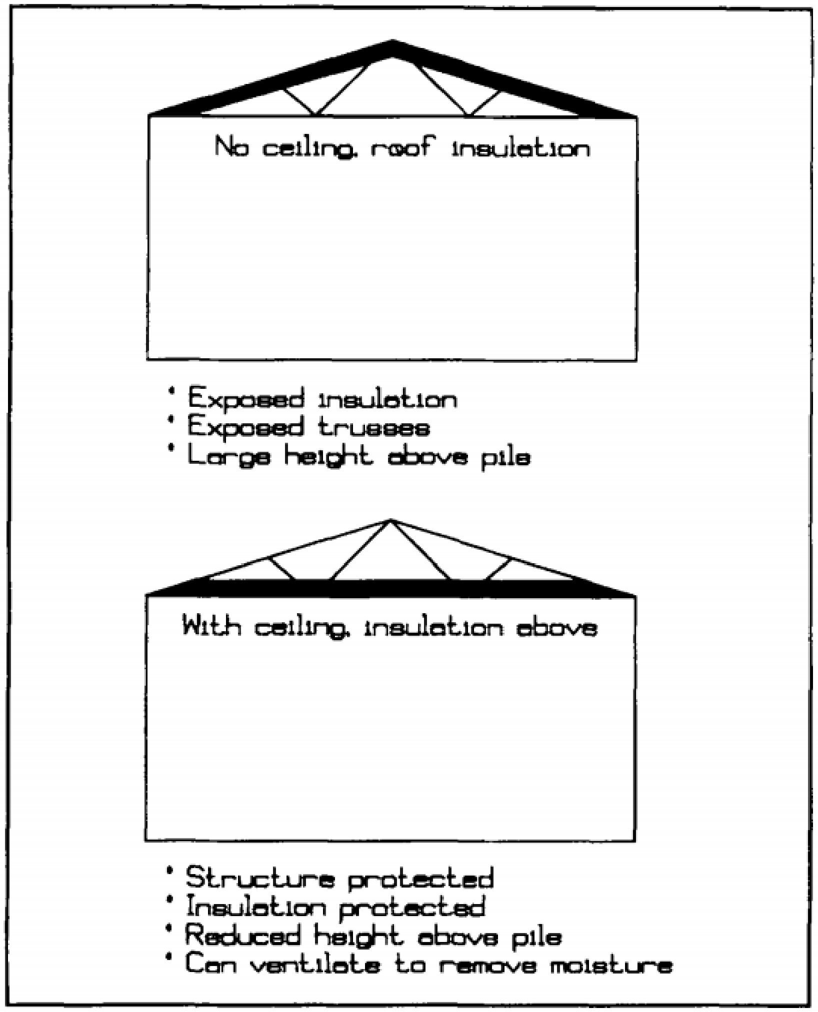
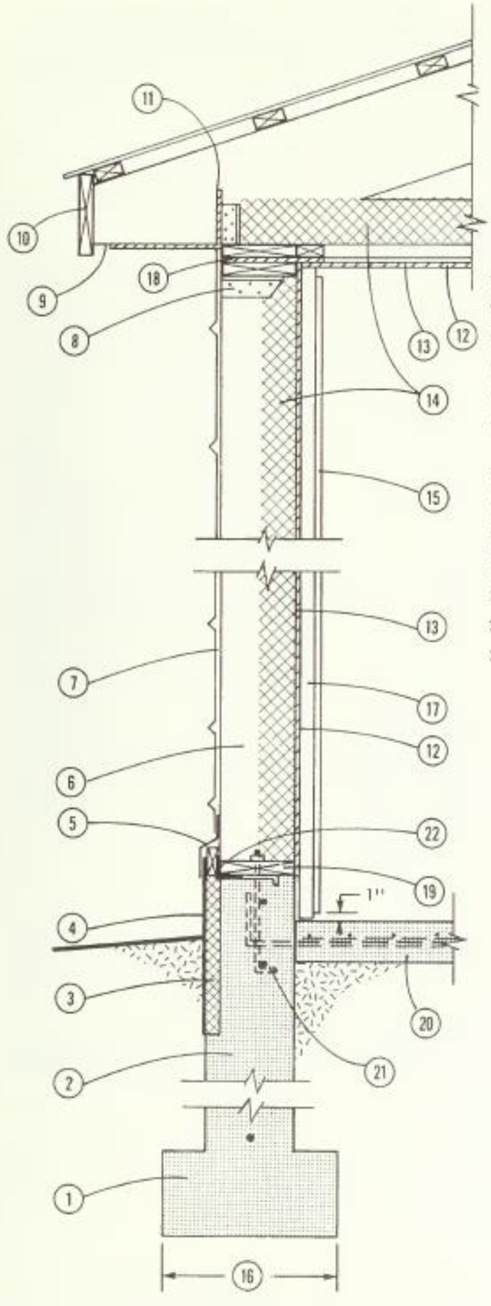


Figure 4. Importance of a ceiling in a potato storage.

Figure 2.4: J.A. Roberts, 15.



1. footing below frost
2. concrete foundation
3. 2" x 22" rigid insulation
4. 3/16" high density exterior type cement asbestos board
5. galvanized metal flashing
6. 2" studding
7. metal siding applied horizontally
8. joist hanger
9. 2" slot screened
10. 2" face board
11. plywood baffle
12. plywood sheathing
13. 4 mil polyethylene
14. friction fit glass fiber insulation batts
15. 3/8" fir plywood or 3/4" T & G lumber or 28 ga. corrugated galvanized steel. Bottom part removable for inspection
16. dim. varies as per soil bearing capacity
17. 2" x 2" blocking every stud
18. plywood strip, width of plates plus 3 1/2"
19. 2" pressure treated sill
20. 5" concrete floor reinforced with 6" x 6" x 6/6 wire mesh
21. 1/2" Ø x 18" anchor bolt
22. 3" x 3" x 1/4" angle iron

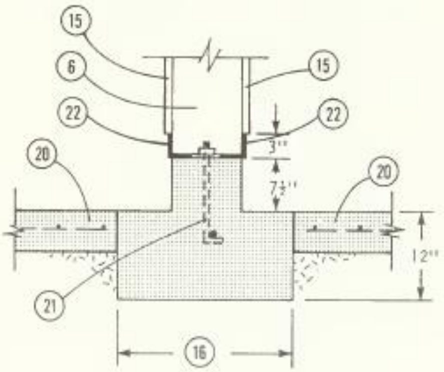
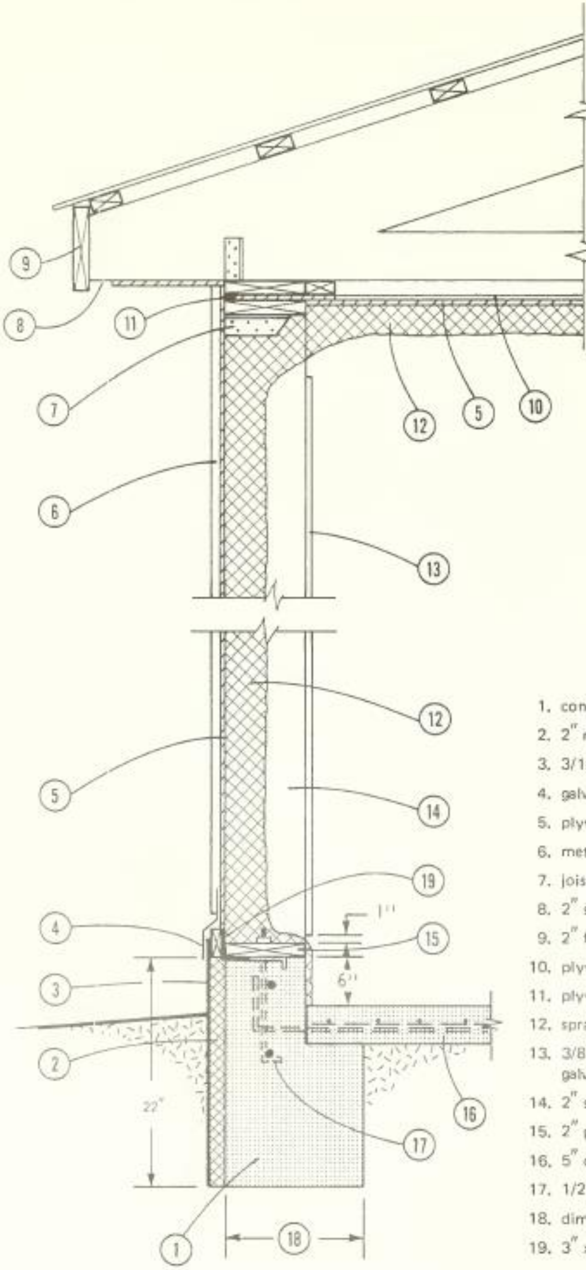


Fig. 7 Typical exterior and partition wood stud wall construction showing deep foundation at exterior wall.

Figure 2.5: J.A. Roberts, 16.

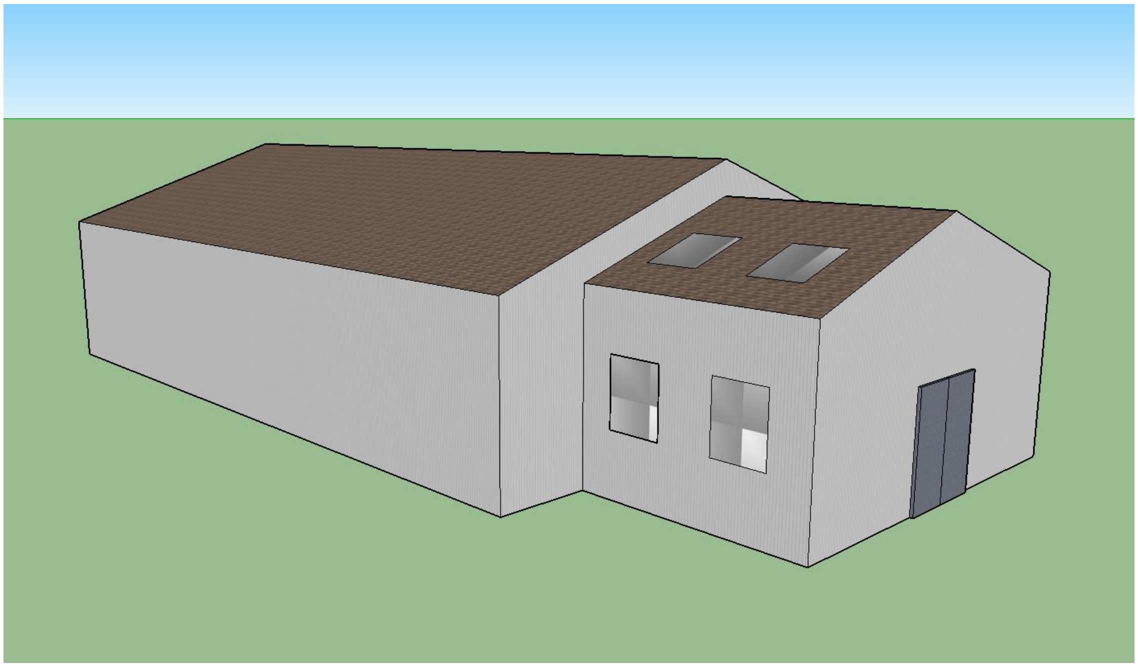


1. concrete foundation
2. 2" rigid insulation
3. 3/16" high density exterior type cement asbestos board
4. galvanized metal flashing
5. plywood sheathing
6. metal siding applied vertically
7. joist hanger
8. 2" slot screened
9. 2" face board
10. plywood spacer
11. plywood strip, width of plates plus $3^1/_2$"
12. sprayed on polyurethane insulation
13. 3/8" fir plywood or 3/4" T & G lumber or 28 ga. corrugated galvanized steel. Bottom part removable for inspection
14. 2" studding
15. 2" pressure treated sill
16. 5" concrete floor reinforced with 6" x 6" x 6/6 wire mesh
17. 1/2" ø x 18" anchor bolt
18. dimension varies as per soil bearing capacity
19. 3" x 3" x $^1/_4$" angle iron

Fig. 8 Typical wood stud wall construction showing polyurethane insulation and shallow foundation. Exposed foam insulation may be in variance with local fire codes.

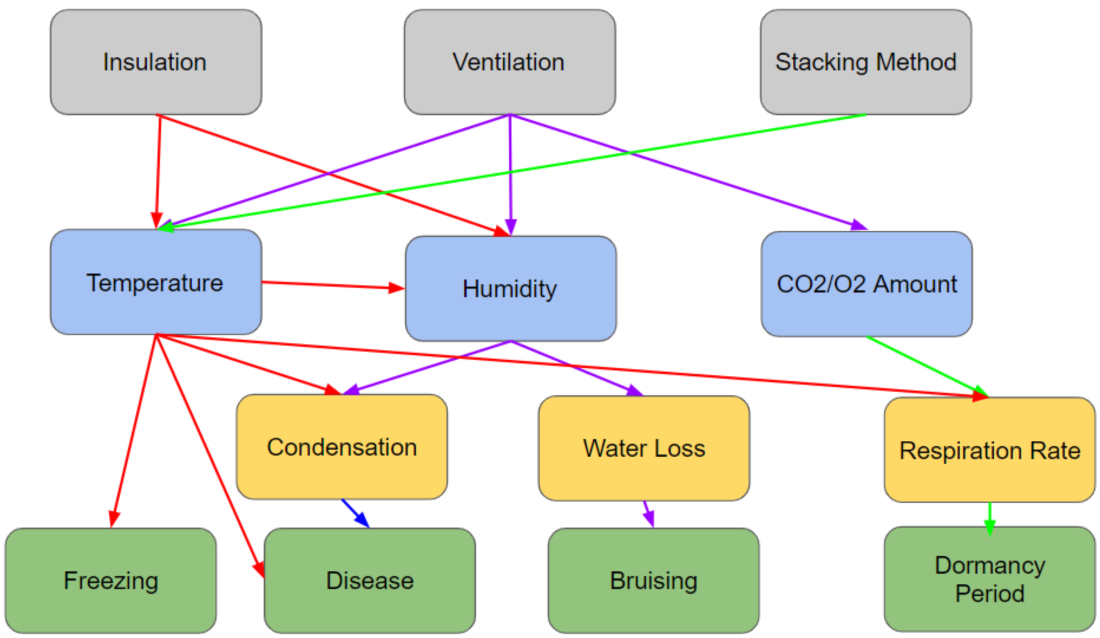
16

Figure 2.6



3. HVAC

Figure 3.1: HVAC System Map



Legend

Box Color	Meaning

Gray	Design factors in the storage facility
Blue	Observable quantities inside the facility
Yellow	Observable quantities of/on the potato
Green	Factors that affect the quality of the potato

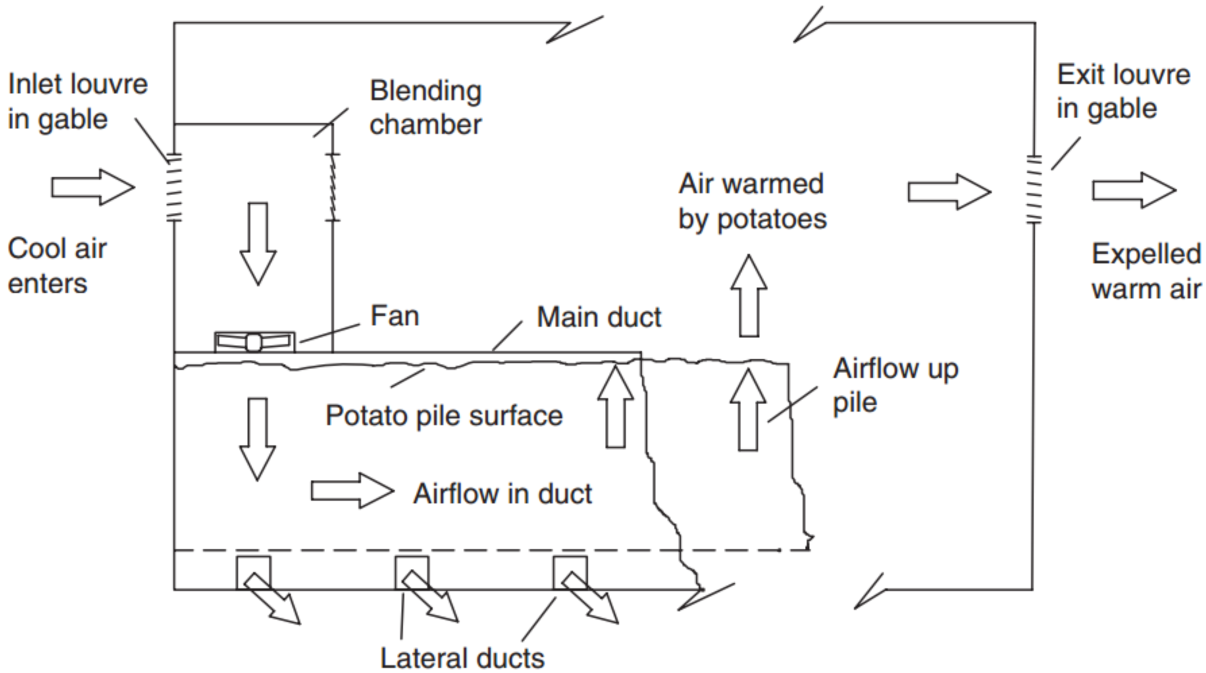
Note: The line colors have no significance and are only to differentiate to what item they belong to

Figure 3.2

Measurement	Aspect measured	Indicates	Indicates in addition
Carbon dioxide in store air	Percentage CO_2 level in store	Risk of increasing sugar levels in crops and danger to staff	When or if store air flushing is required
Tuber skin resistance	Electrical resistance of skin of a tuber	Condensation forming on the tuber or a wet tuber drying	Tuber skin being desiccated by ventilation and recovering when ventilation stops
Simulated tuber condensation sensor	Condensation forming on a simulated potato	Condensation forming on tubers	
Solar sensor	Temperature increase in glass container due to solar radiation	If roof-space warming could be due to solar radiation	If no solar heat gain, roof-space warming due to warm air entry
Anemometer	Wind speed	When increased leakage of air into store is likely	Cause of crop condensation or store warming/cooling
Wind vane	Wind direction	Some wind directions will result in more air leakage than others	

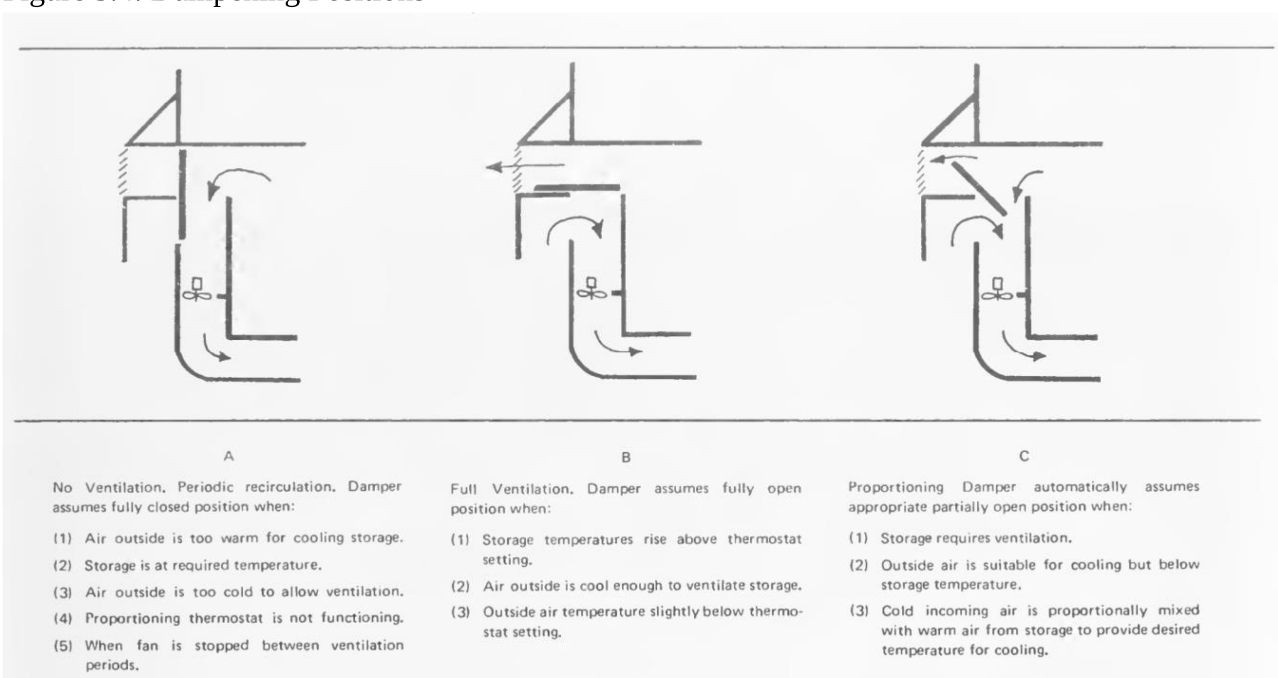
Note: This table has been taken from Potatoes Postharvest pg. 251

Figure 3.3: Ventilation System Side View



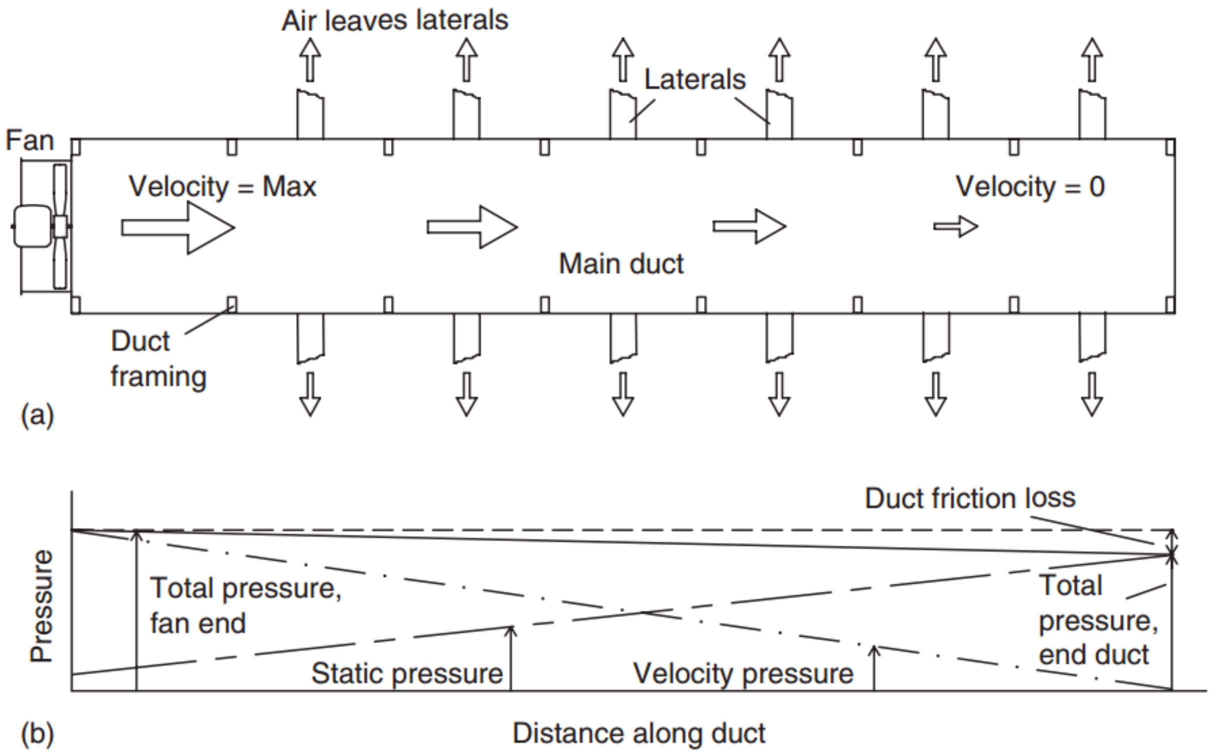
Note: This figure has been taken from Potatoes Postharvest pg. 165

Figure 3.4: Dampening Positions



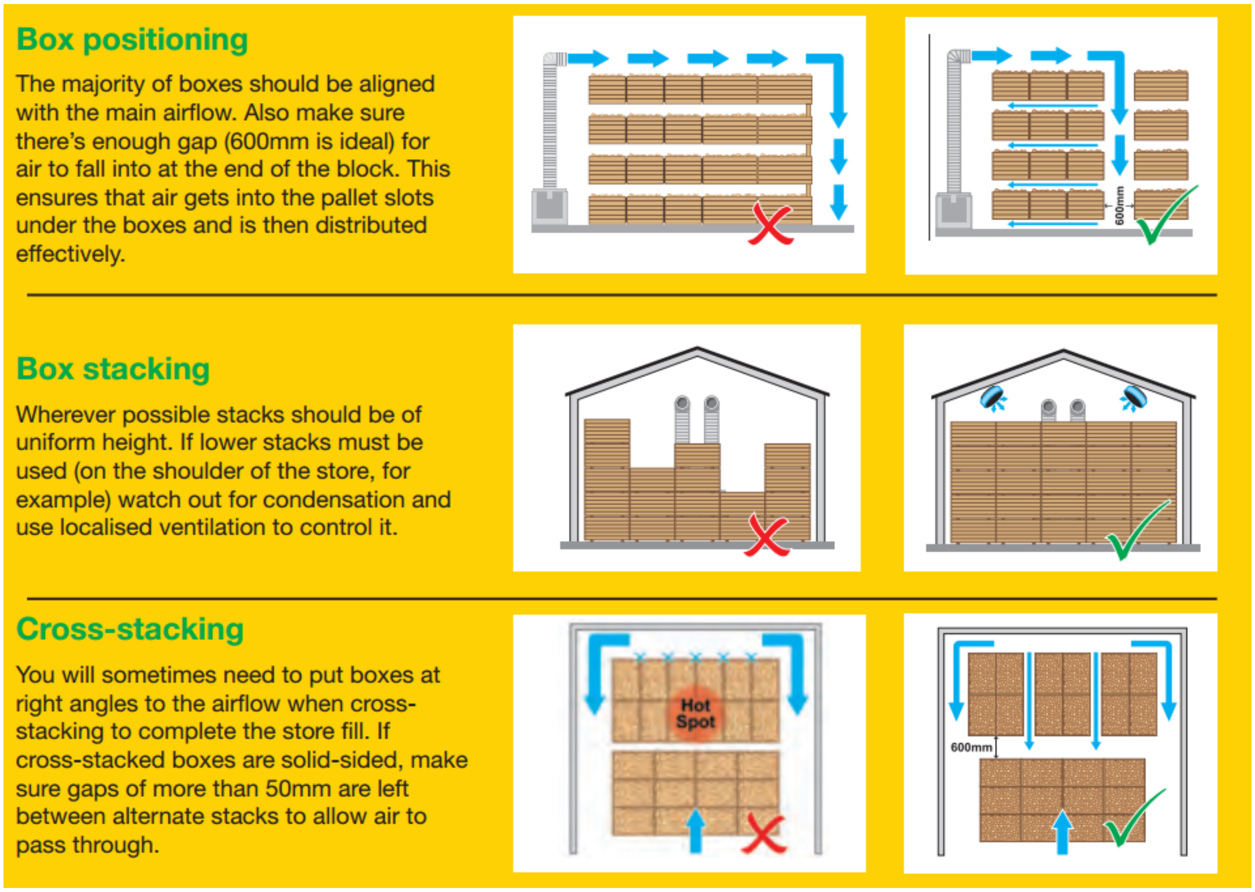
Note: This was taken from Bulk Potato Storage pg. 23

Figure 3.5: Air Vent Distribution



Note: This was taken from Potatoes Postharvest pg. 182

Figure 3.6: Box Stacking



Note: This was taken from Potato Store Managers Guide

4. Layout and Maintenance

Figure 4.1: Potato Box Specification

Potato Storage Box: BS 7611: *Potato Storage Boxes for Mechanical Handling*

BS size code	Pallet Length x Width (mm)	Maximum Pallet Height (mm)	Max Load (kg)
A	1830 x 1220	1070	1000
B	1830 x 1195	1070	1000
C	1805 x 1195	1070	1000
D	1525 x 1195	1220	1000
E	1290 x 1280	1270	1000
F	1270 x 1270	1270	1000

Important Links:

General Information on BS 7611 boxes:
http://www.palletlink.com/potato-boxes/box-design/

Where to Purchase BS 7611 research paper:
https://shop.bsigroup.com/ProductDetail/?pid=000000000000284920

Commercial Seller of BS 7611 Boxes
https://www.hktimbers.com/

*These boxes are not designed to be used for transportation of potatoes. They should not leave the storage facility. Use in transportation from farm to facility would submit the boxes to unexpected loads, forces and jostling, which could weaken or threaten the structural integrity of the boxes. Looking into transportation of potatoes from farm to facility was outside the scope of the paper, but rugged and reusable 50 pound potato bags would be a good option.

Figure 4.2, image from http://www.palletlink.com/potato-boxes/box-design/

Figure 4.3, image from https://www.hktimbers.com/

Figure 4.4: Standard Forklift, image from www.toyotaforklift.com

Figure 4.5: Reach Forklift, image from www.toyotaforklift.com