Let-It-Cold Design Concept for Supporting Temperature-Sensitive Products

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Received: August 14, 2020 / Revised: October 9, 2020 / Accepted: October 28, 2020

***Abstract*—Various factors cause fruits and vegetables spoilage. Sufficient ventilation, heat, light, humidity or temperature may affect both safety and quality of those fruits and vegetables.**

To prevent the situation that the fruits and vegetables are unsuitable for consumption or they decay or go bad quickly, keeping sensitive items in proper temperature-controlled storage system is recommended. *Let-It-Cold* design concept has been introduced in this study where the space and layout between containers used for keeping fruits and vegetables fresh and crisp are the key considerations. For small-sized cold room, arranging containers/crates properly to keep produce fresh much longer than other traditional ways will be reported and analyzed. Three layout designs for positioning and stacking a crate containing 25 kg tomatoes are considered and compared. Ergonomic design for people at work; depalletizing operation was applied in this study as the guideline to design the proper height of the stacked crate in column. For each storage shape, computer fluid dynamics (CFD) has been applied as the tool for cold room analysis. Then, a newly proposed performance index is used to compare and choose the optimum design layout from the simulation result.

***Index Terms*—Design and Development, Stacked Crate Design, Depalletizing Operation, and Cold Room Configuration**

I. Introduction

Many questions have been raised and needed to be revealed for transporting temperature-sensitive products, such as fresh produce, medicines or cosmetic items, in practice, for the largest wholesale fresh market (Talaad Thai in Pathum Thani province, Thailand), a crate is applied as the main container to keep produces in place as illustrated in Fig. 1.

Fig. 1. Applications of crates in wholesale fresh markets

When loading a moving truck; a large number of crates are carried and stacked as layers, the heaviest crates are placed in first, and the experienced workers have tried to apply their gut feelings or perceptions to make sure that the load is evenly balanced (Fig. 2) before transporting to the retail markets, the urban regions surrounding the metropolis of Bangkok, Thailand.

Fig. 2. Traditional style to carry and load crates to the truck

High Density Polyethylene (HDPE) crates are being used in storage and transport of fruits and vegetables like tomato, apple, orange or cucumber. Good crate should provide good ventilation and smooth interiors with sturdy exteriors (i.e., strongly and solidly built) to protect the surface of fruits or vegetables from scratches and bruises during transportation. Since the cost of high-quality crate is very expensive, the sellers prefer to apply use plastic bag (Fig. 3) or foam plate to wrap or cover for keeping produce fresh, crisp, and tasty all week long before putting them into the recycled plastic crates. Plastic bags are made from a ubiquitous polymer substance known as polyethylene (PE). In general, a bag does help keep produce fresh; however, it is not good since it builds up much more moisture since lots of fruits and some vegetables release the hormone as a gas. (Fig. 4).

Fig. 3. Applications of polyethylene (PE) saver storage bag for fruits and vegetables

Fig. 4. The drawback of PE storage bag-moisture and gas found

In practice, the sellers need to launch the fresh produces to the customers as much as possible per trip to minimize transportation cost. Stacking crates with 4 to 5 layers is very popular as shown in Fig. 5. HDPE crates are carried by human (Fig. 6) where a 2-wheel cart is used as the main supporter for reducing physical effort that is required to accomplish a task; *lowering*, *pushing*, *pulling*, *carrying*, *restraining* or *holding* crates manually using human. Delivering heavy packages, pushing a heavy cart, or moving a pallet as manual handling activity is identified as one of the main causes of back, legs, and shoulders injury.

In order to solve those health problems, the developed design of cart has been introduced where the motorcycle-platform function is adapted and modified to be 3-wheel cart as shown in Fig. 7. The bright colors and shapes of tropical fruits and leafy green vegetables will attract customers' attention and urge them to stop for purchasing; however, those fruits and vegetables have reported losses as high percentage during cultivation and postharvest storage, especially during the rainy season that presents the spoilage.

Fig. 5. Carrying and stacking a large number of crates

Fig. 6. 2-Wheel cart designed to satisfy fruit & vegetable markets necessity

Fig. 7. Application of 3-wheel cart

Sometimes, produce is applied and mentioned as the generalized term for many farm-produced crops, including fruits and vegetables (grains, oats or tomatoes). In order to keep delicate produce fresh (e.g., herbs, tomatoes or lettuces) longer, mobile cold room is introduced (Fig. 8). Applying cold storage room and selecting paper box container have become world-wide solutions recently.

In general, from counter-depth refrigerators, door-in-door and side-by-side refrigerators to mini fridges or bottom freezers, the refrigerator humidity effects on produce quality where its components such as crispers (i.e., drawers) can keep fruits and vegetables in good condition longer when the amount of humidity they are exposed to is well controlled.

However, using this cold room practiced method is quite expensive [1]-[5].

The main purpose of this study is to introduce an alternative design of a cold room system by using the simulation application; *computational fluid dynamic (CFD)*, to define optimal condition of products layout according to the physical characteristics and properties of the fresh produce, air ventilation, humidity, physical shape of packaging or crates, temperature, layout of stacking crate inside the cold room, and comfort zone for working area.

Fig. 8. Mobile cold room for keeping produce fresh and crisp

II. Research Background

Presented in this section are the background of the research for identifying and recommending the proper conditions for *Let-It-Cold* storage room where the customer's requirements and perceptions towards the fresh produces and how to keep them fresh are the keys for this study. The interviewed results from the sellers and the business owners who are accounted as the target group and they work in the wholesale-market environment are firstly recorded and analyzed. The processes of translating customer's requirements and perceptions about cold room for storing temperature-sensitive products to be design layouts are taken into consideration in this study before designing process attempts.

A. Product Design and Development

In this study, applying product design and development (PDD) concept can help ensure better forecasts and suggestions about the proper design layout of cold room for storing fresh produce where the air-ventilation and temperature inside the specified area are simulated with various environmental conditions.

Applying PDD can develop general models as well as improving the existing design layout to be competitive with the continuously shifting market needs [6], [7]. In order to serve and satisfy the needs of end users, translating and revealing the hidden perception issues by 5-steps PDD (Fig. 9) can help designers and manufacturers to quickly create a new design or develop an existing product.

- The first stage of PDD is *concept development (CD)*. Concept development consists of various activities to determine the core concept of the product, which satisfies the needs of the customers and markets.
- The second stage is *system-level design*, this is the stage where the components have been identified and classified; the stage continues to detailed design where the classified groups were used to build the virtual model or prototype.
- The next stage is *testing and refinement* where the prototype is tested or checking its physical characteristics.
- The last stage is production ramp-up; the prototype is now entering production in the manufacturing.

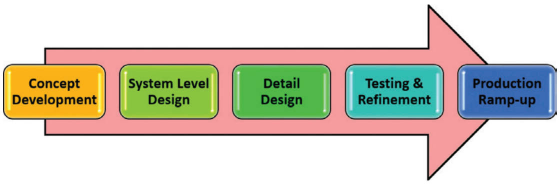


Fig. 9. Product design and development diagram

B. Human Error in Product Design and Development

Before constructing the platform or production planning structure to satisfy customer's requirements, understanding and revealing the employees' experiences and perceptions through their working behaviors when the tasks assigned (i.e., routine tasks) need to be done first. When the workers lack work experience, it should have a mitigating effect on the frequency of minor events; or simply say, this mentions about having the effect of making something bad less severe, serious, or painful. The requirements of *human factors* (HFs) have been considered and identified as the key assisting tool where human factors and ergonomics is the application of *psychological* and *physiological* principles to the engineering activities and design of products, processes, and systems [8]. Understanding human factor in design phase can help the manufacturers and companies to reduce working load, decrease human blunder, time and ensure safety in working environment [9]-[13]where the compliance with deterministic rules shall be shown, and probabilistic analyses where the compliance with risk criteria shall be shown. Human reliability analysis (HRA).

To address human errors in working environment the following human failure activities are mentioned and taken into consideration [12]:

- Poor hazard identification
- Poor design and lack of feature assessment
- Lack procedure
- Lack or poor training

- Workload and overload
- Unclear duties and less responsibilities
- Lack of rest and stress at work

Non-traditional technologies such as an automation system, robotics or smart controlling unit have been become vital and considered to replace human to reduce human error and increase productivity in manufacturing sector [10], [11].

Moreover, understanding the human factor analysis and its concept can help the business owners to create the guidelines for improving the facility or working layout where the equipment is used and maintained correctly to reduce the risk of accidents or damage to health.

In the initial stage of this study, the researchers tried to observe and visit the fresh produce markets and companies around Bangkok metropolitan region for interviewing the business owners about employee strategy to increase profitability. The results presented that, in the business owners' viewpoints; hiring costs generally increase with skill requirements for job applicants.

In their perceptions, placing young people in jobs that require repetitive movements, heavy workload and difficult positions might be the good solution for solving the risk of radiating low back pain that is found in older adults (i.e., high-skilled workers). Moreover, the business owners prefer to work with young generations in the workplace due to the fact that the cost of generating skills from the assigned tasks inside the workplace is lower than that of recruiting skilled workers. So, "in-house skill" is recommended.

However, some questions were raised and considered as the problems in recruitment and selection:

- *Ability to make decisions and solve problems?*
- *Ability to plan, organize, and prioritize works?*
- *Ability to obtain and process the information?*
- *Different backgrounds have the potential to produce violent behavior?*

In order to increase the level of employee's performance, the safety considerations such as the materials' height (i.e., stacking height) and weight, design of the box or crate, and inventory layout should be identified and recommended.

C. Ergonomics Design for Engineering Activities

Human power is mentioned in various activities to support loading or supporting which incorporate pushing, lifting, carrying, lowering, holding and restraining. Currently, many workers are suffering from their work places related to forceful exertion, self-retracting, repetitive motion, discomfort, and injuries with working tools. Those issues affect to their working mood, safety, health, production bottleneck, and product quality and company profit. Ergonomics principle analyses is joining in manufacturing processes and maintenance engineering activities to increase work-welfare and productivities as five principle below:

- *Safety:* reduce human error, however it is intentionally or not would cause to a serious injuries or serious safety violations which lead to loss life.
- *Health:* over exertion may affect to physical health such as chronic symptoms or muscle fatigue.
- *Work comfort:* limitation of work capacities to enhance the comfort zone for employee to eliminate risk and allowing employee to work longer with less fatigue.
- *Efficiency:* to reduce stress on back, shoulder, effort, force, and bending by replacing working tool to increase work productivity.
- *Quality:* ergonomics gives employees a better working environment by minimizes physical fatigue and mental fatigue to replace with overall working performance also increases productivities, service quality, and worker morale.

The fundamental concepts of "*Ergonomic design*" have been considered and applied for supporting the concept development phase of the new layout platform where the height of stacking crate or container will be revealed and designed. Moreover, in order to achieve a low cost, efficiency and comfortably for worker, which is important for productivity.

To eliminate working hazard, ergonomic studies have to be applied into design process to reduce health concern and increase safety to achieved injury free in working place [13], [14]. Several studies and guidelines were proposed for lifting objects [15]-[17]. Muscle pain can be caused by lifting heavy objects or bending forward in an awkward position. The pain that muscle strain produces is usually right around the lower back. The 50^{th} percentile of Asian male is 164 cm which is just a bit more 5 feet 4 inches [18]; according to Ministerial Regulation of the Ministry of Labour, B.E. 2547 [19], the maximum weight that a female labor and male is allow to lift is 25 kg and 45 kg, respectively. The proper amount of crates/containers carried by one worker per shift and the height of stacking crates should be considered and identified, at the same time, air ventilation inside the workplace or storage areas should be recommended for reducing human error and maximizing work performance.

Fig. 10 presents about the depalletizing operation where a stacking column is made of a total of 5 boxes; the height of each box should be around 40.5 cm. per box, this means the total height of the 5-layered boxes is around 202.5 cm [20]. This related article mentioned about the proper height for a worker to carry and lift the container in stack. In conclusion, the *ergonomic design* is aimed to provide user with great working atmosphere and working posture to promote well-being also work performance.

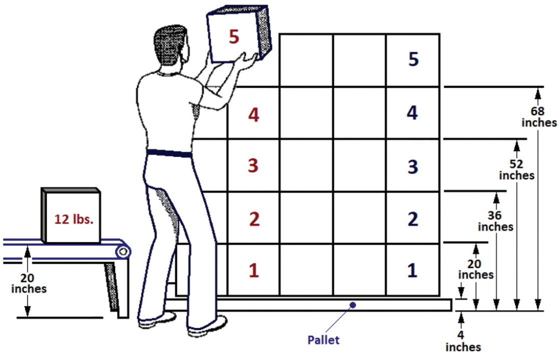


Fig. 10. The proper height and number of boxes recommended for saving health-problem issue [20]

This job consists of a worker inspecting compact containers for damage on a low shelf, and then lifting them with both hands directly in front of the body from shelf 1 to shelf 2 at a rate of 3 per minute for a duration of 45 minutes. For this analysis, assume that (1) the worker cannot take a step forward when placing the object at the destination, due to the bottom shelf, and (2) significant control of the object is required at the destination. The containers are of optimal design, but without handles.

III. Research Concept

Let-It-Cold is introduced in this research as the name of a design concept for smart cold room system that consists of, *crate design unit*, and *crate-stacking layout simulation*. The input parameters which are *product weights and dimensions*, *types of fresh produce* or *temperature-sensitive product*, and *acceptable range of storage temperature/moisture conditions* can be easily assigned into the developed system.

For the crate-stacking layouts considered in this study, *three configurations* which are *A*, *B* and *C* are considered and compared in the testing and simulating section. When the door of a cold storage room is opened for loading the crates in/out, the environmental conditions (e.g., level of humidity, temperature, and air ventilation) might be varied and have direct effects to the quality of the fresh produce. A good design for layout configuration that is a part to contribute for improving cold storage condition can help to reduce post-harvest loss, food waste, reduce energy consumption (air-conditioner can be well controlled) and improve the shelf life of the products.

A. Case Study: Tomato

In this research, "*Tomato*" is used as a sample type of fresh produce for demonstrating the proposed concept. After interviewing the sellers and business owners about "*cold room*" and "*how to keep the fresh produce crisp*", the answers were translated and taken into considerations for applying as the input parameters or criteria in the design phase:

- **25-kg-tomatoes** are stored and kept inside the crate.
- Three layouts of stacking crates; **A/B/C design layouts** are considered and compared to find out a suitable cooling condition and configuration to preserve fresh-and-crisp produce.
- **3D-modeling software** is used to design packaging which is "*crate*" for storing tomatoes.
- **Simulating the airflow** in cold storage is done by CFD application.
- The **suitable temperature** for tomatoes should be 15±2°C .
- The **results** obtained from the simulation; *the amount of storage* space, *load capacity*, and *suitable configuration* can be applied as the guidelines for designing the specific dimensions of the cold room.

B. Packaging Design: Crate

The packaging material is using in this study had been developed by using *SolidWorks*, a 3D modeling software to create the geometry and dimension to follow the most exiting popular packaging design for horticulture products. The packaging is one the most influencing factors for food waste [21], food quality, and food protection [22]. The packaging designed nowadays is very famous for any product in every manufactory. The functions of packaging are separated into four important parts such as convenience, protection, signature, and product advertisement. In Thailand, several packaging designs are used during transportation and storage of fresh produce. In this research, one type of packaging was selected to use in our case study for cold storage simulation. Illustrated in Fig.11 is the crate design that is available and very popular in the markets. The specific characteristics of this crate style are listed as:

- Length: 375 mm
- Breadth: 570 mm
- Height: 308 mm
- Capacity loaded: 25 kilograms

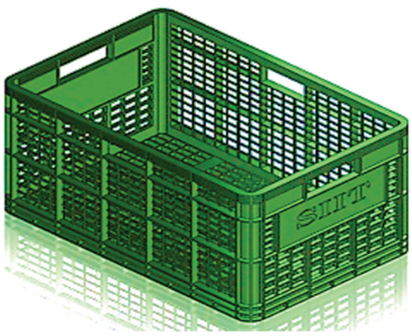


Fig. 11. Packaging design by 3D-modeling software

C. Characteristics of "Tomatoes"

Tomatoes are known as *Lycopersicon esculentum* in scientific names. Fresh cut tomatoes are popular for consuming in any country and provide many nutritional values. Tomato is having many bioactive components such as vitamin C, vitamin E, antioxidant, carotenoids, and phenolic compounds [23]. The redness color is one of the most important colors, which received highest number from selling [24]. Physical qualities of tomatoes come from harvesting, poor postharvest handling, postharvest techniques, and storage condition have effect to the quality of product.

Good postharvest handling is very important to maintain tomatoes qualities and ensures product safety along the process from farm to buyer. Physical losses of tomato would decrease in quantities and qualities of fruit between harvested through consumer according to the majority, mechanical damage, bad packaging, poor harvesting methods, over-ripening and immaturity. Therefore, most of the consumers buying only good appearance of tomatoes according to fruit have to be in a uniform shape, uniform color, and smooth appearance.

Normally any fruit is turning from green maturity to ripen maturity and change till dark red in full of maturity. Tomatoes firmness most of many researchers assumed as an important part of the quality of tomato because it is correlated with eating quality and length of storage condition. Moreover, tomato-eating quality could contribute to consumer feeling also acceptability to select tomato color and firmness measurement. From this, color and physical quality are one of the most important factors that can be influenced to the quality of fruit during storage and transport [25].

D. Traditional Technique of Harvesting, Storage, and Transportation

Harvesting methods by handpicking or using traditional methods normally is happening in a developing country; as shown in Fig. 12. The poor technique of harvesting is often happened by the farmer using a nail finger to cut and pull from the tomato stem. Presented in Table 1 are the traditional transportation techniques applied.

Moreover, the researcher observed that farmers they do not follow good personal hygiene while they are harvesting at the field. Harvested tomatoes should be at a low temperature and high humidity periods like in the early morning and evening. Besides that, fruits have to be place in a clean container and smooth surface to prevent damage during handling. Those poor handling practices could give a result later in both visible and non-visible damages.

The visible damage could happen such as picking, throwing, and dropping tomatoes into containers. Invisible damage can happen inside the fruits like internal bruising. According to this traditional technique of farmer could affect to the physical qualities of tomato and reduce the shelf life of fruit as well.

Fig. 12. Traditional technique of harvesting tomatoes

Presented in Table I are the examples of improper transportation for sensitive products where the local workers are hired and they usually perform the tasks by using their personal perceptions and experiences. Some problems as the aforementioned situations might be occurred when the worker is hired and paid one day at a time, with no promise that more work will be available in the future. They have less access to resources than mid-to-high skilled routine workers.

TABLE I
TRADITIONAL PRACTICE OF POSTHARVEST

Improper Transportation of sensitive products	
Picture	**Description**
A 	*Loading A* • Sitting on the vegetable • Bad packaging • Effect to physical damage
B 	*Retailer B* • Can not be stacked from bottom to top • Difficult for air ventilation • Cause injuries on fruit
C 	*Fruits damage C* • Fruit loss • Effect to food waste • Surface of fruits is compress

E. Tomatoes Harvesting, Storage and Transportation in good practice

Harvests in good management practices have four important elements which are applied and considered during harvest seasons such as maturity of fruits, time of harvesting, harvesting technique, packaging materials, and storage condition. Tomatoes can be harvested in any stage of maturity depending on the logistics condition from the production area to the consumption area. The fruits farmer and buyer select the level of maturity based on distance of transport from the field until selling desk. The mature green of tomatoes is important for keeping and loading during harvesting and transportation because dark red tomatoes are easily affected by physical damage causing loss of the product during operation. Time of harvesting also has to be put in consideration because when farmer harvest in a wrong time would strongly make invisible damage to the fruits [26], [27]. Harvesting fruits in hot duration is increasing the mechanism of maturity and increasing dehydration of fruits itself as well. On another hand, the harvesting technique also considers as critical method to prevent fruit loss and fruit waste. Presented in Table II are the proper transportations for sensitive products. The processes shown were captured from the wholesale (fresh) market in Pathum Thani province, Thailand.

TABLE II
Good Practice of Postharvest

Proper Transportation for sensitive products	
Picture	**Description**
A 	*Loading A* • Rack can stack from bottom to top • No compress to the fruits • Good air ventilation • Easy to swap from location A to B • Fast moving
B 	*Retailer B* • No damage or injuries • No fruits loss • No fruits waste
C 	*Storage C* • Easy to load to cold storage • Convenient • Time saving • Reliable of product quality

Normally, tomatoes are loaded in three different places such as field, packinghouse, and supermarket in order to reduce damage during this main three-operation farmer need to consider a good operation practice during supply chains such as good picking method, hygiene operation, and smoothly preparation. Packaging materials are using to protect fruits from any damage that simply happens during harvesting operation; especially providing space in between plastic bin from bottom to the top for giving an air pass through the stacks.

However, storage facilities are so important for properly protect crops, raw materials, semi-finish products, and finish products [28]. Storage techniques for tomatoes are a main big impact to tomato quality according to storage temperature that would effect to lycopene content and color quality [29]. Since the amount of space of warehouse or the storage area is necessarily required first for determining the layout design where the proper workflow areas and equipment needed to receive and dispatch products are identified.

For setting workstations and storing items inside the warehouse or storage room, two methods are introduced; *clustering or grouping by type*, and *storing in aisles as a grocery store design*. In clustering method, workers feel comfortable to access the area of interest to find items. Applying the aisles in the back and production and workflow in the front can increase the storage capacity and maximize the amount of the current space, since the vertical space as stacking items is applied [30].

F. Cold room Design Concept and Configuration

The cooling system is the one most commonly practiced method to prevent contamination and spoiled between the production and supply chain processes. It is one of the effective methods of perishable commodities in fresh and whole supply chain states for a longer period by humidity and controlling temperature within the storage system [31]. The relative humidity of the storeroom should be kept as high as 80-90% for most of the perishables, below or above; detrimental effect on the keeping quality of the produce [27]. Most vegetable and fruit have a very limited life after harvest from the field if happened at conventional harvesting temperatures it would decrease more on the quality.

Cold storage can be added to some chemicals in storage environment with added carbon dioxide and sulfur dioxide according to the natural product to be preserved. The cold room is designed to access horticulture products such as tomato, cucumber, cabbage, bok choy, eggplant, onion, and fruits. Illustrated in Fig. 13 is about the virtual design of cold room that is considered and applied in the real markets (i.e., small to medium-scaled fresh markets).

The dimensions and shape of the room were obtained from the interviews/self-administered questionnaires from the sellers.

To set up a new cold room normally every factory would like to get a large capacity of a cold room and optimal location to reduce labor costs and transportation costs [32]. That is why the design of warehouse or cold storage is very important to the firm of companies and the overall cost of the logistics supply chain. The overall process of setting up a new warehouse needs to be study such as labor cost, machine configuration, rack configuration, location, capacity of storage, and transportation cost; anyway it could happen a big loss at the end [33]. Warehouse and cold room materials handling plan, operation plan, and configuration plan are the most concerned three factors affect the warehouse configuration design. There are many kinds of factor to involve for warehouse configuration but only three are important factors such as:

- Warehouse *operations* plan includes placement, picking policies, and assignment policies.
- The warehouse *material-handling* plan includes materials handling equipment plan and personnel plan.
- Warehouse *configuration* includes storage area, size, capacity, aisle, rack, location, and sizes of docks.

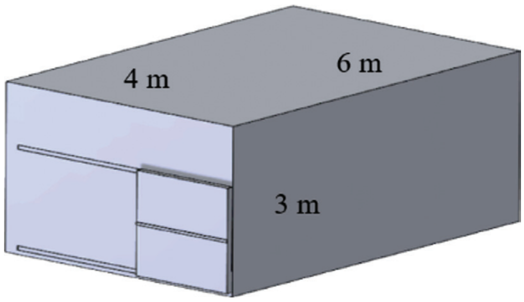


Fig. 13. Cold room concept design for CFD prototype

G. Three-shaped Patterns of Product Flow

Three popular warehouse configurations will be mentioned and analyzed in this study; *I-shaped*, *U-shaped* and, *L-shaped* patterns [34], [35]. The U-shaped configuration in warehouse product flow is the most popular type of configuration. The brief descriptions of these three shape designs or flows are presented in the following three sub-sections below with pictures (Fig. 14-16).

- I-shaped design
  The concept of this design is about the way to receive and dispatch products; receiving at one end and dispatching from the opposite end. The motion is considered as the flow-through or 'I'-shaped layouts as shown in Fig. 14. This pattern is commonly found and applied for "*high-volume operations*" where the complete separation of receiving and dispatch operations is required. I-shaped design is widely used; however, this design requires greater hardstand areas than the "L" or "U"-shaped designs.

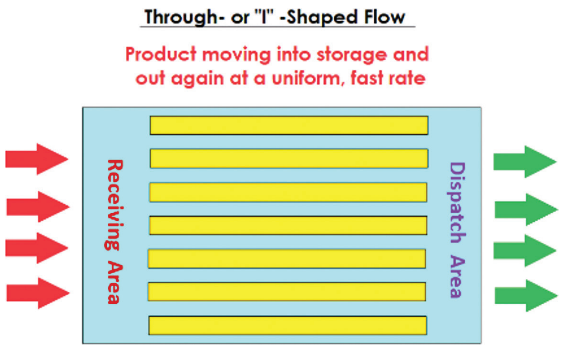


Fig. 14. I-shaped design layout

- *U-shaped design*
  The key characteristic of this design is about receiving and dispatching operations that are adjacent, on the same side of a warehouse are known as "U" shape designs. The majority of distribution centers are designed as U-shaped (Fig.15). The benefit obtained by this design is minimizing space because U-shaped flow is a one-way in and one-way out option where the shipping and receiving vehicles (e.g., trucks) can share the same side of the building, each having its own dock. A receiving truck pulls up to the dock, the employees pull the items off the truck and move it the central inventory location for sorting. Meanwhile, on the other end of the "U," the shipping truck gets loaded with goods to head out to their destination.

The strength of this pattern is that,

- This layout offers the optimal solution for minimizing the amount of a paved or stabilized area required where vehicles.
- Work is occurring simultaneously.
- Shipping and receiving within close proximity to one another means employees can easily move goods from one truck to another with ease and speed.
- U-flow layout can minimize staffs for moving production and inventory even a small production team.
- With this style of warehouse layout optimization, the storage and inventory are taking up the least amount of space in building as possible.

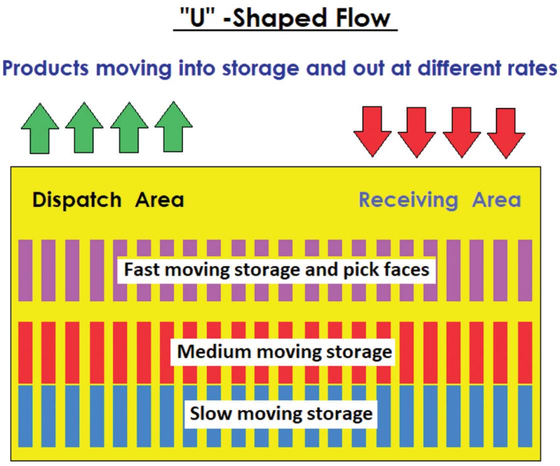


Fig. 15. U-shaped design layout

- *L-shaped design*

  The definition of "L-shaped design" is about receiving on one side and dispatching on an adjacent side at 90 degrees from the receiving side. In practice, some warehouses or docking operations apply an L-shaped design for receiving products in large trailers but dispatching in smaller vehicles as shown in Fig. 16. For some contemporary distributions, the combination between/among two or three of I, U and L-shaped designs is recommended. Currently, various storage systems require multiple rooms or spaces to store temperature sensitive goods such as fresh produce, medicines or cosmetic items. Thus, the key design components are considered on the ways to load/unload parts, air flow inside the room, vehicle types accessing the site, and product capacity.

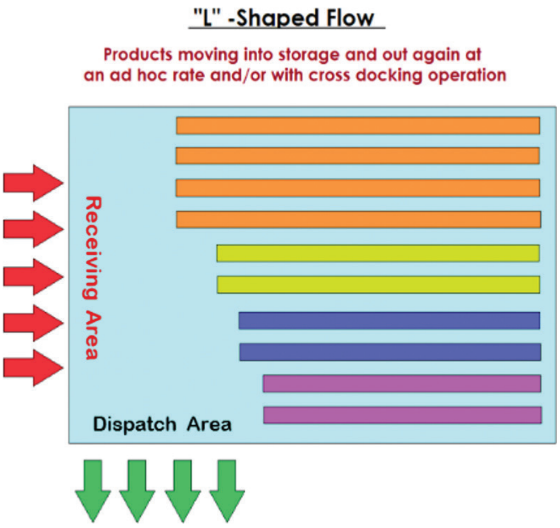


Fig. 16. L-shaped design layout

In this research, three configurations of design layout for supporting cold room system are compared where the air ventilation and temperature inside the room are listed as the main set of considerations to simulate the fluid motion and heat transfer by using numerical approaches; *Computational Fluid Dynamics (CFD)*. The results are reported as the quantitative predictions of fluid-flow phenomena based on the conservation laws (conservation of mass, momentum, and energy) governing fluid motion. Since the average height for Thai male and female population is 168.6 cm and 157.5 cm, respectively [36].

This might imply that the appropriate stacking height of the crates should not exceed 5 layers to avoid overhead lifting action. Presented in Table III is the arrangement of pallet design five layer per one pallet that is widely used in the warehouse and storage room.

TABLE III
THE ARRANGEMENT OF PALLET DESIGN FIVE LAYER PER ONE PALLET

Product stack and Pallet design	
Pallet top view	**Packaging arrangement**
 Top view of packaging 25 kilograms	 Front view of packaging stacked from bottom to top

IV. METHODOLOGY

A. *Computational Fluid Dynamics (CFD)*

Appropriate controlling a uniform cooling and cold storage of fresh produce are quite difficult to provide because of an uneven distribution of the airflow; the airflow distribution inside the area of interest depends upon the product, the cooling medium, the geometry, and the characteristic of the cooling room. Ho [37] mentioned that the increase of development of computers and the field of Computational Fluid Dynamics (CFD) in recent years has opened up the possibilities of a low-cost an effective method for modeling and simulation of airflow and heat transfer in the refrigerated warehouse with fewer experiments required.

The model was subsequently applied to predict the condensation in bulk-stored; CFD was used to investigate the airflow in a cold stored as well as to modify the airflow distribution system in the storage room. Airflow, heat, and mass transfer in cold storage was modeled to predict the velocity distribution, temperature profile, and moisture loss in stored product. CFD was also proven to be a suitable technology for predicting the effect of various design parameters on the flow and temperature fields of cold stored [38].

Fig. 17 and 18 show examples of air velocity and temperature distribution from CFD simulation results of forced airflow over three crates of product positioned in the middle of the cold room. The inlet temperature from the air conditioner was set to 15°C. The inlet air velocity was approximately 4 m/s.

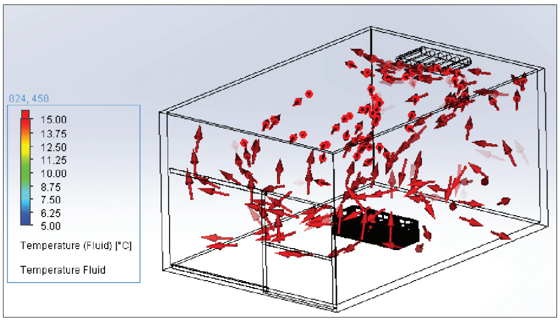


Fig. 17. Temperature-CFD testing by using SolidWorks

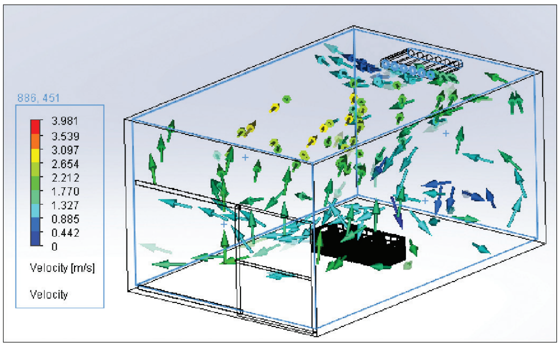


Fig. 18. Velocity- CFD testing by using SolidWorks program

B. *Detail Design*

The computational fluid dynamics are used in a cold storage system to evaluate airflow to the right location of product needed. This part of the research study is an answer to customer needs such as improved quality of fruit/vegetables; reduce cost through minimize electricity consumption and improving shelf life of products. Moreover, this concept designed is truly applied in commercial cold storage and small scale cold storage based on the capacity of cold storage and CFD system to identify the good configuration of product rack to be fit and efficient. The CFD is used to design and study different product arrangement to evaluate the space, airflow, and temperature distribution inside cold storage.

In this study, cold room size with dimensions of 6.0×4.0×3.0 meter was selected as a case study of small cold room for retailers. The room can hold products up to 16 tones (640 bins of 25 kg bins) of tomatoes if filled without space. However, product accessibility and distribution workflow must also be considered in the detail design of the layout.

With many concepts from the literature review, this design would like to design pallets into three different configurations which varies in storage capacity and accessibility with ergonomics considerations. The three configurations are shown as A, B, and C in Fig.19. Five layered stack of 25 kg plastic crates was applied to the simulation.

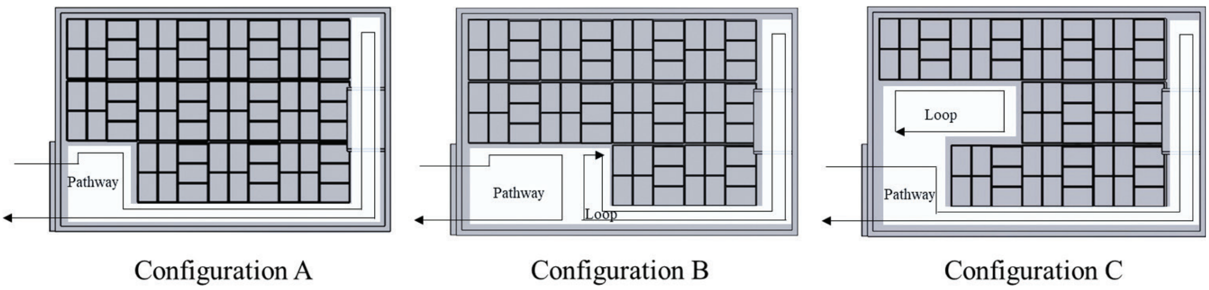


Fig. 19. The three configurations of the cold room layout used in the CFD simulation

Configuration A fills most of the room with the product except the bare minimum space needed for access of the workers. Configuration B removes one pellet out to allow more room for two workers to work in a two-loop workflow.

Configuration C sacrifices more of the storage capacity while gaining more access to the inner area of the cold room. The total number of crates for configuration A, B, and C are 385, 350, and 315 crates, respectively, as mentioned in Table IV.

TABLE IV
THE THREE CONFIGURATION SPECIFICATION

Description	Config. A	Config. B	Config. C
Plastic Bin 25KG	9625 KG	8750 KG	7875 KG
Total number of crates	385	350	315
Number of layer	5 layers	5 layers	5 layers
Number of pallets loaded	11 pallets	10 pallets	9 pallets

This simulation experiment was designed to compare the result of the flow and temperature distribution at the product crates among the three configurations. Since the quality of the product stored depends on the appropriate temperature of the crates, a performance index is defined such that the three configurations can be compared even if the amount of product inside is different.

$$e = C / b$$

Where e is cold room efficiency. C refers to the total capacity of the configuration in number of crates, b is the number of crates that has bad temperature distribution either too warm or too cold for the specific product.

C. Ergonomic Design

The guidelines for creating and designing cold room layout proposed in this study focus on how to locate/form the crates into a proper layout for maximizing profits while maintaining comfort of the workers; the key components for this ergonomic design are *simplicity, accessibility,* and *storage capacity.* In order to achieve the optimal reachability at working area, these following assumptions are taken into considerations:

- *Five stacking layers is recommended to prevent overhead lifting (stacking 5 boxes; the total height is around 150-160 cm).*
- *Providing spaces for a worker to easily move in and out.*
- *Applying CFD to simulate the proper conditions required for cold room to store temperature sensitive products.*

D. Heat Load Calculation

Temperature is a key component to make changes in the quality of products. The range of temperature is very important for any kind of product to maintain both their nutrient and physical qualities. Moreover, the temperature range is one of the most concerns for many researchers to study and evaluated to find a good way to empower cold storage and products. Therefore, to ensure product quality cold storage room could be researched more on temperature, capacity, storage condition, relative humidity and, velocity has to be done to keep as guidelines during operation design.

The cold room conditions have to involve the average of maximum outside cold room temperature and the maximum amount of product cold in a day and the maximum temperature of the product to be cooled. The total heat load produce by products itself and from materials inside the refrigeration system so heat which comes from every part of cold room must be removing from the cold room is called the heat load. The heat load can be produced by product respiration, people, leaking parts and, packaging [39]. The leaks and splashes of heat entering a cooling room come from several sources:

The heat of respiration: heat comes from naturally of product respiration.

Service load: heat from many parts of the cold room such as equipment, lights, people, moist, packaging, and air entering through cracks or the door when opened [40].

E. Vegetable Respiration

Vegetable respiration usually comes from fruit, vegetable, and other horticulture products. The respiration is starting after harvesting from the growing field. Vegetable respiration rate is depending on external and internal factor such as harvesting time, temperature, packaging, oxygen and carbon dioxide [41]. The number of respiration from vegetables is calculating according to the level of CO_2 produce from the product itself.

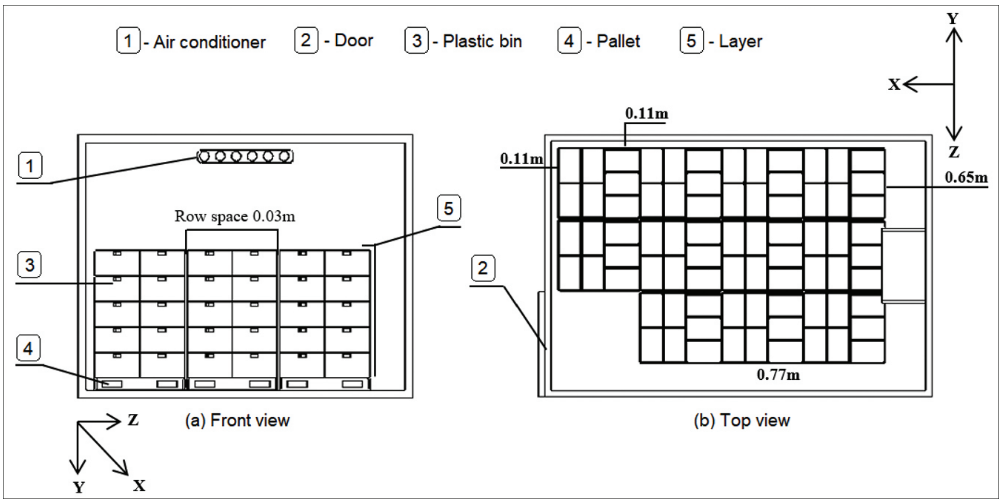
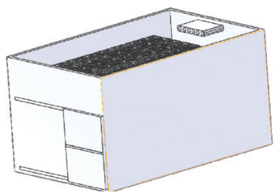
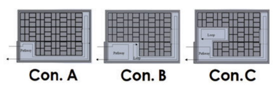
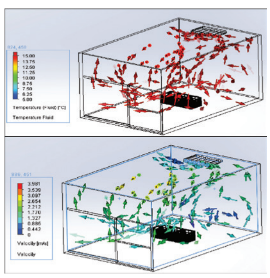
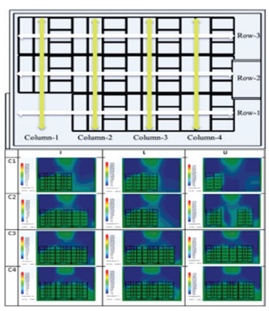
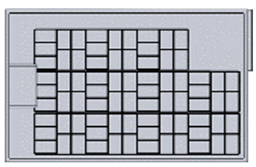


Fig. 20. Schematic of cold room for CFD simulation

The calculation for vegetable respiration normally heat respiration convert glucose ($C_6H_{12}O_6$), and transformed glucose to carbon dioxide (CO_2) and water (H_2O) by using oxygen (O_2) in a cold chamber (1 kg of tomatoes equal to 3.81 BTU per hour) [42], [43]. Heat respiration for every vegetable, fruit and root vegetable were calculated by how much carbon dioxide produce in a single day and convert into calories [44]. Illustrated in Fig. 20 is the Schematic of cold room for CFD simulation applied in this study. The steps required for the proposed research are presented in Table V.

TABLE V
RESEARCH STEPS REQUIRED IN THIS STUDY

Illustration	Description
	**Step 1** Packaging design: • Length: 375 mm • Breadth: 570 mm • Height: 308 mm • 25 kilograms
	**Step 2** Dimension of cold room: • Length: 6 m • Breadth: 4 m • Height: 3 m • Air conditioner types 42PST1U6 (39000BTU/hour)
	**Step 3** Configuration of study • I shape • L shape • U shape
	**Step 4** CFD design: • Temperature (15±2 °C) • Velocity (4 m/s) • Relatives humidity (90-95%)
	**Step 5** Compare the three configurations using performance index *e* • Plot sectioned view of temperature distribution • Count crates that has out-of-range temperature
	**Step 6** • Model selected • Give conclusion • Provides suggestion

F. Boundary and Initial Condition

The model each simulation is using Flow Simulation in SolidWorks to analyzed and solved by applies finite elements to testing the model. For each time to test the model by using full flow simulation in SolidWorks it took 2 or 3 hours on a 64-bit, Intel(R) with Six-Core Processor 3.60 GHz, 8 Gb RAM, Windows 10 PC. This cold room simulation study is assumed the room condition is completely isolated from outside environments such as walls, floor, ceiling, and door. In the room are containing differences number of bins loaded into cold storage (Table VII).

Based on fluid simulation x, y, and z direction to the contour plot of simulation results. The air simulation in the room is defined by adding a momentum source term in the fluid domain. Airflow is using the main parameter of temperature fluid, velocity (X, Y, and Z) and relative humidity. In boundary condition, air velocity is adding 4 m/s with temperature 12 to 15 degrees Celsius with assume relative's humidity 90 to 95 percentage in cold storage.

1) Constraint.

- Number of products loaded with specific configuration
- Manual lifting
- Temperature in the range

2) Target set up. The boundary conditions were used cold room wall to define the airflow direction (Table VI). The airflow velocity, relative humidity and inlet flow temperature were set at the experimental designed.

- Air velocity 4 m/s.
- Room assumption well-isolated.
- Relative humidity assumption in good range from 90-95%.
- Capacity loaded and heat load.
- Temperature 15±2 °C.

3) Inlet mass flow. The inlet mass flow set up was use air conditioner to set up flow direction from air conditioner to cold room and product loaded. Optimization product loaded to get a rage temperature 15±2 °C.

IV. RESULTS AND DISCUSSION

A. Air Velocity and Temperature results

For configuration A, the air velocity profile inside cold storage is shown in Fig. 21 (a,b). The airflow pattern from air conditioner flows directly to cold storage with a maximum air-speed in 4.0 m/s and velocity decreases the speed from 4.0 m/s to 0.004 m/s when reach into every surface of the packaging inside cold storage. There is also flow create circulation zone at Fig. 21 (b) the front part of cold storage next to the entry door of the stack which is a free space for the forklift to loading product.

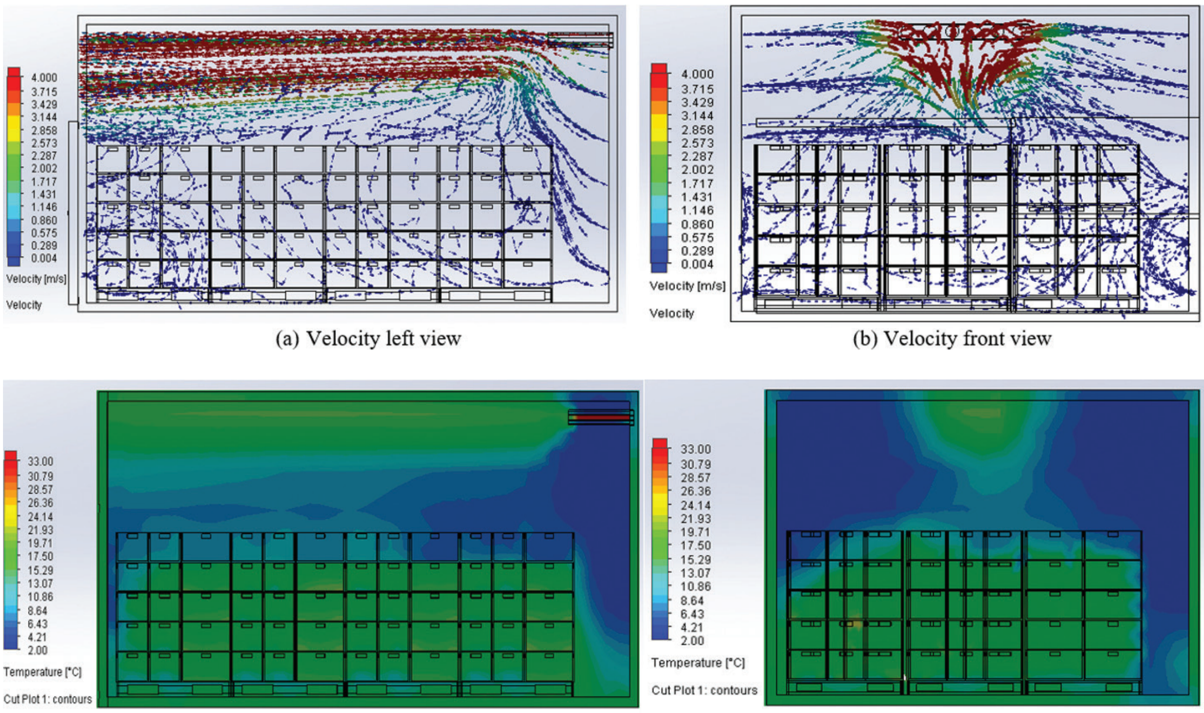
According to the number of air-speed from the result of velocity shows in 0.2 m/s to 0.86 m/s that in a good range for horticulture products [37], [45], [46]. In addition, from velocity characteristics inside cold storage. Fig. 21 (c, d) show temperature distribution from the air conditioner which flows directly to cold storage with a maximum temperature of 21°C. The temperature measurement range were derived from a stable condition after sixty minutes when the temperature around the crates reach a stable point of 15°C. The total range of temperature was found to be from 33°C to 2°C. Some crates positioned at the outer layer experienced very low temperature and may cause issues to the product quality while the majority of the storage gets appropriate temperature range of 15±2°C.

For configuration B, similarly, the air velocity and temperature profile inside cold storage are shown in Fig. 22. The air speed pattern from air conditioner flows directly to cold storage with a maximum airspeed in 4.0 m/s and velocity decreases the speed from 4.0 m/s to 0.004 m/s when travel to every parts in cold storage. There is also a non-uniform flow create circulation zone on the top which is influence by a free space next to the entry door. This may cause better flow of air as compared to configuration A. According to the number of air-speed from the result of velocity, it also provides 0.28 to 0.86 m/s which is a good range for horticulture product [26], [27], [35], [36]

The temperature pattern from the air conditioner flows directly to cold storage with a maximum temperature of 21°C.

For configuration C, the simulation results are shown as the velocity profile (Fig. 23 (a, b)). It shows more air flow upward through the center of the room, creating a wide area circulation zone on the top. This should be the influence of the free space in the middle of the crate arrangement in *configuration C*.

The velocity is also in the suitable range required for horticulture storage as the *configuration A* and *B*. The temperature range is also listed with 33°C to 2°C where some minor parts of the crates are too cold for the target temperature.



(a) Velocity left view (b) Velocity front view

(c) Temperature left view (d) Temperature front view

Fig. 21. Simulated contour of temperature in the middle of cold storage with configuration A with 385 boxes loaded. (Middle row and column)

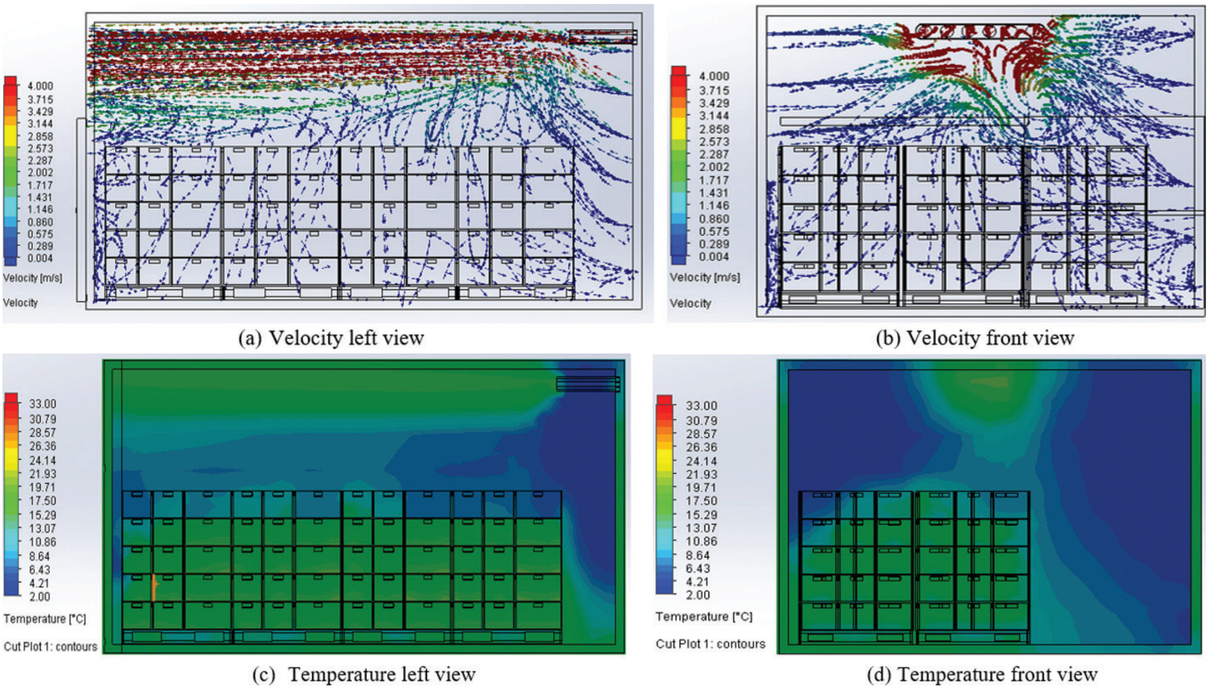


Fig. 22. Simulated contour of temperature in the middle of cold storage with configuration B with 350 boxes loaded. (Middle row and column)

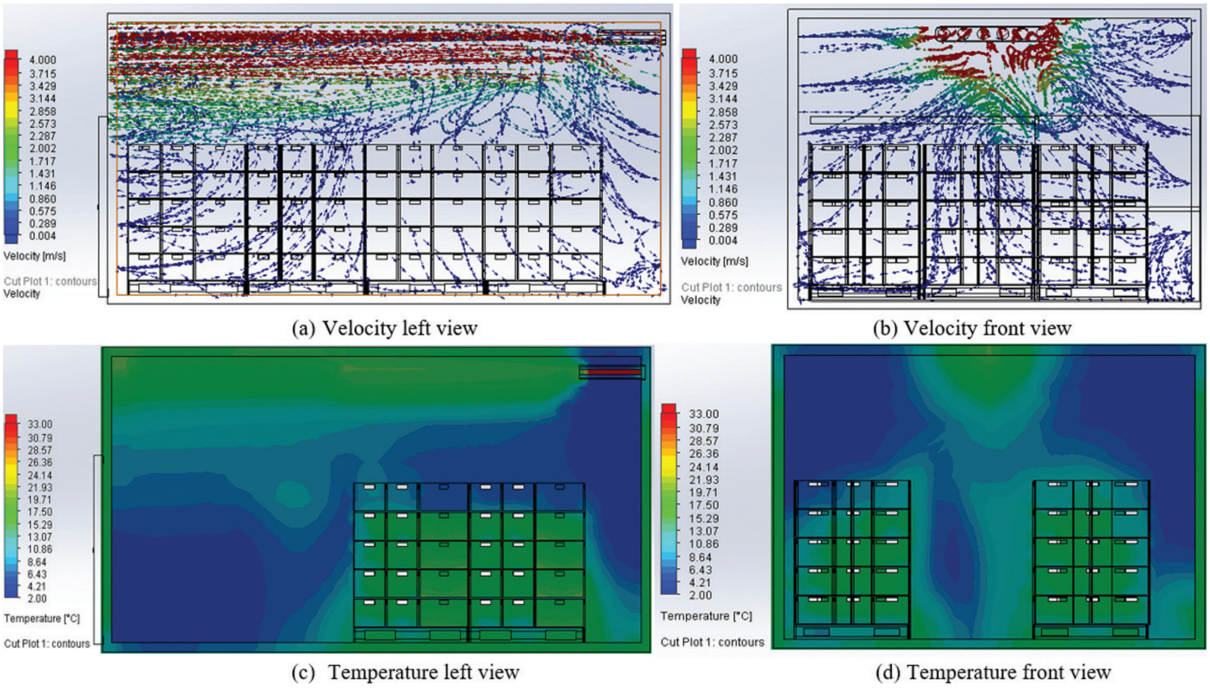


Fig. 23. Simulated contour of temperature in the middle of cold storage with configuration C with 315 boxes loaded. (Middle row and column)

B. Cold room Efficiency

As mentioned before, the *three configurations: A*, *B* and *C* have different loading capacity and each has its own advantage/disadvantage when it comes to cold-room design. This leads to the need to create a comparable performance index defined as cold room efficiency, where C refers to the total capacity of the configuration in number of crates, and *b* is the number of crates that has bad temperature distribution either too warm or too cold for the specific product. *"b"* can be approximated using sectioned plot of the CFD result in all column and rows of the pellets as shown in Fig. 24. One of the sectioned plots of *configuration A*, *Row 1* is shown in Fig. 25. The circles mark the crates that have too low temperature for tomatoes storage.

After the same method has been applied to all available sections, the total number of bad crates across all sections are summarized to *b* for the calculation of the cold-room efficiency. Table V displays the calculated values for all configurations.

The cold room efficiency works as a quantitative comparison tool to help the designer select a layout of the crates to maximize the capacity in the room while having the least number of crates that has out-of-range storing temperature for the specific fresh produce, which is tomato in this case study.

The result shows that while *configuration A* has the highest loading capacity, the configuration B would be a better choice of layout according to the highest performance index (cold room efficiency *e*) of 9.46 among the three configurations. Additionally, *configuration B* provide moderate accessibility and two loops pathways for better task management between workers.

TABLE V
PERFORMANCE COMPARISON BETWEEN LAYOUTS

Description	Config. A	Config. B	Config. C
Column 1	5	4	3
Column 2	4	3	7
Column 3	7	7	6
Column 4	7	5	7
Row 1	9	4	5
Row 2	11	7	5
Row 3	11	7	10
Number of bad crates *b*	54	37	43
Cold room efficiency *e*	7.13	9.46	7.33

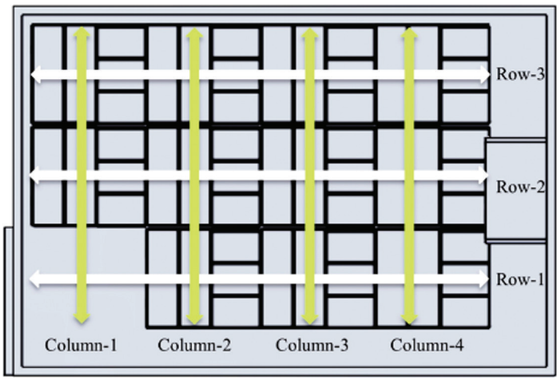


Fig. 24. Section planes for counting the bad crates using sectioned temperature plot technique

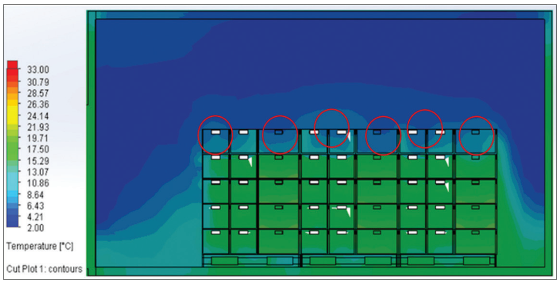


Fig. 25. Sectioned plot of temperature profile (Config. A, Row 1)

V. CONCLUSION

This research study and suggest a design guideline for storage layout of small-sized cold room. Firstly, workflow analysis, ergonomics standard and regulations were used to suggest three basic configurations of crate and pellet layouts. Then, CFD simulation was conduct to analyze the velocity profile and temperature distribution within the room and product area. The simulation result provides beneficial clue to choose the optimal configuration for a specific room size and reduce waste time trying to improve the layout using trial-and-error methods. Additionally, this research propose a performance index called cold room efficiency to be used as one of deciding factors in cold room design.

For the case study of *"tomato cold storage room"*, the **configuration B** was suggested to be the optimum layout because it gives the least defective crate for the loading capacity among the three configurations.

The design method and guideline presented in this study can be extended for other types of product that require different packaging, temperature, velocity, and relative humidity range. Because some products can be placed in a warmer or colder area than others, mixed storage with different product appropriately stored in the same room is also possible with the help of CFD simulation.

For future works, the research should bring this result to do a real experiment for cold room to see how different of layout could give effect to the quality of tomato in term of firmness, color change, and weight loss. Also, the accuracy of the performance index could be improved by changing the approximation method to use a full 3D result and image processing software to count the number of bad crates. However, this improvement would take a lot of computation time unless a high performance computational machine is available.

Acknowledgement

This research study is supported by Ajinomoto Foundation, and School of Manufacturing Systems and Mechanical Engineering, Sirindhorn International Institute of Technology, Thammasat University, Thailand.

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