Financial Analysis of Cooling Conservation Method for Long-Term Paddy Storage in Thailand

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จักรพันธ์ จิตสุทธิภากร : การวิเคราะห์ทางการเงินของการเก็บรักษาข้าวเปลือกในระยะยาวในประเทศไทยด้วยวิธีการใช้ความเย็น (Financial Analysis of Cooling Conservation Method for Long-Term Paddy Storage in Thailand) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: รศ. จิรพัฒน์ เงาประเสริฐวงศ์, 154 หน้า.

งานวิจัยชิ้นนี้ จัดทำขึ้นเพื่อ วิเคราะห์ข้อมูลทางการเงินของการเก็บรักษาข้าวเปลือกในระยะยาวในประเทศไทย ด้วยวิธีการใช้ความเย็น โดยมีปัญหาหลักที่เกิดขึ้นในกระบวนการจัดเก็บข้าว นั่นคือ ข้าวเกิดความเสื่อมสภาพ และ เสียหาย ในช่วงเวลาการเก็บรักษา โดยมีสาเหตุมาจาก มอด แมลงชนิดต่างๆ รวมถึงเชื้อรา ที่สามารถเกิดขึ้นและเพิ่มจำนวนมากขึ้น การเก็บรักษาด้วยวิธีการใช้ความเย็น จะสามารถควบคุมอุณหภูมิและความชื้น ในการเก็บรักษาข้าวเปลือกได้ และทำให้ความเสียหายที่เกิดขึ้น ลดจำนวนและมูลค่าลงได้อย่างมีนัยสำคัญ งานวิจัยนี้ จะรวบรวมประโยชน์ที่จะได้รับจากการจัดเก็บด้วยวิธีนี้ รวมถึง ค่าใช้จ่ายต่างๆ ที่จะเกิดขึ้นจาการใช้เครื่องทำลมเย็น โดยมีขอบเขตในการคำนวน 2 กรณี คือ การเปลี่ยนจากการจัดเก็บด้วยวิธีวนข้าวเพื่อระบายความร้อน มาเป็นการเก็บด้วยวิธีการใช้เครื่องทำลมเย็น และ การเปลี่ยนจากการจัดเก็บด้วยวิธีการใช้พัดลมระบายความร้อน มาเป็นการเก็บด้วยวิธีการใช้เครื่องทำลมเย็น

ในการวิจัยนี้ กระบวนการวิเคราะห์ได้ถูกนำมาใช้และศึกษา และคัดเลือกประโยชน์ที่ได้รับ และ ค่าใช้จ่ายที่จะเกิดขึ้น จากการเก็บรักษาข้าวเปลือกด้วยวิธีการใช้ความเย็น โดยมีทั้งแบบที่ประเมินออกมาเป็นมูลค่าได้ และ แบบที่ไม่สามารถประเมินได้ และยังได้แสดงตัวอย่างการคำนวณประโยชน์และค่าใช้จ่ายที่สามารถประเมิณเป็นมูลค่าได้ รวมถึงคำนวณ ระยะเวลาคืนทุนของการลงทุนเปลี่ยนระบบมาเก็บด้วยวิธีการใช้ความเย็น ยิ่งไปกว่านั้น ยังได้มีการรวบรวมข้อมูลทั้งหมด จัดทำแบบฟอร์มที่จะคำนวณ ผลประโยชน์ ค่าใช้จ่าย และระยะเวลาคืนทุน ซึ่งสามารถให้ผู้ใช้ได้ใส่ข้อมูลของตนเองลงไป เพื่อจะได้ทราบผลลัพธ์ที่ออกมาตรงตามความต้องการอย่างแท้จริง งานวิจัยนี้จะช่วยในการให้ความรู้ต่างๆ ของระบบการเก็บรักษาด้วยวิธีการใช้ความเย็น รวมถึงเป็นเครื่องมือที่ช่วยในการตัดสินใจที่จะเปลี่ยนระบบมาใช้เป็นระบบนี้ เพื่อประโยชน์สูงสุดที่จะเกิดขึ้นแก่ผู้ใช้ รวมถึง ประโยชน์ที่จะเกิดขึ้นกับธุรกิจข้าวในประเทศไทย เพื่อเพิ่มคุณภาพ และลดความเสียหายที่จะเกิดขึ้น

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KEYWORDS: PADDY GRAINS / PADDY STORAGE / RICE STORAGE / COOLING CONSERVATION / COST BENEFIT ANALYSIS / PAYBACK PERIOD ANALYSIS

CHAKAPHAN CHITSUTHIPAKORN: Financial Analysis of Cooling Conservation Method for Long-Term Paddy Storage in Thailand. ADVISOR: ASSOC. PROF. JEERAPAT NGAOPRASERTWONG, ., 154 pp.

The objective of this dissertation is to analyse costs and benefits of using cooling conservation method for long-term paddy storage in Thailand. The main problem of paddy storage is deteriorate paddy and rice during storage period. So, cooling conservation method is a ventilation method that can control temperature and moisture content of paddy during storage to reduce losses and avoid deteriorate paddy.

This research collected all the benefits and costs both tangible and intangible and compared to existing method. The scope of this study is focus on 2 transformation options which are transform from circulation method to cooling conservation method and transform from industrial fan method to cooling conservation method. This research used cost benefit analysis and payback period analysis to analyse all the collected data from surveying. It also shows calculation of all tangible data. Moreover, payback period calculation sheet is also an outcome of this research for put own data and get the result.

This research will be a tool that helps to make a decision to transform from the existing ventilation method to cooling conservation method which will make a lot of benefits for paddy storage and make a better quality of rice which leads to higher selling price of paddy. This will be the method that enhances the perspective of paddy and rice market for Thailand and for the world.

Department:	Regional Centre for Manufacturing Systems Engineering	Student's Signature	.....
		Advisor's Signature	.....
Field of Study:	Engineering Management		
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Chapter 1 Introduction

1.1 Background of thesis

According to Sontag [1], rice is the most significant staple foods for this entire world. Rice industry plays the main role in feeding the world population. There are some lacks of understanding of the rice industry as a business and also lacks the sort of reference book. Rice industry consists of various types of player in the business start with farmers who take care from the planting process to harvesting process. After finished harvesting, middleman is another player who came to the rice filed and buys the paddy from the farmers and selling to the rice mill. There are some farmers who can go directly to the rice mill and sell the paddy with higher price. Rice mill is the main player in the postharvest period of paddy. The ideal goals of every rice mill are buy the good quality paddy with low price, maintain the quality of paddy from the first day that the paddy came into the rice mill until the day that it go to the processing, process-paddy to rice with highest yield, and sell the rice with the highest price to the exporters or customers which can conclude that the objectives are to produce the highest yield and best quality of rice. According to Brun [2], in 2002, world production of paddy rice was 590 million tons equal to 393 million tons of white rice compared with 720 million tons of paddy rice produced in 2011, equal to 480 million tons of white rice. For this research, the main focus is mainly in Thailand which has approximately 7,000 rice mills. The paddy

production for Thailand was slightly increased from 25 million tons in 2000 up to 31 million tons in 2013 as in figure 2. More than a half of rice production in Thailand has been exported to foreign country that makes Thailand been in Top3 rice exporters of the world for more than 20 years.

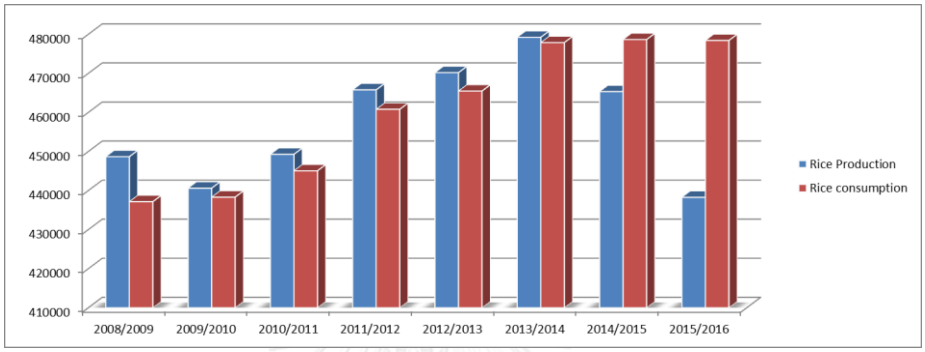


Figure 1 World production and consumption of paddy 2008-2016 [35]

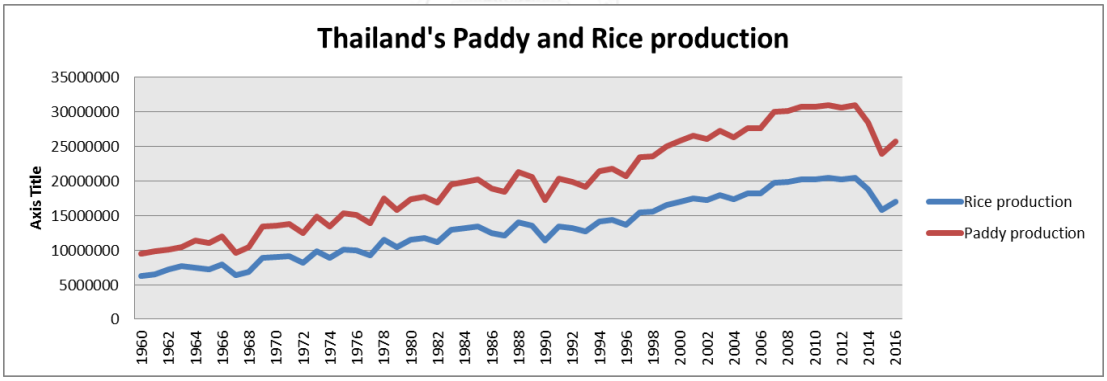


Figure 2 Thailand's Paddy and Rice production from 1960-2016 [31]

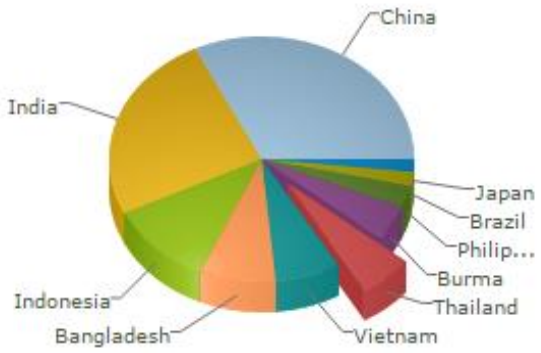


Figure 3 World production of paddy in 2013 [31]

Figure 3 shows that Thailand ranked at 6th position in the world paddy production in the world in 2013 placed behind China, India, Indonesia, Bangladesh and Vietnam. This study is mainly focused on postharvest technology in rice mill in Thailand. There are wide ranges of rice mill in Thailand start from rice mill in the small village which operates with manual machine that have limited capacity lower than 50 kilogram per hour to the huge rice mill that run with automatic machine system which can run for the maximum capacity up to 150 tons an hour. Thailand has around 7,000 rice mills, According to Thai rice mill Association, We can mainly divided the size of rice mill into 3 types which are small, medium and large as shown in Table 1.

Table 1 Size of rice mill categorize by Milling and storage capacity

Size of rice mill	Milling capacity	Storage capacity
Small	0-50 tons / day	< 1500 tons
Medium	50-150 tons / day	1500 – 5000 tons
Large	>150 tons / day	> 5000 tons

1.2 Statement of problems

According to Brun [2], Thailand is an agricultural country which the main agricultural product is paddy rice. The whole rice market capacity in Thailand is around 35 million tons per year. There are several kinds of rice such as white rice, brown rice, Hommali rice and HomPratum rice which have different market price. In average, selling price is around 20 baht per kilograms. So, the total market capacity for rice in Thailand is worth around 70,000 million baht which is around 0.5% of GDP. According to FAO [3], 10-20 % of harvested grain will be losses during the postharvest process especially in storage process. As calculated with Thailand market, **the losses during postharvest process is worth around 7,000 – 14,000 million baht a year**. The main problem of losses is deteriorating of paddy and rice. There are many reasons that paddy and rice are deteriorated such as bad storage techniques in the rice mill, lack of storage knowledge, insects and mildews. The main cause that is the reason of all the problems that may occur during the storage period is the operators cannot control **Temperature** and **Moisture Content** of paddy. There are 4 main problems that may happen during the storage if the storage facility and the ventilation type are not suitable which are

1. **Deteriorate paddy or rice**
2. **Paddy respiration loss**
3. **Length of storage**
4. **High operating costs**

According to Kolb & Braunbeck [4], paddy continues their live and the respiration system after being cut and threshed. Paddy and rice are highly hygroscopic which absorb and release humidity. Hygroscopicity is the ability of a substance that adjusts the moisture content of the surrounding air by absorbing and releasing water. The freshly harvested paddy has a significant losses caused by the cellular respiration and its spontaneous heating. If the temperature and moisture of the paddy increase, its respiration becomes more intensive. On the other hand, **if the temperature and moisture is in the low level, its respiration becomes slow or inactive**. The result of hot spot leads to the discolouring of rice and the development of insects and mildews. For paddy respiration, oxygen in the air is absorbed by the paddy and then interacts with carbohydrates in the paddy and then converted into carbon dioxide, water and heat. The result of respiration is a loss of substance as an equation of 1 kilogram of paddy respiration, approximately 1.54 kg of carbon dioxide, 0.58 kg of water and 16.48 MJ of heat are released

The grain respiration – totals formula of the chemical process:

$C_{12}H_{22}O_{11} + 12\ O_2 \rightarrow 12\ CO_2 + 11\ H_2O + 1.567 \times 10^{-3}$ kWh

carbohydrates + oxygen → carbon dioxide + water + heat

Figure 4 grain respiration formula (Kolb [13])

As a result of paddy respiration, the bulk of paddy that store in the storage facility will produce water and heat over time. So, the temperature in the storage will increase as

long as the paddy respired. Moreover, the amount of water that produced from the respiration system will be absorbed by the paddy and the moisture content of the paddy will be higher. As a result of higher temperature and higher moisture content of paddy during the storage period, there are 2 main reasons that are the main cause of deteriorate paddy which are insects and mildews.

Figure 5 shows the development of insects depends on the range of temperature in the storage facility. In the case of paddy rice, Rice weevil is the main problem of paddy storage. In the red zone, the rate of development of rice weevil is very high if the temperature is higher than 25 degree Celsius. In the orange zone, the rate of development is slow and safer for paddy storage when the temperature in the storage facility is around 15 to 25 degree Celsius. Moreover, if the temperature in the storage facility is lower than 13 degree Celsius, it can confirm that no development of insects can be happened during the storage period.

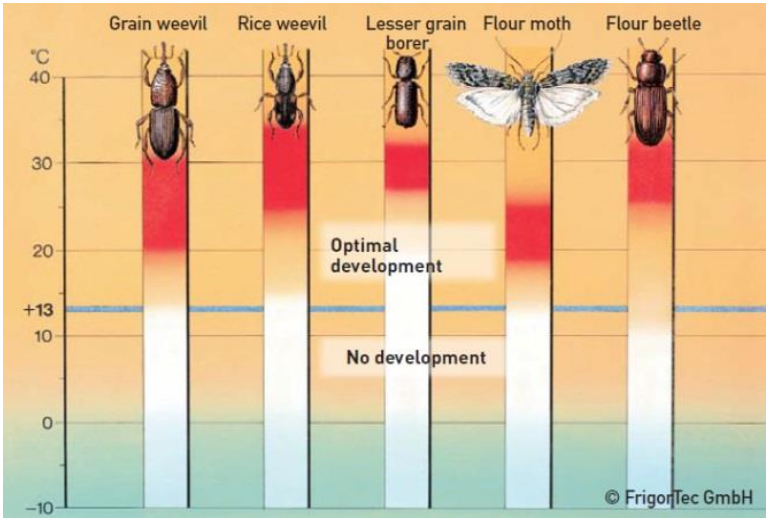


Figure 5 Development of insects dependent on temperature [4]

Figure 6 shows the generation of different types of mildew that can happened during the storage period depend on the grain moisture content and temperature in the storage facility. The worldwide set point of moisture content of grain for safe storage is at 14% moisture content that can avoid any kinds of mildews as in figure 6. In addition, if the operator has ability to cool down the storage facility less than 20 degree Celsius, it possible to store grain slightly higher that 14% to gain weight for higher price that can be sold.

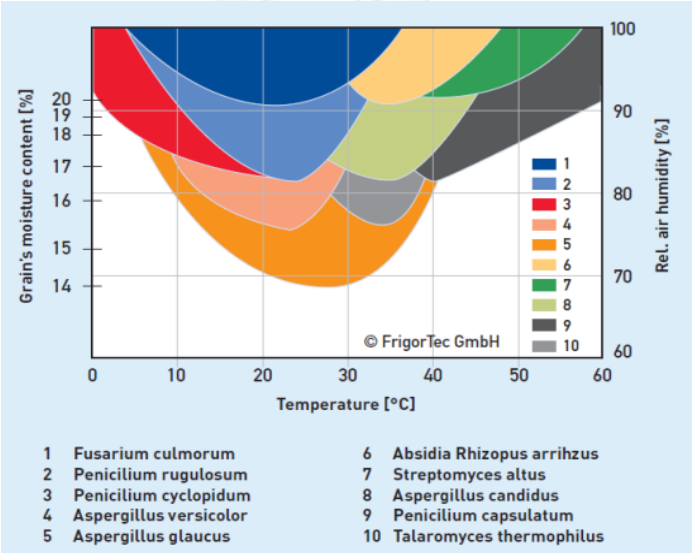


Figure 6 Generation of various mildews depend on moisture content and temperature [4]

The other main problem for rice storage is length of storage. The proper period of time that paddy can be stored after drying depends on ventilation systems. The length of paddy storage can be classified into 3 groups which are short term storage (less than a week), medium term storage (one week up to 2 months) and long term storage (more than 2 months). For short term storage, if the paddy have to be stored less than a week

ventilation system is not necessary for it. Circulation method, fan ventilation method and cooling conservation method can be proper for medium term storage depends on individual conditions and requirements. For long term storage, circulation method is no longer economical for long time storage because it may takes too much cycle of circulation and the paddy that store in the ambient temperature can store maximum up to 2 months.

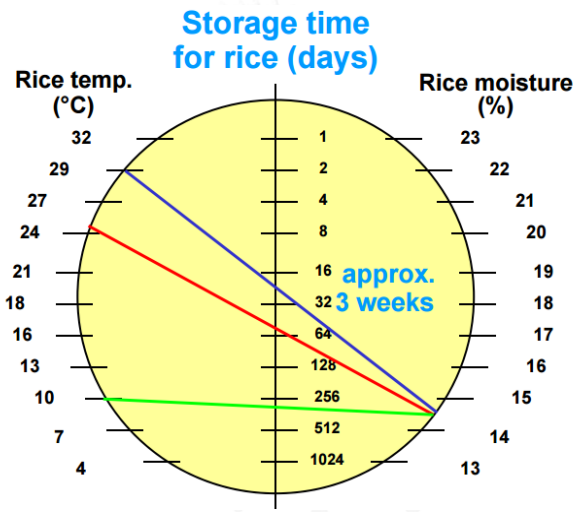


Figure 7 Storage period timer for grain [4]

According to figure 7, this is a tool to estimate the storage period of grains without major losses. First example in the figure is blue line, moisture content of paddy is at 14.5% and the temperature in the storage area is 29 Celsius. The estimated number of days can find by the cross point of the middle axis. In this first case, the result is around 20 days. Next is the red line, with the same moisture content but cooled down the storage area by grain cooling to 24 Celsius. The numbers of days that can be stored is increase to

around 60 days. The last case is the green line, when cooled down the storage area to 10 Celsius. The paddy can store without major losses for more than a year.

The last main problem of paddy storage is cost of storage. Most of the rice mill did not focus on storage cost. They focus more on buying and selling price of paddy and rice. For circulation method, cost of storage is mainly electricity cost of conveyers for silo storage and fuel cost of backhoe for warehouse storage. Moreover, the maintenance cost of both conveyers and backhoe are also the point that need to focus. But this method has the highest risk of losses compared to the fan ventilation method and cooling conservation method because it just a sample way to let some normal air flew into the pile of paddy in randomly basis. For both industrial fans and cooling conservation, it required some investment on air distribution system for warehouse storage. Basically the round silo and square silo are also equipped with the air distribution. Besides the investment of buying fans and grain cooler, there are only 2 main operating costs for these 2 storage methods which are electricity cost and maintenance cost. In conclusion the objective of paddy storage is to control the **temperature** and the **moisture content** of the paddy in the storage facility to maintain the best quality of the paddy and reduce **risks** that can be happen during the storage period.

There are three types of existing storage ventilation methods that has been used in Thailand which are circulation method, industrial fan method and cooling conservation method.

1.2.1 Circulation method

Circulation method is one type of ventilation method that has been used in rice mills especially in Thailand. As we can divided the storage type in rice mills to 2 types which are silo storage and warehouse storage, each type has different ways to done the circulation but the core of the method is the same. For silo storage, circulation method can be done by move the paddy in one silo to another silo with conveyor system to reduce the temperature in the hot spot of the bulk of paddy and also let the air flow to touch paddy during the transportation. As a result of this activity, the temperature in the silo was reducing to the safe zone but it is just a short term method that the temperature will raise again due to the paddy respiration system. For warehouse storage, this method can be done by using wheel loader or backhoe loader to turn and reverse the paddy from one stack to another stack for the same purpose that to reduce the temperature in the stack of paddy.

The only advantage of this method is no investment needed. The conveying system of paddy normally equipped with the silo and warehouse and the loaders is a primary machine that normally use in rice mills. On the other hand, **operating cost of this method is very high** such as electricity cost of conveying system and fuel cost of loaders. Moreover, the **broken rice yield is increased** by using this method because the paddy needs to move through conveying system and some can be damage by the loaders. In addition, the cycle of this method is very short normally around 15 to 20 days and this method need to be done again. **So, the possibility for long term storage is very low because of the high operating cost.**

Figure 8 Silo storage

Figure 9 Circulation method for warehouse storage

1.2.2 Industrial fan ventilation method

Fan ventilation method is another type of method that widely used for paddy storage. This method is done by use the industrial fans to blow the ambient air outside the storage facility into the bulk of paddy inside the storage facility through the air distribution system for both silo storage and warehouse storage. Figure 10 and 11 show the example of fan ventilation for silo storage and figure 12 show the example of warehouse storage.

Figure 10 Example of fan ventilation method for silo

Figure 11 Example of fan ventilation method for silo

There are some advantages of this method compare to circulation method such as the paddy in the storage facility no need to move. So, the electricity cost and fuel cost of moving the paddy is disappeared replace by the fan's energy consumption which is cheaper than circulation method. But, fen ventilation method needs some investment on fans and air distribution system. Moreover, there is another disadvantage of this method which is **weather conditions**. Fans need to be operating by carefully concern about ambient air. If the ambient air which has higher temperature and relative humidity than paddy inside the storage facility has been blown into the storage facility, the paddy will absorb both temperature and moisture that is the main reason of deteriorate paddy. In addition, uncertainty that cause by weather condition lead to unpredictable cycle of ventilation. Operator need to be focus on temperature and relative humidity both inside and outside storage facility. As same as the circulation method, this method is not suitable for long-term paddy storage which storage period more than 3 months because the energy consumption of fans is high and unpredictable.

Figure 12 Example of fan ventilation method for warehouse

1.2.3 Cooling conservation method

Cooling conservation method is a method that suitable for long-term grain storage. It is the method that cools down grain in the storage facility by using grain cooling unit that supply cold and dry air through the air ventilation system into the storage facility. This method can also use for both types of storage facility. There are many advantages of using cooling conservation for long-term paddy storage such as reduce respiration loss, avoid deteriorate paddy, longer storage period and reduce operation costs. The only disadvantage of this method is extra investment is needed to buy the grain cooling unit. Figure 13 show how the grain cooling unit used in real practice to store paddy.

Figure 13 Example of grain cooling unit method

For all 3 types of ventilation methods, circulation method and industrial fan method are 2 types that popular in Thailand for last 20 years. Cooling conservation method has been used in limited number of rice mills due to the price of grain cooling unit and air distribution system. Moreover, some rice mills need good reference users who already used this method and can confirm that the benefits from cooling conservation method

are tangible and realistic. In addition, the financial data of using cooling conservation method is unsystematic and too conservative. **So, with more than 15 years of experience in this business field, this study will collected all the data and information from real practices in Thailand and will make all the data systematic and trustable.**

1.3 Objectives of thesis

Provide the financial analysis and sensitivity analysis of cooling conservation method for long-term paddy storage

1.4 Scope of study

1. Long-term paddy storage – more than 1 month
2. Benefits/costs analysis
3. Payback period for investment
4. 2 cases of investment
    i. From circulation method to cooling conservation method
    ii. From industrial fans method to cooling conservation method
5. One model of grain cooling unit (capacity : 5,000 tons)

1.5 Proposed methodology

a. Study and research related literature

b. Collect and analyze existing data of storage type and ventilation system from rice mill

c. Collect and analyze the data

   i. Advantages

   ii. Disadvantages

   iii. Risk

   iv. Investment

d. Surveying

e. Analyze benefits and costs of grain cooling with real practices

f. Create the payback period sheet template for rice mills to put in their own variables for storage

g. Evaluate the results

h. Summarize the thesis

i. Write up – Submission

2 Literature Review

2.1 Cost Benefit analysis

According to Boardman, A., Greenberg, D., Vining, A., & Weimer, D. [5], Cost benefits analysis (CBA) is a method that helps to make a decision by quantify and list all the related information in financial terms especially on benefits and costs. All the costs and benefits should be assessable and understandably. It is sensitively difficult to accept all certain benefits, particularly the values that rely on human. Moreover, some analyses which can be easily bias in favour of personal interests have to be carefully concerned. According to James & Fransico [6], Johansson & Kristrom [7], to CBA is a suitably tool for project estimation on direct and indirect benefits. It is calculated the net benefits regardless of who pays the expense or who received the benefits. At all level of complexity, figure 14 illustrates the simple diagram of CBA that shows the overview of it with minimal acceptance criteria for every proposal. Net benefits are equal to the present values of all the benefits deduct with the present value of costs. The straightforward calculation of net benefits that expected from implementing a proposal. Each option of proposal has a specific time frame and addresses the benefits and costs described in terms of choice which decision maker has full responsibility. Doing nothing is a default option to consider and compare with every proposal.

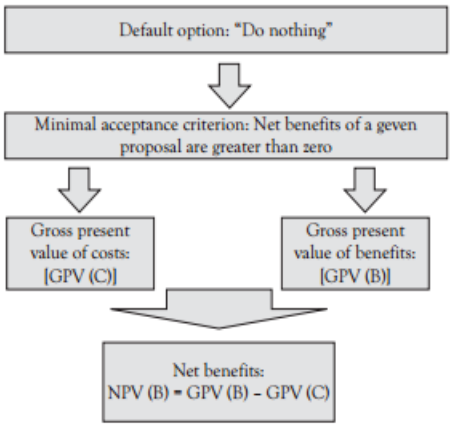


Figure 14 the overview of Cost Benefit Analysis

According to Department of Finance and Administration Financial Management Group [8], decision makers are frequently the man who forced to choose between worthy projects. The highest net benefits project should be the obvious solution. CBA typically involves mathematical calculations which have been done in spread sheets. In case they have two options of proposal but performed by different analysts, the result is unlikely to be identical, as CBA is consists of science and art. Separate studies normally confirm net benefits of analysis to be either positive or negative number. Sensitivity analysis is also been aware of in the analysis which is dealing with the uncertainty. Sensitivity analysis is a method that the analyst solves for expected number with different hypothesis about the discount rates or number of clients. As a result, CBA allow the analyst to surely explain how he or she determined that each option be considered or rejected. The reliable CBA is to accurately evaluate a project in monetary terms as the difference between benefits and costs. However, CBA is a method that should be valued not strictly in terms of its precision but rather in making that option more realistic.

Regrettably, cost benefit analysis (CBA) has come to be a generic term with no general agreement that which costs and benefits should be included or not.

Processes of cost benefit analysis

According to Mind Tools [9], there are 3 steps to conduct the cost benefit analysis which are:

Step one: Compile all costs and benefits

The first step in the process takes time to brainstorm a comprehensive list of all benefits and costs that will happened in the project. Costs need to include both direct and indirect costs, intangible costs, opportunity costs and the costs of potential risks that may occur. As same as benefits, they should be include all direct and indirect income and intangibles benefits, for example, production increased due to the improvement of employee morale and safety.

Step two: Assign a financial term to all costs and benefits

A common unit in financial term should then be applied to all the items. Underestimate costs and overestimate benefits are the things that should be concern and do it very carefully. A traditional approach with a conscious effort to avoid the particular tendencies when doing the estimation is the best way when assigning the number for both benefits and costs.

Step three: Compare costs and benefits

The final step is to compare the results of cumulative benefits and the cumulative costs to know that the benefits or costs have a greater number. If the benefits are greater, then the decision is to go forward with this investment. If not, this project has to reconsider to see that if it possible to increase the benefits or reduce costs. If not, this investment project should be cancel or abandon.

Another tool that helps to do the cost benefit analysis is payback period time. The objective of payback period analysis is to find out how long it will take for the project to reach the breakeven point which is the point of time that the benefits have just repaid the costs and initial investment. The simple calculation of the payback period can be done with following formula:

Total cost / total revenue (or benefits) = length of time (payback period).

Limitations of Cost Benefit Analysis

According to Graham [10], for some projects or investments that involve small to medium capital expenditures and the short period of time, cost benefit analysis may be suitable to make a well-informed decision. But for very large projects with long period of time horizon, cost benefit analysis usually fails to cover all the possible benefits and costs into account. Moreover, some financial concerns such as interest rates, inflation rates, cash flows and the present values are also the problems of the analysis.

2.2 Payback Period Analysis

According to accountingformanagement [11], Investopedia [12], Jan [13] and accountingtools [14], the payback period is the length of time required to recover the cost of an investment by the net cash outflow generated by the asset. The payback period of a given project or investment is an important factor of whether to accept or reject the proposed project. Longer payback periods are usually not appropriate for investment positions. In addition, payback period ignores the time value of money such as net present value, internal rate of return or discounted cash flow. The payback period of a project is expressed in term of years by using the following formula:

$$\text{Payback period} = \frac{\text{Investment required for a project}}{\text{Net annual cash inflow}}$$

In common, the project that has a quick recovery of the original investment is very attractive. If the payback period that calculated by using formula is shorter than the period that management's team maximum desired, this project should be accept. Moreover, payback period analysis is frequently use by the analyst to figure out the reliable way to determine the highest profit project or investment to undertake.

According to Jan [13], there are some advantages of payback period, first is the payback period is very simple to calculate. Second, it provides a good ranking option that would return money faster for the company who face liquidity problems. Next, an option of investment with short payback period makes funds available soon to invest in another project. In addition, a short payback period can reduce the risk of loss that can cause by changing economic conditions or other unpredictable reasons.

On the other hand, the disadvantage of payback period is that it does not take time value of money into the account. Another disadvantage is it does not consider the useful life of assets and inflow of cash after reach the payback period.

2.3 Facts about paddy and rice

According to Vanavichit [15], rice has a long history of co-existence with human growth and civilization. Nowadays, rice feeds nearly half of the world's population, mostly in Asia. More than 150 million hectares was occupied by paddy which covering 112 countries. About 90 percent of paddy growing area is in Asia which around 60 percent is produced in China and India. Paddy can also grow in Australia and USA but mainly for export to Africa and South America which are the area of big rice's importer.

Rice is a product that has its own story. It is different from other kinds of grain in term of market, production and consumption. According to Brun [2], in 2011, world production of paddy rice was 720 million tons, equivalent to 480 million tons of which feeds 7 billion people around the world giving the average number of consumption of 63.4 kilograms a year for 1 person. As the number of population always increasing day by day, rice has to be produce more and more in order to feed the increasing population. In numbers, according to Aulakh and Regmi [16], world population is expected to reach 10.5 billion people by 2050. It makes the world concern with global food security. This number of increasing world population translates into 33% more human need of food with the greatest demand mainly in poor communities around the world. Food supplies would need to increase by 60% to meet the demand level in 2050. To increase the food availability and accessibility, production of food must be increase together with

improving distribution channels and another main point that needs to focus is reducing losses.

According to Vanavichit [15], rice is mainly produced in tropical area, for it needs plenty of sun and water. Normally, the overwhelming majority of rice produced is for home markets, especially for top 2 producers which are China and India. China is the biggest rice producer in the world but their rice production is still not enough for their own consumption. They still need to import rice from other countries such as Thailand, Vietnam or Philippines. As this study focused on Thailand rice industry, Thailand market is a rare case that they export to other countries more than internal consumption.

Almost factors that affect rice production are often outside human control. There are some example that the rice production heavily drops due to the natural disaster known as “El Nino” or “La Nina”, which cause excessive dryness in humid areas and heavy rains in arid ones. As a result of this example, there are some shortages in rice production. Due to many factors that can cause some difficulties to rice production, new technology and new methods that help in the production process have been used in last 10 years. But climate disruption nevertheless makes the process difficult to ensure regular number of rice production.

2.4 Postharvest processes for paddy rice

According to Latin [17], FAO [18], NDAL&JICA [19], postharvest technology for paddy is a set of processes in the cycle of rice cultivation. All the handling techniques and treatments that applied to the crop since the paddy freshly harvested from the rice field until it transforming into the composition that adds value to the products and make it suitable for long storage period to prolong its quality. Paddy rice is a grain crop and is not ready for cooking after harvest. Paddy needs to be dried by several techniques from the farmer themselves or rice mill that bought the freshly harvested paddy from the farmer. Before drying, paddy has to be separated from its straw and panicles or any foreign matter by the pre-cleaner. Paddy has to be dried to the required moisture content before it can be storage for future processing. For practical processes that have been used with paddy in Thailand, postharvest process can be divided into 8 steps which are harvesting, threshing, cleaning, drying, storage, milling, grading and packing. After the paddy pass all the process it will be transform to be rice that proper for human consumption. All the processes strongly need to observe carefully as each stages will affect the other to determine the quality of rice, head rice rate and also to minimize losses which is controllable.

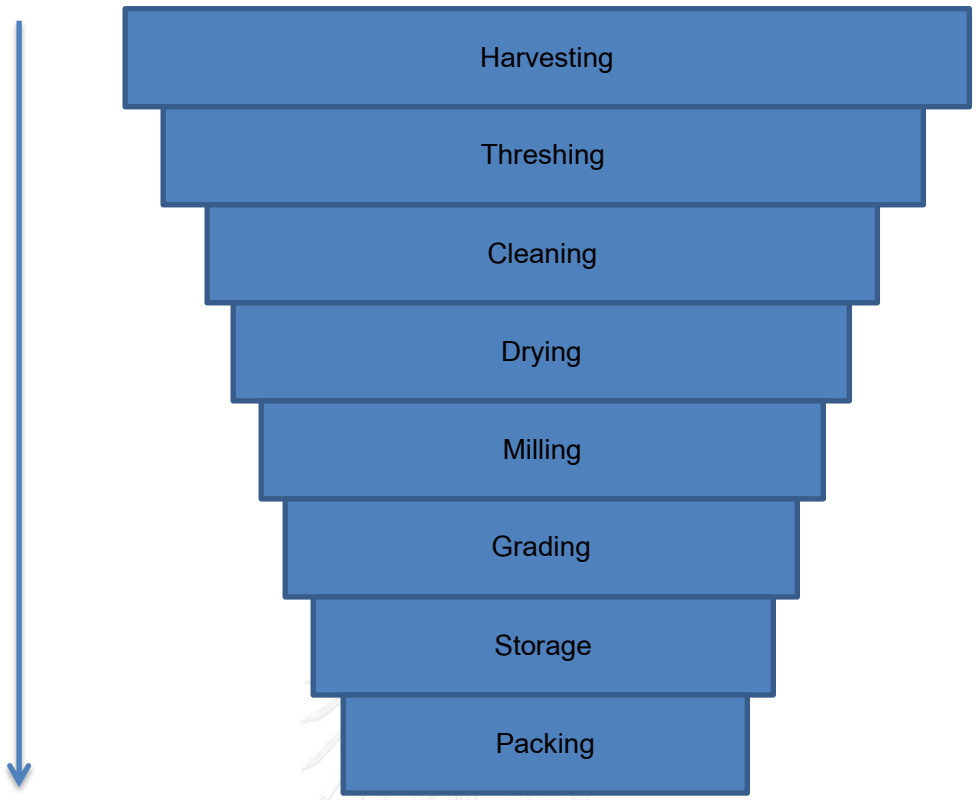


Figure 15 Postharvest processes for paddy rice

Harvesting

The first process for postharvest of paddy rice is harvesting. This process is to obtain the paddy that reached its physiological maturity separating it from the rice field. There are several techniques of harvesting such as hand-picking, pulling, slashing, stripping, shaking or use harvester to collect the economic part of the plant. Another key factor for harvesting is harvesting period. In general, the period of harvesting is related to the type of grain, weather and terrain of the fields. In case of paddy in Thailand, Harvesting period is twice a year on October and March. The proper time to harvest is mainly determined by visual appearance such as color and moisture content of the paddy.

When the paddy ripens, the moisture content is around 20 percent to 24 percent on weight basis and the color change from green to olive-green and finally to yellow.

Threshing

This is the physical process of detachment paddy from the rice straw and the panicles. Threshing of paddy can be done by hand, foot and also machines. In case of paddy, farmers need to study and learn the proper operation and techniques. Threshed paddy will contain a lot of contaminations, so its need to be clean by the pre-cleaner to carried the contaminations out. Harvested paddy has to be threshed on the same day of harvest.

Cleaning

The objective of cleaning process is to remove rice straw chaff, contaminations and empty grains with in paddy after threshing. All the contaminations or foreign matters which include soil piece, sand, stones, metal, plastic, paper pieces, wood piece, chemical, etc., will unnecessarily increase the weight of paddy which cost the higher number of transport fees and milling fees. There are many advantages of the cleaning process which are remove the foreign matters and broken paddy, increase milling efficiency, reduce electricity consumption and also decrease damage to the machine. Rice for home consumption is desired to be clean. In commercial rice mills, cleaning is the first process in the industrial process that removed most of the foreign matters to

reduce drying cost, eliminate the damage to the conveying equipment and prevent paddy deterioration during the storage period. The second cleaning stage occurs after drying process and the third cleaning process is when the paddy prior to milling process after storage. The cleaning machine may include vibrating or rotating sieves, aspirators, destoners and magnetic separators.

Drying

Paddy is a hygroscopic and living material that still respiring all the time. The objective of drying process is to reduce the moisture content of the paddy down to the set-point that safe for storage and proper for milling. This process is a critical process that need to be done as fast as possible after harvesting the paddy. Any delay or ineffective of drying process will reduce the paddy quality and losses. There are two main types of drying process which are sun-drying and use flat-bed dryer. The advantage of sun-drying is lower cost but it takes time and need to concern about weather conditions. The main advantages of dryer are shorter dryer time and can run whenever they want, no need to concern about weather conditions. In Thailand, paddy normally harvested at moisture content about 23-26 percent, the moisture content maybe higher in rainy season and lower during the summer. At high moisture content, paddy has a high rate of respiration that susceptible to attack by insects, animals and pests. So, freshly harvested paddy need to be dried within 24 hours to about 14 percent of moisture

content for safe storage and milling process or dried to at most 18 percent for temporary storage that can be store up to 2 weeks. At 14 percent of moisture content, paddy will be less sensitive to fungal and likely to keep its germination potential. It shelf life of paddy will be prolonged and its quality conserved.

Milling

This is the main transformation process of paddy that transform paddy to rice. Paddy is milled through several machines to remove the outer skin, husk and bran to reveal the white kernel which utilized as food product for normal consumption. Moreover, all the by-products such as husk and brans can be sold and utilized as feeds for poultry, other livestock and also can be used as fuel for dryers and power plant.

Grading

The process of grading is to sorting the milled rice by sizing and visualization into categories such as head rice, broken rice, off-types, coloured rice and some um-milled paddy. There are several factors that use for sorting which are moisture content, head rice percentage, broken rice percentage, defects, impurity are un-milled paddy.

Storage

This goal of paddy storage facility is to provide the safe storage conditions for paddy and rice in order to prevent the loss that cause by grain respiration, weather conditions, moisture content, rodents, birds, insects and fungi. The safe point of moisture content

for storage is at 14% or less and need to maintain it. Longer period of paddy storage required good storage facilities such as grain cooler, fans or circulation process to reduce the heat that occurs from paddy respiration.

Packing

The process of packing or weighing is the process that defines the mass of milled rice. The measurement must be precise and accurate. Normally in Thailand, rice sack is the proper way to pack the rice. There are different sizes of sack that has been used in Thailand market such as 5 kg, 10 kg, 20 kg and 100 kg. The other way to pack the rice for exporting is called jumbo bag which contains 1 ton of rice in each bag for easy transportation.

2.5 Postharvest technology

2.5.1 Paddy drying

According to Laxhuber [20], FAO [21], Wimberly [22], IRRI [23], the main objective of paddy drying is to reduce the volume of paddy for transport purpose and to condition the paddy in order to prolong the shelf life. There are 2 main ways to extract the water out from the paddy through a thermal process which are sun drying and industrial drying.

The most common and popular method of drying paddy is to dry it in the sun. The cost of this method in term of equipment and energy is zero. But the disadvantages are the lack of control over the process, unpredictable weather conditions and the high loss of grain to many kinds of animals.

For industrial dryer, the principal physical process that occurs during drying is the hot air flows across the surface of paddy kernels, and the moisture on their surface is extracted first. Then, when the surface moisture has evaporated, the heat is transferred to the inside of the kernels. This will cause the moisture in the kernels move towards the surface where it evaporates and then absorbed by the hot air. In fact, the water is very tightly fixed in the cells of the kernels, so it hard to evaporate. Therefore, the main challenge in the drying process is to avoid breakage of the paddy. If the temperature of hot air is too high or dry it too quickly there is a risk that kernels will be cracks and leads to high percentage of broken rice. To avoid this problem, it is commonly to reduce the moisture content down for 4%at a time and leave the paddy to rest for 10 to 12 hours so that the water in the kernels will re-establishes equilibrium. There are different kinds of industrial paddy dryers but the most popular one in Thailand is done in continuous mixed flow dryers.

The drying process involves several stages of drying and tempering over period of time. Figure 16 shows the steps of drying start from the wet paddy that came into the process.

In this case assumed that the initial moisture content is at 24%, the process begins with wet paddy filled in the wet bin and then passes continuously to the first dryer where it reduced the moisture content down to 20%. After it done with first dryer, this pre-dried rice needs around 10-12 hours for tempering period. After that, the second drying step dried the paddy from 20% to 16% and the process of tempering is repeated. For the final drying step, the dryer will reduce the moisture content from 16% down to 14% where the paddy is needed for safe storage. After the Third dryer, the paddy will be passed continuously to the storage silo or warehouse for long-term storage and ready for milling process.

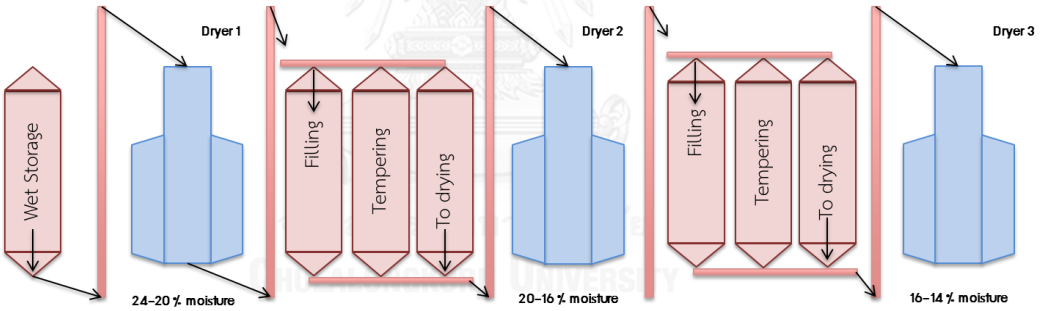


Figure 16 Conventional drying process (Laxhuber [9])

2.5.2 Cooling conservation

According to Kolb [24], this section illustrates how cooling conservation can assure the quality of paddy and rice by using grain cooling unit. Figure 17 shows the principle of grain cooling unit that explained how the unit supplies the cooled and dried air for safe storage. Begin with the process of grain cooling unit; a fan in the grain cooler sucks ambient air, which the temperature around 28 Celsius and the relative humidity at 75%,

around the unit through a dust filter (position 1). Due to the friction, the air heats up in the fan to around 32 Celsius and the relative humidity is down to around 60% (position 2). Then, the air is cooled to the set-point temperature, in this case is 8 Celsius (position 3), by an air conditioner and dehumidification takes place by condensation of water except the case that the air is extremely dry. When the air is cooled down to 8 Celsius, the relative humidity is increased up to nearly 100%. Afterwards, the chilled air goes to the hygotherm which is the unit that heat up the cold moist air (position 4). As a result the relative humidity is lowered and the air becomes dry. The cold dry air is fed through a hose in the air distribution system of the storage facility and is forced through the bulk of paddy or rice.

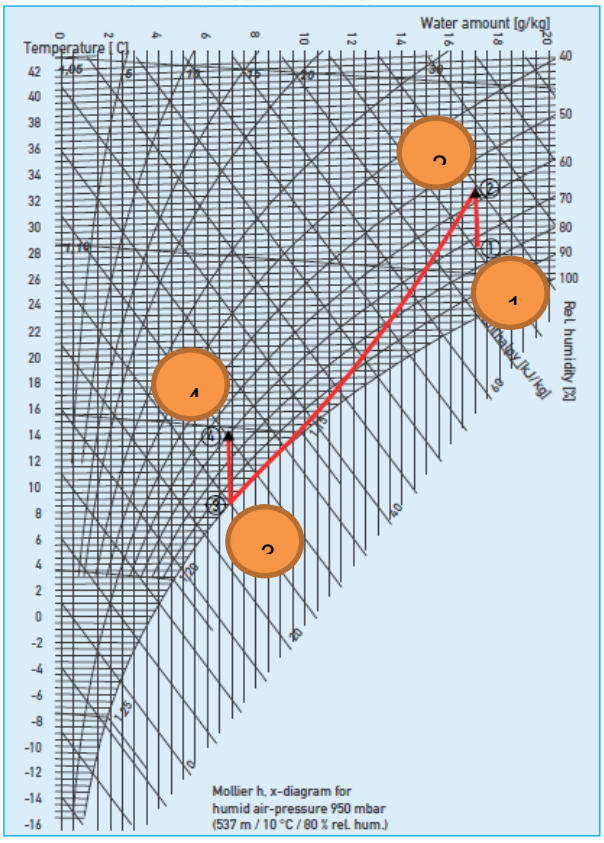


Figure 17 Principle of grain cooling unit (Kolb & Braunbeck [15])

This process can be done both in the grain silo and in the flat warehouse. After the start of cooling process, the lower area of the grain in the silo cools as in figure 18, while the upper area, its temperature initially rises. The air absorbs the energy and humidity from the grain before it leaves the area at the top, saturated with humidity and heat. Cooling process can be stopped when the paddy temperature reached the set-point which set by the owner. A slight different in temperature between the lower area and the upper area may remain due to the pressure drop caused by the bulk. After the cooling cycle is completed, all the connections and openings in the storage should be closed to protects against the formation of condensation due to the introduction of warmer air and to protect the grain from animals.

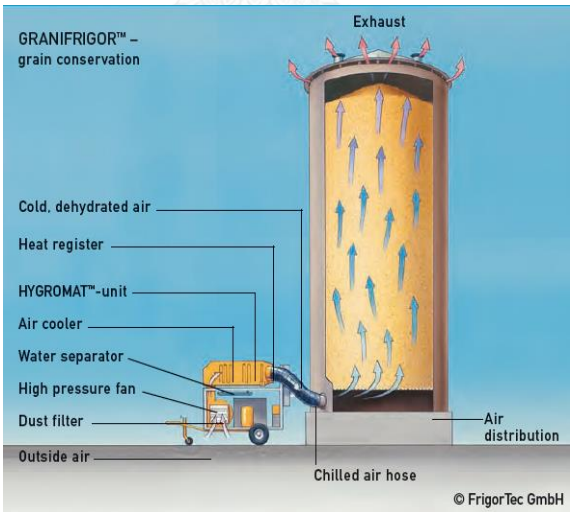


Figure 18 the overview of grain cooling unit (Kolb & Braunbeck [15])

According to Kolb & Braunbeck [4], Grain cooling system operates independently of weather conditions. The unit can be used during rain or fog as well as in the humid

tropical conditions. The energy consumption of cooling conservation depends on the ambient temperatures, the relative humidity of the ambient air and the moisture content and temperature of grain. Moreover, grain cooling unit can be used to help the dryer dried the paddy. This process called combination drying process as in figure 19. While using cooling conservation method for storage, the final moisture content that take out from the last dryer can increased to 15% instead of 14% which will reduce the drying cost and also increased the drying capacity of the dryers. For the final moisture content from 15% to 14%, this range will be dried by cooling method. According to Kolb & Braunbeck [4], the drying effect for paddy for one cooling cycle is on average approximately 0.75%. This drying effect by cooling conservation takes around 5 days as shown in figure 19. Moreover, paddy continues to live after being harvested. Primary losses can be happened to freshly harvest paddy which caused by its respiration and its consequent spontaneous heating. In cellular respiration, oxygen is absorbed and carbohydrates are converted into carbon dioxide, water and heat. The result of the respiration is the weight of paddy is loss as long as it respiring. This will be explained in section 3.1.

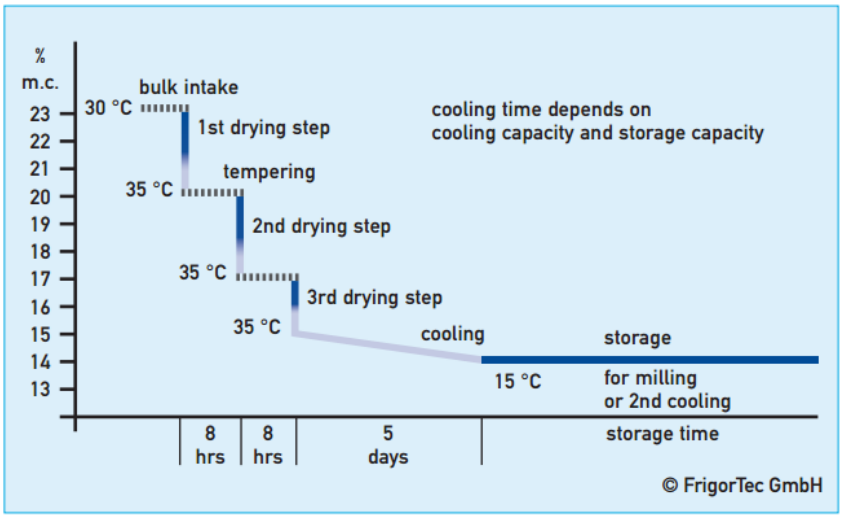


Figure 19 Combination drying process of paddy (Kolb & Braunbeck [15])

2.5.3 Paddy storage

According to Wimberly [22], Aung [25], FAO [26], paddy is regarded as a living organism which respire as do any living organisms. During the respiration process, the paddy releases water, carbon dioxide and heat. Harvested paddy usually has high moisture content so it cannot be stored without drying it down to the proper moisture content. Paddy with high moisture content has a higher respiration rate which is the main reason of spoilage during the storage period. When paddy respires with high rate thus more heat and water are produced. Within days, hot spots can be founded and the paddy starts spoiling which occurs in the area of hot spots first and then spread out.

Paddy storage is an important task in post-harvest handling of paddy and rice. Paddy and rice spends most of their time in the storage period. For example, if this bulk of paddy had been in the rice mill for 2 months, it will be in the drying process for maximum 2-3 days and will be in the milling and packing process for maximum 1-2 hours. Apart from that it will be in the storage period for almost 90 percent of their time in

the rice mill. Storing paddy means very much more than merely keeping it. Storage involves monitoring and treating the paddy as necessary in order to preserve its quality. Proper way of paddy storage can display qualities in the later process of milling, cooking and eating. Even good quality of paddy but stored in a bad storage facility, it will not give a good results.

There are 3 main types of storage in the practical used which are storage at farm level, flat warehouse in rice mill and silo storage in rice mill. The storage of paddy is a traditional practice that initiate with the rice farmers. Normally, they store part of their own production for in-house consumption and the surplus is available for sell. However, farmers do not invest much on storage facilities and do it instead with natural materials such as wood or bamboo. If the paddy has been sun-dried before storage, it can be store in this type of storage facilities up to 6 months. All farmers keep their paddy bins well above the ground in order to protect them from damp from the ground and rodents. It also lets the ambient air flow in under the bins for natural ventilation. For flat warehouse in rice mill, Rice traders and millers store paddy and rice in large quantities. Normally, rice mill need to store at an amount of paddy around annual milling capacity, and some more surplus storage to pre-empt the price hike in the post-harvest season. Formerly, flat warehouse was built with no ventilation system. The stored paddy need to turn upside down and transferred to another compartment, to allow air to circulate and prevent the grain from overheating which is the main reason of losses in storage period.

In modern warehouse, flat warehouse storage is usually built with grain transportation and ventilation system. Aeration channels are dug into the area of the floor where the paddy will be piled up. Air is blown through these channels to ventilate paddy or rice in the warehouse. The fans which required for this purpose normally installed outside the warehouse. For the silo storage, the main advantage of the silo is saving space in the rice mill. Large rice mill would need a very huge space if they stored paddy and rice in the flat warehouse. Silos are much more compact. In silos, paddy is always stored in bulk which makes it easy to monitor the grain temperature, to provide the effective ventilation and also easy to re-circulated from silo to silo.

2.5.4 Storage method in Thailand

In Thailand, there are 4 storage types that normally used which are Warehouse, Round Silo, Square Silo and Jumbo bag.

Figure 21 Round Silo

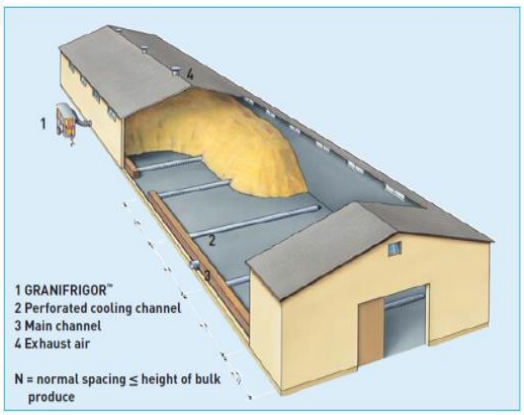


Figure 20 Warehouse (Kolb [13])

Figure 22 Jumbo bag

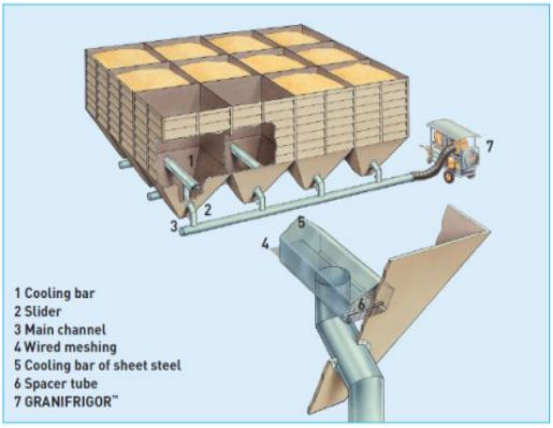


Figure 23 Square Silo (Kolb [13])

The most important thing in storage process is ventilation systems. The proper ventilation system for rice mill, that has different conditions and variables, may be different to each other. There are 3 practical ventilation systems that has been use in Thailand for last 10 years. First is circulating systems, this system is circulate the paddy with several types of conveyors to ventilate the paddy with normal air during the path. Another ways of circulation is use the backhoe to scoop the paddy from the bottom of the pile to the top to let some air move into the middle of the pile. Second is fan, Industrial fans is the normal ventilating system in Thailand but the main disadvantage of this system is weather conditions as the phase “Never introduce moist air into dry grain and never introduce warm air into cooler grain” [24]. So, this ventilation system need good care of using it and cannot generate cooler air to avoid the insects and mildews. Third is using grain cooler, according to Kolb & Braunbeck [4], the grain cooling unit is the smartest ways to storage every grains especially for paddy. The grain cooler can generate the cold air at the set-point that user wants to blow inside the storage area.

There are a lot of advantages that grain cooler can bring to the rice mill, for example, long-term storage without quality loss, protection from insects and mildews, avoid unecological chemical treatment, minimizing respiration losses, conservation of harvest freshness and much more.

Figure 24 Grain cooling unit (Kolb [13])

Figure 25 Industrial fans (Schmelzer [30])

3 Chapter 3 - Model development

The objective of this study is to analyze the benefits and costs of using cooling conservation for long-term paddy storage by using the cost-benefits analysis and breakeven analysis. This methodology has been used widely to analyze the financial information for every kinds of project which also can be applied with our study. For this study, the storage method in Thailand's rice mill will be applied with the methodology. There are three types of storage's method that will be analyzed in this study which are circulation, industrial fans and grain cooler. For both cost benefit analysis and payback period, two transformation cases will be used to analyze. First case is transform from circulation method to cooling conservation method. Another case is transform from industrial fans to cooling conservation method. This section can be divided into 4 parts. The first part shows the overview of cooling conservation method that used for long-term paddy storage and also explain the overview of this method. Then, the second part will describe all the benefits of using grain cooler method for paddy storage. On the other hand, costs of using grain coolers unit will be illustrate in the third part of this section. The last section will describe the process of data collection, some difficulties during the process and analysis of the data that has been collected.

According to Kolb & Braunbeck [4], paddy grows during the harvest season, normally once a year in Europe and America but in some area of Asia especially in South-east

Asia, paddy grows twice a year. According to FAO [18], the period of growing paddy on the rice field averaging around 90-100 days and it will ready for harvesting. With the new method of harvesting by using machine and tractors, the freshly harvest paddy has a high moisture content and need to be dry immediately to reduce the moisture content for safe storage. During the storage time, to maintain the quality of paddy or rice is the key of storage. There are basic requirements on the storage process such as protected from the weather, protected from animals, dry and easy to access. The materials used of storage must be suitable for paddy and rice. According to Kolb & Braunbeck [4], there are two main types of storage that widely used in general which are Silo system and Warehouse system. The main advantage of silo system is it very well closed off. It protected from many kinds of animals and also need smaller area of land than warehouse. For modern silo, it usually made from galvanized steel. For warehouse storage, when suitable structure already exists, it will be integrated into the storage structure. The main advantage is it can used temporary for other applications. On the other hand, the most significant problem is discharging the paddy bulk out of the warehouse. It typically used shovel excavators which can damage the air distribution system and also increase the broken rice ratio. Stationary and moveable conveyor belt is the function that normally used for filling process into the warehouse. The variation of air distribution has to be calculated according to the diameter and height of the silo or the length, width and height of the warehouse. For silo storage, the only air distribution

type is air distribution floor that have to be equipped with the silo since it built. But for warehouse storage, according to Chavapradit [27], there are three types of distribution channels that widely used depends on the owner's requirement which are underfloor, half-round and telescope pipe. Each type has its own advantages and disadvantages. The storage facility is recommended to be well cleaned and dry before bringing in the paddy. Air distribution must also equip with the facility. All distribution channels must be dry and free of dust and dirt. In addition, old paddy stocks and new harvested paddy should be stored separately.

3.1 Cooling conservation method

According to Kolb & Braunbeck [4], the process of grain cooling unit and how the unit supplies the cooled and dried air for safe storage has been explained in section 2.3.2. This process can be used for both types of storage system. The outgoing air is lead outside via exhaust fans which extracting absorbed moisture and heat from the grain bulk in the storage. If in case that the temperature outside the silo or warehouse is lower, modern grain cooling unit can automatically switch from cooling mode to ventilation mode. Moreover, when the ambient air rises again, the compressor is automatically switched back on which can be save electricity costs and improves the profitability. In the tropical area, after start of cooling, the paddy in the storage becomes cold in the lower area first. At the higher area, the temperature rises initially. The air from the unit

absorbs the energy and humidity from the grain before it leaves the storage area at the top, saturated with humidity and heat. Once cold air escaped from the top, the paddy in the storage has been cooled all the way through. With no circumstances that the cooling process e stopped too early, it will leads to major problems in the upper area of the paddy bulk. Cooling process should be stopped when the paddy temperature at 20 cm below the top surface has reached a temperature 2 to 4 Celsius above the temperature of the chilled air that supply from the grain cooling unit. After the cooling cycle is complete, all the connections and openings must be closed to protects against animals and the formation of condensation due to the introduction of warm air.

The cooling process also creates a drying effect that must be taken into the account. The drying effect for paddy in one cycle of cooling by the grain cooling unit is reduce the moisture content of paddy approximately 0.75% in average. It depends on the paddy temperature and moisture content and also the cooled air that supply from the unit. Where the relative humidity of the supplied cooling air is significantly below the equilibrium moisture content of the paddy, the drying effect will be higher.

Paddy respiration

According to Kolb & Braunbeck [4], paddy continues their live and the respiration system after being cut and threshed. Paddy and rice are highly hygroscopic which absorb and release humidity. Hygroscopicity is the ability of a substance that adjusts

the moisture content of the surrounding air by absorbing and releasing water. The freshly harvested paddy has a significant losses caused by the cellular respiration and its spontaneous heating. If the temperature and moisture of the paddy increase, its respiration becomes more intensive. On the other hand, if the temperature and moisture is in the low level, its respiration becomes slow or inactive. The result of hot spot leads to the discolouring of rice and the development of insects and mildews. For paddy respiration, oxygen in the air is absorbed by the paddy and then interacts with carbohydrates in the paddy and then converted into carbon dioxide, water and heat. The result of respiration is a loss of substance as an equation of 1 kilogram of paddy respiration, approximately 1.54 kg of carbon dioxide, 0.58 kg of water and 16.48 MJ of heat are released.

Animals and microorganisms in the storage facility

According to Food and Agriculture Organization of the United Nations (FAO), total losses of grain worldwide in the period of post-harvest approximately 15% of harvest crops. This means around 270 million tons of grain decayed each year. The following causes of losses can be divided into 3 reasons which are 80% of losses due to insects, 10% of losses due to rodents and birds and another 10% due to fungi. According to Kolb & Braunbeck [4], there are various types of insects that can be found in storage facility. They all have one thing similar is that they are more active or less active

depending on the temperature in the storage facility. For example, rice weevils are very active in tropical and humid countries such as Thailand. Insects can generate uncountable children in one year if the weather condition is suitable as seen in figure 27. The development of microorganisms such as fungi and bacteria also depends on temperature, humidity in the air and grain moisture content. By drying paddy to the safe moisture content and cooling it during the storage period, the development of them is prevented.

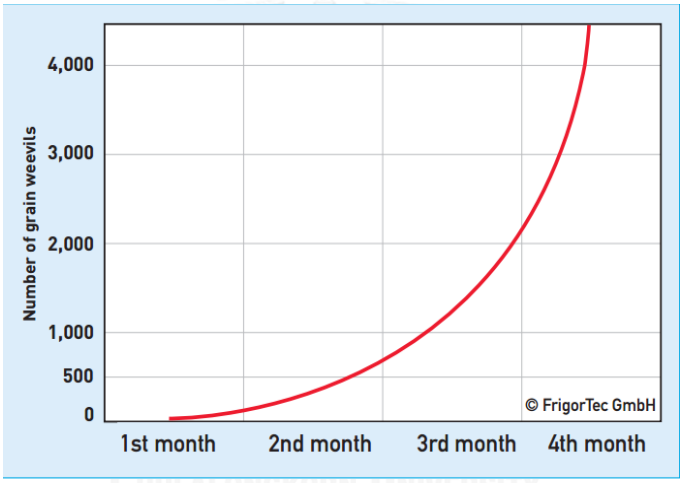


Figure 27 proliferation of the grain weevil dependent on time

(Kolb & Braunbeck [15])

3.2 Advantages of cooling conservation method

There are many advantages of using cooling conservation to storage many kinds of grains such as paddy, corn or wheat. All advantages of cooling are directly targeted at avoidance of post-harvest losses during storage. Both quality and quantity of grains are

conserved and additional advantage for milling process in rice mill. These are the overview of following text of benefits of cooling conservation of paddy and rice.

Securing the quantity of rice

According to Kolb & Braunbeck [4], there respiration process of paddy during storage represents a continuous loss which depends on storage temperature and moisture content of paddy. The example in the table 2 is used to demonstrate the fact which using typical values of storage conditions in the tropics area.

Table 2 Example of respiration loss

Respiration losses – dry substances loss				
Given:				
	Paddy moisture content	14.5%		
	Paddy temperature	30 °C *		
	Paddy price	300 EUR/t		
	Storage period	8 months		
	Storage quantity	10,000 t		
Formula:				
Substance loss (t) =	heat generation [MJ/t, day] ** x storage duration [day] x storage mass [t] / 15,000 [MJ/t]			
Result				
		Substance loss [t]	Mass loss [%]	Loss [EUR] ***
uncooled at	30 °C **	128	1.28	52,650
uncooled at	25 °C	64	0.64	26,325
cooled at	10 °C	minimal (≤ 1)	–	–

From the values in the example, the objective is to store 10,000 tons of paddy for 8 months with the moisture content of paddy at 14.5% and temperature in the storage facility at 30 Celsius. And the market price of paddy at that point is 300 euro per ton. As can see in the result, there are 3 cases that have been showed in the table. First case is

to store paddy at 30 Celsius with no cooling conservation. 128 tons of paddy has been losses by paddy respiration and can be calculated at 1.28 percentage which can be converting to the market price as 52,650 euro. The second case which store paddy at 25 Celsius with also no cooling. Half of the losses in the first case have been covered, only 64 tons of paddy has been losses. In third case, if cooled the storage facility down to 10 Celsius, less than 1 ton of paddy substance has been loss. Some comments on the example calculation, most of the operator, who did not use grain cooling unit, lower the grain temperature by circulation the grain or ventilation with ambient air by industrial fan. In conclusion of the example, according to Kolb & Braunbeck [4], loss of paddy can be should be considerable which has a negative impact on the financial sheet of the operating company. By using grain cooling unit, losses can be essentially limited as the paddy respiration process is reduced due to the lower temperature in storage area. Moreover, another loss from insects, fungi and bacteria was also been reduced by using grain cooling unit. The use of the unit brings the activity of fungi, bacteria and other microbes to a standstill condition.

To maintaining paddy quality, a subjective parameter of rice is taste which can evaluate differently from area to area. The point is not the basic taste of dissimilar rice varieties, but rather the purity of it. According to Kolb & Braunbeck [4], by using grain cooling unit, the specific taste is maintained as it was after freshly harvest from the field. This is achieved by reducing undesirable storage conditions that have a harmful effect on

taste. Damaged and discoloured rice are also the factors in the evaluation process for rice quality. Damaged grains can be caused by insect infestation. The example of damaged grain is the grain that has been eaten by insects and drilling holes which leads to the devaluation of the rice quality. According to FAO [28], Due to the lower temperature in the storage facility that slows down and reduces the activity of the insects and also minimized the damaged grains which all leads to ensure the quality of freshly harvest paddy. Moreover, a low temperature in storage area is the method that reduces the number of yellow discolouration. As described above that cooling conservation also helps to reduce the moisture content of the paddy during storage. The drying process occurs slowly so that only minimal stress occurs and the grains do not crack. As a result of less cracking paddy, the head rice ratio is increase that means significant higher selling price of whole rice instead of broken rice.

Combination of cooling conservation and drying

Nowadays, paddy is harvest with higher moisture content than before because of using tractor or other machine instead of manpower. According to Barth [29], the drying process is very necessary to achieve the storage life. Normally, drying process during the harvest time is a bottleneck process, which relies on the moisture content of the harvested paddy. By using grain cooling unit, it can increase the drying capacity of the dryers around 20-30% without any loss and no need extra dryers. Paddy can be dried

down to a moisture content of 15-17% and then cooled with the grain cooling unit. This combination of drying and cooling leads to savings of costs and times.

Efficient milling processing using cooling conservation

Above all of the factors that increase the quality of paddy make the milling process run more effectively. Due to the gentle drying process by combination cooling and drying, less stress cracks of paddy which would lead to high broken rice ratio. Possibility of good input grains to the milling process; it makes the setting of processing machine more efficient and increase the throughput rate without the case of broken rice. It is no need to polish as aggressively as the poor input paddy by bad storage.

3.3 Costs of cooling conservation method

Tangible costs of using cooling conservation method can be divided into initial investment and costs of operating. Grain cooling unit and air distribution system need an initial investment. The number of unit of grain cooling that need is depends on the storage quantity. According to Kolb & Braunbeck [4], there are several models of grain cooling unit which has low cooling capacity around 20 tons per day up to the biggest model that has a cooling capacity around 400 tons per day. The second kind of investment is the air distribution system which needs to be equipped with the storage facility. Some storage facility such as silo normally equipped with the air distribution system. But for warehouse, it needs more investment to convert from normal warehouse

to the warehouse that suitable for ventilation system for both industrial fans and grain cooling unit. Costs to operate the cooling conservation method can be split in to 2 parts. First cost is energy consumption of grain cooling unit which depends on the outside temperature and the humidity of the outside air. Another cost is maintenance cost of the grain cooling unit. To make the units run effectively and efficiency, preventive service is needed.

3.4 Data collection and data analysis

According to the surveying and interviews with 84 rice mills in Thailand which store paddy more than 3 months per year. 59 of them are the rice mills who use the cooling conservation method to store paddy. 15 rice mills are use industrial fans method and the others 10 rice mills are using circulation method for their storage. Details of the data that collected from all rice mills are shown in Appendix.

There are 10 data that the surveying collected from the rice mills that use the cooling conservation method for their paddy storage which show in Table 3.

Table 3 Data collection of cooling conservation method users

	Storage Capcity per year (Tons)	Storage period per year (days)	Initial Moisture content (%)	Target Moisture content (%)	Real moisture content in the storage (%)	Target temperature in the storage (Celsius)	Supply air temperature (Celsius)	Energy consumption per ton per cycle (Baht)	Former rice yield (%)	Rice yield after use cooling conservation (%)
C1	2000	180	25	14.5	14.2	22	17.5	19	50	53.5
C2	3500	120	26	15	14.6	23	18	20	51.5	54
C3	4000	150	26	15	14.8	23	18	19	49	51.5
C4	8000	120	27	15.5	15.3	22	18	20	50	53.5
C5		120	27	15.5	15.3	22	18	20	50	53.5

Average number of some data that collected will be used in calculation sheet. Table 4 shows the average number from 59 rice mills that use the cooling conservation method.

Table 4 Average numbers of cooling conservation method's

	Storage Capcity per year (Tons)	Storage period per year (days)	Initial Moisture content (%)	Target Moisture content (%)	Real moisture content in the storage (%)	Target temperature in the storage (Celsius)	Supply air temperature (Celsius)	Energy consumption per ton per cycle (Baht)	Former rice yield (%)	Rice yield after use cooling conservation (%)
Avg.	4381.36	171.86	27.25	14.84	14.73	22.03	17.44	19.51	50.8	53.89

Next, 6 types of data that the surveying collected from the rice mills that use the fan ventilation method for their paddy storage were shown in Table 5.

Table 5 Data collection of fan ventilation method users

	Storage Capcity per year (Tons)	Storage period per year (Days)	Target Moisture content (%)	Real moisture content in the storage (%)	Energy consumption per ton per cycle (Baht)	Head rice yield (%)
C1	2500	60	14	13.7	32	50.5
C2	3500	70	14	13.8	29	50.5
C3	5000	60	14	13.8	35	49.5

Then, the average numbers from 15 rice mills who use the fan ventilation method were shown in Table 6.

Table 6 Average numbers of fan ventilation method's users

	Storage Capcity per year (Tons)	Storage period per year (Days)	Target Moisture content (%)	Real moisture content in the storage (%)	Energy consumption per ton per cycle (Baht)	Head rice yield (%)
Avg.	7066.67	73.67	14.13	13.97	31.53	50.5

For circulation method users, 7 types of data that have been collected from the rice mills. Table 7 shows all the collected data.

Table 7 Data collection of circulation method users

ID	Storage Capcity per year (Tons)	Storage period per year (Days)	Circulation cycle	Target Moisture content (%)	Real moisture content in the storage (%)	Energy consumption per ton per cycle (Baht)	Head rice yield (%)
C1	1500	60	25	14	13.7	45	50
C2	3000	70	21	14	13.6	50	51.5
C3	5000	60	25	14.5	14.1	40	49

Then, the average numbers from 10 rice mills who use the circulation method were shown in Table 8.

Table 8 Average numbers of circulation method's users.

	Storage Capcity per year (Tons)	Storage period per year (Days)	Circulation cycle	Target Moisture content (%)	Real moisture content in the storage (%)	Energy consumption per ton per cycle (Baht)	Head rice yield (%)
Avg	4500.00	76.00	24.00	14.10	13.75	47.70	50.4

Data Analysis

This section will compare the data which collected by the survey and interviews. Three storage methods of paddy storage have different numbers that can show the advantages and disadvantages for each method. First, the highest average storage capacity per year is fan ventilation method follow by circulation and then cooling conservation. 5 to 10 years ago, fan ventilation method is very popular for big rice mills that need to reduce cost of circulation. Cooling conservation method is a new method in Thailand and in the growing period. The number of storage quantity is in the uptrend, In contrast, fan ventilation method is in the downtrend due to the higher energy

consumption. Next, the storage period per year of cooling conservation is highest at around 171 days per year. Followed by circulation method at 76 days and then fan ventilation method at around 73 days. This number shows the main advantage of cooling conservation that paddy can be store longer than other methods with good quality. Another important one is target moisture content. For average around 0.7 to 0.8% of moisture content that the safety zone of cooling conservation method is higher than fan ventilation and circulation. This leads to more weight was gain from higher moisture content that can be stored. Energy consumption is a real different in this comparison. The circulation cost is average 47.7 baht per ton per circulation cycle and the circulation cycle is 24 days. By using simple calculation, 1.99 baht per ton per day is the cost of circulation. Furthermore, energy consumption of fan ventilation method is at 2.25 baht per ton per day which is the highest compared to other methods. The cheapest energy consumption method is cooling conservation, only 0.31 baht per ton per day is a cost of this method. Lastly, the head rice yield by using cooling conservation method is significant higher than other two methods. Around 3.5% better yield is worth a lot of money in financial term.

Table 9 Comparison table of each storage method

Methods	Storage Capcity per year (Tons)	Storage period per year (days)	Target Moisture content (%)	Real moisture content in the storage (%)	Target temperature in the storage (Celsius)	Ventilation Cycle (Days)	Energy consumption per ton per cycle (Baht)	Energy consumption per ton per day (Baht)	Head rice yield (%)
Cooling coservation	4,381.36	171.86	14.84	14.73	22.03	63	19.51	0.31	53.9
Fan ventilation	7,066.67	73.67	14.13	13.97	Ambient	14	31.53	2.25	50.5
Circulation	4,500.00	76	14.1	13.75	Ambient	24	47.7	1.99	50.4

4 Analysis of results

4.1 Benefits analysis

Benefits from using cooling conservation can mainly divided into 2 main types which are tangible benefits and intangible benefits. There are five tangible benefits which are reduce respiration losses, greater head rice yield, weight gain, reduce drying cost and reduce existing operating cost. In addition, there are 7 intangible benefits which also got by using this method which are longer storage time, protection from insects, protection from mildews, no yellow discoloration of rice, conservation of harvest freshness, implemented independently of weather conditions and chemical free

4.1.1 Tangible benefits

A. Reduce respiration loss

As mentioned above that paddy is a hygroscopic grain that continues their live and respiration system in the storage period. According to Kolb & Braunbeck [4], for paddy respiration, oxygen in the air is absorbed by the paddy and then interacts with carbohydrates in the paddy and then converted into carbon dioxide, water and heat as in the formula that shows in the figure 28.

The grain respiration molecular formula of the chemical process [5]:

$C_{12}H_{22}O_{11}$ + 12 O_2 → 12 CO_2 + 11 H_2O + 5,637.64 KJ

carbohydrates + oxygen → carbon dioxide + water + heat energy

For 1 kg grain, the mass balances are:

1,000 g + 1,122.81 g = 1,543.86 g + 578.95 g + 16.48 MJ heat

Figure 28 Grain respiration formula (Kolb [13])

As the chemical formula above, it leads to another formula to calculate the substance loss in the respiration process. Figure 29 shows the formula which has to use the number of heat generation, storage duration and storage mass.

Formula:

$$\text{Substance loss (t)} = \frac{\text{heat generation [MJ/t, day] ** x storage duration [day] x storage mass [t]}}{\text{15,000 [MJ/t]}}$$

Figure 29 Substance loss formula (Kolb

According to Barth [29], for heat generation number in the substance loss formula, it can be calculated by using the graph according to Frigortec in the figure 30. Then, the table 9 shows the detailed number of heat generation in paddy respiration process. The range of moisture content in the table is from 13 to 15 percent moisture content and the range of storage temperature from 11 degree Celsius to 35 degree Celsius.

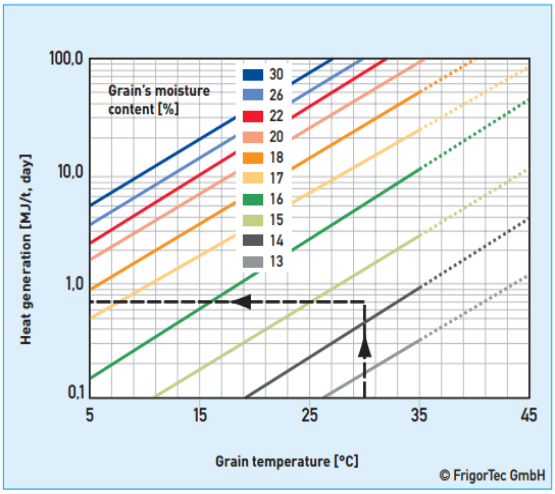


Figure 30 Heat generation during grain storage (Kolb [13])

Table 10 Heat generation ratio table (modified by Author)

Storage Temperature	Paddy Moisture Content (MJ/ton)				
	13.000	13.500	14.000	14.500	15.000
11	0.000	0.000	0.000	0.000	0.100
12	0.000	0.000	0.000	0.000	0.120
13	0.000	0.000	0.000	0.000	0.140
14	0.000	0.000	0.000	0.000	0.160
15	0.000	0.000	0.000	0.100	0.180
16	0.000	0.000	0.000	0.120	0.200
17	0.000	0.000	0.000	0.140	0.233
18	0.000	0.000	0.000	0.160	0.266
19	0.000	0.000	0.100	0.180	0.300
20	0.000	0.000	0.120	0.200	0.350
21	0.000	0.000	0.140	0.233	0.400
22	0.000	0.000	0.160	0.266	0.475
23	0.000	0.000	0.180	0.300	0.550
24	0.000	0.100	0.200	0.350	0.675
25	0.000	0.125	0.233	0.400	0.800
26	0.100	0.150	0.266	0.450	0.900
27	0.116	0.175	0.300	0.500	1.000
28	0.132	0.200	0.350	0.600	1.050
29	0.148	0.233	0.400	0.700	1.100
30	0.164	0.266	0.500	0.800	1.125
31	0.180	0.300	0.600	0.950	1.150
32	0.200	0.350	0.700	1.100	1.175
33	0.230	0.400	0.800	1.117	1.200
34	0.260	0.500	0.950	1.134	1.250
35	0.300	0.600	1.100	1.150	1.300

As we already calculated the example 1 in the section 3.2, 128 tons of paddy will be loss in the case that storage facility does not have the cooling system and the ambient air is average around 30 degree Celsius. It refers to the above table that shows the heat generation ratio. When the temperature is at 30 degree Celsius and the moisture content is at 14.5, the heat generation ratio is 0.8 MJ per ton which have to be added in the equation for calculation. In addition, second case with 25 degree Celsius on the storage facility and the same moisture content, the heat generation ratio is 0.4 MJ per ton. Finally for the third case, as you can see in the table that if cooled down the storage facility to 10 degree Celsius, no heat generation will occur and it leads to the result in the example.

Table 11 Example of respiration loss (Kolb [13])

Respiration losses – dry substances loss				
Given:				
	Paddy moisture content	14.5%		
	Paddy temperature	30 °C *		
	Paddy price	300 EUR/t		
	Storage period	8 months		
	Storage quantity	10,000 t		
Formula:				
Substance loss (t) = $\frac{\text{heat generation [MJ/t, day] ** x storage duration [day] x storage mass [t]}}{\text{15,000 [MJ/t]}}$				
Result				
		Substance loss [t]	Mass loss [%]	Loss [EUR] ***
uncooled at	30 °C **	128	1.28	52,650
uncooled at	25 °C	64	0.64	26,325
cooled at	10 °C	minimal (≤ 1)	–	–

B. Greater head rice yield

According to Kolb & Braunbeck [4], with a bulk of paddy that pass the milling process in the rice mill will transform to head rice, broken rice, husk and bran. the head rice yield is around 45 to 55 percentage of the paddy and the broken rice yield is around 15 to 25 percentage. The yield of head rice is depend on evry process in post-harvest but the significant process which has the most impact on the ratio is drying process. Figure 25 shows how the yield of head rice increase whie changing from the conventional process to combination of drying and cooling. It is more econimical to dry paddy by the dryer to only 15-16% of moisture content and then to store it in the cooled storage facility instead of conventional method that dry the paddy down to 14% moisture content. At the moisture content of 15-16%, the husk of paddy is more resistant and there is less breakage during the milling process. Moreover, the cooling effect will reduces the moisture content by approximately 0.5 to 0.75% when the temperature in the storage is lower than the ambient air by 10 degree. In addition, around 0.2-0.3% of moisture content will be decrease during the milling process in the rice mill. So, the final moisture content of rice when finished the milling process will be around 14% which is the safe zone for rice storage and available for sale.

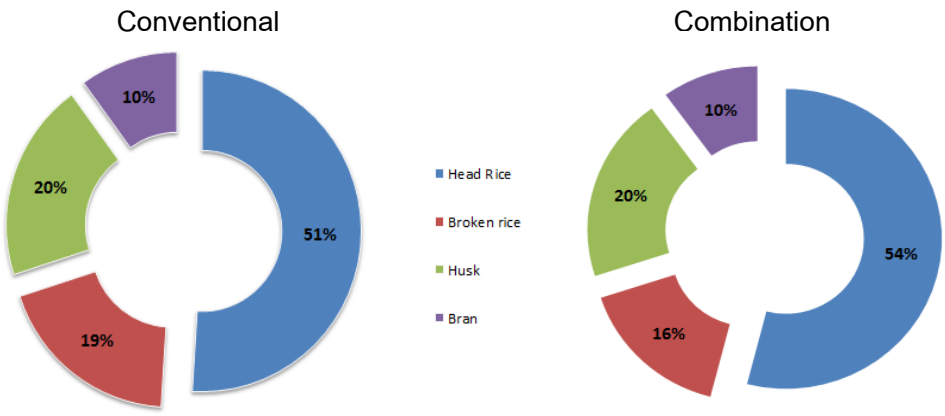


Figure 31 Greater head rice yield (Kolb & Braunbeck [4])

The advantages of combination is not only the higher yield of head rice but also the weight of paddy that increase according to higher moisture content that the operator take it out from the dryers. For example according to Frigortec, if dry the paddy by the dryers down to 15% of moisture instead of 14% of moisture. The higher weight of paddy is increase by 1.16 percent. Moreover, the drying cost of the dryers also decrease due to the shorter time that the paddy need to be in the dryers.

C. Weight gain

While using grain cooling unit combine with dryers to reduce the moisture content of paddy, the paddy can be take out from the final step of dryer at 15% moisture content instead of 14% moisture content. Figure 32 shows the combination drying process that use dryers combine with grain cooling unit to reduce the moisture content of paddy. As a simple calculation, 1 percent of moisture content that can been kepp higher than conventional drying process leads to weight gain for 1.16 percent.

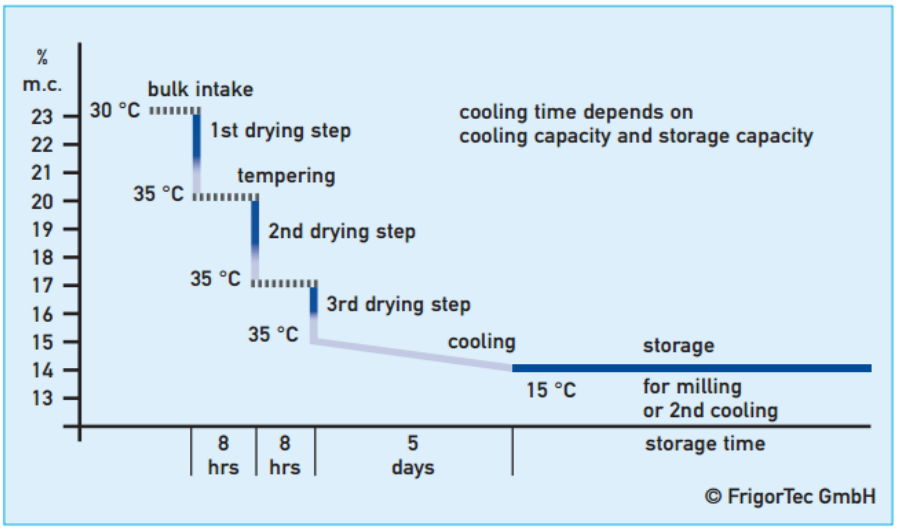


Figure 32 Combination drying process of paddy (Kolb & Braunbeck

D. Dryer cost saving

As mentioned above that while using grain cooling unit combine with grain dryers to dry the wet paddy down to the safe zone for storage, 1 percent of moisture content is a benefit for this process. According from surveying, average drying cost per 1 percent moisture content per ton of paddy is at 22 baht. So, if 10,000 tons of paddy has been dried by using combination process, cost of drying will be 220,000 baht lower than conventional process.

E. Existing method operation cost saving

When transforming to use cooling conservation method, the cost that needed to run the existing method will be disappear replaced by the cost of running cooling conservation which is cheaper than both circulation method and industrial fan method. According to survey, the average cost of running the circulation method of both warehouse and silo storage is at 47.70 baht per ton per cycle and the cycle of circulation is 24 days which

average from real practices in Thailand. Moreover, the average cost of using industrial fan method is around 31.50 baht per ton per cycle and the cycle of this method is only 14 days.

4.1.2 Intangible benefit

A. Protection from insects and mildews

As also mentioned in the section 3.1, several types of insects have one thing in similar that their activities rate is depending on the temperature in the storage facility. In our study of paddy storage, rice weevil is the kind of insect that the operator have to monitoring during the storage period. According to Kolb & Braunbeck [4] , as in Figure 21, the red zone in the bar graph shows the danger zone that the number of rice weevils can be dramatically increased. The red zone of rice weevil is more than 25 degree Celsius. In addition, orange zone in the figure shows the probable safe zone of temperature for paddy storage. For rice weevil, 15 to 25 degree Celsius is the range of temperature that the facility needs to be cooled down. According to our data collection, 22 degree Celsius is the average number of the storage facility that already used the cooling conservation. This number is the most economic target point when considered both benefits and costs. The certainly safety zone for all kinds of insect is at 13 degree Celsius but this rate is not economic for the tropical countries due to the electrical consumption of the grain cooling unit.

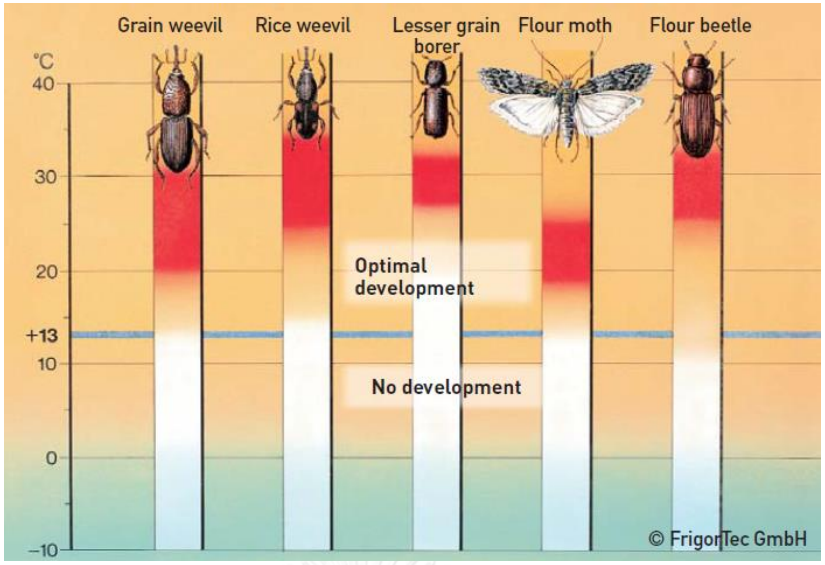


Figure 33 Generation of insect species dependent on temperature

B. Longer storage time

According to Kolb & Braunbeck [4], Figure 34 shows the storage period timer that can calculated the safe storage period to store paddy without circulation, ventilation or cooling conservation. In the example, it has three cases that have been drawn in the figure. First, case A (red line) is to store the paddy which has 14.5% moisture content and the storage facility is at 24 degree Celsius. This bulk of paddy can be stored around 60 days. Second, case B (blue line) is to store the paddy which also has 14.5% moisture content and cooled the storage facility down to 10 degree Celsius. This bulk of paddy can be stored up to 300 days. And for the third case, case C (green line), to store at the same moisture content with first two cases but the temperature of storage facility is around 32 degree Celsius which is the typical number in the tropical area such as Thailand. This bulk of paddy can be stored just only 2 weeks with no deteriorate. So,

temperature in the storage facility is the key factor that told how long the grain can be stored with no deteriorate and losses such as respiration loss, losses due to insects and mildews and discolouring of the rice.

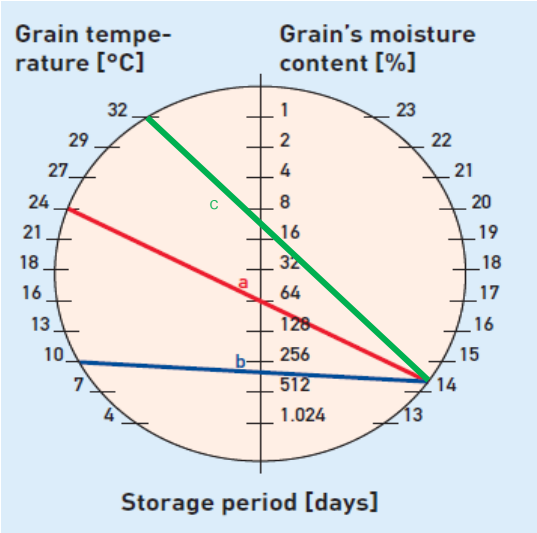


Figure 34 Storage period timer (Kolb & Braunbeck [14])

Moreover, conservation of paddy harvest freshness is also an intangible benefit of cooling conservation method. Another benefit is the grain cooling unit can be implemented independently of the weather condition which is the main advantage when compared with the industrial fan method. In addition, while using grain cooling unit, no chemical is needed to exterminate any kinds of insect. So, paddy which passed the cooling conservation method will be chemical free and very good for consumers.

4.2 Investment Analysis

There are two main parts of investment for using cooling conservation in paddy storage which are the grain cooling unit and air distribution system. This study is focused on two

companies of grain cooling manufacturer. First, Company A is a grain manufacturer which located in Germany and has several models of the unit. This study selected A5000 model to do the financial analysis. Another manufacturer is Company B which is located in Spain and the model B5000 has been chosen to be compared. Almost 90 percent of the market share in Thailand is covered by these two companies. For the air distribution system, only the warehouse house storage type that needs the transformation from the normal warehouse to the warehouse that suitable for cooling conservation.

4.2.1 Grain cooling unit

In this section, this study focused on the investment part of the grain cooling unit. Two manufacturers have been chosen to do the comparison for the advantage and disadvantages of the unit. Both units have the same cooling performance that can take care 5,000 to 6,000 tons of paddy for each unit. The cooling performance of both models is around 280 to 300 tons of paddy per day. With the basic calculation, it can be cooled the paddy around 8,400 tons to 9,000 tons of paddy in one month. According to the cooling cycles, one cycle of the cooling conservation is around 9 weeks. The step of cooling is to cooled down the bulk of paddy in the storage facility down to the targeted temperature as it depends on each operators. In real practices, it normally takes around 3 weeks to cooled the bulk of 5,000 tons paddy with this model. After the temperature in the facility reach the targeted point, the grain colling unit can be closed. The next step of

cooing cycle is monitoring process by the operators. When the temperature in the storage facilities rise to the unsafe zone, the recooling process should be done by turn on the grain cooling unit again. Normally, it takes around 6 weeks in the monitoring process. For safety reasons and easy for calculation, one unit of grain cooling can takes care 5,000 tons of paddy or rice. If the operators need to store 20,000 tons of paddy, 4 units of grain cooling are required for this project.

A. Company A

This company is located in southern part of Germany, which produced the grain cooling unit for more than 50 years. This company has the most market share of grain cooling unit in the world. In Thailand market, more than 100 units of grain cooling unit from company A have been sold to Thailand in last 20 years. Most of units have still in operation to store paddy or white rice.

Grain cooling unit model A5000 has been chosen for this study. The cooling performance of this model is at 280 to 300 tons of paddy per day. This model can take care the paddy approximately around 5,000 tons of paddy because of the cooling cycle that mentioned above. The selling price of this unit in Thailand that have to take into the account for calculation is 2,980,000 Thai baht.

There are many advantages of Company A in Thailand. First is the company A has very strong brand image with many refrences customers around the world. Second is the

quality of the unit which can confirmed by the users that the unit performance is very stable. In addition, the distributor in Thailand is the long history company which already in the rice mlls business for more than 65 years. Moreover, the distributor has very strong and reliable after-sales service with their own service teams. The only weakness of the company A is price that is higher than other brands in Thailand.

B. Company B

This company is located in Spain, which produced the grain cooling unit for 10 years. Main market of this company is limited only in Spain and Thailand. In Thailand market, around 40 to 50 units of grain cooling unit from company B have been sold to Thailand. Grain cooling unit model B5000 has been chosen for this study to compared with Company A. The selling price of this unit in Thailand is 2,750,000 Thai baht. One of the advantage of company is their Thailand's distibutor is the owner of a rice mill in northeast of Thailand. The group of the customers who buy the unit from the company B are mostly have close relationship with the distributor which are family related and close friends. Another advantages for company B is the price of the unit is lower than the company A which is the main competitor in Thailand market. There are some weak points of the Company B which are the performance of the unit is not to stable, limited number of reference customers and after sales service. The distributor of Company B has only one service team that has limited skills. In some case, they need to outsorced the service team to serve the customers.

C. Comparison

The objective of this section is to choose the better choice of grain cooling unit to be in the calculation of cost-benefits analysis and breakeven analysis by doing the comparison. Table 12 shows the comparison of Company A and Company B in several topics such as quality, distributor, after-sales service, references customers and price.

Company A

Model A5000

Figure 35 Company A - grain cooling unit

Company B

Model B5000

Figure 36 Company B - grain cooling unit

Table 12 Comparison table of company A and company B

Comparison Table	Company A	Company B
Origin	Germany	Spain
Model	A5000	B5000
Quality	Good quality with high technology and user friendly operation	Good quality but lack of stability
Distributor	Have an experience in rice mill business for more than 60 years	Rice mill owner
Service Team	Highly skilled service team which trained by the engineer from Germany	Limited resources of service team which need to be outsourced service team in some cases.
References customers	More than 50 countries around the world and more than 100 units in Thailand	Mostly in Spain and Thailand and also limited in the group of family and close friends
Price	2,980,000 Baht	2,750,000 Baht

As a comparison in the table, the grain cooling unit from company A has been picked for calculation in this study. There are many advantages which are better than the company B. With the same cooling performance, the quality of company is more reliable and stable than company B. Moreover, the distributor of the company has a lot of experience in the business and they have their own service team that passed the training program from Germany. In addition, the reference customers around the world, who use the unit from company A, increase the trust and make new users confident in the product. And the price of the unit from company A is only 7.7% higher than the company B.

4.2.2 Air distribution system

According to Schmelzer [30], air distribution system for cooling conservation method is also another significant investment that needs to be calculated. There are two types of storage that widely used for paddy storage which are silo storage and warehouse storage. Every silo manufacturers which are produces in last 20 years are already equipped with the air distribution system. So, this study will focused only the warehouse storage. There are 3 types of air distribution systems in the market. First is the underfloor type which needs to be done since the beginning of warehouse construction. Second system is half- round ventilation which is very popular in Thailand market to transform the existing warehouse with no air distribution system to the warehouse that suitable for

cooling conservation. Third system is telescope pipes which is the new technology for air distribution process. Table 13 shows the comparison of 3 systems of air distribution.

Figure 37 Air distribution system - telescope pipes

Figure 38 Air distribution system - Underfloor

Figure 39 Air distribution system - Half round

Table 13 Comparison table of 3 types of air ventilation system

Comparison Table	Underfloor	Half-round ventilation	Telescope pipes
Installation	Need to be done since the beginning of warehouse construction	Suitable for existing warehouse	Suitable for existing warehouse
Paddy output from the warehouse by Backhoe loader	Possibly damaged to the underfloor steel sieves	Possibly damaged to the half-round steel sieves	No damage
Height of bulk of paddy	Up to 10 meters	Up to 18 meters	Up to 6 meters
Price of outside air distribution	9,000 baht per meter	9,000 baht per meter	9,000 baht per meter
Price	1,200 baht per meter without structure	1,500 baht per meter	4,000 baht per meter

As a comparison in the table, the half-round ventilation system has been picked for calculation in this study. The main advantage of the half round is it suitable for the existing warehouse. In addition, the possible height of paddy is up to 18 meters which is a lot better compared to the telescope pipes. Moreover, the price of half-round ventilation is lower more than a half of telescope pipes. Some damaged that may happen due to the crash by the backhoe loader is acceptable and some spare unit can be easily replace the damaged one.

4.3 Costs analysis

There are two variable costs of using cooling conservation method for paddy storage which are electricity cost and maintenance cost. As mentioned above, this study chooses the grain cooling unit model A5000 of company A to analyses cost.

4.3.1 Electricity cost

According to Kolb & Braunbeck [4], the energy consumption of cooling conservation depends on the relative humidity of the outside air, the ambient temperature and the moisture content. Figure 40 shows the experiential values for energy consumption for one cooling cycle of paddy in tropical area.

Cooling [K]	20 (e.g. from 35 °C to 15 °C)
Region	Asia
Climate zone	Tropics
Energy consumption in [kWh/t]	6-12

Figure 40 experiential values for energy consumption for one cooling cycle of paddy in tropical area (Kolb & Braunbeck [14])

For real practices in Thailand, the average energy consumption from surveying 59 rice millers who used the grain cooling unit is at 19.51 Thai baht per one cooling cycle. With the average targeted temperature at 22.03 degree Celsius.

Cooling	10 Celsius (From 32 to 22 Celsius)
Country	Thailand
Average energy consumption	19.51 Baht per ton per one cycle
Average electricity cost	1.9 baht per unit (Industrial rate)
Energy consumption	Around 10 kWh/t

Figure 41 Energy consumption for cooling conservation method

4.3.2 Maintenance cost

Maintenance cost in cooling conservation method for long term paddy storage is rather low compared to another method. Distributor of Company A also offers a service contract together with the grain cooling unit. They have 2 kinds of service contract which are gold and Platinum. Gold contract offers system checked and cleaning 4 times a year and the price covered all the labour cost, transportation cost and filters that need to be changed once a year. But it not includes the spare parts that need to be changed. The price of gold contract is 30,000 baht per year for model A5000. Platinum contract offers all the things in the gold contract plus the spare parts cost. The only spare part that not

covered in the platinum contract is compressor which is the most expensive parts in the grain cooling unit. The price of platinum contract is 75,000 baht per year for model A5000.

4.4 Options for conversion

This study considered two transformation options:

Transformation option 1: Transformation from circulation method to cooling conservation method by using grain cooling unit

Transformation option 2: Transformation from industrial fans ventilation method to cooling conservation method by using grain cooling unit.

Benefits and costs of each option were estimated and results have been compared. Breakeven calculation template sheet was also carried out. More details of analysis appear below.

Transformation option 1: ***Transformation from circulation method to cooling conservation method by using grain cooling unit.***

This transformation option was assumed the circulation method of both silo storage and warehouse storage was used with no ventilation. In case of silo storage, the circulation can be done by moving the bulk of paddy from one silo to another silo to reduce the temperature in the silo and avoid the deteriorate paddy due to hot spot. For warehouse storage, the circulation method is done by using backhoe loader to flip over paddy

stack and let the air flow inside to reduce the temperature of the hot spot in the middle of the stack.

Transformation option 2: ***Transformation from Industrial fans ventilation method to cooling conservation method by using grain cooling unit.***

This transformation option was assumed the industrial fans ventilation method of both silo storage and warehouse storage was already equipped with the air distribution system. So, the only investment in this option is grain cooling unit. There are some differences between this 2 method which are the energy consumption costs, temperature in storage facility and the yield of head rice and broken rice.

4.5 Cost and Benefits Calculation

This section will shows how to calculate all tangible benefits and costs that will happen when transforming from circulation method to cooling conservation method and from industrial fan method to cooling conservation method. One example for each transformation option will be picked to show the calculation. There are many variables data that need for calculation and it shown in the table below

Summary table of numbers for calculation

Average numbers from the survey which shown in the following table will be used in the cost benefits analysis and payback period calculation.

Table 14 summary numbers for calculation

Cooling performance of A5000	5,000 tons / 1 unit
Temperature in storage facility - Cooling	22 Celsius
Heat generation ratio - Cooling	0.16 MJ / ton
Temperature in storage facility - Circulation	32 Celsius
Heat generation ratio - Circulation	0.70 MJ / ton
Temperature in storage facility - Fans	30 Celsius
Heat generation ratio - Fans	0.50 MJ / ton
Drying costs	22 Baht / ton / 1% moisture content
Electricity cost – industrial fans	31.50 Baht / ton / cycle
Fans ventilation cycle	14 days
Circulation cost	47.70 Baht / ton / cycle
Circulation cycle	24 days

Electricity cost - cooling	1.95 Baht / 1 kWh
Grain cooling energy consumption	10 kWh / ton / cycle
Head rice / broken rice yield - Cooling	53.89% / 16.11%
Head rice / broken rice yield - Circulation	50.4% / 19.6%
Head rice / broken rice yield - Fans	50.5% / 19.5%
Grain cooling unit maintenance cost	30,000 Baht / year

4.5.1 Transformation option 1's example calculation

This section will show the calculation of all tangible benefits and costs while transforming from circulation method to cooling conservation method. Author picked one case as a calculation example which is 3,000 tons storage quantity per year, 3 months of storage period per year, price of paddy at 8,000 baht per ton, price of head rice at 15,000 baht per ton and price of broken rice at 9,000 baht per ton with the warehouse which has 50 meters in length and 25 meters in width.

Table 15 Variable numbers for option a's calculation example

variables number for option 1's calculation example	
Storage Quantity per year	3,000 tons
Storage period per year	90 days
Paddy price	8,000 baht per ton
Head rice price	15,000 baht per ton
Broken rice price	9,000 baht per ton
Existing storage facility	Warehouse
Warehouse dimension	Width : 25 M , Length : 50 M

So, from variables number in the table above, the calculation will begin with benefits from A. to E. and follow by initial investment and variable cost of running the grain cooling unit.

A. reduce respiration loss

Circulation method: storage temperature at 32 degree Celsius and moisture content of paddy at 14%. So, the heat generation number can be found from table 10 is 0.7 MJ per

ton. As a substance loss formula in section 4.1.1, the calculation can be done as shown below:

Respiration loss - Circulation	$\frac{0.7 \text{ MJ/t} * 90 \text{ days} * 3{,}000 \text{ tons}}{15{,}000 \text{ MJ/t}}$ = 12.6 tons * 8,000 baht = 100,800 Baht

Cooling conservation method: storage temperature at 22 degree Celsius and moisture content of paddy at 14%. So, the heat generation number can be found from table 10 is 0.16 MJ per ton.

Respiration loss – cooling conservation	$\frac{0.160 \text{ MJ/t} * 90 \text{ days} * 3{,}000 \text{ tons}}{15{,}000 \text{ MJ/t}}$ = 2.88 tons * 8,000 baht = 23,040 Baht

Benefit from A.	Total benefit = 100,800 – 23,040 = 77,760 Baht

B. Greater head rice yield

Circulation method: from the survey, the average head rice yield of this method is 50.4% with broken rice yield at 19.6%

Selling price - circulation	(50.40% * 15,000 * 3,000 + 19.60% * 9,000 * 3,000) = 27,972,000 Baht

Cooling conservation method: from the survey, the average head rice yield of this method is 53.89% with broken rice yield at 16.11%

Selling price – cooling conservation	(53.89% * 15,000 * 3,000 + 16.11% * 9,000 * 3,000) = 28,600,200 Baht

Benefit from B.	Total benefit = 28,600,200 – 27,972,000 = 628,200 Baht

C. Weight gain

As mentioned above that while using cooling conservation method, the paddy can be take out from the dryer at 15% moisture content instead of 14% moisture content. So, the weight of paddy has gain for 1.16%.

Weight gain –	1.16% * 3,000 tons * 8,000 baht

cooling conservation	= 278,400 Baht

Benefit from C.	Total benefit = 278,400 Baht

D. Dryer cost saving

As also mentioned above that while using cooling conservation method, the paddy can be take out from the dryer at 15% moisture content instead of 14% moisture content. So, there are some costs saving on dryer that need to dried paddy for average 22 baht per ton per 1% moisture content.

Dryer cost – conservation drying	22 baht * (25-14) * 3,000 tons = 726,000 baht

Dryer cost – combination drying	22 baht * (25-15) * 3,000 tons = 660,000 Baht

Benefit from D.	Total benefit = 726,000 – 660,000 = 66,000 Baht

E. Existing method operating cost saving

As also mentioned above, the cost of running circulation method is averaging 47.70 baht per ton per one cycle and one circulation cycle is 24 days.

Existing operation cost - circulation	= 47.70 baht * storage quantity * circulation cycle(s) = 47.70 * 3,000 * (90 days / 24 days) = 47.70 * 3,000 * 4 cycles = 572,400 Baht

Benefit from E.	Total benefit = 572,400 Baht

Total Benefits from A.+ B. + C. + D. + E.	Total benefits = 77,760 + 628,200 + 278,400 + 66,000 + 572,400 = 1,622,760 Baht

There are two main parts of cost which are initial investment which included grain cooling unit and air distribution system and the variable costs which included energy consumption of grain cooling unit and maintenance cost.

F. Grain cooling unit

The grain cooling unit that used in this study is the model A5000 which has a capacity of 5,000 tons of paddy. So, if the storage quantity per year is lower or equal to 5,000 tons, only 1 unit of grain cooling will be needed. But if the storage quantity per year is more than 5,000 tons, more than 1 unit of grain cooling will be needed.

Grain cooling unit	3,000 tons need 1 unit of grain cooling = 2,980,000 Baht

Cost from F.	Total cost = 2,980,000 Baht

G. Air distribution system

The investment on air distribution system is only needed for option 1 which has the warehouse as an existing storage facility type. The cost of outside air distribution is at 9,000 baht per meter and the cost of inside air distribution is at 1,500 baht per meter. Normally, the outside air distribution is installed along the length of the warehouse and the inside air distribution is need to installed along the width of the warehouse which the gap between each row for 5 meter.

Outside air distribution system	= 9,000 baht * 50 Meters = 450,000 Baht

Inside air distribution system	= 1,500 baht * 30 Meters * (50 meters / 5 meters) = 1,500 Baht * 25 Meters * 10 rows = 375,000 Baht

Cost from G.	Total cost = 825,000 Baht

Total initial investment from F. + G.	Total costs = 2,980,000 + 825,000 = 3,805,000 Baht

H. Energy consumption

As mentioned above, the average energy consumption of grain cooling unit is 19.51 baht per ton per one cooling cycle and one cooling cycle is 7 weeks or 63 days.

Energy consumption	= 19.51 Baht * 3,000 * (90 days / 63 days) = 19.51 * 3,000 * 2 cycles = 117,060 Baht

Cost from F.	Total cost = 117,060 Baht

I. Maintenance cost

The maintenance cost of grain cooling unit is 30,000 baht per one unit per year

Maintenance cost	= 30,000 * 1 unit = 30,000 Baht

Cost from I.	Total cost = 30,000 Baht

Total costs from H. + I.	Total costs = 117,060 + 30,000 = 147,060 Baht

Net annual cash inflow	= 1,622,760 – 147,060

Total benefits – Total costs	= 1,475,760 Baht

So, payback period of this example can be calculated by using payback period formula:

Payback period	Total initial investment Net annual cash inflow 2,980,000 + 825,000 1,475,760 = 2.58 years

4.5.2 Transformation option 2's example calculation

This section will show the calculation of all tangible benefits and costs while transforming from industrial fan method to cooling conservation method. Author picked the same case as option 1 for calculation example which is 3,000 tons storage quantity per year, 3 months of storage period per year, price of paddy at 8,000 baht per ton, price of head rice at 15,000 baht per ton and price of broken rice at 9,000 baht per ton but this case the warehouse already equipped with the air distribution system.

Table 16 Variable numbers for option 2's calculation example

variables number for option 2's calculation example	
Storage Quantity per year	3,000 tons
Storage period per year	90 days
Paddy price	8,000 baht per ton
Head rice price	15,000 baht per ton
Broken rice price	9,000 baht per ton

A. reduce respiration loss

Industrial fan method: storage temperature at 30 degree Celsius and moisture content of paddy at 14%. So, the heat generation number can be found from table 10 is 0.5 MJ per ton.

Respiration loss – Industrial fan	$\frac{0.5 \text{ MJ/t} * 90 \text{ days} * 3{,}000 \text{ tons}}{15{,}000 \text{ MJ/t}}$ = 9 tons * 8,000 baht = 72,000 Baht

Cooling conservation method: storage temperature at 22 degree Celsius and moisture content of paddy at 14%. So, the heat generation number can be found from table 10 is 0.16 MJ per ton.

Respiration loss – cooling conservation	0.160 MJ/t * 90 days * 3,000 tons / 15,000 MJ/t = 2.88 tons * 8,000 baht = 23,040 Baht

Benefit from A.	Total benefit = 72,000 – 23,040 = 48,960 Baht

B. Greater head rice yield

Industrial fan method: from the survey, the average head rice yield of this method is 50.5% with broken rice yield at 19.5%

Selling price - Industrial fan	(50.50% * 15,000 * 3,000 + 19.50% * 9,000 * 3,000) = 27,990,000 Baht

Cooling conservation method: from the survey, the average head rice yield of this method is 53.89% with broken rice yield at 16.11%

Selling price – cooling conservation	(53.89% * 15,000 * 3,000 + 16.11% * 9,000 * 3,000) = 28,600,200 Baht

Benefit from B.	Total benefit = 28,600,200 – 27,999,000 = 610,200 Baht

C. Weight gain

As mentioned above that while using cooling conservation method, the paddy can be take out from the dryer at 15% moisture content instead of 14% moisture content. So, the weight of paddy has gain for 1.16%.

Weight gain – cooling conservation	1.16% * 3,000 tons * 8,000 baht = 278,400 Baht

Benefit from C.	Total benefit = 278,400 Baht

D. Dryer cost saving

As also mentioned above that while using cooling conservation method, the paddy can be take out from the dryer at 15% moisture content instead of 14% moisture content. So, there are some costs saving on dryer that need to dried paddy for average 22 baht per ton per 1% moisture content.

Dryer cost – conservation drying	22 baht * (25-14) * 3,000 tons = 726,000 baht

Dryer cost – combination drying	22 baht * (25-15) * 3,000 tons = 660,000 Baht

Benefit from D.	Total benefit = 726,000 – 660,000 = 66,000 Baht

E. Existing method operating cost saving

As also mentioned above, the cost of running industrial fan method is averaging 31.50 baht per ton per one cycle and one industrial fan cycle is 14 days.

Existing operation cost - circulation	= 31.50 baht * storage quantity * industrial fan cycle(s) = 31.50 * 3,000 * (90 days / 14 days) = 31.50 * 3,000 * 7 cycles = 661,500 Baht

Benefit from E.	Total benefit = 661,500 Baht

Total Benefits from	Total benefits = 48,960 + 610,200 + 278,400 + 66,000 +

A.+ B. + C. + D. + E.	661,500 = 1,665,060 Baht

F. Grain cooling unit

The grain cooling unit that used in this study is the model A5000 which has a capacity of 5,000 tons of paddy. So, if the storage quantity per year is lower or equal to 5,000 tons, only 1 unit of grain cooling will be needed. But if the storage quantity per year is more than 5,000 tons, more than 1 unit of grain cooling will be needed.

Grain cooling unit	3,000 tons need 1 unit of grain cooling = 2,980,000 Baht

Cost from F.	Total cost = 2,980,000 Baht

G. Air distribution system

The investment on air distribution system is only needed for option 1. So, this example is not need an air distribution system.

Outside air distribution system	= 0 Baht

Inside air distribution system	= 0 Baht

Cost from G.	Total cost = 0 Baht

Total initial investment from F. + G.	Total costs = 2,980,000 + 0 = 2,980,000 Baht

H. Energy consumption

As mentioned above, the average energy consumption of grain cooling unit is 19.51 baht per ton per one cooling cycle and one cooling cycle is 7 weeks or 63 days.

Energy consumption	= 19.51 Baht * 3,000 * (90 days / 63 days) = 19.51 * 3,000 * 2 cycles = 117,060 Baht

Cost from F.	Total cost = 117,060 Baht

I. Maintenance cost

The maintenance cost of grain cooling unit is 30,000 baht per one unit per year

Maintenance cost	= 30,000 * 1 unit = 30,000 Baht

Cost from I.	Total cost = 30,000 Baht

Total costs from H. + I.	Total costs = 117,060 + 30,000 = 147,060 Baht

Net annual cash inflow Total benefits – Total costs	= 1,665,060 – 147,060 = 1,518,060 Baht

So, payback period of this example can be calculated by using payback period formula:

Payback period	Total initial investment Net annual cash inflow 2,980,000 + 0 1,518,060 = 1.96 years

4.6 Calculation sheet

By using all the data that we collected and compile all the benefits and costs that will happen in the transformation option. Payback period calculation sheet was created by the author for each option.

Transformation option 1 calculation sheet

Option 1 - Circulation to Cooling conservation							
Payback period calculation sheet							
1	Storage Quantity per year		Ton(s)		Grain cooling unit	0	Unit(s)
2	Storae period per year		Days		Price of grain cooling unit A5000	2,980,000.00	Baht
3	Average moisture content (input)		%		Unit investment	-	Baht
4	Storage moisture content		%		Warehouse dimension		
5	Paddy price		Baht per ton		Length		Meters
6	Head rice price		Baht per ton		Width		Meters
7	Broken rice price		Baht per ton		Recommended Height		Meters
8	Storage Temperature		Celsius		Outside air distribution costs	-	Baht
9	Heat generation ratio		KJ per ton		Inside air distribution costs	-	Baht
10	Drying cost		Baht per ton		Air distribution costs	-	Baht
11	Electricity cost		Baht per unit		Total Investment	-	Baht
A.	**Respiration Loss**			D	**Dryers costs saving**		
	Circulation Method				Conservation drying - 14%		
	StorageTemperature	32	Celsius		Average energy consumption (1% moisture content)	0	Baht
	Paddy respiration loss	0	Tons		Energy consumption	-	Baht
	Losses Value	-	Baht		Combination drying - 15%		
	Cooling Conservation method				Energy consumption	-	Baht
	StorageTemperature	22	Celsius		**Benefits**	-	**Baht**
	Paddy respiration loss	0	Tons	E.	**Circulation cost saving**		
	Losses Value	-	Baht		Average circulation cost per ton per circulation cycle	47.70	Baht
	Benefits	-	**Baht**		Circulation cost saving	-	Baht
B	**Greater rice yield**				**Benefits**	-	**Baht**
	Conservation drying				Total Benefits		
	Rice yield	50.4	%	A	Respiration loss	-	Baht
	Price	-	Baht	B	Greater head rice yield	-	Baht
	Broken rice yield	19.6	%	C	Weigh gain	-	Baht
	Price	-	Baht	D	Dryer costs saving	-	Baht
	Total selling price	-	Baht	E	Circulation cost saving	-	Baht
	Combination drying				**Benefits**	-	**Baht**
	Rice yield	53.89	%		Variable costs		
	Price	-	Baht		Energy consumption	-	Baht
	Broken rice yield	16.11	%		Maintenance cost	-	Baht
	Price	-	Baht		**Costs**	-	**Baht**
	Total selling price	-	Baht		Net Benefit		
	Benefits	-	**Baht**		**Total Benefits - Variable costs**	-	**Baht**
C.	**Weight Gain**						
	Conservation	14% moisture content			Total Investment		
	Combination	15% moisture content				-	**Baht**
	Weight gain	100*(15-14)/100-14			**Payback Peiod**		**Year(s)**
	Weight gain	1.16	%				
	Benefits	-	**Baht**				

Figure 42 Payback period calculation sheet for option 1

In the calculation sheet, there are 11 independent variables that need to be filled case by case in the top left yellow area such as storage quantity per year, storage period per year, price of paddy, price of head rice and storage temperature. In case of warehouse storage that needs to be invest in air distribution system, the warehouse dimension need to be filled. Then, the sheet will calculate air distribution cost. There are 5 tangible benefits which can assign in financial term which are A., B., C., D. and E. in the sheet. A. is benefit from respiration loss which calculates the loss by using circulation system and the loss when using cooling conservation and then benefit can be easily calculate. B. is benefit from greater head rice yield. 53.89% head rice yield which is an average number from survey will be used as cooling conservation yield and 50.4% will be used as circulation method calculation. C. is benefit from weight gain which can be store 1% higher moisture content than circulation method. D. is benefit from dryer cost saving and E. is benefit from circulation cost saving. Payback period for each case is a result of this calculation sheet. It will help to make a decision between 'do nothing' or transform to use cooling conservation method.

Transformation option 2 calculation sheet

Option 2 - Fans to Cooling conservation							
Payback period calculation sheet							
1	Storage Quantity per year		Ton(s)		Grain cooling unit	0	Unit(s)
2	Storae period per year		Days		Price of grain cooling unit A5000	2,980,000.00	Baht
3	Average moisture content (input)		%		Unit investment	-	Baht
4	Storage moisture content		%		Warehouse dimension		
5	Paddy price		Baht per ton		Length		Meters
6	Head rice price		Baht per ton		Width		Meters
7	Broken rice price		Baht per ton		Recommended Height		Meters
8	Storage Temperature		Celsius				
9	Heat generation ratio		KJ per ton				
10	Drying cost		Baht per ton				
11	Electricity cost		Baht per unit		Total Investment	-	Baht
A.	**Respiration Loss**			D	**Dryers costs saving**		
	Circulation Method				Conservation drying - 14%		
	StorageTemperature	30	Celsius		Average energy consumption per 1% moisture content	0	Baht
	Paddy respiration loss	0	Tons		Energy consumption	-	Baht
	Losses Value	-	Baht		Combination drying - 15%		
	Cooling Conservation method				Energy consumption	-	Baht
	StorageTemperature	22	Celsius		**Benefits**	**-**	**Baht**
	Paddy respiration loss	0	Tons	E.	**Fans energy cost saving**		
	Losses Value	-	Baht		Average energy cost per ton per cycle	31.50	Baht
	Benefits	**-**	**Baht**		Fans energy cost saving	-	Baht
B	**Greater rice yield**				**Benefits**	**-**	**Baht**
	Conservation drying				Total Benefits		
	Rice yield	50.5	%	A	Respiration loss	-	Baht
	Price	-	Baht	B	Greater head rice yield	-	Baht
	Broken rice yield	19.5	%	C	Weigh gain	-	Baht
	Price	-	Baht	D	Dryer costs saving	-	Baht
	Total selling price	-	Baht	E	Fans energy cost saving	-	Baht
	Combination drying				**Benefits**	**-**	**Baht**
	Rice yield	53.89	%		Variable costs		
	Price	-	Baht		Energy consumption	-	Baht
	Broken rice yield	16.11	%		Maintenance cost	-	Baht
	Price	-	Baht		**Costs**	**-**	**Baht**
	Total selling price	-	Baht		Net Benefit		
	Benefits	**-**	**Baht**		**Total Benefits - Variable costs**	**-**	**Baht**
C.	**Weight Gain**						
	Conservation	14% moisture content			Total Investment		
	Combination	15% moisture content				-	**Baht**
	Weight gain	100*(15-14)/100-14			**Payback Peiod**		**Year(s)**
	Weight gain	1.16	%				
	Benefits	**-**	**Baht**				

Figure 43 Payback period calculation sheet for option 2

There is a little difference between two calculation sheets for each option. There is no air distribution system cost in this option due to the existing method is fan ventilation which the storage facility must already equipped with air distribution system. Average storage temperature of fan ventilation method is lower than circulation method for 2 degree Celsius which leads to different heat generation ratio. Head rice yield is at 50.5% instead

of 50.4% in last option. In addition, E. is benefit from fans energy costs saving instead of circulation cost saving.

4.7 Calculation examples

Transformation option 1: ***Transformation from circulation method to cooling conservation method by using grain cooling unit.***

In transformation option 1, this study used 12 examples to show as many cases to explain and analyze the results of benefits and costs for each example. Moreover, the payback period of each example also calculated. There are 3 independent variables for each example which are storage quantity per year, storage period per year and the storage type. Others variables are constant number to clearly show the differences between each example. First constant variable is average input moisture content which fixed at 25%. Second, the target moisture content for storage is 14%, In addition, paddy price is 8,000 baht per ton. Head rice price is 15,000 Baht per ton. Broken rice price is 9,000 Baht. Temperature in the storage facility is at 22 degree Celsius. Heat generation is 0.16 KJ per ton. Drying cost is 220 Baht per ton and electricity cost is 1.95 baht per kWh. Then, all the independent variables for each example show in the following table.

Table 17 independent variables for example 1 to 12

Example	Storage Quantity per year	Storage period per year	Storage type
1	3,000 tons	90 days	Silo
2	3,000 tons	90 days	Warehouse (L: 50 m, W: 25 m.)
3	5,000 tons	90 days	Silo
4	5,000 tons	120 days	Silo
5	10,000 tons	120 days	Silo
6	12,000 tons	120 days	Silo
7	12,000 tons	120 days	Warehouse (L: 50 m, W: 25 m.)
8	12,000 tons	120 days	Warehouse (L: 60 m, W: 30 m.)
9	12,000 tons	300 days	Warehouse (L: 60 m, W: 30 m.)
10	12,000 tons	365 days	Warehouse (L: 60 m, W: 30 m.)
11	10,000 tons	365 days	Warehouse (L: 60 m, W: 30 m.)
12	10,000 tons	365 days	Silo

Every example shows the difference between each case. For example, the difference between example 1 and 2 is the type of storage, between 1 and 3 is storage quantity per year, between 3 and 4 is storage period per year and between 7 and 8 is the size of warehouse that affects the investment of air distribution system.

Option 1 - Circulation to Cooling conservation			
Payback period calculation sheet - Example 1			
1	Storage Quantity per year	3000	Ton(s)
2	Storae period per year	90	Days
3	Average moisture content (input)	25	%
4	Storage moisture content	14	%
5	Paddy price	8,000.00	Baht per ton
6	Head rice price	15,000.00	Baht per ton
7	Broken rice price	9,000.00	Baht per ton
8	Storage Temperature	22	Celsius
9	Heat generation ratio	0.16	KJ per ton
10	Drying cost	220	Baht per ton
11	Electricity cost	1.95	Baht per unit

A.	**Respiration Loss**		
	Circulation Method		
	StorageTemperature	32	Celsius
	Paddy respiration loss	12.6	Tons
	Losses Value	100,800.00	Baht
	Cooling Conservation method		
	StorageTemperature	22	Celsius
	Paddy respiration loss	2.88	Tons
	Losses Value	23,040.00	Baht
	Benefits	**77,760.00**	**Baht**
B	**Greater rice yield**		
	Conservation drying		
	Rice yield	50.4	%
	Price	22,680,000.00	Baht
	Broken rice yield	19.6	%
	Price	5,292,000.00	Baht
	Total selling price	27,972,000.00	Baht
	Combination drying		
	Rice yield	53.89	%
	Price	24,250,500.00	Baht
	Broken rice yield	16.11	%
	Price	4,349,700.00	Baht
	Total selling price	28,600,200.00	Baht
	Benefits	**628,200.00**	**Baht**
C.	**Weight Gain**		
	Conservation	14% moisture content	
	Combination	15% moisture content	
	Weight gain	100*(15-14)/100-14	
	Weight gain	1.16	%
	Benefits	**278,400.00**	**Baht**

	Grain cooling unit	1	Unit(s)
	Price of grain cooling unit A5000	2,980,000.00	Baht
	Unit investment	**2,980,000.00**	Baht
	Warehouse dimension		
	Length	0	Meters
	Width	0	Meters
	Recommended Height		Meters
	Outside air distribution costs	-	Baht
	Inside air distribution costs	-	Baht
	Air distribution costs	-	Baht
	Total Investment	**2,980,000.00**	Baht

D	**Dryers costs saving**		
	Conservation drying - 14%		
	Average energy consumption (1% moisture content)	22.00	Baht
	Energy consumption	726,000.00	Baht
	Combination drying - 15%		
	Energy consumption	660,000.00	Baht
	Benefits	**66,000.00**	**Baht**
E.	**Circulation cost saving**		
	Average circulation cost per ton per circulation cycle	47.70	Baht
	Circulation cost saving	572,400.00	Baht
	Benefits	**572,400.00**	**Baht**
	Total Benefits		
A	Respiration loss	77,760.00	Baht
B	Greater head rice yield	628,200.00	Baht
C	Weight gain	278,400.00	Baht
D	Dryer costs saving	66,000.00	Baht
E	Circulation cost saving	572,400.00	Baht
	Benefits	**1,622,760.00**	**Baht**
	Variable costs		
	Energy consumption	117,000.00	Baht
	Maintenance cost	30,000.00	Baht
	Costs	**147,000.00**	**Baht**
	Net Benefit		
	Total Benefits - Variable costs	**1,475,760.00**	**Baht**
	Total Investment	**2,980,000.00**	**Baht**
	Payback Peiod	**2.02**	**Year(s)**

Figure 44 Calculation example 1

Option 1 - Circulation to Cooling conservation							
Payback period calculation sheet - example 2							
1	Storage Quantity per year	3000	Ton(s)		Grain cooling unit	1	Unit(s)
2	Storae period per year	90	Days		Price of grain cooling unit A5000	2,980,000.00	Baht
3	Average moisture content (input)	25	%		Unit investment	**2,980,000.00**	Baht
4	Storage moisture content	14	%		Warehouse dimension		
5	Paddy price	8,000.00	Baht per ton		Length	50	Meters
6	Head rice price	15,000.00	Baht per ton		Width	25	Meters
7	Broken rice price	9,000.00	Baht per ton		Recommended Height	4.36	Meters
8	Storage Temperature	22	Celsius		Outside air distribution costs	450,000.00	Baht
9	Heat generation ratio	0.16	KJ per ton		Inside air distribution costs	375,000.00	Baht
10	Drying cost	220	Baht per ton		Air distribution costs	**825,000.00**	Baht
11	Electricity cost	1.95	Baht per unit		Total Investment	**3,805,000.00**	Baht
A.	**Respiration Loss**			D	**Dryers costs saving**		
	Circulation Method				Conservation drying - 14%		
	StorageTemperature	32	Celsius		Average energy consumption (1% moisture content)	22.00	Baht
	Paddy respiration loss	12.6	Tons		Energy consumption	726,000.00	Baht
	Losses Value	100,800.00	Baht		Combination drying - 15%		
	Cooling Conservation method				Energy consumption	660,000.00	Baht
	StorageTemperature	22	Celsius		**Benefits**	**66,000.00**	**Baht**
	Paddy respiration loss	2.88	Tons	E.	**Circulation cost saving**		
	Losses Value	23,040.00	Baht		Average circulation cost per ton per circulation cycle	47.70	Baht
	Benefits	**77,760.00**	**Baht**		Circulation cost saving	572,400.00	Baht
B	**Greater rice yield**				**Benefits**	**572,400.00**	**Baht**
	Conservation drying				Total Benefits		
	Rice yield	50.4	%	A	Respiration loss	77,760.00	Baht
	Price	22,680,000.00	Baht	B	Greater head rice yield	628,200.00	Baht
	Broken rice yield	19.6	%	C	Weight gain	278,400.00	Baht
	Price	5,292,000.00	Baht	D	Dryer costs saving	66,000.00	Baht
	Total selling price	27,972,000.00	Baht	E	Circulation cost saving	572,400.00	Baht
	Combination drying				**Benefits**	**1,622,760.00**	**Baht**
	Rice yield	53.89	%		Variable costs		
	Price	24,250,500.00	Baht		Energy consumption	117,000.00	Baht
	Broken rice yield	16.11	%		Maintenance cost	30,000.00	Baht
	Price	4,349,700.00	Baht		**Costs**	**147,000.00**	**Baht**
	Total selling price	28,600,200.00	Baht		Net Benefit		
	Benefits	**628,200.00**	**Baht**		**Total Benefits - Variable costs**	**1,475,760.00**	**Baht**
C.	**Weight Gain**						
	Conservation	14% moisture content			Total Investment		
	Combination	15% moisture content				**3,805,000.00**	**Baht**
	Weight gain	100*(15-14)/100-14			**Payback Peiod**	**2.58**	**Year(s)**
	Weight gain	1.16	%				
	Benefits	**278,400.00**	**Baht**				

Figure 45 Calculation example 2

Option 1 - Circulation to Cooling conservation							
Payback period calculation sheet - example 3							
1	Storage Quantity per year	5000	Ton(s)		Grain cooling unit	1	Unit(s)
2	Storae period per year	90	Days		Price of grain cooling unit A5000	2,980,000.00	Baht
3	Average moisture content (input)	25	%		Unit investment	**2,980,000.00**	Baht
4	Storage moisture content	14	%		Warehouse dimension		
5	Paddy price	8,000.00	Baht per ton		Length		Meters
6	Head rice price	15,000.00	Baht per ton		Width		Meters
7	Broken rice price	9,000.00	Baht per ton		Recommended Height		Meters
8	Storage Temperature	22	Celsius		Outside air distribution costs	-	Baht
9	Heat generation ratio	0.16	KJ per ton		Inside air distribution costs	-	Baht
10	Drying cost	220	Baht per ton		Air distribution costs	-	Baht
11	Electricity cost	1.95	Baht per unit		Total Investment	**2,980,000.00**	Baht
A.	**Respiration Loss**			D	**Dryers costs saving**		
	Circulation Method				Conservation drying - 14%		
	StorageTemperature	32	Celsius		Average energy consumption (1% moisture content)	22.00	Baht
	Paddy respiration loss	21	Tons		Energy consumption	1,210,000.00	Baht
	Losses Value	168,000.00	Baht		Combination drying - 15%		
	Cooling Conservation method				Energy consumption	1,100,000.00	Baht
	StorageTemperature	22	Celsius		**Benefits**	**110,000.00**	**Baht**
	Paddy respiration loss	4.8	Tons	E.	**Circulation cost saving**		
	Losses Value	38,400.00	Baht		Average circulation cost per ton per circulation cycle	47.70	Baht
	Benefits	**129,600.00**	**Baht**		Circulation cost saving	954,000.00	Baht
B	**Greater rice yield**				**Benefits**	**954,000.00**	**Baht**
	Conservation drying				Total Benefits		
	Rice yield	50.4	%	A	Respiration loss	129,600.00	Baht
	Price	37,800,000.00	Baht	B	Greater head rice yield	1,047,000.00	Baht
	Broken rice yield	19.6	%	C	Weight gain	464,000.00	Baht
	Price	8,820,000.00	Baht	D	Dryer costs saving	110,000.00	Baht
	Total selling price	46,620,000.00	Baht	E	Circulation cost saving	954,000.00	Baht
	Combination drying				**Benefits**	**2,704,600.00**	**Baht**
	Rice yield	53.89	%		Variable costs		
	Price	40,417,500.00	Baht		Energy consumption	195,000.00	Baht
	Broken rice yield	16.11	%		Maintenance cost	30,000.00	Baht
	Price	7,249,500.00	Baht		**Costs**	**225,000.00**	**Baht**
	Total selling price	47,667,000.00	Baht		Net Benefit		
	Benefits	**1,047,000.00**	**Baht**		**Total Benefits - Variable costs**	**2,479,600.00**	**Baht**
C.	**Weight Gain**						
	Conservation	14% moisture content			Total Investment		
	Combination	15% moisture content				**2,980,000.00**	**Baht**
	Weight gain	100*(15-14)/100-14					
	Weight gain	1.16	%		**Payback Peiod**	**1.20**	**Year(s)**
	Benefits	**464,000.00**	**Baht**				

Figure 46 Calculation example 3

Option 1 - Circulation to Cooling conservation							
Payback period calculation sheet - example 4							
1	Storage Quantity per year	5000	Ton(s)		Grain cooling unit	1	Unit(s)
2	Storae period per year	120	Days		Price of grain cooling unit A5000	2,980,000.00	Baht
3	Average moisture content (input)	25	%		Unit investment	**2,980,000.00**	Baht
4	Storage moisture content	14	%		Warehouse dimension		
5	Paddy price	8,000.00	Baht per ton		Length		Meters
6	Head rice price	15,000.00	Baht per ton		Width		Meters
7	Broken rice price	9,000.00	Baht per ton		Recommended Height		Meters
8	Storage Temperature	22	Celsius		Outside air distribution costs	-	Baht
9	Heat generation ratio	0.16	KJ per ton		Inside air distribution costs	-	Baht
10	Drying cost	220	Baht per ton		Air distribution costs	-	Baht
11	Electricity cost	1.95	Baht per unit		Total Investment	**2,980,000.00**	Baht
A.	**Respiration Loss**			D	**Dryers costs saving**		
	Circulation Method				Conservation drying - 14%		
	StorageTemperature	32	Celsius		Average energy consumption (1% moisture content)	22.00	Baht
	Paddy respiration loss	28	Tons		Energy consumption	1,210,000.00	Baht
	Losses Value	224,000.00	Baht		Combination drying - 15%		
	Cooling Conservation method				Energy consumption	1,100,000.00	Baht
	StorageTemperature	22	Celsius		**Benefits**	**110,000.00**	**Baht**
	Paddy respiration loss	6.4	Tons	E.	**Circulation cost saving**		
	Losses Value	51,200.00	Baht		Average circulation cost per ton per circulation cycle	47.70	Baht
	Benefits	**172,800.00**	**Baht**		Circulation cost saving	1,192,500.00	Baht
B	**Greater rice yield**				**Benefits**	**1,192,500.00**	**Baht**
	Conservation drying				Total Benefits		
	Rice yield	50.4	%	A	Respiration loss	172,800.00	Baht
	Price	37,800,000.00	Baht	B	Greater head rice yield	1,047,000.00	Baht
	Broken rice yield	19.6	%	C	Weight gain	464,000.00	Baht
	Price	8,820,000.00	Baht	D	Dryer costs saving	110,000.00	Baht
	Total selling price	46,620,000.00	Baht	E	Circulation cost saving	1,192,500.00	Baht
	Combination drying				**Benefits**	**2,986,300.00**	**Baht**
	Rice yield	53.89	%		Variable costs		
	Price	40,417,500.00	Baht		Energy consumption	195,000.00	Baht
	Broken rice yield	16.11	%		Maintenance cost	30,000.00	Baht
	Price	7,249,500.00	Baht		**Costs**	**225,000.00**	**Baht**
	Total selling price	47,667,000.00	Baht		Net Benefit		
	Benefits	**1,047,000.00**	**Baht**		**Total Benefits - Variable costs**	**2,761,300.00**	**Baht**
C.	**Weight Gain**						
	Conservation	14% moisture content			Total Investment		
	Combination	15% moisture content				**2,980,000.00**	**Baht**
	Weight gain	100*(15-14)/100-14			**Payback Peiod**	**1.08**	**Year(s)**
	Weight gain	1.16	%				
	Benefits	**464,000.00**	**Baht**				

Figure 47 Calculation example 4

Option 1 - Circulation to Cooling conservation							
Payback period calculation sheet - example 5							
1	Storage Quantity per year	10000	Ton(s)		Grain cooling unit	2	Unit(s)
2	Storae period per year	120	Days		Price of grain cooling unit A5000	2,980,000.00	Baht
3	Average moisture content (input)	25	%		Unit investment	**5,960,000.00**	Baht
4	Storage moisture content	14	%		Warehouse dimension		
5	Paddy price	8,000.00	Baht per ton		Length		Meters
6	Head rice price	15,000.00	Baht per ton		Width		Meters
7	Broken rice price	9,000.00	Baht per ton		Recommended Height		Meters
8	Storage Temperature	22	Celsius		Outside air distribution costs	-	Baht
9	Heat generation ratio	0.16	KJ per ton		Inside air distribution costs	-	Baht
10	Drying cost	220	Baht per ton		Air distribution costs	-	Baht
11	Electricity cost	1.95	Baht per unit		Total Investment	**5,960,000.00**	Baht
A.	**Respiration Loss**			D	**Dryers costs saving**		
	Circulation Method				Conservation drying - 14%		
	StorageTemperature	32	Celsius		Average energy consumption (1% moisture content)	22.00	Baht
	Paddy respiration loss	56	Tons		Energy consumption	2,420,000.00	Baht
	Losses Value	448,000.00	Baht		Combination drying - 15%		
	Cooling Conservation method				Energy consumption	2,200,000.00	Baht
	StorageTemperature	22	Celsius		**Benefits**	**220,000.00**	**Baht**
	Paddy respiration loss	12.8	Tons	E.	**Circulation cost saving**		
	Losses Value	102,400.00	Baht		Average circulation cost per ton per circulation cycle	47.70	Baht
	Benefits	**345,600.00**	**Baht**		Circulation cost saving	2,385,000.00	Baht
B	**Greater rice yield**				**Benefits**	**2,385,000.00**	**Baht**
	Conservation drying				Total Benefits		
	Rice yield	50.4	%	A	Respiration loss	345,600.00	Baht
	Price	75,600,000.00	Baht	B	Greater head rice yield	2,094,000.00	Baht
	Broken rice yield	19.6	%	C	Weight gain	928,000.00	Baht
	Price	17,640,000.00	Baht	D	Dryer costs saving	220,000.00	Baht
	Total selling price	93,240,000.00	Baht	E	Circulation cost saving	2,385,000.00	Baht
	Combination drying				**Benefits**	**5,972,600.00**	**Baht**
	Rice yield	53.89	%		Variable costs		
	Price	80,835,000.00	Baht		Energy consumption	390,000.00	Baht
	Broken rice yield	16.11	%		Maintenance cost	60,000.00	Baht
	Price	14,499,000.00	Baht		**Costs**	**450,000.00**	**Baht**
	Total selling price	95,334,000.00	Baht		Net Benefit		
	Benefits	**2,094,000.00**	**Baht**		**Total Benefits - Variable costs**	**5,522,600.00**	**Baht**
C.	**Weight Gain**						
	Conservation	14% moisture content			Total Investment		
	Combination	15% moisture content				**5,960,000.00**	**Baht**
	Weight gain	100*(15-14)/100-14					
	Weight gain	1.16	%		**Payback Peiod**	**1.08**	**Year(s)**
	Benefits	**928,000.00**	**Baht**				

Figure 48 Calculation example 5

Option 1 - Circulation to Cooling conservation							
Payback period calculation sheet - example 6							
1	Storage Quantity per year	12000	Ton(s)		Grain cooling unit	3	Unit(s)
2	Storae period per year	120	Days		Price of grain cooling unit A5000	2,980,000.00	Baht
3	Average moisture content (input)	25	%		Unit investment	**8,940,000.00**	Baht
4	Storage moisture content	14	%		Warehouse dimension		
5	Paddy price	8,000.00	Baht per ton		Length		Meters
6	Head rice price	15,000.00	Baht per ton		Width		Meters
7	Broken rice price	9,000.00	Baht per ton		Recommended Height		Meters
8	Storage Temperature	22	Celsius		Outside air distribution costs	-	Baht
9	Heat generation ratio	0.16	KJ per ton		Inside air distribution costs	-	Baht
10	Drying cost	220	Baht per ton		Air distribution costs	-	Baht
11	Electricity cost	1.95	Baht per unit		Total Investment	**8,940,000.00**	Baht
A.	**Respiration Loss**			D	**Dryers costs saving**		
	Circulation Method				Conservation drying - 14%		
	StorageTemperature	32	Celsius		Average energy consumption (1% moisture content)	22.00	Baht
	Paddy respiration loss	67.2	Tons		Energy consumption	2,904,000.00	Baht
	Losses Value	537,600.00	Baht		Combination drying - 15%		
	Cooling Conservation method				Energy consumption	2,640,000.00	Baht
	StorageTemperature	22	Celsius		**Benefits**	**264,000.00**	**Baht**
	Paddy respiration loss	15.36	Tons	E.	**Circulation cost saving**		
	Losses Value	122,880.00	Baht		Average circulation cost per ton per circulation cycle	47.70	Baht
	Benefits	**414,720.00**	**Baht**		Circulation cost saving	2,862,000.00	Baht
B	**Greater rice yield**				**Benefits**	**2,862,000.00**	**Baht**
	Conservation drying				Total Benefits		
	Rice yield	50.4	%	A	Respiration loss	414,720.00	Baht
	Price	90,720,000.00	Baht	B	Greater head rice yield	2,512,800.00	Baht
	Broken rice yield	19.6	%	C	Weight gain	1,113,600.00	Baht
	Price	21,168,000.00	Baht	D	Dryer costs saving	264,000.00	Baht
	Total selling price	111,888,000.00	Baht	E	Circulation cost saving	2,862,000.00	Baht
	Combination drying				**Benefits**	**7,167,120.00**	**Baht**
	Rice yield	53.89	%		Variable costs		
	Price	97,002,000.00	Baht		Energy consumption	468,000.00	Baht
	Broken rice yield	16.11	%		Maintenance cost	90,000.00	Baht
	Price	17,398,800.00	Baht		**Costs**	**558,000.00**	**Baht**
	Total selling price	114,400,800.00	Baht		Net Benefit		
	Benefits	**2,512,800.00**	**Baht**		**Total Benefits - Variable costs**	**6,609,120.00**	**Baht**
C.	**Weight Gain**						
	Conservation	14% moisture content			Total Investment		
	Combination	15% moisture content				**8,940,000.00**	**Baht**
	Weight gain	100*(15-14)/100-14					
	Weight gain	1.16	%		**Payback Peiod**	**1.35**	**Year(s)**
	Benefits	**1,113,600.00**	**Baht**				

Figure 49 Calculation example 6

Option 1 - Circulation to Cooling conservation							
Payback period calculation sheet - example 7							
1	Storage Quantity per year	12000	Ton(s)		Grain cooling unit	3	Unit(s)
2	Storae period per year	120	Days		Price of grain cooling unit A5000	2,980,000.00	Baht
3	Average moisture content (input)	25	%		**Unit investment**	**8,940,000.00**	Baht
4	Storage moisture content	14	%		Warehouse dimension		
5	Paddy price	8,000.00	Baht per ton		Length	50	Meters
6	Head rice price	15,000.00	Baht per ton		Width	25	Meters
7	Broken rice price	9,000.00	Baht per ton		Recommended Height	17.45	Meters
8	Storage Temperature	22	Celsius		Outside air distribution costs	450,000.00	Baht
9	Heat generation ratio	0.16	KJ per ton		Inside air distribution costs	375,000.00	Baht
10	Drying cost	220	Baht per ton		Air distribution costs	**825,000.00**	Baht
11	Electricity cost	1.95	Baht per unit		Total Investment	**9,765,000.00**	Baht

A.	**Respiration Loss**			D	**Dryers costs saving**		
	Circulation Method				Conservation drying - 14%		
	StorageTemperature	32	Celsius		Average energy consumption (1% moisture content)	22.00	Baht
	Paddy respiration loss	67.2	Tons		Energy consumption	2,904,000.00	Baht
	Losses Value	537,600.00	Baht		Combination drying - 15%		
	Cooling Conservation method				Energy consumption	2,640,000.00	Baht
	StorageTemperature	22	Celsius		**Benefits**	**264,000.00**	**Baht**
	Paddy respiration loss	15.36	Tons	E.	**Circulation cost saving**		
	Losses Value	122,880.00	Baht		Average circulation cost per ton per circulation cycle	47.70	Baht
	Benefits	**414,720.00**	**Baht**		Circulation cost saving	2,862,000.00	Baht
B	**Greater rice yield**				**Benefits**	**2,862,000.00**	**Baht**
	Conservation drying				Total Benefits		
	Rice yield	50.4	%	A	Respiration loss	414,720.00	Baht
	Price	90,720,000.00	Baht	B	Greater head rice yield	2,512,800.00	Baht
	Broken rice yield	19.6	%	C	Weight gain	1,113,600.00	Baht
	Price	21,168,000.00	Baht	D	Dryer costs saving	264,000.00	Baht
	Total selling price	111,888,000.00	Baht	E	Circulation cost saving	2,862,000.00	Baht
	Combination drying				**Benefits**	**7,167,120.00**	**Baht**
	Rice yield	53.89	%		Variable costs		
	Price	97,002,000.00	Baht		Energy consumption	468,000.00	Baht
	Broken rice yield	16.11	%		Maintenance cost	90,000.00	Baht
	Price	17,398,800.00	Baht		**Costs**	**558,000.00**	**Baht**
	Total selling price	114,400,800.00	Baht		Net Benefit		
	Benefits	**2,512,800.00**	**Baht**		**Total Benefits - Variable costs**	**6,609,120.00**	**Baht**
C.	**Weight Gain**						
	Conservation	14% moisture content			Total Investment		
	Combination	15% moisture content				**9,765,000.00**	**Baht**
	Weight gain	100*(15-14)/100-14					
	Weight gain	1.16	%		**Payback Peiod**	**1.48**	**Year(s)**
	Benefits	**1,113,600.00**	**Baht**				

Figure 50 Calculation example 7

Option 1 - Circulation to Cooling conservation							
Payback period calculation sheet - example 8							
1	Storage Quantity per year	12000	Ton(s)		Grain cooling unit	3	Unit(s)
2	Storae period per year	120	Days		Price of grain cooling unit A5000	2,980,000.00	Baht
3	Average moisture content (input)	25	%		Unit investment	**8,940,000.00**	Baht
4	Storage moisture content	14	%		Warehouse dimension		
5	Paddy price	8,000.00	Baht per ton		Length	60	Meters
6	Head rice price	15,000.00	Baht per ton		Width	30	Meters
7	Broken rice price	9,000.00	Baht per ton		Recommended Height	12.12	Meters
8	Storage Temperature	22	Celsius		Outside air distribution costs	540,000.00	Baht
9	Heat generation ratio	0.16	KJ per ton		Inside air distribution costs	540,000.00	Baht
10	Drying cost	220	Baht per ton		Air distribution costs	**1,080,000.00**	Baht
11	Electricity cost	1.95	Baht per unit		Total Investment	**10,020,000.00**	Baht
A.	**Respiration Loss**			D	**Dryers costs saving**		
	Circulation Method				Conservation drying - 14%		
	StorageTemperature	32	Celsius		Average energy consumption (1% moisture content)	22.00	Baht
	Paddy respiration loss	67.2	Tons		Energy consumption	2,904,000.00	Baht
	Losses Value	537,600.00	Baht		Combination drying - 15%		
	Cooling Conservation method				Energy consumption	2,640,000.00	Baht
	StorageTemperature	22	Celsius		**Benefits**	**264,000.00**	**Baht**
	Paddy respiration loss	15.36	Tons	E.	**Circulation cost saving**		
	Losses Value	122,880.00	Baht		Average circulation cost per ton per circulation cycle	47.70	Baht
	Benefits	**414,720.00**	**Baht**		Circulation cost saving	2,862,000.00	Baht
B	**Greater rice yield**				**Benefits**	**2,862,000.00**	**Baht**
	Conservation drying				Total Benefits		
	Rice yield	50.4	%	A	Respiration loss	414,720.00	Baht
	Price	90,720,000.00	Baht	B	Greater head rice yield	2,512,800.00	Baht
	Broken rice yield	19.6	%	C	Weight gain	1,113,600.00	Baht
	Price	21,168,000.00	Baht	D	Dryer costs saving	264,000.00	Baht
	Total selling price	111,888,000.00	Baht	E	Circulation cost saving	2,862,000.00	Baht
	Combination drying				**Benefits**	**7,167,120.00**	**Baht**
	Rice yield	53.89	%		Variable costs		
	Price	97,002,000.00	Baht		Energy consumption	468,000.00	Baht
	Broken rice yield	16.11	%		Maintenance cost	90,000.00	Baht
	Price	17,398,800.00	Baht		**Costs**	**558,000.00**	**Baht**
	Total selling price	114,400,800.00	Baht		Net Benefit		
	Benefits	**2,512,800.00**	**Baht**		**Total Benefits - Variable costs**	**6,609,120.00**	**Baht**
C.	**Weight Gain**						
	Conservation	14% moisture content			Total Investment		
	Combination	15% moisture content				**10,020,000.00**	**Baht**
	Weight gain	100*(15-14)/100-14			**Payback Peiod**	**1.52**	**Year(s)**
	Weight gain	1.16	%				
	Benefits	**1,113,600.00**	**Baht**				

Figure 51 Calculation example 8

Option 1 - Circulation to Cooling conservation							
Payback period calculation sheet - example 9							
1	Storage Quantity per year	12000	Ton(s)		Grain cooling unit	3	Unit(s)
2	Storae period per year	300	Days		Price of grain cooling unit A5000	2,980,000.00	Baht
3	Average moisture content (input)	25	%		Unit investment	**8,940,000.00**	Baht
4	Storage moisture content	14	%		Warehouse dimension		
5	Paddy price	8,000.00	Baht per ton		Length	60	Meters
6	Head rice price	15,000.00	Baht per ton		Width	30	Meters
7	Broken rice price	9,000.00	Baht per ton		Recommended Height	12.12	Meters
8	Storage Temperature	22	Celsius		Outside air distribution costs	540,000.00	Baht
9	Heat generation ratio	0.16	KJ per ton		Inside air distribution costs	540,000.00	Baht
10	Drying cost	220	Baht per ton		Air distribution costs	**1,080,000.00**	Baht
11	Electricity cost	1.95	Baht per unit		Total Investment	**10,020,000.00**	Baht
A.	**Respiration Loss**			D	**Dryers costs saving**		
	Circulation Method				Conservation drying - 14%		
	StorageTemperature	32	Celsius		Average energy consumption (1% moisture content)	22.00	Baht
	Paddy respiration loss	168	Tons		Energy consumption	2,904,000.00	Baht
	Losses Value	1,344,000.00	Baht		Combination drying - 15%		
	Cooling Conservation method				Energy consumption	2,640,000.00	Baht
	StorageTemperature	22	Celsius		**Benefits**	**264,000.00**	**Baht**
	Paddy respiration loss	38.4	Tons	E.	**Circulation cost saving**		
	Losses Value	307,200.00	Baht		Average circulation cost per ton per circulation cycle	47.70	Baht
	Benefits	**1,036,800.00**	**Baht**		Circulation cost saving	7,441,200.00	Baht
B	**Greater rice yield**				**Benefits**	**7,441,200.00**	**Baht**
	Conservation drying				Total Benefits		
	Rice yield	50.4	%	A	Respiration loss	1,036,800.00	Baht
	Price	90,720,000.00	Baht	B	Greater head rice yield	2,512,800.00	Baht
	Broken rice yield	19.6	%	C	Weight gain	1,113,600.00	Baht
	Price	21,168,000.00	Baht	D	Dryer costs saving	264,000.00	Baht
	Total selling price	111,888,000.00	Baht	E	Circulation cost saving	7,441,200.00	Baht
	Combination drying				**Benefits**	**12,368,400.00**	**Baht**
	Rice yield	53.89	%		Variable costs		
	Price	97,002,000.00	Baht		Energy consumption	1,170,000.00	Baht
	Broken rice yield	16.11	%		Maintenance cost	90,000.00	Baht
	Price	17,398,800.00	Baht		**Costs**	**1,260,000.00**	**Baht**
	Total selling price	114,400,800.00	Baht		Net Benefit		
	Benefits	**2,512,800.00**	**Baht**		**Total Benefits - Variable costs**	**11,108,400.00**	**Baht**
C.	**Weight Gain**						
	Conservation	14% moisture content			Total Investment		
	Combination	15% moisture content				**10,020,000.00**	**Baht**
	Weight gain	100*(15-14)/100-14			**Payback Peiod**	**0.90**	**Year(s)**
	Weight gain	1.16	%				
	Benefits	**1,113,600.00**	**Baht**				

Figure 52 Calculation example 9

Option 1 - Circulation to Cooling conservation							
Payback period calculation sheet - example 10							
1	Storage Quantity per year	12000	Ton(s)		Grain cooling unit	3	Unit(s)
2	Storae period per year	365	Days		Price of grain cooling unit A5000	2,980,000.00	Baht
3	Average moisture content (input)	25	%		Unit investment	**8,940,000.00**	Baht
4	Storage moisture content	14	%		Warehouse dimension		
5	Paddy price	8,000.00	Baht per ton		Length	60	Meters
6	Head rice price	15,000.00	Baht per ton		Width	30	Meters
7	Broken rice price	9,000.00	Baht per ton		Recommended Height	12.12	Meters
8	Storage Temperature	22	Celsius		Outside air distribution costs	540,000.00	Baht
9	Heat generation ratio	0.16	KJ per ton		Inside air distribution costs	540,000.00	Baht
10	Drying cost	220	Baht per ton		Air distribution costs	**1,080,000.00**	Baht
11	Electricity cost	1.95	Baht per unit		Total Investment	**10,020,000.00**	Baht
A.	**Respiration Loss**			D	**Dryers costs saving**		
	Circulation Method				Conservation drying - 14%		
	StorageTemperature	32	Celsius		Average energy consumption (1% moisture content)	22.00	Baht
	Paddy respiration loss	204.4	Tons		Energy consumption	2,904,000.00	Baht
	Losses Value	1,635,200.00	Baht		Combination drying - 15%		
	Cooling Conservation method				Energy consumption	2,640,000.00	Baht
	StorageTemperature	22	Celsius		**Benefits**	**264,000.00**	**Baht**
	Paddy respiration loss	46.72	Tons	E.	**Circulation cost saving**		
	Losses Value	373,760.00	Baht		Average circulation cost per ton per circulation cycle	47.70	Baht
	Benefits	**1,261,440.00**	**Baht**		Circulation cost saving	9,158,400.00	Baht
B	**Greater rice yield**				**Benefits**	**9,158,400.00**	**Baht**
	Conservation drying				Total Benefits		
	Rice yield	50.4	%	A	Respiration loss	1,261,440.00	Baht
	Price	90,720,000.00	Baht	B	Greater head rice yield	2,512,800.00	Baht
	Broken rice yield	19.6	%	C	Weight gain	1,113,600.00	Baht
	Price	21,168,000.00	Baht	D	Dryer costs saving	264,000.00	Baht
	Total selling price	111,888,000.00	Baht	E	Circulation cost saving	9,158,400.00	Baht
	Combination drying				**Benefits**	**14,310,240.00**	**Baht**
	Rice yield	53.89	%		Variable costs		
	Price	97,002,000.00	Baht		Energy consumption	1,404,000.00	Baht
	Broken rice yield	16.11	%		Maintenance cost	90,000.00	Baht
	Price	17,398,800.00	Baht		**Costs**	**1,494,000.00**	**Baht**
	Total selling price	114,400,800.00	Baht		Net Benefit		
	Benefits	**2,512,800.00**	**Baht**		**Total Benefits - Variable costs**	**12,816,240.00**	**Baht**
C.	**Weight Gain**						
	Conservation	14% moisture content			Total Investment		
	Combination	15% moisture content				**10,020,000.00**	**Baht**
	Weight gain	100*(15-14)/100-14			**Payback Peiod**	**0.78**	**Year(s)**
	Weight gain	1.16	%				
	Benefits	**1,113,600.00**	**Baht**				

Figure 53 Calculation example 10

Option 1 - Circulation to Cooling conservation							
Payback period calculation sheet - example 11							
1	Storage Quantity per year	10000	Ton(s)		Grain cooling unit	2	Unit(s)
2	Storae period per year	365	Days		Price of grain cooling unit A5000	2,980,000.00	Baht
3	Average moisture content (input)	25	%		Unit investment	**5,960,000.00**	Baht
4	Storage moisture content	14	%		Warehouse dimension		
5	Paddy price	8,000.00	Baht per ton		Length	60	Meters
6	Head rice price	15,000.00	Baht per ton		Width	30	Meters
7	Broken rice price	9,000.00	Baht per ton		Recommended Height	10.10	Meters
8	Storage Temperature	22	Celsius		Outside air distribution costs	540,000.00	Baht
9	Heat generation ratio	0.16	KJ per ton		Inside air distribution costs	540,000.00	Baht
10	Drying cost	220	Baht per ton		Air distribution costs	**1,080,000.00**	Baht
11	Electricity cost	1.95	Baht per unit		Total Investment	**7,040,000.00**	Baht
A.	**Respiration Loss**			D	**Dryers costs saving**		
	Circulation Method				Conservation drying - 14%		
	StorageTemperature	32	Celsius		Average energy consumption (1% moisture content)	22.00	Baht
	Paddy respiration loss	170.3333333	Tons		Energy consumption	2,420,000.00	Baht
	Losses Value	1,362,666.67	Baht		Combination drying - 15%		
	Cooling Conservation method				Energy consumption	2,200,000.00	Baht
	StorageTemperature	22	Celsius		**Benefits**	**220,000.00**	**Baht**
	Paddy respiration loss	38.93333333	Tons	E.	**Circulation cost saving**		
	Losses Value	311,466.67	Baht		Average circulation cost per ton per circulation cycle	47.70	Baht
	Benefits	**1,051,200.00**	**Baht**		Circulation cost saving	7,632,000.00	Baht
B	**Greater rice yield**				**Benefits**	**7,632,000.00**	**Baht**
	Conservation drying				Total Benefits		
	Rice yield	50.4	%	A	Respiration loss	1,051,200.00	Baht
	Price	75,600,000.00	Baht	B	Greater head rice yield	2,094,000.00	Baht
	Broken rice yield	19.6	%	C	Weight gain	928,000.00	Baht
	Price	17,640,000.00	Baht	D	Dryer costs saving	220,000.00	Baht
	Total selling price	93,240,000.00	Baht	E	Circulation cost saving	7,632,000.00	Baht
	Combination drying				**Benefits**	**11,925,200.00**	**Baht**
	Rice yield	53.89	%		Variable costs		
	Price	80,835,000.00	Baht		Energy consumption	1,170,000.00	Baht
	Broken rice yield	16.11	%		Maintenance cost	60,000.00	Baht
	Price	14,499,000.00	Baht		**Costs**	**1,230,000.00**	**Baht**
	Total selling price	95,334,000.00	Baht		Net Benefit		
	Benefits	**2,094,000.00**	**Baht**		**Total Benefits - Variable costs**	**10,695,200.00**	**Baht**
C.	**Weight Gain**						
	Conservation	14% moisture content			Total Investment		
	Combination	15% moisture content				**7,040,000.00**	**Baht**
	Weight gain	100*(15-14)/100-14					
	Weight gain	1.16	%		**Payback Peiod**	**0.66**	**Year(s)**
	Benefits	**928,000.00**	**Baht**				

Figure 54 Calculation example 11

Option 1 - Circulation to Cooling conservation							
Payback period calculation sheet - example 12							
1	Storage Quantity per year	10000	Ton(s)		Grain cooling unit	2	Unit(s)
2	Storae period per year	365	Days		Price of grain cooling unit A5000	2,980,000.00	Baht
3	Average moisture content (input)	25	%		Unit investment	**5,960,000.00**	Baht
4	Storage moisture content	14	%		Warehouse dimension		
5	Paddy price	8,000.00	Baht per ton		Length		Meters
6	Head rice price	15,000.00	Baht per ton		Width		Meters
7	Broken rice price	9,000.00	Baht per ton		Recommended Height		Meters
8	Storage Temperature	22	Celsius		Outside air distribution costs	-	Baht
9	Heat generation ratio	0.16	KJ per ton		Inside air distribution costs	-	Baht
10	Drying cost	220	Baht per ton		Air distribution costs	-	Baht
11	Electricity cost	1.95	Baht per unit		Total Investment	**5,960,000.00**	Baht
A.	**Respiration Loss**			D	**Dryers costs saving**		
	Circulation Method				Conservation drying - 14%		
	StorageTemperature	32	Celsius		Average energy consumption (1% moisture content)	22.00	Baht
	Paddy respiration loss	170.3333333	Tons		Energy consumption	2,420,000.00	Baht
	Losses Value	1,362,666.67	Baht		Combination drying - 15%		
	Cooling Conservation method				Energy consumption	2,200,000.00	Baht
	StorageTemperature	22	Celsius		**Benefits**	**220,000.00**	**Baht**
	Paddy respiration loss	38.93333333	Tons	E.	**Circulation cost saving**		
	Losses Value	311,466.67	Baht		Average circulation cost per ton per circulation cycle	47.70	Baht
	Benefits	**1,051,200.00**	**Baht**		Circulation cost saving	7,632,000.00	Baht
B	**Greater rice yield**				**Benefits**	**7,632,000.00**	**Baht**
	Conservation drying				Total Benefits		
	Rice yield	50.4	%	A	Respiration loss	1,051,200.00	Baht
	Price	75,600,000.00	Baht	B	Greater head rice yield	2,094,000.00	Baht
	Broken rice yield	19.6	%	C	Weight gain	928,000.00	Baht
	Price	17,640,000.00	Baht	D	Dryer costs saving	220,000.00	Baht
	Total selling price	93,240,000.00	Baht	E	Circulation cost saving	7,632,000.00	Baht
	Combination drying				**Benefits**	**11,925,200.00**	**Baht**
	Rice yield	53.89	%		Variable costs		
	Price	80,835,000.00	Baht		Energy consumption	1,170,000.00	Baht
	Broken rice yield	16.11	%		Maintenance cost	60,000.00	Baht
	Price	14,499,000.00	Baht		**Costs**	**1,230,000.00**	**Baht**
	Total selling price	95,334,000.00	Baht		Net Benefit		
	Benefits	**2,094,000.00**	**Baht**		**Total Benefits - Variable costs**	**10,695,200.00**	**Baht**
C.	**Weight Gain**						
	Conservation	14% moisture content			Total Investment		
	Combination	15% moisture content				**5,960,000.00**	**Baht**
	Weight gain	100*(15-14)/100-14					
	Weight gain	1.16	%		**Payback Peiod**	**0.56**	**Year(s)**
	Benefits	**928,000.00**	**Baht**				

Figure 55 Calculation example 12

Transformation option 2: ***Transformation from Industrial fans ventilation method to cooling conservation method by using grain cooling unit.***

This transformation option was assumed the industrial fans ventilation method of both silo storage and warehouse storage was already equipped with the air distribution system. So, the only investment in this option is grain cooling unit. There are some differences between this 2 method which are the energy consumption costs, temperature in storage facility and the yield of head rice and broken rice.

In transformation option 2, this study used 5 examples to show the results of benefits and costs for each example and also the payback period of each example as same as the option 1. There are 2 independent variables for each example which are storage quantity per year and storage period per year. Others variables are constant number to clearly show the differences between each example. All the constant variables are the same number as in option 1. First constant variable is average input moisture content which fixed at 25%. Second, the target moisture content for storage is 14%, In addition, paddy price is 8,000 baht per ton. Head rice price is 15,000 Baht per ton. Broken rice price is 9,000 Baht. Temperature in the storage facility is at 22 degree Celsius. Heat generation is 0.16 KJ per ton. Drying cost is 220 Baht per ton and electricity cost is 1.95 baht per kWh. Then, the independent variables for each example show in the following table.

The difference of storage quantity and storage period between each case in option 2 is only to show which case is the best case for paddy storage when the air distribution system is already equipped with the storage facility.

Table 18 independent variables for example 13 to 17

Example	Storage Quantity per year	Storage period per year
13	3,000 tons	90 days
14	5,000 tons	90 days
15	5,000 tons	120 days
16	8,000 tons	365 days
17	10,000 tons	365 days

Option 2 - Fans to Cooling conservation							
Payback period calculation sheet - example 13							
1	Storage Quantity per year	3000	Ton(s)		Grain cooling unit	1	Unit(s)
2	Storae period per year	90	Days		Price of grain cooling unit A5000	2,980,000.00	Baht
3	Average moisture content (input)	25	%		Unit investment	**2,980,000.00**	Baht
4	Storage moisture content	14	%				
5	Paddy price	8,000.00	Baht per ton				
6	Head rice price	15,000.00	Baht per ton				
7	Broken rice price	9,000.00	Baht per ton				
8	Storage Temperature	22	Celsius				
9	Heat generation ratio	0.16	KJ per ton				
10	Drying cost	22	Baht per ton				
11	Electricity cost	1.95	Baht per unit		Total Investment	**2,980,000.00**	Baht
A.	**Respiration Loss**			D	**Dryers costs saving**		
	Circulation Method				Conservation drying - 14%		
	StorageTemperature	30	Celsius		Average energy consumption per 1% moisture content	22	Baht
	Paddy respiration loss	9	Tons		Energy consumption	726,000.00	Baht
	Losses Value	72,000.00	Baht		Combination drying - 15%		
	Cooling Conservation method				Energy consumption	660,000.00	Baht
	StorageTemperature	22	Celsius		**Benefits**	**66,000.00**	**Baht**
	Paddy respiration loss	2.88	Tons	E.	**Fans energy cost saving**		
	Losses Value	23,040.00	Baht		Average energy cost per ton per cycle	31.50	Baht
	Benefits	**48,960.00**	**Baht**		Fans energy cost saving	661,500.00	Baht
B	**Greater rice yield**				**Benefits**	**661,500.00**	**Baht**
	Conservation drying				Total Benefits		
	Rice yield	50.5	%	A	Respiration loss	48,960.00	Baht
	Price	22,725,000.00	Baht	B	Greater head rice yield	610,200.00	Baht
	Broken rice yield	19.5	%	C	Weight gain	278,400.00	Baht
	Price	5,265,000.00	Baht	D	Dryer costs saving	66,000.00	Baht
	Total selling price	27,990,000.00	Baht	E	Fans energy cost saving	661,500.00	Baht
	Combination drying				**Benefits**	**1,665,060.00**	**Baht**
	Rice yield	53.89	%		Variable costs		
	Price	24,250,500.00	Baht		Energy consumption	117,000.00	Baht
	Broken rice yield	16.11	%		Maintenance cost	30,000.00	Baht
	Price	4,349,700.00	Baht		**Costs**	**147,000.00**	**Baht**
	Total selling price	28,600,200.00	Baht		Net Benefit		
	Benefits	**610,200.00**	**Baht**		**Total Benefits - Variable costs**	**1,518,060.00**	**Baht**
C.	**Weight Gain**						
	Conservation	14% moisture content			Total Investment		
	Combination	15% moisture content				**2,980,000.00**	**Baht**
	Weight gain	100*(15-14)/100-14					
	Weight gain	1.16	%		**Payback Peiod**	**1.96**	**Year(s)**
	Benefits	**278,400.00**	**Baht**				

Figure 56 Calculation example 13

Option 2 - Fans to Cooling conservation							
Payback period calculation sheet - example 14							
1	Storage Quantity per year	5000	Ton(s)		Grain cooling unit	1	Unit(s)
2	Storae period per year	90	Days		Price of grain cooling unit A5000	2,980,000.00	Baht
3	Average moisture content (input)	25	%		Unit investment	**2,980,000.00**	Baht
4	Storage moisture content	14	%				
5	Paddy price	8,000.00	Baht per ton				
6	Head rice price	15,000.00	Baht per ton				
7	Broken rice price	9,000.00	Baht per ton				
8	Storage Temperature	22	Celsius				
9	Heat generation ratio	0.16	KJ per ton				
10	Drying cost	22	Baht per ton				
11	Electricity cost	1.95	Baht per unit		Total Investment	**2,980,000.00**	Baht
A.	**Respiration Loss**			D	**Dryers costs saving**		
	Circulation Method				Conservation drying - 14%		
	StorageTemperature	30	Celsius		Average energy consumption per 1% moisture content	22	Baht
	Paddy respiration loss	15	Tons		Energy consumption	1,210,000.00	Baht
	Losses Value	120,000.00	Baht		Combination drying - 15%		
	Cooling Conservation method				Energy consumption	1,100,000.00	Baht
	StorageTemperature	22	Celsius		**Benefits**	**110,000.00**	**Baht**
	Paddy respiration loss	4.8	Tons	E.	**Fans energy cost saving**		
	Losses Value	38,400.00	Baht		Average energy cost per ton per cycle	31.50	Baht
	Benefits	**81,600.00**	**Baht**		Fans energy cost saving	1,102,500.00	Baht
B	**Greater rice yield**				**Benefits**	**1,102,500.00**	**Baht**
	Conservation drying				Total Benefits		
	Rice yield	50.5	%	A	Respiration loss	81,600.00	Baht
	Price	37,875,000.00	Baht	B	Greater head rice yield	1,017,000.00	Baht
	Broken rice yield	19.5	%	C	Weight gain	464,000.00	Baht
	Price	8,775,000.00	Baht	D	Dryer costs saving	110,000.00	Baht
	Total selling price	46,650,000.00	Baht	E	Fans energy cost saving	1,102,500.00	Baht
	Combination drying				**Benefits**	**2,775,100.00**	**Baht**
	Rice yield	53.89	%		Variable costs		
	Price	40,417,500.00	Baht		Energy consumption	195,000.00	Baht
	Broken rice yield	16.11	%		Maintenance cost	30,000.00	Baht
	Price	7,249,500.00	Baht		**Costs**	**225,000.00**	**Baht**
	Total selling price	47,667,000.00	Baht		Net Benefit		
	Benefits	**1,017,000.00**	**Baht**		**Total Benefits - Variable costs**	**2,550,100.00**	**Baht**
C.	**Weight Gain**						
	Conservation	14% moisture content			Total Investment		
	Combination	15% moisture content				**2,980,000.00**	**Baht**
	Weight gain	100*(15-14)/100-14			**Payback Peiod**	**1.17**	**Year(s)**
	Weight gain	1.16	%				
	Benefits	**464,000.00**	**Baht**				

Figure 57 Calculation example 14

Option 2 - Fans to Cooling conservation			
Payback period calculation sheet - example 15			
1	Storage Quantity per year	5000	Ton(s)
2	Storae period per year	120	Days
3	Average moisture content (input)	25	%
4	Storage moisture content	14	%
5	Paddy price	8,000.00	Baht per ton
6	Head rice price	15,000.00	Baht per ton
7	Broken rice price	9,000.00	Baht per ton
8	Storage Temperature	22	Celsius
9	Heat generation ratio	0.16	KJ per ton
10	Drying cost	22	Baht per ton
11	Electricity cost	1.95	Baht per unit

A.	**Respiration Loss**		
	Circulation Method		
	StorageTemperature	30	Celsius
	Paddy respiration loss	20	Tons
	Losses Value	160,000.00	Baht
	Cooling Conservation method		
	StorageTemperature	22	Celsius
	Paddy respiration loss	6.4	Tons
	Losses Value	51,200.00	Baht
	Benefits	**108,800.00**	**Baht**
B	**Greater rice yield**		
	Conservation drying		
	Rice yield	50.5	%
	Price	37,875,000.00	Baht
	Broken rice yield	19.5	%
	Price	8,775,000.00	Baht
	Total selling price	46,650,000.00	Baht
	Combination drying		
	Rice yield	53.89	%
	Price	40,417,500.00	Baht
	Broken rice yield	16.11	%
	Price	7,249,500.00	Baht
	Total selling price	47,667,000.00	Baht
	Benefits	**1,017,000.00**	**Baht**
C.	**Weight Gain**		
	Conservation	14% moisture content	
	Combination	15% moisture content	
	Weight gain	100*(15-14)/100-14	
	Weight gain	1.16	%
	Benefits	**464,000.00**	**Baht**

	Grain cooling unit	1	Unit(s)
	Price of grain cooling unit A5000	2,980,000.00	Baht
	Unit investment	**2,980,000.00**	Baht
	Total Investment	**2,980,000.00**	Baht

D	**Dryers costs saving**		
	Conservation drying - 14%		
	Average energy consumption per 1% moisture content	22	Baht
	Energy consumption	1,210,000.00	Baht
	Combination drying - 15%		
	Energy consumption	1,100,000.00	Baht
	Benefits	**110,000.00**	**Baht**
E.	**Fans energy cost saving**		
	Average energy cost per ton per cycle	31.50	Baht
	Fans energy cost saving	1,417,500.00	Baht
	Benefits	**1,417,500.00**	**Baht**
	Total Benefits		
A	Respiration loss	108,800.00	Baht
B	Greater head rice yield	1,017,000.00	Baht
C	Weight gain	464,000.00	Baht
D	Dryer costs saving	110,000.00	Baht
E	Fans energy cost saving	1,417,500.00	Baht
	Benefits	**3,117,300.00**	**Baht**
	Variable costs		
	Energy consumption	195,000.00	Baht
	Maintenance cost	30,000.00	Baht
	Costs	**225,000.00**	**Baht**
	Net Benefit		
	Total Benefits - Variable costs	**2,892,300.00**	**Baht**
	Total Investment	**2,980,000.00**	**Baht**
	Payback Peiod	**1.03**	**Year(s)**

Figure 58 Calculation example 15

Option 2 - Fans to Cooling conservation							
Payback period calculation sheet - example 16							
1	Storage Quantity per year	12000	Ton(s)		Grain cooling unit	3	Unit(s)
2	Storae period per year	365	Days		Price of grain cooling unit A5000	2,980,000.00	Baht
3	Average moisture content (input)	25	%		Unit investment	**8,940,000.00**	Baht
4	Storage moisture content	14	%				
5	Paddy price	8,000.00	Baht per ton				
6	Head rice price	15,000.00	Baht per ton				
7	Broken rice price	9,000.00	Baht per ton				
8	Storage Temperature	22	Celsius				
9	Heat generation ratio	0.16	KJ per ton				
10	Drying cost	22	Baht per ton				
11	Electricity cost	1.95	Baht per unit		Total Investment	**8,940,000.00**	Baht
A.	**Respiration Loss**			D	**Dryers costs saving**		
	Circulation Method				Conservation drying - 14%		
	StorageTemperature	30	Celsius		Average energy consumption per 1% moisture content	22	Baht
	Paddy respiration loss	146	Tons		Energy consumption	2,904,000.00	Baht
	Losses Value	1,168,000.00	Baht		Combination drying - 15%		
	Cooling Conservation method				Energy consumption	2,640,000.00	Baht
	StorageTemperature	22	Celsius		**Benefits**	**264,000.00**	**Baht**
	Paddy respiration loss	46.72	Tons	E.	**Fans energy cost saving**		
	Losses Value	373,760.00	Baht		Average energy cost per ton per cycle	31.50	Baht
	Benefits	**794,240.00**	**Baht**		Fans energy cost saving	10,206,000.00	Baht
B	**Greater rice yield**				**Benefits**	**10,206,000.00**	**Baht**
	Conservation drying				Total Benefits		
	Rice yield	50.5	%	A	Respiration loss	794,240.00	Baht
	Price	90,900,000.00	Baht	B	Greater head rice yield	2,440,800.00	Baht
	Broken rice yield	19.5	%	C	Weight gain	1,113,600.00	Baht
	Price	21,060,000.00	Baht	D	Dryer costs saving	264,000.00	Baht
	Total selling price	111,960,000.00	Baht	E	Fans energy cost saving	10,206,000.00	Baht
	Combination drying				**Benefits**	**14,818,640.00**	**Baht**
	Rice yield	53.89	%		Variable costs		
	Price	97,002,000.00	Baht		Energy consumption	1,404,000.00	Baht
	Broken rice yield	16.11	%		Maintenance cost	90,000.00	Baht
	Price	17,398,800.00	Baht		**Costs**	**1,494,000.00**	**Baht**
	Total selling price	114,400,800.00	Baht		Net Benefit		
	Benefits	**2,440,800.00**	**Baht**		**Total Benefits - Variable costs**	**13,324,640.00**	**Baht**
C.	**Weight Gain**						
	Conservation	14% moisture content			Total Investment		
	Combination	15% moisture content				**8,940,000.00**	**Baht**
	Weight gain	100*(15-14)/100-14			**Payback Peiod**	**0.67**	**Year(s)**
	Weight gain	1.16	%				
	Benefits	**1,113,600.00**	**Baht**				

Figure 59 Calculation example 16

Option 2 - Fans to Cooling conservation							
Payback period calculation sheet - example 17							
1	Storage Quantity per year	10000	Ton(s)		Grain cooling unit	2	Unit(s)
2	Storae period per year	365	Days		Price of grain cooling unit A5000	2,980,000.00	Baht
3	Average moisture content (input)	25	%		Unit investment	**5,960,000.00**	Baht
4	Storage moisture content	14	%				
5	Paddy price	8,000.00	Baht per ton				
6	Head rice price	15,000.00	Baht per ton				
7	Broken rice price	9,000.00	Baht per ton				
8	Storage Temperature	22	Celsius				
9	Heat generation ratio	0.16	KJ per ton				
10	Drying cost	22	Baht per ton				
11	Electricity cost	1.95	Baht per unit		Total Investment	**5,960,000.00**	Baht
A.	**Respiration Loss**			D	**Dryers costs saving**		
	Circulation Method				Conservation drying - 14%		
	StorageTemperature	30	Celsius		Average energy consumption per 1% moisture content	22	Baht
	Paddy respiration loss	121.6666667	Tons		Energy consumption	2,420,000.00	Baht
	Losses Value	973,333.33	Baht		Combination drying - 15%		
	Cooling Conservation method				Energy consumption	2,200,000.00	Baht
	StorageTemperature	22	Celsius		**Benefits**	**220,000.00**	**Baht**
	Paddy respiration loss	38.93333333	Tons	E.	**Fans energy cost saving**		
	Losses Value	311,466.67	Baht		Average energy cost per ton per cycle	31.50	Baht
	Benefits	**661,866.67**	**Baht**		Fans energy cost saving	8,505,000.00	Baht
B	**Greater rice yield**				**Benefits**	**8,505,000.00**	**Baht**
	Conservation drying				Total Benefits		
	Rice yield	50.5	%	A	Respiration loss	661,866.67	Baht
	Price	75,750,000.00	Baht	B	Greater head rice yield	2,034,000.00	Baht
	Broken rice yield	19.5	%	C	Weight gain	928,000.00	Baht
	Price	17,550,000.00	Baht	D	Dryer costs saving	220,000.00	Baht
	Total selling price	93,300,000.00	Baht	E	Fans energy cost saving	8,505,000.00	Baht
	Combination drying				**Benefits**	**12,348,866.67**	**Baht**
	Rice yield	53.89	%		Variable costs		
	Price	80,835,000.00	Baht		Energy consumption	1,170,000.00	Baht
	Broken rice yield	16.11	%		Maintenance cost	60,000.00	Baht
	Price	14,499,000.00	Baht		**Costs**	**1,230,000.00**	**Baht**
	Total selling price	95,334,000.00	Baht		Net Benefit		
	Benefits	**2,034,000.00**	**Baht**		**Total Benefits - Variable costs**	**11,118,866.67**	**Baht**
C.	**Weight Gain**						
	Conservation	14% moisture content			Total Investment		
	Combination	15% moisture content				**5,960,000.00**	**Baht**
	Weight gain	100*(15-14)/100-14			**Payback Peiod**	**0.54**	**Year(s)**
	Weight gain	1.16	%				
	Benefits	**928,000.00**	**Baht**				

Figure 60 Calculation example 17

4.8 Results analysis

Table 19 Results of examples 1 to 12

Example	Storage Quantity per year	Storage period per year	Storage type	Payback Period
1	3,000 tons	90 days	Silo	2.02 Years
2	3,000 tons	90 days	Warehouse (L: 50 m, W: 25 m.)	2.58 Years
3	5,000 tons	90 days	Silo	1.20 Years
4	5,000 tons	120 days	Silo	1.08 Years
5	10,000 tons	120 days	Silo	1.08 Years
6	12,000 tons	120 days	Silo	1.35 Years
7	12,000 tons	120 days	Warehouse (L: 50 m, W: 25 m.)	1.48 Years
8	12,000 tons	120 days	Warehouse (L: 60 m, W: 30 m.)	1.52 Years
9	12,000 tons	300 days	Warehouse (L: 60 m, W: 30 m.)	0.90 Years
10	12,000 tons	365 days	Warehouse (L: 60 m, W: 30 m.)	0.78 Years
11	10,000 tons	365 days	Warehouse (L: 60 m, W: 30 m.)	0.66 Years
12	10,000 tons	365 days	Silo	0.56 Years

Table 19 shows the results of 12 examples of transformation option 1. Example 1 and 2 have the same storage quantity per year and storage period per year but the storage type is different. Example 2 need to invest more on air distribution system because it does not equipped. So, 2.58 years is a payback period for example 2 which longer than example 1 around half a year. When compare example 1 and 3, the only different number is storage quantity that increase to 5,000 tons from 3,000 tons in example 1. As the selected model of grain cooling unit has a capacity of 5,000 tons and to get the best result of payback period, the storage quantity per year should be in the numbers that can be divided by 5,000 tons divisibly such as 5,000 tons, 10,000 tons or 20,000 tons.

For example 4, its storage period per year is 120 days which is longer than example 3 for 30 days. The result of payback period shows that example 4 is faster than example 3 for 0.12 year. With the same amount of storage quantity but different in storage period, the longer storage period leads to the shorter payback period. The different between example 4 and 5 shows that different amount of storage which divisibly by the capacity of the grain cooling unit is not affect the length of payback period. Both cases got the same payback period at 1.08 years. The different of example 6 and 7 is the same as the different between the example 1 and 2. In addition, example 8 has the different size of warehouse compare to the example 7 with the same storage quantity and period. Example 8 has a bigger warehouse than example 7 which need more investment on air distribution system. If the storage period per year is up to 10 months in example 9, the

length payback period of the investment is shorter than a year. Moreover, if the storage period is up to the maximum at 365 days per year, the payback period of example 10 is 0.78 years. If reduce the number of storage quantity from 12,000 tons to 10,000 tons of paddy with same storage period and type. The length of payback period goes down to 0.66 years. Finally, the best case of transformation option 1 was shown in example 12. With the storage quantity per year at 10,000 tons and the storage period is 365 days a year and no air distribution system needed, the shortest payback period time of transformation from circulation method to cooling conservation method is 0.56 years.

Table 20 Results of example 13 to 17

Example	Storage Quantity per year	Storage period per year	Payback period
13	3,000 tons	90 days	1.96 years
14	5,000 tons	90 days	1.16 years
15	5,000 tons	120 days	1.03 years
16	8,000 tons	365 days	0.67 years
17	10,000 tons	365 days	0.54 years

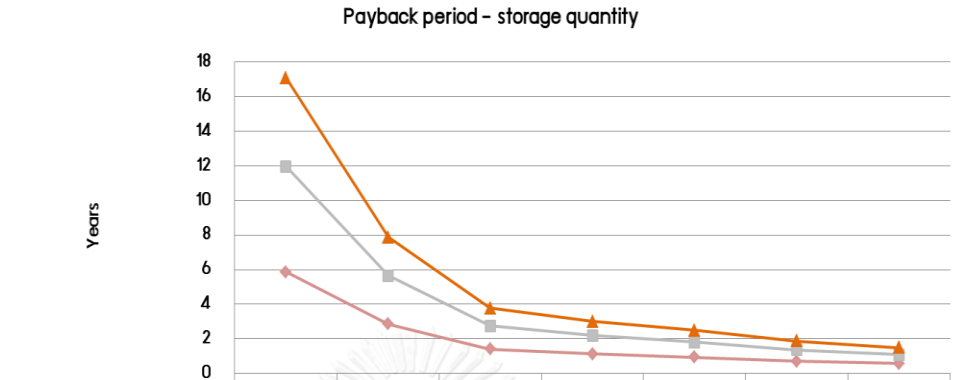
For transformation option 2 which changes from fan ventilation method to cooling conservation method for paddy storage, all the results of examples show in table 17. When compare example 13 to example 1 of option 1, the payback period of example 13 is shorter than example 1 because the cost of running the old method of example 13 is higher than example 1. So, the more benefits were happened in example 13 that leads to the shorter payback period. Example 14 to 16 show the different numbers of storage quantity per year and storage period per year for each case that affect the results. Lastly, the best case for option 2, which also the best case for both options, is example 17. With the divisibly storage quantity and maximum storage period per year, the shortest payback period for transforming to use cooling conservation method is 0.54 years.

Sensitivity Analysis

For every cases and options, there is sensitivity in the data that will be put into the calculation sheet. In this study, three types of data have been picked for analyze the sensitivity that can be happened in real practices which are storage quantity, storage period and the price difference between head rice price and broken rice price.

Figure 61 shows the sensitivity that happens when storage quantity per year change in the range between 500 tons to 5,000 tons. As in this study, the selected model of grain cooling unit is A5000 which has the capacity of 5,000 tons. So, the case that has storage

quantity per year slightly below 5,000 tons up to 5,000 tons will get the shortest payback period. As in figure 51, the shortest payback period is at 0.56 years which has storage



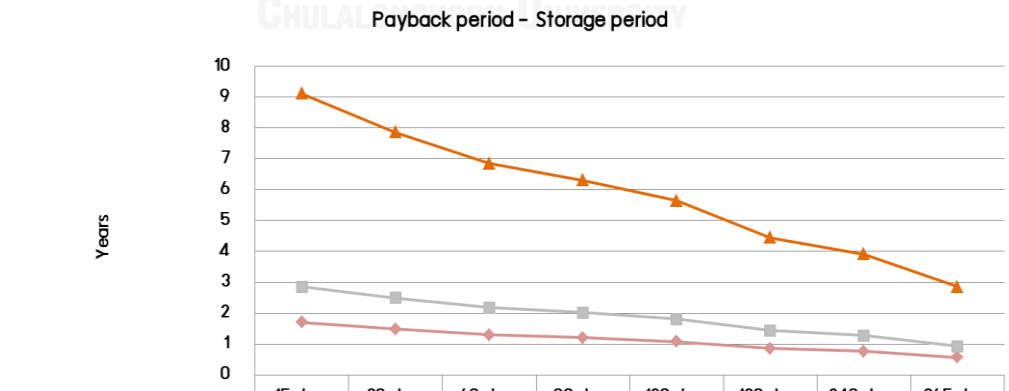
	500 tons	1000 tons	2000 tons	2500 tons	3000 tons	4000 tons	5000 tons
Payback period - 365 days	5.87	2.85	1.4	1.12	0.93	0.7	0.56
Payback period - 120 days	11.96	5.64	2.74	2.18	1.81	1.35	1.08
Payback period - 30 days	17.09	7.87	3.78	3	2.49	1.86	1.48

Figure 61 Sensitivity analysis - Storage quantity per year

quantity per year at 5,000 tons and storage period at 365 days per year. This is the best case that can be happened when transform to use cooling conservation method. So, the more storage quantity per year would get the shorter payback period result. On the other hand, the less storage quantity per year would also get the longer payback period. For example, with the same storage period at 365 days per year, but the storage quantity per year is only 500 tons, the payback period for this case is 5.87 years which extremely longer than the 5,000 tons case. In addition, the longest payback period in the figure 61 is the case that has storage quantity per year at 500 tons and the storage period per year at 30 days, the payback period for this case is 17.09 years. With this sensitivity that happened from the range of storage quantity per year, the range of payback period is change dramatically because of the limitations of this research that

selected the A5000 model. So, for future research, the model of the grain cooling unit should be selected base on the storage quantity per year. There are several models of grain cooling unit in the market start from 300 tons per year up to 8,000 tons per year.

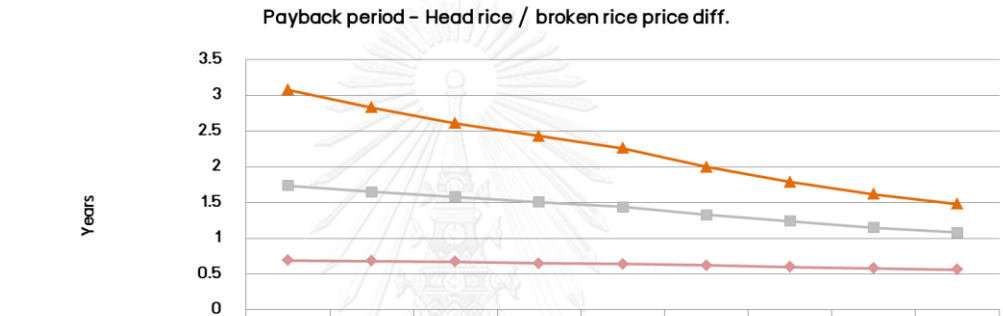
Next, the storage period per year is the factor that has been picked for analyze. Figure 52 shows the results of payback period that happened when the storage period has change in the range between 15 days to 365 days. The figure shows that the more storage period per year will get the shorter payback period. The best case is the same case as in figure 61 which has 5,000 tons storage quantity and 365 days storage period per year. But when the storage period per year is shorter down to 15 days, the payback period for this case is longer up to 1.7 years. In addition, the longest payback period in the figure 62 is the case that has 1,000 tons storage quantity per year and 15 days storage period per year which has a result of payback period at 9.12 years.



	15 days	30 days	60 days	90 days	120 days	180 days	240 days	365 days
Payback period - 5000 tons	1.7	1.48	1.3	1.2	1.08	0.86	0.76	0.56
Payback period - 3000 tons	2.86	2.49	2.18	2.02	1.81	1.44	1.27	0.93
Payback period - 1000 tons	9.12	7.87	6.85	6.31	5.64	4.45	3.91	2.85

Figure 62 Sensitivity analysis - Storage period per year

The last factor that has been picked is the price difference between the head rice price and the broken rice price. Figure 63 shows the trends while the difference price is shifting between 0 baht to 6,000 baht. The best case show the same result at 0.56 years with 6,000 baht price difference. But if the price difference is dissolve to 0 baht. The payback period is slightly longer up to 0.69 years. But if the storage period is down to 30 days with 0 baht price difference, the payback period is up to 3.08 years.



	0 Baht	500 Baht	1000 Baht	1500 Baht	2000 Baht	3000 Baht	4000 Baht	5000 Baht	6000 Baht
Payback period - 365 days	0.69	0.68	0.67	0.65	0.64	0.62	0.6	0.58	0.56
Payback period - 120 days	1.74	1.65	1.58	1.51	1.44	1.33	1.24	1.15	1.08
Payback period - 30 days	3.08	2.83	2.61	2.43	2.26	2	1.79	1.62	1.48

Figure 63 Sensitivity analysis - Price difference between head rice and broken rice

While comparing three sensitivity factors, the results show that storage quantity per year has the most impact to the payback period result follow by the storage period per year and the price difference between head rice price and broken rice price. But for future research that can choose the suitable grain cooling model which matched the storage quantity. Storage period per year would be the factor that impact the payback period the most.

5 Discussion and Conclusion

This is the last section of this study which includes the discussion of the cost benefits analysis and payback period which calculated and shows in the examples. The reasons that paddy storage operators have to use the cooling conservation method for long-term paddy storage will be listed. In addition, the advantages of long-term paddy storage will also be discussed to show why the operators need to store paddy for a period of time instead of just buy paddy, processing from paddy to rice and sell it. Next, three types of storage method will be compared and discussed that which one is suitable for which case because there are different goal for each business. The storage purpose for farmers, rice mills and rice exporters maybe different from each other. Moreover, how to use the grain cooling unit more efficient and effective will be recommended by the reference users. Furthermore, the limitations and difficulties of this study will be listed. Finally, the future trend of paddy storage in Thailand for next 5 to 10 years will be shown in the following context. Then, the conclusion of this study will be shown to summarize the overview of this research that the results are matched with the objective of the study. Lastly, the recommendations for further study and research were shown. This is another main reason for these study that to be helpful for other researchers and can be used all the information and results in real business.

5.1 Discussion of findings

5.1.1 The need of cooling conservation

According to Kolb [24], cooling conservation method for grain storage is widely accepted for all area around the world. Maintaining the quality of the grains, avoid insects and microorganisms and minimize all the losses that can be occurred during the storage period are the main objectives for grain storage. In this study, long-term paddy storage in Thailand has been picked for study and research. According to the surveys, circulation and fans ventilation method are extensively used in Thailand for last 20 years. With these two methods, there are many losses that happened during the storage that some operators did not mentioned about it or some operators know that the losses occurred but only speculate the amount of money that loss. With this study, calculation on benefits and costs of using grain cooling unit can be calculated and also the payback period of investment. According to Kolb & Braunbeck [4], there are five main benefits that can be calculated in number which are the respiration loss, greater head rice yield, weight gain, dryer cost saving and cost of running the existing method that can be dissolve by using grain cooling unit. Moreover, there are some more advantages that cannot be calculated in numbers which are conservation of harvest freshness, conservation of germinating quality, no yellow discoloration of rice and the cooling conservation can be implemented independently of weather conditions. In conclusion,

cooling conservation for long-term paddy storage presents many advantages, minimize losses and reduce risk on weather conditions.

5.1.2 Advantages of long-term paddy storage

Paddy is a type grain that needs to be store for a period of time before processing because of the taste of rice after cooked. In Thailand practices, rice need to be stored at least 3 months before selling for the best taste. So, rice that stored more than 3 months will be named as “old rice” and the price of old rice is higher than the price of freshly rice. Moreover, rice is agriculture goods which have daily sale price which possibly changes every day. In addition, the price of rice in Thailand changed seasonally. According to Ricepedia [31], in Thailand, it has 2 harvesting season which are in-season crop and out-season crop. Some varieties of rice can be growing once a year such as Hommali rice and Jasmine rice and some varieties can be growing twice a year. For that reason, the advantage of the long-term paddy storage is the rice mills can sell the good quality rice at the price that they satisfied. On the other hand, if the storage method is not proper, rice is forced to be sold at low price otherwise rice will be deteriorating and rotten.

5.1.3 Suitable method for paddy storage

As mentioned above, there are 3 different methods to store paddy which are circulation, fans ventilation and cooling conservation. Each method has different benefits and costs. For circulation method, this method is suitable for short-term paddy storage which store less than one month and also the small amount of paddy storage per year. For fans ventilation method, the main disadvantage of this method is weather condition. Fans can be turn on only when the ambient air is suitable for ventilate. The suitable air is the air that has lower temperature and lower relative humidity than the paddy bulk inside the storage facility. So, rainy season in Thailand which starts from May until October is the period that this method can be in trouble and need to monitor very carefully. According to Kolb & Braunbeck [4], for cooling conservation method, this method is suitable for any rice mill that store a bulk of paddy average more than 3 months per year. This method minimizes all the losses and also reduces the costs of operation.

5.1.4 How to use the grain cooling unit effectively

According to Barth [29], grain cooling unit is the unit that supplies the cold and dry air into the storage facility through the air distribution system. So, the size of silo and warehouse need to be calculated to plan the appropriate air distribution system for the maximum performance of the grain cooling unit. Moreover, the temperature monitoring system in the storage facility is another thing that can help to reduce the energy costs of the grain cooling unit. In practices, storage operator used the temperature monitoring

rod to measure the temperature by stab it into the bulk of paddy and then recorded by hand and only done once a day. According to Pfeuffer [32], there are the new temperatures monitoring system which is fully automatic and can be measure the temperature in the silo on operator's demand. This system also has the alert when the temperature reaches the target temperature. According to Kolb [24] when the temperatures reached, the grain cooling unit can be stopped to save the energy cost. On the other hand, when the temperature rises to the risky zone, the re-cooling process should begin by turn on the grain cooling unit. In addition, preventive maintenance of the grain cooling unit should be carefully done such as cleaning the air filters that should be done once a week and also system cleaning that can be done by the service team from the distributor.

5.1.5 Limitations of study and research

There are some characteristics that impacted the interpretation in this study. First thing that author faced is lack of prior research studies on this topic. There are some studies that linked with this topic but very limited number of research that focused on the financial part of paddy storage. Moreover, this study is mainly focus on rice mills in Thailand that has their own characteristic that different from others country. Next, the data that collected from the rice mills is not that accurate because of some secret on running the business and some data that this study need did not collect by the rice mills. For example, the temperatures in the storage facility or the target moisture content that

can be different depend on owner's requirement. In addition, there are some self-reported data that the author collected in term of selective memory from interviews and questionnaires. Therefore, average numbers from the data that collected from the surveying have been used in calculation formula such as head rice yield, circulation cost, circulation period, ventilation period and target storage temperature. Accessibility to the owner of the rice mills is another limitation for this study. Some data were collected from the operators or grain cooling users which they did not concern much on the financial part. In addition, a longitudinal effect on the data that has been collected is another problem that happened during the research. Some data need 3 to 6 months to collect because of the cooling cycle.

5.1.6 Future trends of paddy storage in Thailand

According to Thairicemillers [33], in last 10 to 20 years, more than 95 percent of paddy storage in Thailand was stored in rice mills. Circulation method is a traditional method that use for both silo storage and warehouse storage. Industrial fans ventilation is a method that some rice mill that store big amount of paddy because the costs of electricity is lower than the circulation cost and can avoid the broken percentage that can be increase during the circulation. For cooling conservation, the first unit of grain cooling has been used in Thailand since 1995, but it become more popular since there are the distributors in Thailand. Because, after sales service is needed with special knowledge that have to be trained. In 2016, more than 150 units of grain cooling were

operating but it still only used in big rice mill and exporters. With a little reference in financial view of using grain cooling unit, this study should be a tool for rice millers and farmers who interested in using this method. They can calculate with their own case of storage and also get the estimated payback period for their investment. As the contents and all the storage techniques knowledge can be found easily on the internet, the trends of paddy storage will be spread out to the small rice mills, farmer cooperative and individual farmers. The price of paddy will rise slowly with the stable rate because of growing rice need a period of time around 90 to 100 days before harvesting. New technology cannot speed up this process on the rice field not like electronic things that the price will drop year by year due to the better technology of assembling. So, cooling conservation method will be the top prefer method for future paddy storage all around the world. There are different models of grain cooling unit that suitable for every types of storage and the amount of paddy that need to be stored. To maximize profits and minimizes losses and costs are the main objectives of every business and in case of paddy storage the method that leads to that objectives is cooling conservation.

5.2 Conclusion

The main purpose of this study has been to provide financial analysis of cooling conservation method for long-term paddy storage. There are several methods that have been used to store paddy and rice. The method that this study provided is cooling

conservation which uses the grain cooling unit to supply the cold and dry air into the storage facility through the air distribution system.

Chapter 1 provided the introduction of this study. Begin with the background of this study that gives the basic information of paddy and rice. Then, the statement of problems will be explained such as the disadvantages and losses due to the bad and not suitable storage facility. Next, the objectives and scope of this study was listed. This study focused on long-term paddy storage. In addition, benefits and costs of each storage method also been discussed. Moreover, the payback period calculation sheet will be created. There are 2 cases of transformation that picked to calculate in this study which are transformation from circulation to cooling conservation and transformation from industrial fan to cooling conservation. Chapter 2 provided the literature review of this study that covered 6 main parts of this study. First part is costs-benefits analysis. Cost benefits analysis (CBA) is a method that helps to make a decision by quantify and list all the related information in financial terms especially on benefits and costs. This study mainly used this analysis to list all the benefits and costs that would happen when transform to use the cooling conservation method. Second part was focused about is about the payback period analysis. Payback period is the period of time that takes for a company to recover their original investment in a transformation project when net cash flow equals to zero. Payback period is a calculation that needs all the projected benefits and costs that will happened in the project. The shorter the payback period of the

project, the more attractive project will be to investment. Then, the facts about rice and paddy have been explained which told how was the rice and paddy market in this world. Fourth part was focused on the postharvest processes of paddy. There are the explanations of each process begin with harvesting, threshing, cleaning, drying, milling, grading, storage and packing process. In the fifth part, three kinds of postharvest technology, that related to this study has been intensively research, which are paddy drying, cooling conservation method and paddy storage. It shows explication of techniques and how to apply with existing method and facility. For paddy drying, this is a suddenly process that needs to be done within 24 hours after harvesting to avoid the losses due to spoilage of paddy. The safety moisture content for storage is worldwide accepted at 14%. Both types of drying which are sun drying and industrial drying have their own advantages and disadvantages. Industrial drying is suitable for big scale of drying capacity. Cost of sun drying is lower than industrial drying but it can be done only the sunny time and the broken rice rate is higher than industrial drying. For cooling conservation, the main benefits of this method are higher yield of rice that leads to higher selling price, reduce respiration loss of paddy, weight gain by using it combine with the dryers to reduce the moisture content and cost savings on dryers and existing method operation costs. The technique of cooling conservation method is to supply the cold and dry air through the air distribution system into the storage facility to avoid the losses and deteriorate paddy. The cost of using cooling conservation consists of 2 main

parts. First part is the investment on grain cooling unit and air distribution system. Second part is variable cost which consists of energy consumption of the unit and the maintenance cost of the unit. For paddy storage, it is an important task in post-harvest handling of paddy and rice. Paddy and rice spends most of their time in the storage period. Storage involves monitoring and treating the paddy as necessary in order to preserve its quality. Proper way of paddy storage can display qualities in the later process of milling, cooking and eating. The most important thing that need for storage facility is air distribution system. For warehouse storage, there are 2 traditional systems which are underfloor ventilation and half round ventilation. The new innovation method is telescope pipe ventilation which combines the advantages of both types together with the limitation of the maximum height that the bulk of paddy can be stored.

Chapter 3 provided the model development of this study. The benefits of using cooling conservation method for long-term paddy storage were explained in details. This section describe the reason that cooling conservation is better than others method. All benefits and costs were present in both financial term and non-financial term. Next, the data collection from the surveys and interviews was illustrated in the term that needed for this study. Data was collected from 84 rice mills in Thailand which covered all 3 types of storage methods. 59 of them are the rice mill that use the cooling conservation method, 15 of them use fans ventilation method and 10 of them use circulation method. There are many collected data that has been used in this study such as the target moisture

content before storage, target temperature in the storage facility, energy consumption of grain cooling unit, circulation cost, energy consumption of industrial fan and the head rice yield.

Chapter 4 provided all the analysis in this study. Begin with the analysis of advantages of using cooling conservation in financial terms. There are 5 benefits that can calculate in economic terms which are recovered of respiration loss, greater head rice yield, weight gain, dryer cost savings and cost of operates existing method will be disappear. Next is the investment analysis of transformation to cooling conservation method. The main original investment is the grain cooling unit and another investment is air distribution system. For air distribution system, it depends on the existing storage type and facility. There is the only one case that need to invest in air distribution system which is the existing method is circulation and store the paddy in warehouse storage. For silo storage and fan ventilation method user, the air distribution system is already equipped. Then, the costs of running the cooling conservation were analysed. There are 2 main costs which are energy consumption of the grain cooling unit and the maintenance cost of the unit. Then, the calculation of all benefits and costs, that will happen when transforming to use cooling conservation method, was shown by using an example for each option. After that, payback period calculation sheet template was created by the author. This template was combined all the benefits and costs of using cooling conservation method instead of existing method. There are 2 templates for each

transformation option. First option is transformation from circulation method to cooling conservation method and the second option is transformation from industrial fans ventilation method to cooling conservation method. Examples for each option, with different variables such as storage quantity per year and storage period per year, were calculated by using the template and shown the payback period for each example. In addition, the results of all examples have been analyzed to show which factor is affecting the result the most. With this study that picked the A5000 model to make a calculation, storage quantity per year is the factor that has the most impact to the payback period. Follow by the storage period per year that also impact the payback period but not at the same rate as storage quantity per year. But for further study, by selecting the model of grain cooling unit to suite with any amount of storage quantity per year, storage period per year will be the factor that have the most impact to the payback period instead of the storage quantity per year.

Discussion and conclusion were provided in chapter 5. The important of cooling conservation method has been discussed in this section. To Maintaining the quality of the grains, avoid insects and microorganisms and minimize all the losses that can be occurred during the storage period are the main objectives which can be done by using cooling conservation. Moreover, the advantage of the long-term paddy storage is the rice mill can sell the good quality rice at the price that they satisfied. On the other hand, if the storage method is not proper, rice is forced to be sold at low price otherwise rice

will be deteriorating and rotten. In addition, cooling conservation method may not be the best method for some cases. As there are 3 different methods to store paddy which are circulation, fans ventilation and cooling conservation, each method have their own strength and weakness. Circulation method is suitable for short-term paddy storage. Fans ventilation method can reduce all cost that need to circulate paddy substitute by the cost of energy consumption which lower than the circulation method. But the disadvantage of this method is weather conditions. For cooling conservation method, this method is suitable long-term paddy storage which store more than 3 months per year. This method minimizes all the losses and also reduces the costs of operation. Next, how to use the grain cooling unit most efficient and effective will be recommended by the reference users. Furthermore, the limitations and difficulties of this research will be listed. Then, the prediction about future trends of paddy storage in Thailand was discussed.

Eventually, the purpose of this study is to explain the advantages and disadvantages of cooling conservation. This method can be applied and adjusted with all types of grain and storage facilities to reduce insignificant losses and costs. This method will makes advantages and benefits for entire world of grain storage.

5.3 Recommendations for further study and research

There are some further study that can be used this study as a reference. First, this study selected only one model of grain cooling which has cooling capacity to take care 5,000 tons of paddy. So, there are different models of grain cooling unit that suitable for preferred storage quantity of each case. With different purpose of paddy storage in different business, farmers who may need to use the cooling conservation method is recommended to use the smallest model of grain cooling to reduce the energy consumption of the unit and no need a big investment on the grain cooling unit. For rice mills, it depends on their strategy on paddy storage, just selected the suitable model of grain cooling unit and try to focused on the selling price of the rice that change every day to maximize their profit with no concern about deteriorate paddy and rice. For rice exporters, in this type of business, grain cooling unit may use to store white rice which ready to ship. The advantages of storing rice is less than paddy but to protect the rice just from insects and mildews is worth for using grain cooling unit. Second, this study is only focused on paddy storage in Thailand. So, different kinds of grain can also use cooling conservation method for their storage. But the benefits and costs for each type of grain can be different. Also different area, landscape and weather conditions are also the main different on benefits and costs of cooling conservation method. Third, there are new technology product in the market that can be used to reduce operating cost and risks of cooling conservation method. This product is temperature monitoring system.

This system can be used with every types of storage facility to monitor the temperature in the silo storage. While using temperature monitoring system combined with cooling conservation method, the energy consumption will be reduced due to the accurate data of temperature inside the silo that will be show when to open the grain cooler and when to stop the grain cooler. Fourth, this study can be lead to doing the new business which is the paddy storage operator. Normally, the process of paddy storage will be done by rice mills and farmer. By using this study, new business can be done by knowing the benefits and costs of paddy storage by using cooling conservation method. It can be done by collecting the storage fees from farmer or rice mills or in term of trader that buy the paddy from farmers and then store it in the storage facility and then sell it to the rice mill for processing with the acceptable price. Fifth, this study can be proposed to the government for their paddy policy. For example, Thailand has a rice subsidy scheme policy that government promulgated. This is the scheme that government will buy the paddy directly from farmer and then rent the rice mill's storage facility to store the paddy. Rice mills will received the storage free from the government depends on the storage facility and storage method. This study will help rice mills to make a decision on transformation their existing method to cooling conservation method to gain more benefits. Moreover, the benefits of cooling conservation method will make Thailand's rice has better quality, reduce huge number of losses and the price of paddy will be higher.

6 Appendix

Surveying data – Cooling conservation method

ID	Storage Capcity per year (Tons)	Storage period per year (Tons)	Initial Moisture content (%)	Target Moisture content (%)	Real moisture content in the storage (%)	Target temperature in the storage (Celsius)	Supply air temperature (Celsius)	Energy consumption per ton per cycle (Baht)	Former rice yield (%)	Rice yield after use cooling conservation (%)
C1	2000	180	25	14.5	14.2	22	17.5	19	50	53.5
C2	3500	120	26	15	14.6	23	18	20	51.5	54
C3	4000	150	26	15	14.8	23	18	19	49	51.5
C4	8000	120	27	15.5	15.3	22	18	20	50	53.5
C5		120	27	15.5	15.3	22	18	20	50	53.5
C6	4000	150	24	14.5	14.4	24	18	19	51.5	54
C7	4500	90	25	15	14.8	23	17.5	20	50	53.5
C8	5000	90	26	15	14.8	22	18	18.5	49.5	53
C9	3000	120	26	14.5	14.5	22	18	18.5	49	52
C10	10000	180	28	15	14.7	24	18	19	50.5	53
C11		180	28	15	14.7	24	18	19	50.5	53
C12	8000	90	-	14.5	-	20	17	20	-	-
C13		90	-	14.5	-	20	17	20	-	-
C14	3000	120	26	15	15	23	18	18.5	51	54
C15	3500	120	28	15	14.8	23	17	22	51.5	54.5
C16	4000	150	25	15	14.6	22	17	20	50.5	53
C17	4000	150	28	15	14.7	23	17	20	51	53.5
C18	5000	90	-	14	-	20	17	20	-	-
C19	5000	90	-	14	-	20	17	19	-	-
C20	5000	180	28	15	14.9	21	17	18.5	51	55
C21	20000	90	-	14	-	20	17	21	-	-
C22		90	-	14	-	20	17	21	-	-
C23		90	-	14	-	20	17	21	-	-
C24		90	-	14	-	20	17	21	-	-
C25	10000	180	28	15	14.5	23	17	19	50.5	54
C26		180	28	15	14.5	23	17	19	50.5	54
C27	10000	180	28	15	14.7	23	17	18	50.5	53.5
C28		180	28	15	14.7	23	17	18	50.5	53.5
C29	4000	180	28	15	14.8	23	17	18.5	49.5	53
C30	7500	150	27	15	15	23	17	20	50.5	53
C31		150	27	15	15	23	17	20	50.5	53
C32	8000	150	28	15	14.7	22	17.5	19	51	54.5
C33		150	28	15	14.7	22	17.5	19	51	54.5
C34	10000	180	27	15.5	15.5	23	17.5	20	52.5	55.5
C35		180	27	15.5	15.5	23	17.5	20	52.5	55.5
N1	8500	90	28	15	14.8	21	17	22	49	52.5
N2		90	28	15	14.8	21	17	22	49	52.5
N3	4000	90	29	15	14.8	22	17	19	51	53.5
N4	9000	240	28	14.5	14.2	20	17	19	52	54.5
N5		240	28	14.5	14.2	20	17	19	52	54.5
N6	8000	180	27	14.5	14.1	22	17	18	50.5	53
N7		180	27	14.5	14.1	22	17	18	50.5	53
N8	4000	240	29	15	15	21	17	20	52	54.5

ID	Storage Capcity per year (Tons)	Storage period per year (Tons)	Initial Moisture content (%)	Target Moisture content (%)	Real moisture content in the storage (%)	Target temperature in the storage (Celsius)	Supply air temperature (Celsius)	Energy consumption per ton per cycle (Baht)	Former rice yield (%)	Rice yield after use cooling conservation (%)
NE1	4000	240	28	14.5	14.3	22	18	18	51	53.5
NE2	4000	240	27	14.5	14.4	23	18	18.5	51	54
NE3	10000	300	29	14.5	14.5	23	18	20	52.5	55
NE4		300	29	14.5	14.5	23	18	20	52.5	55
NE5	4500	300	28	15	14.8	22	17	18	50	54
NE6	15000	270	27	15	14.6	23	18	19	49.5	53
NE7		270	27	15	14.6	23	18	19	49.5	53
NE8		270	27	15	14.6	23	18	19	49.5	53
NE9	8000	300	28	14.5	14.3	23	18	18.5	52.5	56
NE10		300	28	14.5	14.3	23	18	18.5	52.5	56
NE11	20000	180	27	15.5	15.2	21	17.5	20	52	55.5
NE12		180	27	15.5	15.2	21	17.5	20	52	55.5
NE13		180	27	15.5	15.2	21	17.5	20	52	55.5
NE14		180	27	15.5	15.2	21	17.5	20	52	55.5
NE15	4000	240	26	15	15	23	18	22	49.5	53
NE16	4500	240	27	15	14.8	22	18	19	51	54.5
Avg.	4381.36	171.86	27.25	14.84	14.73	22.03	17.44	19.51	50.8	53.89
				Diff	0.11				Diff	3.09

Surveying data – Industrial fan ventilation method

ID	Storage Capcity per year (Tons)	Storage period per year (Tons)	Target Moisture content (%)	Real moisture content in the storage (%)	Energy consumption per ton per cycle (Baht)	Head rice yield (%)
C1	2500	60	14	13.7	32	50.5
C2	3500	70	14	13.8	29	50.5
C3	5000	60	14	13.8	35	49.5
C4	6000	90	14	14	35	49.5
C5	8000	45	14.5	14.3	32	51.5
N1	4000	60	14	14	33	51
N2	5000	60	14.5	14.2	34	50.5
N3	7500	75	14	13.8	29	50.5
N4	8000	60	14.5	14.3	35	50.5
N5	10000	90	14	14	28	51
NE1	5000	120	13.5	13.2	32	49.5
NE2	7000	90	14	13.9	33	49.5
NE3	7500	75	14	13.8	29	51
NE4	12000	90	14.5	14.4	28	51.5
NE5	15000	60	14.5	14.3	29	50.5
	7066.67	73.67	14.13	13.97	31.53	50.5
			Diff	0.17		

Surveying data – Circulation method

ID	Storage Capcity per year (Tons)	Storage period per year (Days)	Circulation cycle	Target Moisture content (%)	Real moisture content in the storage (%)	Energy consumption per ton per cycle (Baht)	Head rice yield (%)
C1	1500	60	25	14	13.7	45	50
C2	3000	70	21	14	13.6	50	51.5
C3	5000	60	25	14.5	14.1	40	49
C4	6000	90	20	14	13.8	42	50
N1	3500	60	28	14	13.6	48	49
N2	4000	60	30	14.5	14.2	52	49
N3	7500	75	25	14	13.8	45	51
NE1	3500	120	20	13.5	13.1	52	51
NE2	5000	90	21	14	13.5	55	51
NE3	6000	75	25	14.5	14.1	48	52.5
Avg	4500.00	76.00	24.00	14.10	13.75	47.70	50.4
				Diff	0.35		

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APPENDIX

VITA

Mister Chakaphan Chitsuthipakorn was on on 27th January 1990 in Nakhonsawan, Thailand. In 2008, he finished the high school from Saint Gabriel's College in Bangkok, Thailand. Then he continued his education in the bachelor degree of engineering as Information and communication Engineer from Chulalongkorn University, Thailand between 2008-2012. After bachelor graduation, he started his first job as an assistant managing director at DeeRungRuang co., Ltd. In 2013, he started the dual master degree of engineering from Chula System Engineering program which was cooperated between Chulalongkorn university, Thailand and University of Warwick, United Kingdom.