DEA & EESD
Energy Partnership Programme
between Vietnam and Denmark

Technology guideline for energy efficient dryers and heating systems in the wood processing industry

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Final

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INTRODUCTION

This guideline for optimization of heat supply and dryers in Vietnamese wood processing industry has been developed as a part of the cooperation between EESD and the Danish Energy Agency during 2022 and 2023.

The purpose of the guideline is to provide a structured workflow for how driers and heat supply systems in the wood processing industry can be analysed and optimized, i.e. which data that should be collected, which assessments should be made, which solutions that should be considered and how structured proposals for investments can be presented for the management in the companies.

The guideline is to be seen as a document that will undergo continued updates when new experiences are gathered from ongoing assessments in various Vietnamese wood processing industries. The guideline further has an important interface to other documents developed in the cooperation between EESD and the Danish Energy Agency, by example technology catalogues for efficiency of boiler and steam distribution systems.

The guideline has been prepared in close cooperation between The Danish Energy Agency, Viegand Maagøe and VETS.

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ABOUT THIS GUIDELINE

During site visits in wood processing industries in Vietnam, it has been experienced that significant energy saving potentials can be identified.

This is first of all caused by the fact that biomass waste from the production is considered to be a very cheap fuel so as the incentive for optimizing drier systems and steam boilers, where all thermal energy is used, is very limited. Next, drying chambers and management of the operation of these have traditionally not looked into all details regarding energy efficiency measures and therefore equipment and instrumentation to control the process are often of a relatively poor quality.

It must be expected that the market demand for biomass-fuels will increase significantly with increasing focus on CO_2-emissions in Vietnam as well as other countries in the region and therefore the value of biomass fuel must be expected to increase.

By that, the incentive to operate more efficient driers and steam boilers will be significant and there will be a need to stimulate the efforts to identify and implement more efficient solutions – first of all in terms of energy efficiency, but related to that also in terms of benefits like increased capacity, improved product quality, improved production logistics etc.

This guideline is intended to be used by industrial managers, technology providers and energy efficiency experts for the purpose of optimizing systems for drying of wood in wood industries, including the heat supply systems.

The guideline describes:

1. Fundamentals about the drying process in the wood processing industry
2. Measures to evaluate when improving energy efficiency
3. Initial screening/auditing of a drying system
4. Pre-feasibility study of energy efficiency investments
5. Feasibility study for the preferred solutions

The document makes reference to other documents developed under the Danish-Vietnamese cooperation on energy efficiency in industry.

1 Fundamentals of wood drying

Overall, fundamental aspects of wood drying are to be understood when designing energy- and cost-efficient solutions, both when rehabilitating existing installations and when planning new installations/expanding capacity.

This section describes how drying chambers and heat supply most often are built in Vietnamese wood processing industry and which energy losses and energy saving opportunities that can be identified both regarding the drying process and regarding the utility systems.

1.1 Conventional drying systems – technology description

Most wood drying systems consist of a serial of drying chambers that are operated individually with shared heat supply systems.

The drying chambers are operated in "batch mode", i.e. the chambers are initially loaded with wooden sticks/boards/other wood products and then heated over longer periods of time to remove moist in the wood to make it ready for furniture production.

An example of such drying chambers is shown in the below figure 1.

Figure 1 Typical example of a batch dryer in Vietnamese wood processing industry.

The drying process is operated under varying conditions during the drying sequence as the wood has a high moist content in the beginning of the drying phase and gradually becomes drier towards the end of the drying cycle. Temperature and humidity in the chamber therefore vary significantly during the drying.

Figure 2 below shows a cross-section of the installations in a typical drying chamber.

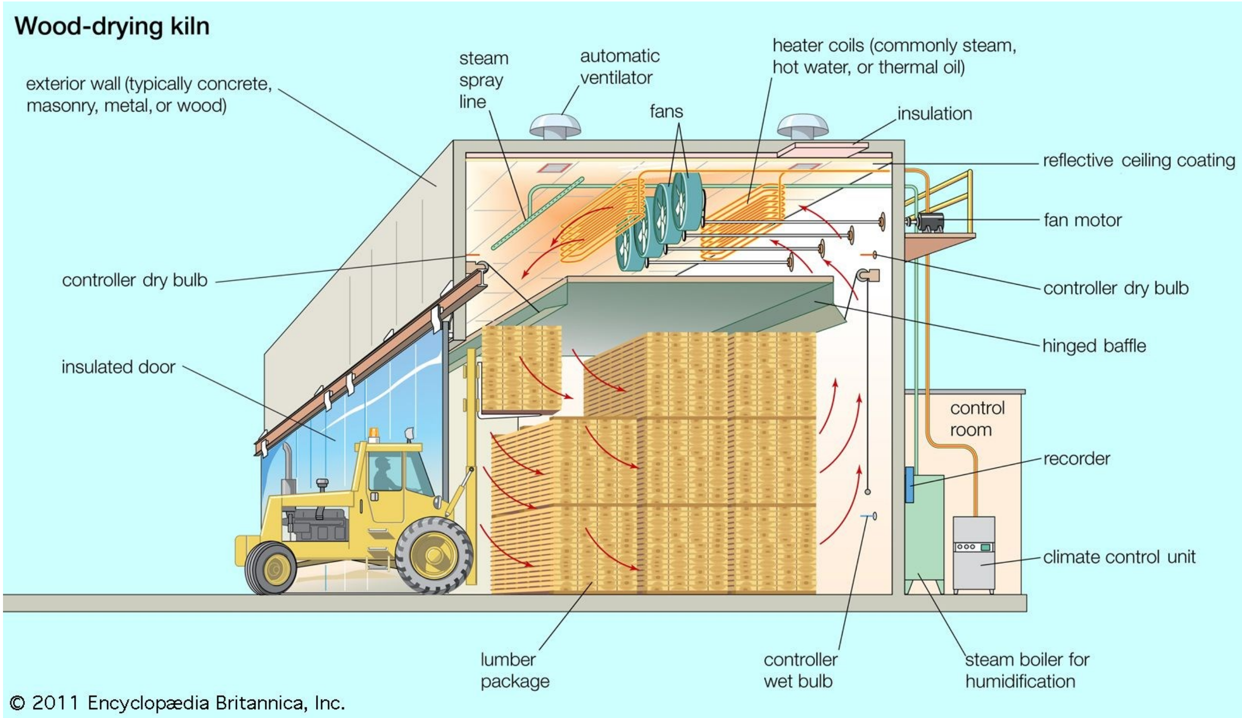

Figure 2 Typical example of installations in a batch dryer in wood processing industry.

As it is seen from the illustration above, the following major installations are used:

- Fans are installed under at roof in the chamber to circulate air through stacks of wooden sticks/boards etc.
- The air flow goes from the top of the chamber towards the door of the chamber and then through the wood and back to the fans. After a specific time period the fans (at best) shall reverse and force the air to flow in opposite direction.
- Heating coils are installed before the returning air meets the fans
- On the top of the chamber, ventilators and dampers are installed to ventilate very wet air into the surroundings during the initial humid phases of the drying sequence
- Spraying nozzles are installed enabling humidification of the wood in case this is needed. They are mostly needed during heating up to drying temperature and in the end of drying, in the so-called conditioning regime.
- Temperature and moist sensors are (at best) installed before and after the stacks of wood to monitor the Equilibrium Moisture Content (EMC) of the drying atmosphere.

Control equipment is usually installed on the back of the chambers to monitor progress of the drying cycle.

1.2 Key parameters in the wood drying process

The character and duration of the drying process depends on a range of parameters, first of all:

- <u>The initial moisture content of the wood</u>
  The moisture content of the wood can vary significantly depending on how the wood has been transported to and stored at the facility and if any "pre-drying" of the wood at ambient conditions has been applied.

  The moisture content will also depend on the time of year (i.e. wet vs. dry season) and the relative humidity of the air surrounding the wood before packing the wood into the drying chambers.

- <u>The thickness of wood planks</u>
  It is a challenge that water is bounded in the core of the wood and has a long transportation time from the core of the wood to the surface.

  Therefore, thick planks will have a much longer drying time than thin planks. Increasing temperatures and/or reducing humidity of drying air to speed up the drying process might result in poor quality of the wood planks (cracks etc.).

- <u>The fibre saturation point (FSP)</u>
  The moisture content at which cell walls are completely saturated (all 'bound water') but no water exists in cell cavities, is called the 'fiber saturation point'. The fiber saturation point of wood averages about 30 percent moisture content.

  The FSB however depends on the type of wood, and different sorts of wood should therefore have different drying times and parameters.

- <u>The equilibrium moisture content (EMC)</u>
  The equilibrium moisture content definition (EMC) is the moisture level where the wood neither gains nor loses moisture since it is at equilibrium with the relative humidity and temperature of the surrounding environment.

  Also, the EMC depends on the type of wood, and different sorts of wood should therefore also for this reason have different drying times and parameters.

Because of large variations in the above listed parameters, the drying time can be from a few days up to over 20 days. The temperature in the drying chamber varies typically between 40ºC and 95ºC. Figure 3 below shows a typical example of how the moisture content in wood is gradually decreased.

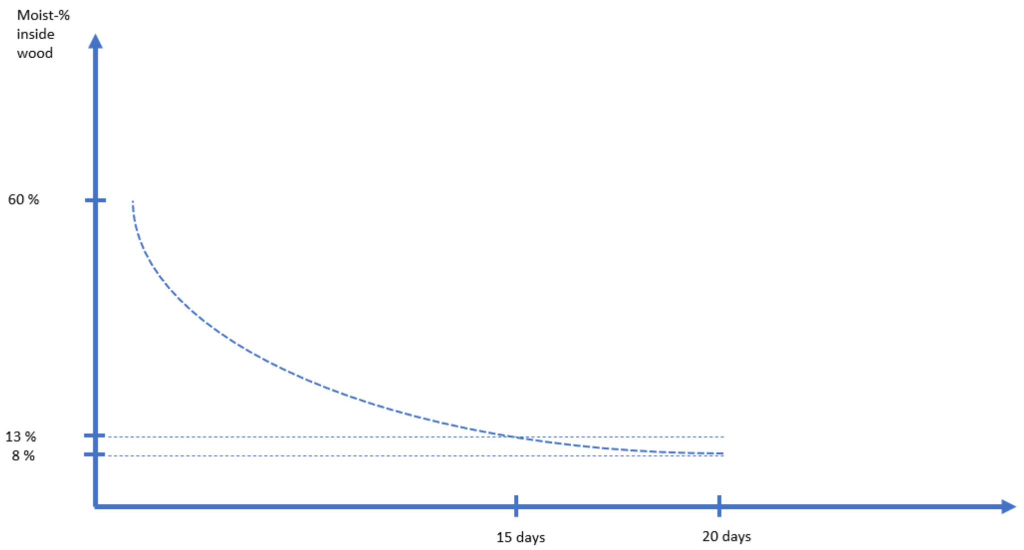

Figure 3. Example of moist content in wooden sticks over a drying period of 20 days.

It is characteristic for the drying process that moisture content is reduced rapidly in the beginning of the drying process, while the last percentages of moist takes many hours (days) to remove due to a slower transportation of the water below fibre saturation point.

More detailed information about the theory behind wood drying can be found in the references below.[1]

1.3 Heating supply and distribution

Most wood processing industries operate boilers where biomass waste from the production (saw dust and offcuts) is combusted.

Figure 4. Example of boiler installation in Vietnamese wood processing industry

The boilers normally produce steam at a temperature/pressure of the magnitude 6 bars/150°C, that via steam piping systems is distributed to a number of drying chambers, where circulating air is heated in a heat exchanger under condensation of the steam.

In some cases, heat to the drying chambers is delivered as hot oil, but also hot water systems are applicable.

2 Energy efficiency measures for drying processes

Overall, a wide range of energy efficiency measures can be identified for driers and heat supply systems in Vietnamese wood processing industries.

This section addresses the drying process it-self while heat generation and supply systems are addressed later in the sections below.

Overall energy efficiency of a drying process can be categorized in the following main areas:

1. Handling of raw materials
2. Loading of drying chamber

[1] *"Fundamentals of wood drying", report issued by ARBOLOR and edited by Patrick Perré, 2003.*

"Air drying of lumber", report issued by USDA (United States Department of Agriculture), 2020.

3. Efficiency of drying chamber
4. Control of drying process
5. Heat recovery systems
6. Heat supply and distribution

Each of these categories comprise a number of energy efficiency measures to be considered.

2.1 Handling of raw materials

Quality of wood
Overall quality of raw materials can vary significantly depending on the type of wood, the moisture content and wood thickness etc. and the starting point for each drying sequence should be carefully understood in order to operate a drying chamber with minimum energy usage, to improve product quality and to ensure a good production capacity of the process.

Pre-humidification
It happens that raw materials have been stored or even dried in the sun, which means that the surface can be relatively dry, still with a high moisture content in the core of the raw material.

This can be a barrier for a fast and efficient drying process delivering high quality products – it is necessary to have a relatively constant moisture gradient from the core of the material to the surface in order to enable a fast moist transportation during the drying.

Therefore, it can be necessary to humidify the raw material during the initial phases of the drying cycle – either with water or via steam from the steam distribution system. Steam from the steam boiler is not to be recommended as it is not saturated and then will dry and burn the wood surfaces.

2.2 Loading of drying chamber

Stacking of raw materials
Both in terms of energy efficiency and in terms of product quality it is important to load the drying chamber with materials so as circulating air flows are distributed evenly across the raw materials. The risk is that drying air always will find the “easiest” way to pass the wood, which can leave “dead” zones where the wood planks are only slow dried while other areas are dried rapidly.

If separate stacks of raw materials are placed with just a little distance between each other, then the airflow tends to find the “easiest way” through the stacks, which will be not to pass in between the individual wood sticks/boards.

Careful loading of the chambers is crucial for a fast and efficient drying process with a high quality of dried wood.

Below, an example of recommended stacking of wood in a dryer is shown.

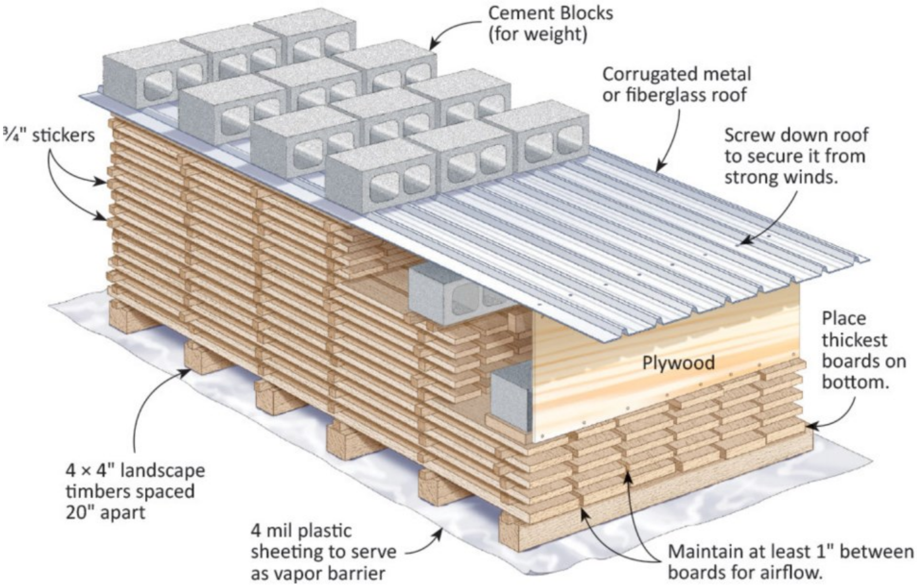

Figure 5. An example of stacking wood in a conventional wood dryer.

As illustrated, stacking of wood should allow for the air to circulate freely and evenly distribute across as much surface as possible, but several more detailed recommendations should be given:

- Wood of uneven thickness should not be dried in the same chamber.
- Stickers have to be placed at the end of boards to prevent ends splitting.
- No room should be left for free air flow.
- Etc.

In order to have a good quality and energy efficiency of the drying, a guideline should be prepared for each type of wood handled in the driers.

More inspiration regarding stacking wood can be found in several international references[2].

Removal of water from humidification

If the raw material initially is sprayed with water or steam to secure a good and uniform starting point for the drying process, there will often be large amounts of water or condensed steam on the floors in the initial phase of the drying cycle.

As the heating capacity on the drying process basically not is very high (the process is designed for long and careful drying sequences), evaporation of remaining water from humidification can take long periods thus requiring a lot of heating for no purpose.

An initial humidification should always be followed with manual removal of water on the floors, and, at best, the kilns should have proper drainage systems to allow for the water to be removed.

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[2] *"Air drying lumber", technical guideline issued by Wisconsin Department of Natural Resources, University of Wisconsin/Madison and Northcentral Technical College.*

"Sawn timber steaming and drying", technical report issued by University of Natural Resources and Life Sciences (Vienna) and University of British Columbia, April 2023.

2.3 Efficiency of drying chamber

<u>Reduce leaks</u>
Doors of the drying chambers are mostly sliding doors and have in many cases been observed to have leaks so as warm, heated air from the inside is lost to the surroundings.

Losses from leaks impairs energy efficient operation of the chambers but can also reduce the drying capacity significantly.

Therefore, the doors should be inspected on a regular basis and any leak repaired.

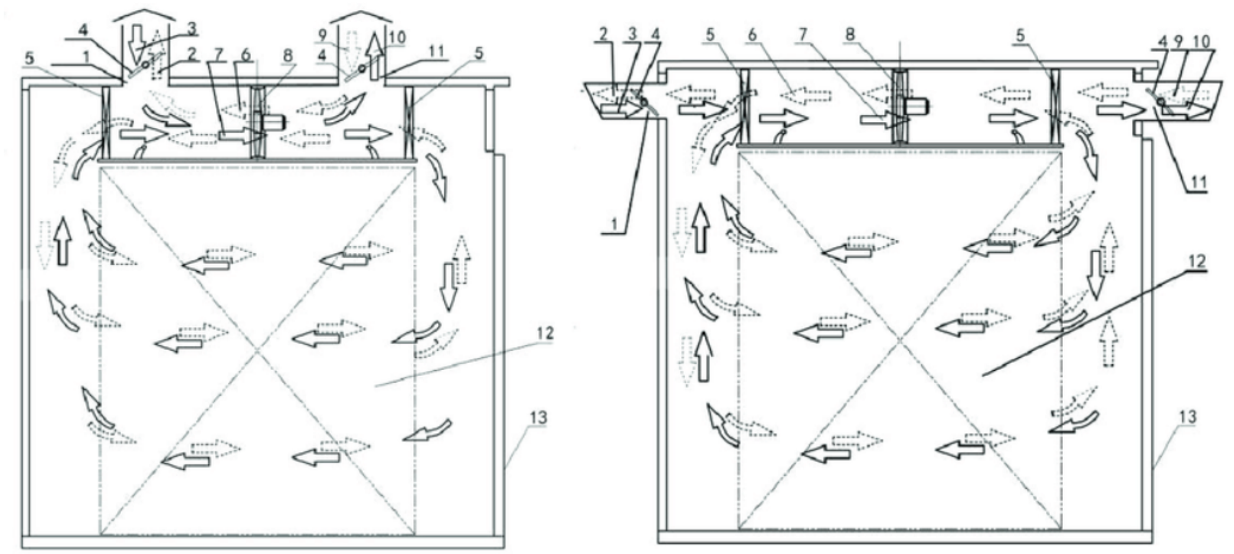
<u>Insulate surfaces</u>
Many drying chambers have been designed for low-cost heat supply, with little attention to insulation of the walls, roofs and doors. With increasing fuel prices, it should be considered to add insulation to the chambers.

An energy audit or screening of energy saving potentials should measure surface temperatures and assess magnitude of heat losses.

<u>Controlled air flows</u>
A uniform airflow across the chambers is important to ensure a good product quality (uniform drying) thus utilizing the supplied energy in the best possible way.

Modern type drying chambers are installed with guiding vanes to direct air flows uniformly across the chambers thus securing energy efficient operation and increased product quality.

More importantly, reversible fans with frequency converters should be used to make varying air flows possible as illustrated in figure 6 below.



Airflow circulation of conventional drying kiln. 1. Forward (reverse) inlet (outlet) duct; 2. Reverse exhaust wet air; 3. Forward fresh air; 4. Butterfly valve; 5. Heating coils; 6. Reverse circulating air; 7. Forward circulating air; 8. Axial fan; 9. Reverse fresh air; 10. Forward exhaust wet air; 11. Reverse (forward) inlet (outlet) duct; 12. Wood stacks; 13. Kiln gate.

Figure 6. Example of installations and reversible air flow in a wood dryer.

Varied air flows and a well-stacked dryer prevents certain areas of the kiln not to be dried more than others thus improving the product quality.

Efficiency of fans
Old fans for circulation of air in the chambers can be of very low efficiency thus increasing operating costs significantly and basically also prolonging the drying process due to in-accuracy in air flows.

The total fan installation should be placed above a ceiling in the chamber and the fan installation it-self designed for the purpose of being in a drying chamber of the specific type.

It is important to note that the efficiency of the fan installation depends not only on the fan, but also on whether it is built correctly into the kiln securing a controlled air flow across the blades of the fan as illustrated in figure 7 below.

Figure 7. Example of fans with efficient and controlled airflow across the blades

To secure uniform air flow, the sub-ceiling must be on both sides of the fans, not only on one side.

2.4 Control of drying process

Correct use of dampers
Drying chambers are fitted with ducts, ventilators and dampers at the top of the chambers so as hot, humid air from the drying can be ventilated to the surroundings not to be circulated again and again.

Especially during the initial phases of the drying, this kind of operation is important to shorten the drying cycle when relatively high amounts of water are dried out of the wood.

During later stages of the drying cycle, the need to ventilate moist out of the chambers will decrease and for energy optimal operation, more air should be re-circulated inside the chamber.

The control of dampers and fans to ventilate humid air out of the chambers is important to reduce energy consumption and reduce drying time. It is often seen that simple drying chambers have manually controlled dampers in the top of the chambers not operated very accurately but such solutions should be automated to be efficient.

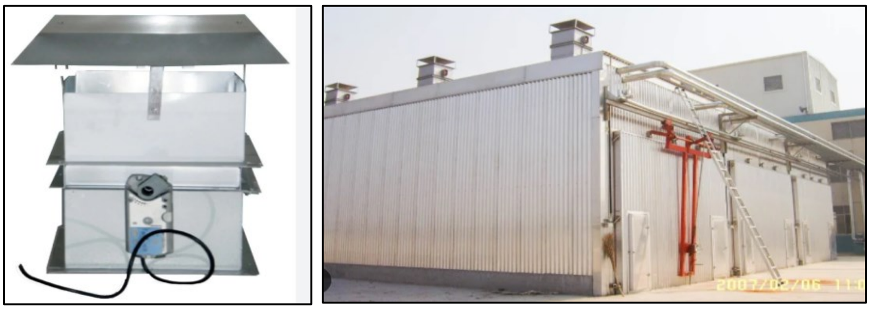


Figure 8. Example of automated dampers in wood drying kiln

<u>Control systems</u>

It is difficult to measure moisture content inside the wood precisely, which can lead to inaccurate drying, i.e. "over"-drying with increased drying time and increased energy losses from the chambers – as well as quality issues for the dried wood (increased loss).

Probes in the wood will therefore not be a safe path towards energy efficient operation. Meters to measure wet and dry bulb temperatures before and after the stacks of wooden sticks/boards are judged to be a better way to improve accuracy of operation.

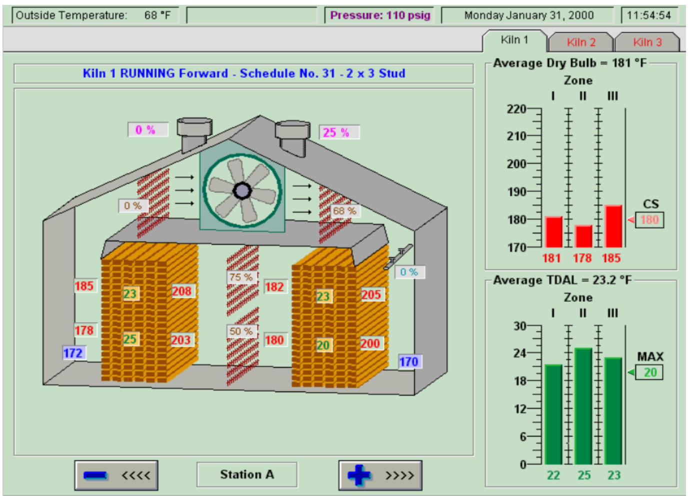


Figure 9. Example of advanced moist control system in wood drying kiln.

Measurement probes should be combined with a significant experience on how each type of raw materials (wood) performs during the drying, i.e. a historic log for drying of different types of raw materials.

<u>VSD for fans</u>

Next to control of temperature and humidity of the air circulating in the drying chambers, also air speed can be adjusted during the drying sequence.

This requires the fans to be fitted with variable speed drives (VSD), which is a very energy efficient way to operate this. Just small changes in air speeds will lead to significant electricity savings.

But overall, control of exhaust fans, dampers, temperature, moisture and air speed is a complex question to be studied carefully for each type of raw materials and with many externalities (also parameters as outside temperature and humidity will influence the drying process). It is necessary to establish a precise recipe for how to dry each type of material in the most energy efficient way.

2.5 Heat recovery systems

Waste heat can be recovered to partly heat the drying process as a supplement to the traditional heating of the drying chambers with steam or other media, by example by utilizing the waste heat from compressed air plants.

Modern type compressed air stations can recover as much as 96% of the electricity used in the compressors to produce hot water at temperatures up to 90°C.

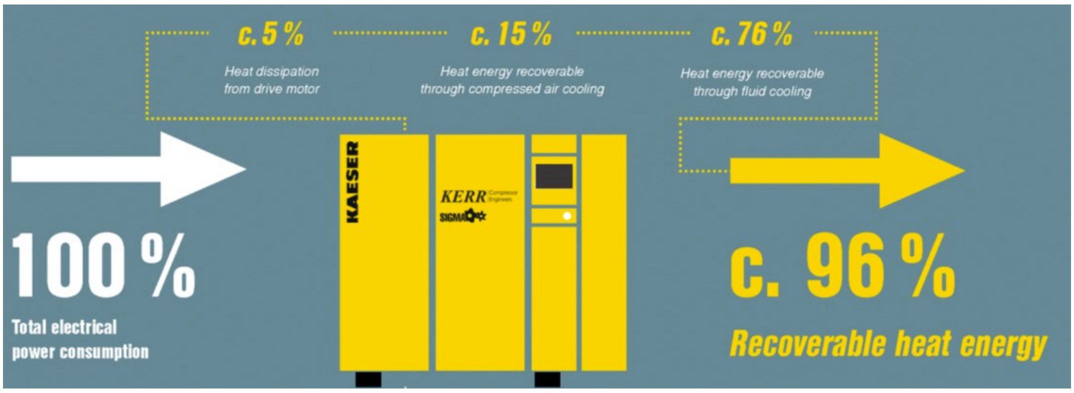


Figure 10. Example of heat recovery efficiency for a compressed air station

Such a solution will include installation of a piping system from the compressed air station to the drying chambers and often also installation of heat exchangers so as heat can be transferred from the hot water to the drying air circulating in the chambers – to supplement the existing heating system (typically steam based).

2.6 Boilers and heat distribution systems

As for the heating system, measures to improve energy efficiency can be of widely different character:

- Optimizing the boiler
- Establishment of new utility system
- Use of heat pump technologies
- Use of hybrid solutions
- High frequency assisted drying (vacuum)

These opportunities a briefly discussed below.

2.6.1 Boiler installation

The efficiency of the boiler installation itself can be assessed following the Technology Catalogue for boiler installations developed by EESD and the Danish Energy Agency[3].

In brief an improvement of a boiler installation could comprise:

[3] https://depp3.vn/Document/Detail/116

- Control of unburned biomass in ashes
- Insulation of boiler installation and related auxiliary equipment in the boiler house
- Automated combustion control to minimize oxygen- and carbon monoxide content in exhaust gases
- Recovery of waste heat from exhaust gases in economizers and air-preheaters
- Recovery of heat from blow down of the boiler
- Installation of water treatment to reduced scaling and blow-downs
- Optimization of boiler load compared to design capacity

Often boilers in the wood processing industry are of a fairly simple type (fixed grate, manually feeding of biomass) with low efficiency, and new high efficiency boilers should be considered as an option.

2.6.2 Heat distribution systems

The efficiency of the heat distribution systems supplying heat from the boilers to the drying chambers has to be assessed during the screening of energy saving potentials, see the Technology Catalogue for boiler installations developed by EESD and the Danish Energy Agency as mentioned above.

- Often piping, valves and installations are poorly insulated leading to high losses due to the high temperature of the steam piping. Also piping installations returning condensate should be properly insulated.

- Steam traps should be frequently checked and maintained to ensure a proper efficiency of the steam distribution systems – and often more steam traps could be installed to minimize the losses in the distribution system.

- Condensate should be returned to the boiler installation to utilize the energy content in the hot water and minimize consumption of fresh water.

At best it should be considered to replace an in-efficient steam piping systems with hot water supply, as the losses from such are much smaller than from steam systems and further enables to collection of waste heat from other areas of the facility – by example from compressed air plants. Replacing steam drying with hot water drying requires investment in replacing the boiler and heat exchangers. This solution must be evaluated carefully in terms of the effectiveness of investment in replacing the system.

2.6.3 Heat pump technology

Use of heat pump technology is to be considered as the most energy efficient operation possible for drying in the wood processing industry.

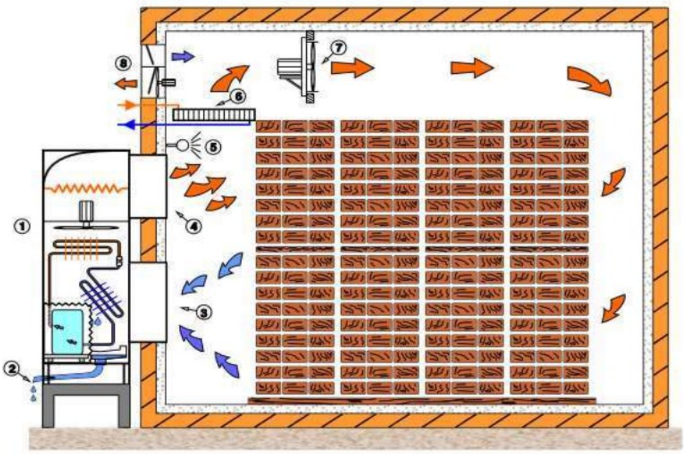
The advantages with heat pump solutions are several, by example:

- The drying process can be operated more controlled and accurate thus improving product quality

- As heat pumps de-humidify the air in the champers, drying time can be reduced – however depending on material properties.

- If electricity from solar PV or wind is available, heat supply will become carbon neutral.

In figure 11 below an example of how a heat pump is integrated into a drying chamber is illustrated.



1 - Heat pump; 2 – Drainage pipe; 3 - Heat pump intake; 4 - Heat pump outlet; 5 - Nebulizer; 6 - Heat exchanger (combined furnaces only); 7 – Flow fan; 8 - Air exchange system

Figure 11. Principle of applying heat pumps for drying of wood

The working principles of the heat pump system is as the following:

- When warm and humid air returns from the stacks of wood planks, it meets a heat exchanger circulating cold refrigerant in the heat pump (point 3 in figure 11). This heat exchanger is called the heat pump's "evaporator".

- When meeting such a "cold" surface, the circulating air is cooled and a certain proportion of moisture content in the air saturates and can be removed as water.

- The cooled air then meets a "hot" surface circulating hot gas in the heat pump (point 4 in figure 11). This heat exchanger is called the heat pump's "condenser".

- When meeting such a hot surface, the circulated – and now dry – air is heated so as it can be circulated in the drying chamber again absorbing more moist from the wood planks.

- The amount heat transferred to the drying air equals the amount of energy absorbed in the evaporator plus the electricity used by the compressor in the heat pump. The ratio between the produced heat and the power consumption of the compressor is called the "Coefficient of performance" – COP.

- The COP of the heat pump is important to optimize, and in practical applications there might be limitations of high temperatures of air the heat pump can produce – both in terms of practical limitations and because the power consumption of the compressors increases significantly at high temperatures.

The disadvantage of heat pumps is that electricity in Vietnam is expensive and if biomass is considered as "free" or very cheap, then operating costs for the heat pump can increase compared to the baseline – however depending on how much the drying time can be reduced and how efficient the drying chambers are constructed (heat losses).

Also, it should be considered carefully whether a specific heat pump uses environmentally friendly refrigerants and if maintenance costs are expected to increase compared to the baseline.

Changing an existing biomass heating system into a heat pump system might not be feasible from an economic point-of-view, but if new capacity is needed or old installations are to be significantly rehabilitated, then the business case to select heat pump technology should be assessed carefully also considering product quality and production capacity-questions.

2.6.4 Hybrid solutions

In principle it is possible to combine existing steam production from biomass boilers with use of heat pumps to partly cover the heat demand in the kiln.

Such a solution will allow for higher temperatures in the drying chambers without impairing the efficiency of the heat pumps and can be applied to improve the quality of dried wood and reduce drying time.

2.6.5 High-frequency vacuum kilns

An advanced solution to dry wood will be to dry under vacuum assisted with high frequency heating as illustrated in figure 12 below.

Drying under vacuum allows for faster transportation of moist from the centre of the wood to the surface thus reducing drying time significantly. Especially for drying of thick pieces of wood this is an advantage as a traditional thermal drying process can be very lengthy.

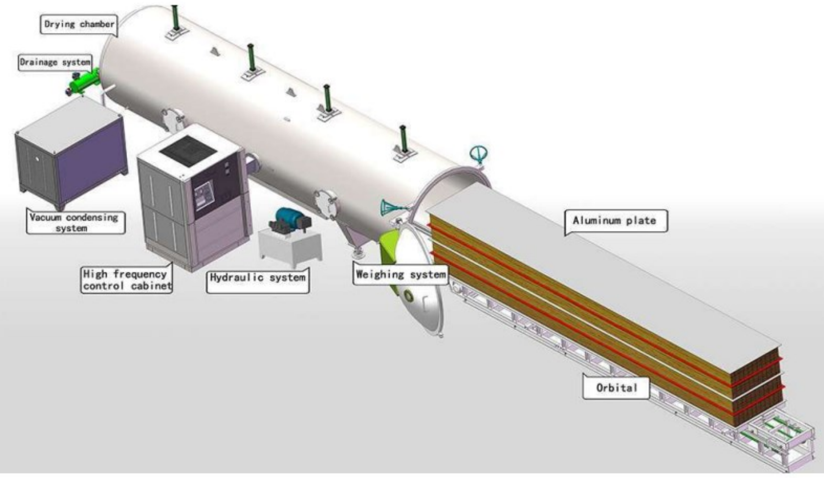


Figure 12. Vacuum drying with high-frequency technique.

With vacuum drying also product quality is experienced to be very high minimizing some of the dis-advantages with traditional thermal drying (colour change, deforming wood, shrinkage etc.).

Figure 13 below shows an example of how the drying time can be reduced with high-frequency vacuum drying (RFV) as compared to traditional steam based drying (KD):

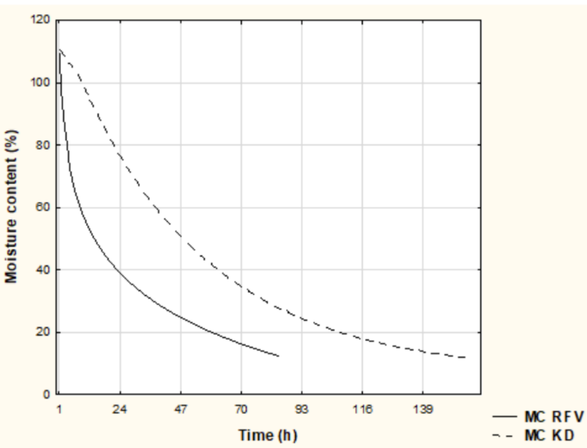


Figure 13. Drying time for vacuum drying with high-frequency technique (RFV) compared to traditional drying (KD).

The dis-advantage with this technology is that the investment costs are much higher than with traditional steam heated kilns.

More details about such advanced solutions can be found in international references[4].

3 Screening, audit and feasibility studies

Usually, an energy screening or energy audit in the wood processing industry will identify immediate energy losses and opportunities to improve the drier systems and the boiler station and steam distribution.

Following these initial observations, a pre-feasibility study in more detail can clarify which specific solutions that should be considered before a feasibility study should lock a final business case for a specific improvement project, which can be presented to the management of the company for a final investment decision (FID).

It is important to note that the decision process to improve a drier and boiler installation in a wood processing industry often will address many other questions that energy efficiency and fuel costs alone, by example capacity and product quality. Such questions (non-energy benefits) can contribute significantly to the positive outcome of the overall business case and should be explored in the further work towards locking the business case.

The contents of each of the recommended work-phases are described in more detail in guidelines elaborated under the Danish-Vietnamese cooperation[5] but will be briefly described below.

3.1 Screening and energy audit

The initial assessments of the dryer and heat supply systems can be done as a screening or an energy audit following the current Vietnamese legislation as well as supplementary guidelines[6]. In any case, the work should aim at mapping of the energy balance, efficiency and losses of the dryer and heating systems, which would in most cases involve measurements to be carried out to clarify the present state of operation.

The screening/audit should aim at carefully documenting the initially collected data and assessments of current state of operation as such data will be the foundation for any further work in later phases.

In Annex 1, a table to support any data collection at this stage of the project is attached.

3.1.1 Initial data collection for biomass

The initial data collection should provide an overview of the yearly energy consumption for the heating and dryer systems along with key data for raw materials, production volume, operating hours etc.

[4] *"Tests to dry thick eucalyptus boards in vacuum using high frequency heating" which was presented at the 4th COST E15 Workshop "Method for improving drying quality of wood", 30-31 May 2002 in Spain.*

"Drying wood with high frequency electric current", technical report issued by SWST – International Society of Wood Science and Technology, Madison/Wisconsin, ISBN 978-0-9817876-1-9, 2009.

[5] https://depp3.vn/Document/Detail/116, https://depp3.vn/Document/Detail/60; https://depp3.vn/Document/Detail/61
[6] https://depp3.vn/Document/Detail/59

In the wood processing industry, waste biomass (saw-dust and cut-offs from the production) from the production is widely used as fuel for steam boilers. The initial data collection should aim at establishing an overall mass balance of biomass for the facility, i.e.:

- How much wood is received as raw materials for the production?
- How much wood leaves the facility as products?
- How much water is removed from the wood during the drying process?
- How much wood waste is generated from the production?
    - Saw dust from cutting and planning of wood etc.
    - Cut-offs from the production
    - Wood wasted from quality inspections
    - Imported or exported wood waste
- Estimated water content in combusted wood

Along with this mass balance, the value of combusted biomass should be assessed (VND/year) in order to have a clear picture of the current operating costs for energy for the boilers and dryer systems. This will also include data collection for the current electricity consumption for the dryers.

3.1.2 Review of the drying system

The screening/energy audit should collect further details about the dryer system, by example as presented in the table below.

Drier system		Data / Comments
	Number of drying chambers	
	Age of drying chambers	
	Volume per chamber	
	Annual number of batches dried	
	Features of control system - Number of probes for humidity and temperature control - Manually or automated control of dampers - Etc.	
	Features of fan system in dryers - High or low efficiency fans - Variable speed fans - Availability of guiding vanes - Operation with reversed air flows - Etc.	
	Air proofness of chambers good or bad (visual impression)	
	Insulation of walls, roofs, doors and floors (surface temperatures)	
	Quality of drying (experienced waste-percentage of wood)	

Table 1. Data collection for drying chambers

From these observations, losses and inaccuracies in the operation of the dryers should be assessed, by example:

- Are heat losses from surfaces significant and could they be reduced?
- Are the chambers leaking air to the surroundings and should they be sealed better?
- Are pro-longed drying periods observed due to inaccuracies in the operations?
- Are fan systems and guiding vanes of too simple construction to allow for optimal air distribution?

- Are fans and motors/drives of high or low efficiency?
- Can air flows be varied and reversed during a batch?

The estimated losses from each of such areas should be assessed in order to conclude whether the drying chambers are operated with losses so high that they should be rehabilitated or even replaced with new and better technology.

Next to immediate observations of the energy efficiency of the drying chambers, other challenges in the operation of these should be understood carefully, by example capacity restrictions, quality issues, maintenance problems, logistic challenges in loading and un-loading of chambers, limitations related to sourcing of relevant raw materials etc.

These aspects should be understood carefully as drier optimization often impacts many other questions than just energy efficiency.

3.1.3 Review of the heat supply and heat distribution system

During the screening/energy audit, the current heating and heat distribution system shall be assessed carefully in order to understand if it is operated with a proper energy efficiency.

The Technology Catalogue for boilers and heating systems[7] provide guidance on losses in industrial boilers and should be used for this initial mapping.

Next to energy efficiency questions, current maintenance problems, breakdowns and challenges in the operation of boilers and heat distribution systems should clarified in order to present a detailed understanding of any need to rehabilitate or even replacing the current solutions.

3.1.4 Reporting from screening/audit

As a minimum the initial screening/audit should present and document the following results:

- A summary of data collected for dryers and heating system including measurements

- An overview of which losses and efficiencies the various sections of the installations are operated with, i.e. drying chambers, heat distribution and boiler installation.

- An assessment of which saving potential can be identified described by the proposed solution, potential energy saving, expected level of investments and by that expected payback time.

- A first estimate of related "non-energy benefits", i.e. potential gains in capacity, product quality, maintenance, flexibility etc. if installing certain of the recommended solutions

- A proposal for priority of further work to be undertaken in order to get more precise estimates of investment costs and benefits for the most promising improvement solutions.

The screening/energy audit should be presented at management level to discuss observations and to align proposed solutions with other facility plans (expansions, market developments, supply chain questions etc.).

Based on such a presentation, conclusions on further work should be reached.

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[7] https://depp3.vn/Document/Detail/116

3.2 Pre-feasibility study

A pre-feasibility study shall be conducted in order to more accurately describe and compare different solutions that can be considered to optimize the dryer and heating systems at the facility.

The aim of this work is to identify, quantify and compare specific solutions in terms of technology, investments (CAPEX), and operating costs (OPEX) so that these can be presented for the management of the company for further discussion.

The general guideline for pre-feasibility elaborated in the Danish/Vietnamese cooperation studies should be used in order to present the alternative business cases.

3.2.1 Design basis

At this stage it is important to lock the design basis for the project (s), i.e. on which expectations for present and future operation the business cases shall be calculated.

A design basis will usually comprise:

- A summary of current state of operations and any challenge driving a rehabilitation project
- Expectations for present and future production volume for the relevant area of the facility
- Expectations for present and future energy demand
- Expectations for present and future energy prices
- Expectations for any expected CO_2-abatement costs
- Expectations for requests to become carbon neutral among clients and in the supply chain

Other questions might be important for the design basis and overall, it is strongly recommended to document data in a written memo or report as a basis for any further work.

3.2.2 Solution strategies

As for dryer and heating systems in the wood processing industry, a range of overall types of solutions should be considered in this phase of the project, by example:

- Should the current dryer systems be rehabilitated to improve energy efficiency?
- Will rehabilitation of drying chambers bring other benefits than energy efficiency?
- Is it relevant to fully or partly replace old and in-efficient chambers with new chambers?
- Will new drying chambers and technology enable the facility to dry certain products better?
- Which non-energy benefits can in general be achieved for the drying process (capacity, quality etc.)?
- Can the heating media be changed from steam to hot water in order to reduce losses?
- Should the boiler station be rehabilitated to improve energy efficiency?
- Can waste heat utilization be integrated into a rehabilitated utility structure?
- Can heat pumps technology be applied – at least for certain raw materials – in order to:
  - reduce energy costs?
  - reduce drying time?
  - improve product quality?
- Is vacuum drying with high-frequency technique relevant for certain products?
- Etc.

From assessment of such solutions, preferred solution strategies in terms of energy efficiency should be concluded for further work, while related non-energy benefits should be explored further, see below.

3.2.3 Non-energy benefits

Non-energy benefits from rehabilitating or replacing drying chambers and heat supply might comprise a wide range of areas, by example:

- Is the company expecting needs for more production capacity?
- Are new products to be introduced requesting new production technology?
- Is the company experiencing frequent production stops due to break-downs of heating supply?
- Is the company experiencing challenges in reaching a good product quality?
- Are current maintenance and labour costs too high compared to best practice?
- Is there a market demand to become more sustainable and even carbon neutral?

The value of non-energy benefits should be assessed from an economic perspective at this stage of the project development and might be equally important – or even more important – than benefits from improved energy efficiency.

As such, economic benefits might have to be assessed from the following parameters:

- What is the economic benefit from reducing cycle time for drying by 30%?
- What is the value of reducing shrinkage during drying from 10% to 6%?

Many of the questions raised above are of "non-engineering" character and it is therefore important that the energy auditor and the company discuss involvement of sector- and product specialists to justify any benefit further – whether these come from the company's own organization, a main office or must be hired as external consultants.

Along with estimates for non-energy benefits, also immediate project risks should be identified and discussed – by example uncertainties in market developments, changes in product mix and raw materials, new legislation requirements, difficulties in applying for building permits and environmental permits etc.

3.2.4 NPV-assessments (Net Present Value)

For relevant solution strategies/alternative business cases, the Net Present Value (NPV) should be assessed in order to compare total investment- and operating costs over a relevant period of time – by example 10 years.

An NPV-assessment requires that each alternative project option is to be assessed by:

- Investments (CAPEX)
- Operating costs (OPEX) for
  - Energy
  - Maintenance
  - Labour
  - Other related questions
- Income from any other benefit (capacity quality etc.)

Typically, the NPV approach allows for comparing high-CAPEX solutions with low operating costs (OPEX) with low-CAPEX-solutions with high OPEX so as the total lifetime costs for alternative solutions can be compared.

At this stage of the project development, a first dialogue with relevant suppliers is usually initiated in order to get more exact estimates of specific solutions and their investments and operating costs.

At this stage it might also be relevant to initiate dialogue with banks on financing options, as certain loan opportunities for sustainable solutions might have better conditions than traditional loans.

Each relevant solution strategy is to be presented including data CAPEX, OPEX, TCO, ROI and payback periods.

3.2.5 Management meeting

On the basis of the pre-feasibility study, a meeting with the management of the company should be arranged to present results from the analysis and conclude on a preferred case for further work.

3.3 Feasibility Study

While the work in the pre-feasibility phase mostly has a focus on the decision-making process inside the facility, the next phases of the project will have a different focus involving external parties as suppliers, local authorities as well as financing institutions. This in order to present the management of the company for a final business case so that a Final Investment Decision (FID) can be made.

By that, a preliminary solution design shall be prepared and accurate expectations for investments (CAPEX) and operating costs (OPEX) should be made.

3.3.1 Scope for project

As a first activity in the feasibility phase, the scope of the project shall be locked.

A project might address a dryer system and/or a heat generation plant, but often rehabilitation or replacement projects will involve many other activities and disciplines, by example:

- Building works
- Electrical works
- Piping and plumbing work
- Automation systems
- Water treatment systems
- Etc.

It shall be carefully described what the preferred project will comprise and who is expected to carry out work for each of the disciplines involved.

3.3.2 Preferred supplier (s)

To get accurate information on specific solutions, expected investments and operating costs, a dialogue will most often have to be initiated with relevant suppliers.

For some areas – by example electrical works - the company most likely already have preferred suppliers, while for others, new suppliers might have to be identified.

It is recommended to involve suppliers in the project development to an extent that a preliminary solution design can be presented with capacity data and drawings for all major equipment and installations.

For large investment projects, external consultants might be needed to prepare the FS and bidding documents.

3.3.3 Preliminary solution design

Drawings and 3D-animations should be developed to present a visual solution design for the preferred solution.

Usually, a preferred solution will include a main scenario with relevant sub-scenarios to consider further to choose the most suitable solution for the specific company.

The main scenario and relevant sub-scenarios should be described in terms of investment costs and operating costs so that the management of the company can make decision on a preferred path forward.

Still – at this stage – suppliers are to be involved in the project development to an extent where the preferred solutions can be presented – where a tendering process at a later stage will enable the company to select the supplier with the most advantageous solution.

3.3.4 Bank-financing

For major rehabilitation or replacement projects, the company will most often need to seek external financing of the investments.

For the dialogue with financing institutions, a summarizing feasibility study-report should be prepared.

3.3.5 Final investment decision (FID)

On the basis of the feasibility study-report and financing proposals from relevant financing institutions, the management of the company should be able to make a final decision on the preferred project.