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BIOKÜTUSE RAKENDAMISE SOOJUSTOOTMISES TASUVUSE ANALÜÜS KA VAIKO AS-IS

Autor taotleb
tehnikateaduse magistri
akadeemilist kraadi

Tallinn 2014

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TUT Faculty of Mechanical Engineering

Master's thesis task

2013 /2014 academic year …6… semester

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Field of study Production Engineering

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Master's thesis topic (estonian and english languages):
Profitability analysis of biomass fuel implementation into heating production in KA Vaiko AS**.**
Biokütuse rakendamise soojustootmises tasuvuse analüüs KA Vaiko AS-is.
…………………………………………………………………………………………
Tasks and timeframe for their completion:

Nr	Task description	Completion date
1	Select the topic of master thesis	09.2013
2	Analysis of current situation in the company, define the problem and collect the required data.	11.2013
3	Creating simulation model. Analysis of results.	03.2014
4	Thesis writing. Cost calculations, evaluation of investments and economic indicators finding.	04.2014
5	Suggest solution to solve problem. Prepare the presentation.	05.2014

Engineering and economic problems to be solved:
Cost-effective analysis; suggestions of steps for further improvement; preparation of optimal layout;
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Defence application submitted to deanery not later than …..…. Deadline ……..........

Student Mihhail Knjazetski /signature/ ………..…………. date …..........………

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Enterprise based confidentiality and other terms to formulate on the reverse side

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EESSÕNA

Tänapäevases maailmas energeetika on väga aktualne küsimus. Eesti on üks põhjamaadest ning seetõttu soojusenergia küsimus puutub iga inimest meie riigis. Koostatakse soojusmajandus arengu kavad, et energia kasutamise efektiivsust tõsta ja mõju keskonnale vähendada. Eestis on siiamaani väga palju soojustootmisega tegelevaid ettevõtted, kus kasutatakse soojusenergia tootmiseks põhiliselt maagaasi või põlevkiviõli.

Soojusettevõtja KA Vaiko AS toodab soojusenergiat kasutades maagaasi väikeses asulas Olgina, mis paikneb Narva linna ääres. Soojusmajandus arengukava kohaselt KA Vaiko AS vaatleb võimalusi kuidas üle viia oma maagaasi katlamaja biokütesele. Ettevõtte lubas autorile teostada tasuvusanalüüs ning välja selgitama kas on mõiste kasutada biokütus maagaasi vastu. Magistritöös on kirjeldatud modeleerimis meetoodikad, soojuse piirhinna arvutamis metoodikad, arvutatud investeeringud ja lisaks on tehtud soojuse tootmise protsessi imitatsiooni mudel. Graafilises osas on kujutatud uue katla ühendusskeem ja torude montaaži joonis.

Imitatsiooni mudel on koostatud andmete põhjal, mis on võetud gaasi tarbimisel tunni aja jooksul. Andmed on saadud Ronald Vari käest, kes on metroloogia osakonna juht firmas Gaasivõrgu AS. Piirhinna arvutamisel on kasutatud konkurentsiameti poolt kooskõlastatud piirihinna valemit. Mõningate majandusalaste küsimuste ning graafilise osaga seotatud küsimuste vastuste väljaselgitamiseks magistri töö autor konsulteeris Tallinna Tehnikaülikooli Soojustehnika Instituudi õppejõududega - Sulev Soosaar ja Ivan Klevtsov.

Töö koostamine toimus KA Vaiko AS-is. Töös kasutati andmeid Vaivara vallavalitsuselt, ettevõtetelt KA Vaiko AS, AS Narva Soojusvõrk ja AS Võrguteenus.

ABBRIVIATIONS

EIC **-** Environmental Investment Centre

ECCP - European Climate Change Programme

ERDF **-** European Regional Development Fund

ESF **-** European Social Fund

CF - Cohesion Fund

NCV – Net calorific value

LHV – Low heating value

NPV – Net present value

IRR – internal rate of return

ROI – return on investment

HDD- heating degree day

AS – aktsialselts (in Estonian as Ltd. In English)

INTRODUCTION

The problem of air pollution becomes more and more actual in Europe and in the rest of the world nowadays. CO_2 emissions have a negative effect on the nature that results in global warming. The main goal of the European Union over the past several years was to reduce the negative impact of the energy production and to improve the quality of our ambient air. The trend of using renewable sources of energy is very popular in Estonia because of high prices of oil shale and natural gas used for heat power production across the country. The use of biomass becomes a priority. It is already used by a number of boiler houses along with some other renewable sources of energy such as heat pumps, solar battery/collectors or wind power generators. These projects are financially supported by the Environmental Investment Centre (EIC) and the EU.

Due to the climate conditions in Estonia the cost of heating is very important for citizens. That's why the suppliers and producers of thermal power energy should provide reliable heating for acceptable prices. To reach this goal modern developments and technologies are used. Though the heat energy market in Estonia is still highly dependent on fossil fuels at the moment.

In this master thesis of Product Development and Production Engineering the studies of mechanical engineering will be carried out. The profitability of using biomass will be analyzed basing on Arena Rockwell simulation software. The main goal of this thesis is to do a profitability analysis of thermal power production process and to simulate heating production based on biomass. The simulation model will give some actual economic indicators of the usage of an alternative fuel in heating production. It will also introduce a dynamic picture of heating production process.

The process of heat production by small municipal company KA Vaiko AS in settlement Olgina is the object of the research and the analysis within this master thesis.

A theoretical research will introduce the main part of the study. The European Union climate policy goals and ways of financing environmental projects will be explained. The theory of modelling and simulation will be introduced further. The reasons of choosing simulation modelling as tools for this analysis as well as its advantages and disadvantages will be explained.

Since the main tool for simulation modelling in this master thesis is the Arena Rockwell Software it will be given a detailed description followed by natural gas and biomass fuel property characteristics. The technologies descriptions will be next in the theory part of the thesis. It includes an analysis of concrete technical solutions suggested by the company ÅF-Consulting AS. Furthermore some formulas for calculating electricity consumption and CO_2 emissions will be given.

The most important issue of implementing an alternative fuel for companies is a comparative rate of profit. With reference to Environmental Charges Act and Ambient Air Protection Act the calculations of natural gas price and environmental taxes are presented. The price for heat sales in thermal power production sector is regulated by the Estonian Competition Authority. The methodology and the formulas for seen by the ECA were used for cost calculations including variable cost, capital expenditure, justified return and operation expenses. Furthermore, the internal rate of return, net present value and payback period will be explained. These economic indicators help to answers the question „When a project will pay?''. The last part of the theory research deals with investments.

The theory research part is followed by a real analysis being the main part of this thesis. The analysis starts with a description of the company and deals with the actual problems of heat energy production. Here heat energy production process and some of the equipment involved in it are described, some technical solutions are suggested in a few words. After that an AS-IS model and its objectives are defined. Then a step by step description of the process of creating simulation model by means of using the Arena Rockwell software follows. Next to that the simulation results and the real data are compared. Finally, the figures received within simulation model are used in cost calculations.

When an AS-IS model is completed and checked the most extensive work of analyzing and creating TO-BE model begins. First of all the technical conditions of a solution are introduced. Prior to the implementation of new technologies based on biomass and natural gas the advantages and disadvantages of a new project should be analysed. The costs based on a normal year heat energy demand and the usage of wood chips as a biomass fuel are calculated. The cost calculations give us a clear picture of the advantage of wood chips use compared with natural gas. The next point of the study is evaluation of the investment amount.

The TO-BE simulation model made in Arena Rockwell software has the same principles as AS-IS model but there are some differences in methodology. The stages of simulation modelling process are shown stepwise and logically constructed in this study. The results of TO-BE simulation model give a clear picture of fuel consumption, carbon dioxide emissions, electricity consumption.

A conclusion is the final part of this master thesis. It contains some concrete suggestions of future activities of the company.
The conclusion is followed by the summary of the master thesis both in English and Estonian languages.

The list of literature resources which are used to understand methodologies and techniques of analyzing could find after conclusion part.
In appendix can be seen some tables of calculations and drawings.

Master thesis were formatted according to the general guide to writing and defending master`s thesis for MATM, MASM, MAHM - Product Development and Production Engineering studnets.

1. THEORY RESEARCH

1.1. The policy of heat energy development

There are two main directions in energy policy today. The first is energy efficiency and the second is environmental protection.

1.1.1 European Climate Change Programme and EIC

The European Union has long been committed to international efforts to tackle climate change and felt the duty to set an example through robust policy-making at home. At European level a comprehensive package of policy measures to reduce greenhouse gas emissions has been initiated through the European Climate Change Programme (ECCP). Each of the EU Member States has also put in place its own domestic actions that build on the ECCP measures or complement them.

In Estonia to achieve European Union proposes Environmental Investment Centre (EIC) was founded on 11 May 2000 by the Ministry of Finance. The main activities of EIC are to channel the proceeds from the exploitation of the environment into environmental projects, to perform as the implementing agency for the environmental projects funded by the European Regional Development Fund (ERDF), the European Social Fund (ESF) and the Cohesion Fund (CF) and to lend money for the implementation of environmental projects. [1]

1.1.2 Ambient air protection.

The ambient air protection programme is a part of the Environmental Programme and its objective is to support improvement of the quality of ambient air, alleviation of the consequences of climate change, and ensuring radiation safety. Grants are applied for and projects implemented in accordance with the Environmental Programme rules and the relevant Regulation of the Minister of the Environment. The amount allocated for grants varies from year to year, because it is directly dependent on the environmental charges received. [2]

1.1.3 Renewable energy.

Renewable energy sources for the generation of energy have an extended use in the world.

The goal of energy policy, financed from the CO_2 quota sales, is to rise the quantity of renewable energy production and to lower the level of pollution. There are several activities are supported: construction of combined generation plants that are based on renewable energy, reconstruction of boiler houses, reconstruction of district heating networks to lower the amount of energy lost through it.

The activities supported by EIC [3]

1. Construction of renewable sources of energy stations combined heat and power with networks and infrastructure;
2. Boiler house reconstruction for using renewable fuel instead fossil fuel;
3. Reduction of energy losses thought the repair and reconstruction of district heating networks, including the creation of the necessary additional compounds;

1.2 A simulation model as a tool to analyze consumption of fuel.

A system is defined to a collection of entities, e.g., people or machines that act and interact together toward the accomplishment of some logical end.

Definition by Schmidt and Taylor 1970

In practice, what is meant by "the system" depends on the objectives of a particular study. The collection of entities that comprise a system for one study might be only a subset of the overall system for another.

At some point in the lives of most systems, there is a need to study them to try to gain some insight into the relationships among various components, or to predict performance under some new conditions being considered. [4]

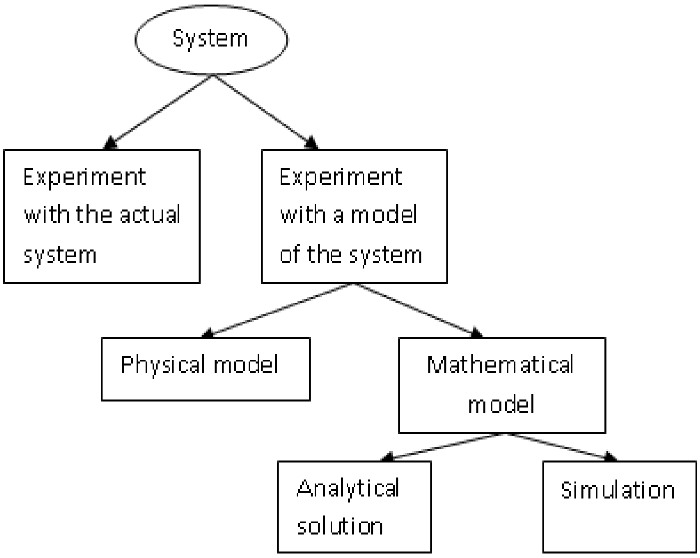

Figure 1.1 Ways to study a system [4]

Experiment with the Actual System vs. Experiment with a Model of the System. IF it is possible (and cost-effective) to alter the system physically and then let it operate under the new conditions, it is probably desirable to do so, for in this case there is no question about whether what we study is valid. However, it is rarely feasible to do this, because such an experiment would often be too costly or too disruptive to the system. [4]

Physical Model vs. Mathematical Model. It found be useful to build physical models to study engineering or management system; examples include table top scale models of material-handling systems or full-scale physical model of a fast-food restaurant inside warehouse, complete with full-scale, real humans (Swart and Donno 1981). But the vast majority of models built for such purposes are mathematical, representing a system in terms of logical and quantitative relationships that are then manipulated and changed to see how the model reacts, and thus how system would react –if the mathematical model is a valid one. Perhaps the simplest example of a mathematical model is the familiar relation $d=rt$, where r is the rate of travel, t- is the time spent travelling, and d is the distance travelled. [4]

Analytical vs. simulation. If model is simple enough, it may be possible to work with its relationships and quantities to get an exact, analytical solution. If an analytical solution to a mathematical model is available and is computationally efficient, it is usually desirable to study the model in this way rather than via a simulation. However, many systems are highly complex, so that valid mathematical models of them are themselves complex, precluding any possibility of an analytical solution. In this case, the model must be studied by means of simulation, i.e., numerically exercising the model for the inputs in question to see how they affect the output measures of performance. [4]

1.2.1 Definition of simulation

Simulation refers to a board collection of methods and applications to mimic the behavior of real systems, usually on a computer with appropriate software. In fact, "simulation" can be an extremely general term since the idea applies across many fields, industries, and applications. These days, simulation is more popular and powerful than ever. Simulation, like most analysis methods, involves systems and models of them. A computer simulation is an attempt to model a real-life or hypothetical situation on a computer so that it can be studied to see how the system works. By changing variables in the simulation, predictions may be made about the behaviour of the system. It is a tool to virtually investigate the behaviour of the system under study. [5]

Computer simulation refers to methods for studying a wide variety of models of real-word systems by numerical evaluation using software to imitate the system's operations or characteristics, often over time. From a practical viewpoint, simulation is the process of designing and creating a computerized model of a real or proposed system for the purpose of conducting numerical experiments to give us a better understanding of the behavior of that system for a given set of conditions. [5]

Simulation is used before an existing system is altered or a new system built, to reduce the chances of failure to meet specifications, to eliminate unforeseen bottlenecks, to prevent under or over-utilization of resources, and to optimize system performance

Figure 1.2 is a schematic of a simulation study. The iterative nature of the process is indicated by the system under study becoming the altered system which then becomes the system under study and the cycle repeats. In a simulation study, human decision making is required at all stages, namely, model development, experiment design, output analysis, conclusion formulation, and making decisions to alter the system under study. The only stage where human intervention is not required is the running of the simulations, which most simulation software packages perform efficiently. The important point is that powerful simulation software is merely a hygiene factor - its absence can hurt a simulation study but its presence will not ensure success. Experienced problem formulators and simulation modellers and analysts are indispensable for a successful simulation study. [6]

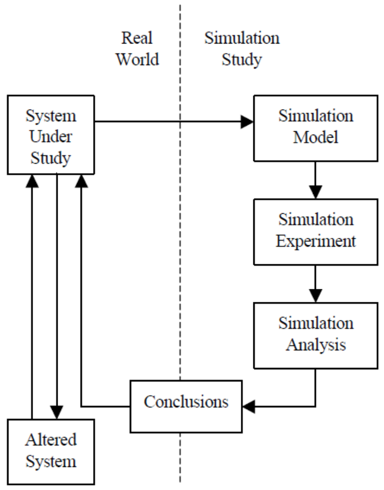

Figure 1.2 Simulation Study Schematic [6]

The steps involved in developing a simulation model, designing a simulation Experiment, and performing simulation analysis are:

Step 1 Identify the problem.
Step 2 Formulate the problem.
Step 3 Collect and process real system data.
Step 4 Formulate and develop a model.
Step 5 Validate the model.
Step 6 Document model for future use.
Step 7 Select appropriate experimental design.
Step 8 Establish experimental conditions for runs.
Step 9 Perform simulation runs.
Step 10 Interpret and present results.
Step 11 Recommend further course of action.

1.2.2 Benefits of simulation modelling and analysis.

According to practitioners, simulation modelling and analysis is one of the most frequently used operations research techniques. When used judiciously, simulation modelling and analysis makes it possible to: [6]

- Obtain a better understanding of the system by developing a mathematical model of a system of interest, and observing the system's operation in detail over long periods of time.

- Test hypotheses about the system for feasibility.
- Compress time to observe certain phenomena over long periods or expand time to observe a complex phenomenon in detail.
- Study the effects of certain informational, organizational, environmental and policy changes on the operation of a system by altering the system's model; this can be done without disrupting the real system and significantly reduces the risk of experimenting with the real system.
- Experiment with new or unknown situations about which only weak information is available.
- Identify the "driving" variables - ones that performance measures are most sensitive to - and the inter-relationships among them.
- Identify bottlenecks in the flow of entities (material, people, etc.) or information.
- Use multiple performance metrics for analyzing system configurations.
- Employ a systems approach to problem solving.
- Develop well designed and robust systems and reduce system development time.

1.2.3 Arena Simulation software

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Figure 1. 3 Arena Simulation Software brand picture

Arena software enables you to bring the power of modelling and simulation to your business. It is designed for analyzing the impact of changes involving significant and complex redesigns associated with supply chain, manufacturing, processes, logistics, distribution and warehousing, and service systems. Arena software provides the maximum flexibility and breadth of application coverage to model any desired level of detail and complexity.

Arena software is designed for manufacturing or business process consultants and analysts and industrial or systems engineers. It is typically deployed as an enterprise business analysis and productivity tool.

Possibility of Arena: [5]

- Model processes to define, document, and communicate.
- Simulate the future performance of your system to understand complex relationships and identify opportunities for improvement.
- Visualize your operations with dynamic animation graphics.
- Analyze how your system will perform in its "as-is" configuration and under a myriad of possible "to-be" alternatives so that you can confidently choose the best way to run your business.

Entities

Most simulations involve "players" called entities that move around, change status, affect and are affected by other entities and the state of the system, and affect the output performance measures. Entities are the dynamic objects in the simulation – they usually are created, move around for a while, and then are disposed of as they leave. It`s possible, though, to have entities that never leave but just keep circulating in the system. However, all entities have to be created, either by user or automatically by software. To individualize entities, user attaches attributes to them. An attribute is a common characteristic of all entities, but with a specific value that can differ from one entity to another. [5]

Entities are the items—customers, documents, parts—that are being served, produced, or otherwise acted on by your process. In business processes, they often are documents or electronic records (checks, contracts, applications, purchase orders). In service systems, entities usually are people (the customers being served in a restaurant, hospital, airport, etc.). Manufacturing models typically have some kind of part running through the process, whether it’s raw material, a subcomponent, or finished product. Other models might have different types of entities, such as data packets in network analysis or letters and boxes in package-handling facilities.[5]

The basic building blocks for Arena models are called modules. These are the flowchart and data objects that define the process to be simulated. Modules come in two basic flavours: flowchart and data.

Flowchart modules describe the dynamic process in the model. You can think of flowchart modules as being nodes or places through which entities flow, or where entities originate or leave the model. Flowchart modules are typically connected to each other in some way. In this master thesis uses Basic process panel that include next kinds of flowchart modules: Create, Dispose, Process, Decide, Batch, Separate, Assign and Record.

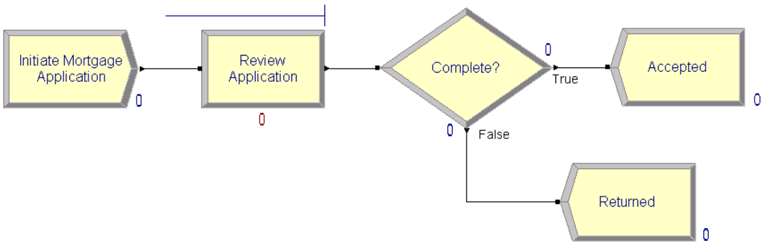


Figure 1.4 Example of flow chart in Arena

Further are described modules that used in modelling of heat power production and gas consumption for master this thesis.

- Create module is the, "birth" node for arrival of entities to our model`s boundary, representing parts in this case, into the model from outside.
- Dispose module is intended as the ending point for entities in a simulation model. Entity statistics may be recorded before the entity is disposed.
- Process module this module is intended as the main processing method in the simulation. Options for seizing and releasing resource constraints are available. Additionally, there is the option to use a "sub model" and specify hierarchical user-defined logic. The process time is allocated to the entity and may be considered to be value added, non-value added, transfer, wait, or other. The associated cost will be added to the appropriate category.

Statistical Distributions

Arena contains a set of built-in functions for generating random numbers from the commonly used probability distributions. These distributions appear on pull-down menus in many Arena modules where they’re likely to be used. They also match the distributions in the Arena Input Analyzer. This appendix describes all of the Arena distributions. Each of the distributions in Arena has one or more parameter values associated with it. You must specify these parameter values to define the distribution fully. The number, meaning, and order of the parameter values depend on the distribution. A summary of the distributions (that were used in this case of study) is given in the table below. [7]

Table 1.1 Summary of Arena Probability Distributions

Distribution	**Parameter**	**Values**
Beta	BETA	Beta, Alpha
Gamma	GAMM	Beta, Alpha
Lognormal	LOGN	LogMean, LogStd
Normal	NORM	Mean, StdDev
Triangular	TRIA	Min, Mode, Max
Weibull	WEIB	Beta, Alpha

The description of distributions was taken from Arena users guide reference number 4.

Beta

Because of its ability to take on a wide variety of shapes, this distribution is often used as a rough model in the absence of data. The beta is often used to represent random proportions, such as the proportion of defective items in a lot.

Gamma

The gamma is often used to represent the time required to complete some task (e.g., a machining time or machine repair time).

Lognormal

The lognormal distribution is used in situations in which the quantity is the product of a large number of random quantities. It is also frequently used to represent task times that have a distribution skewed to the right.

Normal

The normal distribution is used in situations in which the central limit theorem applies; i.e., quantities that are sums of other quantities. It is also used empirically for many processes that appear to have a symmetric distribution. Because the theoretical range is from $-\infty$ to $+\infty$, the distribution should only be used for positive quantities like processing times.

Triangular

The triangular distribution is commonly used in situations in which the exact form of the distribution is not known, but estimates (or guesses) for the minimum, maximum, and most likely values are available. The triangular distribution is easier to use and explain than other distributions that may be used in this situation (e.g., the beta distribution).

Weibull

The Weibull distribution is widely used in reliability models to represent the lifetime of a device. If a system consists of a large number of parts that fail independently, and if the system fails when any single part fails, then the time between successive failures can be approximated by the Weibull distribution. This distribution is also used to represent nonnegative task times that are skewed to the left.

1.3 Fuels

The main important part in new boiler installation is fuel selection. The investigation of fuel availability, the price as well as properties of available fuels will help to select the most reasonable fuel type for Olgina boiler house. And result of research shows that wood chip is better option for Olgina boiler house.

Solid and liquid fuels, calorific value is determined in accordance with standards ISO 1928, GOST 147-95, ASTM D 4868.

1.3.1 Natural gas.

Natural gas is a fossil fuel formed when layers of buried plants and animals are exposed to intense heat and pressure over thousands of years. Natural gas is a non-renewable resource because it cannot be replenished on a human time frame.

Quantity of heat released during the complete combustion of one cubic meter of gas under "normal"temperature and pressure conditions (1.01325 bar or 101 325 Pascal at 0°C) when the water formed during combustion remains as steam and the combustion products are evacuated under normalised test conditions. [8]

The heating value (or energy value or calorific value) of a natural gas is the amount of heat released during the combustion of a specified amount of it.

Average lower heating value (LHV) the same as net calorific value (NCV) of a natural gas – 9, 35 MWh/1000 m^3 (33.66 MJ/m^3) If multiply Natural gas amount to LHV we can get primary energy amount that contains in energy source.

1.3.2 Biomass (renewable fuel)

Biomass is a renewable CO_2-neutral fuel with low sulphur content and could be used for transformed to electricity, heat, liquid and gaseous fuels. There are numerous environmental and socio-economical advantages from growing and producing biomass energy
Properties of wood fuel:

- Ash (calcium, magnesium, phosphorous). approx. 0.5%
- Combustible materials: carbon (50-52%), hydrogen (6-6.5%), sulphur (around 0.2%), nitrogen (around 0.2%)
- oxygen (40-44%)
- Water (20-60%)

In this master thesis as the renewable biomass were used wood chips. Woodchips are a medium-sized solid material made by cutting, or chipping, larger pieces of wood. Woodchips may be used as a biomass solid fuel and are raw material for producing wood pulp. According to the different chemical and mechanical properties of the masses, the wood logs are mostly peeled, and the bark chips and the woodchips processed in different processes.

For all calculates in simulation model and for other analyses was taken wood chips with next properties:

Wood chips heating value 0.70 MWh/m^3
Considering that moisture of that wood chips 40%

1.4 Technologies.

The technical solution provides using a wood chips boiler for production of 85% of energy and the remaining 15 % will still be based on using natural gas. (figure1.4).

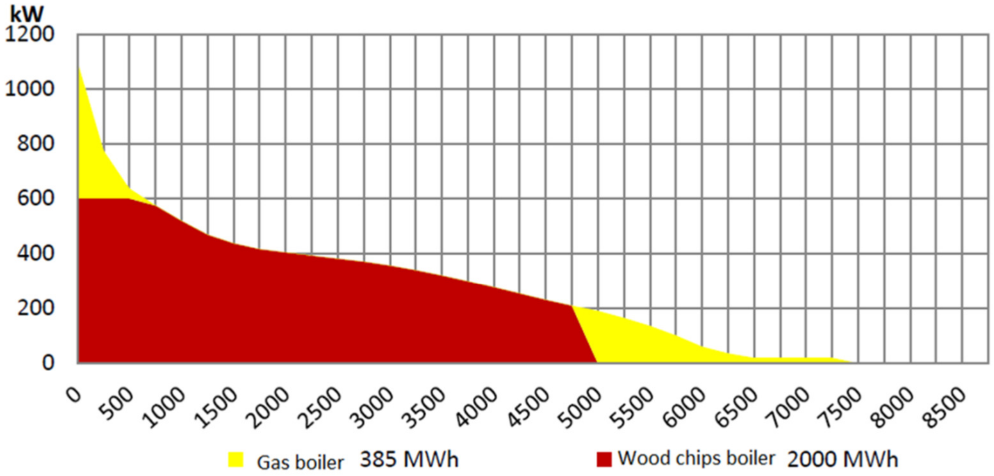


Figure 1.5 Load curve [9]

Table 1.2 Production indicators

Year	Degree days	Production	Norm. Year production	Consumption	Hot water	Norm. Year consumption	Heat lost	
		MWh	MWh	MWh	MWh	MWh	MWh	%
2011	4084	2275	2500	1834	157	2012	441	19,4%
2012	4592	2304	2269	1960	149	1931	344	14,9%
Avg. (norm. year)	**4518**	**2290**	**2385**	**1897**	**153**	**1972**	**393**	**17,1%**

The technical solution was suggested by consultants from company ÅF-Consulting AS. They suggests install boiler with capacity 0.6 MW it is enough to cover base load for covering peak and low loads it`s profitable use gas boiler.

Heat degree day

Heating degree day (HDD) is a measurement designed to reflect the demand for energy needed to heat a building. It is derived from measurements of outside air temperature. The heating requirements for a given structure at a specific location are considered to be directly proportional to the number of HDD at that location. A similar measurement, cooling degree day (CDD), reflects the amount of energy used to cool a home or business. [10]

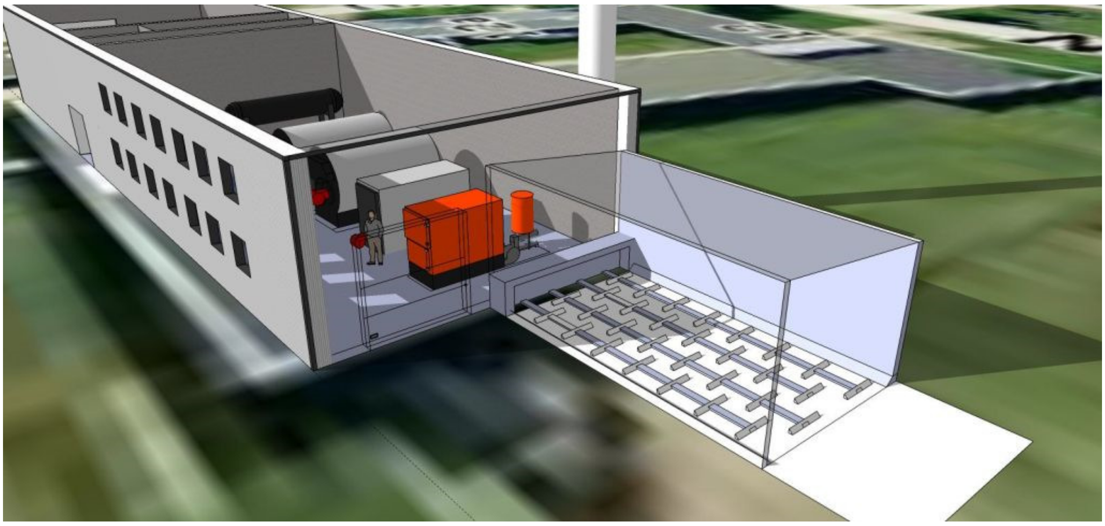


Figure 1.6 Sketch of Olgina boiler house reconstruction. [9]

The new wood chips boiler assumes to install in old room there are enough space for boiler installation. The best place for fuel storage building is near the north wall of the existing boiler house.

Nowadays the best automotive technology to feed biomass into the boiler it is ’’walking floors’’ or moving floors. These floors can be designed to take the weight of a delivery vehicle where wood chips are tipped directly onto the floor (figure 8). Fuel is extracted from the walking floor by either a cross-feed auger.

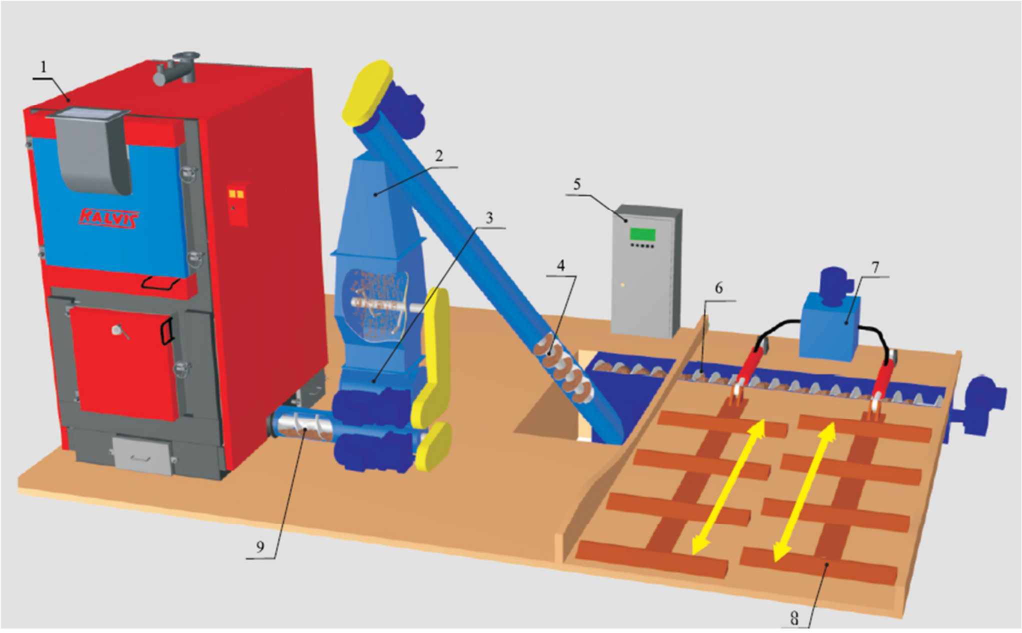


Figure 1.7 Boiler ,,Kalvis'' and fuel feed system [20]

Equipment description

1) wood chip boiler

2) intermediate tank
3) batcher
4) lifting conveyor (auger)
5) control cabinet
6) storage conveyor
7) hydrostation
8) Equipment walking flow system
9) furnace auger

To reduce operation cost and human resource cost should design cross-feed auger near the storage gate because track could dump fuel directly to the storage and this system provides maximum occupancy of storage volume. These feed mechanisms require more investment but investment will return soon. Alternative needs human resource and more operation cost. For example track could dump wood chips on the site or to storage for biomass holding and from there worker transports fuel by tractor.

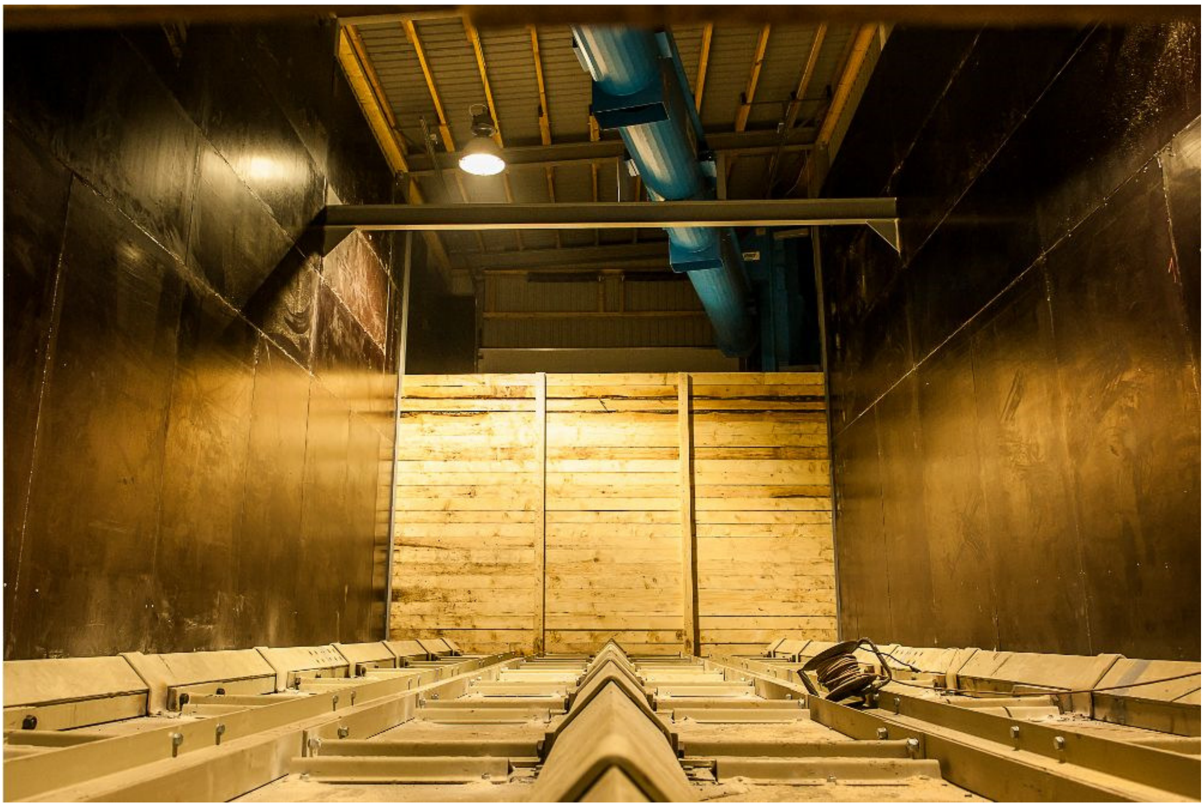


Figure 1.8 Empty fuel storage with cross-feed auger [21]

1.4.1 Electricity

Electricity consumption is 49 000 kWh per year for two boiler houses. Olgina boiler house approximately 21 000 kWh per year it is forecast based on forecast production of 2281 MWh per year.

$$P_{e.gas} = 21\,000/2\,281 = 9.2\ kWh$$

Where:

$P_{el.gas}$ – 9.2 kWh is power consumption (electricity) to produce one MWh of heat energy with gas boiler (kWh)

$PC_{el.gas}$– electricity consumption for gas boiler

GC – natural gas consumption

$$PC_{el.gas} = P_{el.gas} \times Q_{heat.gas} (1)$$

It means that for 1 MWh of heat energy required 9.2 kWh of electricity for gas boiler. Known from the report „ Olgina aleviku biokütuse katlamaja tasuvusurng'' that electricity consumption grow up for 40%. So it could be easily calculated:

For 1MWh produced by bio fuel boiler required 40% more electricity.

$P_{e.wood}$ – power consumption (electricity) for production 1MWh heat energy based on wood chips boiler (kWh)

$$P_{el.wood} = P_{el.gas} \times 1{,}4\ (kWh)$$

$$P_{el.wood} = 9.2 \times 1.4 = 12.88 (kWh)$$

$P_{el.wood}$ – electricity required for production 1MWh heat energy using wood chips boiler ($Q_{heat.wood}$)

$$PC_{el.gas} = P_{el.gas} \times Q_{heat.gas}\ (2)$$

$PC_{el.gas}$ – electricity consumption (gas boiler)

$$PC_{el.wood} = P_{el.wood} \times Q_{heat.wood}\ (3)$$

$PC_{el.gwood}$ – electricity consumption (wood chips boiler)

1.4.2 Emissions

Calculate the fuel consumption per unit mass of B (t) into thermal units (GJ) energy units using the conversion corresponding fuel type of the lower heating value Q^r_i as follows:

$$B_1 = B \times Q_i^r \quad \text{(GJ) (4)}$$

Where:

B – Fuel consumption, thou m^3;

Q^r_i – LHV- low heating value , MJ/kg;

For measurement of carbon dioxide emissions uses the Minister of Environment Regulation no. 94 16.07.2014 validated determination method: [11]

$$M_{CO2} = M_c \times 44/12$$

Where:

M_{CO2} – The amount of CO_2 emitted into the ambient air

Mc – amount of carbon emission (Gg C)

$$M_c = 10^{-3} \times B' \times q_c \times Kc \text{ (12)}$$

B'– recalculated fuel consumption, TJ

$$B' = B_1 \times n$$

n – ratio, $n=10^{-3}$

q_c – specific emissions, tC/T; for natural gas – 15.3;

Kc – part of the oxidized carbon; for natural gas – 0.995;

$$M_{CO2} = 10^{-6} \times B \times Q_{ri} \times qc \times Kc \times 44/12 \text{ (5)}$$

1.5 Cost calculation.

1.5.1 Natural gas price

KA Vaiko AS buys natural gas from AS Eesti Gaas. The price of natural gas is different every month due to open market policy. [12]

The formula calculate natural gas price for different consumptions.

1) Consumption under 10 000 m^3 /month:
   Gh = [(0.3 × Õr + 0.7 × Õk × 0,36 + 22.25) / C] × (Qi /Q),

2) Consumption from 10 000 to 100 000 /month:
   Gh = [(0.3 × Õr + 0.7 × Õk × 0,36 + 19.25) / C] × (Qi /Q),

3) Consumption from 100 000 to 500 000 m^3 /month:
   Gh = [(0.3 × Õr + 0.7 × Õk × 0.36 + 16.25) / C] × (Qi /Q),

4) Consumption from 500 000 m^3 and more/month :
   Gh = [(0.3 × Õr + 0.7 × Õk × 0.36 + 13.25) / C] × (Qi /Q),

Where:

Gh – gas price by the accounting month EUR/1000 m^3;

Õr – the average price of the heavy fuel oil during the last nine month by the accounting month (accounting period). An average price of the heavy fuel oil (USD) in any month is the arithmetical average price of the average price of the each day lowest prices in this month and the average price of the each day highest prices in this month. Disclosed 1PCT Fuel Oil could be found in “European low/high product averages” month statements of information channel ”Platt’s European Marketscan” under the column heading “Barges FOB ARA”

Õk – the average price USD/tonne of the light fuel oil during last nine months by the accounting month. An average price of the Light fuel oil (USD) in any month is the arithmetical average price of the average price of the each day lowest prices in this month and the average price of the each day highest prices in this month. Disclosed Gasoil 0,1 could be found in “European low/high product averages” month statements of information channel ”Platt’s European Marketscan” under the column heading “Barges FOB ARA”

0,36 – fuel coefficient;

13.25; 16.25; 19.25; 22.25 – monthly consumption sale constant;

C – Euro and USD last business day exchange rate based on Europe Central Bank (five significant figures, four decimal place). Exchange rate published Europe Central Bank: http://www.ecb.europa.eu/stats/exchange/eurofxref/html/index.en.html.

Qi – actual average by the accounting month`s heating kWh/m³;

Q – contract heating value 10.19 kWh/m³;

Account of Alcohol, Tobacco, Fuel and Electricity Excise Duty Act, § 66 paragraph 10 foregoing: natural gas excise 23.45 EUR/ 1000 m^3 [13]

Also adds network service pay 32.70 EUR/ 1000 m^3

1.5.2 Heat price regulation.

Primary energy for heat energy productiong could found bu next formula [12]:

$$Q_{fuel} = \frac{Q_{heat.sale.}}{\eta_{prod.} \times (1 - q_{losses})} \quad (6)$$

where:

Q_{fuel} –primary energy amount (MWh)

$Q_{heat.sale.}$ – produced heat sale amonut (MWh)

$\eta_{prod.}$ –heat energy production efficiency (%)

q_{losses} – network losses (%)

The Competition Authority coordinated price formula has the following shape: [12]

$$price_{new} = \frac{costs}{Q_{heat}} + \frac{k_{fuel}}{Q_{heat}} \times price_{fuel} - \frac{compensation}{Q_{heat}} \pm coreection\ (€/MWh)$$

where:

$price_{new}$ - new marginal price for heating production based on formula (€/MWh)

costs - The Competition Authority approved costs excluding liquefied fuels and natural gas (fixed cost, capital cost, operating profit, other variable costs, purchased the heat, the cost of solid fuel expenses, etc.);

k_{fuel} – the quantity of fuel (coordinated according to the competition authority)

$price_{fuel}$ – new price of fuel (converted the heating value, which was based on coordination with the Competition Authority)

Q_{heat} – quantity of heat sales (coordinated according to the competition authority)

Compensation - compensation paid to the company due to increasing price of fuel (the government, local government, etc.);

Correction - marginal price change due to difference between calculated price of fuel and actual price of fuel. Coefficient "correction" is calculated during the year but a correction will be introduced after a 12-month period so that correction no effect in 2014 year. It will calculate in 2015 year.

In addition to above mentioned costs, the following costs should be considered (the list of costs is formed based on the cost breakdown proposed by the Estonian Competition Authority):

- Purchased heat, electricity, chemicals;
- Consumed water and sewerage costs;
- Land Use Tax;
- Government duties;
- Operation and maintenance of the equipments and buildings;
- Office building and rooms related costs;
- Technical consultancies and legal advices;
- Corporate fees;
- Transport costs;
- Telecommunication costs;
- Insurance costs;
- Office costs;
- Labour costs, etc.

1.5.3 Environmental costs.

The environmental impact of combustion boiler houses and power plants through the emission of sulphur dioxide, nitrogen oxides, carbon oxide, volatile organic compounds, solid particles and heavy metals into the ambient air depends on combustion technologies.

To estimate the environmental costs it is important to know the amount of emitted pollutants during the period of time and pollution charge rates upon the emission of pollutants into the ambient air.
Emission taxes regulate Environmental Charges Act (RTI 2005, 67,512) and Estonian Environment Ministry. [14]

§ 16. Application of pollution charge for emission of pollutants into ambient air
The pollution charge shall be applied for the emission into the ambient air, from a stationary source of pollution, of the following pollutants:

1) sulphur dioxide (SO_2) or other inorganic sulphur compounds;
2) carbon monoxide (CO);
3) carbon dioxide (CO_2);
4) particulates;
5) nitrogen oxides or other inorganic nitrogen compounds;
6) volatile organic compounds;
7) mercaptans;
8) heavy metals or compounds of heavy metals.

Methodology and calculations for emissions controls Estonian Environment Agency and Ambient Air Protection Act. The regulation comes from Ambient Air Protection Act (RT I 2004, 43, 298) § 46 bases on first paragraph. [14]

Table 1.2 shows tariffs for emissions. Source: Estonian Environment Ministry.

Table 1.3 Tariffs for emissions

Tariffs	**2013**	**2014**
	EUR/T	EUR/T
NOx	101,1	111,2
CO2	2	2
CO	6,35	6,99
NMVOC	101,1	111,2

PE_{co2}- Price CO_2 emissions

Table 1.3 shows KA Vaiko AS forecast for emissions in 2013 and 2014 years.

Table 1.4 Forecast for emissins in KA Vaiko AS

Amount	**2013**	**2014**
Olgina	*T*	*T*
NOx	0,5254	0,5254
CO2	488,8	488,8
CO	0,5254	0,5254
NMVOC	0,035	0,035

Table 1.4 shows environmental costs forecast this data uses in maximum heat price calculations. [16]

Table 1.5 Environment cost forecast

Costs	**2013**	**2014**
	EUR	**EUR**
NOx	53,1	58,4
CO2	977,6	977,6
CO	3,3	3,7
NMVOC	3,5	3,9
Summa	***1037,6***	***1043,6***

The listed above data shows that CO_2 emissions are very expensive also amount of CO_2 is biggest one. That is why for calculation of emissions in master thesis would be use only CO_2 amounts. It makes calculating simpler.

1.5.4 Financial calculations

Inside the company using calculation principles from the competition authority, there are special document that uses to calculate costs and generate price. This methodology called „Principles of approval of maximum price of heat” is prepared by the Estonian Competition Authority (CA) on the basis of the District Heating Act (DHA).

In analysis the operating charges of an undertaking are broken up as follows:

- non-controllable expenses
- variable cost
- operating expenses

- capital expenditure

Today KA Vaiko AS uses competition authority`s methodology for heat price. Decision from 13.12.13 nr. 7.1-3/13-111 The Estonian Competition Authority agreed approval of formula for maximum price of heat and calculation.

Formula below uses in Olgina and Sinimäe district, this is end price for consumers. [16]

$$price_{heat} = 21.239 + 0.13807 * price_{gas} \ (€/MWh),$$

where:

coefficient 21,239 cost sharing is set up with the following heat sales volume:

Volume of heat sales	3579	MWh
	thou €	€/MWh
Electricity cost	5.16	1.441
Water and sewage disposal	0.28	0.079
Chemicals cost	0.05	0.014
Environmental taxes	1.99	0.556
Operation expenses	42.42	11.853
Capital expenditure	9.785	2.734
Justified return	16.33	4.562
Total	**76.016**	**21.239**

coefficient 0,13807 Takes from fuel amount used for heat production 494.17 thou m^3 divided by volume of heat sales 3579 MWh so 494.17 /3579 = 0.13807;

price$_{gas}$ Natural gas price €/thou m^3 *(with excise and network service pay);*

Table below shows Decision from 13.12.13 nr. 7.1-3/13-111 The Estonian Competition Authority. It is components of price formula for accounting sales of 3579 MWh:

Table 1.6 Components of heat price calculations

	Unit	**Components of formula**
Fuel primary energy*	MWh	4624.62
Volume of heat production*	MWh	4356.00
Efficiency	%	94.19
Heat losses	%	17.84
	MWh	777
Volume of heat sales	**MWh**	**3579**
Heating value of natural gas	MWh/thou m^3	9.358
Fuel consumption	MWh	4624.62
	thou m^3	494.17
Natural gas price *(include excise and network service pay)*	€/MWh	40.84
	€/thou m^3	382.18
Electricity consumption	kWh	**49000**
Electricity price *(include network service, excise and renewable energy pays)*	€/kWh	0.105
Variable cost	**thou €**	**196.34**
Fuel costs	thou €	188.86
Other variable costs	thou €	5.49
Electricity costs	thou €	5.16
Water and sewage disposal costs	thou €	0.28
Chemicals costs	thou €	0.05
Environmental taxes	thou €	1.99
Operating expenses	**thou €**	**42.42**
Capital expenditure	**thou €**	**9.785**
Justified return	**thou €**	**16.33**
Allowed sales revenue	**thou €**	**264.88**
Maximum price of heat	**€/MWh**	**74.01**

So this table describes figures for both boiler houses Olgina and Sinimäe. We need to exclude Sinimäe figures from this table.

To calculate costs for production of heat power by using wood chips there are necessary to change several components of price formula in the following table introduced components that will be change after implementation of bio fuel.

From variable costs were exclude water and sewage disposal consumption and chemicals because demand (heat load) still the same as now.

Table 1.7 Fuel and electricity prices

Name	**Units**	**Price (EUR)**	***Short name***
Variable costs			
Fuel wood chips *(primary energy)*	*MWh*	28	WP_{energy}
	m^3	19.6	WP_{volume}
Natural gas price *(include excise and network service pay)*	*MWh*	40.84	GP_{energy}
	m^3	382.18	GP_{energy}
Electricity *	*kWh*	*0.105*	EP

Operating expenses have many components but in the table were highlighted the most important and components that will change after reconstruction such as human resources, materials, transport.

Table 1.8 Operationf expenses

Operating expenses	***Description***	**EUR per year**	***Short names***
Human resources	1,5 human	18 400	HR
Materials, spare parts and tools		5 300	MC
Other operating cost		14421	OC
Total operating cost		**42 421**	**TC**

Total operating cost includes all listed above costs.

Operation cost calculations

Human resource (salary for one worker per year)

$$HR_1 = 9\,900\ EUR\ per\ year$$

Due to wood boiler required more maintenances material cost will rise up to 15%:

$$MC_w = 1.15 * MC(7)$$

So total operation cost is or TC:

$$TC = HR + TR + MC + OC$$

TC_w total operation cost for wood chips boiler will be next:

$$TC_w = HR + HR_1 + TR_w + MC_w + OC \text{ (8)}$$

Variable cost calculation

For calculating variable cost there are simple formulas:

$$COST_{fuelwood} = WC \; x \; WP \; (EUR)\text{(9)}$$

Were:

$COST_{fuelwood}$ – cost of the wood chips consumption EUR

WC – wood chips consumption in m^3

WP –wood chips price (m^3/EUR)

$$COST_{fuelgas} = GC \; x \; WP \; (EUR)\text{(10)}$$

Were:

$COST_{fuelwood}$ – cost of the wood chips consumption EUR

GC – natural gas consumption in m^3

GP –natural gas price (1000 m^3/EUR)

$$COST_{electricity}=Pel.total \; x \; EP \; (EUR) \text{ (11)}$$

Were:

$COST_{electricity}$ – cost of the consumed electricity

$P_{el.}$ – Electricity consumption kWh

ER – electricity price

Capital expenditure

Capital cost for current year ($A_{c.y}$). could find by usage next formula from Competition Authority maximum heat price methodology:

$$A_{c.y.} = CA_{c.y.} \times norm_{c.y.}$$

$CA_{c.y.}$- residual value of the acquired assets;

$norm_{c.y.}$ - capital expenditure rate (for all equipment include building were taken 8%)

Justified return

The formula shown below calculates justified return. [16]

$$JR = r_p \times RA$$

RA - regularly asset

$$RA = \frac{RV_0 + RV_1}{2} + WC$$

WC- working capital

RA_0 - regularly asset`s residual value to beginning of the year

RA_1 - regularly asset`s residual value to the end of year

1.5.5 Investment calculation

> *"I would not pre-pay. I would invest instead and let the investments cover it."*
>
> *- Dave Ramsey*

There are different measures for evaluating the investments. The mostly used cash flow based measures:

- Net Present Value of Cash Flows (NPV);
- Internal Rate of Return (IRR);
- Payback time;

These measures for investment evaluating should be understood for company owners also they help to do right choice for making. The profitability calculations of new boiler house intended for the government (to get co-financing) and to bank (to get loan).

NPV definition

In finance, the net present value (NPV) of a time series of cash flows, both incoming and outgoing, is defined as the sum of the present values (PVs) of the individual cash flows of the same entity.

In the case when all future cash flows are incoming (such as coupons and principal of a bond) and the only outflow of cash is the purchase price, the NPV is simply the PV of future cash flows minus the purchase price (which is its own PV).

Formula:

$$\mathrm{NPV}(i,N) = \sum_{t=0}^{N} \frac{R_t}{(1+i)^t}$$

where

t – the time of the cash flow

i – the discount rate (the rate of return that could be earned on an investment in the financial markets with similar risk.); the opportunity cost of capital

R_t – the net cash flow i.e. cash inflow – cash outflow, at time t . For educational purposes, R_0 is commonly placed to the left of the sum to emphasize its role as (minus) the investment.

As discount rate could also use weighted average cost of capital approach (WACC)
Derive a weighted cost of the capital obtained from the various sources and use that discount rate to discount the cash flows from the project. How to calculates WACC could find from document called Guidelines for the Determination of Weighted Average Cost of Capital 2013.

Advantages: Overcomes the requirement for debt capital finance to be earmarked to particular projects.

Disadvantages: Care must be exercised in the selection of the appropriate income stream. The net cash flow to total invested capital is the generally accepted choice.

IRR

The internal rate of return (IRR) or economic rate of return (ERR) is a rate of return used in capital budgeting to measure and compare the profitability of investments. IRR calculations are commonly used to evaluate the desirability of investments or projects.

The formula for *IRR* is:
$0 = P_0 + P_1/(1+IRR) + P_2/(1+IRR)_2 + P_3/(1+IRR)_3 + . . . +P_n/(1+IRR)_n$
where P_0, P_1, . . . P_n equals the cash flows in periods 1, 2, . . . n, respectively; and
IRR equals the project's internal rate of return.[18]

Payback Period

Payback period in capital budgeting refers to the period of time required to recoup the funds expended in an investment. Payback period as a tool of analysis is often used because it is easy to apply and easy to understand for most individuals, regardless of academic training or field of endeavor. When used carefully or to compare similar investments, it can be quite useful. As a stand-alone tool to compare an investment to "doing nothing," payback period has no explicit criteria for decision-making (except, perhaps, that the payback period should be less than infinity).
Payback period is usually expressed in years. Start by calculating Net Cash Flow for each year: Net Cash Flow Year 1 = Cash Inflow Year 1 - Cash Outflow Year 1. Then Cumulative Cash Flow = (Net Cash Flow Year 1 + Net Cash Flow Year 2 + Net Cash Flow Year 3, etc.) Accumulate by year until Cumulative Cash Flow is a positive number: that year is the payback year. [19]

2. ANALYSIS

Company KA Vaiko AS is a municipal shareholding company that is located in Vaivara district and 100% owned by Vaivara district. One manager is responsible for water supply, another one for heat production/providing and the third one is administrator. The company scheme is shown below.

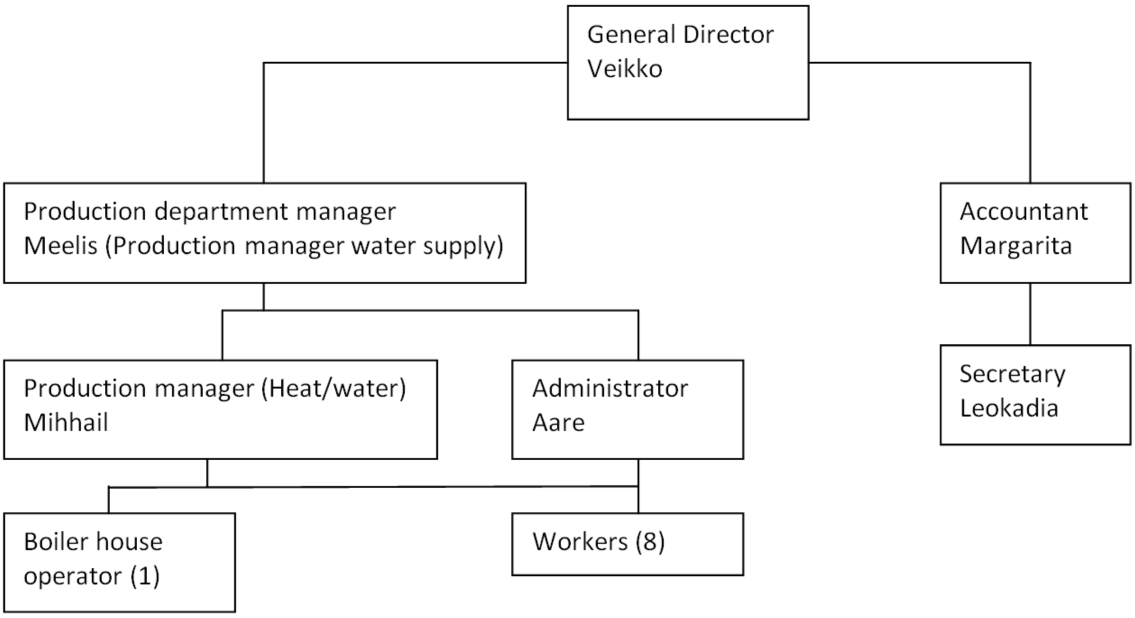


Figure 2.1 Organisation chart

Main fields of company activities:

- Heat providing,
- drinking water supply,
- sewage disposal,
- maintenance of the roads
- sauna services
- different services in the household

2.1 Actual situation of heat energy sector in district Vaivara

At present the heating supply causes a number of problems. The main of them is pricing. The thermal power production is very expensive due to high prices for natural gas, the CO2 emission taxes and a limited number of clients. Table 1 presents the prices of heating in different area in Estnoia. The price in Vaivara district is one of the highest in the country.

Table 2.1 Prices for heating in different areas in Estonia

Company	**Location**	**Price €/MWh**
AS Tallinna Kütte	Tallinn	66.14
AS Narva soojusvõrk	Narva	27.48
SW Energia OÜ	Paikuse	65.76
KA Vaiko AS	Vaivara vald	74.01

* Data from Estonian Competition Authority 28.02.2014

The main problem of high price for heating is high price for natural gas, this component makes 80% of price.

2.1.1 Quantity of heat production.

Normal year heat production - 2385 MWh/year
Including hot water production - 160 MWh/year
Peak load – 1.1 MW

2.2 Development program

In 2013 a long term program of thermal power development for Vaivara district was worked out by the Department of Thermal Engineering of the Tallinn University of Technology. Some alternative methods of heat generation were considered within this program.

For example: biomass fuel, heat pump, CHP, renewable sources of energy (wind power, solar power). The replacement of natural gas by biomass was estimated as the most efficient one at present. A detailed cost-efficiency analysis was carried out by experts from AF-Consulting AS and some concrete solutions to the use of biomass fuel were suggested. They will be analysed in this master thesis.

2.3 Process of heat production

In Olgina boiler house installed a gas boiler 1.12 MW„Viessmann''. It provides heat to customers in heating period from September till May and produces hot water for settlement's sauna around the year. A „Kiviõli-80'' natural gas boiler and „Kiviõli-80'' shale oil boiler are installed in boiler house for emergency. The Viessmann is activated at the beginning of heating season and in summer time when it is necessary for sauna. The process of thermal power production is fully automatic, heat demand depends of outside temperature and controls by automatics.

For correct work of boiler house four main resources are required.

1) Fuel – Natural gas
2) Water – feed water for system
3) Electricity – pumps, automatics
4) Human resource – boiler house operator

The demand for heat energy depends on outside temperature. Boiler`s automatic system controls quantity of burning fuel via outside temperature sensor.

The produced heat energy is measured in MWh.

Figure 2.2 Water heat boiler Viessmann Vitoplex 100 1.12 MW

2.3.1 Transportation of fuel.

Gas pipeline comes to the boiler house. Gas counter is installed in the boiler building.

Figure 2.3 Natural gas supply point

2.3.2 Burning process

Combustion is the sequence of exothermic chemical reactions between a fuel and an oxidant accompanied by the production of heat and conversion of chemical species.

Combustion of natural gas in boiler produces hot water. Figure

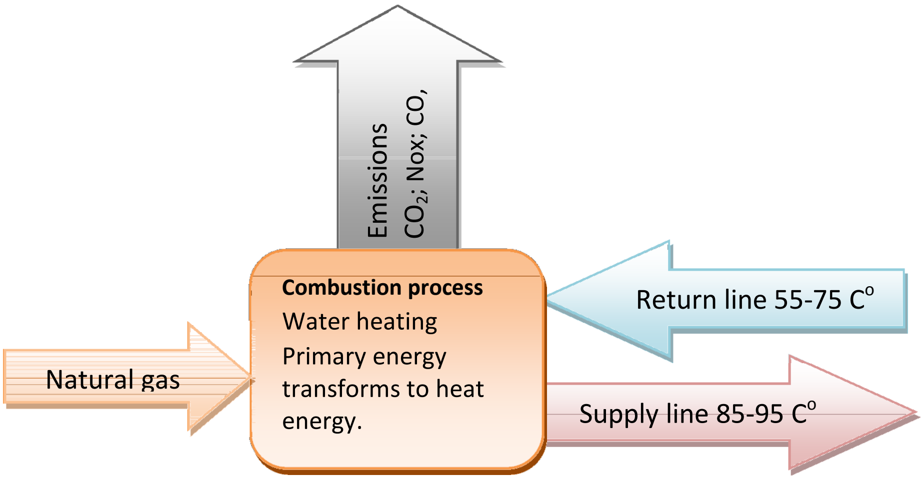


Figure 2.4 Processes of heat generation

During the combustion process the water in boiler is warmed up to 85-95 C° and fed to supply line and delivered to consumers. The temperature of water in the return line is 55-75 C°.

2.4 AS-IS Model

Process of heat production differs from traditional industrial production processes. It is simpler and fully automatic. Production process which is going to be analyzed, is introduced as a process flow of heat production.

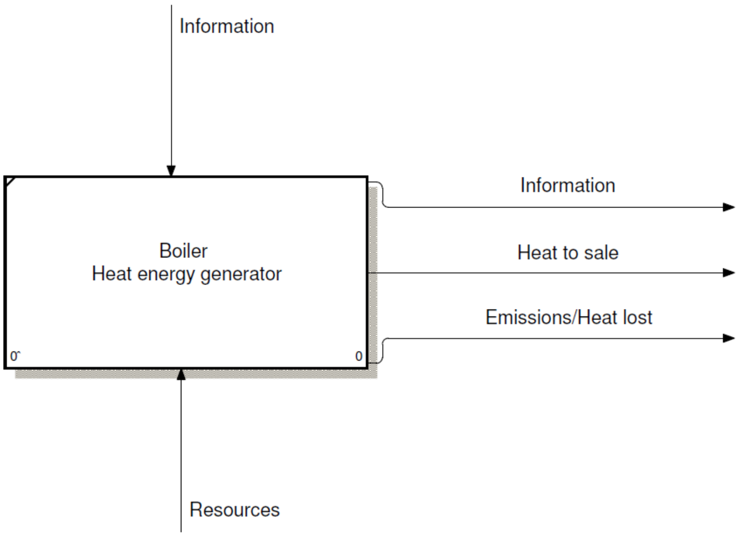


Figure 2.5 IDEF0 representation of the heat energy generation

Input constitutes: Resources (water, electricity, fuel, human resources) also information of heat loses, efficiency, tariffs, heat demand, fuel consumption, emissions (see figure 2.5). Further all pass into „black box'', that means into source of heat generation. At the output of the model have heat energy, emissions and heat losses, also information about economic balance.

2.4.1 The objective of the model

1. To analyse daily gas consumption
2. To simulate heat energy production process

2.4.2 Analysis of data

In the given master thesis real data of gas consumption in Olgina boiler house in the period from 11.04.2013 to 14.02.2014 were used. The information was provided by Eesti Gaas AS.

2.4.3 AS-IS model in Arena Simulation Software

The simulation model will be focused on the consumption of fuel and on the output heat value. So a simplified principal scheme for the simulation model was created.

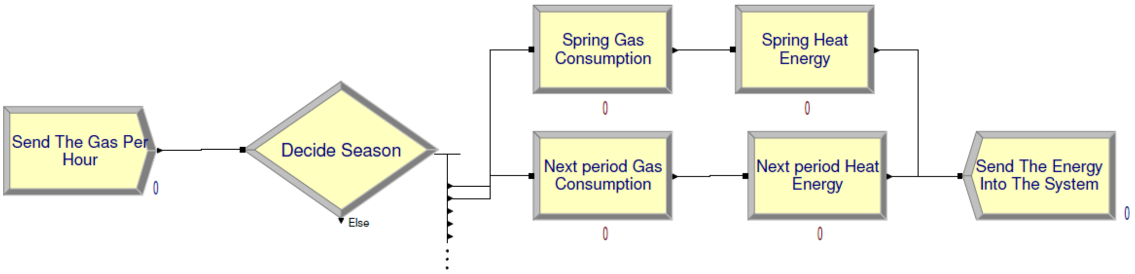


Figure 2.6 Simplified principal scheme for simulation model

Firstly it was necessary to divide heat period into several parts since the consumption depends on the temperature and differs from day to day and from season to season like the following:

January – 47 029 m^3
February – 52 764 m^3
June – 1 562 m^3
July – 1 244 m^3
August – 1 377 m^3

Due to special climate condition in Estonia the data was divided into six parts.

1. Spring is not so cold as the winter but should be cold than summer
2. Summer is very hot and the energy is produced for sauna only.
3. In September the temperature varies a lot and the consumption this period can be called transitional period.
4. The next goes the deep autumn.
5. In winter period temperature condition is stable cold.
6. Deep winter is the is the bigger season of heat consumption

Building a model

1) This model differs from normal production flow models. There is gas consumption every day (except in summer). One hour time period is understood by entity. Entity is a variable in this model. Gas consumption is calculated basing on the number of entity entries into the boiler system. It has no queue and the entity is the gas.

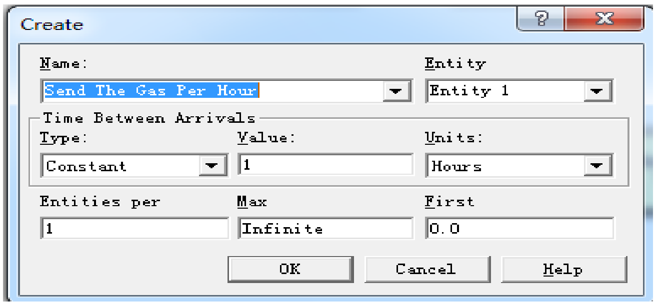
2) The consumption depends on the season. Consequently it is necessary to simulate it separately.

Steps in creating a simulation model

A Create Module (Figure 8) has to be first. One entity entry is equal to one hour. The number of entity's entries was used to simulate the time. One year has 365(day)*24=8760 hours. When we have reach this entities it means one year has passed.Several periods were created for comfortable simulation (Table 4).

Table 2.2 Periods for simulation model

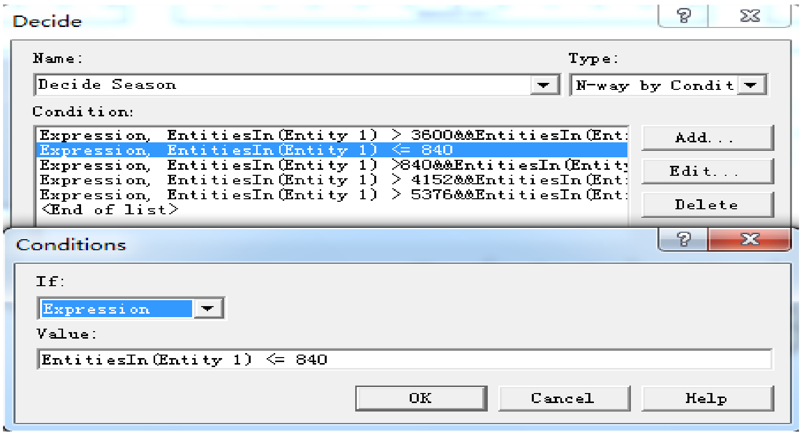
Period	***Duration***	***Hours***
Spring	11.04.2013-15.05.2013	840
Summer	16.05.2013-07.09.2013	2760
Autumn	08.09.2013-30.09.2013	552
Deep autumn	01.10.2013-20.11.2013	1224
Winter	15.02.2013-10.04.2013	1296
Deep winter	21.11.2013-14.02.2014	2064



Name: Send The Gas Per Hour
Entity: Entity 1
Time Between Arrivals
Type: Constant
Value: 1
Units: Hours
Entities per: 1
Max: Infinite
First: 0.0

Figure 2.7 Create module

Then a Decide Module (Figure 9) was used to indicate the season should go. As mentioned above, the entity quantity is the time. For example, the spring is from 11.04 to 15.05 so it has 35*24=840 hours. We choose the N-way by condition in the Module.



Name: Decide Season

Type: N-way by Condit

Condition:

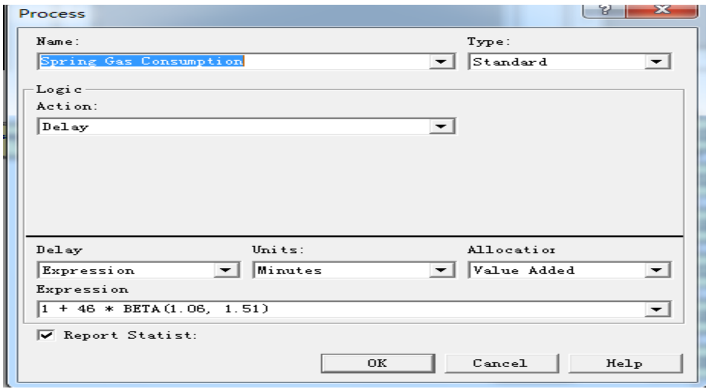
Expression, EntitiesIn(Entity 1) > 3600&&EntitiesIn(Ent:
Expression, EntitiesIn(Entity 1) <= 840
Expression, EntitiesIn(Entity 1) >840&&EntitiesIn(Entity
Expression, EntitiesIn(Entity 1) > 4152&&EntitiesIn(Ent:
Expression, EntitiesIn(Entity 1) > 5376&&EntitiesIn(Ent:
<End of list>

If: Expression

Value: EntitiesIn(Entity 1) <= 840

Figure 2.8 Decide module

When the number of entities is less than the 840 it goes to the spring Process module, however when the number of entities is more than 840 it means coming over the summer Process module. As the entity enters the system it goes into a Process Module (Figure 10), here we use the process time to simulate the gas consumption, since it does not use the resource we choose the delay option in the process module .



Name: Spring Gas Consumption

Type: Standard

Action: Delay

Delay: Expression

Units: Minutes

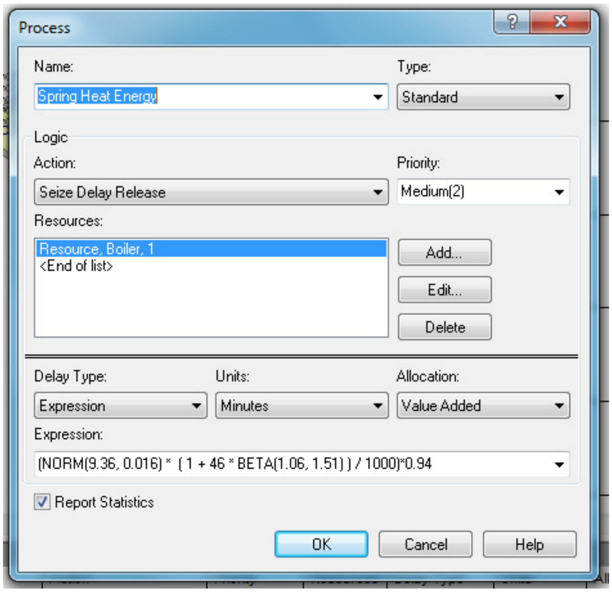
Allocation: Value Added

Expression: 1 + 46 * BETA(1.06, 1.51)

☑ Report Statist:

Figure 2.9 Process module

At the next point the gas enters into the boiler, combustion process begins. So the gas energy equals the consumption multiplied by heat value and the heat energy is also a distribution. And these distributions were multiplied to coefficient 0, 94 because it corresponds to boiler efficiency (Figure 11).



Name: Spring Heat Energy

Type: Standard

Action: Seize Delay Release

Priority: Medium(2)

Resources: Resource, Boiler, 1
<End of list>

Delay Type: Expression

Units: Minutes

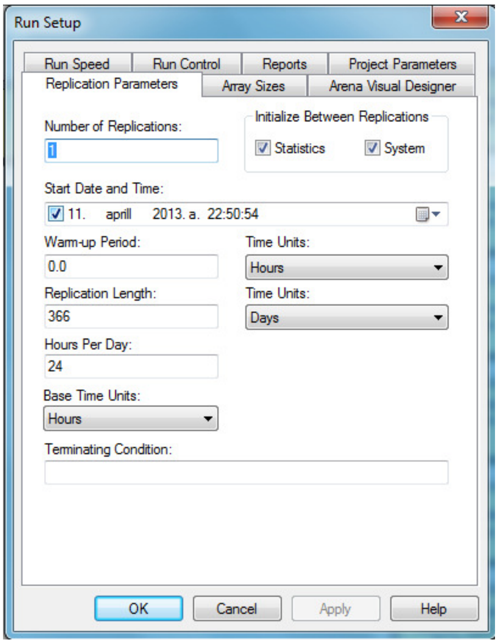
Allocation: Value Added

Expression: (NORM(9.36, 0.016) * (1 + 46 * BETA(1.06, 1.51)) / 1000)*0.94

☑ Report Statistics

Figure 2.10 Process module

Finally the run time was set a supposed, supposed we simulate for one year and spring season which starts from 11.04.2013, so that day was defined as the start point. Run time is set in the run setup option (Figure 13).



Number of Replications: 1

Initialize Between Replications: ☑ Statistics ☑ System

Start Date and Time: ☑ 11. april 2013. a. 22:50:54

Warm-up Period: 0.0

Time Units: Hours

Replication Length: 366

Time Units: Days

Hours Per Day: 24

Base Time Units: Hours

Terminating Condition:

Figure 2.11 Run setup option

Flowchart modules describe the dynamic processes in the model. The AS-IS flowchart (Figure 13) shows how the model is build and gives an opportunity also to display logic of the production flow.

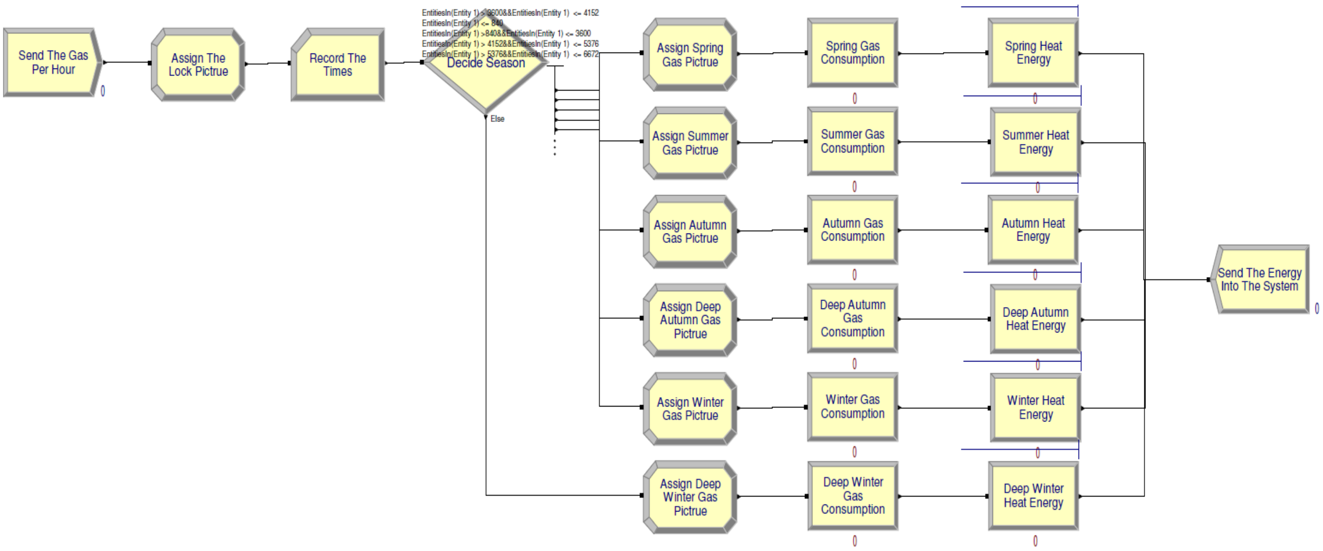


Figure 2.12 Flowchart of AS-IS model in Arena

Simulation model also has visual ads. While the simulation is running the charts of current gas consumption and heat production are being creating in program window. Figure 14 illustrates dynamic curve of the process.

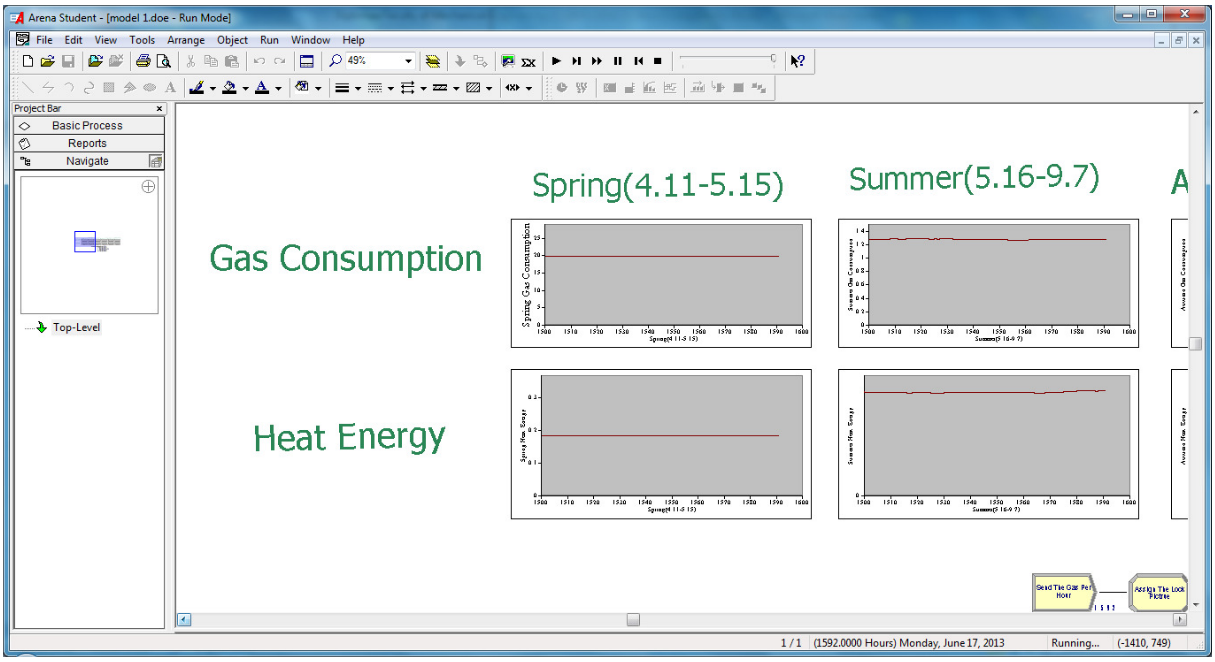
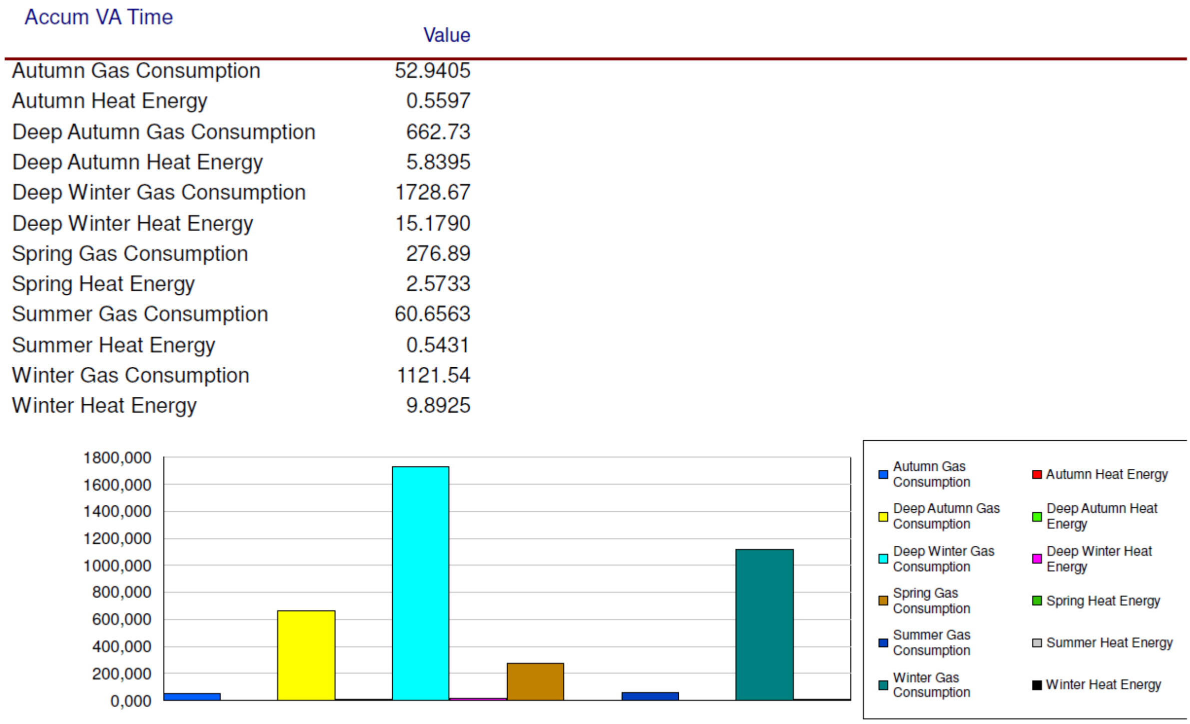


Figure 2.13 Visual curves in Arena

Result.

Figure 9 illustrates result of simulation. Results contain gas consumption and heat production amount by periods.



Accum VA Time

	Value
Autumn Gas Consumption	52.9405
Autumn Heat Energy	0.5597
Deep Autumn Gas Consumption	662.73
Deep Autumn Heat Energy	5.8395
Deep Winter Gas Consumption	1728.67
Deep Winter Heat Energy	15.1790
Spring Gas Consumption	276.89
Spring Heat Energy	2.5733
Summer Gas Consumption	60.6563
Summer Heat Energy	0.5431
Winter Gas Consumption	1121.54
Winter Heat Energy	9.8925

Figure 2.14 Simulation model results for gas consumption in Arena

Since the process is measured in minuets the results should be multiplied by 60 to get the unit which is an hour.

Autumn gas consumption	$52{,}94 \times 60 = 3\ 176$	m^3
Autumn heat energy	$0{,}56 \times 60 = 33{,}58$	MWh
Deep autumn gas consumption	$662{,}73 \times 60 = 39\ 764$	m^3
Deep autumn heat energy	$5{,}840 \times 60 = 350{,}37$	MWh
Deep winter gas consumption	$1728{,}67 \times 60 = 103\ 720$	m^3
Deep winter heat energy	$15{,}179 \times 60 = 910{,}74$	MWh
Spring gas consumption	$276{,}89 \times 60 = 16\ 613$	m^3
Spring heat energy	$2{,}5733 \times 60 = 154{,}40$	MWh
Summer gas consumption	$60{,}6563 \times 60 = 3\ 639$	m^3
Summer heat energy	$0{,}5431 \times 60 = 32{,}59$	MWh
Winter gas consumption	$1121{,}54 \times 60 = 67\ 292$	m^3
Winter heat energy	$9{,}893 \times 60 = 593{,}55$	MWh

Analysis of simulation results

Since the result of simulation is ready it could be compared with real data of heat production and fuel consumption. Comparison table of actual data and simulation results is shown below. KA Vaiko AS has no data for hourly energy production. Instead they use gas consumption to measure hourly heat energy production. The simulation result of heat energy production should be equal or close to actual data.

The gas consumption from actual data 2013-2014 year and simulation result based on actual data shown in Table 2.3

Table 2.3 Simulation results of gas consumption and actual gas consumption.

Period	***Consumption***		***Accuracy***
	actual data	***simulation result***	
	m^3	***m^3***	***(%)***
Winter	67 492	67 292	99,7
Spring	17 373	16 613	95,6
Summer	3 856	*3 639*	94,4
Autumn	*3 024*	*3 176*	95,2
Deep autumn	39 170	39 764	98,5
Deep winter	100 987	103 720	97,4
Total	***231 902***	***234 204***	***99,0***

Heat energy production from actual data 2013-2014 year and simulation result based on actual data shown in table 2.4

Table 2.4 Simulation results of heat production and calculated heat production.

Period	***Heat production***		***Accuracy***
	actual data	***simulation result***	
	MWh	***MWh***	***(%)***
Winter	593	591	99,7
Spring	153	146	95,6
Summer	34	32	94,4
Autumn	27	28	95,2
Deep autumn	344	349	98,5
Deep winter	888	912	97,4
Total	2038	2058	99,0

Fuel consumption and heat production based on simulation results

The simulation results of fuel consumption and heat production are not far from actual data.

Gas boiler heat production: **2 058** MWh **– Q**

Natural gas consumption: **234 204** m^3 **– GC**

Electricity calculations for simulation of AS-IS model

$P_{e.gas}$ =9,2 kWh - power consumption (electricity) of production 1MWh heat energy based on gas boiler (kWh)

$Q_{heat.gas}$=2 058 MWh

Electricity consumption:

Using formula (1)

$$PC_{el.gas} = 2058 \times 9{,}2 = 18\,933\ kWh$$

Electricity consumption for gas boiler is **18 933 kWh**

CO$_2$ Emission calculation in AS-IS model

B_1- Gas consumption (GJ)

$$B_1 = B \times Q_i^r (4)$$

$$B_1 = 234{,}204 \times 33{,}65 = 7\,881 GJ$$

$$M_{CO2} = M_c \times 44/12$$

M_{CO2} – The amount of CO2 emitted into the ambient air

Mc – amount of carbon emission (Gg C)

$$M_c = 10^{-3} \times B' \times q_c \times Kc$$

$$M_c = 10^{-3} \times 7{,}881 \times 15{,}3 \times 0{,}995 = 0{,}120 \text{ Gg C} \ (12)$$

B'– recalculated fuel consumption, TJ

$$B' = B_1 \times n$$

$$B' = 7\,881 \times 10^{-3} = 7{,}881$$

n – ratio, n=10^{-3}

q_c – specific emissions, tC/T; for natural gas – 15,3;

Kc – part of the oxidized carbon; for natural gas – 0,995;

$$M_{CO2} = 10^{-6} \times B_1 \times q_c \times Kc \times 44/12 \ (5)$$

$$M_{CO2} = 10^{-6} \times 7\,881 \times 15{,}3 \times 0{,}995 \times \frac{44}{12} = 0{,}439\ Gg\ CO2\ or\ 439\ t$$

M_{CO2}=439 t amount of CO$_2$ emissions.

2.4.4 Cost calculations for AS-IS model

Variable costs such as fuel and electricity consumption and emission tax will be calculated here.

Variable cost.

- **Fuel cost**

Gas boiler heat production: 2 058 MWh - Q

Natural gas consumption: 234 204 m^3 – GC

$$COST_{fuelgas} = GC \times GP_{volume} \; (EUR) \; (10)$$

$$COST_{fuelgas} = 234\,204 \times \frac{382{,}18}{1000} = 89\,508 \; (EUR)$$

Cost of natural gas consumption **89 508 EUR**

- **Electricity cost**

$$COST_{electricity} = PC_{el.total} \times EP \; (EUR) \; (11)$$

Amount of consumed electricity $PC_{el.total}$=18 933kWh

Price of electricity ER=0,105 EUR/kWh

$$COST_{electricity} = 18\,933 \times 0{,}105 = 1\,988 (EUR)$$

Cost of consumed electricity is **1 988 EUR**

- **Enviromental tax (CO_2)**

M_{C02}=439 T

PE_{co2}=2 EUR/T

$COST_{CO2}$= 439*2=878 EUR

Cost of CO_2 emissions **878 EUR**

2.5 TO-BE model

The heat production based on biomass and natural gas will be analysed in this section. The technical solution provides using a wood chips boiler for production of 85 % of energy and the remaining 15 % will still be based on using natural gas. This solution was suggested in the development program.

Further two kinds of fuel would be compared to show the advantage of using wood chips.

2.5.1 Pros and Cons of fuels

In the table below advantages and disadvantage of fossil fuel (natural gas) and biomass (wood chip) are presented.

Table 2.5 Advantages of fuels

Advantages	
Natural gas	***Wood chips***
Ease of use – no ash, no transportations, and no storages.	Renewable energy – no CO_2 emission costs (green energy)
Cheap equipment. Gas boilers are cheaper than wood chips boiler or other renewable sources like wind power generator, solar collectors/batteries.	Cheap fuel, ash can be used as fertilizer.
High efficiency – new gas boiler has at least 98%, old boilers under 93%.	Modern wood chip boilers could achieve up to 90% efficiency and even more.
Fully automatic systems need no everyday maintenance. Automatics are very reliable.	Modern automatic systems of wood chips boiler houses allowed to avoid permanent maintenance of equipment. Fuel is fed in furnace by screw conveyor. Feeding is controlled by automatics.
Natural gas does not contain moisture or ash, it is resistant to environmental conditions (gas in pipeline is always under the pressure). Natural gas cannot caused any serious problems in equipment work or reduce boiler efficiency.	Energy independence from foreign countries. This is local fuel. Price does not depend on oil prices or exchange rates.

Table 2.6 Disadvantages of fuels

Disadvantages.	
CO_2 emission tax	Process of burning is difficult due to fuel feed system (screw conveyor, moving floor system, ash removing system)
Natural gas price is high; it depends on exchange rate and world oil prices. The price includes excise.	Using on low load is not effective.
Natural gas is imported fuel. So energy sector based on gas depends on foreign countries especially Russia.	The quality of using wood chips must be very special for concrete boiler. Fraction and moisture are crucial importance.
	At least a week time storage is needed.
	Risk of wood chip price increasing if Auvere CHP plant would use local wood for production and combustion of wood chips.

Table 2.7 Energy prices of natural gas and wood chips (2006-2013)

	2006	***2007***	***2008***	***2009***	***2010***	***2011***	***2012***	***2013***
Wood chips, €/m³	6,20	7,29	9,97	12,40	12,53	12,97	15,84	16
€/MWh	8,86	10,41	14,24	17,71	17,90	18,53	22,63	28
Gas, €/1000 m³	109,93	145,40	240,69	248,94	283,38	312,78	369,70	388,0
€/MWh	11,82	15,63	25,88	26,77	30,47	33,63	39,75	41,59

Table (2.6) shows prices of energy resources for the last 8 years. An average heat value of natural gas is 9.35kWh/m^3 (33,5 MJ/m^3). A wood chips heat value varies from 0.6 – 0.9 MWh/m^3 .It depends from many factors such as moisture, kind of wood, fraction.We shell use the value of 0,7 MW/m^3 (2,5 GJ/m^3) in our calculation. Based on this data the comparison chart was built and as shown below.

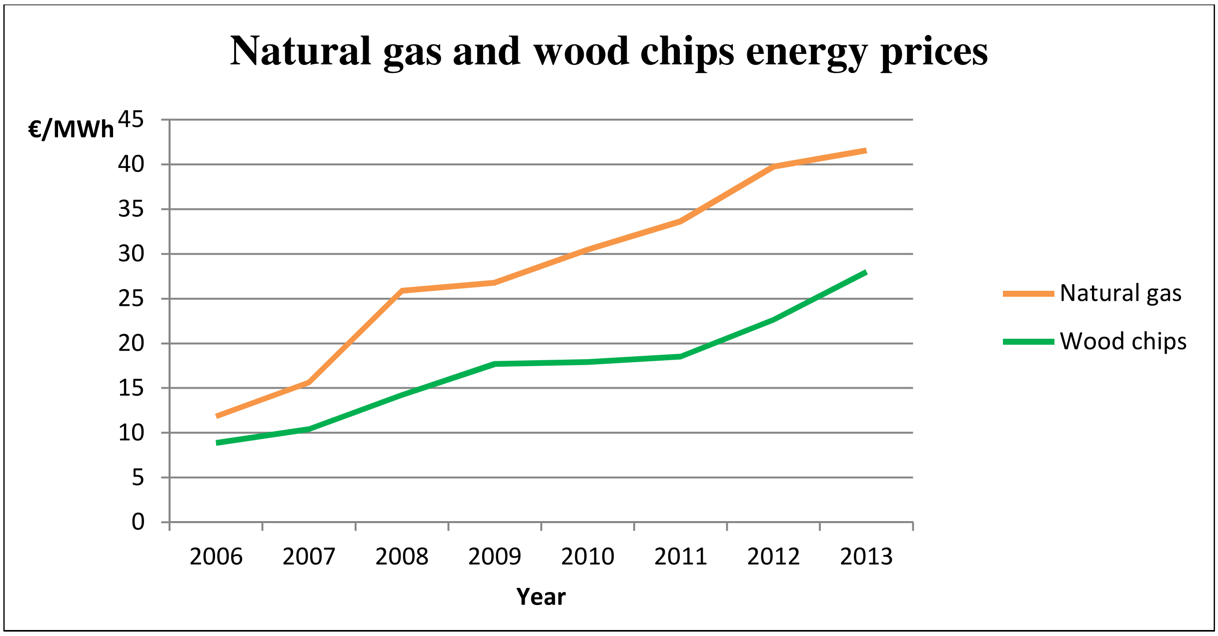


Figure 2.15 Chart of natural gas and wood chips prices

This chart shows that wood price is more stable and is more than two times lower than that natural gas. There is also a risk of the government rising excise for natural gas.

The above information allows to come to a conclusion that biomass is better and cheaper alternative fuel.

2.5.2 Technical solution.

The technical solution provides using a wood chips boiler for production of 85% of energy and the remaining 15 % will still be based on using natural gas.

Required steps for the implementation biomass into heat production:

- Wood chips storage building
- Wood chip boiler installation
- Design project (automatics, communications, mechanisms)
- Training of personnel
- Finding the wood chips supplier

In Estonia we can buy 600kw boiler by company KALVIS. So for pipeline assembly drawings we will use boiler KALVIS K-600 M in http://www.kalvis.lt/ see parameters of woodchips boiler KALVIS K-600M [22]

Industrial central heating boilers on solid fuel with moving and automated fuel supply and automatic processor control. This boiler is very suitable for Olgina boiler house. By parameters in Appendix 4 use geometrical parameters of this boiler.

- Nominal heat output – 600 kW
- Minimal heat output – 180 kW
- Main fuel – saw dust, chips length not more 50 mm
- Moisture main fuel up to – 40%
- Efficiency – 82% but using automatics can reach 90%
- Maximum water pressure – 6 bar
- Boiler water temperature – 60...110 °C
- Weight – 4100 kg

2.5.3 Price calculation.

Operation cost calculations

Human resource (salary for one worker per year):

$$HR = 9\,900\ EUR\ per\ year$$

An additional worker is needed for maintenance of new boiler and storage. That means human resource cost will raise up to:

$$HR_w = 18\,400 + 9\,900 = 28\,300 EUR$$

The material cost will rise up to 27.15%:

MC – 5 300 EUR;

$$MC_w = 1{,}27 * MC \text{ (7)}$$

$$MC_w = 1{,}2715 * 5\,300 = 6\,740$$

So total operation cost is TC_w:

OC – 14 421 EUR; other

TC_w total operation cost for wood chips boiler will be next:

$$TC_w = HR_w + MC_w + OC \text{ (8)}$$

$$TC_w = 28\,300 + 6740 + 14421 = 53\,761 EUR$$

Operation cost rise up **to 53 761 EUR** per year when using biomass fuel.

Electricity cost

The consumption of electricity of two boiler houses makes 49 000 kWh per year which means 5 160 EUR per year. 21 000 kWh is consumed by Olgina present. After reconstruction the consumption of electricity will rise up to 40%

So total amount of consumed electricity $PC_{el.\ total}$ would be:

$$PC_{total} = (49\,000 - 21\,000) + 21\,000 * 1{,}4 = 57\,400\ (kWh)$$

$$COST_{electricity} = PC_{el.total} \times\ EP\ (EUR) \text{ (11)}$$

$PC_{el.total}$=57 400 kWh

ER=0,105 EUR/kWh

$$COST_{electricity} = 57\,400 \times\ 0{,}105 = 6\,027 (EUR)$$

Environmental taxes

Upon the implementation of biomass fuel in Olgina the environmental taxes will decrease at least double. So approximate cost make 1 000 EUR per year

Fuel consumption

The volume of annual heat sales is 3 579 MWh including 17.84% loses at boiler efficiency 94 %) These figures are calculated basing on primary energy amount.

Natural gas consumption in Olgina and Sinimäe for heat production is 494.17 thou m^3 .

Sinimäe boiler house still consumes 237 100 m^3 of natural gas

Olgina forecast consumption for 2014 is 257 069 m^3 or 2 406 MWh of natural gas

Olgina boiler house would use wood for covering 85 % of load and it means that gas consumption would be:

$$Gas\ energy\ required = 0{,}15 * 2\ 406 = 360\ MWh$$

So after the installation of wood chips boiler 360 MWh of primary energy should still be produced based on natural gas. The volume required is (360*9.35= 38.5) 38.5 thou m^3 of natural gas.

So the total consumption of natural gas in Sinimae and Olgina will amount to:

$$Gas\ consumption\ after\ reconstruction\ = 237.1 + 38.5 = 275{,}6\ m^3 \text{or 2 576 MWh}$$

Heat sales based on natural gas amount to:

$$Q_{gaas} = 2\ 576 * 0{,}94 * 0{,}8216 = \mathbf{2\ 037\ MWh}$$

The rest of heat energy will be produced and sold basing on wood chips. Total heat sales is 3579 MWh. 2037 MWh of heat are produced and sold basing on gas. Now we can see how many MWh we need to produce for sale basing on biomass:

$$Q_{wood} = 3579 - 2037 = \mathbf{1542\ MWh}$$

We need to find out primary energy for this sales amount. So the simple way to do it is to add losses and consider efficiency. Wood chips boiler efficiency is 90% and losses are 17.84%

$$wood\ chips\ energy\ required\ \ 1\ 542 \times 1{,}2784 = 1\ 971 MWh$$

Required volume of wood chips (V_{wood}) is:

$$V_{wood} = 1\ 971 \times 0{,}7 = 1\ 379\ m^3$$

Capital expenditure

Capital cost for current year ($A_{c.y}$). Can be finding out by using of the formula from Competition Authority maximum heat price methodology:

$$A_{c.y.} = CA_{c.y.} \times norm_{c.y.}$$

$CA_{c.y.}$ - residual value of the acquired assets. 150 000 EUR should be own investments governmental financing is not included in this sum.

$norm_{c.y.}$ - capital expenditure rate (for all equipment including building were taken 8% at average)

$$A_{c.y.} = 150000 \times 0{,}08 = 12\ 000\ EUR$$

So now we can calculate total capital expenditure after reconstruction:

$$Capital\ expenditure = 12\,000 + 9\,785 = 21\,857\ EUR$$

Justified return

Justified return upon biomass fuel implementation is 21 930 EUR

coefficient 29,29 cost sharing is set up upon the following heat sales volume:

Volume of heat sales	3579	MWh
	thou €	€/MWh
Electricity cost	6,03	1,68
Water and sewage disposal	0,28	0,079
Chemicals cost	0,05	0,014
Environmental taxes	1,00	0,28
Operation expenses	53,76	15,67
Capital expenditure	21,78	6,09
Justified return	21,93	6,13
Total	**104,83**	**29,29**

coefficient 0,1352 Comes from fuel amount used for heat production of 275,6 thou m^3 divided by volume of heat sales (produced by gas boiler) 2010 MWh so 275,6 /2037 = 0,1352;

coefficient 0,8942 Comes from fuel amount used for heat production of1,432 thou m^3 divided by volume of heat sales (produced from biomass) 1528 MWh so 1,379 /1542 = 0,8942;

price$_{gas}$ Natural gas price 381,12€/thou m^3 *(inclusive excise and network service pay);*

Price$_{wood}$ Wood chips price 28 €/ m^3 *(inclusive excise and transport);*

Results of price calculation

$$Price_{heat} = 29{,}29 + 0{,}1352 \times 382{,}18 = 80{,}96(€/MWh),$$
$$Price_{heat} = 29{,}29 + 0{,}8942 \times 19{,}6 = 46{,}81(€/MWh),$$

Due to the decision of Estonian Competition Authority Olgina and Sinimäe are regarded as one district heating area. KA Vaiko AS should apply same price for both settlements, so the price would be as follows:

$$Price\ for\ customers = \frac{81{,}61}{47{,}47} = 63{,}89\ EUR/MWh$$

2.5.4 Investments

Approximate investment for reconstruction of Oligna boiler house is 300 000 €.

50% of this investment will be financed by EIC otherwise it is unprofitable. These kinds of projects are never accomplished in Estonia without co-financing from EIC or EU fonds.

Approximate costs for reconstruction in Euros

Table 2.8 Approximate investment for reconstruction in Euros

Name	**cost (EUR)**
Project	7 000
Wood chip storage	100 000
Wood chip boiler 0,6 MW	20 000
Auxiliaries and pipes	75 000
Automatics and control	20 000
Installation	40 000
General construction	40 000
Total	***300 000***

NPV, IRR and ROI calculations

To find out the profitability of the investment NPV calculations were used.

The investment cost is 150 000 EUR. This sum will be taken as a loan from bank for five years repay period with approximate interest rate of 1.5%. Table (2) below shows positive net cash flow for the first year.

Table 2.9 NPV, IRR, ROI calculations

Wood chips use (invest)	150 000	First year
Fuel cost		145 408
Electricity cost		6030
Water and sewage disposal		280
Chemicals cost		50
Environmental taxes		1000
Operation expenses		53760
Financial expenses (loan)	-150 000	31257
Justified return		21930
Total expenditure		**215 855**

Natural gas	0	First year
Fuel cost		188 832
Electricity cost		5 160
Water and sewage disposal		280
Chemicals cost		50
Environmental taxes		1 990
Operation expenses		42 420
Justified return		16 330
Total expenditure		**238 732**

Net Cash Flow		**6 547**

For NPV, IRR and ROI calculations next initial data were used.

- Investment 150 00 EUR
- Discount rate 7,58% (based on WACC)
- Duration of project 15 Years

All calculations were done in Excel software. The table of calculations is introduced in appendix 1

Calculation shows the following economic indicators:

- NPV 112 204 EUR
- IRR 14,5%
- ROI 8.8 years

The project will return investments within 8.8 years, NPV being more than 0. It means the project is cost-effective and the investments done would add value to the firm.

2.5.5 Simulation model TO-BE

Objectives for TO-BE simulation model are presented below:

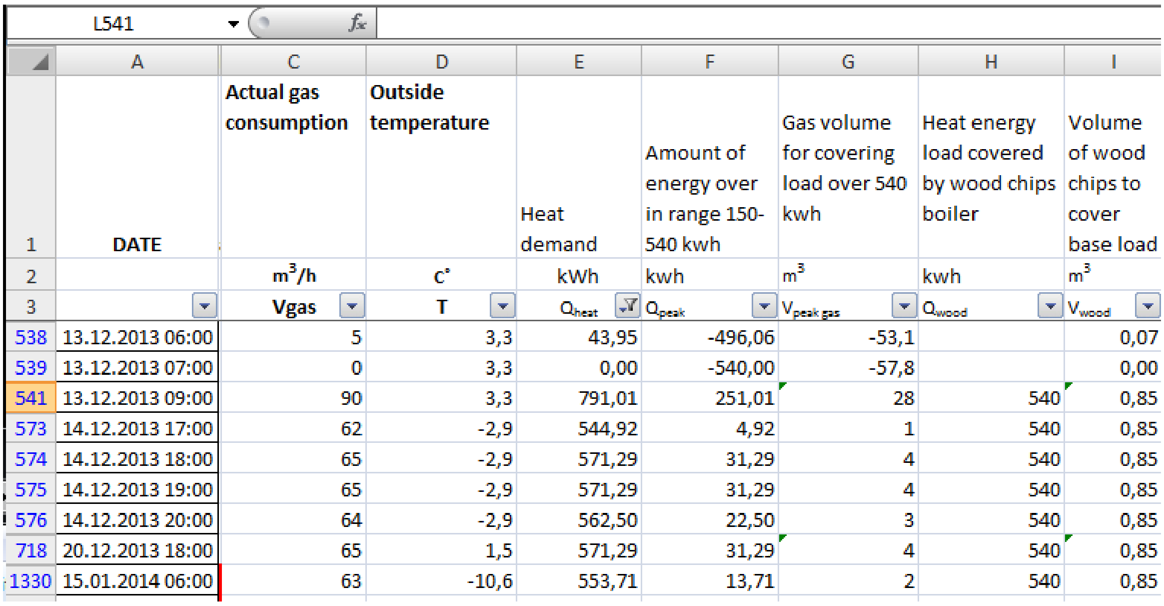
1. To analyse the mixed (wood or gas) daily consumption of fuel.
2. To simulate heat energy production process.
3. To prove that wood chips boiler is cheaper.

The process of the simulation is similar to the AS-IS model. The difference is when the temperature is higher than 10 C° degrees or lower than -10 C° degrees the gas boiler will cover the load, otherwise it is the wood chip boiler.

Data analysis

For the given master thesis actual data of gas consumption were used. It is the same data as we have used for AS-IS model. Where the temperature had only average daily value. But It cat be used in TO-BE model. To know the demand covered by wood chip boiler we need to know primary energy of natural gas. To define loads covered by gas and covered by wood chips the data were separated into two groups. The load under 120 kwh and more than 540 kwh would be covered by gas boiler. The wood chips boiler covers load from 150 to 540 kwh. This approach gives more accurate figure than using temperature range.

Here we already have the data of the hourly gas consumption, covering the complete temperature range. So we need to divide the data into two parts. Depending on the situation the boiler works. The most efficient range for using wood chips boiler is 150 – 540 kWh. The consumption data under 150 kWh and over 540 kWh goes to gas model.



L541

	A	C	D	E	F	G	H	I
1	DATE	Actual gas consumption	Outside temperature	Heat demand	Amount of energy over in range 150-540 kwh	Gas volume for covering load over 540 kwh	Heat energy load covered by wood chips boiler	Volume of wood chips to cover base load
2		m^3/h	c°	kWh	kwh	m^3	kwh	m^3
3		Vgas	T	Q_{heat}	Q_{peak}	$V_{peak\ gas}$	Q_{wood}	V_{wood}
538	13.12.2013 06:00	5	3,3	43,95	-496,06	-53,1		0,07
539	13.12.2013 07:00	0	3,3	0,00	-540,00	-57,8		0,00
541	13.12.2013 09:00	90	3,3	791,01	251,01	28	540	0,85
573	14.12.2013 17:00	62	-2,9	544,92	4,92	1	540	0,85
574	14.12.2013 18:00	65	-2,9	571,29	31,29	4	540	0,85
575	14.12.2013 19:00	65	-2,9	571,29	31,29	4	540	0,85
576	14.12.2013 20:00	64	-2,9	562,50	22,50	3	540	0,85
718	20.12.2013 18:00	65	1,5	571,29	31,29	4	540	0,85
1330	15.01.2014 06:00	63	-10,6	553,71	13,71	2	540	0,85

Figure 2.16 Fragment of datasheet for gas boiler simulation model

The column F shows the amount of energy that wood chips boiler is unable to cover. So this amount of heat energy must be produced by gas boiler. Column G shows the volume of gas needed to cover peak load.

In column G required volume of gas is shown. It was found out by using formula [5]

Primary Energy

$$Q_{heat} = V_{gaas}/LHV_{gas}\ [5]$$

Consequently

$$V_{gaas}=Q_{heat}/LHV_{gas}$$

Where

LHV– Low heating value for natural gas 9.35 kWh/m^3

Q_{heat} – primary energy

These principals were used to find out the data for gas boiler simulation on peak load To find out necessary data from datasheet when demand is under 150 kWh an excel filter should be applied. That's why TO-BE model contains two models. One for gas boiler heat energy production and fuel consumption and another one is for wood chips boiler simulation.

Building the „Gas boiler model''

According to the data classified, we find the distribution in different seasons. So next steps are also similar to the AS-IS model that we created where all around the year hours were used. In TO-BE model the duration is the sum of boilers working hours. But the period of simulation is also still the same 15.02.2013-14.02.2014

Duration of periods presented in table 6. This duration also reflects boiler working hours of equals the number of entities that enter the model.

Table 2.10 Durations of seasons in simulation model

Name of period	**Duration**
	h
Spring	329
Summer	626
Autumn	518
Deep autumn	20
Deep winter	384
Winter	276
Total	**2 153**

Flow chart in figure 18 shows resemblance to the concept of AS-IS model

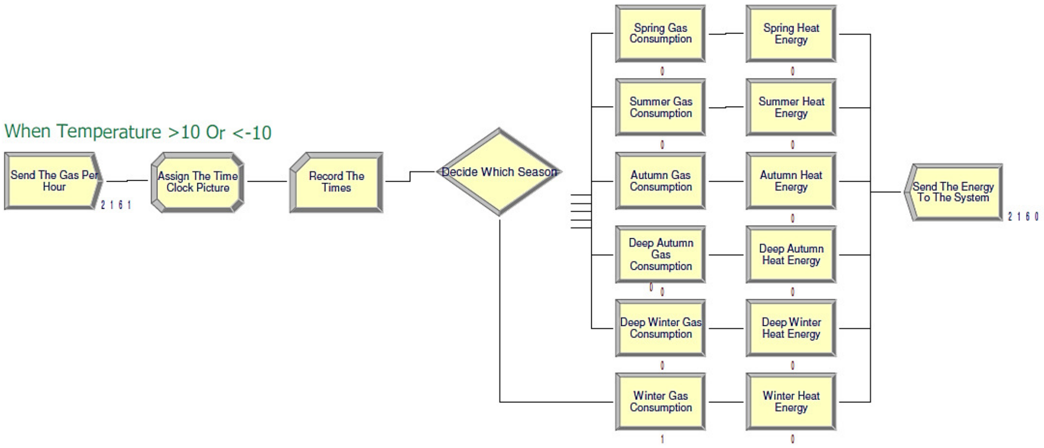
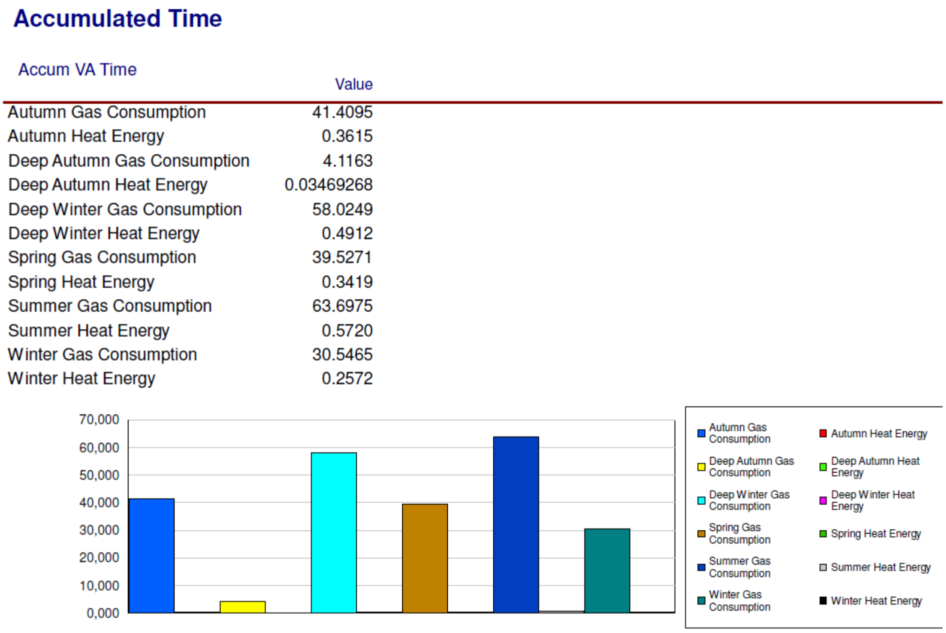


Figure 2.17 Flow chart of Gas model

Distributions in Process Modules differ from those in AS-IS model due to a change of entities number. To find out the required distribution Input Analyser was used.

So each period has its own distribution. Gamma distribution is used for deep winter and winter periods while Lognormal distribution is used to summer and autumn periods. Beta distribution was used for spring gas consumption and Weibul one for finding out consumption in deep autumn period.

Result of simulation presented below.



Accumulated Time

Accum VA Time

	Value
Autumn Gas Consumption	41.4095
Autumn Heat Energy	0.3615
Deep Autumn Gas Consumption	4.1163
Deep Autumn Heat Energy	0.03469268
Deep Winter Gas Consumption	58.0249
Deep Winter Heat Energy	0.4912
Spring Gas Consumption	39.5271
Spring Heat Energy	0.3419
Summer Gas Consumption	63.6975
Summer Heat Energy	0.5720
Winter Gas Consumption	30.5465
Winter Heat Energy	0.2572

Figure 2.18 Result of simulation model „Gas boiler"

The „Gas Boiler'' model simulation results are introduced in hours as in AS-IS model so it is necessary to multiplied them by 60.

Autumn gas consumption	$41{,}41 \times 60 = 2\,484$	m^3
Autumn heat energy	$0{,}3615 \times 60 = 23{,}4$	MWh
Deep autumn gas consumption	$4{,}12 \times 60 = 247$	m^3
Deep autumn heat energy	$0,0347 \times 60 = 2{,}4$	MWh
Deep winter gas consumption	$58{,}02 \times 60 = 3\,481$	m^3
Deep winter heat energy	$0{,}4912 \times 60 = 31{,}2$	MWh
Spring gas consumption	$39{,}53 \times 60 = 2\,370$	m^3
Spring heat energy	$0{,}3419 \times 60 = 21{,}6$	MWh
Summer gas consumption	$63{,}7 \times 60 = 3\,821$	m^3
Summer heat energy	$0{,}5720 \times 60 = 36$	MWh
Winter gas consumption	$30{,}54 \times 60 = 1\,832$	m^3
Winter heat energy	$0{,}2572 \times 60 = 16{,}2$	MWh

Table 2.11 Comparison table of actual data and simulation result

Gas consumption in range <-10˚C and 10˚C<	*Demand (Actual heat produced)*	*Simulated heat production*	*Actual consumption*	*Arena results of consumption*	*Accuracy Consump-tion*
	MWh	*MWh*	*m^3*	*m^3*	*%*
Spring	20	21	2 249	2 370	94,9
Summer	34	34	3 853	3 821	99,2
Autumn	21	22	2 374	2 484	95,6
Deep autumn	2	2	258	247	95,6
Deep winter	29	29	3 284	3 481	94,3
Winter	15	15	1 751	1 832	95,6
	121	**123**	**13 768**	**14 236**	**96,7**

Simulation results analysis of „Gas boiler'' model.

Simulation result shows the consumption of natural gas in period15.02.2013-14.02.2014 at the condition base load would be covered by wood chips boiler. For current period **14 236 m^3** of natural gas are required to cover the demand of 123 MWh. The results of simulation model are very close to real data.

Next part will show wood consumption and heat production.

Wood boiler model.

Since the company has not built the wood boiler yet, there is no consumption information. But we have the data of hourly gas consumption and outside temperature. This information could be easily transformed to heat demand.

Heat demand - Heat energy produced by gas boiler

$$Q_{heat} = V_{gas} \times LHV_{gas} \times k_{gasboiler}$$

So we know that wood chips boiler covers base load or demand from 150 kWh to 540kWh, if demand greater than 540 kWh or less than 150 kWh gas boiler comes into action. This range in is chosen by using excel filters. The required volume of fuel will be calculated like this:

$$V_{wood} = Q_{heat} \div LHV_{wood} \times 1.1$$

LHV_{wood}=0.7 MW·h/m^3

1,1 – wood chips boiler efficiency is 90% so volume should be increased by10% greater.

In Table 2.11 a fragment of excel datasheet is shown. This excel datasheet is used as data for generating distribution. Like other models the distributions were built by using Arena tool - Input analyser.

Table 2.12 Sample of datasheet for wood chips boiler simulation

DATE	**Gas consumption actual data**	**Outside temperature**	Heat demand	Amount of energy over 540 kwh	Gas volume for covering load over 540 kwh	Heat energy load covered by wood chips boiler	Volume of wood chips to cover base load
	m^3/h	**C°**	kWh	kwh	m^3	kwh	m^3
	V_{gaas}	**T**	Q_{heat}	Q_{peak}	$V_{peak\ gas}$	Q_{wood}	V_{wood}
15.01.2014 6:00	63	-10,6	553,71	13,71	2	540	0,85
15.01.2014 7:00	64	-10,6	562,50	22,50	3	540	0,85
15.01.2014 8:00	65	-10,6	571,29	31,29	4	540	0,85
15.01.2014 9:00	65	-10,6	571,29	31,29	4	540	0,85
15.01.2014 10:00	66	-10,6	580,07	40,07	5	540	0,85
17.01.2014 0:00	58	-9,4	509,76	-30,24	-3,2		0,80

What we can do now is to figure out how much wood the wood boiler needs every day. Wood chip boiler model is oriented on wood chip consumption.

The heat energy produced by wood chips boiler will be found out without using a simulation but by using simulation results of wood chips consumption. That is why flow chart of „Wood chip boiler'' model is different.

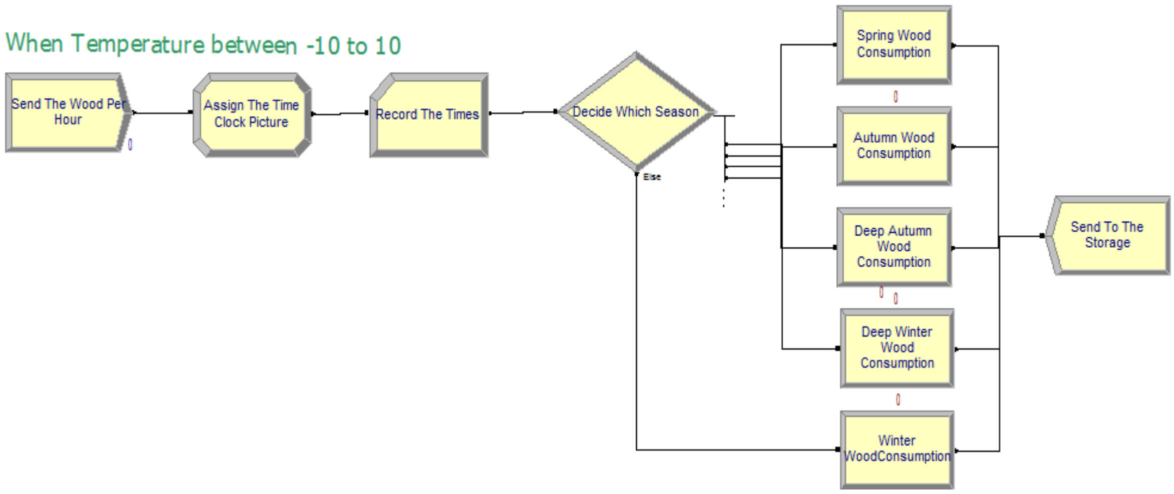


Figure 1 Wood chips boiler model in Arena

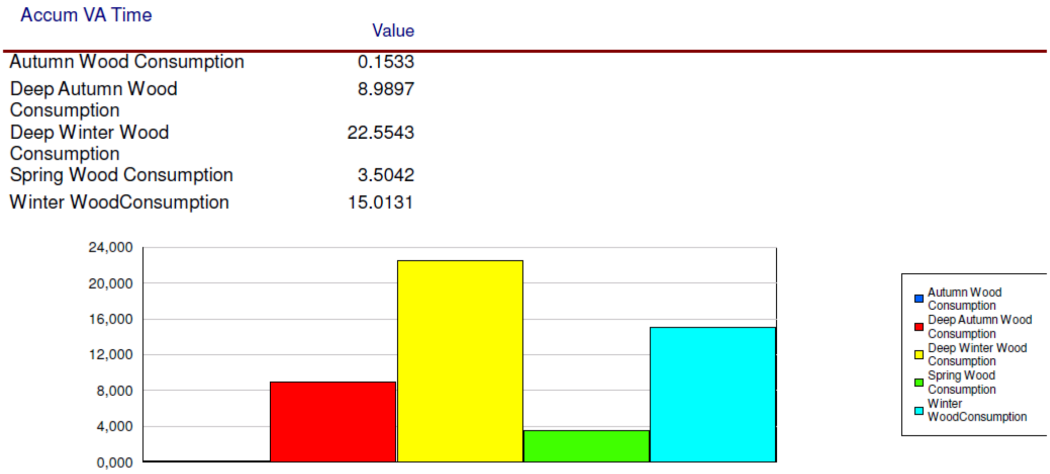
Both in „Wood chips boiler'' and „Gas boiler'' simulation models the consumption is greater than 0 so the time in „Wood Chip Boiler'' model is the sum of working hours.

Table 2.12 shows periods and durations.

Table 2.13 Durations of seasons in simulation model

Name of period	**Duration**
	h
Spring	1 306
Summer	0
Autumn	13
Deep autumn	1 208
Deep winter	2 053
Winter	511
Total	**5 091**

Collected data shows that wood chips boiler should work 5 091 hours.



```
Accum VA Time
                                              Value
Autumn Wood Consumption                      0.1533
Deep Autumn Wood                             8.9897
Consumption
Deep Winter Wood                            22.5543
Consumption
Spring Wood Consumption                      3.5042
Winter WoodConsumption                      15.0131
```

Figure 2.19 Wood chips boiler model simulation results

The „Wood Chips boiler'' model simulation results are introduced in hours as in AS-IS model so it is necessary to multiply them by 60.

Autumn wood consumption	$0.15 \times 60 = 9$	m^3
Deep autumn wood consumption	$8.9 \times 60 = 534$	m^3
Deep winter wood consumption	$22.55 \times 60 = 1\,353$	m^3
Spring wood consumption	$3.5 \times 60 = 210$	m^3
Winter wood consumption	$15.01 \times 60 = 901$	m^3

Simulation results analysis of „Wood chips boiler'' model.

Simulation result provides information on wood consumption. So it can be compared with theoretically calculated figures of wood chips consumption.

Table 2.14 Wood consumption in TO-BE model

	Arena result (consumption)	**Actually consumption**	**Accuracy**
	$V_{wood.sim.}$	V_{wood}	
Name of period	m^3	m^3	**%**
Spring	210	208.89	99.5
Autumn	9	8.97	99.7
Deep autumn	534	543.00	98.3
Deep winter	1353	1342.00	99.2
Winter	901	907.00	99.3
	3006.78	**3009.86**	

Now we could find out heat energy production for simulation model results.

$$Q_{wood.sim.} = V_{wood.sim.} \times LHV_{wood} \times k_{woodboiler}$$

Spring heat energy $210 \times 0.7 \times 0.9 = 132.2$ MWh

Autumn heat energy $9 \times 0.7 \times 0.9 = 5.67$ MWh

Deep autumn heat energy $534 \times 0.7 \times 0.9 = 336.42$ MWh

Deep winter heat energy $1353 \times 0.7 \times 0.9 = 852.39$ MWh

Winter heat energy $901 \times 0.7 \times 0.9 = 567.49$ MWh

Total $3006.78 \times 0.7 \times 0.9 = 1894.27$ MWh

2.5.6 TO-BE model simulation results.

Despite the fact that wood chips and gas boiler had to work 85% and 15% accordingly the simulation based on actually weather conditions in period 5.02.2013-14.02.2014 shows that the load was divided in different ways.

Fuel consumption and heat energy

Result of simulation based on combined fuel:

- Total simulated demand: 2 017 MWh
- Wood chips boiler produced: 1 894 MWh
- Wood chips boiler working hours: 2 153 h
- Gas boiler covers low and peak loads : 123 MWh
- Gas boiler working hours: 5 091 h

Wood chips boiler covers 93% of total demand and only 7% of demand is covered by gas boiler.

Fuel:

Wood chips consumption – 3 006.78 m^3

Natural gas consumption – 14 236 m^3

Electricity calculation

$$PC_{el.gas} = P_{el.gas} \times Q_{heat.gas}$$

$PC_{el.gas}$ – electricity consumption (gas boiler)

$$PC_{el.gas} = 9.2 \times 123 = 1\,131\ kWh$$

Electricity for production using gas boiler is 1 131 kWh

$$PC_{el.wood} = P_{el.wood} \times Q_{heat.wood}$$

$PC_{el.gwood}$ – electricity consumption (wood chips boiler)

$$PC_{el.wood} = 12.88 \times 1\,894 = 24\,394\ kWh$$

Electricity for production using gas boiler is 24 394 kWh

$$PC_{el.total} = P_{el.wood} + P_{el.gas}$$

$$PC_{el.total} = 1\,131 + 24\,394 = 25\,525\ kWh$$

Consumption of electricity for simulation period (combined fuel consumption) is **25 525 kWh**

Calculation of CO_2 emissions amount

$$B_1 = B \times Q_i^r$$

$$B_1 = 14.236 \times 33.65 = 479$$

$$M_{CO2} = M_c \times 44/12$$

M_{CO2} – The amount of CO_2 emitted into the ambient air

Mc – amount of carbon emission (Gg C)

$$M_c = 10^{-3} \times B' \times q_c \times Kc$$

B'– recalculated fuel consumption, TJ

$$B' = B_1 \times n$$

$$B' = 479 \times 10^{-3} = 0.479$$

n – ratio, $n=10^{-3}$

q_c – specific emissions, tC/T; for natural gas – 15.3;

Kc – part of the oxidized carbon; for natural gas – 0.995;

$$M_{CO2} = 10^{-6} \times B_1 \times q_c \times Kc \times 44/12$$

$$M_{CO2} = 10^{-6} \times 479 \times 15.3 \times 0{,}995 \times \frac{44}{12} = 0{,}0268\ Gg\ CO_2\ or\ 26.8\ t$$

Amount of CO_2 emissions is **26.8 T**

Cost calculations for simulation model

Variable cost

Fuel cost

Wood chips boiler produced: 1 894 MWh – $Q_{heat.wood}$

Wood chips consumption: 3 007 m^3 – WC

$$COST_{fuelwood} = WC\ x\ WP_{volume}\ (EUR)$$

$$COST_{fuelwood} = 3007\ \times\ 19.6 = 58\,937\ (EUR)$$

Cost of wood chips per year 58 937 EUR

Gas boiler covers low and peak loads: 123 MWh - Q

Natural gas consumption: 14 236 m^3 – GC

$$COST_{fuelgas} = GC \times\ GP_{volume}\ (EUR)$$

$$COST_{fuelgas} = 14\,236 \times \frac{382{,}18}{1000} = 5\,440\ (EUR)$$

Cost of natural gas consumption is 5 440 EUR

$$COST_{fuel} = COST_{fuelgas} +\ COST_{fuelwood}\ (EUR)$$

$$COST_{fuel} = 58937 +\ 5440 = 64377\ (EUR)$$

Cost of fuel after implementation of biomass fuel boiler is ***64 377 EUR***

- *Electricity cost*

$$COST_{electricity} = PC_{el.total} \times\ EP\ (EUR)$$

$PC_{el.total}$=25 525 kWh

ER=0,105 EUR/kWh

$$COST_{electricity} = 25\,525 \times\ 0.105 = 2\,680 (EUR)$$

Cost of consumed **electricity 2 680 EUR**

- *Environmental tax (CO_2)*

M_{C02}=26.8Gg

PE_{co2}=2 EUR/T

$COST_{CO2}$= 26.8*2=53.6 EUR

Cost of CO_2 emissions is **53.6 EUR**

Total variable cost is 67 057

Table 2.15 Comparison of costs in AS-IS and in To-BE models

Name of cost	**AS-IS**	**TO-BE**
	EUR	**EUR**
CO_2 emissions	878	54
Fuel	89 508	64 377
Electricity	1 988	2 680
Operation expenses	42 420	53 760
Total	134 794	120 871

In table 2.14 introduced variable costs of heat production. Nevertheless a figure from simulations shows that project is profitable.

CONCLUSION

To make a clear and the most informative conclusion all parts of cost effectiveness analysis presented above should be summarized. Within the current master thesis the suggested method of implementation of biomass fuel for heat generation was analysed. The analysis shows that combustion of biomass fuel is cheaper than that of natural gas. The calculations demonstrate that the price of heat energy produced by means of biomass fuel drops from 74.01 EUR/MWh to 63.89 EUR/ MWh and it means that final consumers will pay 14 % less. The next stage of the analysis is the determination of economic indicators such as IRR, NPV and the definiton of payback period. These results are quite positive for the project of Olgina boiler house reconstruction. The estimated time of investment return will be 8.8 years. Considering that the project life cycle is 15 years this period of payback is acceptable, net present value is 112 204 EUR, internal rate of return is 14.5%. These figures make a good reason for the company to invest in the project. Though a number of employees will slightly increase. The use of renewable fuel will reduce CO_2 impact to ambient air and improve environment in the region.

To prove that wood chips boiler can provide a chipper heat energy the author of this master thesis has created a simulation model based on the real outside temperatures and heat demand in the period from 15.02.2013 to 14.02.2014. The simulation result demonstrates that wood chips boiler covers in fact 93% instead of the theoretical 85% of total demand. Only 7% of the demand will be covered by gas combustion. Since the winter was rather warm this year the profit resulted in 13 919 EUR which is less than theoretical 25 000.

So the advantages of the investment in this project are quite evident: the final consumers will pay less, the company will get independence from natural gas, the price for heating will be stable for a long period of time.

KOKKUVÕTTE

Kasaagses maailmas energia on elujõud tööstuses ja sotsiaalses elus. Kõik energiaga seotud probleemid arutatatakse kõrgemal riiklikul tasemel. Energeetika on pidevalt arenev tegevusala, milles iga aastaga töötatakse välja uued tehnoloogia lahendused. Arvestades seda, et kütteperiood Eestis kestub kaheksa kuud, siis võime öelda, et meie riik on väga suuresti sõltuv soojusenergiast. Paljud külad ja asulad Eestis kasutavad siiamaani soojusetootmiseks maagaasi või põlevkiviõli. Need fossiilkütused on väga kallid ning kahjustavad loodust. Käesolevas magistritöös teostatakse soojustootmise tasuvusanalüüs biokütuse rakendamisel.

"Tootearendus ja tootmistehnika" suuna magistritöö eesmärk on teostada tasuvusanalüüs biokütuse rakendamisel soojustoomises KA Vaiko AS-s. KA Vaiko AS on munitsipaalne ettevõtte, kus toodetakse, jaotatakse ja müüakse soojusenergiat Vaivara valla piires. Firma haldab ühte küttepiirkonda, mis omakorda koosneb kahest asulast: Olginast ja Sinimäest. Vastavalt soojusmajanduse arengukavale 2013-2020, soojuse hinna vähendamiseks lõpptarbijatele on vaja üle viia katlamajad biokütusele. Püstitatud eesmärgi saavutamiseks teostatakse soojustootmise protsessi modeleerimine ja simulatsioon. Arena Rockwell tarkvara on kasutatud peavahendina simulatsiooni mudeli moodustamiseks.

Eesimene osa magistritööst koosneb teooriast, kus on algselt ära toodud väike ülevaatus Euroopa Liidu keskonnapoliitikast. Järgnevalt on kirjeldatud seaduseid ja akte, mis reguleerivad soojustootmise tegevusalasi, välja on toodud ka fondid Euroopa Liidult toetuse taotlemiseks. Edasises on esitatud modeleerimise ja simulatsiooni põhimõtted ning tarkvara kirjeldus. Peale seda on magistritöös välja toodud kütuste omadusi iseloomustav analüüs. Praktilises osas on kirjeldatud biokütuse rakendamise viis Olgina katlmajas. Soojusmajanduse arengukava järgi on vaja toota 85% kasutades biokütusega ja 15% kasutades maagaasi. Järgnevalt on kujutatud valemid elektrienergia ja saaste kooguse arvutamiseks. Viimases osa on esitatud finantsi, piirhinna ja investeeringu arvutuspõhimõtted ja valemid.

Põhiosas on välja toodud tasuvusanalüüs. Esialgselt on tehtud ülevaade arvestades tänapäevast seisukorda ja lahenduse võimalusi. Edasises osas autor kirjeldab detailsemalt "as-is" simulatsioonimudeli moodustamise protsess ja teostab väärtuste arvutamised. Peale "as-is" mudeli moodustamist magistritöö autor otsib tehnilisi lahendusi "to-be" mudeli ehitamiseks ja selgitab välja biokütuse rakendamise eelised ja puudused. Järgnevalt teistkordselt teostatud kalkulatsioon põhinedes "as-is" mudeli arvutustele ja koostatud simulatsiooni protsessi analüüsiks.

Peale analüüsi lõpetamist on esitatud vastavad järeldused ja kokkuvõtte. Teostatud arvutuste kohaselt tasub projekt ennast ära vähem kui 9 aastaga. Projekt annab tulu 15 aasta jooksul 112 204 EUR ulatuses ja välja toodud teised majandusnäitajad on samuti rahuldavad: tulusisenorm (IRR) on 14.4%. Soojushind lõpptarbijatele alaneb 14% võrra, mis annab projekti realiseerimiseks suure põhjuse. Sealjuures biokütuse rakendamine soojusetoomiseks parandab välisõhu kvaliteeti.

Simulatsioonimudeli tulemused näitavad ja kinnitavad prjojekt efetktiivsust ja realiseerimise vajalikkust. Simulatsiooniperioodil biokütuse katel katab 93% kogutoodangust ja gaasikatel vaid 7% ning selle periodi kasum on 13 917 EUR.

Kõik ülenimetatud näitajad annavad hea ülevaate Olgina katlamaja üleviimise vajalikkusest biokütusele ja seega see on otstarbekas samm KA Vaiko AS-i jaoks.

SUMMARY

Nowadays energy is a vital part of industrial and social word. The energy issues are discussed on a high political level. The energy sector is in a constant developing process and new technologies are steadily introduced in energy production. An 8 month long heating period in Estonia makes this country very much dependent on heat energy. A lot of settlements all over the country use natural gas or shale oil for heat production at present. The disadvantages of these types of fuel are high price, high emission taxes and dependence on natural gas supplier country. This master thesis provides a cost efficiency analysis of implementation of renewable fuels instead of fossil ones.

The profitability analysis for the master thesis of Mechanical engineering was carried out at municipal company KA Vaiko AS. This company provides heating for two settlements in Vaivara district. The main aim of the current thesis is to analyse the usage of wood chips as renewable fuel for the production of heat energy in settlement Olgina. A process simulation method was chosen as a general method to reach aims of this research work. The Arena Rockwell software was used as the main tool for modelling simulation process.

The cost calculations constituted a major part of the analysis. The methodology of price calculation was presented by Estonian Competition Authority and is based on several state laws and regulations such as District Heating Act, Ambient Air Protection Act, Environmental Charges Act and others. To evaluate the amount of investments the traditional cash flow based indicators such as payback period, net present value and internal rate of return were used.

The final part of this research work provides an analysis of simulation results, economic calculation results and suggests a solution in favour of biomass fuel.

REFERENCES

1. European Climate Change Programme [*Online*] http://ec.europa.eu/clima/policies/eccp/index_en.htm (10.12.2013)

2. Ambient air protection [*Online*]http://www.kik.ee/en/energy/ambient-air-protection (10.12.2013)

3. Renewable energy [*Online*] http://www.kik.ee/en/energy/renewable-energy (10.12.2013)

4. Averill M. Law. W. David Kelton. Simulation Modelling and Analysis. Third Edition: McGraw Hill, 2000.

5. WD Kelton, RP Sadowski, DA Sadowski. Simulation with Arena. Fifth edition: McGraw Hill, 2010

6. Anu Maria (1997). Introduction to modelling and simulation. – *Proceedings of the 1997 Winter Simulation Conferenced. S. Andradóttir, K. J. Healy, D. H. Withers, and B. L. Nelson*

7. Arena user's guide. 2007. [Online] http://www.act-operationsresearch.com/File/Arena/Arena%20User's%20Guide.pdf (10.02.2014)

8. Solid mineral fuels – Determination of gross calorific value by the bomb calorimetric method and calculation of net calorific value. 2004 ISO 1928

9. KA Vaiko AS website. [*Online*] http://www.vaiko.ee/?Arengukavad (03.11.2013)

10. Heating degree day. *Wikipedia.* [*Online*] http://en.wikipedia.org/wiki/Heating_degree_day (01.03.2014)

11. July 16, 2004 the Minister of Environment Regulation no. 94 "Method for Determining Emissions of carbon dioxide into Ambient Air" [*Online*] https://www.riigiteataja.ee/akt/12755030 (01.03.2014)

12. Principles of approval of maximum price of heat. *Estonian Competition Authority* [*Online*] http://www.konkurentsiamet.ee/?id=18306 (01.03.2014)

13. Account of Alcohol, Tobacco, Fuel and Electricity Excise Duty Act Riigi teeataja [*Online*] https://www.riigiteataja.ee/en/eli/ee/518112013012/consolide (01.03.2014)

14. Environmental Charges Act [*Online*]
https://www.riigiteataja.ee/en/eli/513012014001/consolide (01.03.2014)

15. Ambient Air Protection Act [*Online*] https://www.riigiteataja.ee/akt/789462 (01.03.2014)

16. Decision from 13.12.13 nr. 7.1-3/13-111 The Estonian Competition Authority

17. Guidelines for the Determination of Weighted Average Cost of Capital 2013 [*Online*] http://www.konkurentsiamet.ee/?id=11920 (01.04.2014)

18. Internal rate of return [*Online*] http://en.wikipedia.org/wiki/Internal_rate_of_return (01.04.2014)

19. Payback period [*Online*] http://en.wikipedia.org/wiki/Payback_period (01.04.2014)

20. Kalvis boilers website [*Online*] http://www.kalvis.lt (01.04.2014)

21. SW Energia OÜ website [*Online*] http://www.swenergia.ee (01.04.2014)

22. KALVIS website [*Online*] http://www.kalvis.lt/ (02.05.2014)

APPENDIX 1 – Table of NPV, IRR and Payback period calculation

Table 1. 1. NPV, IRR, ROI calculations

Biofuel implementation	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
investment cost	-150 000															
Fuel cost		145 408	149 770	154 263	158 891	163 658	168 568	173 625	178 833	184 199	189 724	195 416	201 279	207 317	213 537	219 943
Electricity cost		6 030	6 211	6 397	6 589	6 787	6 990	7 200	7 416	7 639	7 868	8 104	8 347	8 597	8 855	9 121
Water and sewage disposal		280	288	297	306	315	325	334	344	355	365	376	388	399	411	424
Chemicals cost		50	52	53	55	56	58	60	61	63	65	67	69	71	73	76
Environmental taxes		1 000	1 030	1 061	1 093	1 126	1 159	1 194	1 230	1 267	1 305	1 344	1 384	1 426	1 469	1 513
Operation expenses		53 760	55 373	57 034	58 745	60 507	62 323	64 192	66 118	68 102	70 145	72 249	74 416	76 649	78 948	81 317
Financial expenses (loan)*	- 150 000	31 257	32 195	33 161	34 155	35 180	0	0	0	0	0	0	0	0	0	0
Justified return		21 930	22 588	23 266	23 964	24 682	25 423	26 186	26 971	27 780	28 614	29 472	30 356	31 267	32 205	33 171
Total expenditure		**215 855**	**222 331**	**229 001**	**235 871**	**242 947**	**214 000**	**220 420**	**227 032**	**233 843**	**240 859**	**248 084**	**255 527**	**263 193**	**271 088**	**279 221**
***Bank loan interest rate is 1% +EURIBOR (for current calculations EURIBOR=0,5%) loan takes for 5 years**																
Still use natural gas	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Fuel cost		188 832	194 497	200 332	206 342	212 532	218 908	225 475	232 240	239 207	246 383	253 774	261 388	269 229	277 306	285 625
Electricity cost		5 160	5 315	5 474	5 638	5 808	5 982	6 161	6 346	6 537	6 733	6 935	7 143	7 357	7 578	7 805
Water and sewage disposal		280	288	297	306	315	325	334	344	355	365	376	388	399	411	424
Chemicals cost		50	52	53	55	56	58	60	61	63	65	67	69	71	73	76
Environmental taxes		1 990	2 050	2 111	2 175	2 240	2 307	2 376	2 447	2 521	2 596	2 674	2 755	2 837	2 922	3 010
Operation expenses		42 420	43 693	45 003	46 353	47 744	49 176	50 652	52 171	53 736	55 348	57 009	58 719	60 481	62 295	64 164
Justified return		16 330	16 820	17 324	17 844	18 380	18 931	19 499	20 084	20 686	21 307	21 946	22 605	23 283	23 981	24 701
Total expenditure		**222 402**	**229 074**	**235 946**	**243 025**	**250 315**	**257 825**	**265 560**	**273 526**	**281 732**	**290 184**	**298 890**	**307 856**	**317 092**	**326 605**	**336 403**
Net Cash Flow	**- 150 000**	**6547**	**6743,41**	**6945,712**	**7154,084**	**7368,706**	**43825,2**	**45139,95**	**46494,15**	**47888,98**	**49325,65**	**50805,41**	**52329,58**	**53899,46**	**55516,45**	**57181,94**

Discount rate	7,58	%
IRR	14,5	%
NPV with discount rate7,58%	112 204	EUR
ROI (return of investment)	8,8	years

APPENDIX 2 – Table of loan repayments schedule

Table 2 1Shedule of loan repayments

№	Payment date	After payment of the balance owed	Repayment of principal	Accrued interest	Amount of payment
1	January 2015	147 591,02	2 408,98	187,5	2 596,48
2	February 2015	145 179,02	2 411,99	184,49	2 596,48
3	March 2015	142 764,01	2 415,01	181,47	2 596,48
4	April 2015	140 345,98	2 418,03	178,46	2 596,48
5	May 2015	137 924,93	2 421,05	175,43	2 596,48
6	June 2015	135 500,86	2 424,08	172,41	2 596,48
7	July 2015	133 073,75	2 427,11	169,38	2 596,48
8	August 2015	130 643,61	2 430,14	166,34	2 596,48
9	September 2015	128 210,43	2 433,18	163,3	2 596,48
10	October 2015	125 774,21	2 436,22	160,26	2 596,48
11	November 2015	123 334,94	2 439,27	157,22	2 596,48
12	December 2015	120 892,63	2 442,31	154,17	2 596,48
13	January 2016	118 447,26	2 445,37	151,12	2 596,48
14	February 2016	115 998,84	2 448,42	148,06	2 596,48
15	March 2016	113 547,35	2 451,48	145	2 596,48
16	April 2016	111 092,80	2 454,55	141,93	2 596,48
17	May 2016	108 635,19	2 457,62	138,87	2 596,48
18	June 2016	106 174,50	2 460,69	135,79	2 596,48
19	July 2016	103 710,73	2 463,77	132,72	2 596,48
20	August 2016	101 243,89	2 466,84	129,64	2 596,48
21	September 2016	98 773,96	2 469,93	126,55	2 596,48
22	October 2016	96 300,94	2 473,02	123,47	2 596,48
23	November 2016	93 824,84	2 476,11	120,38	2 596,48
24	December 2016	91 345,64	2 479,20	117,28	2 596,48
25	January 2017	88 863,33	2 482,30	114,18	2 596,48
26	February 2017	86 377,93	2 485,40	111,08	2 596,48
27	March 2017	83 889,42	2 488,51	107,97	2 596,48
28	April 2017	81 397,80	2 491,62	104,86	2 596,48
29	May 2017	78 903,06	2 494,74	101,75	2 596,48
30	June 2017	76 405,21	2 497,85	98,63	2 596,48
31	July 2017	73 904,23	2 500,98	95,51	2 596,48
32	August 2017	71 400,13	2 504,10	92,38	2 596,48
33	September 2017	68 892,89	2 507,23	89,25	2 596,48
34	October 2017	66 382,53	2 510,37	86,12	2 596,48
35	November 2017	63 869,02	2 513,51	82,98	2 596,48
36	December 2017	61 352,38	2 516,65	79,84	2 596,48
37	January 2018	58 832,58	2 519,79	76,69	2 596,48
38	February 2018	56 309,64	2 522,94	73,54	2 596,48
39	March 2018	53 783,54	2 526,10	70,39	2 596,48
40	April 2018	51 254,29	2 529,25	67,23	2 596,48
41	May 2018	48 721,88	2 532,42	64,07	2 596,48
42	June 2018	46 186,29	2 535,58	60,9	2 596,48
43	July 2018	43 647,54	2 538,75	57,73	2 596,48

44	August 2018	41 105,62	2 541,92	54,56	2 596,48
45	September 2018	38 560,52	2 545,10	51,38	2 596,48
46	October 2018	36 012,24	2 548,28	48,2	2 596,48
47	November 2018	33 460,77	2 551,47	45,02	2 596,48
48	December 2018	30 906,11	2 554,66	41,83	2 596,48
49	January 2019	28 348,26	2 557,85	38,63	2 596,48
50	February 2019	25 787,21	2 561,05	35,44	2 596,48
51	March 2019	23 222,96	2 564,25	32,23	2 596,48
52	April 2019	20 655,51	2 567,45	29,03	2 596,48
53	May 2019	18 084,85	2 570,66	25,82	2 596,48
54	June 2019	15 510,97	2 573,88	22,61	2 596,48
55	July 2019	12 933,87	2 577,09	19,39	2 596,48
56	August 2019	10 353,56	2 580,32	16,17	2 596,48
57	September 2019	7 770,02	2 583,54	12,94	2 596,48
58	October 2019	5 183,25	2 586,77	9,71	2 596,48
59	November 2019	2 593,24	2 590,00	6,48	2 596,48
60	December 2019	0	2 593,24	3,24	2 596,48
Total loan:			**150 000,00**	**5 788,99**	**155 788,99**

APPENDIX 3 - Pictures

Figure 3.1 Olgina boiler house outside

Figure 3.2 Olgina boiler house inside