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"DRYPACK" - A CALCULATION AND ANALYSIS TOOL

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ABSTRACT

"DryPack" is a calculation tool that visualises the energy consumption of air-based and superheated steam drying processes. With "DryPack", it is possible to add different components to a simple drying process, and thereby increase the flexibility, which makes it possible to analyse the most common drying processes. Moreover, it is possible to change the configuration of the dryer by including/changing energy saving components to illustrate the potential of the new configuration. The calculation tool is demonstrated in four different case studies, where the actual energy consumption and possible energy consumption reductions by using "DryPack" are calculated.

With the "DryPack" calculation tool, it is possible to calculate four different unit operations with moist air (dehumidification of air, humidification of air, mixing of two air streams, and heating of air). In addition, a Mollier diagram with temperatures above 100°C may be generated.

INTRODUCTION

The objective of the "DryPack" project is to develop a calculation and analysis tool that can be used for finding energy savings in a large number of common drying processes and describe and calculate energy saving opportunities for drying plants. "DryPack" is relevant for energy advisers, equipment suppliers and end users of drying processes. "DryPack" is available as shareware on various websites (www.dti.dk and www.elforsk.dk).

DryPack is a program package consisting of five simulation tools:

1. **Thermal properties of moist air:** this program converts and calculates thermodynamic properties of moist air.
2. **Unit operations for moist air:** this program performs calculation of single unit operations for moist air which includes: heating, cooling and humidification operations as well as mixing operations of two air stream.

3. **Mollier diagram with temperatures above 100°C:** this program generates Mollier diagrams for temperatures above 100°C.
4. **Batch dryer simulation tool:** this program calculates the energy consumption and drying kinetics for convective batch dryer processes. More information about the program can be found in a companion paper (M.R. Kærn et al., 2013)
5. **Continuous dryer simulation tool:** This program is presented in details in the following sections.

Many handbooks, articles and general knowledge about specific drying processes are available, but there is no user-friendly tool, which can be used for analysing and optimising products and energy flow for the most common drying processes and thereby find energy savings. The energy saving potential for industrial drying processes is large.

A report (Danish Energy Agency, 2009) concludes that approx. 1200 GWh can be saved in industrial drying processes. The industry using drying processes uses 20% of the Danish industry's energy consumption (Danish Energy Agency, 2008) and energy consumption is the largest operating cost in productions that include drying. Energy savings in the drying industry have a high priority due to the rising energy prices and the increasing focus on climate changes.

The project group consisted of partners representing advisers, end users, universities and a variety of industrial companies using drying processes. It is expected that "DryPack" will be the standard tool for the analysis of drying processes for energy advisers and end users.

DRYERS OPTIONS

The main user interfaces of "DryPack" are shown in Figures 1 and 2. These figures show a convective and superheated steam drying process, respectively. In both systems, the models/calculations are based on a continuous dryer where the product is conveyed to the dryer.

In the main user interface, the user enters different parameters related to the process. Most of the parameters are accessible from measurements available from the dryer control software.

Based on the inlet and outlet conditions of the product and the states of the air flow/steam flow, the system calculates online energy balances, and a total specific energy consumption of the process is presented to the user.

When the specific energy consumption or a SMER (Specific Moisture Extraction Rate) value is known, it is possible to estimate the current dryer's effectiveness and hereby estimate whether optimisation of the process is possible. As the system creates online mass and energy balances, the output of the program can also be used as an onsite validation of the measurements to detect any inconsistencies in the measured values.

In general, the system operates with two main kinds of dryers: air-based dryers and superheated steam dryers.

Air-based dryer

A simple convective dryer to which it is possible to add different extensions:
- Recirculation of a fraction of the air outlet to increase the final relative humidity of the exhaust from the drying process.
- Addition of a recuperator to recover a fraction of the energy of the outlet steam to preheat the inlet air. It is also possible to utilize the latent heat of the exhaust stream.
- Addition of a water based energy recovery system to heat exchange the energy from the inlet to the outlet.
- Finally, it is possible to add a simple heat pump to transfer the energy from the outlet to the inlet.

All additional configurations can be implemented with a single click and a few additional inputs.
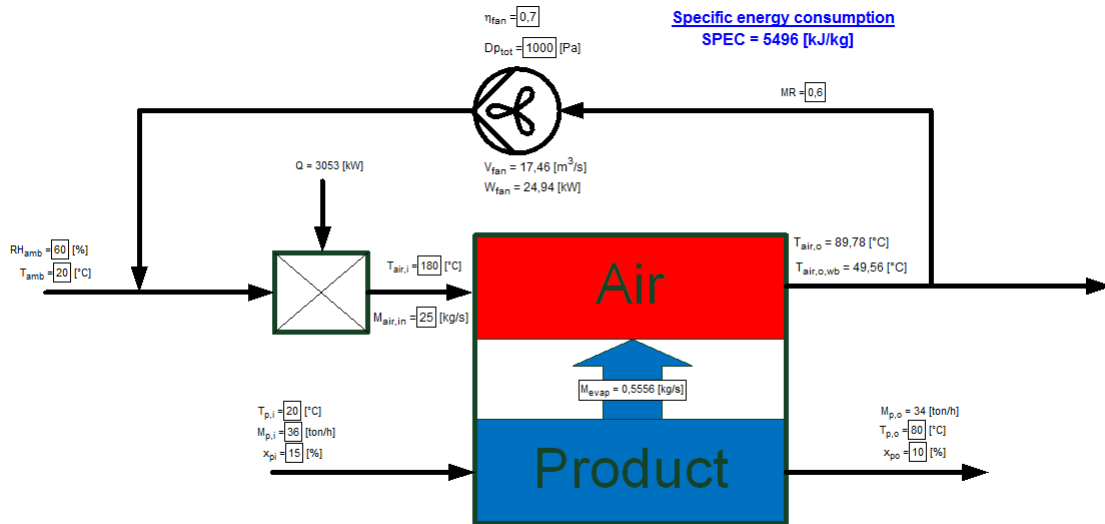
Figure 1 Convective drying process with recirculation of the outlet stream.

Superheated steam dryer

Another option is to analyse a superheated steam drying process during which the dryer can be operated at different pressures and superheated steam temperatures. It is possible to add a compressor unit to this process that can recompress the generated steam and by condensation in a condenser, retransfer the energy to the drying process.
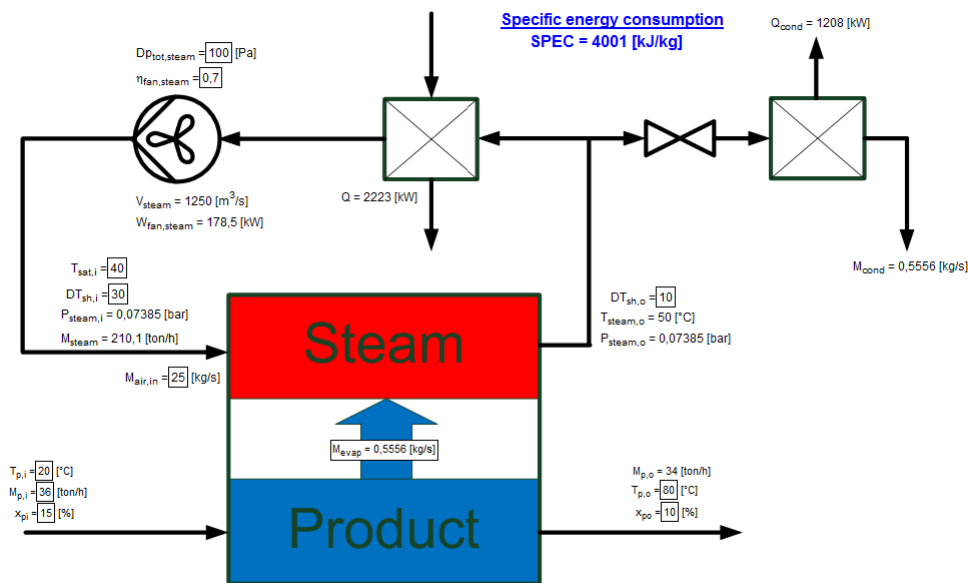

Figure 2 Superheated steam drying process

OPTIMISATION OF THE SYSTEM

One of the major advantages of the program is the simple user interface to which it is easy to add energy saving components, change drying processes and illustrate their potential directly - on location - based on an actual set of operational parameters. Secondly, but even more important, it is possible for the dryer operator or the adviser to change a single parameter of the product or the drying medium to visualise the effect directly and see how this affects the drying process.

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As an example, it is possible to increase the recirculation rate or the product flow. Based on the new inputs, the system calculates the specific energy consumption and a new exhaust stream for the drying medium. The key output from "DryPack" is the specific energy consumption of the drying process, and this calculated number can be compared to the evaporation energy of water at 2500 kJ/kg. By changing a single process parameter, the operator can get an intuitive understanding of the drying process and how this affects the output such as the specific energy consumption.

Often the drying process is a single element in a large industrial process and therefore, it is unimaginable to use the real process for experimental purposes. "DryPack" can help and act as a visualisation or training program that allows the operator to play with necessary parameters without affecting the real process.

CASE STUDY

"DryPack" was used to evaluate energy consumption and used to suggest energy savings on three cases which are presented in the following:
1. Drying of grain at Vestjyllands Andel (two cases with grain dryers)
2. Drying of asphalt at Arkil asphalt

Drying of grain at Vestjyllands Andel

Figure 3 shows sketches of two similar grain dryers located at Borris and Vildbjerg.
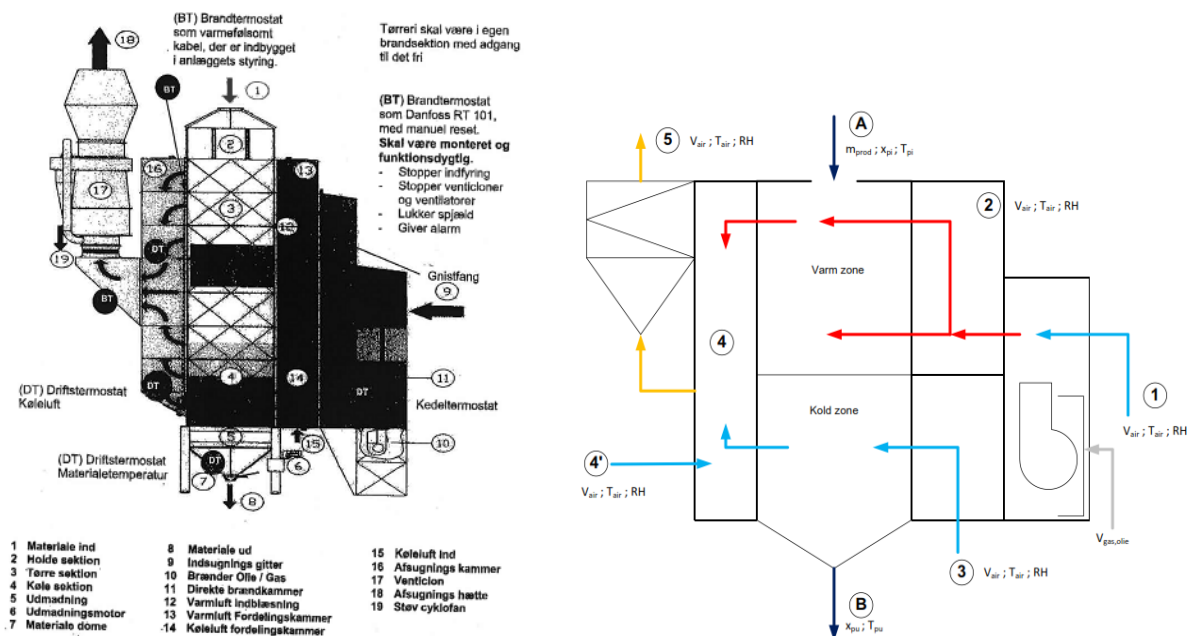

Figure 3 Sketch of the grain dryers in Boris and Vildbjerg

Ambient air enters the dryer at location (1) and is heated up by a gas fired heater (2). Afterwards, the hot air is distributed in the hot section of the dryer. The wet grain flows to the dryer at location (A) where the mass flow and moisture content in the product is measured. The grain drops through the dryer and it is cool down by the ambient air (3) in the cold section of the dryer. At grain exhaust (B), the moisture content of the product is measured. The air from the hot and cold section of the dryer is mixed (4) and it streams to cyclone separator where the dust is separated.

Measurements carried out at the two dryer locations are shown in Table 1.

Table 1 Measurement carried out in gas and product flow at locations shown in Figure 3

VILDBJERG		1	2	3	4'	5
Air						
Temperature	[°C]	16.1	78.5	16.1	16.1	28.1
Humidity	[%]	80.6		80.6	80.6	69.6

Product		A	B
Mass flow	[kg/s]	8.333	
Moisture content	[%]	0.148/0.118	0.123/0.092

BORIS		1	2	3	5
Air					
Temperature	[°C]	16.3	100	17	32.2
Humidity	[%]	63.4		61.8	68.6

Product		A	B
Mass flow	[kg/s]	6.08	
Moisture content	[%]	19.4	15.5

Figure 4 and 5 also show the calculation made in "DryPack" on the current dryer configuration. From the figures it can be seen that the specific energy consumption is 8519 kJ/kg in Vildbjerg while it is 7509 kJ/kg in Boris.
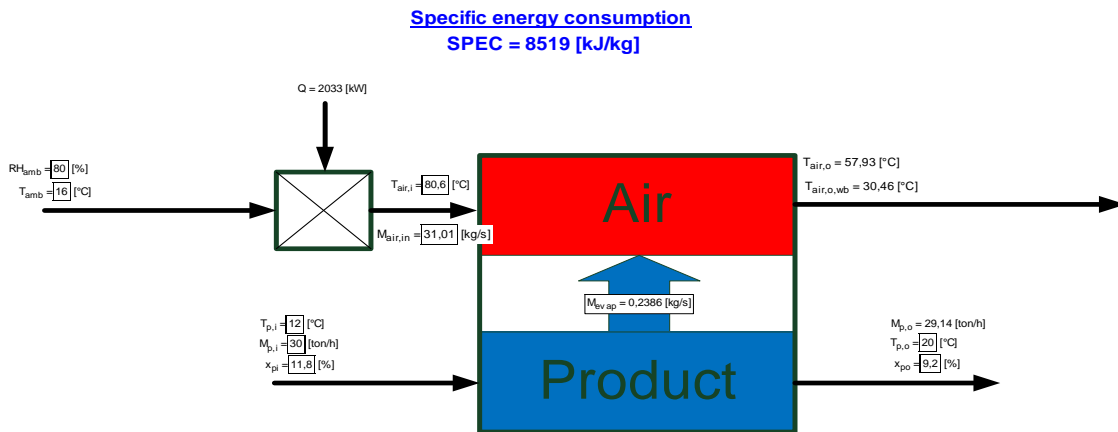
Specific energy consumption
SPEC = 8519 [kJ/kg]

Q = 2033 [kW]

RH_{amb} = 80 [%]
T_{amb} = 16 [°C]

$T_{air,i}$ = 80,6 [°C]

$M_{air,in}$ = 31,01 [kg/s]

Air

$T_{air,o}$ = 57,93 [°C]
$T_{air,o,wb}$ = 30,46 [°C]

M_{evap} = 0,2386 [kg/s]

$T_{p,i}$ = 12 [°C]
$M_{p,i}$ = 30 [ton/h]
x_{pi} = 11,8 [%]

Product

$M_{p,o}$ = 29,14 [ton/h]
$T_{p,o}$ = 20 [°C]
x_{po} = 9,2 [%]

Figure 4 Calculation of the energy consumption in Vildbjerg carried out in "Drypack".

Specific energy consumption
SPEC = 7509 [kJ/kg]

Q = 2108 [kW]

RH_{amb} = 63,4 [%]
T_{amb} = 16,3 [°C]

$T_{air,i}$ = 100 [°C]

$M_{air,in}$ = 24,85 [kg/s]

Air

$T_{air,o}$ = 67,95 [°C]
$T_{air,o,wb}$ = 33,16 [°C]

M_{evap} = 0,2808 [kg/s]

$T_{p,i}$ = 12 [°C]
$M_{p,i}$ = 21,9 [ton/h]
x_{pi} = 19,4 [%]

Product

$M_{p,o}$ = 20,89 [ton/h]
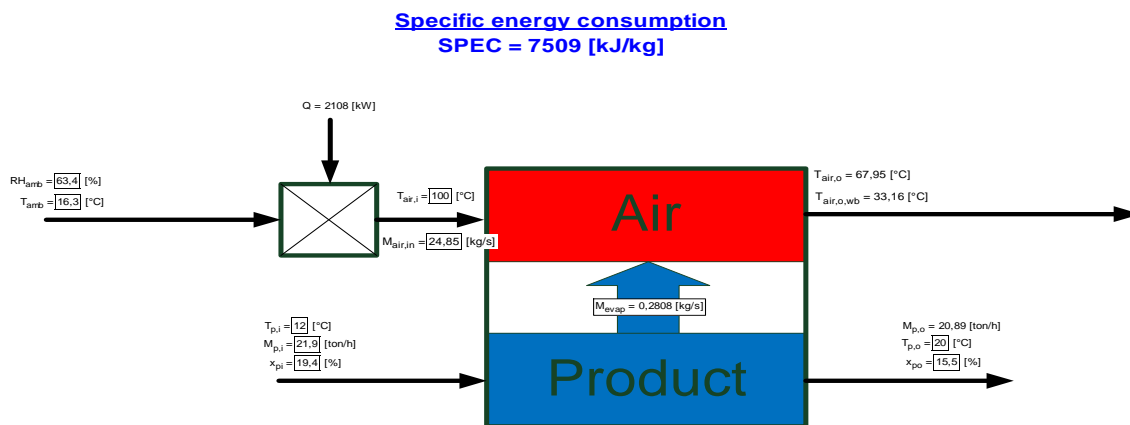$T_{p,o}$ = 20 [°C]
x_{po} = 15,5 [%]

Figure 5 Calculation of the energy consumption in Boris carried out in "Drypack".

Recirculating part of the exhaust gas will result in considerable energy reduction. Figure 6 shows the user interface in "DryPack" for the setup where part of the air is recirculated. The figure shows the calculation on the plant in Boris where 60% of the exhaust air is recirculated. From the figure it can be seen that the specific energy consumption is reduced to 4716 kJ/kg which corresponds to an energy reduction of 37%.
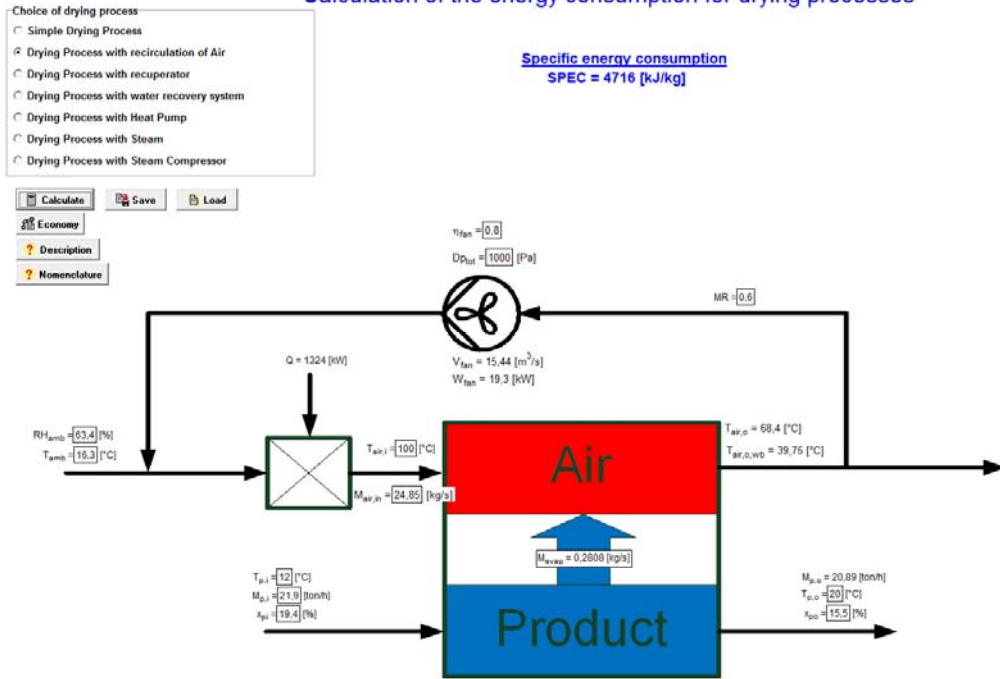
Figure 6 Example of a calculation on a plant in Boris where part of the exhaust gas is recirculated.

In Figure 7, specific energy consumption is plotted as a function of the recirculation factor for both the plant in Vildbjerg and in Boris.
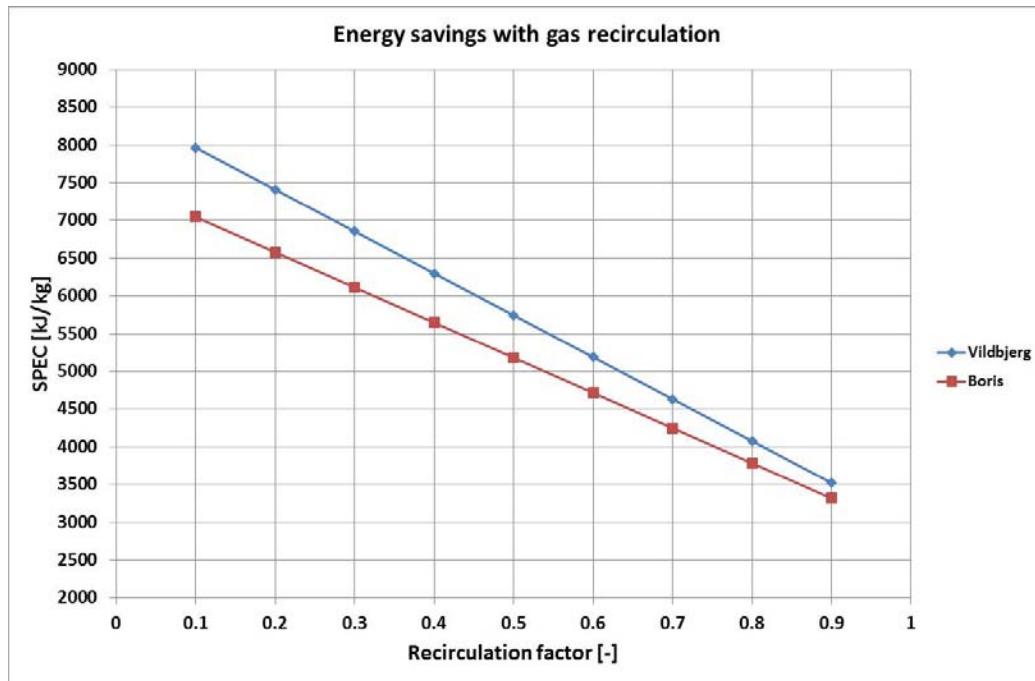

Figure 7 Estimated energy savings with gas recirculation on plants in Boris and Vildbjerg

In the setup shown in Figure 8, some of the exhaust air stream energy is recovered in the recuperator before being exhaust to the surroundings. The recovered energy is used to preheat the incoming air stream. The figure shows the calculation on the plant in Vildbjerg where the exhaust air temperature was reduced to 30°C in the recuperator. This results in a specific energy reduction from 8516kJ/kg to 3901kJ/kg which corresponds to an energy reduction of 54%.
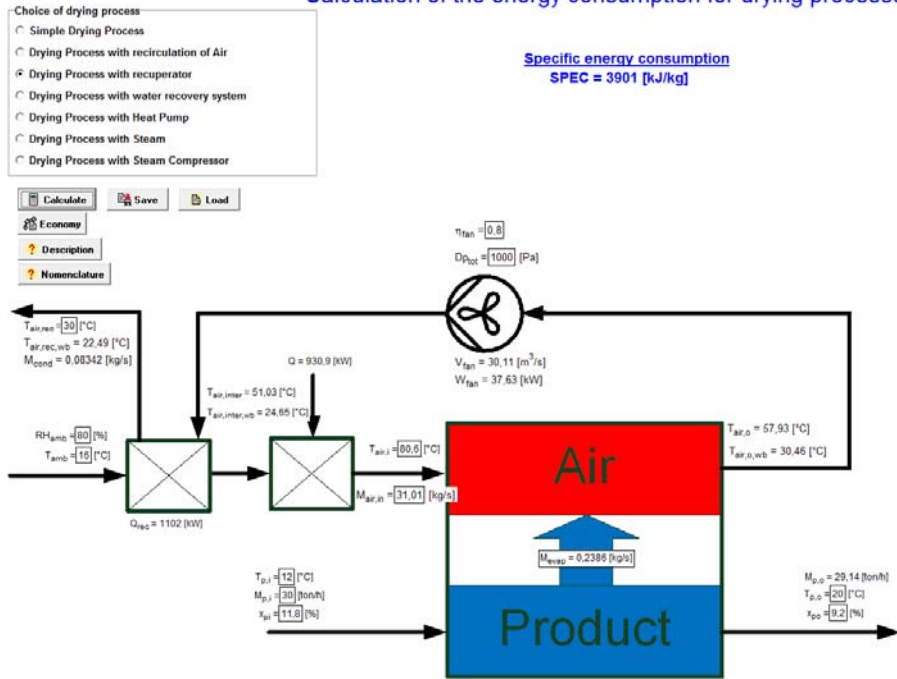
Figure 8 Example of a calculation on a plant in Vildbjerg where exhaust air stream energy is recovered in a recuperator

In Figure 9, specific energy consumption is plotted as a function of the exhaust gas temperature after the recuperator for both the plant in Vildbjerg and in Boris.
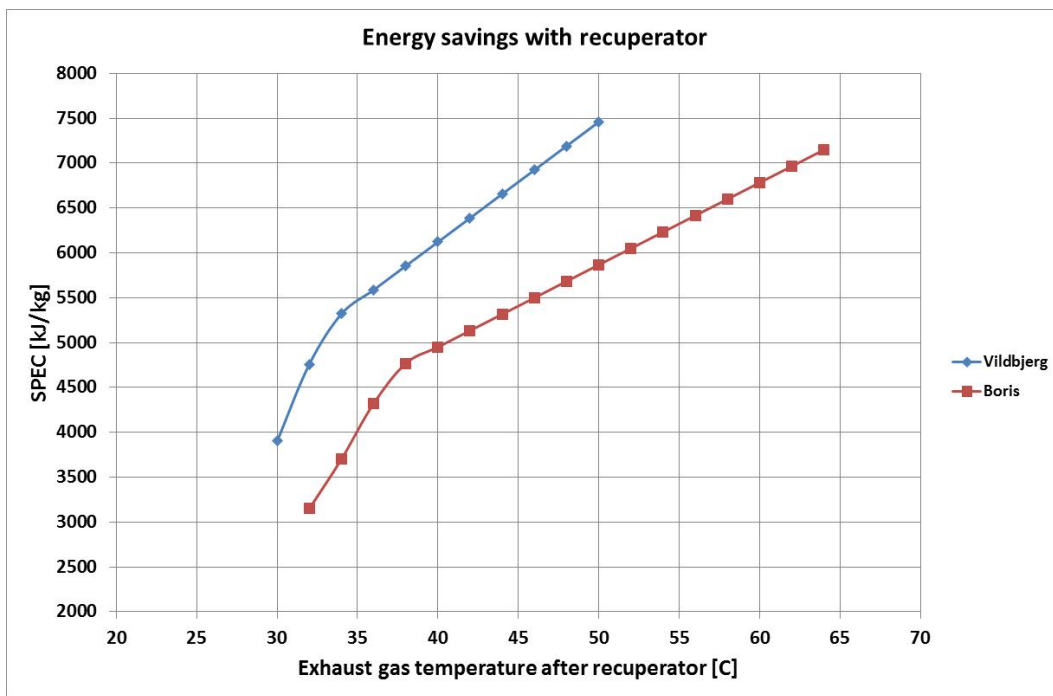

Figure 9 Estimated energy savings with recuperator on plants in Boris and Vildbjerg

Drying of asphalt at Arkil asphalt

The production of asphalt takes several processing steps. The following focuses on the drum dryer where wet gravel material is heated up and dried. After the drying section, the product flows to a mixing tower where it is mixed with other components and becomes asphalt. The heat input is

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regulated to reach product exhaust temperature of about 160°C-180°C. The picture of the plant is shown in Figure 10.
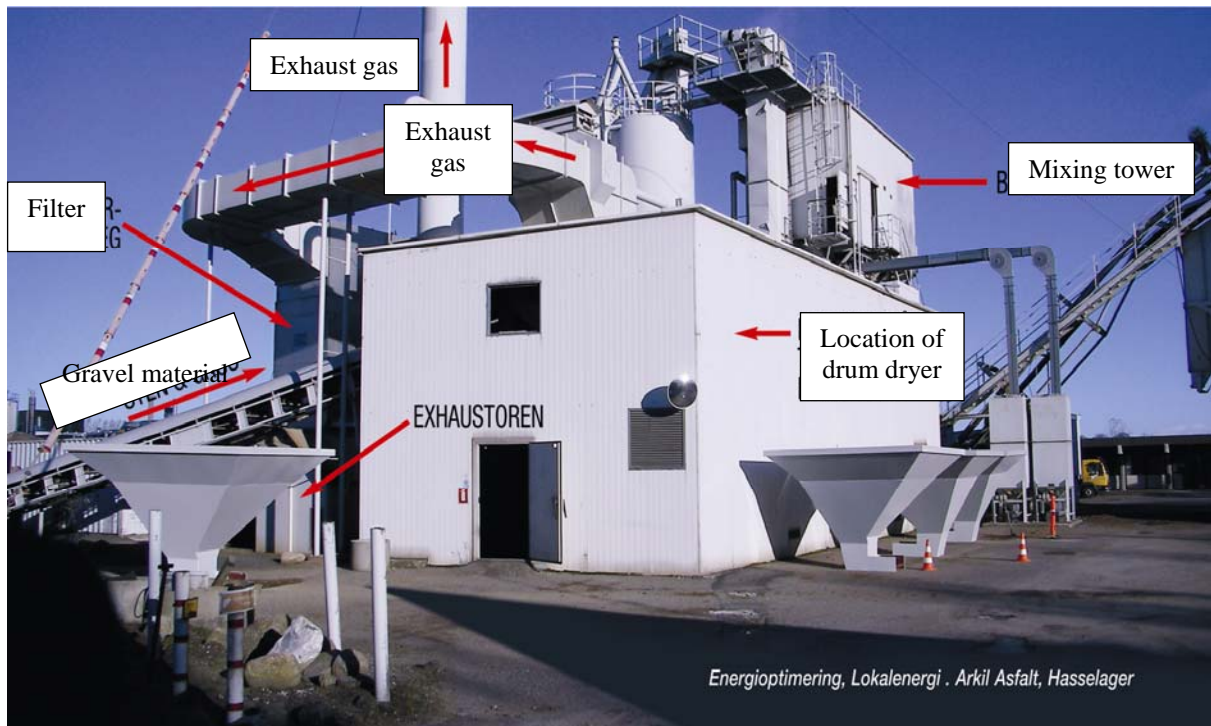

Figure 10 Picture of the asphalt plant

At the location, the temperature of the air and product was measured as well as the moisture content of the product was established, see Table 2.

Table 2 Onsite measurements on the asphalt plant

Air		Ambient	Inlet to dryer	Exhaust air
Temperature	[°C]	12	265	120-177
Humidity	[%]	54		

Product		Inlet	Outlet
Temperature	[°C]	12	203
Moisture content	[%]	3.57	0.03

The mass flow of the product and the mass flow of the air are unknown. The max product capacity of the dryer is known; 160ton/h. However, it is far from certain that the dryer when loaded reaches its max capacity of 160ton/h. From the energy consumption over the last year, it could be estimated that on an average, the dryer is loaded with 42ton/h, however, it is also know that there are some months during the year where the plant is not producing asphalt.

As the product and air temperature is known as well as the moisture content of the product at inlet and outlet, the "DryPack" program can be used to make calculations at different product flows to see what influence it has on the energy consumption and air mass flow. With an increase of product flow, the air mass flow needs to be likewise increased and thereby the specific energy consumption remains the same. Therefore, in the following calculations, the product flow is assumed to be 80ton/h.

Based on the production of 80ton/h, the energy consumption can be estimated to 16MW, see Figure 11.
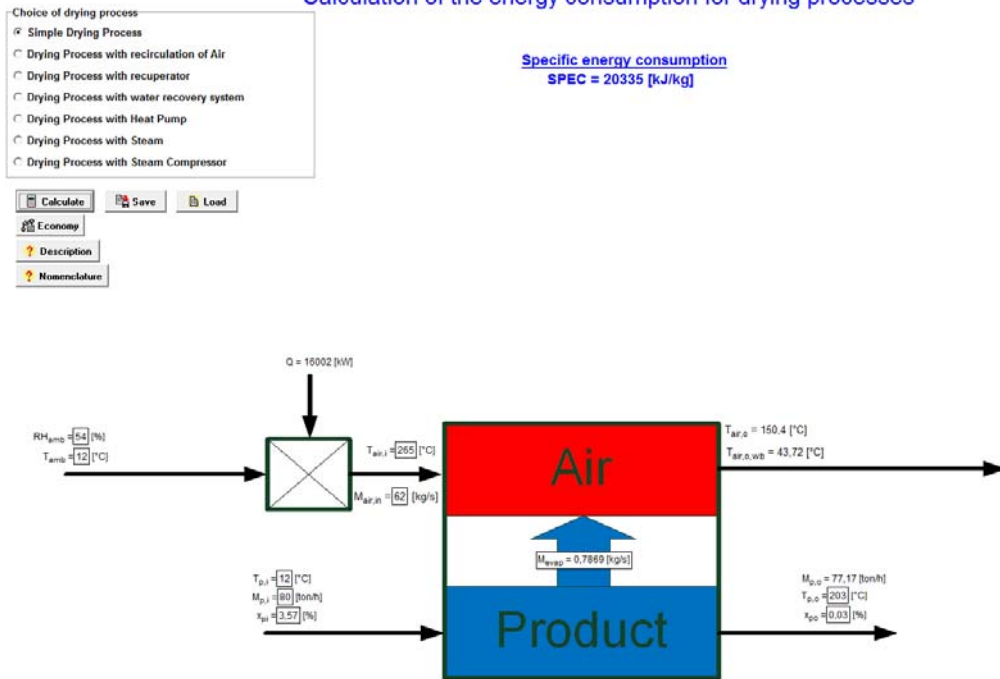
Figure 11 Calculation of the energy consumption on the asphalt plant carried out in "Drypack".

Recirculating part of the exhaust gas will result in considerable energy reduction, see also Figure 12. When recirculating 50% of the exhaust gas, the energy consumption can be reduced with about 27%.
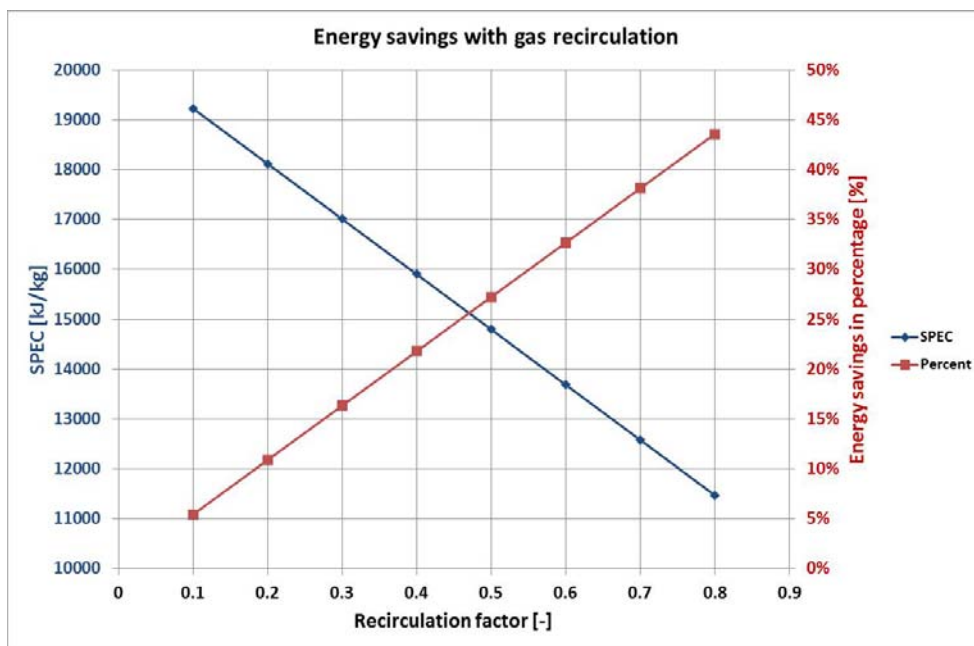

Figure 12 Estimated energy savings with gas recirculation on the asphalt plant.

Another alternative is an integration of the recuperator where the exhaust air stream energy is recovered before being exhaust to the surroundings. Energy savings are shown in Figure 13. From the figure it can be seen that a reduction in the exhaust air temperature to 60°C will reduce the energy consumption with 37%. The additional advantage of this setup is that the drying conditions remain the same and the drying time is therefore unchanged.
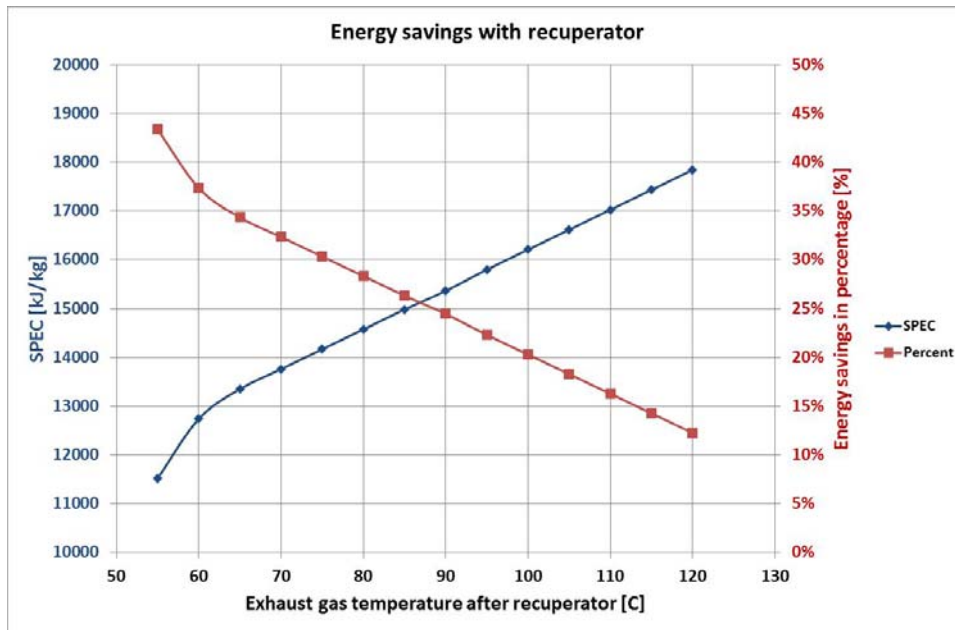
Figure 13 Estimated energy savings with recuperator on the asphalt plant

CONCLUSION

A calculation tool designed to calculate the energy consumption in drying processes has been developed. The program can be used to determine current energy consumption on a plant and afterwards used to estimate the energy reduction by applying different measures. The program provides a quick overview of potential energy savings.

Furthermore, a calculation tool for convective batch dryer processes has been developed. The program calculates the energy consumption and drying kinetics and it is a part of the total simulation package called "DryPack".

So far, the convective dryer has been demonstrated successfully with grain, asphalt and high temperature isolating material drying facilities. "DryPack" has been well received by the energy advisers and based on their experiences, the program will be optimised and adjusted in accordance with their demands. "DryPack" software is accessible as freeware at www.dti.dk and www.elfosk.dk under "DryPack".

ACKNOWLEDGEMENTS

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