Compressed Air System Optimization

Sandie Brændgaard Nielsen, Soren Draborg and
Claus Martin Hvenegaard

August 28, 2024

Compressed air system optimization

Sandie B. Nielsen

Søren Draborg

Claus M. Hvenegaard

Danish Technological Institute, Department of Energy & Climate

Abstract

There are considerable opportunities for increased efficiency in compressed air systems that can be realized through demand-based control methods and use of energy efficient components. Experiences from studies show that in many cases a potential of up to 20% still can be realized despite years of focus on energy efficiency.

The primary purpose of the project was to develop a calculation tool for compressed air systems, which enables the user to quickly and easily make calculations of different configurations of air compressors with varying capacity control. The calculation program is accompanied by a user guide that illustrates the use of the calculation tool.

In connection with the above-mentioned calculation tool, a guide in design of energy-efficient compressed air systems has been developed, as the experience is that the interaction between the capacity of compressors, air treatment, compressed air tanks and the overall control of the installations in relation to the actual needs is far from optimal.

In addition, a guide has been developed in which it is explained how measurements should be performed on compressed air systems.

The development of the calculation tool has taken place in close collaboration with a supplier of compressed air systems, an educational institution and an industrial company represented by:

- Kaeser Kompressorer A/S Denmark
- The Mechanical Engineering School Copenhagen
- Topsoe A/S

The project was funded by the Danish ELFORSK programme, and the participating companies was led by Danish Technological Institute.

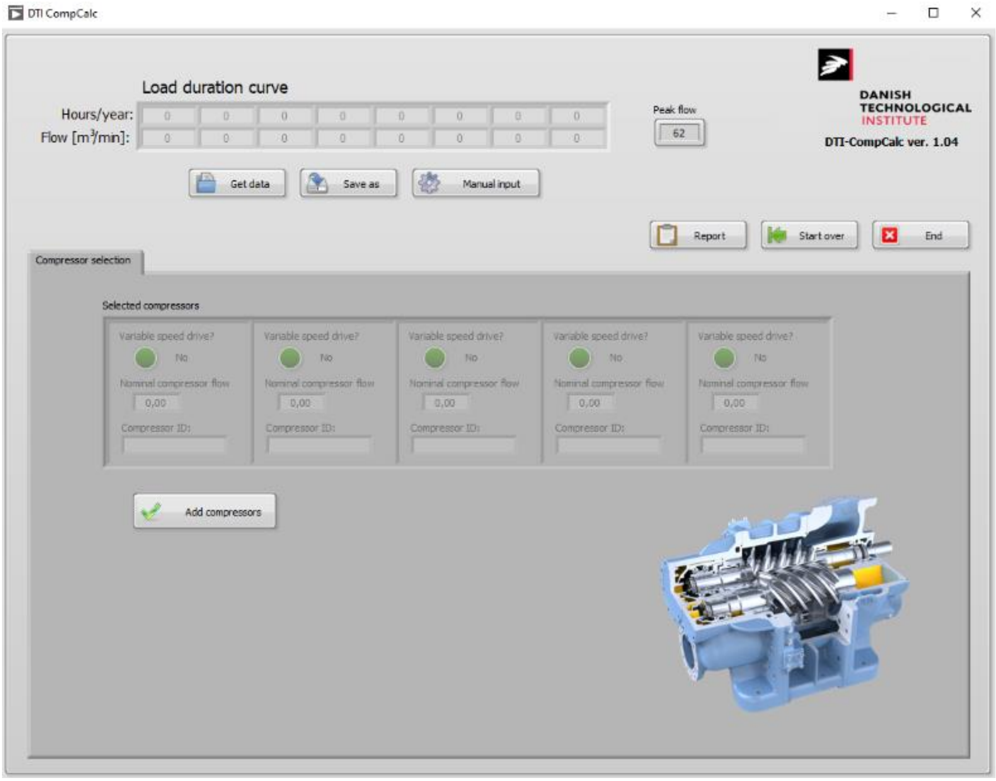

Figure 1 Main screen of Compressed Air Optimization Tool.

Introduction

The use of compressed air is one of the most important areas of energy use in industry and despite the fact that there has already been a significant improvement in the efficiency of compressed air systems, there is still a large untapped potential. Therefore, there is a need for a completely new approach to making this type of plant more efficient, so that the full potential is realized.

For decades, the focus has been on implementing energy savings on compressed air systems. However, experience shows that additional energy savings of the order of 20% of the energy consumption for generating compressed air can be achieved by focusing on the entire system from compressor to end user. Furthermore, this can also result in a compressed air supply, which creates fewer production problems, including less production waste and increased production.

Compressed air is the absolute most expensive form of energy to use in a company as only app. 10% of the energy input is transformed into work at the end users. Compressed air must therefore only be used where there are no other alternatives. The method to uncover possible potentials is thus to first map where the compressed air is used in the company (end users), what it is used for, at what quality it should be delivered, etc., and then review the design, as well as set up a consumption profile based on the combination of necessary compressed air flow and pressure. The registrations also provide the opportunity to discover countless facts about the entire system, if you have the experience in interpreting the registrations and if this knowledge is translated into concrete action plans.

Optimizing compressed air systems is primarily about choosing the right size or sizes of compressors in the right configuration with appropriate load control and control strategy - thereby achieving maximum energy efficiency of the entire system.

Basic considerations

The optimization is based on the duration curve for the compressed air system, see figure 2, and the system pressure. The duration curve in figure 2 could be based on actual measurements, or estimations for a future system.

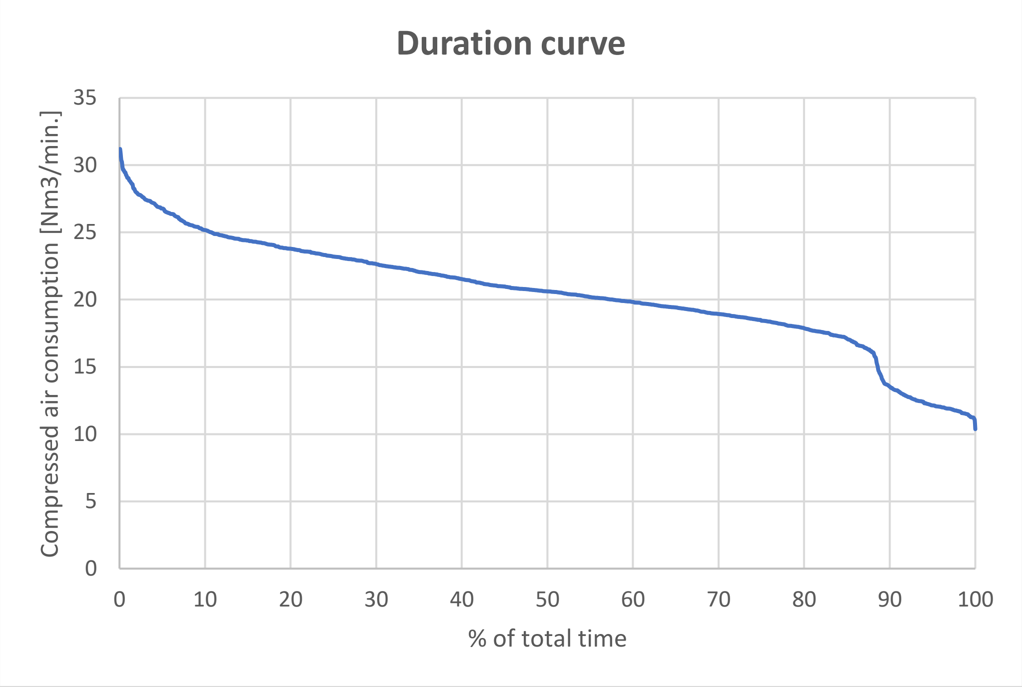

Figure 2 **Duration curve**

The calculation tool is based on systems with one compressor and systems with several compressors. The tool can handle systems with up to five compressors that are operated at between 6-8 bar pressure. For each compressor data for capacity and capacity control is stated in the tool by the user.

The tool is based on mathematical expressions for compressors developed from data sheets and performance curves achieved from the major European supplier Kaeser /1/. An advanced energy calculator part has been developed that can handle the various forms of control that are normally used in the industry. The developed calculation tool can handle the types of control mentioned below. The tool can be used both for analysis of existing plants and when planning new installations.

1. On/off control – the compressor runs at full capacity until the system pressure reaches upper limit and then stops until system pressure reaches the lower limit.

2. On/off control with relief – the compressor runs at full capacity until the system pressure reaches upper limit and then run in idle mode until the required system pressure reaches the lower limit.

3. VSD speed control – the compressor capacity is adjusted by speed control to obtain required system pressure, and if actual capacity goes below 25% the compressor switches to on/off with relief mode.

Compressor model

The compressor calculations are based on specifications and data sheets from the German compressor manufacturer Kaeser. The model contains data from a large number of compressors in different sizes and with the different types of capacity control stated above.

Specifications for consumed power in the data sheet are without motor and VSD efficiencies so Motor Systems Tool /2/ has been integrated into the compressor model, so efficiencies of motor and VSD if present depending on load are taken into account.

An example from the field

Below is an example of use of the Compressor Optimization Tool in practice. The example originates from Topsoe A/S and deals with a large existing compressor installation.

Figure 3 Compressor at Topsøe A/S

Input for flow of compressed air and system pressure has been established by measurements at the compressor station. The duration curve is shown below and it can be seen that the compressed air flow is beyond 43 Nm³/min. in app. 90% of the time.

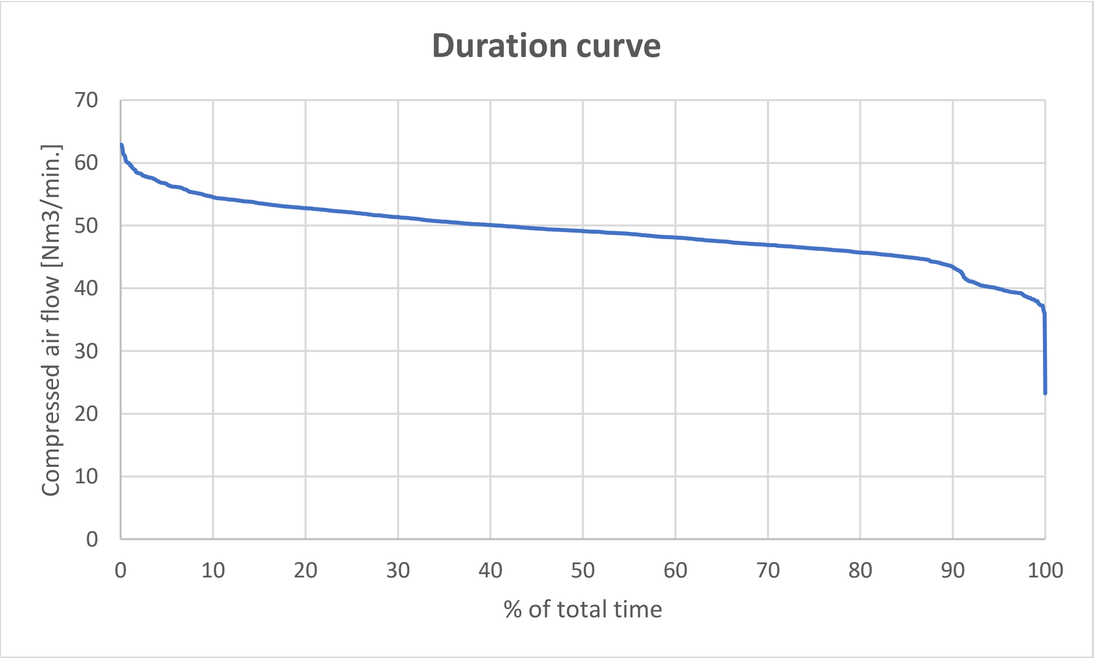

Figure 4 Duration curve for compressed air at Haldor Topsøe A/S

The demand for compressed air is covered by one Atlas Copco GA75 with a capacity of 12,3 Nm³/min., one Kaeser DSD241 with a capacity of 24,0 Nm³/min., one Atlas Copco GA90 VSD with a capacity of

17,0 Nm³/min. and a Kaeser CSDX165SFC with a capacity of 16,0 Nm³/min. At present the Kaeser CSDX165SFC compressor is the primary compressor, that also covers load variations.

When the tool is activated, the main screen appears.

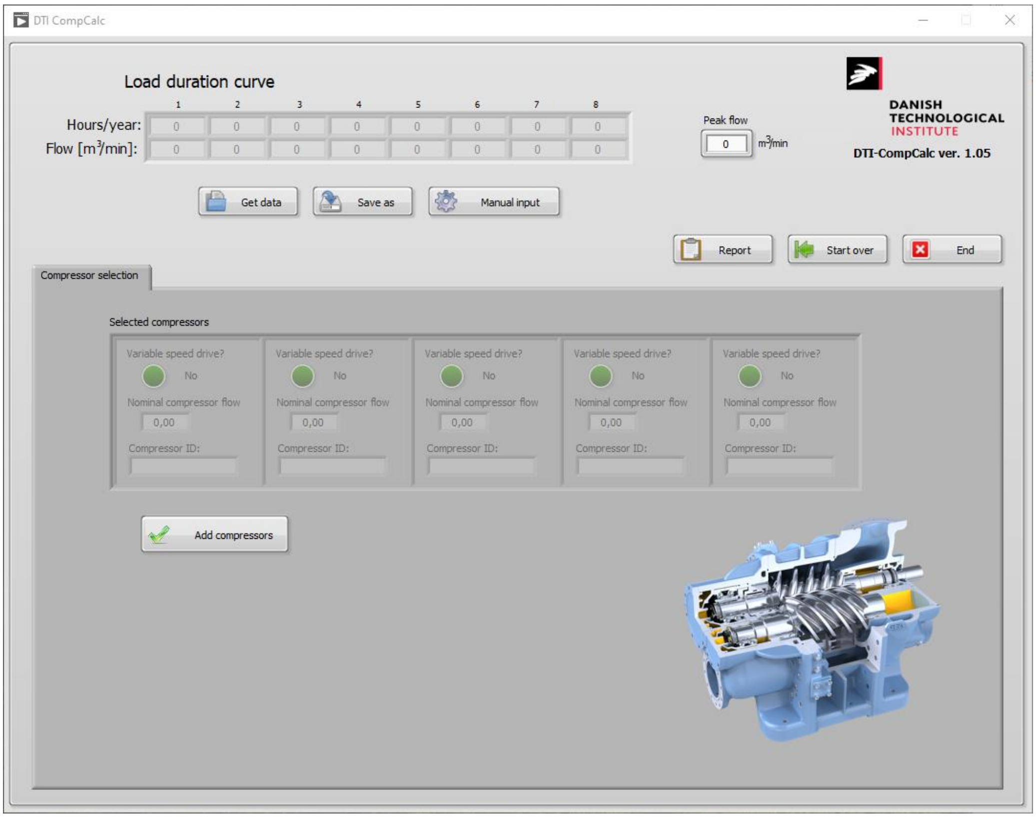

Figure 5 **Main screen of Compressed Air Optimization Tool.**

At first a duration curve must be entered, i.e. data for compressed air flow over time as the curve in Figure 4. The flow of compressed air is entered in up to eight interval as average values. The entered data sets are automatically sorted from left to right, so that the data set with the lowest flow is first. In Figure 6 the compressed air flows from the duration curve in Figure 4 have been entered.

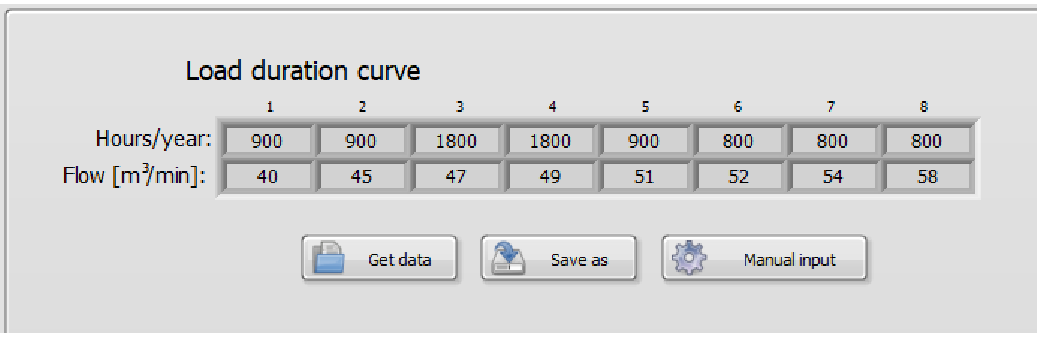

Figure 6 **Load duration curve**

To ensure that the total capacity of the compressor installation is sufficient the peak flow is entered in the field in upper right-hand side, see Figure 5.

Next, data for the compressors and the pressure must be entered. This is done by pressing the "Add compressors" button at the main screen and then the pop-up menu below appears.

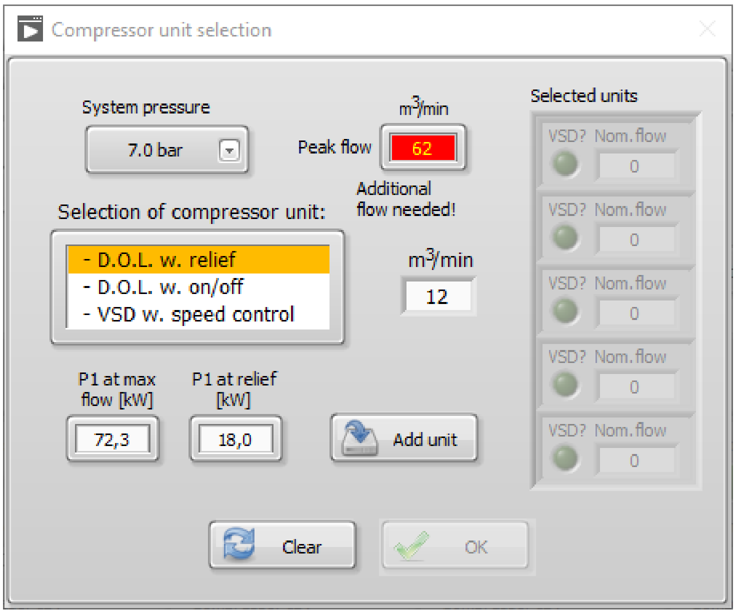

Figure 7 **Data for system pressure and compressor units**

The pressure in the compressed air system is selected under "System pressure", and a pressure between 6-8 bar can be selected.

The value in the "peak flow" field is transferred from the previous entry and it will flash red until the total capacity of the entered compressors is sufficient to deliver the maximum flow.

The compressed air compressors are entered by selecting whether a given compressor is:

• directly driven and capacity controlled with load/unload (D.O.L w. relief)

• directly driven and capacity controlled on/off (D.O.L w. on/off)

• frequency controlled (VSD w. speed control)

The capacity of the individual compressor is entered in the "m^3/min" field, and the compressor is saved by pressing the "Add unit" button. The number of compressors can be up to five units. If a compressor has a frequency converter, the "dot" is light green. In the example below, there are thus two compressors running load/unload and two compressors with frequency converters, see Figure 8.

In the lower left side of the menu there are two fields, "P1 at max flow" and "P1 at relief". These fields are used for compressors running load/unload and for frequency-controlled compressors when these reach their minimum speed. In the fields there is a default value, which is the absorbed power when the compressor is loaded, and the absorbed power is unloaded. The default values apply to new compressors depending on the selected compressor size. If measurements have been carried out (or there is other knowledge) of the absorbed power when the compressor is loaded and/or during unloaded operation, the default values can be overwritten, and this is done before pressing "Add unit".

When entering capacity values for a new system that includes a VSD driven compressor along directly driven compressors it should as always be observed that capacity of the VSD compressor should be app. 50% larger than the capacity of largest directly driven compressor, so capacity regulation of the system will operate smoothly.

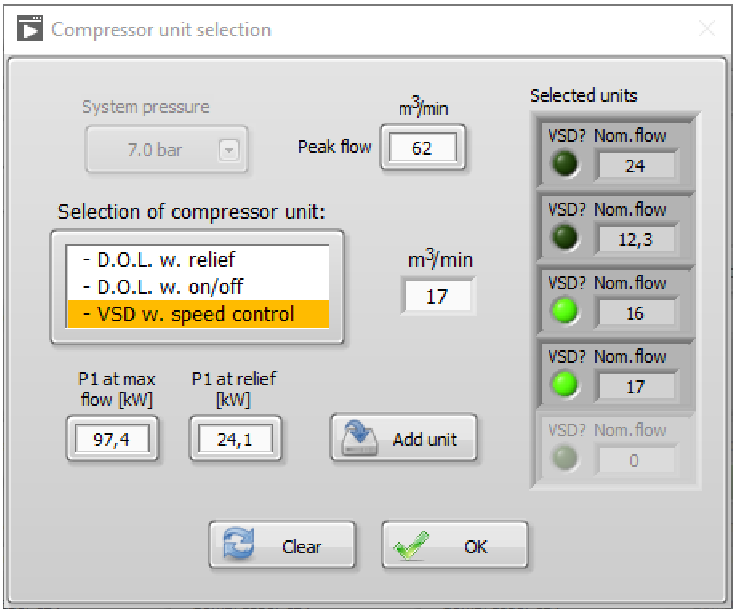

Figure 8 **Example of compressor configuration**

When all compressors have been entered the "OK" button is pressed.

The program now calculates in which order the compressors should be started and stopped to achieve the most energy-optimal solution(-s), see Figure 9 below.

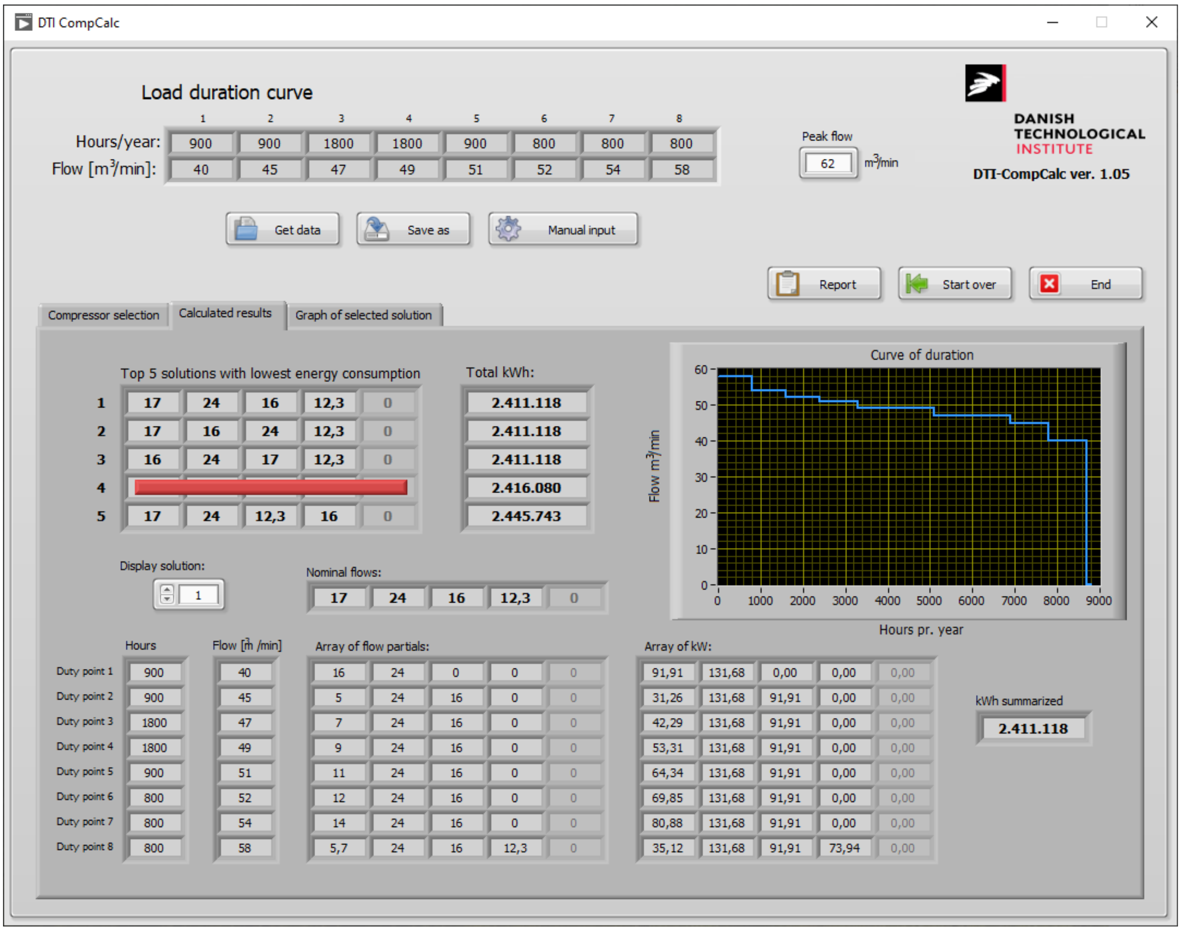

Figure 9 **Calculation of annual energy consumption of different start/stop combinations**

In the center on the left side, an overview of the five combinations of the switch-on order that gives the lowest energy consumption is displayed. The switch-on order is read from left to right. The compressors are identified by their capacity in the table (Figure 8). In the figure above, it can be seen that combination no. 1-3 gives the same energy consumption. It is thus subordinate which of the first three engagement combinations is selected.

The calculations are based on a mathematical model, and solutions may arise from combinations that are not valid. If a solution is not valid, it is marked in red as shown in the Figure 9 above (combination no. 4).

It is possible to scroll down through connection combinations other than the five most energy-optimal by pressing the arrows in "Display solution" or by entering the number in the field next to "Display solution" on the solution you want to display.

The result of the calculation can be saved and printed by pressing the "Report" button. The report can be saved by pressing "Ctrl P" and selecting "Print to PDF", after which the report can be saved in a location of your choice.

It is also possible to see graphs of the flow from each compressor in the different duty points, see Figure 10. The graphs can be shown for different solutions by pressing "Display solution".

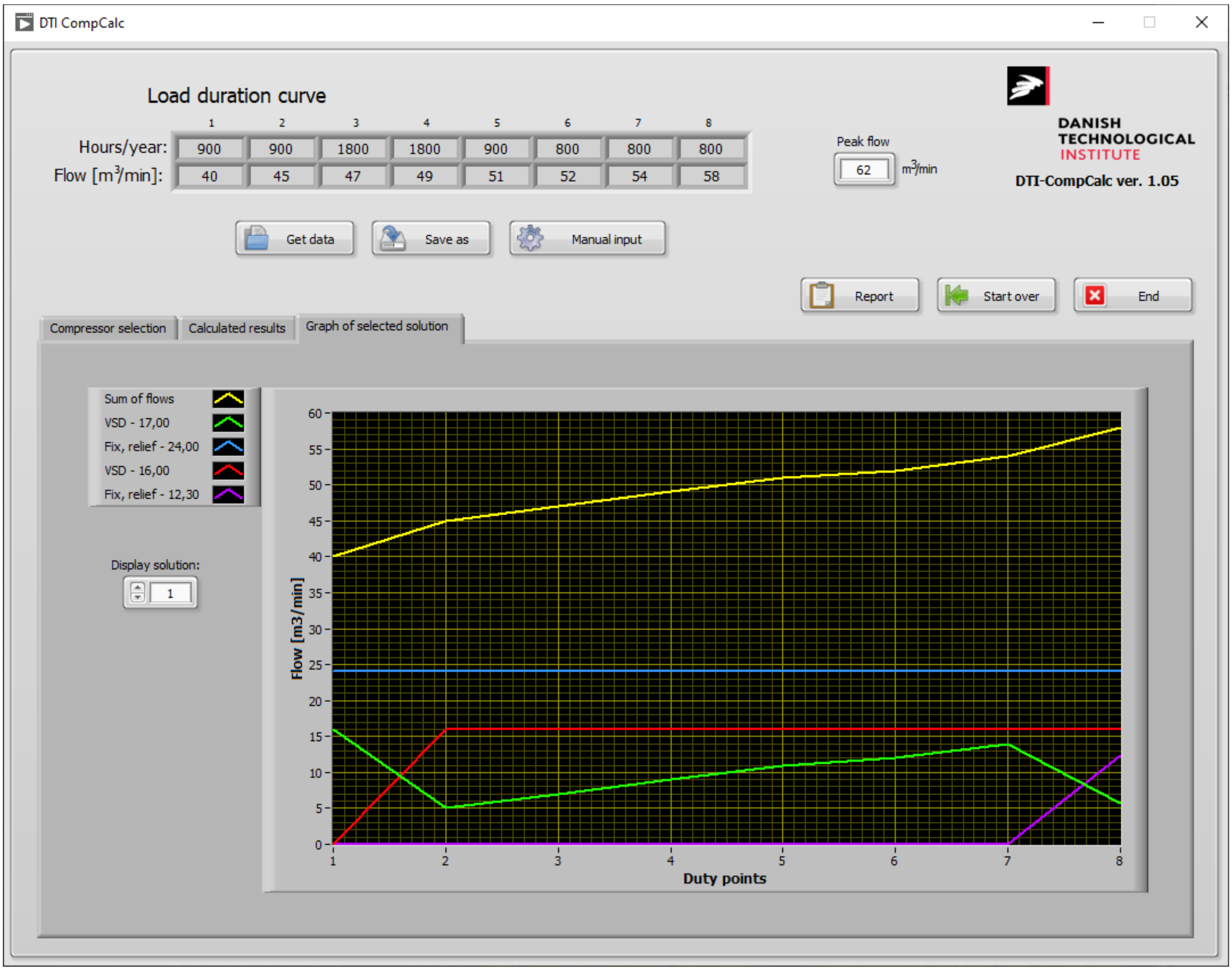

Figure 10 **Graphical presentation of compressed air flow from the compressor in different duty points**

Conclusion

The tool can efficiently help the user to calculate many different combinations of compressor configurations due to sizes and capacity control systems, and in that way reveal energy saving options by changing start/stop sequence or replacing an existing compressor to another size etc. The tool can assist energy managers in industry and energy consultants to investigate a larger number of possible energy saving options in an easy and quick way. This will encourage to examine compressor systems with much greater frequency than is the case today.

The tool can be used for design of new systems and for analyses of existing systems. The tool is also valuable for training and demonstration purposes.

References

[1] Kaeser: https://www.kaeser.com/int-en

[2] Motor Systems Tool: http://motorsystems.org