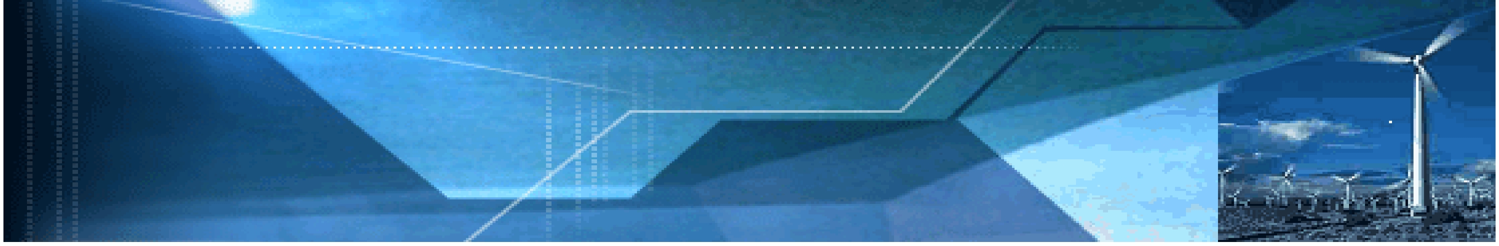


Cold Storage of Wind Energy – Cold Store Economics

Economy of using NWCS for Cold Store operators.

A number of simulations on capacity switching for individual cold stores have been performed. Capacity switching is defined in this case as adjusting the cooling capacity of the cold store to requirements. The basic requirement, of course, is that the temperatures in the cold store are kept within the set boundary conditions (a maximum air temperature and a minimum air temperature). The secondary requirement is, in this case, that the costs for electricity consumption are minimal. Thus we have 2 requirements:

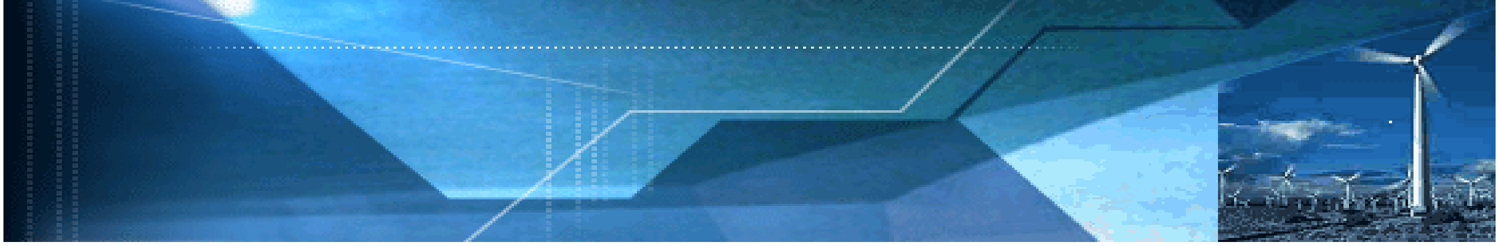
Requirement #1: To keep the cold store air temperature between the upper and lower limit
Requirement #2: To run with minimum energy costs

Cold stores with standard capacity control on temperature only

Individual cold stores normally operate with Requirement #1 only: to keep the cold store air temperatures within the set boundary conditions. In this case, the energy costs are the equal to the average kWh costs multiplied with the total energy consumption in kWh. For the Partner logistics Cold Store in Bergen op Zoom (The Netherlands), the energy consumption over the year 2007 is given in the table below.

Table 1: *Energy consumption data Partner Logistics Bergen op Zoom (2007)*

2007	Total Energy Consumption (in kWh)	Maximum load (in kW)
January	984.258	1.940
February	911.317	2.088
March	1.129.199	2.092
April	984.688	2.064
May	1.174.652	2.080
June	1.043.316	2.108
July	1.043.238	1.816
August	1.143.857	2.144
September	1.156.575	2.144
October	1.112.108	2.112
November	992.594	2.036
December	962.236	1.836
Total	12.638.038	2.144



The costs for the energy over 2007 were as follows:

Energy costs (kWh) excluding VAT	€ 690.249,82
VAT on Energy costs (19 %)	€ 131.147,47
Energy taxes excluding VAT	€ 104.797,41
VAT on energy taxes (19 %)	€ 19.911,51
Total including VAT	€ 946.106,21
(total = 7,5 ct/kWh including 19 % VAT)	

It can be seen from table 1 that the energy consumption of the cold store is not depending to a large extent on the outdoor (ambient) conditions; the energy consumption in the summer months and in the winter months does not greatly differ. This also becomes apparent when the energy consumption data for one year is depicted graphically, as in the figure below.

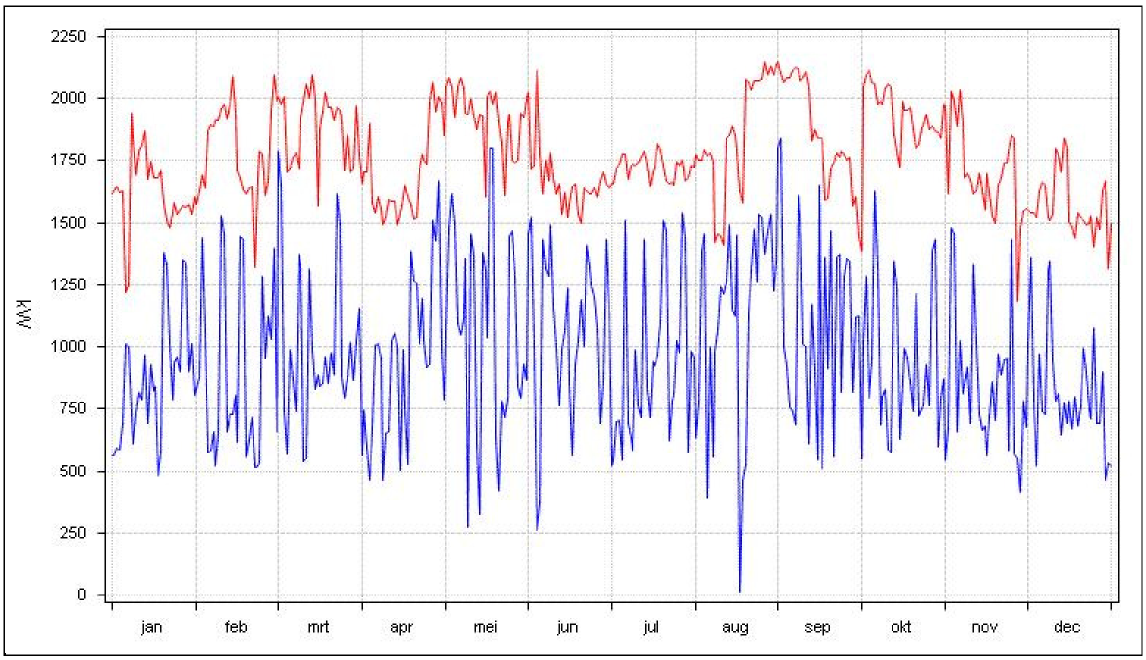


figure 1: *2007 Electrical load (maximum, minimum) in kW for Partner Logistics cold store Bergen op Zoom.*

In terms of daily energy consumption pattern, the Partner logistics facility in Bergen op Zoom follows a reasonably flat pattern (figure below). In effect, there is a slight preference noticeable for the nighttime (low tariff) hours, which is explained in the next section (operation with capacity control on day / night tariffs).

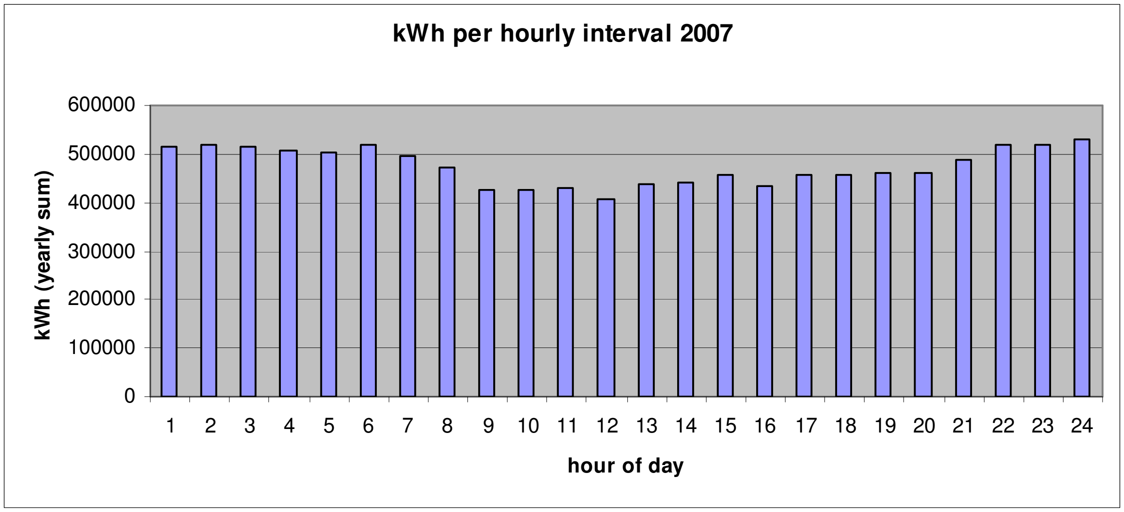


figure 2: *Hourly consumption (total 2007) for the Partner Logistics Cold Store, Bergen op Zoom.*

Cold stores with capacity control on day / night tariffs

More and more, cold stores operate in such a way that preferably energy is consumed during the nighttime low tariff hours. This is in effect an implementation of the Requirement #2: To run with minimum energy costs
In this case the capacity control is set to lower the temperature of the cold store at night. During the daytime the capacity control then further operates on the basis of requirement #1 : to keep the cold store air temperatures within preset boundaries.

The perfect implementation would be a cold store that operates at maximum capacity during the nighttime low tariff hours, and operates at zero capacity during the daytime peak hours. This is only feasible when the maximum capacity is large enough to supply all the "cold" that is needed for a full day in only the nighttime hours. A quite common situation is that the night tariff runs from 23:00 PM to 07:00 AM, which means there are 8 hours per day in the low tariff. When the average load on the cold store – which is determined physically – equals "P" then the refrigeration machinery needs to deliver "3P" at maximum capacity in order to supply all the cold needed for the full day (24 hours) in just 8 hours.

In realistic cold stores however, the maximum capacity of the refrigerating machinery is chosen smaller for reasons of investment costs. The maximum capacity is chosen on the basis of maximum expected load (which is theoretically the load on the hottest day of the year). From table 2, the average and maximum load for the Partner Logistics cold store in Bergen op Zoom can be evaluated. The average (physically determined) load "P" equals 1.366 kW, and the maximum capacity (2.140 kW) equals 1,57 P.

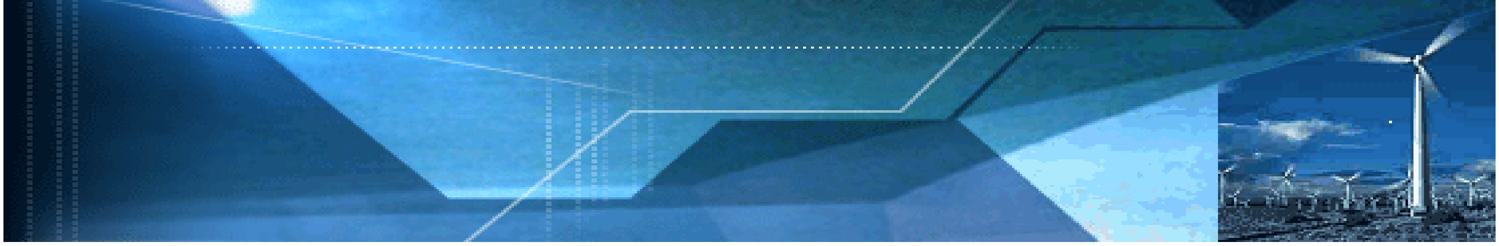


Table 2: *Energy consumption data Partner Logistics Bergen op Zoom (2008)*

2008	Total Energy Consumption (in kWh)	Maximum Load (in kW)
January	945.145	1.924
February	932.420	2.024
March	952.499	2.040
April	994.385	2.092
May	1.072.494	2.084
June	1.031.969	2.068
July	1.006.737	2.140
August	1.030.003	2.116
September	1.019.292	2.044
October	1.017.091	2.024
November		-
December		-
Total (kWh)	**10.002.035**	2.140
Average (in kW)	1.366	

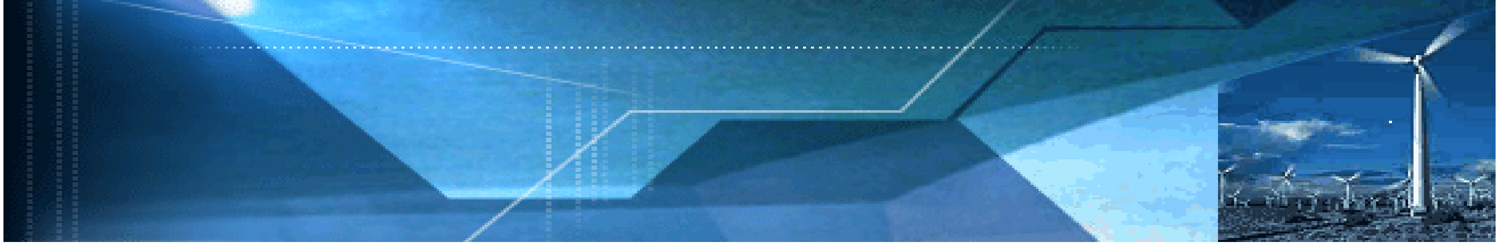
From these data it is already obvious that the ideal situation of running only during nighttime low tariff hours is not feasible with this installation.
Data from ESSENT for The Netherlands, January – September 2007, show an average price for base (low tariff) hours of 59,17 € / MWh and a price of 81,04 € / MWh for peak hours. The average price level then is equal to 73,75 € / MWh.

The ideal capacity control based on day / night tariffs, with operation during nighttime hours only, would then operate at a level of 59,17 € / MWh whereas a cold store without capacity control based on costs would operate at a level of 73,75 € / MWh. The energy costs savings would thus be at a level of 20 %.

However, during both daytime and nighttime the requirement #1 (to keep air temperatures within set boundaries) is still in place, and causes a deviation form the ideal load pattern.

Cold stores with capacity control based on minimum energy costs

The availability of wind energy is reflected in the energy price: when large amounts of wind energy are available, the energy price drops. Therefore, taking energy price as basis for the capacity control is equivalent to taking the wind energy production as basis for the capacity control: which is the night Wind concept. On the Amsterdam Power exchange (APX) market, energy prices are given per hour, one day in advance. The cold store owner can then create his own strategy for “loading” at low prices, and switching off at peak prices.



Dutch Power Day Ahead Market Summary for 10-07-2008

APX Indices for the NL Hub

		Average Price (in EUR/MWh)	Volume (in MWh)
Base	(01 to 24)	81.36	66,842.5
Peak	(08 to 23)	94.81	46,508.9
Super-Peak	(09 to 20)	99.90	35,560.5
Off-Peak	(01 to 07 & 24)	54.47	20,333.6

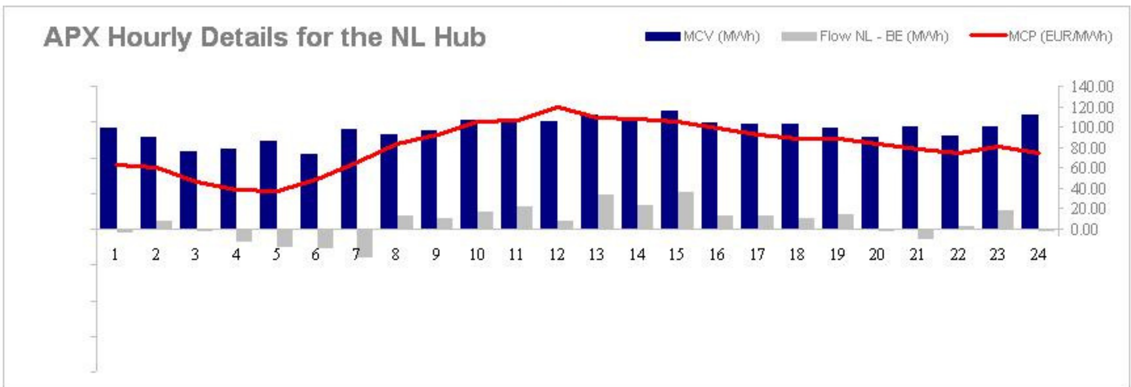
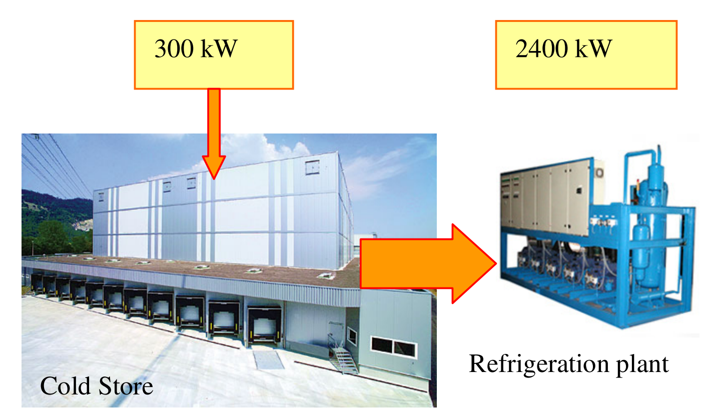


figure 3: *example of spot market energy prices (Dutch day ahead market, APX)*

The benefits that can be obtained by controlling capacity on the basis of APX energy price in this case are depending on the “on/off” time of the refrigeration plant and the time constant of the cold store. A refrigeration installation that is almost 100 % “on” must buy energy at any time, also at high costs – whereas a refrigeration plant that is “on” for very limited time spans, can make use ideally of low cost periods.

The perfect implementation would be a cold store that operates at maximum capacity during only the hour with the least energy costs, and operates at zero capacity during all other hours. This is only feasible when the maximum capacity is large enough to supply all the “cold” that is needed for a full day in just the one hour with least energy costs. When the average load on the cold store – which is determined physically – equals “P” then the refrigeration machinery needs to deliver “24P” at maximum capacity in order to supply all the cold needed for the full day (24 hours) in just one hour. In figure 4 an example is given where the refrigeration machinery delivers “8P” and thus essentially only needs to operate 3 hours per day.

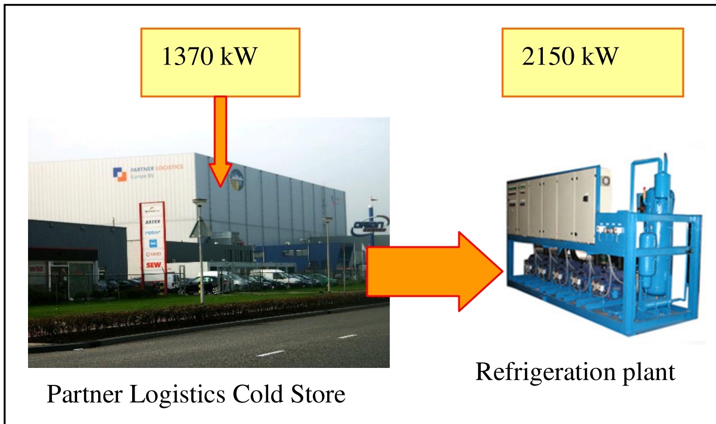


	€/MWh	%
Normal	73,75	100
Night Tariff	59,17	80
NWCS	31,43	43

NWCS:
Night Wind Control System
APX based capacity control

figure 4: *cost based capacity control with high capacity installation (cooling capacity 8 times average load)*

In realistic cold stores, the maximum capacity of the refrigerating machinery is chosen smaller for reasons of investment costs. The maximum capacity is chosen on the basis of maximum expected load (which is theoretically the load on the hottest day of the year). From table 2, the average and maximum load for the Partner Logistics cold store in Bergen op Zoom can be evaluated. The average power consumption “P” equals 1.366 kW, and the maximum power consumption (2.140 kW) equals 1,57 P. This system needs to be active on average for 15 ¼ hours per day to supply the required load. The results of a simulation on the system at Partner Logistics cold store is given in figure 5.



	€/MWh	%
Normal	73,75	100
Night Tariff	69,57	94
NWCS	53,19	72

NWCS:
Night Wind Control System
APX based capacity control

figure 5: *cost based capacity control simulated for the Partner logistics Cold store*

The simulations are made with a computer algorithm that switches the refrigeration capacity off or on depending on the energy costs. The program automatically downloads the energy costs for the next 24 hours from the internet. The code selects the moments with the lowest possible energy costs to turn on the refrigeration capacity. A dynamic model of the cold store is implemented and tests the possible solutions against requirement #1 (to keep air temperatures within set boundaries). The final solution is provided together with a prediction of the cold store temperature over the next 24 hours, as presented in figure 6.

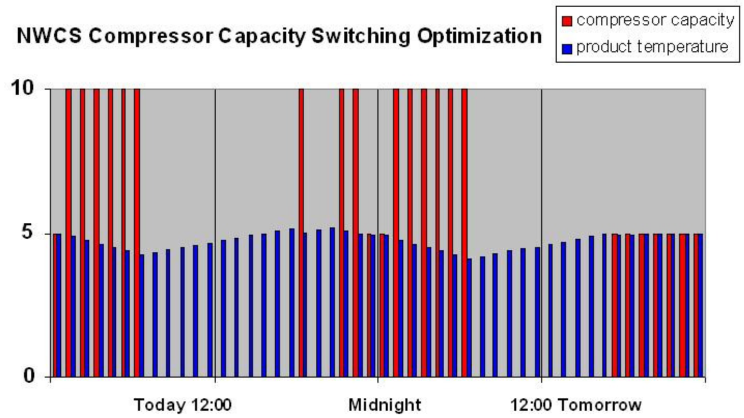


figure 6: *Cooling Capacity optimization result (product temperature < 5 ºC)*

These simulations can be run for a number of different cold store dynamic models, each with a specific capacity of the refrigeration machines as compared to the average needed refrigeration capacity over a full day. What results is the average costs for energy, depending on this main characteristic of the cold store. These prices can be compared to running same cold store without cost optimized control, but with optimum usage of the night electricity tariff. The results are shown in figure 7.

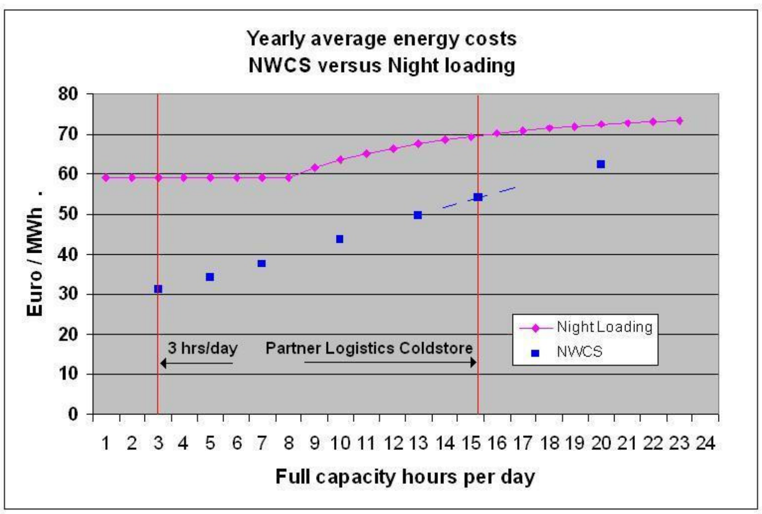


figure 7: *Average energy costs with capacity control based on cost optimization (NWCS) versus the same cold stores using night tariff preferentially. In the figure, the situations described earlier have been indicated.*

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