Heat Buffers Improve Capacity and Exploitation Degree of Geothermal Energy Sources

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Abstract

This research focuses on the role of heat buffers to support optimal use of combinations of traditional and renewable heat sources like geothermal heat for greenhouse heating. The objective was to determine the contribution of heat buffers to effective new combinations of resources that satisfy greenhouse heat, carbon dioxide and electricity demand at minimum cost. Tank buffers, basement buffers and aquifers were considered as short and long term buffers. Simulations were carried out for a 10ha sweet pepper and a 30ha tomato greenhouse (15ha intensively lighted). Standard heating systems based on central boiler and co-generation were used as a reference and compared with combinations of boilers, co-generators, geothermal heat and heat buffer strategies. Crop production and greenhouse climate were simulated and resource demand determined for normal greenhouse operation. A linear programming algorithm was used to apply resources and equipment available to the model at minimum cost. Results show that heat buffers help to reduce the required capacity of a geothermal heat source, and increase both the utilisation degree of the source and the cover percentage of greenhouse heat demand. The technically most feasible solution for long term buffering was the basement buffer which allows high buffer volumes without loss of useful space and heat loss contributes to greenhouse heating, however this solution was economically not feasible. Also the deep aquifer was a good option, however exploitation risks and manageability are potential problems. Integration of geothermal heat with other sources resulted in the best solutions that were both technically and economically feasible. Simulation showed at gas price level 30€ct.m^{-3}, that geothermal heat was cheaper than central boiler and even co-generation heat when hours of operation exceed 1000h.y^{-1}. Instead of using large buffers, peak loads can also be covered by central boilers. Simulated solutions reduced gas consumption with 60 to 95%.

INTRODUCTION

The Dutch government and greenhouse horticultural practice aim for reduction of fossil energy use and of environmental loads by producing energy neutral greenhouses in 2020. Secondly rising energy prices make the use of the traditional central boiler based systems less interesting for growers. Nowadays many growers use cogeneration with good contracts for electricity delivery to the grid to decrease the price for heating. Despite the high energy use efficiency co-generators increase fuel demand and CO_2-production of the horticultural production site and compete with sustainable energy sources.

Amongst renewable heat sources, geothermal heat is interesting for part of Dutch greenhouse horticulture (Van de Braak et al., 2001). Geothermal heat however needs a high investment and only when the source has a high enough degree of utilisation the costs per unit of delivered energy are acceptable. To cover peaks in heat demand a high capacity is needed which negatively affects costs and use of the source. Heat buffers can diminish this kind of timeliness problems. When new sustainable heat sources like geothermal heat are integrated in the greenhouse heat, CO_2 and electricity supply system, its components need to be reconsidered with respect to feasibility and optimal use. The focus of this research was therefore on integration of geothermal heat in state-of-art heat,

CO_2 and electricity supply systems in greenhouses and on the role of heat buffers there in. The aim was to design adequate combinations of traditional heating (central boiler and co-generator), geothermal heating and buffer functions both for greenhouses with and without supplementary lighting. A feasibility study for short term application of geothermal heat in combination with a buffer function to reach a high utilisation degree of the source and a high covering the greenhouse heat demand is very relevant.

Buffering of heat is an important element in the energy household of a greenhouse. Both heat demand and supply can vary strongly and need to be balanced. Well managed buffers handle peak heat demands and allow equipment with lower capacity and less capacity costs for grid use (peak shaving). In coupled production processes of heat and CO_2 (central boiler) or heat, electricity and CO_2 (co-generator) buffers help to partially or fully decouple these processes. In applying geothermal heat, buffers 1) enable a higher degree of utilisation of the source, 2) result in a better coverage of greenhouse heat demand, 3) increase maximum heating capacity of the source, 4) help manage utilisation of the heating power. In order to reach this, buffer functions must 1) be available with enough capacity (kW_{th}) to allow a lower capacity of the equipment, 2) be manageable at all times (flexible), 3) be integrated in the heating system to buffer heat from one or more heat sources, 4) minimize heat loss, 5) allow both short and long term conservation of heat.

MATERIAL AND METHODS

In a preliminary evaluation alternatives for greenhouse heating based on current technology combined with geothermal heat and alternatives for heat storage were evaluated technically and economically. In an economic outline costs were explored and compared at different use intensities, expressed in hours of operation ($h.y^{-1}$) of the heat sources central boiler, co-generator and geothermal heat. Next in a simulation study buffers were added and realistic hours of operation were determined. Heat sources were evaluated in combination with the buffer types: 1) tank buffer (100-500$m^3.ha^{-1}$), 2) basement buffer under the greenhouse (till 10,000 $m^3.ha^{-1}$) and 3) deep aquifer (> 500m deep). The ideal buffer size depends on installations available and their capacities. At theoretical minimal capacity the heat source has just enough capacity to produce the required heat by running at full capacity all year. The upper limit of capacity covers peak heat demand without using a buffer.

Full year simulations were carried out to find most efficient use of resources and equipment to cover greenhouse heat, CO_2 and electricity demand. The plans of two large growers in Agriport-A7, that is a new glass district in Wieringermeer, the Netherlands, were used in a pilot case. Agriport-A7 is a region in the Northern part of the Netherlands with promising options for geothermal heat. The region has plans to cover at least 10% of total heat demand with geothermal heat. First crop growth, greenhouse climate and heat, CO_2 and electricity demand was determined for the two newly built greenhouses based on local weather, greenhouse construction, crop planning, growth and handling, optimised CO_2 enrichment and use of supplementary lighting. The results were evaluated with and approved by the growers. Secondly with currently planned standard equipment (central boiler, co-generator and day-buffers), heat demand was covered in the most efficient way also including CO_2 and electricity demand in the process. The algorithm used a linear programming algorithm to find minimum costs in every simulated time step. The results of these simulations were used as a reference for further analysis on incorporation of geothermal heat and buffer strategies in the system. All simulations were carried out with the greenhouse simulation package GTa-tools (Van 't Ooster, 2007).

The simulations with geothermal heat assume equal demand for heat, CO_2 and electricity as in the reference situations. However different sources supply the resources to the greenhouses. First, two extreme situations on geothermal heat were simulated in an attempt to cover full heat demand with geothermal heat: 1) geothermal heat source with enough capacity to cover the peak load in heat demand and 2) minimised capacity of the geothermal heat source, but with enough heat production to cover the full heat demand. In case of capacity shortage a large buffer supplies the heat and in case of surplus heat the heat is stored to the source dedicated buffer. Finally the source-buffer combination is optimised by letting geothermal compete with the equipment present in the reference and by minimising the costs including the costs to supply CO_2 and electricity. As in the economic outline a coefficient of performance (COP) of 30 was used for the geothermal source. The variable costs of geothermal heat used in the simulations was 1.04€/GJ and for movement of heat to and from a deep aquifer 0.52€/GJ. The investment needed for a geothermal heat source was 5M€ per unit of 10MW. The commodity costs for gas and electricity were 0,30€.m^{-3} and 80€.MWh^{-1} and 40€.MWh^{-1} at peak and off peak hours respectively for both the simulations and the economic outline. Variable costs for industrial CO_2 were 11€ct.kg^{-1}.

A problem with deep aquifer buffers is that risks are involved. For practical reasons the stored water should not be warmer than the original temperature in the source, for instance lime could block parts of the system when released as a result of high temperature (Van Elswijk and Willemsen, 2003). Water treatment can solve this problem but is also a vulnerable part of the system.

Case Greenhouses

In order to find feasibility of a smartly buffered geothermal system, the two references were used as a point of departure. They are shortly described below.

1. Kwekerij De Wieringermeer. (KdW). This sweet pepper producing company plans to realise a greenhouse area of 60ha in units of 10ha (L·W= 384m·260m, column length 6.4m). A crop cycle starts early December and ends the third week of November. Target temperature day/night is 20.5°C and 17-19°C respectively. The planned heating system has a total capacity of 13.6MW and consists of two central boilers of 5.8MW_{th} each, 2 co-generators of 4.4MW_{th} and a short term heat buffer of 2640m^3. The greenhouse is equipped with a 40% energy saving screen (SLS10 ultra). In the simulations the two central boilers were replaced by one with 9.8MW capacity. One production unit of 10ha is considered with cluster options for application of geothermal heat.

2. Royal Pride Holland BV. (RPH). This cocktail tomato producing company plans a total greenhouse area of 120 hectares and two greenhouses of 14.7ha each (L·W= 500m·292m, column length 6.0m) in phase 1, one with and one without supplementary lighting (15.000 lx). Crop is grown all year with replants in week 9 and 33. Target temperature day/night is 22°C and 14-15°C respectively. CO_2 enrichment to a high level, but no external CO_2 is used. The planned heating system consists of three central boilers of 15MW_{th} each, 6 co-generators of 4.4MW_{th} and a short term heat buffer of 5000m^3. The greenhouse is equipped with a 40% energy saving screen (LS10). For supplementary lighting 1000W lamps were used with one lamp at each 8.7m^2 and lighting for 2660h.y^{-1}.

RESULTS

Economic Outline of Costs

Figure 1 gives the main result of the economic outline. It indicates the costs of the heat sources used per unit of energy produced for two gas price levels in relation to the number of hours full load operation per year. It shows geothermal heat is cheaper than boiler heat when used more the 2000 hours a year even at 18 €cts.m^{-3}. At a gas price of 18 €cts.m^{-3} geothermal heat is competitive with co-generators at 5000 running hours or more, at 30€cts.m^{-3} geothermal heat is cheaper than heat generated by a co-generator. It is assumed here that all electricity is sold to the grid.

Reference Simulations

The results for the reference simulations for both companies are presented in Figure 2 and Table 1. The overall costs for covering heat, CO_2 and electricity demand were 18.54€.m^{-2} and 29.63€.m^{-2} for KdW and RPH respectively and the latter has 19GWh residual heat when electricity uptake from the grid was prevented. When residual heat production is not tolerated and electricity was taken from the grid in case no internal destination for the heat was available the price was higher 29.97€.m^{-2}, but gross natural gas consumption drops 12%. The realised number of hours of operation for all equipment units can be read from Figure 2. Overall CO_2 and electricity demand and supply is given in Table 1. Gross and net gas use (m^3.m^{-2}) was 115.2, 68.4 for RPH and 96.2 and 56.4 for KdW.

Geothermal Heat without Buffer

The maximum peak load in heat demand for KdW is 18.6MW, in order to realise 100% heat supply from geothermal heat without use of a buffer (extreme situation 1), two pits with a total capacity if 20MW were made available. CO_2 supply must originate from external sources. The costs for heat and CO_2 supply is 12.46€.m^{-2} at on average 2924 full load hours a year for both geothermal sources. This variant already has lower yearly costs than the reference, despite a tripling of the investment and fourfold higher costs for CO_2 supply. Return of investment is about half the predicted lifetime of 30 years for the geothermal source. The use of geothermal heat results in 96.2m^3.m^{-2} (9.6Mm^3) less natural gas use and in a saving of 56.4m^3.m^{-2} for heating. Also 31GWh of electricity is not produced and CO_2 production drops from 17.1 to 1.9kt of industrial CO_2. 10kt can be marked as real reduction in CO_2 production and the greenhouse turns into a CO_2 consumer allowing other industries to deliver their surplus CO_2 to greenhouses. The geothermal heat requires 1.6GWh of electricity, this is however not included in electricity demand of the greenhouse in this study. The maximum peak load for RPH is 77MW, this would mean 8 sources of 10MW, which is practically hard to realise since each source strikes a zone of about 4km^2. Sufficient capacity is only possible when sources are realised outside the Agriport-A7 region and also transport costs will rise. Since all heat is geothermal heat electricity and CO_2 must be purchased. The total costs for heating, electricity and CO_2-supply is 35.39€.m^{-2}. This includes 8.86€.m^{-2} and 13.73€.m^{-2} for CO_2 and electricity from the grid respectively. The total costs are almost 5.76€.m^{-2} higher than the reference situation.

Minimal Geothermal Heat Capacity with Buffer

In case a minimised capacity is applied and the geothermal source is used full time, extreme situation 2, for KdW a capacity of 6.74MW is needed. Since the investment on a 7MW and a 10MW capacity is not much different, a cluster of 14.8ha is assigned to a source of 10MW, allowing KdW to use a share of 67.5% of it on 10ha. Because of full operation and partial use of the source capacity the costs of the geothermal heat source (excluding the buffer) are lower. The simulation indicated 4.84€.m^{-2} instead of 10.17€.m^{-2} in the first simulation. A large buffer is needed to level heat production and heat demand. From the simulations it followed that a 300,000m^3 buffer size is needed. When designed as a basement buffer this means a 3m deep basement under the full greenhouse. At an investment of 100€.m^{-3} this means yearly costs of 28.30€.m^{-2}. This buffer levels less than 40% of the heat demand including inevitable heat loss from the buffer to the greenhouse (13.4GWh total, 8.5GWh useful heating). The overall buffer efficiency is 82% but buffer costs are little over fivefold the cost reduction in the geothermal heat source. Total costs including electricity and CO_2 were 35.42€.m^{-2}. For RPH the required source capacity is 23.7MW. Two buffer types were combined with this geothermal heat source a basement buffer (650,000m^3) and a deep aquifer (9 pits of 700m depth, 130m^3.h^{-1} each, buffer efficiency 70%). Total costs including electricity and CO_2 were 48.85€.m^{-2} (geothermal source 5.30€.m^{-2}, buffer 20.96€.m^{-2}) and 32.99€.m^{-2} (buffer 5.10€.m^{-2}) for the two buffer types respectively.

Optimal Use of Geothermal Heat with Buffer

Between the two theoretical extremes described a smarter buffer system was designed for KdW, that allowed thermal balance on a yearly basis and full use of the capacity of one 10MW source. The long term buffer needs a capacity 90,000 m^3 and a day buffer of 2640m^3 to cover the full heat demand and to enable thermal balance. The overall costs of this system are 17.45€.m^{-2}, which is under the costs of the reference and to compete with the less realistic solution of 20MW geothermal heat without a buffer, the investment of the basement buffer should drop to 41€.m^{-3}. In this solution the heat source has 6009 full load hours of operation, 4670 real full load and the rest partial load of the source. Combined with a deep aquifer as buffer (2 pits of 700m depth, 140m^3.h^{-1} each, buffer efficiency 70%) the total costs are 12.13€.m^{-2}, well below the cost of the reference and the two theoretical extremes, but the risks mentioned should be considered in the strategic decision making on the system. For RPH a higher capacity for geothermal heat than 20MW is not realistic, therefore full coverage of the heat demand with geothermal heat alone is not considered. Supplementary heating capacity from other equipment is inevitable.

Competition Geothermal Heat with Equipment in the Reference Situation

By letting the geothermal heat compete with the other equipment and given the heat, electricity and CO_2 demand of the greenhouse the simulation model selected the solution with lowest variable cost every simulated moment in time. If insufficient use of equipment to accept fixed costs followed from simulation that equipment was removed. For RPH the cheapest option that resulted was a geothermal heat source (20MW, 2 sources) combined with 3 co-generators (3.04MW$_e$) and a total buffer size of 85,000m^3 (basement buffer 80,000m^3, day buffer 5,000m^3). This variant saved 42.9m^3.m^{-2} natural gas and reduced total gas use for heating to 25.5m^3.m^{-2}. Overall total gas use including electricity generation is 46.6m^3.m^{-2}. The variant came to surface because of limited availability of geothermal heat and the co-generators contribution to electricity demand. On a total electricity use of 44,746MWh an uptake from the grid of 22,866MWh is needed, mainly because of timeliness, since also 28,408MWh is delivered to the grid. The overall costs of this variant for heating, CO_2 and electricity were 29.42€.m^{-2}, this is slightly under that of the reference even though investment costs are higher. A rising trend in the energy price will work to the benefit of this variant. Full load hours of operation for the 3 co-generators were respectively 7505, 5192 and 3922h, for the geothermal heat source 5507h. Figure 3 indicates the performance of this system. Despite higher costs a basement buffer was chosen to prevent deep aquifer risks. Overall costs of a deep aquifer would be 28.49€.m^{-2}. Total CO_2 production is 29.4kt and gas consumption total is 46.6m^3.m^{-2} and 25.56m^3.m^{-2} to compensate heat demand.

For KdW the solutions cannot yet compete with extreme situation 1 or risks are involved. From simulation another solution emerged using a central boiler (9.8MW), a geothermal heat source of 10MW with a dedicated buffer of 2640m^3. Since the investment for a central boiler is relatively low this variant is relevant. Despite high variable costs for the central boiler, the boiler can contribute to the heating process thus saving buffer space. The total costs for this system were 10.50€.m^{-2}, this is 1.96€.m^{-2} under the theoretical solution without buffers and 8.04€.m^{-2} under the reference situation. Full load hours of operation are 5119h for the geothermal heat and 493h for the central boiler. The cover percentage of heat demand by the geothermal heat source is 92.3% and the degree of utilisation is 58.4%. Total gas use is 5.0m^3.m^{-2}. In a total of CO_2 production of 0.9kt by the boiler 0.1ktonne is used for CO_2 enrichment and an additional 1.8kt industrial CO_2 is needed. If the buffer of 2640m^3 is not used the utilisation of the geothermal heat source decreases with 298h and the central boiler is used 211h more. Costs increase with 0.49€.m^{-2}, the increased variable costs over compensate buffer costs and operational costs of the geothermal source. Gas consumption increases to 7.2m^3.m^{-2}.

CONCLUSIONS

Application of geothermal heat has consequences for compensation of CO_2 and electricity demand. Changes in the supply system must therefore be assessed for all demands. Economic feasibility was proven for both companies, but the economic effect for RPH was small because of supplementary lighting. Three different buffer types were analysed for long term buffering of geothermal heat. Technically the basement buffer is most suitable because of high reliability, low variable costs and acceptable heat loss, since part of the losses pass through the greenhouse. Basement buffers allow very large buffers without loss of space and high temperature water can be stored. However because of high investment costs these buffers are not (yet) economically feasible. Deep aquifers share many of the advantages of the basement buffer, high temperature storage, no loss of space and thanks to lower investment costs this buffer type is economically feasible. However variable costs are higher and risks of malfunctioning exist. A tank buffer with the size of a large short term buffer contributes to the performance of the geothermal heat source, both the cover percentage of the heat demand and the source utilisation improve. For KdW the best solution consisted of a central boiler and a 10MW geothermal heat source with a tank buffer of $2640m^3$. For RPH the best solution was a geothermal heat source (20MW, 2 sources) combined with 3 co-generators ($3.04MW_e$) and a total buffer size of $85,000m^3$ (basement buffer $80,000m^3$, day buffer $5,000m^3$). Gross gas consumption and CO_2 production were strongly reduced on both companies with 94.8% and 84.3% for KdW and with 59.6% and 50.5% for RPH. The use of a linear programming based algorithm that selected the minimum supply cost for heat, CO_2 and electricity demand every time step proved to be a very relevant tool in finding best combinations of equipment. Finally basement buffers must be available at lower investment costs to be economically feasible.

ACKNOWLEGDEMENTS

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Tables

Table 1. Yearly fixed and variable costs (€) for heating, CO_2 and electricity (El.) supply to the greenhouse for the reference situation of two growers.

'Wieringermeer'	Fixed costs	Variable costs	Heat (MWh)	CO_2 (kt)	El. (MWh)
Co-generator	371,758	2,857,427[a)] -1,881,126[b)] 39,867[c)]	44,958	15.0	31,120
Central boiler	40,940	359,647[a)] 4,622[c)]	10,025	2.1	-
Buffer	42,570	0	*7,897*[*]	-	-
Industrial CO_2	-	15,051	-	0.1	-
Total	455,268	1,395,488	54,983	17.2	31,120
		Required	54,907	1.9	0
		Residue	76	15.3	31,120
'Royal Pride'	Fixed costs	Variable costs	Heat (MWh)	CO_2 (kt)	El. (MWh)
Co-generator	1,115,300	9,750,632[a)] -3,523,940[b)] 345,026[c)]	153,393	51.1	106,185
Central boiler	167,847	523,058[a)] 193,728[c)]	41,668	8.8	-
Buffer	80,625	0	*21,308*[*]	-	-
Industrial CO_2	-	0	-	0	-
Total	1,363,772	7,288,504	195,061	59.9	106,185
		Required	175,352	21.6	44,746
		Residue	19,084[**]	38.3	61,439

[*] Not part of heat production, [**] Residual heat, necessary to prevent electricity uptake from the grid. [a)] heat, [b)] electricity, [c)] internal transport costs CO_2

Figures

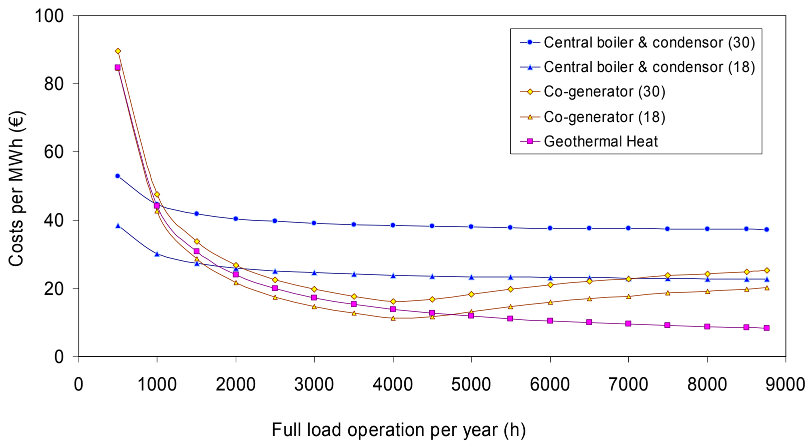

Fig. 1. Costs of geothermal heat ($€.MWh^{-1}$) compared with costs of a central boiler and co-generator in relation to the hours of operation at a gas commodity price of 18 and 30 $€cts.m^{-3}$ and an electricity price of 80 $€.MWh^{-1}$ and 40 $€.MWh^{-1}$ at peak and off peak hours respectively for delivery to the grid at a fixed spark spread.

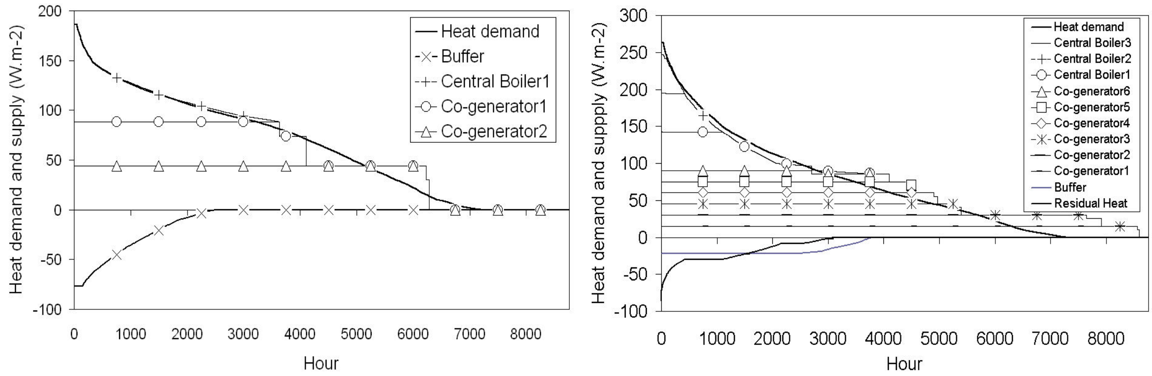

Fig. 2. Heat demand and supply for the reference situations of both case companies: Kwekerij De Wieringermeer (left) and Royal Pride Holland bv (right).

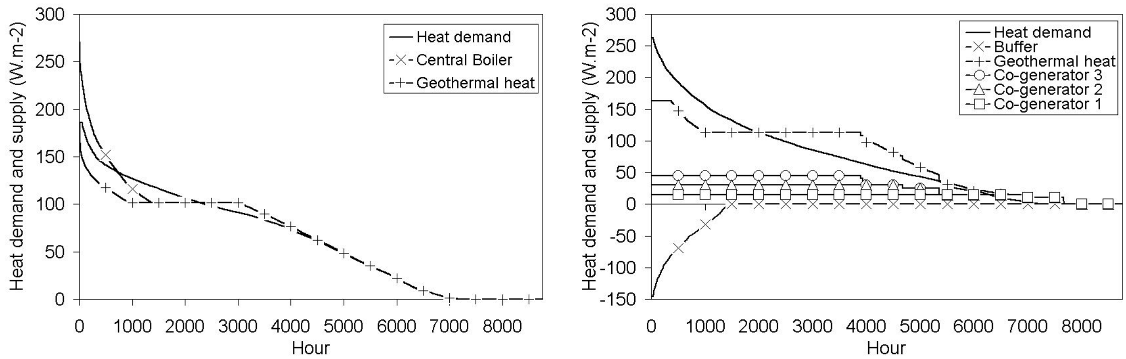

Fig. 3. Heat demand and supply for integrated solutions with minimum costs for both case companies: Kwekerij De Wieringermeer (left); Royal Pride Holland bv (right).