GEOFOOD - Energy model of geothermal greenhouse aquaponic systems

Part II: Simulations for geothermal greenhouse production in the Netherlands

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Rapport WPR-969

WAGENINGEN UNIVERSITY & RESEARCH

Referaat

Voor het EU-project GEOFOOD is een aquaponics model ontwikkeld dat gericht is op gebruik van geothermische energie. Om de functionaliteit en toepasbaarheid van het model te demonstreren bevat dit rapport de resultaten van twee scenario studies die productie van groenten in kassen aan de hand van aardwarmte in Nederland als uitgangspunt hebben. In deze scenario's worden een tomaten- en slateelt in de kas gecombineerd met een recirculerende aquacultuur faciliteit waarin snoekbaars wordt geproduceerd. De resultaten omvatten warmtevraagprofielen van de kas- en aquacultuurproductie, evenals een indicatie van de mate waarin een aquaponics systeem geothermische warmte kan benutten.

Abstract

To illustrate the functionality and applicability of a geothermal aquaponic model that has been developed for the EU project GEOFOOD, this report contains two scenarios based on geothermal greenhouse production in the Netherlands. In these scenarios a tomato- and lettuce greenhouse production are combined with an aquaculture facility that produces pike-perch. The results include heat demand profiles of greenhouse- and aquaculture production as well as an indication on the performance of an aquaponic thermal treatment network with respect to geothermal heat use.

Report info

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1 Introduction

GEOFOOD is a GEOTHERMICA research, innovation and demonstration project that aims to determine how and to what extent the heat use efficiency of geothermal wells can be increased by means of circular food production systems. In these systems several activities such as agricultural production, (waste)water treatment, nutrient recovery, as well as food processing are connected by the exchange of energy and mass flows. Since the subsystems have a variety of heating (and cooling) requirements throughout the year, they could be operated as a thermal treatment network in order to optimise the heat extraction from a geothermal well.

To investigate the potential of this principle one of the main research topics within the GEOFOOD project is the direct use of geothermal energy for aquaponics. Aquaponics is a farming system that connects hydroponic cultivation of vegetables with aquaculture by exchanging water- and nutrient flows. Building on this circular concept, a predictive model was developed to design and assess geothermal aquaponic systems consisting of a geothermal well, greenhouse and recirculating aquaculture system (RAS).

Figure 1 shows a schematic overview of the model. A starting point of the model is a geothermally heated greenhouse which utilizes a RAS as a sink for residual heat. This means that the greenhouse heat demand has priority over RAS heat demand. The RAS is therefore supplied with heat in two distinct ways. First, whenever the greenhouse does not require the full heating capacity of the geothermal well, the remaining capacity can be utilized directly by the RAS. Second, the greenhouse can supply residual heat to the RAS when the temperature of the return water from the pipe heating system in the greenhouse exceeds the temperature of the fish rearing water.

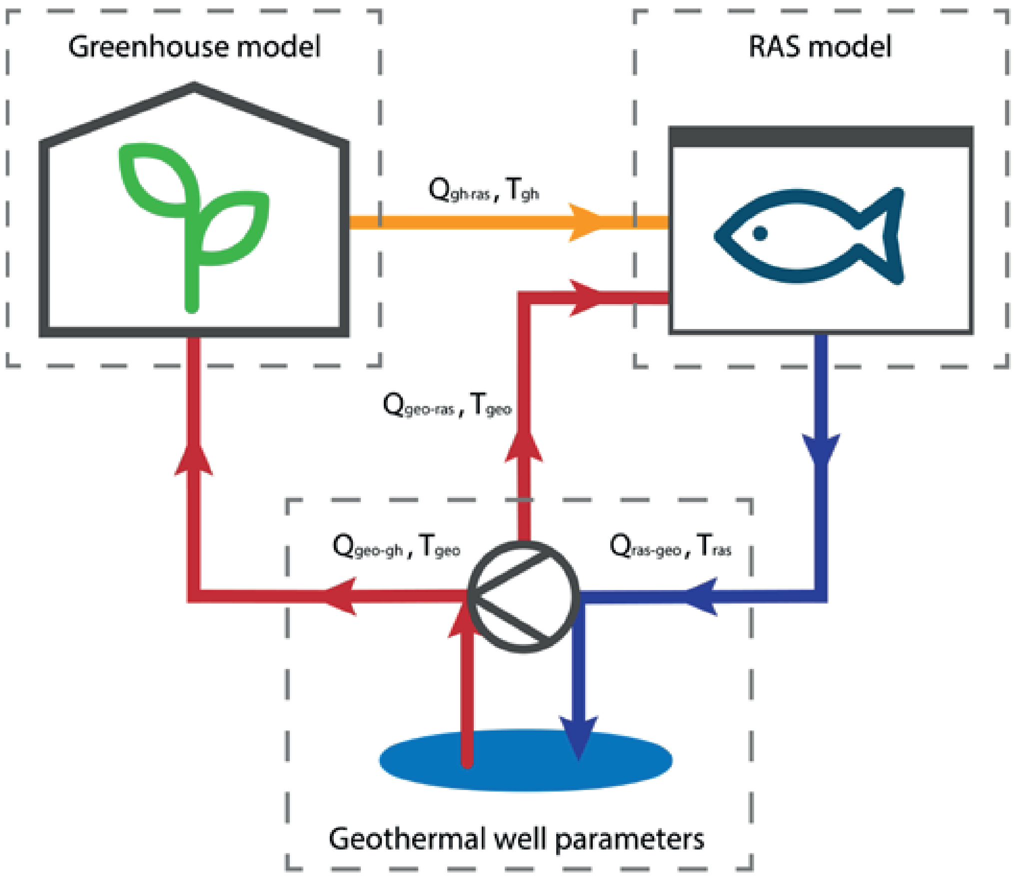

Figure 1 *Schematic overview of the modelled geothermal aquaponic system.*

The core model consists of two parts to calculate hourly values for the energy and mass flows: (1) a greenhouse climate and energy model and (2) a newly developed RAS energy model. The combined outputs as well as geothermal well parameters are used to compute when and how much heat is extracted by the aquaponic thermal treatment network. A full description of the model can be found in part I of this report.

To illustrate the functionality and applicability of the developed model, this report contains two scenarios based on geothermal greenhouse production in the Netherlands. In these scenarios a tomato- and lettuce greenhouse production are combined with a RAS facility that produces pike-perch. The Netherlands were selected as a test case because geothermal energy use in the greenhouse horticulture sector is steadily rising. In 2019 a total of 21 geothermal doublets were operational that supplied 5,600 TJ of heat, mostly for commercial greenhouse production (TNO, 2019).

2 Scenario description

To illustrate the functionality of the geothermal aquaponic model, two scenarios are simulated; (1) a tomato greenhouse and (2) a lettuce greenhouse, both located in the Netherlands are combined with a RAS facility for pike-perch production. The choice of these two crops is based mostly on the fact that tomato is a "warm" crop and lettuce a "cold" one, so they differ considerably in their greenhouse heat demand. The objective of the simulations is to identify suitable geothermal wells and RAS facilities for greenhouses of which the surface area is known. The boundary conditions and inputs for the simulation of the greenhouses are presented in Table 1.

Table 1

Boundary conditions and inputs for the greenhouse simulations.

Simulation parameters	Tomato greenhouse	Lettuce greenhouse
Latitude	52	52
Weather data	SEL2000*	SEL2000*
Area	5 ha	5 ha
Covering material	Single glass	Single glass
Lower pipe heating net Upper pipe heating net	Ø 51 mm, 5 per span Ø 32 mm, 2.5 per span	Ø 51 mm, 10 per span None
Energy saving screen	SLS10 Ultra Plus	Luxous 1243
Growing cycle	Planting date 15-Dec Clean out date 20-Nov	Continuous, year-round
Heating setpoint range	14 – 25°C	9 – 13°C
Humidity setpoint range	90%	85 – 90%

* Typical meteorological year available for De Bilt (Netherlands)

The hourly heating demand of the RAS facility is computed per unit floor area (m^2) because the potential size is a model outcome, not an input. The main boundary conditions and inputs for the simulation of the RAS facility are presented in Table 2.

Table 2

Boundary conditions and inputs for the RAS facility simulations.

Simulation parameters	Pike-perch RAS
Latitude	52
Weather data	SEL2000*
Target indoor air temperature	26°C
Target relative humidity of indoor air	85%
Source water temperature	10°C
Heat loss coefficient cover	0.25 W/m^2K
Target tank water temperature	26°C
Water exchange rate	3.85 $l/m^2/hr$
Feeding rate	0.25 $kg/m^2/day$
Feed to oxygen ratio	0.6 kg/kg of feed
Oxygen to heat ratio	13.6 x 10^6 J/kg of oxygen

Figure 2 illustrates how geothermal energy is extracted within the Netherlands. At a depth of 2000 meters, ground temperature ranges between 60 – 100°C (Veldkamp *et al.* 2018). To utilize those high temperatures, geothermal installations consist of two wells connected to an aquifer, one for pumping up the hot water and another to return the cooler water. Energy is extracted from the geothermal water by running it through a heat exchanger. There it warms up water from another heating network such as a greenhouse pipe heating system. Though one of the first successful geothermal greenhouse projects in the Netherlands utilizes a well that supplies water of 60°C, most other projects aim at a higher temperature of 75 – 90°C (Van den Bosch *et al.* 2013). For the model simulations a supply temperature of 80°C is used.

The temperature of the returning geothermal water depends on heating system design. Most projects that have been realized in the Netherlands achieve temperatures around 35°C (Stichting Platform Geothermie, 2020). Further cooling can be achieved by increasing the surface of heat transfer. For instance by using more piping. However, the pipe heating design has to ensure that the homogeneity of the greenhouse climate is not affected by the large difference in supply- and return temperature (De Zwart, 2013). The present study aims to investigate the potential of residual heat coming from a geothermal greenhouse for use in aquaculture. Therefore the minimum temperature of the geothermal water after heating the greenhouse is set at 35°C.

Finally, it is assumed that 70% of yearly greenhouse heat demand must be supplied by the geothermal well. This heating capacity will not be sufficient for peak demands of the greenhouse. However, investment costs for a geothermal well increase with higher heating capacity. Based on typical conditions in the Netherlands, Table 3 shows an overview of the input parameters chosen for the geothermal well.

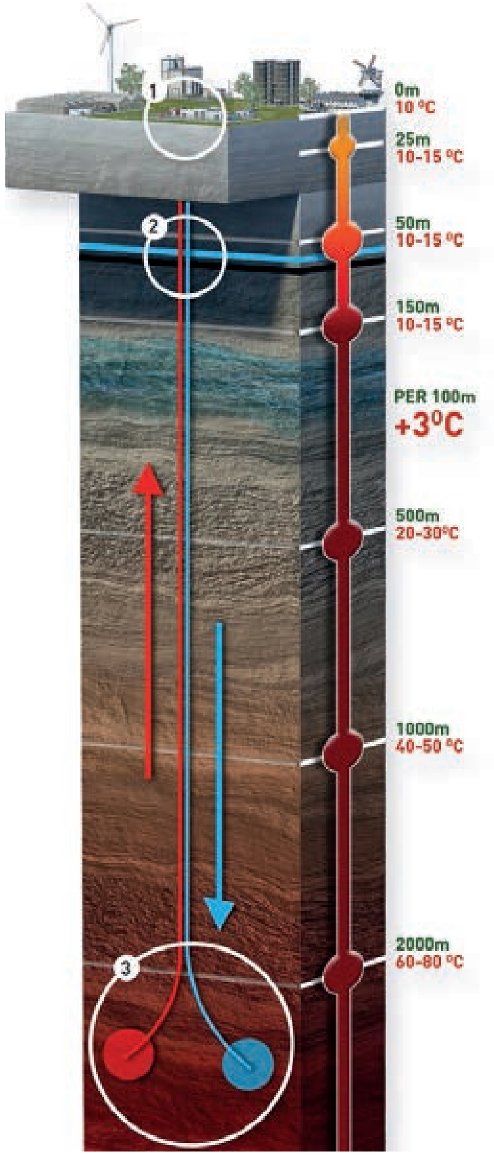

Figure 2 *Geothermal energy extraction in the Netherlands. Source: Platform Geothermie.*

Table 3

Boundary conditions and inputs for the geothermal well.

Simulation parameters	Geothermal greenhouse
Geothermal supply water temperature	80°C
Minimum temperature geothermal water after greenhouse heating	35°C
Heating capacity	70% of yearly greenhouse heat demand

3 Greenhouse simulation results

The hourly mean heat demands of the tomato- and lettuce greenhouses are presented in Figures 3 and 4, respectively. Simulations show that the tomato production has a much higher yearly heat demand than lettuce; 1483 MJ/m^2 compared to 439 MJ/m^2, respectively. This is due to large differences in required temperature set points (see Table 1). These outcomes agree well with values found in practice (Vermeulen, 2016).

Both greenhouses show a similar heat demand curve throughout the year, with peaks during the winter period and little to almost no demand during summer. However, the period with low heat demand is shorter for tomato than it is for lettuce. The tomato greenhouse has low heat demand in July and August as well as during the crop change that starts in November. For the lettuce greenhouse the period of low heat demand extends from May until October.

As a stand-alone production system, the economic feasibility of geothermal heating will therefore be lower for the lettuce greenhouse than for the tomato greenhouse. However, from a perspective of circular food production, the heat demand curves indicate potential in terms of periods during which geothermal heat is available for other food production or processing systems. For example, the period of tomato crop change in November can be used for an energy intensive process such as food drying (Duijvestijn Tomaten, 2020; Van Nguyen *et al.* 2015).

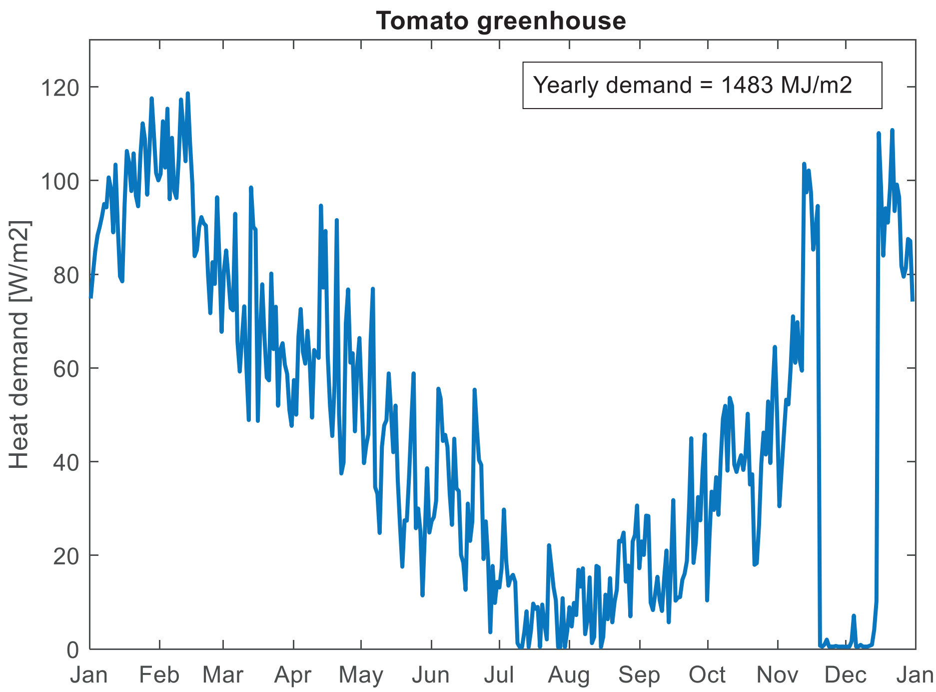

Figure 3 *Hourly mean heat demand of the simulated tomato greenhouse.*

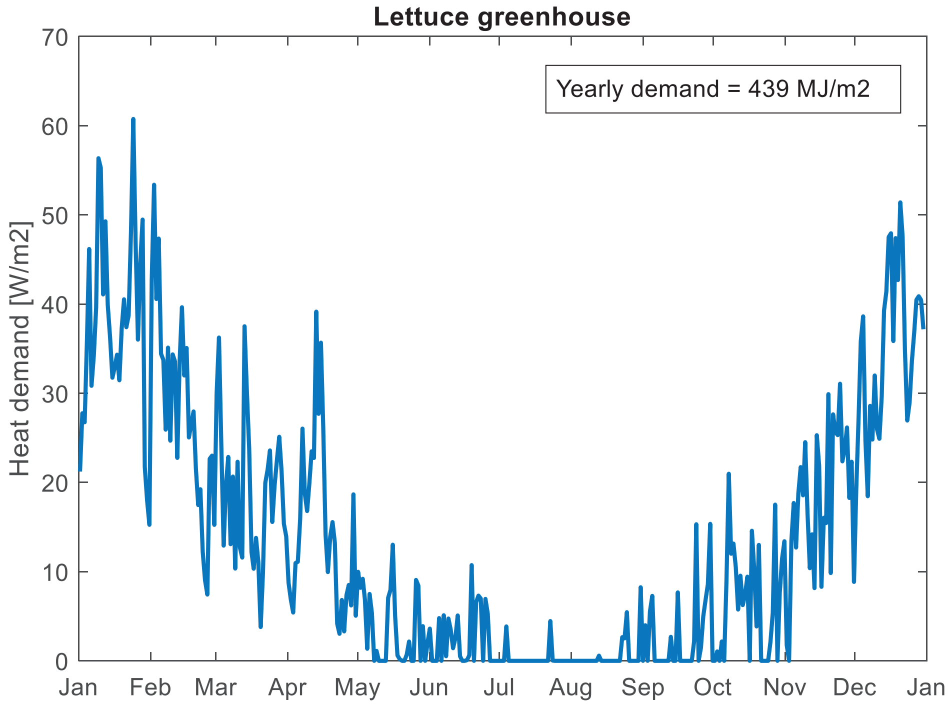

Figure 4 *Hourly mean heat demand of the simulated lettuce greenhouse.*

4 RAS simulation results

The hourly mean heat demand of the RAS facility is presented in Figure 5. Yearly heat demand amounts to 2468 MJ/m^2. This process is more energy intensive than the simulated greenhouse production. Another relevant difference is the consistency in heat demand throughout the year compared to greenhouse production. It suggests that RAS production as a stand-alone system is a suitable application for geothermal energy use, and it does not necessarily have to be connected to a greenhouse as a heat sink to optimize heat extraction.

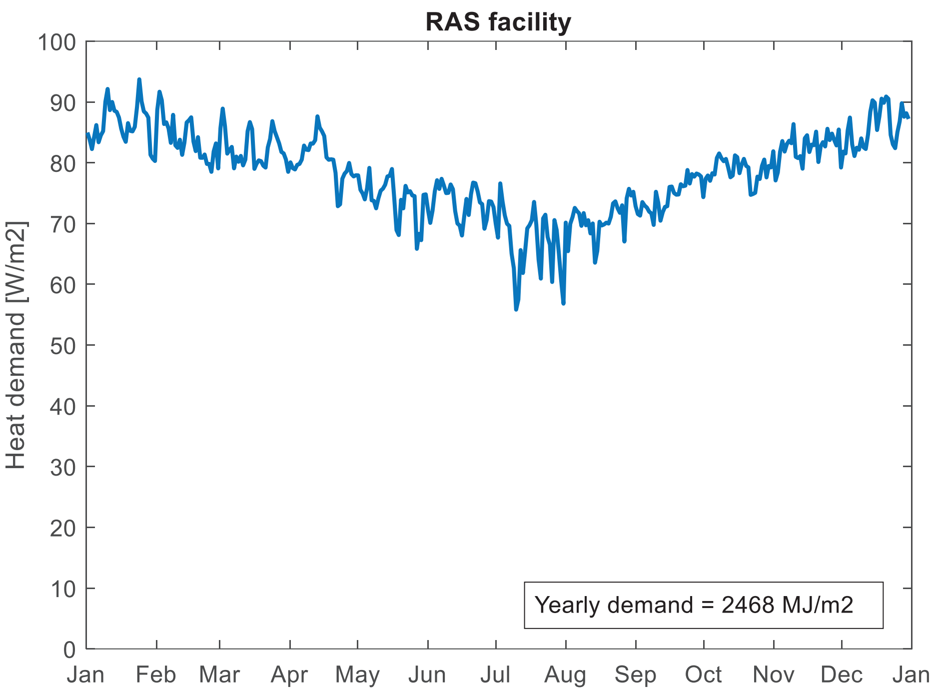

Figure 5 *Hourly mean heat demand of the RAS facility growing pike-perch.*

The reason that the heat demand of the indoor aquaculture system does not fluctuate as much is twofold. First, the climate within an opaque structure is less influenced by heat gain from solar radiation and, when properly insulated, is also less effected by outdoor temperature. In summary, it is more independent from the outside climate variations. Second, water exchange is the major mode of heat loss for the RAS facility. An overview of the different modes of heat loss and their respective impact on heat demand is shown in Figure 6. Since the exchange of water is almost constant throughout the year and it is assumed that the source water temperature is also constant, so is the resulting heat demand.

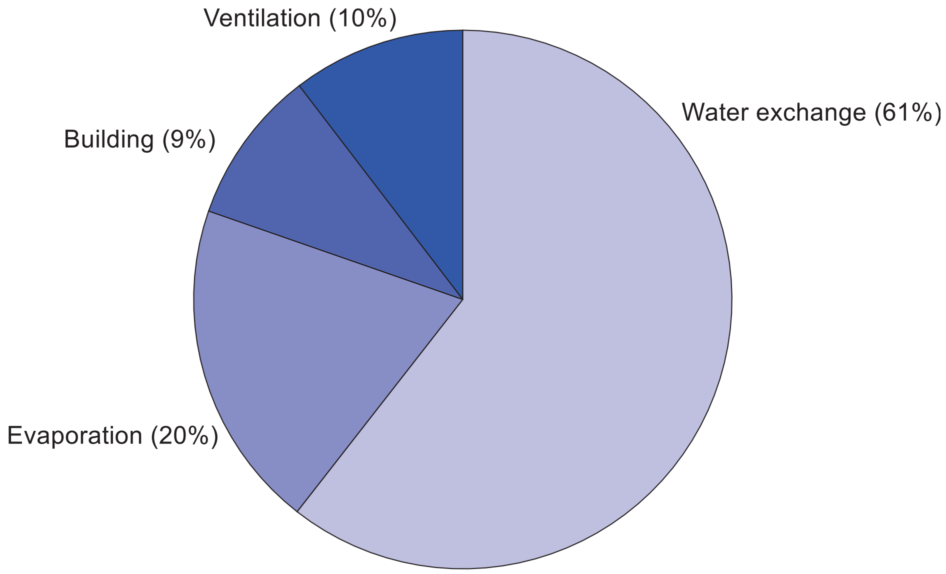

Figure 6 *Modes of heat loss for the simulated RAS facility growing pike-perch.*

This indicates that the source water temperature greatly influences the heat demand of any RAS facility. Another determining factor is to which extent water can be recirculated in order to minimize water exchange. This in turn depends on which equipment is available within the RAS facility that can treat water and effluents such as denitrification- or mineralization reactors (Goddek *et al.* 2018; Piedrahita, 2003). Within aquaponics nitrate accumulation, which has a negative impact on fish health and growth, can be reduced through uptake by the plants in the hydroponic cultivation system. Water can then be circulated back to the RAS, thereby reducing the need for water exchange (Timmons *et al.* 2018).

The second largest mode of heat loss is evaporation. Fish tanks and filter tanks could be covered to decrease the surface area of open water and thereby mitigate evaporation. However, a cover does introduce some practical issues taking into account that fish are sensitive to photoperiod and it may also hinder work processes such as feeding, grading and harvesting. Then again, given the potential heat savings it is a measure worth further investigation (Davison & Piedrahita, 2015; Fuller, 2007).

Multiple simulation runs show that the target value for indoor humidity greatly impacts overall heat demand. Condensation can lead to deterioration of equipment and building structure and should therefore be avoided. However, a lower humidity target increases heat demand since ventilation must be increased. This is illustrated in Figure 7 where heat demands for a range of indoor humidity targets are displayed. It should therefore be considered to avoid condensation in an indoor RAS by installing proper insulation and if necessary controlled ventilation with pre-heating (e.g. heat recovery using an air-to-air heat exchanger), rather than simply increasing ventilation rate.

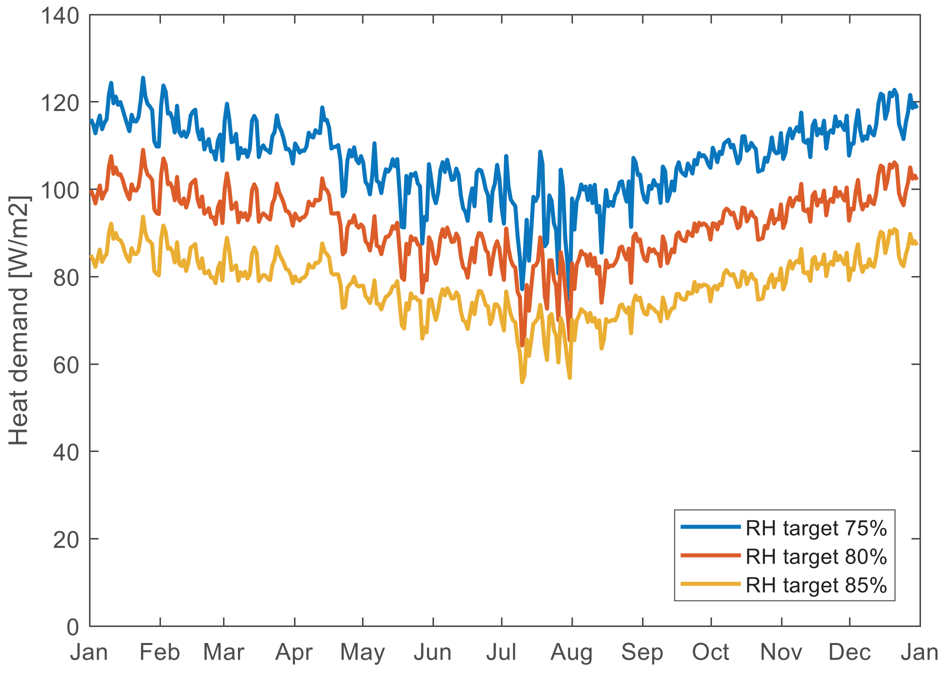

Figure 7 *Hourly mean heat demand for the recirculating aquaculture system at indoor relative humidity targets of 75, 80 and 85%.*

5 Aquaponic thermal treatment network simulation results

The calculated maximum capacities of the geothermal well are 62.3 m^3/h for the tomato greenhouse and 35.3 m^3/h for the lettuce greenhouse. These flows ensure that the geothermal heat supply target of 70% of yearly greenhouse heat demand is maintained. Figure 8 shows the hourly mean heat demand of the greenhouse and the geothermal heat supply. The area underneath the geothermal heat curve is equal to 70% of yearly greenhouse demand.

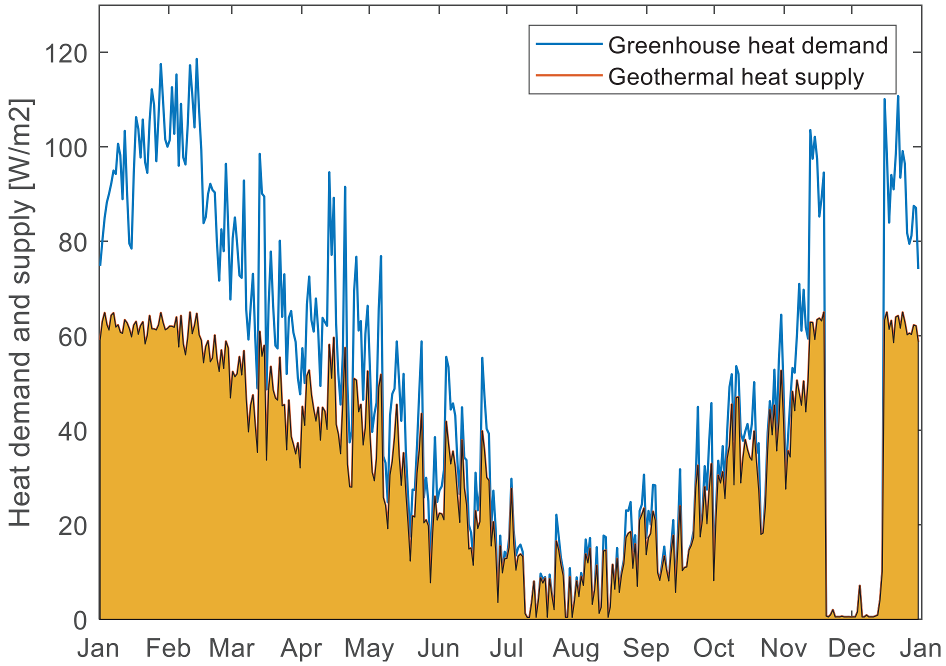

Figure 8 *Hourly mean heat demand of the simulated tomato greenhouse and heat supply of the geothermal well.*

The available heat for other food production systems, in this case a RAS facility, consists of residual heat coming from the greenhouse pipe heating system and/or geothermal heat that is not required by the greenhouse. The minimum RAS surface areas, for which only the available heat is sufficient, are 6544 m^2 and 3725 m^2 for the tomato greenhouse and lettuce greenhouse, respectively. Combining the greenhouses with such RAS facilities into circular aquaponic systems would increase geothermal heat extraction by 30.9% and 59.6% respectively, compared to stand-alone greenhouse production. The mean hourly available heat as well as the heat used by the minimum size RAS facility are presented for the tomato greenhouse scenario in Figure 9. The area underneath the RAS heat use curve represents the total heat used by the RAS, which is equal to the additional heat extracted from the geothermal well.

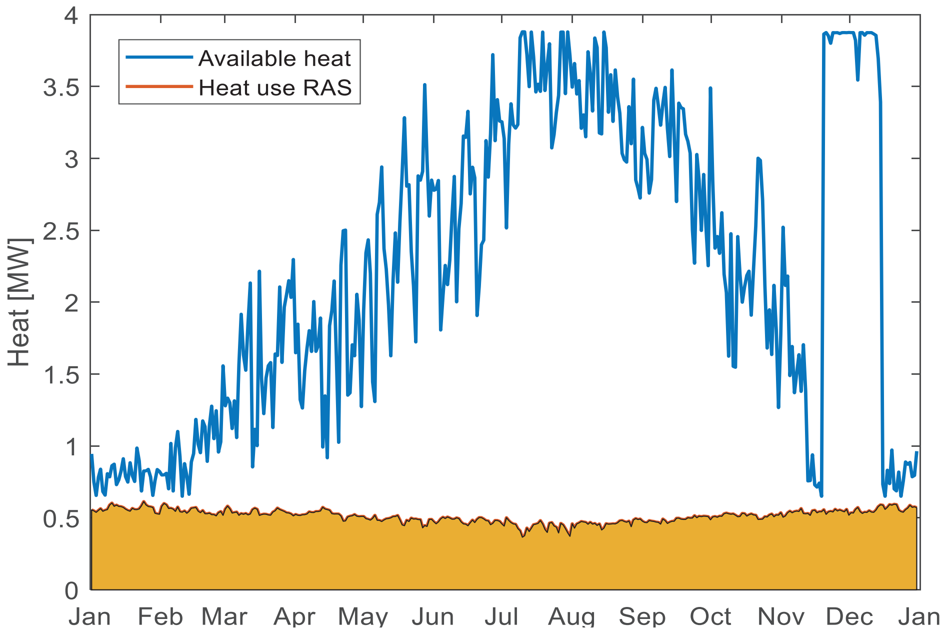

Figure 9 *Hourly mean available heat and heat use of the minimum size RAS facility for the tomato greenhouse scenario.*

From Figure 9 it can be observed that still a large part of the available heat remains unused. Therefore the model also calculates results for when the RAS facility is increased in size. Figure 10 illustrates what happens when the RAS facility in the tomato greenhouse scenario is increased from 6544 m^2 to almost 2 ha. The green area indicates how much additional geothermal heat will be extracted whereas the red area indicates how much heat from an alternative source the RAS facility would need.

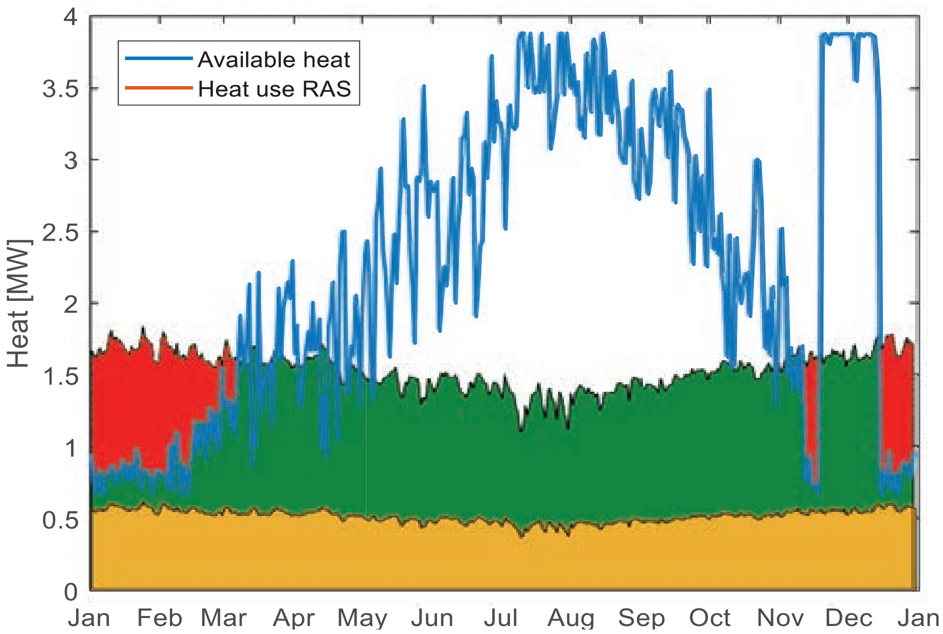

Figure 10 *Hourly mean available heat and heat use of the RAS facility as size increases.*

In order to optimize the direct use of geothermal energy for a given aquaponic project, the appropriate size of the RAS facility can be evaluated using graphs as the one presented in Figure 11. The left graph of Figure 11 shows the additional heat extracted from the geothermal well and the heat demand from an alternative source for an increasing surface area of RAS. The right graph shows the increase in geothermal heat extracted as a percentage, as well as the percentage of heat that cannot be supplied to the RAS facility by the geothermal well. Both graphs start at the minimum RAS size. The surface area for which further increase will cost more heat from an alternative source than is additionally extracted from the geothermal well, is indicated by a vertical dashed line. For both the tomato- and lettuce (data not shown) greenhouse scenarios this size is determined at approximately 4 ha of RAS production.

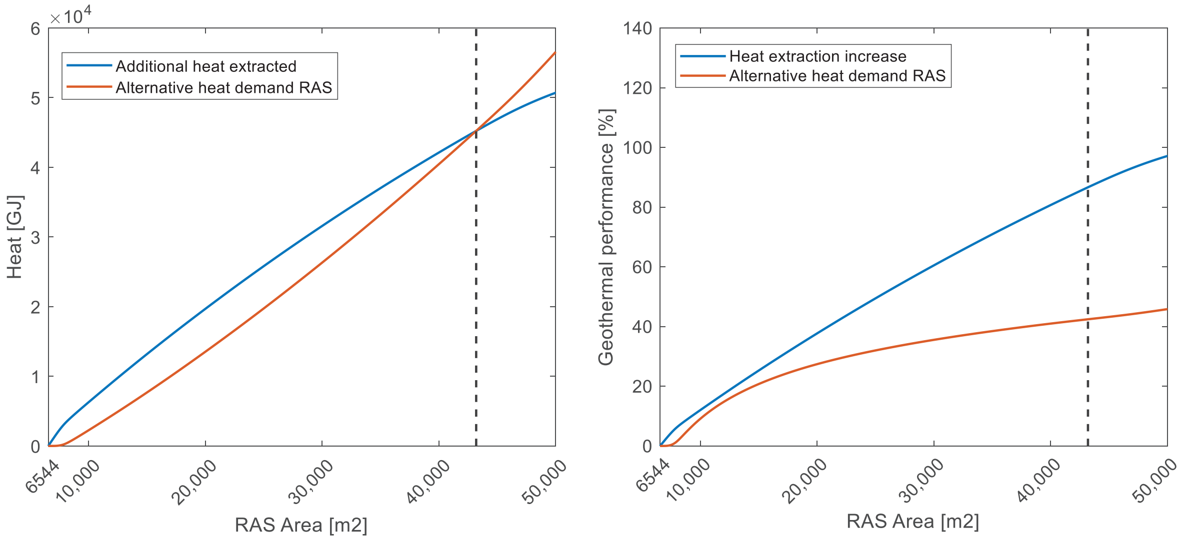

Figure 11 *Graphs to evaluate an increase in RAS facility size for the tomato greenhouse scenario. Left: Additional heat extracted and alternative heat demand (GJ). Right: increase in geothermal heat extracted and alternative heat demand (%).*

The model outcomes show that the difference in minimum and maximum RAS facility size is very large. Therefore, when dimensioning an aquaponic facility, the trade-off between extracting additional geothermal heat and requiring heat from an alternative source should be carefully considered, taking into account cost factors and sustainability targets. For instance, the RAS facility of the tomato greenhouse can be increased from 6544 m^2 to 8894 m^2, and only at peak demand an alternative heat source would be needed, amounting to only 5% of total demand. Finally, it can be considered that at a given RAS size it may be more valuable to consider other food production and processing systems to increase geothermal energy extraction than to further increase the size of the RAS facility.

6 Discussion and conclusions

The initial results from the model indicate that integrating RAS production with a geothermal greenhouse can increase heat extraction from the well when compared to a stand-alone greenhouse and make the heat extraction more balanced throughout the year. However, the RAS energy model needs to be validated. Furthermore, the practical challenges of combining a geothermal greenhouse and RAS (e.g. control strategies and heating system design) are not taken into account as the model assumes the availability of energy based only on mass flows and temperature. Besides, in the RAS facility rather stable set points are assumed year round, when in practice, these and other parameters related to the fish production cycle are not constant.

Still, integration of the newly developed RAS model and the greenhouse model into a thermal treatment network, enables assessment of geothermal energy use potential within circular food production systems, in particular aquaponics. The model outcomes show that an integral part of designing geothermal aquaponic facilities is the trade-off between extracting additional geothermal heat and requiring heat from an alternative source during peak demand. This can be done by sizing the RAS facility as a heat sink for the greenhouse. However, the results show that heat demand of the RAS is more consistent throughout the year than that of a greenhouse. Therefore, it is also an option to have a greenhouse function as a heat sink for aquaculture production.

It is also interesting to highlight, that if a RAS is implemented within a part of the greenhouse structure to save investment costs, then, the heat demand pattern of the RAS would become more similar to that of the greenhouse. As a result peak heat demand of both systems would occur more simultaneous, which would hamper the option of using one system as the heat sink of the other. This option will be considered in future upgrades of the models.

Results indicate that in The Netherlands, the maximum RAS size that can be built without alternative heat sources exceeding the additional heat extraction from the well, is rather large. As a matter of fact, it makes sense to add other potential heat sinks related to circular food production, instead of considering such large facilities. These could be, for instance, production of microalgae in bioreactors, water and effluent treatment, drying, pasteurization, peeling and blanching etc. In the future, separate model modules for these systems can be produced and coupled to the greenhouse and RAS model.

After proper validation, the model could be used in any world location to dimension aquaponic systems whose energy demand is fed by geothermal wells, in such a way that heat extraction from the well is optimized to the specific needs of every project. Operators of existing geothermal wells can be stimulated to consider the potentiality and synergy of establishing connections with food production systems by showing them the increase in heat extraction that could be achieved in their wells.
In Europe specifically the model can stimulate efforts to connect established greenhouse horticulture areas with an emerging RAS sector, thereby moving towards more circular food production systems.

Literature

Davison, A. V., & Piedrahita, R. H. (2015).
Temperature modeling of a land-based aquaculture system for the production of Gracilaria pacifica: possible system modifications to conserve heat and extend the growing season. *Aquacultural Engineering*, *66*, 1–10.

De Zwart, H. F. (2013).
Lage temperatuurverwarming in de Glastuinbouw.

Duijvestijn Tomaten. (2020).
Innovaties Duijvestijn Tomaten - Duurzame droogoven. https://duijvestijntomaten.nl/innovaties/#duurzame-droogoven

Fuller, R. J. (2007).
Solar heating systems for recirculation aquaculture. *Aquacultural Engineering*, *36*(3), 250–260.

Goddek, S., Delaide, B. P. L., Joyce, A., Wuertz, S., Jijakli, M. H., Gross, A., Eding, E. H., Bläser, I., Reuter, M., & Keizer, L. C. P. (2018).
Nutrient mineralization and organic matter reduction performance of RAS-based sludge in sequential UASB-EGSB reactors. *Aquacultural Engineering*, *83*, 10–19.

Piedrahita, R. H. (2003).
Reducing the potential environmental impact of tank aquaculture effluents through intensification and recirculation. *Aquaculture*, *226*(1–4), 35–44.

Stichting Platform Geothermie. (2020).
Platform Geothermie. https://www.geothermie.nl/index.php/nl

Timmons, M. B., Guerdat, T., & Vinci, B. J. (2018).
Recirculating Aquaculture (4th ed.). Ithaca Publishing Company.

TNO. (2019).
Delfstoffen en aardwarmte in Nederland.

Van den Bosch, R., Flipse, B., & Vorage, R. (2013).
Stappenplan Winning Aardwarmte voor Glastuinbouw.

Van Nguyen, M., Sigurjón, A., Margeir, G., & Pálsson, P. G. (2015).
Uses of geothermal energy in food and agriculture - Opportunities for developing countries. www.fao.org/publications

Veldkamp, J. G., Van Wees, J. D. A. M., Brunner, L. G., De Jong, A. P. A. M., Heijnen, L. J., & Van Langen, C. (2018).
Play-based portfoliobenadering, eerste inzicht in zes voordelen voor veilig en verantwoord, kosteneffectief versnellen van geothermie Het geheel is groter dan de som der delen.

Vermeulen, P. (2016).
Kwantitatieve informatie voor de glastuinbouw 2016-2017: kengetallen voor groenten, snijbloemen, pot en perkplanten teelten.

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