KIEAE Journal, Vol. 22, No. 6, Dec. 2022, pp.21-27.

KIEAE Journal

Korea Institute of Ecological Architecture and Environment

118

Review of Semi-closed Greenhouse Previous Studies and Required Technology Analysis for Improving Energy Efficiency

Mi-Lan Park* · Jae-Weon Jeong**

* Ph.D. Candidate, Division of Architectural Engineering, Hanyang Univ., Seoul, Korea (mipark@ekr.or.kr)
** Corresponding author, Professor, Division of Architectural Engineering, Hanyang Univ., Seoul, Korea (jjwarc@hanyang.ac.kr)

ABSTRACT

Purpose: With the spread of smart farms in Korea, there is a clear tendency to consume electricity and heat energy in the agricultural sector. In line with the carbon-neutrality policy, measures to reduce energy in the greenhouse industry should be developed. Although Korea is currently focusing on expanding the number of smart farms, developed countries such as the Netherlands have been researching and developing semi-closed greenhouses, which increase crop productivity and improve energy efficiency, since the early 2000s. In this study, the necessity of a semi-closed greenhouse, which is being introduced as an alternative to the existing greenhouse technology, was considered, and the applied technology elements were examined and directions for future research were suggested. **Method:** From 2005 to 2020, we analyzed 26 foreign papers and articles on semi-closed greenhouses. Semi-closed greenhouse research was conducted from the viewpoints of energy efficiency and crop productivity improvement. **Result:** A semi-closed greenhouse starts by closing the windows on the roof, to use the surplus heat produced during summer or during daytime in winter. The technological elements used in the efficient environmental control of semi-closed greenhouses are 1) heat storage, 2) air treatment system, 3) air conditioning system, 4) heating system, and 5) dehumidifier system. Semi-closed greenhouse systems have been introduced and proven in Europe. It is necessary to verify the system suitability for the hot and humid Korean climate in summer and study the energy efficiency performance of each element.

KEYWORD

반밀폐형 온실
에너지 효율
잉여잠열
열저장
공기처리장치

Semi-closed Greenhouse
Energy Efficiency
Surplus Latent Heat
Heat Storage
Air Treatment Unit

ACCEPTANCE INFO

Received Nov. 4, 2022
Final revision received Nov. 22, 2022
Accepted Nov. 25, 2022

1. Introduction

1.1. Background and purpose of research

In 2021, the smart farm supply area in Korea was 6485ha, an increase of approximately 16 times from that over eight years ago (405ha) in 2014 when statistics monitoring began[1)]. Following the development of the "Agricultural Food ICT Convergence Expansion Plan"in 2013, the government has been supporting the expansion of smart farm sites since 2014, with an emphasis on facility horticulture. In 2017, smart farms were chosen as one of the major creative growth projects in the direction of the economic strategy of the government. Since then, efforts have been made to develop them as future growth sectors by improving technological innovation and competitiveness. With focus on productivity improvement by scale-up, facility integration, and convergence with information and communications technology devices, smart farms are becoming energy-consuming businesses and electric energy-oriented enterprises. The increasing energy usage and electrification in the agroforestry industry contradict the national energy transition and carbon-neutrality goals.

Although the 2050 carbon-neutrality vision was established in October 2020, practical negotiations including sectoral objectives are lacking[1]. In the Netherlands, where greenhouse agriculture has grown, attempts to preserve greenhouse energy and reduce carbon dioxide emissions have been underway since the 1990s. In 1997, the Dutch greenhouse business sector signed the Glasshouse Horticulture and Environmental Agreement with the government[2)]. The agreement called for a 65% improvement in energy efficiency in 2010 as well as a 4% decrease in renewable energy consumption compared to those in 1980[2]. Following this agreement, greenhouse crop productivity was increased based on the concept of a greenhouse system, which improves energy efficiency, beginning with "closed greenhouses." Closed greenhouses are sustainable greenhouses because they eliminate windows for ventilation and improve the energy efficiency[3], or proof of the future[4] has been established. Semi-closed greenhouses have been established in Korea since 2017; however, research on them is lacking[3)]. The aims of this study were to examine the concepts of closed and semi-closed greenhouses, assess the necessity and present the energy efficiency improvement element technology, and recommend future directions.

pISSN 2288-968X, eISSN 2288-9698
https://doi.org/10.12813/kieae.2022.22.6.021

1.2. Research scope

From 2005 to 2020, 25 overseas publications and professional journal articles on closed and semi-closed greenhouses were examined. Semi-closed greenhouse research has mostly focused on improving the energy efficiency, agricultural output, and irrigation water conservation. In this study, we focused on energy efficiency and the technologies employed to achieve it. A semi-closed greenhouse is a large-scale smart greenhouse, also known as a commercial or corporate greenhouse. It is equipped with air-conditioning and heating, ventilation, dehumidification, and environmental control technology. As a first step in ensuring energy efficiency in greenhouses, greenhouse covers and shade films that combine insulation and light transmittance are typically examined. These passive features were excluded in this study because they are frequently considered in existing greenhouses. In this study, active aspects that occur in large-scale open greenhouses supplied with facilities were primarily covered.

A total of 17 (65%) of the 26 research on the Dutch climate involved testbed experiments, monitoring, simulations, and literature reviews. Furthermore, 7 examples (27%) were for Europe, including France, Germany, and Spain, and the remaining two cases were from North America, indicating a lack of studies on suitability to the four unique seasons of Asia. In particular, six cases (23%) specifically investigated cooling and dehumidification, among facility component technology elements, and much research was devoted to surplus heat treatment in summer. It is critical to investigate system configuration and capacity planning suited for the conditions in Korea, where the operation of cooling and dehumidifying facilities is expensive owing to high temperature and humidity, leading to the loss of the summer cropping season. Furthermore, studies were undertaken to demonstrate the impact of introducing semi-closed greenhouses by measuring the energy saving based on the technical features and system design of greenhouse facilities compared to those of current greenhouses. Empirical and monitoring approaches were utilized for quantification verification in 11 cases (42%), simulations in 7 cases (27%), and theory and literature research in 9 cases (35%). This study extracted technical aspects and improvement concepts from a literature survey, and further research on energy savings in semi-closed greenhouses applicable to Korea's environment should be continued.

2. Concept and theory of semi-closed greenhouses

2.1. Definition

A closed greenhouse is defined as a greenhouse in which the roof ventilation windows are closed[6]. Its development started with the concept of generating electricity from the heat generated in a summer greenhouse[9]. When the windows that enable

Table 1. Target literature

Researcher	Year	Nation	Contents	Method
Bot et al. [5]	2005	Netherland	Quantify energy saving (ES)	Simulation
Opdam et al. [6]	2005	Netherland	Quantify ES	Test bed
Buchholz et al. [7]	2005	Germany	Water balance, Cooling	Theory
Nederhoff [8]	2006	Netherland	Technology element	Theory, Research
de Zwart et al. [9]	2008	Netherland	Technology element, Quantify ES	Simulation
Heuvelink et al. [10]	2008	Netherland	Greenhouse climate and yield	Simulation
Ooster, et al. [11]	2008	Netherland	Zero fossil energy, Technology element	Simulation
Hoes et al. [12]	2008	Belgium	Quantify ES	Test bed + Simulation
Bakker, et al. [13]	2008	Netherland	ES system	Theory, Research
Lee [14]	2010	USA	US climate, Cooling	Test bed
Nederhoff et al. [4]	2010	Netherland	Technology element	Theory, Research
Harmelink [2]	2011	Netherland	Agricultural policy	Policy
Vadiee [15]	2011	Sweden	Energy analysis	Simulation
Grisey et al. [16]	2011	France	France climate, Cooling	Test bed
Campen et al. [17]	2011	Netherland	Comparison	Test bed
de Zwart et al. [18]	2011	Netherland	Quantify ES	Test bed
Gieling et al. [19]	2011	Netherland	Heat and cooling element technology monitoring	Test bed
Qian et al. [20]	2011	Netherland	Cooling effect analysis	Test bed
de Zwart et al. [28]	2012	Netherland	Technology element	Theory, Research
Ooster, et al. [21]	2012	Spain	Mediterranean climate	Simulation
Teitel, et al. [22]	2012	Netherland	Water balance	Test bed
Vallières, et al. [23]	2014	Canada	Canada climate, Cooling dehumidifying	Test bed
Timalsena [24]	2014	Austria	Technology element	Theory, Research
Polman et al. [25]	2017	Netherland	Agricultural policy	Policy
Le Quillec, et al. [3]	2017	France	France climate, Comparison	Test bed
Sapounas et al. [26]	2020	Netherland	Technology element	Theory, Research

surplus heat and steam to escape are closed, more heat is created than a greenhouse requires. An early plan was to provide the heat of a greenhouse to surrounding homes[8]. Thus, closed greenhouses have been referred to as solar greenhouses[5], heat production[8], zero-fossil energy use greenhouses[11], large solar collectors[15], and Sunergy[18].

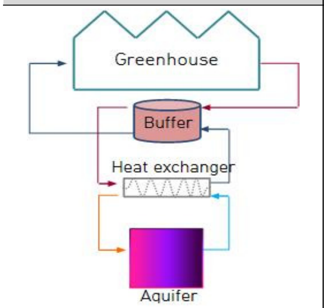
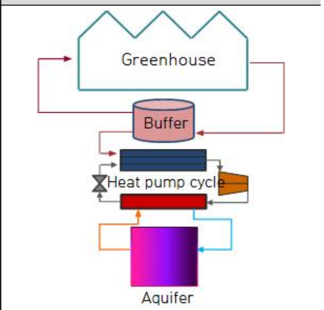
Closed Greenhouse Cooling Process	Closed Greenhouse Heating Process
	

Fig. 1. Closed greenhouse concept (Source: [6][10][15])

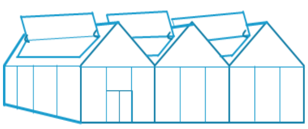
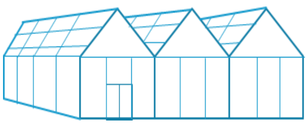
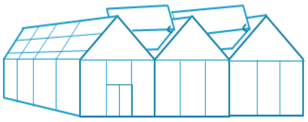
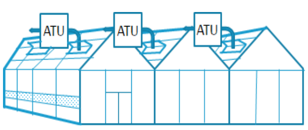
Division	Contents	Form
Conventional greenhouse	Massive ventilation through window	
Closed greenhouse	No ventilation window	
Partly Closed greenhouse	Conventional + Closed greenhouse	
Semi-closed greenhouse	Temperature and humidity-controlled ventilation system	

Fig. 2. Forms of conventional, closed, and semi-closed greenhouses (Source: [27])

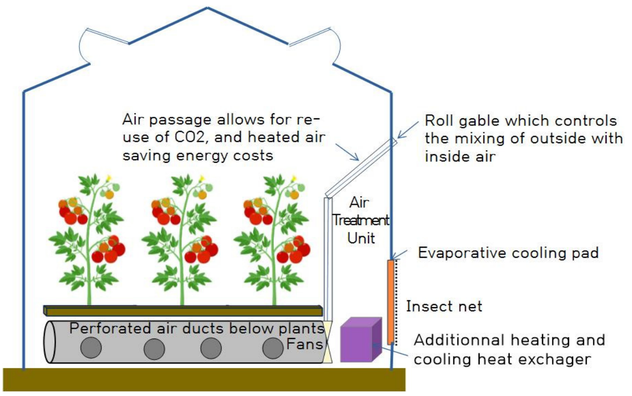


Fig. 3. Semi-closed greenhouse composition

Closed greenhouses provide a yearly excess of solar energy. The majority of solar energy is produced in summer; however, because heat energy is required in winter and spring, the timing of energy demand and supply is difficult[10]. Summer heat is stored in aquifers and used to meet the winter heat demand, resulting in reduced yearly energy usage[5]. The use of aquifers as heat storage is a common feature of Dutch closed greenhouses (Fig. 1.).

Owing to the high cost of removing the extra latent heat in summer, a closed greenhouse with all windows removed is not economically feasible[6][10][11]. In the process of examining the economical sealing rate, the concept of a partially closed greenhouse that transfers the heat generated in a closed greenhouse to an open greenhouse by combining closed and existing open greenhouses appeared (Fig. 2.).

A totally closed greenhouse may save 19% energy consumption, whereas combining closed and open greenhouses can save 33% main energy use. 1 The reduction in the primary energy consumption is proportional to the area of the closed and open greenhouses[6], and the appropriate closure rate is estimated based on climatic conditions[9]. A semi-closed greenhouse is one that combines may be entirely closed and partially opened greenhouses by installing a very small ventilation window and an air conditioning system. Semi-closed greenhouses manage some ventilation heat through strategically positioned vents. Basically, an air treatment unit (ATU) that regulates the exchange of air between the outside and the inside is used. In addition, an air conditioning system for a closed greenhouse that provides the air processed therein to the greenhouse via a distribution system is applied. (Fig. 3.)

2.2. Advantages and disadvantages of semi-closed greenhouses

First, the energy requirements of a greenhouse may be decreased by recycling and storing the heat released by the existing ventilation. In a semi-closed greenhouse, a heat pump, combined heat and power generation, and a quarterly energy storage system using an aquifer are set to generate 35% primary energy saving[6] and 60% secondary energy saving[5]. Second, the positive pressure in a closed greenhouse improves production by managing the carbon dioxide (CO_2) content and reducing the entry of insect repellants and fungal spores. In a closed greenhouse, the concentration of CO_2 can continuously be in the range of 1000–2000ppm, which increases the photosynthesis of plants and increases the production by 22. The amount of water for irrigation is decreased by 50% owing to the lowered evaporation loss by ventilation[26]. Moreover, the usage of herbicides and insecticides is reduced by 80% because the positive pressure greenhouse environment prevents pest invasion[6][7][8][9][14][26].

Despite these advantages, the problems of semi-closed greenhouses necessitate complex equipment to control the internal climate, such as efficient energy storage systems, air distribution ducts, air conditioning systems, dehumidifiers, heat exchangers, and forced ventilation systems. In addition, a passive insulating structure and a screen system are used to reduce the heat loss from the greenhouse itself. The initial investment cost is increased by these facility systems and greenhouse constructions[4][21]. This suggests that farmers must acquire professional training to operate the equipment incorporating these new technologies[15].

Because the technical level of a facility impacts performance, a semi-closed greenhouse is beneficial for application to large-scale greenhouse projects of at least 1ha[28], and it can balance the high investment costs by ensuring a high production[26].

3. Semi-closed greenhouse element technology for energy efficiency improvement

Controlling the surplus latent heat generated by closing windows for ventilation is critical in semi-closed greenhouses. This is accommodated in a traditional greenhouse by heating and ventilation. However, in a semi-closed greenhouse, air is circulated and distributed to control the internal climate, and the ATU cools, dehumidifies, and heats the greenhouse. Heat load collection and storage devices are introduced based on environmental scenarios. During heating, a semi-closed greenhouse independently manages the temperature, humidity, and CO_2 concentration as well as the cooling mode function. A system adapted to each region and condition was built, and the climates of the Netherlands, Spain, and France as well as their technological elements were studied.

3.1. Climatic conditions influence use of technology elements

If the sealing rate in a semi-closed greenhouse is high and the cooling capacity is raised, the microclimate of the greenhouse becomes lesser dependent on the external environment, and the regional features disappear[26]. However, as the cooling capacity increases, the energy consumption also increases. This reduces the effect of the energy savings obtained using a semi-closed greenhouse. To meet the objective of introducing a semi-closed greenhouse, which is to enhance the energy efficiency and economic feasibility, an appropriate cooling technique and capacity must be chosen based on the external climate.

As summarized in Table 2., Dutch and Spanish greenhouses plan heat storage in the forms of aquifers or rock formations, whereas French greenhouses do not provide heat storage separately. Heat pump systems are utilized at all three locations for cooling and heating. A top cooler, fog system, and fan pad system are used for cooling along with each heat pump. Air conditioning facilities focused on ATU are established in greenhouses in the Netherlands and France. A Spanish greenhouse lowers CO_2 emissions by combining biomass and wind power as the electrical energy sources for the facility. Although the greenhouses summarized in Table 3. cannot be considered to reflect the complete climate of the Netherlands, Spain, and France, common technical aspects of semi-closed greenhouses may be determined. The results suggest that, in particular, the seasonal heat storage system and cooling technique are set in various methods to match the features of the location and the greenhouse environment.

3.2. Technical components for increasing energy efficiency

1) Heat Storage

Heat is created or obtained in a semi-closed greenhouse in summer, stored in an aquifer, and used as a heat source for

Table 2. Applied technology elements under climatic condition

Division	de Zwart, 2011 [18]	Ooster, 2012 [21]	Le Quillec, 2017[4)] [3]
Location	Netherlands	Spain	Western France
Heat storage	Aquifer	Water-filled rock-bed	
Heat source		Biomass and wind power	
Heating	Heat pump / ATU. hot water pipe, and rail	Heat pump, hot water pipe, and rail	Heat pump / ATU and heat exchanger
Cooling	ATU and overhead cooler	Heat pump and fog system	ATU Fan and pad
Dehumidification	ATU	Heat pump	ATU
Ventilation	ATU / roof window	Roof window	ATU / roof window
Air distribution duct	Air duct		Air duct
Screen	Double screen	Double screen	Double screen

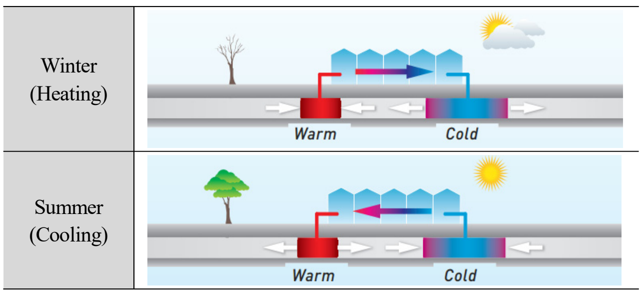


Fig. 4. Aquifer heat storage principle [4]

heating energy in winter[5]. The aquifer maintains a steady temperature of 8–12°C. To remove heat from the greenhouse, cold water is pumped from one side of a pair of well holes and the raised hot water (approximately 20°C) is transported to the aquifer to store the heat. During winter, warm water (approximately 18°C) held in the aquifer is pumped, heated by a heat pump, and utilized as hot water for heating. Aquifers are employed as seasonal heat storage in the Netherlands, where they are well accessible. By installing aquifers and heat pumps, energy usage may be reduced by 25%[4]–40%[28]. (Fig. 4.)

Opdam[6] focused on reducing energy consumption by storing the excess heat generated in summer for winter heating. de Zwart [28] used the discarded cold water after heat exchange for heating in winter as cooling water in summer. Therefore, reducing the cooling energy in greenhouses is an important consideration. Seasonal heat storage causes an imbalance in the cooling and heating heat demand. In northern latitudes, the energy required for cooling is almost double that required for heating. Considering the performance coefficient of a heat pump, cold water produced is only 30% of that required during summer. A partially closed greenhouse is formed of 1ha closed greenhouse and 2 ha open greenhouse. The issue with seasonal heat storage systems is that they must balance the yearly thermal inputs and outputs of cooling and heating. If the winter energy demand is smaller than the summer thermal energy saved, it is necessary to determine when to terminate the energy storage.

2) ATU + Air Duct System

Using a heat exchanger, an ATU feeds fresh outside air to a greenhouse, recirculates the inside air, or mixes the outside and inside air to generate harmonized air for heating, cooling, and dehumidification. ATU hallway-type (Fig. 5.) outside air passes through an evaporative cooling pad and enters an air handling hallway (Unit). An air treatment corridor, which is installed on the side wall, is a space where the recovered inside air and outside air are mixed before being distributed to the interior of the greenhouse. It is a distinct compartment positioned at the short border of the greenhouse, and it is generally 1.5–2.0m wide. A roll gable can be used to manage the air flow[26]. A heat exchanger that can control the temperature of the air distributed to the greenhouse, a humidification spray system, an evaporative cooling pad, and a CO_2 injection system are installed in this area.

The semi-closed greenhouse ATU is constructed with two heat exchangers. In summer, cold water is supplied to both heat exchangers for cooling, whereas in winter, cold water is supplied from the first heat exchanger and hot water is supplied from the second heat exchanger. Before being delivered to the greenhouse, it is dehumidified by condensation in the first heat exchanger and warmed in the second heat exchanger to compensate for the sensible heat. Heating reduces the quantity of energy retrieved from the aquifer; however, the reheated process consumes more energy. Furthermore, if the amount of cold water transported to the aquifer in winter is minimal, the amount of cooling water sent to the aquifer in summer is lowered, and the cooling potential is diminished.

An air distribution system distributes the treated air from the ATU (Fig. 6.). It is spread around the greenhouse by blowers set in perforated polyethylene tubes. The amount of air released from the pipe aperture is determined by the discharge factor of the opening and the static pressure differential. The performance of the air distribution system is critical to the operation of a semi-closed greenhouse because it must be capable of uniformly distributing the air inside the greenhouse at varying ventilation rates. Thus, hole patterns and diameters are created differently in perforated pipes. Furthermore, power consumption inside the hallway-type ATU varies based on the volume of the air delivered and the fan speed.

3) Heating system

In the case of heating, a heat pump circulates hot air via an air duct beneath the crops. Hot water pipe rails are laid on the floor to provide interior temperature uniformity and to decrease the power consumption due to air circulation. It is a mix of an ATU-conditioned air supply and underfloor heating. The arrangement interval of the hot water pipes must be checked to equally regulate the horizontal temperature. When developing a heating system, the sharing ratio of the AHU and the hot water

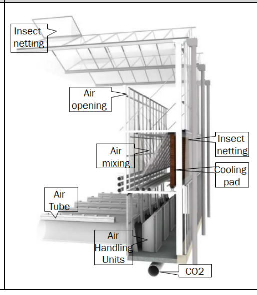
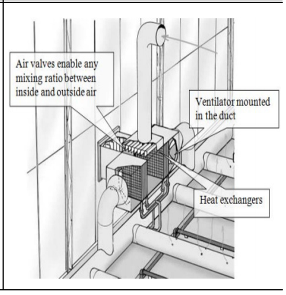
Division	Type of corridor [24]	Type of box [18]
ATU type		

Fig. 5. Classification by ATU type

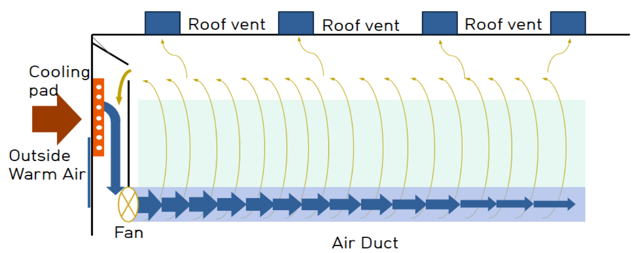


Fig. 6. Conceptual diagram of air distribution for semi-closed greenhouse[7]

pipes as well as the number of hot water rails per span must be considered.

4) Cooling system

The cooled air of the ATU is routed through the air distributor positioned beneath the crop. At this point, cold air lingers close to the air duct, resulting in a vertical temperature gradient. Low temperatures at the base of the crop impede fruit ripening and harm the roots[28]. Therefore, in certain greenhouses, a cooling mechanism is equipped at the upper section of the roof to ensure long-term temperature homogeneity and mix with the greenhouse air before reaching the crops to promote crop development[17]. Considering regional features, fan pad systems, fog systems, top coolers, and cold-water fan coils are used as cooling solutions for semi-closed greenhouses.

5) Dehumidification system

Most greenhouses need a large amount of electricity to manage humidity. Humidity is particularly high in semi-closed greenhouses with closed skylights for ventilation. Temperature and humidity in a semi-closed greenhouse are controlled by forced ventilation of an ATU device. It pulls in outside air with a low absolute humidity.A high-concentration of CO_2 in internal air is combined, passed through a series of cooling coils (or cold water), dehumidified, and subsequently warmed to the correct temperature and supplied to an air distribution duct[28].

4. Conclusion

Greenhouse containment is a natural step toward energy saving and zero fossil fuels in big, marketed greenhouses. The government and the industry have agreed on policy goals, and technical solutions have been linked from theory to empirical work to achieve the objectives. As scaled and equipped greenhouses, such as smart farm innovation valley projects and regionally specialized rental smart farms, emerge in Korea, the greenhouse industry must set policy and quantitative targets. The objectives should be energy consumption and carbon dioxide emission reduction as well as the finding the best methods and tools to achieve them.

Following an analysis of the foreign literature, a semi-closed greenhouse was constructed such that the cooling/heating, ventilation, and dehumidification systems shared their functions complexly and achieved thermal balance. First, determining the ratio of economic energy savings of heat and electricity in the temperature and humidity management system of a greenhouse is an engineering procedure. Its goal is to reduce costly electricity consumption while increasing the thermal energy utilization. This is achieved by analyzing the relationship between the surplus heat storage in greenhouses, seasonal heat storage in aquifers, and electricity consumption required to operate heat pumps and facilities for cooling, heating, ventilation, and dehumidification. An aquifer is the most affordable source of thermal energy. Where aquifers cannot be used for heat storage, geothermal or waste heat can be employed as an alternative in Korea. Studies on the balance of heat storage capacity and heating and cooling energy in these alternative systems should be conducted. Second, it is divided into two stages. The first is temperature and humidity control via outside air mixing, and the second is temperature and humidity control via a heat pump, hot water pipe, or cooling system. During this process, the reasonable ratio of each system and the economic feasibility of the operating cost must be verified. Third, the greenhouse sealing rate must be reviewed considering climatic conditions and economic feasibility. A semi-closed greenhouse uses an ingenious combination of forced ventilation and cooling. A high sealing rate and a high cooling performance imply a high cost of independent implementation in the surrounding climatic environment.The thermal energy to electrical energy ratio, facility balance, and sealing rate should be quantitatively evaluated by system design through operation.

Acknowledgement

This research was conducted with the support of the Basic Laboratory Project of the Korea Research Foundation (2022R1A4A1026503).

References

[1] 김규호, 유재국, 장영주, 농업부문 최종에너지 소비현황 및 향후과제, 국회입법조사처, 2021, pp.9-12. // (K.H. Kim, J.K. You, Y.J. Jang, Final Energy Consumption Status and Future Tasks in the Agricultural Sector, National Assembly Research Service, 2021, pp.9-12.)

[2] M. Harmelink, Energy savings in the horticulture and road transport sector in the Netherlands over the period 1995-2010, Harmelink consulting, 2011, p.2.

[3] S. Le Quillec et al., Benefits of a semi-closed greenhouse for tomato production in the West of France, Acta Hortic., 1170, 2017, pp.883-888.

[4] E. Nederhoff et al., Future proofing, Practical Hydroponics & Greenhouses, 2010, pp.47-55.

[5] G. Bot et al., The Solar Greenhouse: State of the art in energy saving and sustainable energy supply, Acta Hort. 691, 2005, pp.501-508.

[6] J.J.G. Opdam, G.G. Schoonderbeek, E.M.B. Heller, Closed greenhouse: a starting point for sustainable entrepreneurship in horticulture, Acta Hort., 691, 2005, pp.517-524.

[7] M. Buchholz, P. Jochum, G. Zaragoza, Concept for water, heat and food supply from a closed greenhouse - the watergy project, Acta Hort., 691, 2005, pp.509-516.

[8] E. Nederhoff, Closed greenhouse and heat-producing greenhouse, GROWER, 62(10), 2006, pp.67-69.

[9] H.F. de Zwart, Overall energy analysis of (semi) closed greenhouses, Acta Hort., 801, 2008, pp.811-818.

[10] E. Heuvelink et al., Climate and yield in a closed greenhouse, Acta Hort., 801, 2008, pp. 1083-1092.

[11] A. van't Ooster et al., Development of concepts for a zero-fossil-energy greenhouse, Acta Hort., 801, 2008, pp.725-732.
[12] H. Hoes, J. Desmedt and K. Goen, The GESKAS Project, Closed greenhouse as energy source and optimal growing environment, Acta Hort., 801, 2008, pp.1355-1362.
[13] J.C. Bakker et al., Innovative technologies for an efficient use of energy, Acta Hort., 801, 2008, pp.49-62.
[14] W. F. Lee, Cooling capacity assessment of semi-closed greenhouses, Thesis, The Ohio State University, USA, 2010.
[15] A. Vadiee, Energy analysis of the closed greenhouse concept -Toward one sustainable energy pathway, Licentiate Thesis, KTH School. Stockholm, 2011.
[16] A. Grisey et al., Using heat exchangers to cool and heat a closed tomato greenhouse: Application in the south of France, Acta Hort., 893, 2011, pp.405-411.
[17] J.B. Campen, F.L.K. Kempkes, Climatic evaluation of semi-closed greenhouses, Acta Hort., 893, 2011, pp.495-501.
[18] H.F. de Zwart, The sunergy greenhouse - One year of measurements in a next generation greenhouse, Acta Hort., 893, 2011, pp.351-358.
[19] T.H. Gieling et al., Monitoring of climate variables in semi-closed greenhouses, Acta Hort., 893, 2011, pp.1073-1080.
[20] T. Qian et al., Comparison of climate and production in closed, Semi-closed and open greenhouses, Acta Hort., 893, 2011, pp.807-814.
[21] A. van't Ooster, W. van Ieperen, P. Kalaitzoglou, Model study on applicability of a semi closed greenhouse concept in almeria: Effects on greenhouse climate, Crop Yield and Resource Use Efficiency, Acta Hort., 927, 2012, pp.51-58.
[22] M. Teitel, H.F. de Zwart, F.L.K. Kempkes, Water balance and energy partitioning in a semi-closed greenhouse, Acta Hort., 952, 2012, pp.477-484.
[23] M. Vallières et al., Comparison of two cooling and dehumidifying methods for a semiclosed organic tomato greenhouse, Acta Hort., 1037, 2014, pp.611-616.
[24] K. Timalsena, Using semi-closed greenhouses to maximise production while minimising inputs and waste, 2014, p.19.
[25] N. Polman, R. Michel, Agricultural policy objectives on productivity, climate change adaptation and mitigation, Wageningen Economic Researc, 2017, p.11.
[26] A. Sapounas et al., Design, control, and performance aspects of semi-closed greenhouses, Agronomy 2020.10, 1739, 2020, pp.1-22.
[27] A. Vadiee, Energy management in large scale solar buildings, The closed greenhouse concept, Doctoral Thesis. KTH School. Stockholm, 2013, p.65.
[28] H.F. de Zwart, Lessons learned from experiments with semi-closed greenhouses, Acta Hort., 952, 2012, pp.583-588.

---

1) Ministry of Agriculture, Food and Rural Affairs Website Smart Farm Status.
2) It is a voluntary energy saving agreement between the government and the greenhouse industry and will continue thereafter, aiming to improve energy efficiency by 30% (2% per year) from 2005 to 2020.
3) https://www.jeonmae.co.kr/news/articleView.html?idxno=903525: In Korea, starting with Sangju tomato (5ha) in 2017, it is spreading to Gangjin paprika (6 ha) and Goheung tomato (3 ha). In addition, a semi-enclosed greenhouse of 0.6 ha was designed as a standardized technology demonstration greenhouse in Smart Farm Innovation Valley in Goheung, Jeollanam-do.
4) Application of the concept of Ultra-Clima® Kubo.
5) A porous, water-bearing subterranean layer between 20 and 100 m below the soil surface, bounded by horizontal and impermeable clay layers.
6) https://www.hortidaily.com, semi-closed greenhouse, https://www.hortidaily.com/article/9130697/how-does-a-semi-closed-glasshouse-operate

