공학석사 학위논문

Analysis and Validation of Dynamic Thermal Energy for Greenhouse with Geothermal System using Field Data

실측데이터를 적용한 지열 유리온실의 동적 열 에너지 해석 및 검증

2012 년 8 월

서울대학교 대학원

생태조경·지역시스템공학부 지역시스템공학전공

이 성 복

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이 논문을 공학석사 학위논문으로 제출함
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이성복의 공학석사 학위논문을 인준함
2012 년 8 월

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Abstract

At this situation that ever-soaring oil price and increasing the size and area of controlled horticulture, calculation of appropriate size of facilities for heating and cooling system is a task which should be preceded necessarily from an aspect of reasonable farm design, management and energy saving. This study is a basic study which applies BES technique to greenhouses in agricultural field, the contents of analyzing the heating and cooling characteristics of greenhouse were dealt. First, the design method of greenhouse model was sought using TRNSYS that is one of BES programs and the verification of that was conducted. And, based on verified greenhouses, it modeled widespan-type and venlo-type greenhouse which are typically used in the domestic and aimed to compare and analyze characteristics of energy loads by applying weather data for 1 year in 2010 in 6 regions. With this, it aimed to realize geothermal energy system which is being recognized as an alternative energy source in controlled horticulture industry using BES and performed its analysis. As a result of comparison with greenhouse design model using TRNSYS and field experiment data, the vertical model that divides the zone to vertical direction along multi-span of greenhouse showed good agreement both qualitatively and quantitatively. All of the verification was 5.2 and 5.5 %, respectively. As the results of performing the load calculation of widespan-type and venlo-type greenhouse that is the representative domestic greenhouse and 6 domestic regions using BES simulation, seasonal heating load was higher from Chuncheon, high latitude to Jeju a low latitude about 11 ~49 %. On the contrary, the seasonal cooling load showed lower as it goes from low latitudes to high latitudes. Among them, the case of

Daegu where has the topographical characteristic of basin-shape calculated the highest load, and the low loads of about 6, 12, 19 and 22 % each showed in sequential order of Jeonju, Cheongju, Suwon and Chuncheon based on Daegu. And, regarding the load difference between two greenhouses for each region, venlo-type greenhouse whose volume is relatively large was computed as higher by about 3 ~8 % in case heating and about 5~6 % in case cooling than widespan-type. Maximum heating and cooling load appeared similar to the tendency of seasonal load and maximum cooling load appeared at the different time in the simulation in case of maximum cooling load not like actual highest temperature. As the results of comparing between dynamic analysis method and static analysis method, both widespan-type and venlo-type were computed as low by about 30~36 % and 27~33 % in dynamic analysis method and they were computed as low by about 44~49 % and 43~47 % in dynamic analysis method as well, and it could be guessed that the facilities were overestimated through load estimation of greenhouse so far. Geothermal energy system of greenhouse was simulated using BES. The simulation result was validated through the comparison with the installation capacity of geothermal energy system of Top-green greenhouse. Based on the criteria to install the geothermal system (70 % of the maximum heating loads), it generates about 5 % of errors. Also, when the quantity of heat generated for 1 hour by the geothermal energy system through simulation with the installation capacity of the geothermal energy system in the target greenhouse, it generates about 6 % of errors.

In this study, it was recognized that it can be applied to greenhouse that is the agricultural facility by using BES simulation and the more accurate energy consumption of interior greenhouse could be grasped efficiently through the comparison with existing energy analysis method. And, as the example of applying and simulating geothermal energy system to greenhouse by using BES, it is expected that more accurate and predictable simulation method can be applied to greenhouse by simulating various new renewable energies and facility system as well as geothermal energy. It is considered that the reliability of BES method can be risen through the further studies that seek the energy load characteristic of actual greenhouse such as ventilation, warm curtain and crops and can used as the important technology for the calculation of energy load for building up the optimal environment of heating and cooling facilities of greenhouse.

keywords : Building Energy Simulation (BES), Dynamic analysis, Greenhouse, Geothermal energy, Static analysis
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Ⅰ. INTRODUCTION

After the Industrial Revolution, fossil fuel such as coal, petroleum and natural gas is recognized as a main source of energy in modern society. Although rapid growth and technological advancement of today's society owing to use of fossil fuel cannot be ignored. However at the hidden side, we face both environmental crisis such as global warming and climate change due to increase of greenhouse gases in the atmosphere. In addition, we are experiencing energy crisis of due to limited resources which is insufficient to meet the enormous demands for energy. Under such a situation, many countries in the world need various environment-friendly energy sources for stabilizing resources which will replace fossil fuel. In case of Korea, overseas dependence of the primary energy reaches up to 97 % where overseas dependence of fossil energy is also 81 %. In addition, consumption of fossil energy is showing average increase rate of 5.8 % annually from 41,824,000 TOE (tonne of oil equivalent) in 1981 to 204, 848,000 TOE in 2009 (KEEI, 2011; KEEI 2011). Situations like these makes the energy problem one of the significant issues facing the government in the national level. This cultivates more support on commercialization of alternative energy. More so, effective management of energy is being recognized as very important.

In the farming industry, controlled horticulture is an essential prerequisite in producing whole year round crops with equally high quality. The area of controlled horticulture in Korea has constantly increased to 52,000 ha at the end of 2010 that is nearly 2.1 times bigger than 25,000 ha of 1990. Furthermore, the heating area of controlled horticulture has increased to 16,000 ha in 2010 that is nearly 7.2 times bigger in 1990 which is only approximately 2,200 ha. Therefore, the proportion of the heating area of the whole facility area has gone up to about 31 % in 2010 from 9 % in 1990 (MIFAFF, 2010). Also, in the controlled horticulture industry where the portion of heating costs accounts for maximum 58 % of the whole management costs and about 92 % of heating energy sources is oil (non-taxable oil), the increase of international oil price is imposing hardships to farm houses in their operational management (RDA, 2009). At this stage where fossil energy for controlled horticulture is getting harder, energy systems to cut down heating costs for high managerial stability of farmers is required. Calculation of appropriate size of facilities for heating and cooling system is a task which should be preceded necessarily from an aspect of reasonable farm design, management and energy saving. Accordingly, exact calculation of energy consumption in the facility for calculating the size of facility is being recognized as becoming more important. However, the current calculation of loads in agricultural facilities mostly uses static analysis which assumes that the indoor and outdoor conditions are in steady-state. The calculation of the size of facility through this analysis is somewhat overestimated or sometimes underestimated.

In analyzing energy of such facilities, general architectural field attempts to analyze energy of a building by using various ways. These methods of energy building analysis can be characterized into tow such as static and dynamic analysis. Static analysis calculates the existing energy loads and to use maximum load calculation for selecting heating and cooling facility of a building by assuming that the indoor and outdoor conditions are in steady-state. Such approach has disadvantages such that it cannot reflect the changing aspects of various environmental factors and energy cost in a real building. The approach does not consider the concept of heat storage and time. This may result to lower reliability and accuracy. On the other hand, dynamic energy analysis assumes that the actual energy flow is under unsteady-state where all heat transfer phenomena including conduction, convection current and radiation have influences on each other according to meteorological changes such as direction of the wind, wind speed, insolation, location of the sun and temperature. More so, the analysis for instance of the heat storage structure on radiant heat considers the previous analysis since it influences on the calculation in the next stage. Recently, a technique to predict and analyze energy flow by simulating the analysis similar to an actual situation through various unsteady-state simulation programs is being developed, and many studies using the advantages of such simulations are actively conducted. Kim et al. (2006) verified the validity of a program through comparison of empirical experiment data of heating and cooling load in a test space and TRNSYS (ver. 16, Wisconsin, USA) simulation, one of Building Energy Simulation (BES) programs. The result showed good agreement with only about 1.8 % simulation error in the cooling system; and in case of heating system, the error is about 4.1 % when compared with the experiment data values. Lee et al. (2009) compared and verified characteristics of evaluating tools through a simulation targeting a real housing unit family. Energy demand based on direction, glass and walls between the evaluating tools of building energy efficiency rating and TRNSYS was -2~14.4 %, -11.55~2.3 % and -9.8~8.6 % respectively, showing a very similar result. Recently, studies applying BES technique which simulates the unsteady-state are conducted in the agricultural field. As for cases to study agricultural facilities which require more complex and sensitive environmental adjustment than general buildings, Hong et al. (2008) analyzed the efficiency of heating energy in a chicken farm using TRNSYS (ver. 16, Wisconsin, USA). Also, Jang et al. (2009) calculated the annual and peak loads of heating and cooling system in a glass greenhouse facility using TRNSYS (ver. 16, Wisconsin, USA) simulation. However, could the actual greenhouse was not realized as it modeled the arch-type greenhouse in a shape of a box. Verification was also not conducted, which could not confirm the possibility to apply to the greenhouse.

Therefore, this study applies the BES technique used to analyze general buildings to greenhouses in agricultural field, and figure out the designing method of greenhouse models using TRNSYS program. Attempts to verify the result was also conducted. Based on the verified greenhouses, models such as -type and venlo-type greenhouse, naturally-ventilated greenhouses which are typically used in the domestic were conducted; and aimed to compare and analyze characteristics of energy loads by applying virtual data for 1 year in 2010 in the 6 regions of the country. With this, the objective is to realize the geothermal energy system which is being recognized as an alternative energy source in controlled horticulture industry using BES and performed its analysis.

Ⅱ. LITERATURE REVIEW

2.1. METHOD FOR CALCULATING THE ENERGY CONSUMPTION IN A BUILDING

It is expected that the desire for comfort due to improvement of the standard of living will constantly increase the amount of energy required in a building. The portion of building energy toward the whole energy consumption in the country accounts for more than 28 %, and in Seoul, the building energy accounts for 58 % (Min, 2010). Therefore, calculation of suitable energy consumption in a building for making pleasure indoor heating environment as well as reducing building operation costs spent to operate cooling or heating system is recognized as very important.

Ways to analyze energy of a building can be divided into static analysis method and dynamic analysis method. Static analysis method is a way to calculate existing energy loads and to use maximum load calculation for selecting heating and cooling facility of a building by assuming that the indoor and outdoor conditions are in steady-state. It includes a Degree-day method (Shin et al, 1986), an Extended degree-day method (Lee and Lee, 1986; Yee et al., 1986), a variable degree-day method (Kusuda, 1981; Fels, 1986; Claridge et al., 1987; Claridge et al., 1987) and a modified bin method (Pope, 1987; Yee et al. 1987; Sohn et al., 1988; Vadon et al., 1991). Dynamic analysis method is a way which assumes that the actual energy flow is an unsteady-state where all heat transfer phenomena including conduction, convection and radiation have complex influences on each other according to the meteorological changes, and it includes an analytical method (response factor, weighting factor, transfer function method) to calculate the value through Laplace transform and a numerical method (finite difference method, finite element method, finite volume method) to calculate the value.

Static analysis method has an advantage that it has a simple procedure, easy to calculate compared with dynamic analysis method. However, it is difficult to reflect thermal capacity (heat storage) of the structure, changes in outdoor climate conditions, inside heating or variables relevant to time such as setting of ventilation schedule. It has a disadvantage that it cannot reflect the changes of various kinds of environment and energy caused in an actual building, showing a limitation of low reliability and accuracy of the result (Song et al., 2009).

Therefore, it is a trend to increase usefulness of dynamic analysis method recently in order to analyze energy of an actual building, and all over the world, considerable number of users of 200 or more and use BES programs to analyze and verify the building energy use (DOE, 2001). In this case, various kinds of simulation program techniques have their own advantages and disadvantages and unique characteristics according to user's purpose and use. Hong et al (2000) analyzed and introduced the advantages and disadvantages and information of various BES currently used and developed. In the domestic scale, many institutions and societies have developed load analysis programs suitable for characteristics of domestic building or modified and supplemented foreign programs appropriate for domestic conditions (Yoon and Lee, 1999; Kim and Suh, 2001; Kwon et al., 2005; Kang et al., 2008; Park et al., 2009; Woo and Kim, 2009). But, the result of BES can show different result from an actual building due to many assumptions, simplification, unknown variables and variable which were not modeled, and also, it has a disadvantage that it may cause a result different from the intention of developing agent. Accordingly, under a situation where development and use of relevant simulation programs is generalized, it is necessary to verify and confirm programs. Therefore, Lee et al. (1999) has compared and verified domestic and foreign simulation programs calculated under the same conditions, and Hyun et al. (2002) absolutely compared data through calculation of dynamic heating loads using a commercial program by measuring temperature and heating loads from a real building, and attaining climate data during the same period from the Korea meteorological administration (KMA), and its accuracy has been verified through various studies and verifications.

2.2. Method for Calculating the Energy Consumption in a Greenhouse

Solar radiant energy which is penetrated into the greenhouse during daytime is absorbed to the soils, the floor of the greenhouse, or concrete, and long-wave energy which is partly reflected is blocked by glass, the exterior skin, or plastic as shown in Fig. 1. This phenomenon is called as greenhouse effect. This is a reason for increasing temperature inside the greenhouse during daytime, and at night, heat stored on the surface of floor is emitted from the surface of soils to the greenhouse. Like this, greenhouses are a facility to use solar radiant energy by penetrating most of sun light unlike general buildings, and it generates different energy consumption with that of general buildings. Accordingly, thermal environment of greenhouses for adjusting the growing conditions of plants inside the greenhouse appropriately is very important. In foreign countries which already introduced greenhouses such as Holland, USA, Japan and Israel, theoretical establishment and analysis has been conducted which divides composition of thermal environment in the greenhouse into covering materials of the greenhouse, inside air, plants and soil and models characteristics of mutual thermal transfer based on energy and substance equilibrium theory (Businger, 1963; Walker, 1965; Takakura et al., 1971; Kimball, 1973; Froehlich, 1976; Kindelan, 1980; Chandra et al., 1981; Duncan et al, 1981; Glaub and Trezek, 1981). In the domestic level, Suh and Yoon (1996) analyzed thermal environment in the greenhouse using a dynamic model relevant to heating system such as thermal screen effect at night and calculation of heating degree-hour as well as calculation of heating requirements. But, most analysis factors of thermal environment such as shading effect, cooling system as well as ventilation performance were applied to the static model that is a simple numeric computation model.

Analysis methods for calculating energy consumption in the greenhouse are divided into a static method which assumes that indoor and outdoor environmental conditions are in steady-state, and a dynamic method which assumes that they are in unsteady-state. The static analysis method calculates it by assuming that materials have no ability to heat storage, and is mainly used to calculate energy consumption in the domestic greenhouse. This is to calculate the maximum heating loads for calculating facility capacity of the greenhouse, and it includes a rough method to use heating load coefficients and an analytic method to calculate the amount of heat loss which passes the covering material, heat loss through infiltration of the surface of greenhouses and heat loss in the ground through heat exchange between the air in the room and the floor of the greenhouse (RRI, 1997). By using the static method, Song and Yoo, (1994) calculated and compared the maximum heating loads and seasonal heating loads in 11 selected areas. Also, Woo et al. (1998) and Woo et al. (1999) created a model formula applicable to the country by reviewing existing heating load model formula and by modifying and supplementing problems, and also, Woo et al. (2001) made a model formula considering total heat in the ground which is applicable to domestic climate environment. However, as temperature in the greenhouse is constantly changing according to inside supply of insolation penetrated into the greenhouse, the outside temperature and wind speed, it can be said that it is appropriate to use a dynamic analysis method which considers temperature change based on time due to material's ability to store heat by assuming that the characteristics of thermal transfer relevant to them are in unsteady-state. Nevertheless, there are few studies or approaches about the dynamic analysis method in agricultural facilities even in advanced foreign countries as well as in the domestic level. So, this is a basic study which applied BES technique, a dynamic analysis method to agriculture, and conducted multilateral analysis to application and usefulness in the greenhouse.

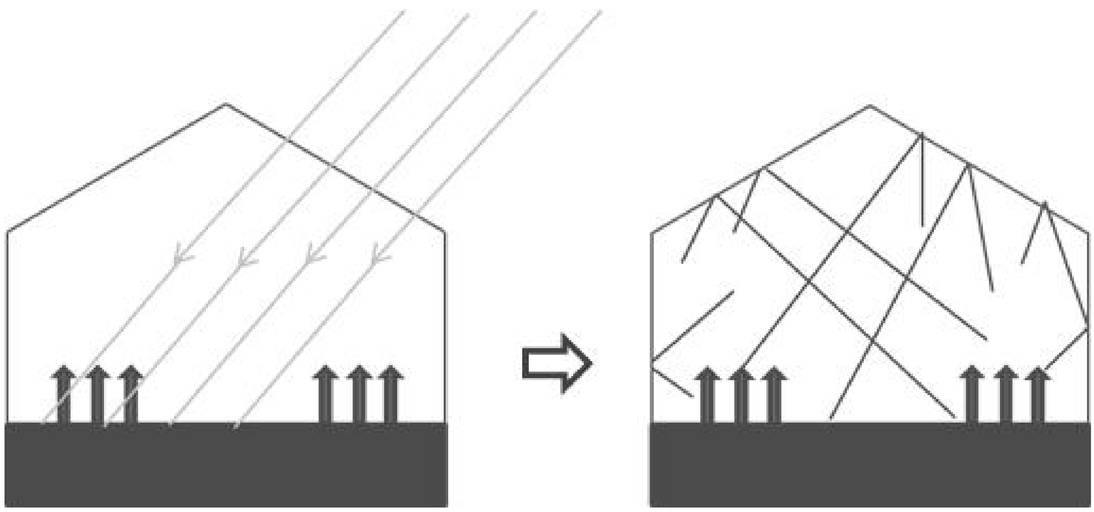


Fig 1 The principle of greenhouse effect

Ⅲ. MATERIALS AND METHODS

This study was conducted with 3 major subjects. The first one designed a greenhouse model for clarifying whether BES is applicable to calculation of greenhouse loads and performed the verification. The second subject calculated characteristics of loads by regions according to the typical domestic greenhouse and compared and analyzed with a simple load calculation program. The third part conducted modeling about geothermal energy system of greenhouse using BES technique.

3.1. BUILDING ENERGY SIMULATION

BES is a numerical technique to calculate and predict energy consumption for adjusting thermal and energy flow and appropriate environment of a building. It is widely used in a general architectural field with high accuracy and usefulness. There are a variety of BES program like DOE-2, EnergyPlus, ESP-r, TRNSYS and so on. TRNSYS (ver. 16, Wisconsin, USA), one of BES program, is a system simulation program commonly used in the world which was developed for dynamic simulation and designed of solar heat system.

A design engineer can consider wanted open air conditions, conditions of sun's radiation, characteristics of walls, conditions of indoor temperature and humidity and amount of ventilation with TRNSYS, it can supplement limitations of field experiment and it also help secure quantitative data for comparison and analysis in a short period of time. TRNSYS is a program analysis in unsteady-state system having a module structure, and is composed of a main program and many sub-routines called as components. Type 56 which is a module especially composing a greenhouse performs dynamic thermal energy analysis through various kinds of complex heat attainment generated in a place. The radiation and convection is very relevant in this type where the heat storage and radiant heat of structures was based on transfer function method. Figs. 2 and 3 show the concept of calculation of indoor and outdoor thermal energy in the greenhouse (TRNSYS 16 Manual, 2007).

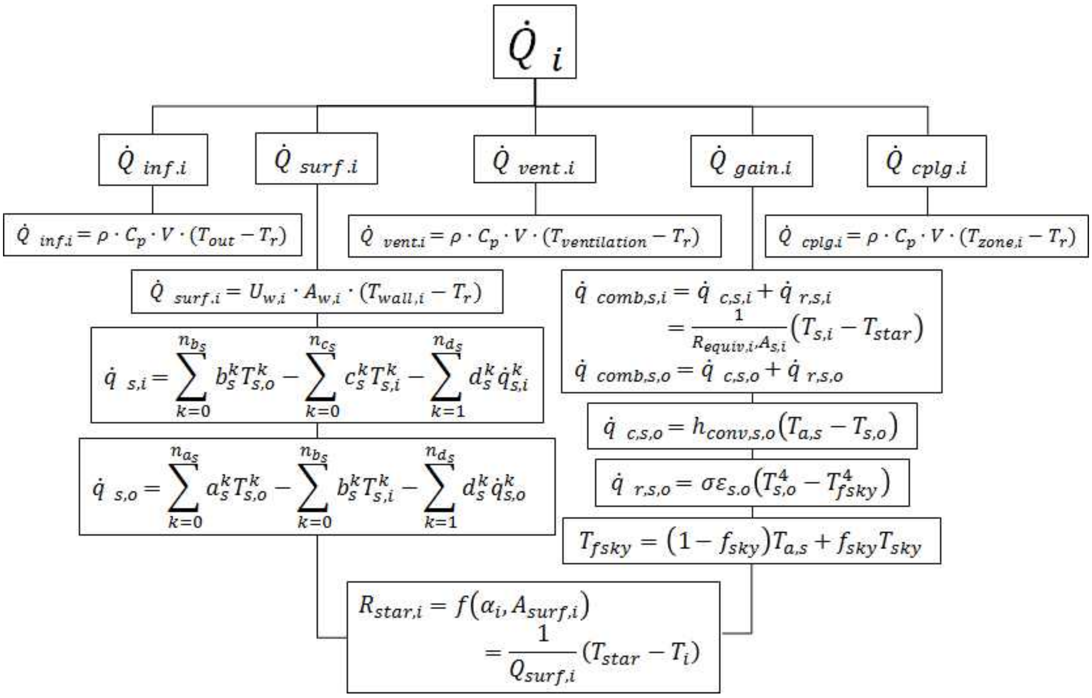


Fig. 2 Flowchart of energy balance in greenhouse considering infiltration, surface of wall, ventilation, internal gain and coupling between zones, etc.

where,

$\dot{Q}_i$	: total gain of zone i ($kJ \cdot h^{-1}$)
$\dot{Q}_{inf,i}$	: the infiltration gains ($kJ \cdot h^{-1}$)
$\dot{Q}_{surf,i}$	: the convective of internal surface gains ($kJ \cdot h^{-1}$)

$\dot{Q}_{vent}$: the ventilation gains (kJ·h^{-1})
$\dot{Q}_{gain,i}$: the internal convective gains (kJ·h^{-1})
$\dot{Q}_{cplg,i}$: the gains due to connective air flow from zone i or boundary condition (kJ·h^{-1})
ρ : density of air (kg·m^{-3})
C_p : specific heat of air (kJ·kg^{-1}·℃$^{-1}$)
V : volume of zone (m^3)
T_{out} : outside temperature (℃)
T_r : inside temperature (℃)
$U_{w,i}$: heat transfer coefficient of wall (kcal·m^2·h^{-1}·℃$^{-1}$)
$A_{w,i}$: wall area (m^2)
$T_{wall,i}$: wall temperature (℃)
$T_{ventilation}$: set temperature of ventilation (℃)
$T_{zone,i}$: inside temperature of zone i (℃)
$\dot{q}_{s,i}$: conduction heat flux from the wall at the inside surface
$\dot{q}_{s,o}$: into the wall at the outside surface
$\dot{q}_{comb,s,i}$: the combined convective and radiative heat flux
$\dot{q}_{comb,s,o}$: combined convective and radiative heat flux to the surface
$\dot{q}_{c,s,i}$: convection heat flux from the inside surface to the zone air
$\dot{q}_{r,s,i}$: net radiative heat transfer with all other surfaces within the zone
$\dot{q}_{c,s,o}$: convection heat flux to the outside surface from the boundary/ambient
$\dot{q}_{r,s,o}$: net radiative heat transfer with all surfaces in view of the outside surface
$R_{equiv,i}$: resistances
$A_{s,i}$: the inside surface area (m^2)
$T_{s,i}$: Inside surface temperature (℃)

$h_{conv,s,o}$: convective heat transfer coefficient at the outside surface ($kcal \cdot m^2 \cdot h^{-1} \cdot ℃^{-1}$)

$T_{a,s}$: outside temperature (℃)

$T_{s,o}$: outside surface temperature (℃)

σ : stephan-boltzmann constant

$\varepsilon_{s,o}$: long-wave emissivity of outside surface

T_{sky} : fictive sky temperature used for long-wave radiation exchange (℃)

f_{sky} : view factor to the sky

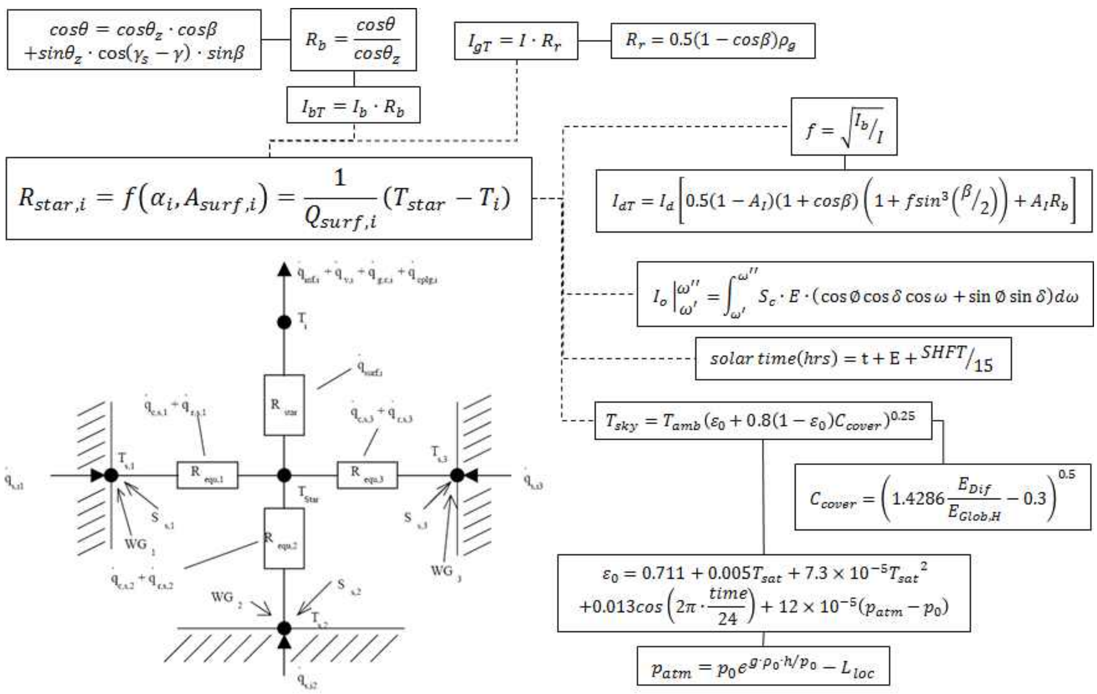


Fig. 3 Flowchart of the detail mechanism of energy balance including radiation, convection, sky temperature, etc.

where,

θ : angle of incidence of beam radiation on surface (°)

θ_z : solar zenith angle (°)

β : slope of surface (°)

γ_s : solar azimuth angle (°)

γ : azimuth angle of surface (°)

R_b : ratio of beam radiation on tilted surface to beam on horizontal

I_{bT} : beam radiation on tilted surface ($kJ \cdot h^{-1} \cdot m^{-2}$)

I_b : beam radiation on horizontal surface ($kJ \cdot h^{-1} \cdot m^{-2}$)

I_{gT} : ground reflected radiation on a tilted surface ($kJ \cdot h^{-1} \cdot m^{-2}$)

I : total radiation on a horizontal surface ($kJ \cdot h^{-1} \cdot m^{-2}$)

R_r : ratio of reflected radiation on tilted surface to total radiation on horizontal

ρ_g : ground reflectance ($kg \cdot m^{-3}$)

f : modulating factor for Reindl titlted surface model

I_{dT} : diffuse radiation on tilted surface ($kJ \cdot h^{-1} \cdot m^{-2}$)

I_d : extraterrestrial radiation ($kJ \cdot h^{-1} \cdot m^{-2}$)

A_l : anisotropy index

I_o : extraterrestrial radiation ($kJ \cdot h^{-1} \cdot m^{-2}$)

ω', ω'' : hour angle at start and end of data (°)

S_c : solar constant

E : factor accounting for the eccentricity of the earth's orbit

ϕ : latitude (°)

δ : solar declination angle (°)

ω : mean hour angle of time step (°)

t : the time in hours corresponding to ω

$SHFT$: shift in solar time relative to the nominal time of data reading

T_{amb} : ambient temperature (℃)

ε_0 : emittance of the clear sky

C_{cover} : cloudiness factor of the sky,

E_{Dif} : diffuse radiation on the horizontal ($kJ \cdot h^{-1} \cdot m^{-2}$)

$E_{Glob,H}$: total radiation on the horizontal ($kJ \cdot h^{-1} \cdot m^{-2}$)

T_{sat} : dew point temperature at ambient conditions (℃)
P_{atm} : atmospheric pressure (atm)
P_0 : atmospheric pressure at the height h_0 (atm)
g : gravitational acceleration (m·s^{-2})
h : elevation above sea level (m)
ρ_0 : air density at the height h_0 (kg·m^{-3})
L_{loc} : longitude of a given location (°)

3.1.1. Simulation Analysis Method

TRNSYS, is a software to analyze building energy, using dynamic load calculation, but it is divided into energy rate control (ERC) and temperature level control (TLC) according. This depends whether it contain facility and controlling system in the analysis.

ERC assumes that the interior remains unheated and uncooled in a certain time-step and takes load quantity of heat required to increase (heating) or decrease (cooling) calculated temperature to set temperature when the indoor temperature calculated due to external heat loss getting out of the set temperature range, and is expressed in equation (1)~(3) as follows.

$$C_i \frac{dT_i}{dt} = \dot{Q}_{surf} + \dot{Q}_{vent} + \dot{Q}_{gain} + \dot{Q}_{inf} + \dot{Q}_{cplg} \tag{1}$$

$$Q_{heating} = MC_p(T_{set} - T_i) \tag{2}$$

$$Q_{cooling} = MC_p(T_{set} - T_i) \tag{3}$$

where,

C_i : thermal capacitance of zone i = $V_r \cdot \rho \cdot C_p$ (kJ·℃$^{-1}$)
V_i : zone volume (m^3)
ρ : density of air (kg·m^{-3})
$\dot{Q}_{surf}$: the heat gain/loss at walls (kJ·h^{-1})
$\dot{Q}_{vent}$: the heat gain/loss from ventilation (kJ·h^{-1})
$\dot{Q}_{gain}$: the heat gain/loss due to internal gains (kJ·h^{-1})
$\dot{Q}_{inf}$: the heat gain/loss from infiltration (kJ·h^{-1})
$\dot{Q}_{cplg}$: the heat gain/loss to adjoining room (kJ·h^{-1})
M : mass (kg)
C_p : the specific heat of air (kJ·kg^{-1}·℃$^{-1}$)
T_{set} : the set temperature for heating and cooling (℃)
T_i : the inside temperature (℃)

T_i, temperature of inside of a greenhouse at a certain point of time is calculated from heat loss through walls and windows and the quantity of heat flowing in and out of a zone due to ventilation, infiltration and etc., and quantity of heat, heating and cooling loads required to increase it to T_{set} is calculated (Hong, 2001).

TLC considers that a certain time-step operates heat source devices (boiler, heat-pump, solar heat, auxiliary heater, auxiliary cooler, etc.) and calculated the indoor temperature by making a heat equilibrium equation about the amount of heat loss and the amount of heat supply. In case of including temperature calculated within the range of set temperature in the controlling system, quantity of the heat source device provided under this situation becomes heat load, but in case of not including it, it repeatedly performs calculation until it reaches a satisfactory situation from on to off, from off to one by changing the condition of heat source device. It takes the quantity of heat required to increase or decrease temperature to set temperature as load, and it is expressed in equation (4) as follows.

$$C_i \frac{dT_i}{dt} = \dot{Q}_{surf} + \dot{Q}_{vent} + \dot{Q}_{gain} + \dot{Q}_{inf} + \dot{Q}_{cplg} - P_i \tag{4}$$

where,

P_i : heat gain/loss from machine for heating and cooling ($kJ \cdot kg^{-1} \cdot ℃^{-1}$)

T_i, temperature in the inside of the greenhouse is calculated from the equation (4) which includes P_i quantity of heat to be provided or removed from heating and cooling system unlike the equation (1), and if such a condition is met, P_i becomes heat load provided from the facility (Hong, 2001).

3.2. Target Facility and Region

3.2.1. Greenhouse 1: Greenhouse for Verification

BES is useful to figure out load characteristics inside the building by simulating characteristics of dynamic heat loads of general buildings. But, in this study, which focused on the application of BES technique to agricultural facility such as greenhouse and not a general building, it is necessary to conduct verification about the target facility in advance. Therefore, the study selected a glass greenhouse located in Hwangsan-ri, Gongdeok-myeon, Gimje-si (latitude: 35.51°, longitude: 126.55°) as a study subject for verification. Greenhouse in Gimje is an energy self-standing village constructed by the government's investment fund for the purpose of realizing the type of resource circulated in a green village. Among them, since there are no facilities and plants inside the greenhouse being recently constructed, it is can be assumed that the temperature changes inside can be easily to observe. Therefore, this was selected purposely for this study. This greenhouse is venlo-type composed of 6 spans with 19.2m in width, 52m in length, 5.76m in eastern height and 4.8m in side height and floor space is 998.4m^2.

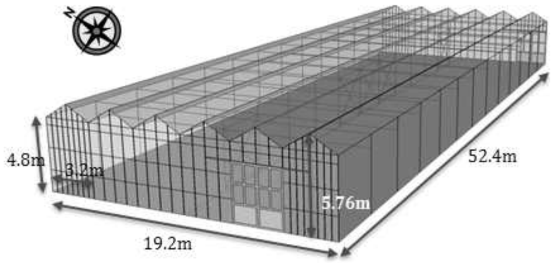
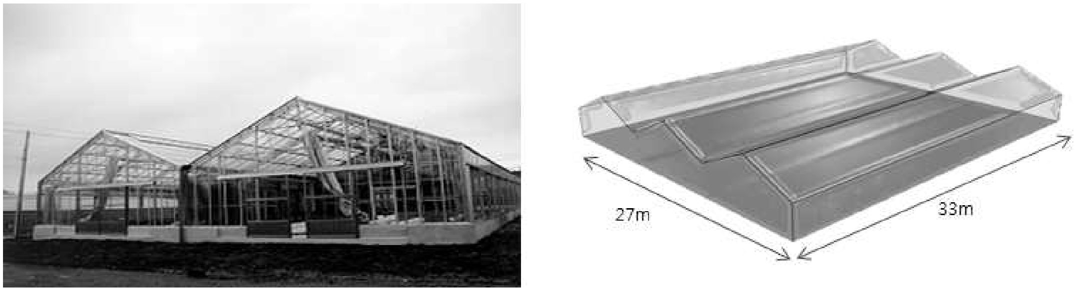


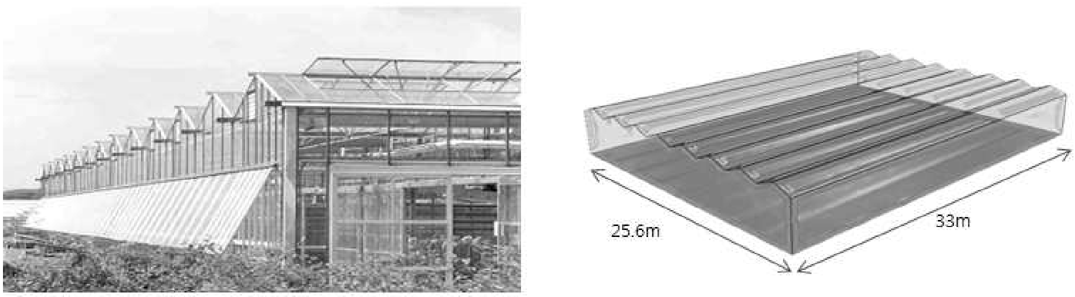
Fig. 4 Schematic diagrams of the experimental greenhouses in Gimje used for this study

3.2.2. Greenhouse 2: Typical Domestic Greenhouse

Until now, major methods to calculate loads in a greenhouse are conducted through static load calculation using a figures or a simple program. But, BES program is a dynamic simulation and conducts load calculation considering thermal phenomenon such as conduction, convection and radiation generated in a greenhouse. Accordingly, it is necessary to compare and analyze the result of load calculation through existing static load calculation and dynamic simulation. This study aimed to predict various load patterns using climate data of 2 types of typical glass greenhouse mainly used in the country in 6 areas and to compare the result with static load calculation. As shown in Fig. 5, the study targeted widespan-type and venlo-type greenhouses, the typical multi-span greenhouses in the domestic. The size of each greenhouse was the same as that of Hong (2006) and it is shown in Table 1. As the country have high temperature difference by each area and topography and four distinct seasons despite of small land area, the study selected 6 cities which represented different climate including Chuncheon (the central and southern inland mountain type), Suwon (the central west coast type), Cheongju (the central flatland type with excess rain fall), Daegu (basin type), Jeonju (the southern flatland type with excess rain fall) and Jeju (mild climate type) as a target area. Latitude and longitude of each area is shown in Table 2.



(a) Widespan type



(b) Venlo type

Fig. 5 Schematic diagrams of the typical glass greenhouses in Korea used for this study

Table 1 Structural specifications of experimental greenhouses

Types	Widespan	Venlo
Model	3-3 S-type	NJ97-NA-1
Number of span	3	8
Ridge height (m)	5.25	4.95
Eaves height (m)	3.0	4.3
Width (m)	27.0	25.6
Length (m)	33.0	33.0
Floor area (m^2)	891.0	844.8
Volume (m^3)	3675.38	3907.2

Table 2 Latitude and longitude of 6 different areas used for this study

	Latitude(°)	Longitude(°)
Chuncheon	37.54	127.44
Suwon	37.16	126.59
Cheongju	36.38	127.26
Daegu	35.53	128.37
Jeonju	35.49	127.09
Jeju	33.17	126.09

3.2.3. Greenhouse 3: Greenhouse using Geothermal Energy

Greenhouses require loads and operating methods totally different from those of a general building. In case of general buildings, required energy is provided through heating and cooling operation only during business hours or living hours while it is necessary to maintain inside temperature and humidity for 24 hours a day for adjusting growing environment of plants in a greenhouse. As a design standard or constructing technology of geothermal heating and cooling system currently used for application to general buildings, not suitable for greenhouses, many farming families make an enormous loss with the failure of agricultural business due to less knowledge of installation techniques, operation and maintenance of geothermal system. Accordingly, it is necessary to distribute an appropriate system suitable for characteristics of greenhouses. This study aims to examine the proper design for system and analyze the characteristics of energy consumption in greenhouse using geothermal energy system as a new alternative source of energy in the controlled horticulture industry. The greenhouse was a Top-green located in Saengam-ri, Daegang-myeon, Namwon-si (latitude: 35.19°, longitude: 127.11°). This greenhouse is 17-span venlo-type greenhouse with approximately 10,015m^2: 108.8m width, 94m length, 5.5m height, 4.5m eaves height, and has heating and cooling with geothermal energy system.

Fig. 6 17-span venlo-type greenhouse using geothermal energy system in Namwon used for this study

3.3. Research Methods

Fig. 7 shows the flow of this study. First, the greenhouse model was designed and the verification of the model was performed through the comparison between the simulation and field experiment. After that, the load was forecasted targeting 2 types of greenhouse and 6 regions based on the verified greenhouse model and the comparative analysis was performed. Lastly, the modeling of geothermal energy system was performed using BES simulation and applied to the greenhouse.

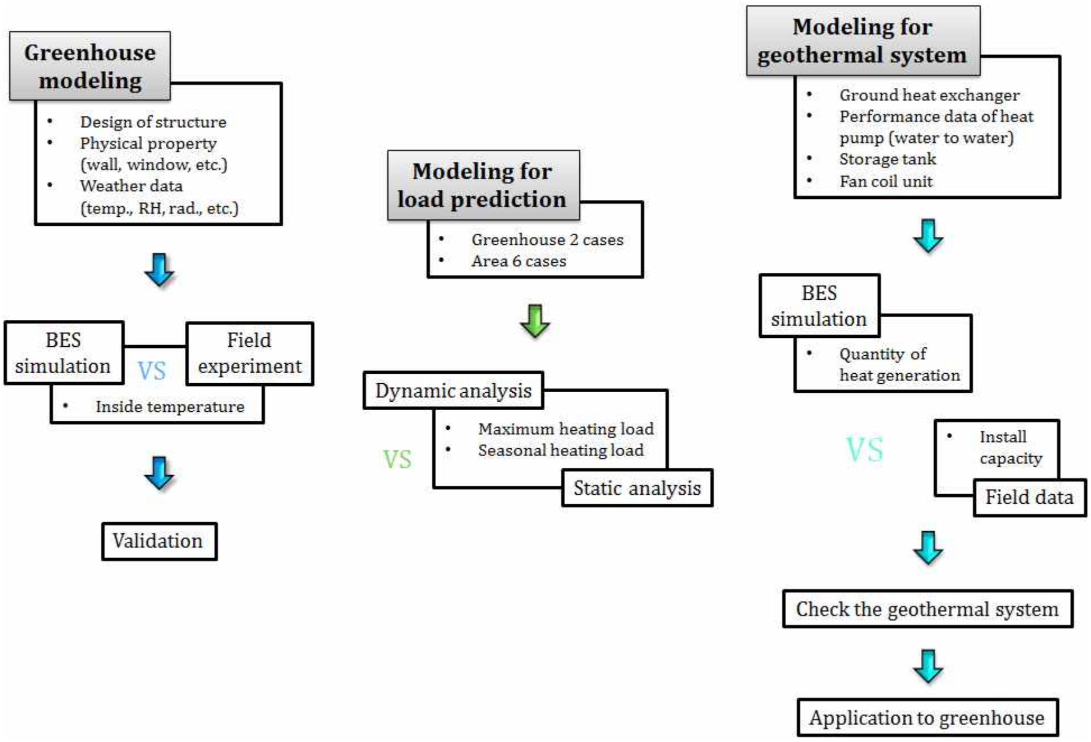


Fig. 7 Flowchart of this study

3.3.1. Modeling and Verifying the Greenhouse using BES

3.3.1.1. Field Experiment

Field experiment for verifying BES program was conducted in a glass greenhouse located in Hwangsan-ri, Gongdeok-myeon, Gimje-si twice. The first test was conducted for 3 days and 2 nights from 6 p.m., on 27th of February, to 6 p.m., February 29th, 2012, and the second one was conducted for 3 days and 2 nights from 2 p.m., May 3rd, 2012 to 2 p.m., May 5th, 2012. For measuring climate, temperature, humidity, sun's radiation, direction of wind and wind speed was measured at 1 minute intervals using a simple weather station

(Watchdog 2900ET, Spectrum Technologies Inc., USA). The simple weather station was installed in a relatively plain place in the test area in order not to be influenced by obstacles around it. As for a device to measure temperature in the greenhouse, temperature and humidity recording sensor (Hobo data logger, Onset computer corp., USA) was used and it measured temperature at 1 minute intervals. In the first test, it aimed to check difference in temperature in the greenhouse by installing the temperature and humidity recording sensor in 13 points in a cross shape at 1.5 m from the floor. In the second test, sensors were installed in total 16 points at 0.2 m, 2 m and 4 m from the floor, checking difference in temperature according to the height. In order to avoid interference in temperature due to direct impact of sun's radiation to the sensor, sunlight was blocked using a plastic dish.

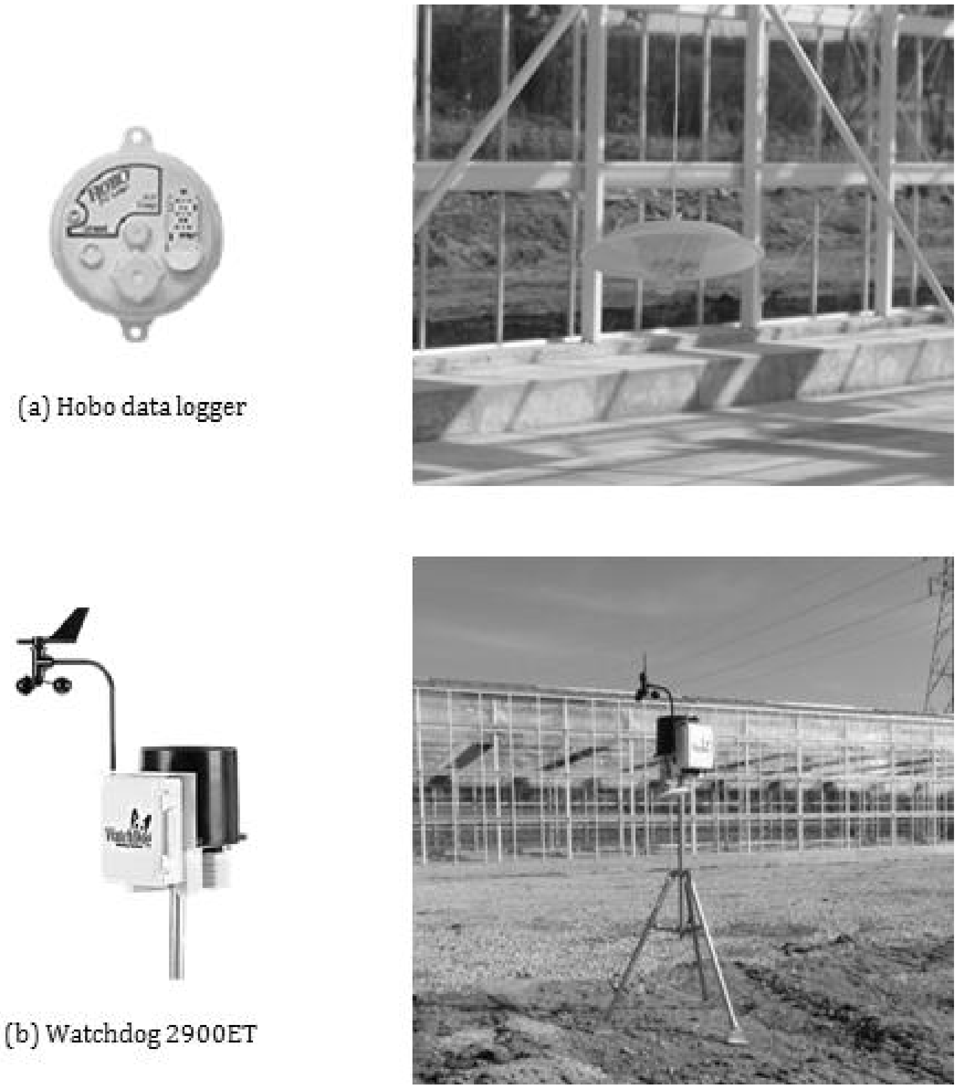
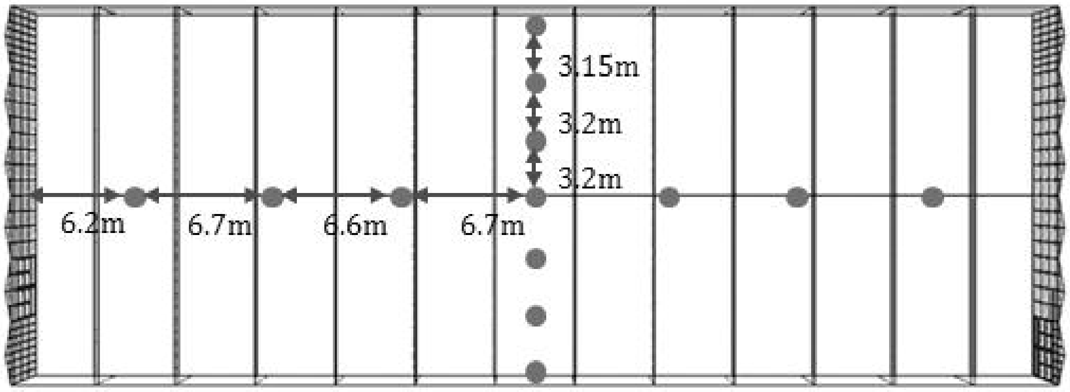
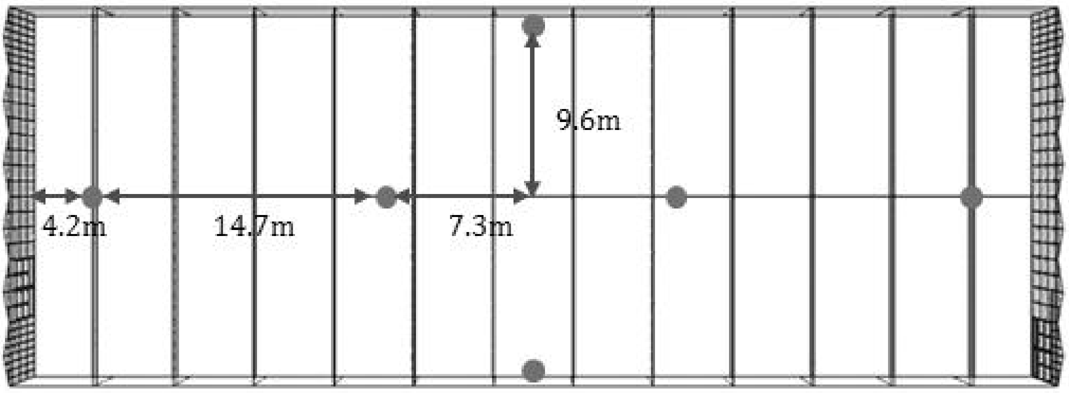


Fig. 8 Installation of sensor for verification experiment; (a) Hobo data logger (Onset computer corp., USA) for measuring the temperature (b) Watchdog 2900ET (Spectrum Technologies Inc., USA) for measuring the outside weather data



(a) Measuring point at 1st field experiment



(b) Measuring point at 2nd field experiment

Fig. 9 The sensor locations of field experiment; (a) measuring point at 1st field experiment by height 1.5m (b) measuring point at 2nd field experiment by height 0.2.m, 2m and 4m

3.3.1.2. Greenhouse Modeling

Modeling of greenhouses for figuring out the possibility of BES program to be applied to greenhouses should be arranged exactly in various ways. Unlike existing constructions, greenhouses are composed of glass, so the amount of solar radiant energy flowing into the greenhouse differs based on the property of glass and the ratio of framework, having influences on heating and cooling loads. So, it is necessary to design materials composing the frame and exterior of the greenhouse exactly and to implement simulation exactly. Also, it is expected that TRNSYS having a system of transfer function will generate different results based on division of zone in the analysis process. Therefore, it is very important to find out the optimal model which copies the real one through diversified analysis after designing the greenhouse model in various ways. Hence, this study compared and analyzed changes in internal temperature of the greenhouse based on various kinds of space division by designing glass greenhouses in Gimje in the following 3 ways mentioned below.

1) simple model
2) horizontal model
3) vertical model

The target facility is 6-span greenhouse, and was realized as one zone as shown in Fig. 10 (a). And it was realized as 4 multi-zone by dividing space based on height as shown in Fig. 10 (b), and modeled by realizing 4 multi-zone as shown in Fig. 10 (c).

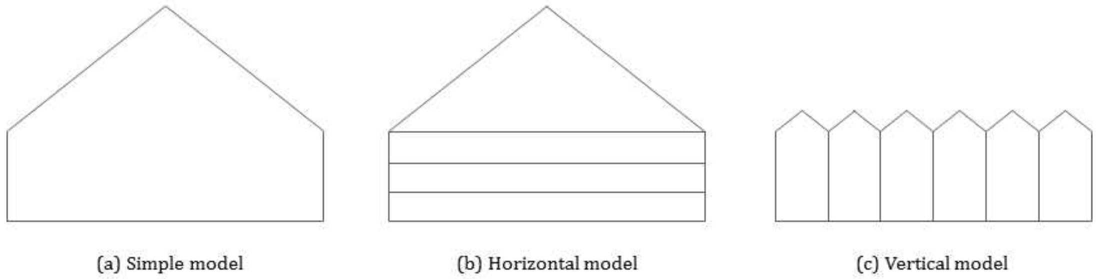


Fig. 10 Design of greenhouse model by division; (a) simple model as one zone (b) horizontal model as 4 multi-zone (c) vertical model as 6 multi-zone

3.3.2. Calculation and Prediction of Load by each Region and each Type of Greenhouse in the Domestic

3.3.2.1. Comparison of BES and Static Analysis Simulation

Calculation of heating and cooling loads in a greenhouse is a very important process for calculating the facility capacity. Accordingly, exact calculation of loads can prevent excessive or insufficient installation of the facility capacity, which can reduce unnecessary investment costs. Therefore, this study predicted load characteristics in domestic typical greenhouses using the advantages of BES simulation. By assuming heating and cooling system using ERC method, it performed load calculation by setting 19 ℃ of heating and 25 ℃ of cooling, the appropriate temperature for growing plants. This study is a basic study applying BES technique to greenhouses in agricultural field, and it did not consider realization of crops in the facility due to its complexity. Also, in order to compare it with static analysis which has been mainly used to calculate loads in a greenhouse, it calculated loads in each greenhouse using a simple program of static load calculation, and aimed to compare and analyze the difference in loads between the two analysis methods.

3.3.2.1.1. GES Program for Static Load Analysis

GES is a program to calculate the maximum heating loads and seasonal heating loads under a steady-state which does not consider the concept of heat storage and time, and it was prepared based on 'the casebook of diagnosing heat loss in agricultural facilities' published by RDA (2009).

GES is a general calculating method used to calculate loads in a greenhouse, and it calculates the maximum heating load considering the heat loss of infiltration, soil, greenhouse area and wind speed compensation factor through the greenhouse structure and covers as shown in the equation (5).

$$Q_g = \{A_g(q_t + q_v) + A_s \cdot q_s\} \cdot f_w \tag{5}$$

where,

Q_g	: Maximum heating load ($kcal \cdot h^{-1}$)
q_t	: The heat loss from covering of greenhouses ($kcal \cdot m^{-2} \cdot h^{-1}$)
q_v	: The heat loss from infiltration ($kcal \cdot m^{-2} \cdot h^{-1}$)
q_s	: The heat loss from ground ($kcal \cdot m^{-2} \cdot h^{-1}$)
A_g	: Surfacce area of greenhouse (m^2)
A_s	: Floor area of greenhouse (m^2)
f_w	: Wind correction factor

The heat loss is the amount of heat which is delivered to the internal surface of the covering materials through radiation and convection heat transfer inside the greenhouse, passes the covering materials through conduction and emitted to the outdoor through radiation and convection current heat transfer. It is calculated as follows.

$$q_t = h_t (T_s - T_d)(1 - f_r) \tag{6}$$

where,

h_t	: overall heat transfer coefficient (kcal·m^{-2}·h^{-1}·℃$^{-1}$)
T_s	: set temperature for heating (℃)
T_d	: outside temperature for design of drawing (℃)
f_r	: proportion of heat saving of covering for heat insulation

The heat loss due to ventilation through infiltration is calculated using ventilation heating coefficient (h_v) as follows.

$$q_v = h_v (T_s - T_d) \tag{7}$$

where,

h_v	: heat transfer coefficient of ventilation (kcal·m^{-2}·h^{-1}·℃$^{-1}$)

3.3.3 Modeling of Geothermal Energy System in Greenhouse

Geothermal energy system includes a system which uses soil, underground water and surface water as heat source and heat sink. When heating or cooling through the geothermal energy system, year-round temperature underground rarely changes and is stable which plays a role as heat sink and heat source, and there is no device exposed to the air, easy to use space. So, this system is receiving attention in the facility horticulture field.

The geothermal energy system is a system for both heating and cooling which is composed of a ground heat exchanger and a heat pump. In case of cooling, the geothermal system emits heat absorbed indoors to underground through the underground heat exchanger, and when heating, the underground heat exchanger absorbs heat underground and provides it to indoors.

This study simulated use of heating energy in a greenhouse applying the geothermal energy system and whether it was designed appropriately using BES modeling, and compared it with energy consumption in the target greenhouse.

3.3.3.1. Data Collection from Geothermal Greenhouse

This study selected Top-green located in Namwon which operates a geothermal system by reflecting the characteristics and the environment of the greenhouse as a target facility. The corporations provided data on heating energy consumption and operation costs before and after installing a geothermal system. Relevant data for modeling of geothermal system such as blueprints and performance data of heat pumps were also provide which was used as input data for modeling BES.

3.3.3.2. Geothermal System Modeling

TRNSYS, one of BES programs can conduct simulation including equipment and controlling system in the facility. Simulation using equipment such as cooling machine, heating machine and dehumidifier is a very important part for figuring out exact energy characteristics. This study realized a greenhouse applying a geothermal system by using BES, to confirm whether the equipment was calculated with appropriate capacity and operation, and to confirm that the inside of a greenhouse was maintained at an appropriate temperature by the geothermal system using TLC method.

Ⅳ. Results and Discussion

4.1. Modeling and Verifying the Greenhouse using BES

4.1.1. Field Experiment

The result of field experiment which measured temperature of the inside and outside of a greenhouse for verifying BES's greenhouse model is shown in Figs. 11 and 12. For the 1st field experiment, on February 28th, it was a bit cloudy with the cloud cover index of 10, and on 29th, it was sunny with the index of 0. As shown in Fig. 11, it can be figured out how much of the sun's radiation influences the inside of a greenhouse according to cloud cover. During the 2nd field experiment, where it was sunny with the index of 0, have not significant influence during the day. This study took average value about temperature data measured in 13 points in the 1st test and 16 points in the 2nd test, and compared it with the result of a greenhouse using TRNSYS.

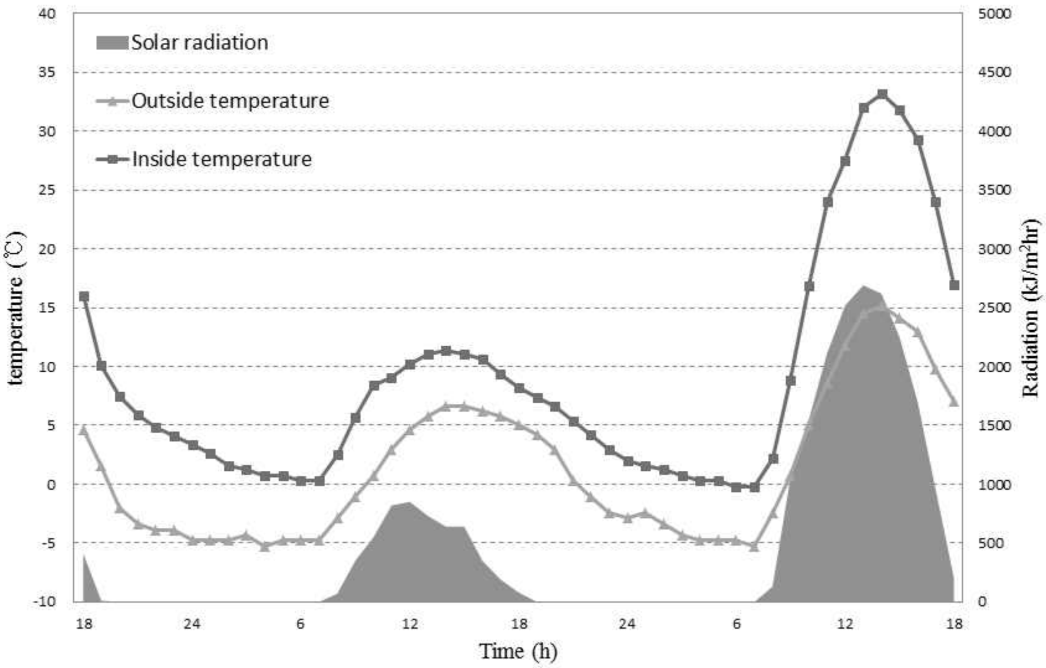


Fig. 11 The first field experiment on February 27th ~ 29th

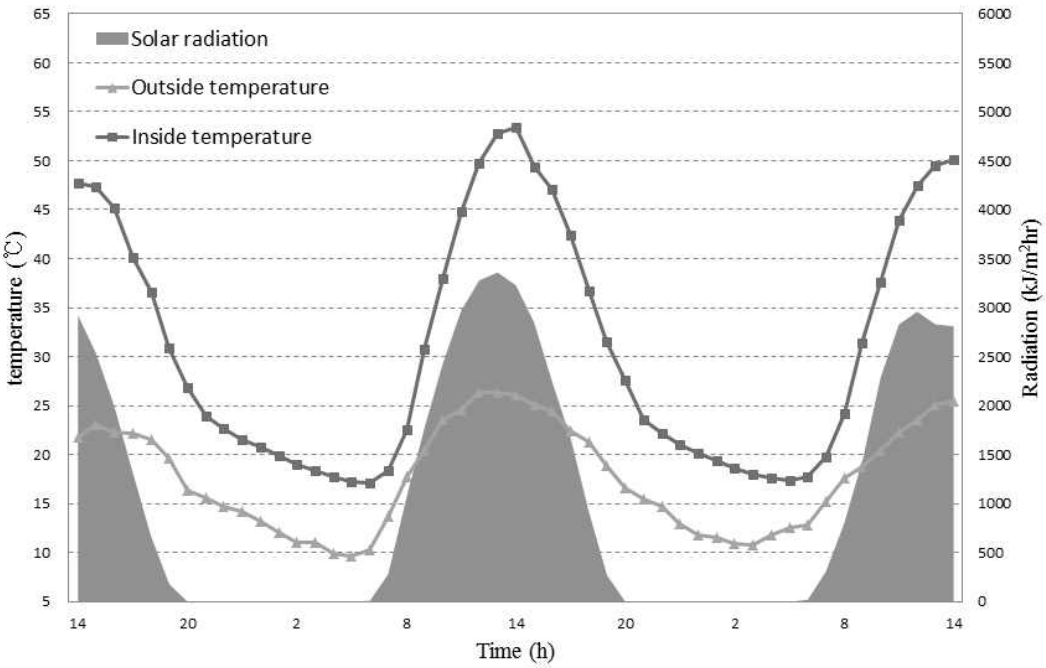


Fig. 12 The second field experiment on May 3rd ~ 5th

4.1.2. Greenhouse Modeling

In the process of BES's designing and analyzing for heating and cooling loads in a greenhouse, composition of walls which decides coefficient of overall heat transmission can be considered as a factor having enormous influences on the result. Windows of the greenhouse are made from glass, and solar energy transmittance through glass during daytime is absorbed into the floor, increasing temperature, and at this time, the glass blocks the radiant heat from the floor, showing a greenhouse effect, increasing temperature in the room. Accordingly, it can be said that physical properties of windows, that is, solar transmittance, exterior and interior facing side of solar reflectance, visible transmittance, exterior and interior facing side of visible reflectance, thermal infrared transmittance, exterior and interior facing side of infrared emittance and conductivity are quite important to calculate inside energy in a greenhouse. Though TRNSYS which is developed and used for energy analysis in buildings includes properties of matter and information about various kinds of windows, it has no information for greenhouses. But, one of advantages of TRNSYS is that it can be mutually linked to various programs. In case of windows, users can make the windows using WINDOW (6.3, LBNL, USA) and use it in TRNSYS. Accordingly, this study designed 5mm clear glass used for the target greenhouse by using WINDOW, a program to design windows. Physical properties of the windows are shown in Table 3, and physical properties of walls are shown in Table 4.

Greenhouse in Gimje, the target facility was modeled by putting property value of windows and walls based on field experiment and blueprints, and the ratio of framework was 10 %. Also, in order to compare the analyzed result based on the shape and design method by each greenhouse on simulation, it was assumed that air is exchanged in each zone by the whole volume, and the volume in modeling of all greenhouses was set the same. And, in order to consider the impact of sun's radiation based on the slope of walls and roofs, it considered the angle of inclination of each wall and roof.

Table 3 The physical properties of window (covering material of greenhouse) used in this study

	Glass 5mm
Solar transmittance	0.816
Solar reflectance (exterior and interior facing side)	0.071
Visible transmittance	0.894
Visible reflectance (exterior and interior facing side)	0.080
Thermal infrared transmittance	0
Infrared emittance (exterior and interior facing side)	0.837
Conductivity ($W \cdot m^{-1} \cdot K^{-1}$)	1
U factor ($W \cdot m^{-2} \cdot K^{-1}$)	5.834
Frame(aluminium alloy) rate of window (%)	10

Table 4 The physical properties of wall (framework of greenhouse) used in this study

	Wall (structure)	Floor		
Materials	Stainless steal	Concrete	PE film	Gravel
Density ($kg{\cdot}m^{-3}$)	7800	2240	0.96	1800
Specific heat ($kJ{\cdot}kg^{-1}{\cdot}K^{-1}$)	0.51	0.92	2.3	1
Thermal conductivity ($kJ{\cdot}h^{-1}{\cdot}m^{-1}{\cdot}K^{-1}$)	56	6.23	0.88	7.2
Thickness (m)	0.05	0.30	0.001	0.20

4.1.3. Dynamic System Modeling using BES

Interconnection of each module for calculating energy loads using TRNSYS is shown in Fig. 13, and description about each module is shown in Table 5. Type 9 plays a role of converting and interpolating data in a required shape for other module by setting the input with date provided by the KMA. Type 16 conducts a function to calculate the quantity of insolation based on latitude and slope of walls of the greenhouse by diffusing the quantity of total solar radiation on the horizontal side with the value of direct radiation and diffuse radiation. Also, type 33 processes data of wet air and type 69 is a module to calculate radiant heat exchange between the air and the surface of the earth by deciding virtual temperature in the sky. Like this, each climate factor has influences on analysis of energy in a greenhouse through each module and it is analyzed by each time through type 56.

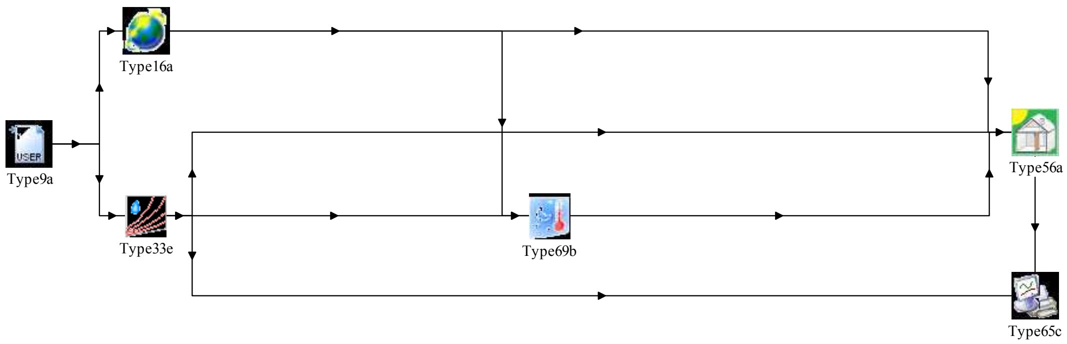
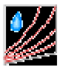


Fig. 13 Connection of modules for energy load calculation in TRNSYS

Table 5 TRNSYS common modules for load calculation of greenhouse

	Modules	Specification
 Type9a	TYPE 9 (Data Reader)	Used to read a weather file in combination with other components
 Type16a	TYPE 16 (Radiation Processor)	To interpolates radiation data, calculates several quantities related to the position of the sun, and estimates insolation on a number of surfaces of either fixed or variable orientation
 Type33c	TYPE 33 (Psychrometrics)	To calculate moist air taking as input the dry bulb temperature and relative humidity
 Type69b	TYPE 69 (Sky Temperature Calculator)	To determine an effective sky temperature, which is used to calculate the long-wave radiation exchange between an arbitrary external surface and the atmosphere
 Type65d	TYPE 65 (Online Plotter)	Used to display selected system variables while the simulation is in-progress
 Type56a	TYPE 56 (Greenhouse)	To model the thermal behaviour inside a greenhouse

4.1.4. Verification of BES model

When comparing the result of temperature simulation inside the greenhouse based on space division and field experiment data, as shown in Figs. 14 and 15, results of 3 greenhouse models showed a similar trend with field experiment date, and among them, vertical model showed the most similar trend to both field experiment data.

But, as temperature is a very important factor in calculating loads in a greenhouse and it may act sensitively to energy consumption even with a small difference, the study compared difference in maximum temperature, minimum temperature and average temperature between each model and field experiment data, and it is shown in Tables 6 and 7. In the first measurement, it showed temperature difference with maximum 5.8 ℃, minimum 0 ℃, and average 2.4 ℃ on the simple model; maximum 8.0 ℃, minimum 0 ℃, and average 2.5 ℃ on the horizontal model; and maximum 3.3 ℃, minimum 0 ℃, and average 1.1 ℃ on the vertical model. And in the second measurement, it showed temperature difference with maximum 4.5 ℃, minimum 0.2 ℃, and average 2.1 ℃ on the simple model; maximum 3.6 ℃, minimum 0.3 ℃, and average 2.6 ℃ on the horizontal model; and maximum 4.4 ℃, minimum 0.2 ℃, and average 1.1 ℃ on the vertical model. It is judged that errors in temperature difference and trends based on division of models are due to calculation methods of the simulation. In case of the horizontal model, the temperature in each divided zone is the highest at the very bottom, and decreases at the upper part. This can be analyzed being caused by air that is exchanged in each divided space area, but the effect of heat storage shows influences in a place adjacent to the floor but its effect is balanced at the upper part. In a vertical model, it showed almost same range of temperature in all space areas, and it is judged that this is because of air exchange between the floor heat storage and adjacent space. But, in case that there is an impact of insolation, temperature in the northern part was relatively low and it showed relatively high temperature in the southern space area, and it is judged that this is due to the extent of glass which is influenced by insolation and the effect of bearing. In case of a simple model, it was influenced by insolation, floor heat storage and bearing the same as the vertical model; but it is judged that it showed a different result due to difference by calculation as total volume became larger than that of division model.

Though error rate based on difference in temperature shows qualitatively similarly corresponding result, it is judged that verification by quantitative result would enhance reliability, so the study was compared and analyzed by calculating seasonal loads using the result of each simulation and field experiment data. As for calculating seasonal loads, it used a static analysis method which calculates the maximum heating loads mainly used in existing greenhouses and the set temperature was assumed as 19 ℃. As shown in Tables 8 and 9, seasonal loads based on temperature change inside the greenhouse measured through the first field experiment was calculated as 5,713,696 kcal and simple was calculated as 6,170,310 kcal, horizontal as 6,265,059 kcal and vertical as 6,010,308 kcal which simulated temperature change inside the greenhouse using BES technique. Also, the seasonal loads based on temperature change inside the greenhouse measured through the second field experiment was calculated as 8,497,244 kcal and simple was calculated as 7,758,431 kcal, horizontal as 7,539,397 kcal and vertical as 8,027,623 kcal which simulated temperature change inside the greenhouse using BES technique. When calculating error rate through this, considering both, the biggest error rate was 11.3 % and 9.6 % using horizontal and the smallest error rate was 5.2 % and 5.5 % using vertical. Accordingly, as for the most appropriate modeling method through comparison and analysis of greenhouse division model, vertical showed the best result both qualitatively and quantitatively, and considering the error rate of simulation, it can be said that verification of the model is with agreement with the experiment data.

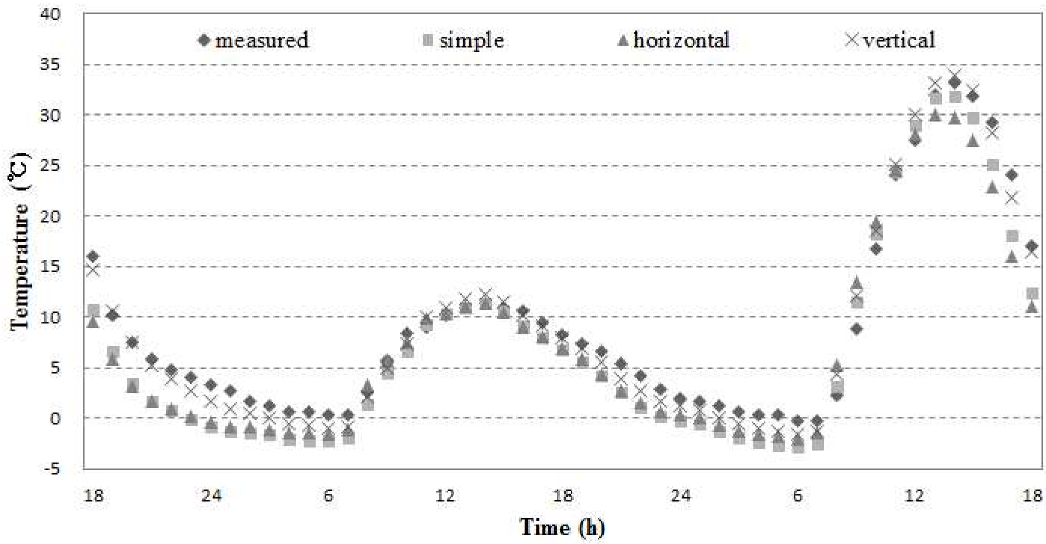


Fig. 14 Comparison of measured and simulation result based on the 1st field experiment

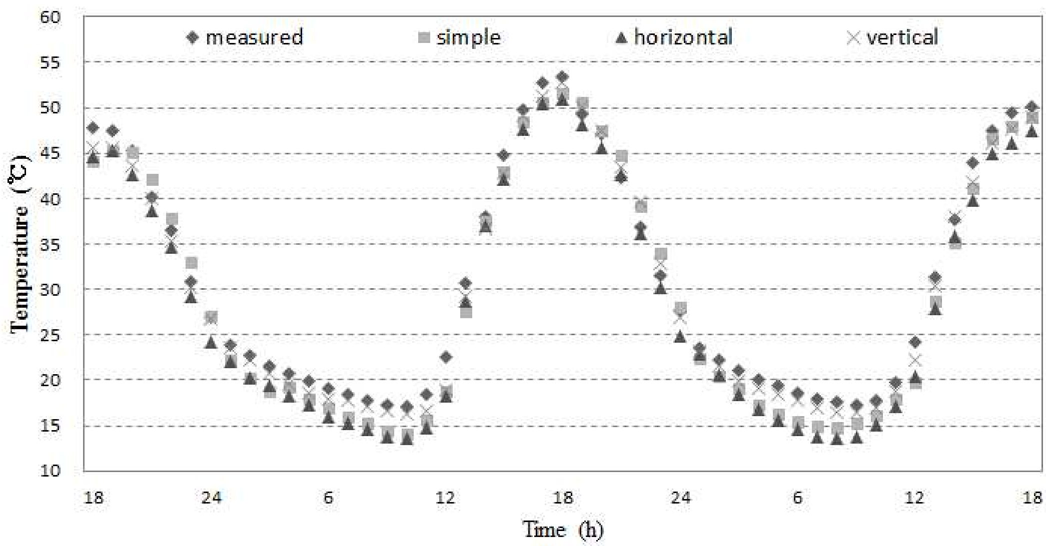


Fig. 15 Comparison of measured and simulation result based on the 2nd field experiment

Table 6 Comparison of measured and simulation result by temperature on the 1st field experiment

		Greenhouse model		
		Simple	Horizontal	Vertical
Difference of temperature (℃)	Max.	5.8	8.0	3.3
	Min.	0	0	0
	Aver.	2.4	2.5	1.1

Table 7 Comparison of measured and simulation result by temperature on the 2nd field experiment

		Greenhouse model		
		Simple	Horizontal	Vertical
Difference of temperature (℃)	Max.	4.5	3.6	4.4
	Min.	0.2	0.3	0.2
	Aver.	2.1	2.6	1.1

Table 8 Comparison of measured and simulation result by seasonal load on the 1st field experiment

	measured	Greenhouse model		
		Simple	Horizontal	Vertical
Seasonal heating load (Mcal)	5,714	6,170	6,265	6,010
Difference (%)	-	8.0	9.6	5.2

Table 9 Comparison of measured and simulation result by seasonal load on the 2nd field experiment

	measured	Greenhouse model		
		Simple	Horizontal	Vertical
Seasonal heating load (Mcal)	8,497	7,758	7,539	8,027
Difference (%)	-	8.7	11.3	5.5

4.2. Calculation and Prediction of Load by each Region and the Domestic Greenhouses

Based on verified greenhouse model, it calculated heating and cooling loads by each region and each domestic greenhouse. TRNSYS simulation can check wanted result in a real time every hour, and has an advantage that it can show the result in various data forms including graph. Fig. 16 is one example of the whole 12 cases, and shows the calculating result of heating and cooling loads according to time passage in a venlo-type greenhouse in Jeonju area for one year in 2010. It calculates the result of real-time heating and cooling loads in each area based on the range of temperature inside the greenhouse set by attaining conditions of external climate as input data.

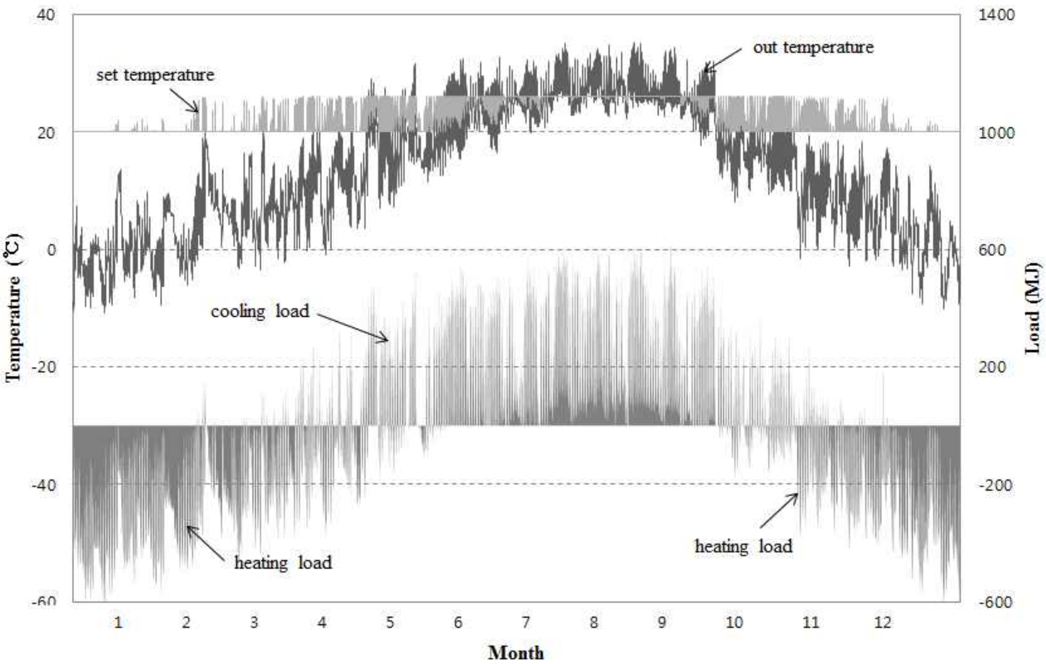


Fig. 16 Output result of cooling and heating load using TRNSYS simulation at Jeonju in 2010

4.2.1. Meteorological Analysis

Figs. 17 and 18 shows temperature change and change in insolation in 6 target areas from January 1st to 3rd, 2010. Temperature in Chuncheon and Jeju shows difference by maximum 20 ℃. With this, considering that the climate has four distinct seasons, it shows difference in climate including temperature based on regions and topography. Accordingly, it analyzed and processed climate data including the amount of insolation, temperature, humidity and underground temperature in each area in 2010 attained from the KMA as a designing condition of simulation and converted and applied as data by each hour for a total 8760 hours from January 1st to December 31st, 2010 by converting them to the form of TRNSYS climate data.

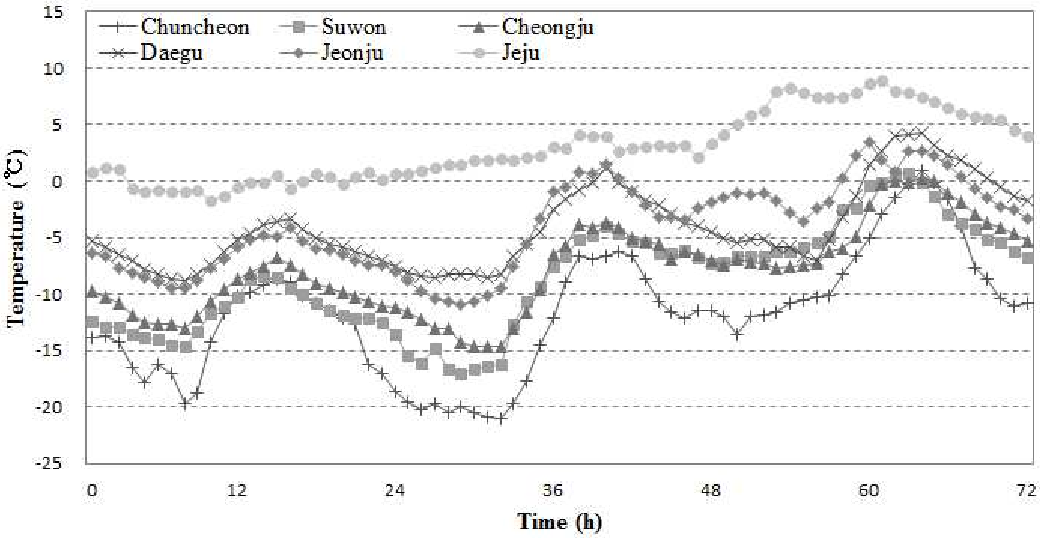


Fig. 17 A change of temperature according to time-step at 6 locations from Jan 1st to 3rd in 2010

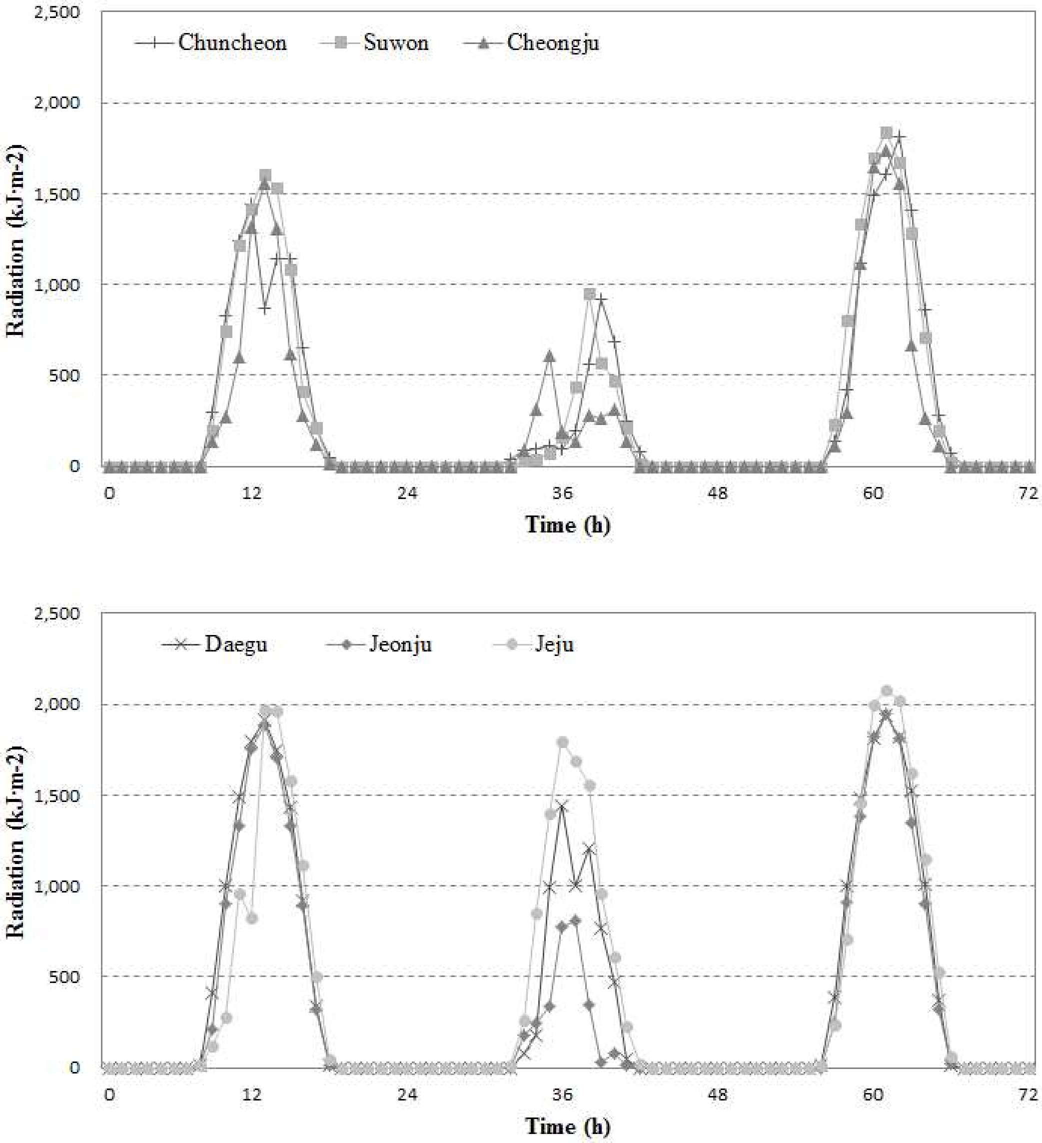


Fig. 18 A change of radiation according to time-step at 6 locations from Jan 1st to 3rd in 2010

4.2.2. BES MODELING

As for the domestic typical glass greenhouse for calculating loads, it used structure, materials and properties based on the standard blueprints of Korean greenhouse issued by the Ministry of

Agriculture and Forestry, and widespan-type and venlo-type greenhouses were divided into 3 and 8 space areas respectively. The ratio of framework of each greenhouse was 18 % for widespan-type and 10 % for venlo-type (RDA, 2006). Glass used in this study was 4mm transparent glass announced in the standard blueprints of Korean-type glass greenhouse issued by the Ministry of Agriculture and Forestry and was designed using the official property of matter of 'Han light' product suggested by HanGlas (KSL-2012, Float, size (W)1000×(L)1800㎜). Dynamic modeling for calculating loads was applied with the same method as the modeling for verification.

4.2.3. Load Calculation by each Region and each Type of Greenhouse

With verified greenhouse model, it calculated heating and cooling loads using climate date in domestic 6 areas and compared them in various ways.

4.2.3.1. Seasonal Heating Load

Total heating loads through TRNSYS according to the shape of a greenhouse and areas in 2010 are shown in Table 10 and Fig 19. First, as for total annual heating loads by each area, Chuncheon which is located in relatively high latitude calculated higher loads than other areas, and on the contrary, Jeju which is located in low latitude calculated the lowest loads. Total heating loads in Chuncheon showed higher loads by about 11～49 % than other areas, Suwon, Cheongju, Jeonju, Daegu and Jeju in order, and it is judged that it was influenced by the characteristics of domestic latitude and topography. As for loads based on the type of a greenhouse, venlo-type greenhouse showed higher loads by about 3~8 % than widespan-type greenhouse. It seems that it may reflect the result of difference in structure. Venlo-type greenhouse has larger volume than widespan-type greenhouse, and it is judged that this difference would have influences on calculation loads.

Table 10 Seasonal heating load of 2 different types of greenhouse at 6 locations in 2010 (Unit : GJ)

Region	Widespan	Venlo
Chuncheon	1,397	1,435
Suwon	1,245	1,280
Cheongju	1,181	1,215
Daegu	1,018	1,049
Jeonju	1,071	1,105
Jeju	718	783

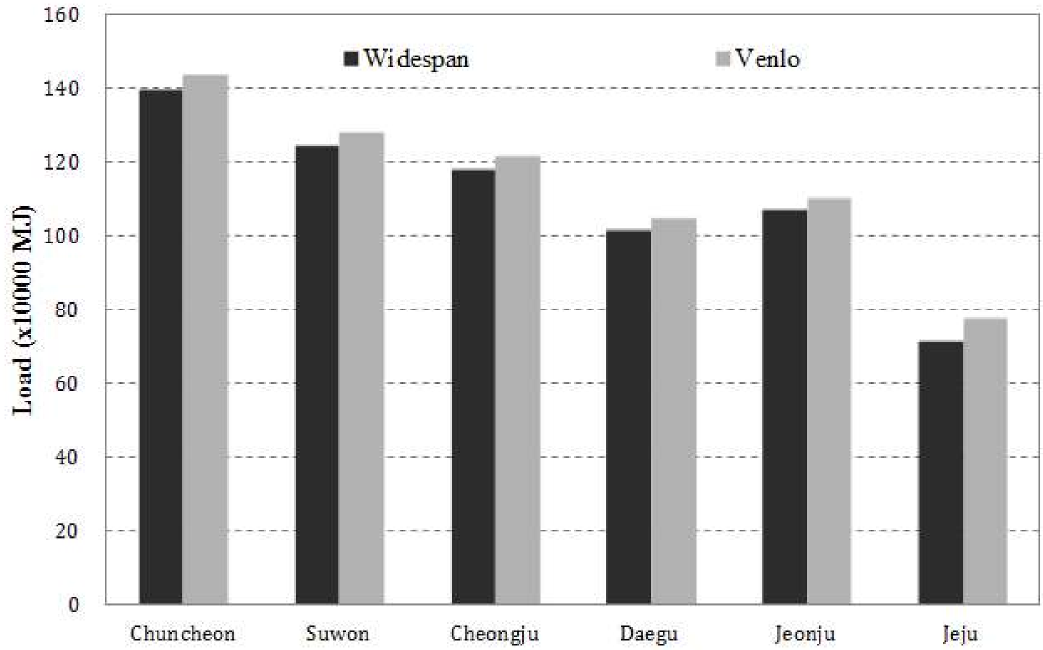


Fig. 19 Seasonal heating load of 2 different types of greenhouse at 6 locations in 2010

4.2.3.2. Seasonal Cooling Load

Table 11 shows total annual cooling loads through simulation by each type of greenhouse and by each area in 2010. Annual cooling loads showed the opposite trend with the heating loads, and it is likely to calculate lower loads as the latitude of the area is higher. But, in Daegu, the topography is a basin shape, and it was confirmed that it is very hot in summer, showing the highest cooling loads. But, cooling loads were calculated almost same in Jeju and increased in Jeonju, Cheongju, Suwon, and Jeju in order by about 6, 12, 19 and 22 % respectively, showing relatively low ratio compared with annual heating loads. It is judged that this is because deviation of temperature based on regions in summer is lower than that in winder in the country. As for loads based on the type of greenhouse, venlo-type greenhouse showed higher loads by about 5~6 % than wide-span type greenhouse.

Table 11 Seasonal cooling load of 2 different types of greenhouse at 6 locations in 2010 (Unit : GJ)

Region	Widespan	Venlo
Chuncheon	666	711
Suwon	690	735
Cheongju	751	791
Daegu	850	898
Jeonju	794	837
Jeju	848	895

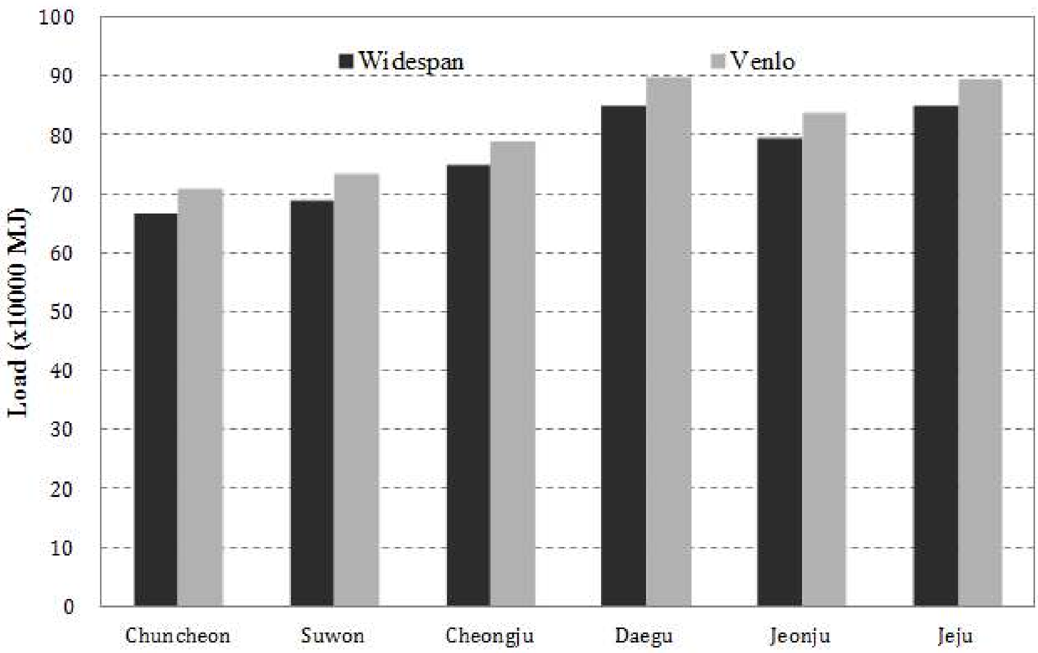


Fig. 20 Seasonal cooling load of 2 different types of greenhouse at 6 locations in 2010

4.2.3.3. Maximum Heating and Cooling Load

The result of calculating maximum heating loads by each region in each greenhouse in 2010 is shown in Table 12, and the point of time of the lowest temperature corresponded to the point of time of the maximum heating loads in TRNSYS simulation. Difference in loads in each region was caused based on the lowest temperature, and this shows a similar trend with the result of calculation of total annual heating loads which are influenced by the latitude. Difference in loads based on the type of greenhouses was about 5 % for both wide-span type and venlo-type, showing a similar trend. The result of calculation of maximum cooling loads by each area in 2010 is shown in Table 13. The result showed difference by 2～14 % as of Daegu showing the largest loads. The maximum cooling loads were caused in some hours in TRNSYS simulation unlike that in the highest temperature. It is judged that this is because of heat storage based on multi-section division and characteristics of dynamic programs.

Table 12 Maximum heating load of 2 different types of greenhouse at 6 locations in 2010 (Unit : $MJ \cdot h^{-1}$)

Region (Date of lowest temp.)	Widespan	Venlo
Chuncheon (Jan 14, 8am, -21.1 ℃)	847	885
Suwon (Jan 6, 6am, -18.2 ℃)	784	822
Cheongju (Jan 14, 7am, -14.7 ℃)	722	754
Daegu (Dec 25, 7am, -9.9 ℃)	621	651
Jeonju (Jan 14, 5am, -10.9 ℃)	632	662
Jeju (Jan 13, 10am, -1.8 ℃)	423	443

Table 13 Maximum cooling load of 2 different types of greenhouse at 6 locations in 2010

		Chun-cheon	Suwon	Cheong-ju	Daegu	Jeonju	Jeju
Date of lowest temp.		Aug 20, 3pm	Aug 5, 3pm	Aug 5, 1pm	Aug 20, 3pm	Aug 19, 3pm	Aug 15, 4pm
Ambient Temp. (℃)		33.9	33.9	35.6	35.7	35.3	35.6
Wide span	Date by simulation	Jul 4, 1pm	Aug 5, 12pm	Aug 9, 4pm	Aug 20, 4pm	Aug 22, 10am	Aug 15, 3pm
	Ambient Temp.(℃)	33.6	32.1	34.5	35.4	35.0	35.5
	Max. cooling load ($MJ \cdot h^{-1}$)	829	843	902	943	927	908
Venlo	Date by simulation	Aug 19, 4pm	Aug 22, 4pm	Aug 20, 4pm	Aug 20, 4pm	Sep 3, 4pm	Sep 21, 4pm
	Ambient Temp.(℃)	33.3	32.1	34.9	35.4	33.5	33.1
	Max. cooling load ($MJ \cdot h^{-1}$)	863	881	943	999	962	938

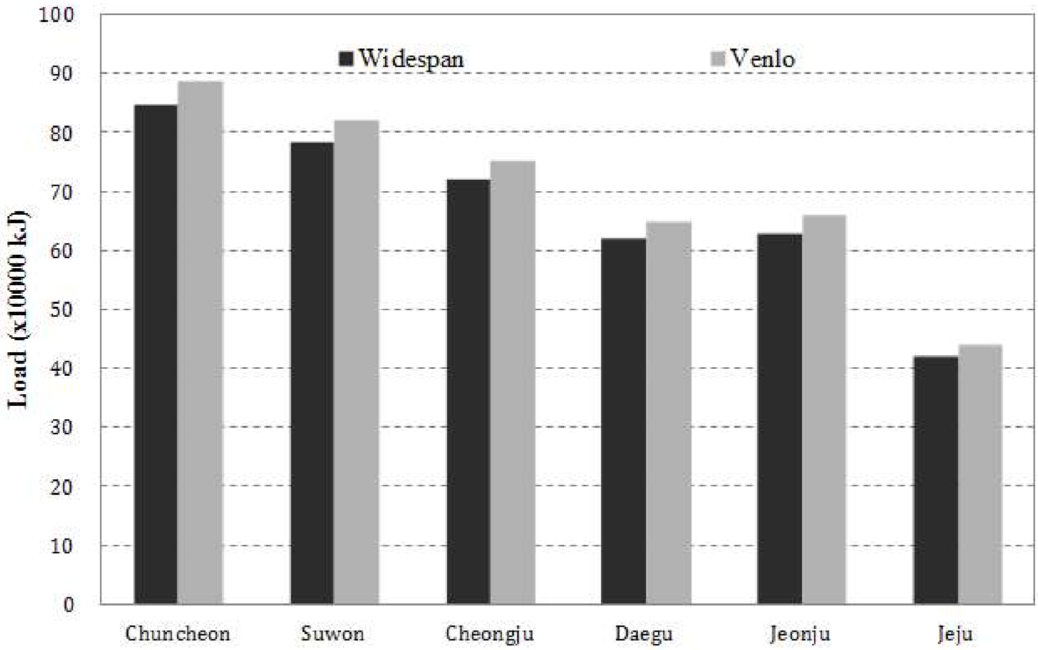


Fig. 21 Maximum heating load of 2 different types of greenhouse at 6 locations in 2010

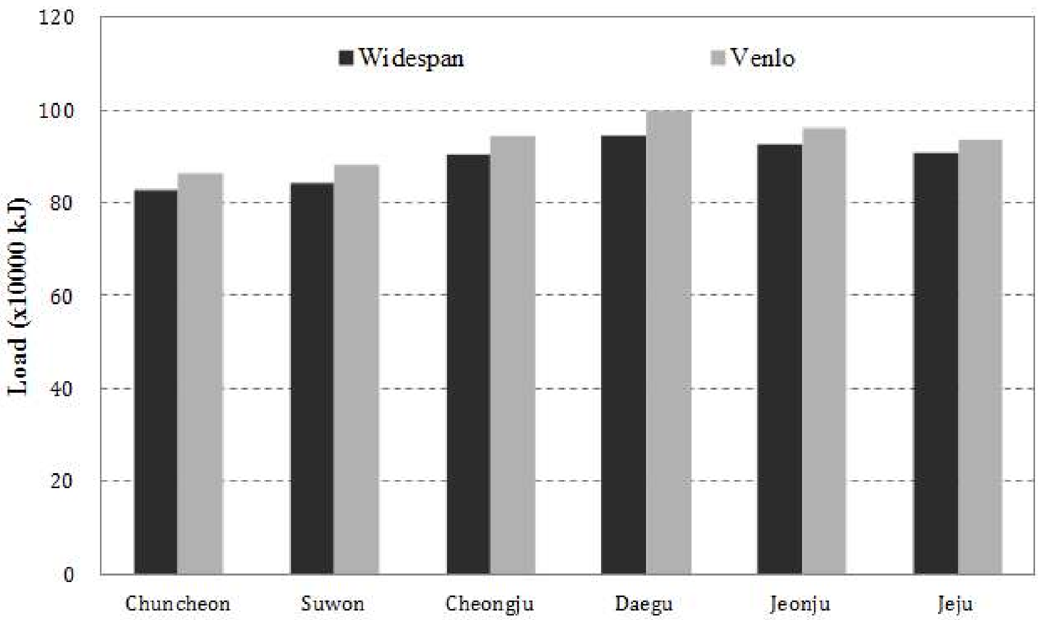


Fig. 22 Maximum cooling load of 2 different types of greenhouse at 6 locations in 2010

4.2.4. Comparison of Dynamic Analysis Method and Static Analysis Method

4.2.4.1. Maximum Heating Load

The value of calculating maximum heating loads between BES program which calculates loads through dynamic analysis method and a simple calculating program GES which calculates loads through static analysis method is show in Tables 14 and 15 for both widespan-type greenhouses and venlo-type greenhouses. The maximum heating loads in both types of greenhouses was calculated relatively low through dynamic loads calculation than through static loads calculation. Widespan-type greenhouses showed difference by about 36~30 % from Chuncheon to jeju, and venlo-type greenhouses showed difference by about 33~27 %. Such a difference in loads according to the type of greenhouses is due to difference in analysis methods. In static analysis, loads are calculated through calculation of extent such as setting the heating expenses by dividing the floor extent with surface extent, showing little difference in loads between the two greenhouses which have similar extent while in dynamic analysis, the result reflected calculation about the air, showing difference by about 5 %.

Calculation of maximum heating loads is a very important factor to calculate capacity of appropriate facility. Assuming that an electric boiler which generates 450 $MJ \cdot h^{-1}$ calorie is used, in a widespan-type greenhouse in Chuncheon generates 31,500,000 won of initial investment costs by installing 3 sets of boiler based on the result calculated through static load calculation method while it generates

21,000,000 won of initial investment costs by installing 2 sets of boiler based on the result calculated through dynamic load calculation method, saving 10,500,000 won of initial installation costs. This value is calculated in a greenhouse of about 890 m^2 extent, and it is expected to generate more cost difference in a large-sized facility. Accordingly, it is necessary to calculate exact loads using a dynamic analysis method when designing a greenhouse in order to prevent excessive investment to facilities and to save initial investment costs.

Table 14 Maximum heating load of widespan-type greenhouse at 6 locations in 2010 (Unit : $MJ \cdot h^{-1}$)

Region	Static method	Dynamic method
Chuncheon	1,316	847
Suwon	1,209	784
Cheongju	1,080	722
Daegu	903	621
Jeonju	940	632
Jeju	604	423

Table 15 Maximum heating load of venlo-type greenhouse at 6 locations in 2010 (Unit : $MJ \cdot h^{-1}$)

Region	Static method	Dynamic method
Chuncheon	1,320	885
Suwon	1,214	822
Cheongju	1,085	754
Daegu	908	651
Jeonju	945	662
Jeju	610	443

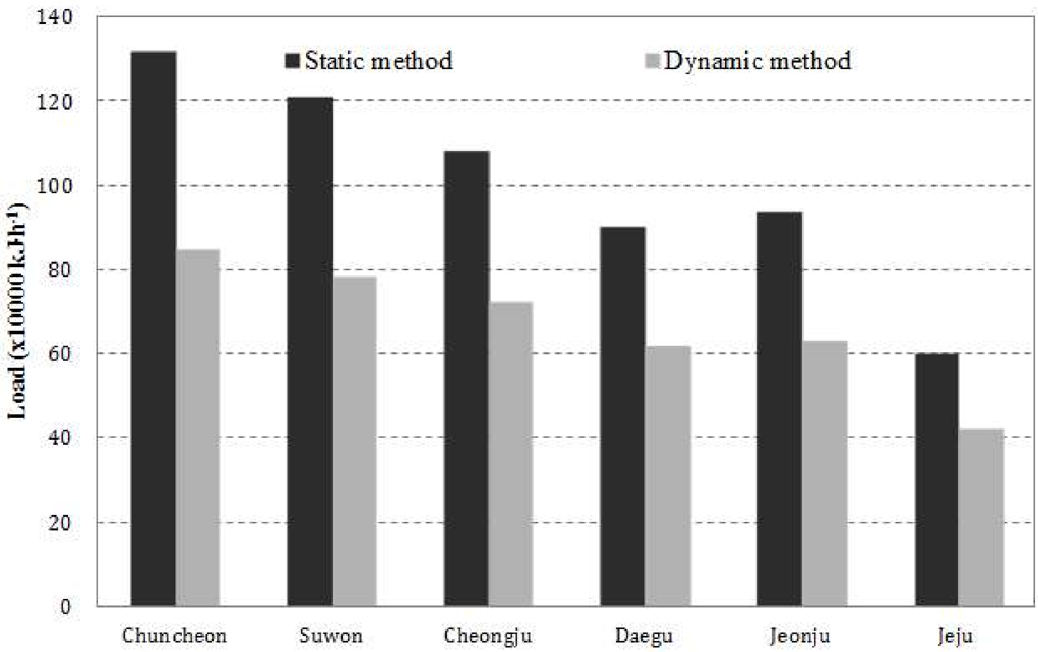


Fig. 23 Comparison to static method and dynamic method by maximum heating load of widespan-type greenhouse at 6 locations in 2010 (Unit : $MJ \cdot h^{-1}$)

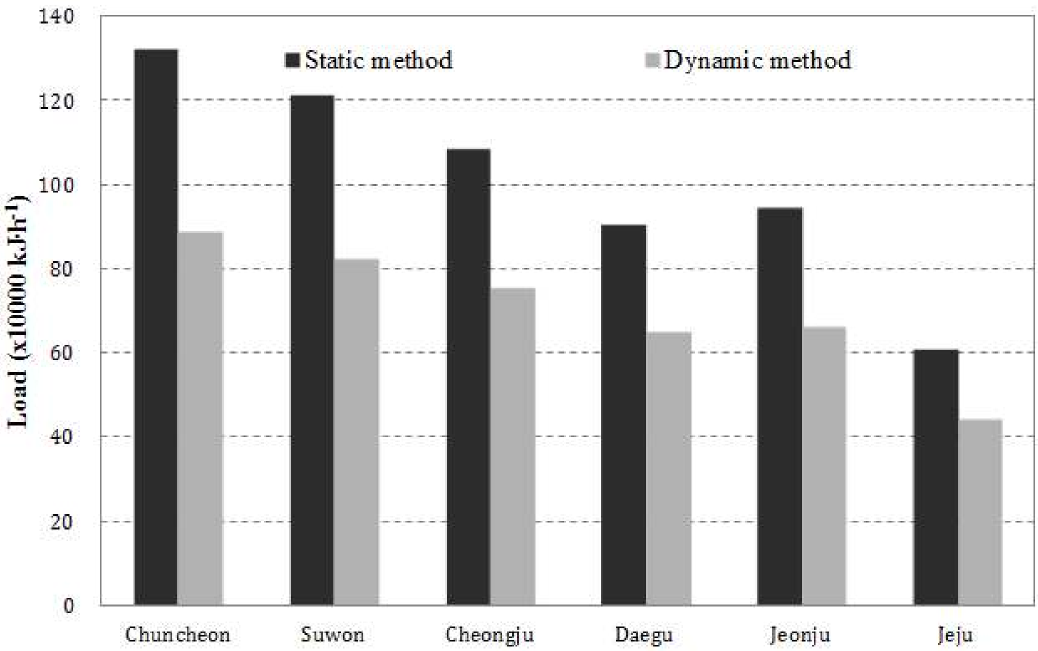


Fig. 24 Comparison to static method and dynamic method by maximum heating load of widespan-type greenhouse at 6 locations in 2010 (Unit : MJ·h^{-1})

4.2.4.2. Seasonal Heating Load

The value of calculating seasonal heating loads between BES program which calculates loads through dynamic analysis and a simple calculating program GES which calculates loads through static analysis is show in Tables 16 and 17 for both widespan-type greenhouses and venlo-type greenhouses. Like the result of comparing maximum heating loads, the value of seasonal heating loads calculated through a dynamic load calculation method is relatively lower than that calculated through a static load calculation method for both greenhouses. Widespan-type greenhouses showed difference by about 44～49 % from Chuncheon to jeju, and venlo-type greenhouses showed difference by about 43~47 %. While there is little difference in loads between the two greenhouses in a static load calculation method, dynamic loads generates about 3 % of difference between the two greenhouses.

Calculation of seasonal heating load is a factor to predict the fuel consumption in a facility. Effective caloric value of diesel is 28 $MJ \cdot \ell^{-1}$, and when calculating the result calculated through a static load in a wide-span type greenhouse in Chuncheon, annual oil consumption is calculated as about 89,000 ℓ. When calculating annual heating expenses with 770 won per 1 ℓ of diesel (non-taxable oil) in 2010, it costs about 70,000,000 won annually. When calculating the result calculated through dynamic loads in the same way, it costs about 40,000,000 won annually. Though this calculated price and fuel consumption is not comparable, it is judged that it can be used as an important index to decide heating budget in a greenhouse.

Table 16 Seasonal heating load of widespan-type greenhouse at 6 locations in 2010 (Unit : GJ)

Region	Static method	Dynamic method
Chuncheon	2,505	1,397
Suwon	2,242	1,245
Cheongju	2,113	1,181
Daegu	1,841	1,018
Jeonju	1,982	1,071
Jeju	1,397	718

Table 17 Seasonal heating load of venlo-type greenhouse at 6 locations in 2010 (Unit : GJ)

Region	Static method	Dynamic method
Chuncheon	2,532	1,435
Suwon	2,267	1,280
Cheongju	2,136	1,216
Daegu	1,862	1,049
Jeonju	2,003	1,106
Jeju	1,413	747

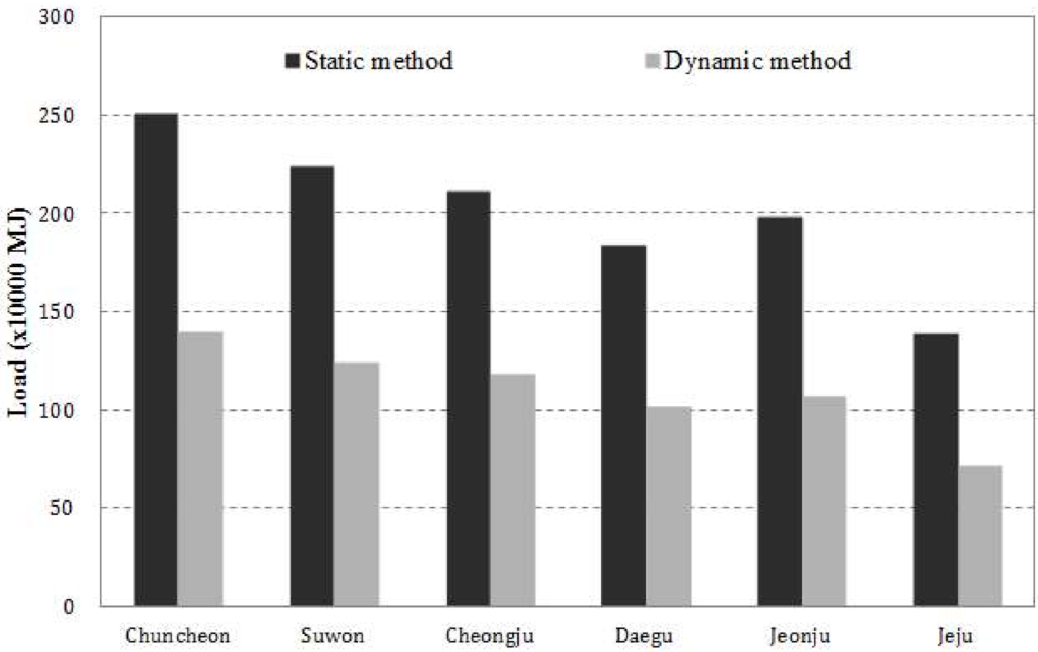


Fig. 25 Comparison to static method and dynamic method by seasonal heating load of widespan-type greenhouse at 6 locations in 2010

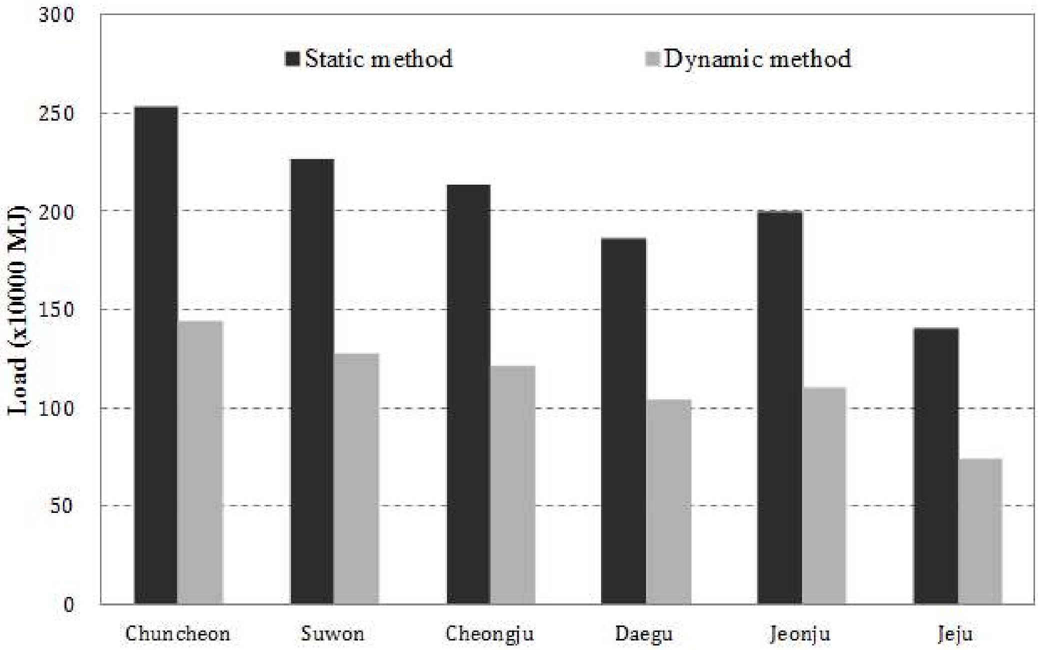


Fig. 26 Comparison to static method and dynamic method by seasonal heating load of venlo-type greenhouse at 6 locations in 2010

4.3. Modeling of Geothermal Energy System in Greenhouse

Though there are not standardized criteria about the project to distribute geothermal energy facilities in facility horticulture, the Research and Development on National Institute of Agricultural Engineering (NIAE) of the RDA has prepared the criteria for calculating geothermal capacity as follows, and it obeys the following installation standard.

- Calculation of geothermal capacity is set within 70 % of total heating loads.
- When calculating maximum heating loads, the lowest external

temperature uses climate date for last 5 years and the internal set temperature is set 20 ℃, assuming to grow megistotherm crops.

- Installed greenhouses should be equipped with enough heating facility such as triple heating or multi-layered heating curtains, and it is set as 60 % of maximum heating loads calculated as of greenhouses installed with double heating clothes.

- The capacity of heat pumps based on total heating loads calculated like this, and the facility is installed at the level of 70 % of calculated capacity.

Table 18 The standard on installation capacity of heat pump

Minimum air temperature	Heater capacity		Installation capacity of heat pump (applying 70 % of heater)	
	RT	kW	RT	kW
over - 2 ℃	21.7	76	15	52.5
-3～-8 ℃	28.1	98	20	70.0
-9～-15 ℃	35.5	124	25	87.5
below - 16 ℃	42.8	150	30	105.0

4.3.1. Data Collection from Geothermal Greenhouse

Top-green have been operated in a geothermal heating and cooling system escaped from existing boiler installation method since 2010 through a project to distribute geothermal energy to controlled horticulture, a government-supported project. Data of geothermal system installed in the target greenhouse is shown in Table 19. It is a vertical closed-type ground heat exchanger, is composed of 80 boreholes in the depth of 150m, and is operated using water-to-water type heat pump with capacity of 240 RT. It possesses heat storage tank of 240 ton and cooling tank of 40 ton, and heating and cooling energy is flowed to the greenhouse through 111 fan coil unit (FCU).

Data about the performance of heat pumps is provided by the geothermal business. Heating performance coefficient was 3.46 and cooling energy efficiency ratio was 4.38. Circulating flux in loads is 7.63 $\ell \cdot s^{-1}$ and circulating flux in heat source is 8.29 $\ell \cdot s^{-1}$.

Fig. 27 shows the annual oil consumption and the cost when Top-green farming corporation used existing boiler system before installing the geothermal system in 2009. Except July to September when the heating system is not operated, it used total 330,000 ℓ oil annually, and spent 264,000,000 won for oil costs. Fig. 28 shows the use of electricity and the cost before and after installing the geothermal system. The use of electricity before installing the system was 169,406 kWh, and that after installing the system was 1,155,774 kWh. When converting it into the amount of money, electricity charge before and after installing the system was 7,981,000 won and 53,211,000 respectively. When considering annual energy consumption before and after installing geothermal system by summing up oil costs and electricity charge, it spent total 271,921,000 won before installing the system and after installing it, it spent 53,211,000 won. Finally, it saved annually 218,770,000 won of heating costs after installing thermal system, and considering the reduction of CO_2 emission due to reduction of the number of times of ventilation, it saved about 245,000,000 won of energy consumption.

Table 19 Geothermal system in Top-green farming corporation

	Specification
Geothermal heat pump	water-to-water, 240 RT
Thermal storage tank	240 ton
Cooling tank	48 ton
Ground heat exchanger	Vertical closed type (150m x 80 borehole)
Fan coil unit	Automatic control by temperature

.

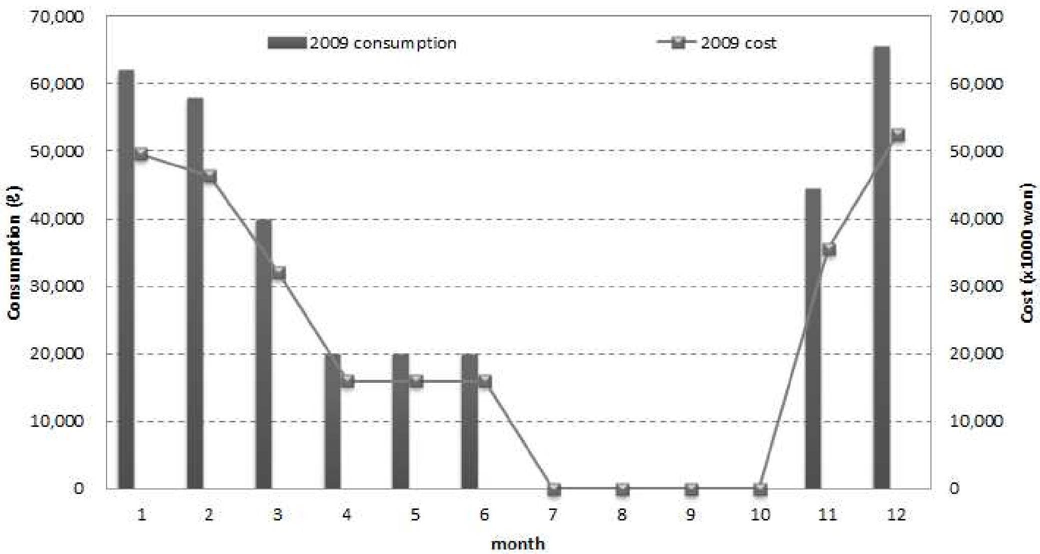


Fig. 27 The annual oil consumption and the cost before and after installing the geothermal system in Top-green farming corporation

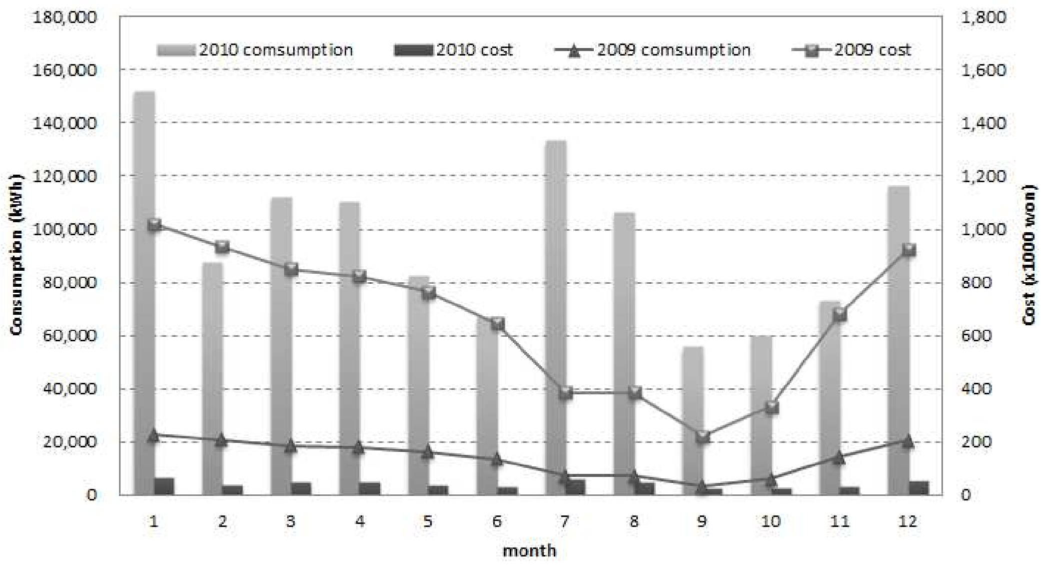


Fig. 28 The annual electricity consumption and the cost before and after installing the geothermal system in Top-green farming corporation

4.3.2. Geothermal System Modeling

Fig. 22 shows TRNSYS modeling which realizes the geothermal energy system in a greenhouse applying BES technique. Modeling of the geothermal system using TRNSYS includes a process to connect geothermal facility component to a process of modeling for calculating loads in a greenhouse. Geothermal facility module used in this study is introduced in Table 20, and operating principles of the system are as follows.

- Circulating water in the ground heat exchanger is flowed to the heat pump by absorbing underground heat and attains heat through a process of heat pump to compression, condensation, expansion and evaporation.

- Hot water which passes through the heat pump is provided to a heat storage tank, maintaining constant temperature (40 ℃ ≦ temperature of storage tank ≦ 50 ℃).
- Hot water stored in the heat storage tank is connected to FCU and turned on/off by set temperature (20 ℃ ≦ inside temperature ≦ 26 ℃), adjusting temperature in a greenhouse.
- Hot water which is used to heat the greenhouse and cooled down repeats the whole process of emitting cooled heat through the underground heat exchanger and absorbing underground heat.

Heating system in a greenhouse using geothermal energy is operated through such a process. Geothermal heat pump model with a water to water system is based on user-supplied data files containing catalog data for the capacity and power draw, based on the entering load and source temperatures. The heat pump's COP in heating is given by equation (8).

$$COP = \frac{Cap}{\dot{P}} \tag{8}$$

where,

COP	:	the heat pump coefficient of performance in either heating or cooling mode
Cap	:	heat pump heating capacity or cooling capacity at current conditions ($kJ \cdot hr^{-1}$)
$\dot{P}$	:	power drawn by the heat pump in heating mode or cooling mode ($kJ \cdot hr^{-1}$)

The amount of energy absorbed and energy rejected from the source fluid stream in heating is given by equation (9) and (10).

$$\dot{Q}_{absorbed} = Cap_{heating} - \dot{P}_{heating} \tag{9}$$

$$\dot{Q}_{rejected} = Cap_{cooling} - \dot{P}_{cooling} \tag{10}$$

where,

$\dot{Q}$: energy absorbed or rejected by the heat pump in heating mode ($kJ \cdot hr^{-1}$)

The outlet temperatures of the two liquid streams can then be calculated using equations (11)~(14).

$$T_{source,\,out} = T_{source,\,in} + \frac{\dot{Q}_{absorbed}}{\dot{m}_{source} Cp_{source}} \tag{11}$$

$$T_{load,\,out} = T_{load,\,in} + \frac{Cap_{heating}}{\dot{m}_{load} Cp_{load}} \tag{12}$$

$$T_{source,\,out} = T_{source,\,in} + \frac{\dot{Q}_{rejected}}{\dot{m}_{source} Cp_{source}} \tag{13}$$

$$T_{load,\,out} = T_{load,\,in} + \frac{Cap_{cooling}}{\dot{m}_{load} Cp_{load}} \tag{14}$$

where,

$T_{source,in}$: temperature of liquid entering the source side of the heat pump (℃)

$T_{source,out}$: temperature of liquid exiting the source side of the heat pump (℃)

$T_{load,in}$: temperature of liquid entering the load side of the heat pump (℃)

$T_{load,out}$: temperature of liquid exiting the load side of the heat pump (℃)

$\dot{m}_{source}$: mass flow rate of the liquid on the source side of the heat pump ($kJ \cdot hr^{-1}$)

$\dot{m}_{load}$: mass flow rate of the liquid on the load side of the heat pump ($kJ \cdot hr^{-1}$)

Cp_{source} : specific heat of the liquid on the source side of the heat pump ($kJ \cdot hr^{-1} \cdot K^{-1}$)

Cp_{load} : specific heat of the liquid on the load side of the heat pump ($kJ \cdot hr^{-1} \cdot K^{-1}$)

The input value used for modeling is shown in Table 21.

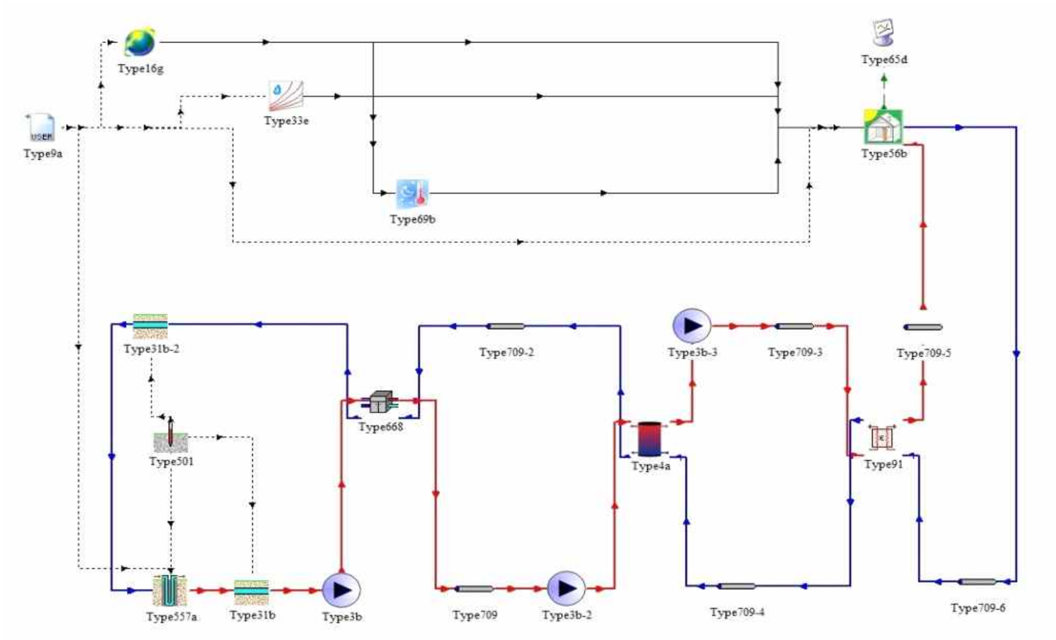


Fig. 29 Connection of modules for geothermal energy system in TRNSYS

Table 20 TRNSYS modules for geothermal system of greenhouse

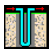
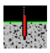
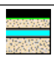
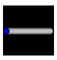
	Modules	Specification
 Type557a	TYPE 557 (Vertical U-Tube Ground Heat Exchanger)	models a vertical heat exchanger that interacts thermally with the ground
 Type668	TYPE 668 (Water to Water Heat Pump)	the heat pump conditions a one liquid stream by rejecting energy to (cooling mode) or absorbing energy from (heating mode) a second
 Type501	TYPE 501 (Soil Temperature Profile)	vertical temperature distribution of the ground given the mean ground surface temperature for the year
 Type4a	TYPE 4 (Storage Tank)	the thermal performance of a fluid-filled sensible energy storage tank
 Type31b  Type709	TYPE 31 and 709 (Pipe)	the thermal behavior of fluid flow in a pipe using variable size segments of fluid
 Type3b	TYPE 3 (Pump)	computes a mass flow rate using a variable control function

Table 21 TRNSYS input data for geothermal energy system used in this study.

	Parameter	Input value
Weather data	Temperature Relative humidity	KMA in Namwon
	Solar radiation	KMA in Gwangju
Greenhouse	Heating	20 ℃
	Cooling	25 ℃
Ground heat exchanger	Type	Vertical U-tube
	Borehole depth	150 m
	Borehole radius	0.075 m
	Borehole number	2
	Borehole gap	0.2 m
	Header depth	1.5 m
	Thermal conductivity of soil	3.6 $W \cdot m^{-1} \cdot K^{-1}$
	U-tube inside diameter	0.015 m
	U-tube outside diameter	0.022 m
Geothermal heat pump	Capacity	240 RT
	Flow rate at source	8.29 $kg \cdot s^{-1}$
	Flow rate at load	7.63 $kg \cdot s^{-1}$
Storage tank	Type	Stratified storage tank
	Volume	240 m^3

4.3.3. Applying and Analyzing for Geothermal System Model

Examining the criteria for calculating geothermal capacity for controlled horticulture by the Rural Development Administration, it clarifies to use climate date for last 5 years in the installation area for the lowest temperature when calculating maximum heating loads in the greenhouse. Therefore, Table 22 shows the lowest temperature in Namwon area for last 5 years including the year when geothermal system was installed. From 2006 to 2010, December 31st, 2009 showed the lowest temperature, －18.4 ℃. So, in order to calculate maximum heating loads, climate data for one year in 2009 was used. Data about direction of wind, wind speed, temperature and humidity was provided by the Namwon Weather Station, and as the station does not measure insolation, the data was provided by the Gwangju Weather Station which is close to Namwon.

The maximum heating loads in 2009, before installing the geothermal system was calculated about 4,800 $MJ \cdot h^{-1}$ using TRNSYS, and seasonal heating loads was calculated about 7,970,000 MJ. When roughly comparing it with 330,000 ℓ, oil costs in Namwon greenhouses before installing the geothermal system, it is 300,000 ℓ, showing difference by about 10 %. Though it is not possible to compare heating costs exactly as it did not consider various variables such as heating materials in the facility and ventilation and crops, it would be helpful to calculate the result which reflects the actual conditions through future studies.

The installing capacity of the geothermal energy system in the target greenhouse is 240 RT, about 3,100 $MJ \cdot h^{-1}$. When comparing it with the result of calculating maximum heating loads through simulation, 4,800 $MJ \cdot h^{-1}$, it shows difference by about 35 %. When applying the criteria to install the geothermal system by the Rural

Development Administration (70 % of the maximum heating loads), it generates about 5 % of errors. Also, when considering 2,900 $MJ \cdot h^{-1}$, the quantity of heat generated for 1 hour by the geothermal energy system through simulation with the installation capacity of the geothermal energy system in the target greenhouse, it generates about 6 % of errors. Considering the error rate of simulation, it can be said that it shows a good agreement.

The study validated heating supply in a greenhouse through the geothermal energy system using TLC method of BES, and the result is shown in Fig. 23. Fig. 23 (b) graph shows that internal temperature in a greenhouse is maintained almost constantly and heating is stable. But, Fig. 23 (a) graph shows that when the external temperature drops under -10 ℃, the internal temperature in a greenhouse cannot maintain 20 ℃, the set temperature and unstable heating conditions where the graph of internal temperature is similar to that of external temperature. This shows that as the installation capacity of geothermal system is set as 70 % of maximum heating loads, it cannot show 100 % of efficiency at extreme temperature. Accordingly, it is judged that it is necessary to prepare additional heating system using auxiliary heaters such as boilers or fan heaters.

(a)

(b)

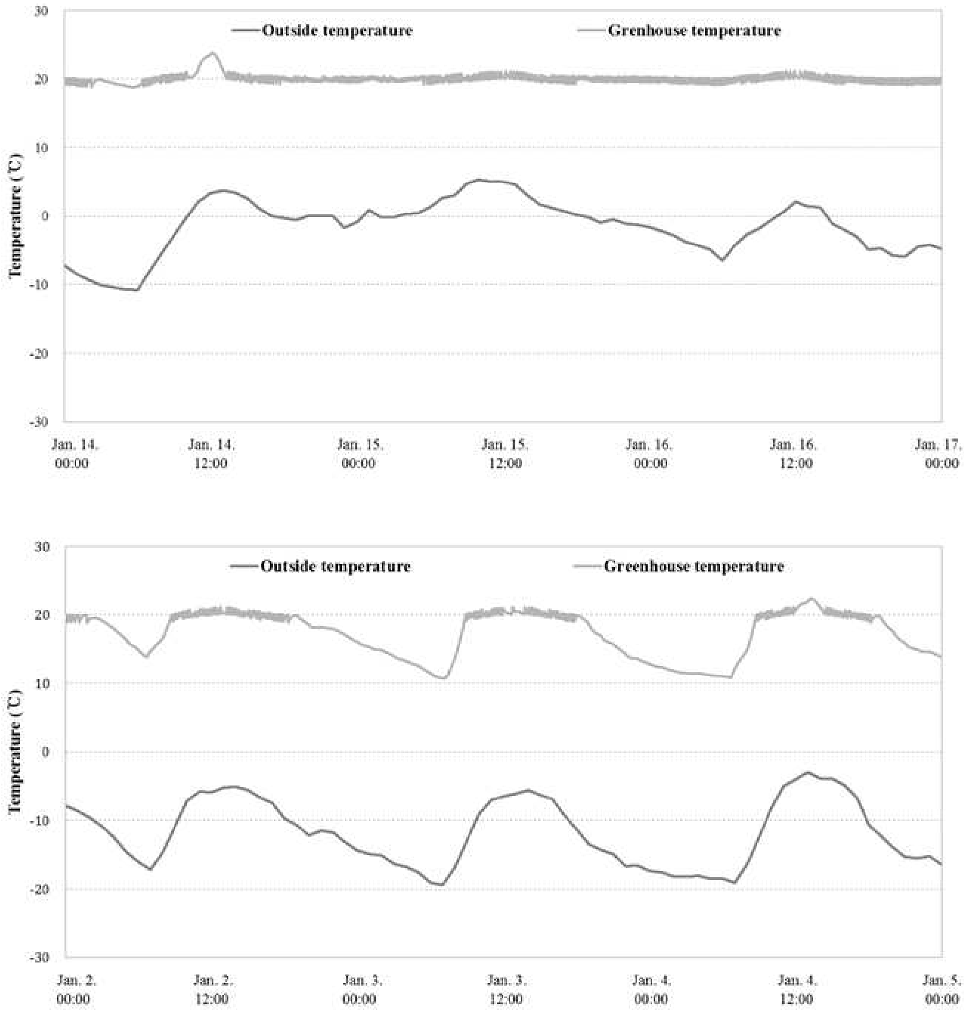


Fig. 30 The change of internal temperature according to external temperature; (a) temperature change on Jan 14^{th}~16^{th} (b) temperature change on Jan 2^{nd}~4^{th}

Table 22 Minimum air temperature in recent 5 years in Namwon

	Minimum air temperature (℃)
2006	-15.1
2007	-9.6
2008	-12.9
2009	-18.4
2010	-18.3

In this study, additionally geothermal energy system simulated in Gimje greenhouse which was used to verification of BES. The Gimje greenhouse is an energy independent green village which has a system for heating and cooling of the greenhouse by using biomass energy and is the greenhouse which uses a geothermal energy system as an auxiliary heat source. However, we conducted modeling based on a blueprint and used it as a reference, because the installment of the equipment systems including a geothermal system is on-going. The geothermal system of the Gimje greenhouse is a vertical closed loop type ground heat exchanger consisting of six borings with 150 m in depth, a 10 RT heat pump with water to water system, and a 3 ton heat storage tank. The result of providing heat energy of the greenhouse by modeling a geothermal system in the same way as the thermal system of the Namwon greenhouse is the same as Fig. 31. According to the result of the simulation conducted for one month in January 2010, it indicated that it does not meet 20 ℃ which is indoor setting temperature in the greenhouse during most of the time except for the peak time of the daytime which has the effect on solar radiation. According to the result of estimating the capacity of a geothermal system by estimating the peak heating load of the Gimje greenhouse which has the size of 1006.08 m^2, it indicated that it showed about 35 RT, but the actual geothermal system was not enough to be an independent heating system because it was installed with the capacity of 10 RT. However, it indicated that the geothermal system of the target facility can meet about 29 % of the heating load as a concept of an auxiliary heat source.

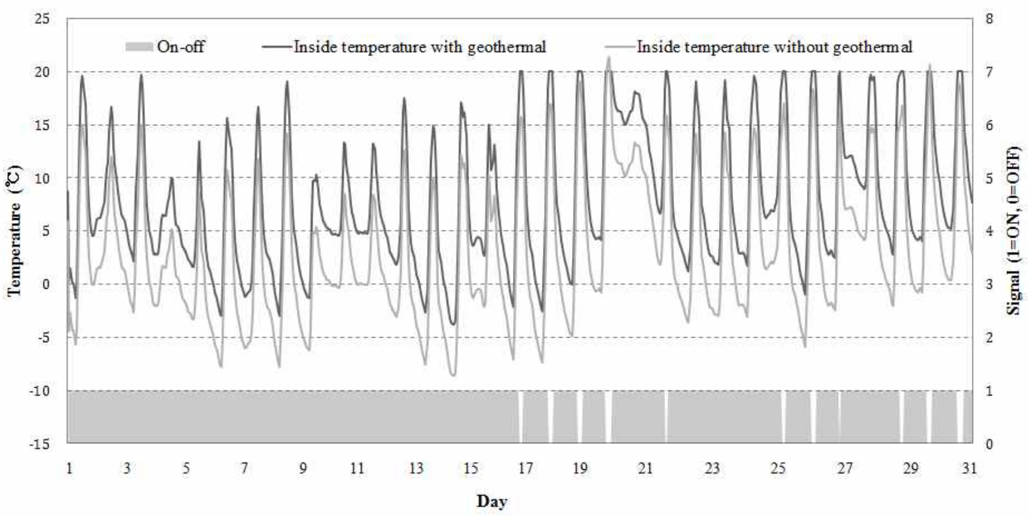


Fig. 31 The change of internal temperature according to geothermal energy system on January in Gimje

This study realized a geothermal energy system using BES and validated heating system in a greenhouse by using it. As a result, the simulation was well realized and performed, but it is debatable to mention reliability in a situation where it cannot reflect the actual greenhouse. But, it is judged that by using BES, more exact and predictable simulation method can be applied to greenhouses by realizing renewable energy and various facility systems as well as the geothermal energy system.

Ⅴ. CONCLUSION

This study is a basic study which applies BES technique to greenhouses in agricultural field, the contents of analyzing the heating and cooling characteristics of greenhouse were dealt. First, the design method of greenhouse model was sought using TRNSYS that is one of BES programs and the verification of that was conducted. And, based on verified greenhouses, it modeled widespan-type and venlo-type greenhouse which are typically used in the domestic and aimed to compare and analyze characteristics of energy loads by applying weather data for 1 year in 2010 in 6 regions. With this, it aimed to realize geothermal energy system which is being recognized as an alternative energy source in controlled horticulture industry using BES and performed its analysis.

The major results are summarized as follows

- Regarding the realization and verification of greenhouse model using TRNSYS that is one of BES programs, the modeling was performed with three methods such as the simple model that simplifies 6-span greenhouse, the horizontal model that divides the zone to horizontal direction along the height and the vertical model that divides the zone to vertical direction along multi-span of greenhouse, and the verification was conducted through the comparison with the field experiment. Considering the error rate of simulation, all of model showed good agreement both qualitatively and quantitatively. Among them, the error rate of vertical model was the best result both 5.2 % and 5.5 %. Through this, it was found that BES program to be applied to greenhouses is possible.

- As the results of performing the load calculation of widespan-type and venlo-type greenhouse that is the representative domestic greenhouse and 6 domestic regions using BES simulation, seasonal heating load was higher from Chuncheon, high latitude to Jeju a low latitude about 11～49 %. On the contrary, the seasonal cooling load showed lower as it goes from low latitudes to high latitudes. Among them, the case of Daegu where has the topographical characteristic of basin-shape calculated the highest load, and the low loads of about 6, 12, 19 and 22 % each showed in sequential order of Jeonju, Cheongju, Suwon and Chuncheon based on Daegu. And, regarding the load difference between two greenhouses for each region, venlo-type greenhouse whose volume is relatively large was computed as higher by about 3～8 % in case heating and about 5～6 % in case cooling than widespan-type. Maximum heating and cooling load appeared similar to the tendency of seasonal load and maximum cooling load appeared at the different time in the simulation in case of maximum cooling load not like actual highest temperature. It is judged that it was caused by time and thermal storage in the calculation process of the program.

- As the results of computing maximum heating load and seasonal heating load and comparing it with BES program that is a dynamic analysis method by using static analysis method that was used for computing load of existing greenhouse, both widespan-type and venlo-type were computed as low by about 30～36 % and 27～33 % in dynamic analysis method and they were computed as low by about 44～49 % and 43～47 % in dynamic analysis method as well, and it could be guessed that the facilities were overestimated through load estimation of greenhouse so far.

- Geothermal energy system of greenhouse was simulated using BES, and as the results of performing the comparative validation through the comparison with the field data, the result of comparing it with maximum heating load in the simulation showed about 35 % based on the installation capacity of thermal energy system of targeting greenhouse. When applying the criteria to install the geothermal system by the Rural Development Administration (70 % of the maximum heating loads), it generates about 5 % of errors. Also, when the quantity of heat generated for 1 hour by the geothermal energy system through simulation with the installation capacity of the geothermal energy system in the target greenhouse, it generates about 6 % of errors. Through this, it could be recognized that the installation of geothermal energy system using BES was conducted.

- As the results of applying geothermal energy system to greenhouse, the heating system was conducted stably by keeping 20 ℃ that is the inside setting temperature of greenhouse at the temperature above -10 ℃, but it showed the unstable heating system showing the tendency that could not keep the setting temperature at the temperature below -10 ℃. This shows that as the installation capacity of geothermal system is set as 70 % of maximum heating loads, it cannot show 100 % of efficiency at extreme temperature. Accordingly, it is judged that it is necessary to prepare additional heating system using auxiliary heaters such as boilers or fan heaters.

Looking at above results, it was recognized that it can be applied to greenhouse that is the agricultural facility by using BES simulation and the more accurate energy consumption of interior greenhouse could be grasped efficiently through the comparison with existing energy analysis method. And, as the example of applying and simulating geothermal energy system to greenhouse by using BES, it is expected that more accurate and predictable simulation method can be applied to greenhouse by simulating various new renewable energies and facility system as well as geothermal energy. It is considered that the reliability of BES method can be risen through the further studies that seek the energy load characteristic of actual greenhouse such as ventilation, warm curtain and crops and can used as the important technology for the calculation of energy load for building up the optimal environment of heating and cooling facilities of greenhouse.

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국문초록

실측데이터를 적용한 지열 유리온실의 동적 열 에너지 해석 및 검증

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나날이 치솟는 유가와 시설재배의 규모 및 면적이 증가하는 시점에서 시설의 냉·난방을 위한 적정 규모의 설비산정은 합리적인 농가 경영 및 에너지 절감 측면에서 반드시 선행되어야 할 과제이다. 본 연구에서는 일반 건축물의 해석에 이용되는 건물 에너지 시뮬레이션 (BES) 기법을 농업분야의 온실에 적용한 기초연구로, 온실의 냉·난방부하 특성을 비교·분석하는 내용을 다루고 있다. 먼저 BES 프로그램 중 하나인 TRNSYS를 이용하여 온실 모델의 설계방법을 강구하고 이에 대한 검증을 수행하였다. 그리고 검증된 온실을 바탕으로 국내대표적 자연환기식 유리온실인 와이드스팬형과 벤로형 온실에 국내 6개 지역의 2010년 1년간의 기상데이터를 적용하여 동적 에너지 부하 특성을 비교 분석하였다. 이와 더불어 최근 시설원예 산업에서 대체에너지원으로 각광받고 있는 지열에너

지 시스템을 BES를 이용하여 구현하고자 하였으며, 이에 대한 분석을 수행하였다.

TRNSYS를 이용한 온실 모델 설계방안과 현장 실험 결과는 온실의 연동 수대로 공간을 분할한 vertical 모델이 1차와 2차 결과 모두 5.2%와 5.5%의 오차를 보여 정성적, 정량적으로 좋은 결과를 보였다. 검증된 결과를 바탕으로 국내 대표적 유리온실인 와이드스팬형과 벤로형 온실과 국내 6개 지역별 부하 예측을 수행한 결과, 연간난방부하는 대체로 고위도 지역인 춘천에서 저위도 지역인 제주 순으로 약 11~49 %정도 높은 부하를 보였으며, 이와 반대로 연간냉방부하는 저위도 지역에서 고위도 지역으로 갈수록 낮은 부하를 보였다. 그 중 분지형태의 지형특성을 가진 대구에서 가장 높은 부하가 발생하여, 이를 기준으로 전주, 청주, 수원, 춘천 순으로 각각 약 6, 12, 19, 22 %의 낮은 부하를 보였다. 또한 각 지역별 두 온실간의 부하차이는 벤로형 온실이 와이드스팬형 온실보다 난방의 경우 약 3~8 %, 냉방의 경우 약 5~6 % 정도 높게 산정되었다. 최대 냉·난방부하는 연간 냉·난방부하의 경향과 유사하게 나타났으며, 최대냉방부하의 경우 실제 최고기온이 발생한 시간과는 다르게 시뮬레이션에서는 다른 일부 시간에서 최대냉방부하가 발생하였다. BES를 이용한 동적해석법의 결과를 정적해석법과 비교한 결과, 두 해석방법간의 최대난방부하 차이는 와이드스팬형과 벤로형 두 온실모두 동적해석법이 약 30~36 %와 27~33 %로 적게 산출되었으며, 기간난방부하 역시 동적해석법이 약 44~49 %와 43~47 %로 적게 산출되었다. BES를 이용하여 온실의 지열에너지 시스템을 모의 하여 대상온실인 남원 탑그린 온실의 지열설치용량과 비교한 결과, 시뮬레이션상의 최대난방부하는 실제 지열 설치의 기준인 최대난방부하의 70 %를 고려하면 약 5 %의 차이를 보였다. 또한 시뮬레이션을 통한 지열에너지 시스템의 1시간동안의 발생열량과의 비교에서는 약 6 %의 차이를 보였다.

본 연구에서는 BES 기법을 이용하여 농업시설인 온실로의 적용 가능성을 확인하였으며, 기존의 에너지 해석방법과의 비교를 통해 보다 정확한 온실 내 에너지 소비량을 효율적으로 파악할 수 있었다. 또한 지열에

너지 시스템을 BES를 이용하여 구현하고 온실에 적용한 예로, 지열에너지뿐만 아니라 다양한 신재생에너지 및 다양한 설비시스템을 구현하여 보다 정확하고 예측 가능한 시뮬레이션 기법이 온실에 적용될 수 있을 것으로 판단된다. 추후 온실의 환기, 보온커튼 및 작물 등 실제 온실의 에너지 부하 특성을 모사하는 연구를 통해 BES기법의 신뢰성을 더욱 높여줄 것이며, 온실의 냉난방 시설 설비의 최적 환경 조성을 위한 에너지 부하 계산에 중요한 기술로 활용될 수 있을 것으로 사료된다.

주요어 : 건물에너지시뮬레이션, 동적해석, 온실, 정적해석, 지열
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