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Development of On-site Heat Loss Audit and Energy Consulting System for Greenhouse

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Abstract

Purpose: Greenhouses for a protected horticulture covered with a plastic or glass are easy to have weakness in a heat loss by deterioration, damage, poor construction, and so on. To grasp the vulnerable points of heat loss of the greenhouses is important for heating energy saving. In this study, an on-site heat loss audit and energy consulting system were developed for an efficient energy usage of a greenhouse. **Method:** Developed system was mounted with infrared thermal and visual cameras to grasp the heat loss from the greenhouse quickly and exactly, and a trial calculation program of heating load of greenhouse to provide farmers with the information of heating energy usage. **Results:** Developed system could print out the reports about the locations and causes of the heat losses and improvement methods made up by an operator. The mounted trial calculation program could print out the information of the period heating load and fuel cost according to the conditions of greenhouse and cultivation. The program also mounted the databases of the information on the 13 horticultural energy saving technologies developed by the Korea Rural Development Administration and simple economic analysis sub-program to predict the payback period of the technologies. **Conclusion:** The developed system was expected to be used as the basic equipment for an instructors of district Agricultural Technology and Extension Centers to conduct the energy consulting service for the farmers within the jurisdiction.

Keywords: Energy consulting, Greenhouse, Heat loss audit, Heating load, Infrared thermal image

Introduction

The protected horticulture of the present time has been transformed to a significantly energy-intensive industry, and particularly, farms which produce high value-added agricultural products by heating are rapidly increasing due to the policy of protected horticulture modernization in the 1990s and the increased demand of high quality agricultural products. In 2011, cultivation area with heating was 16,263ha which amounts to 31% of the entire domestic protected horticulture area (52,393 ha), and compared with the corresponding figures (13,329 ha and 53,408 ha, respectively) in 2008, which the percentage of cultivation area with heating continues to increase despite of the decreasing entire area (MAFRA, 2012a, b). Despite of this trend, domestic protected horticulture is very vulnerable to the change of external factors like soaring international oil price, as about 89% of its heating energy depends on oil. According to horticultural crops, the percentage of light and fuel expenses is very high and amounts to 30~50% of the working expenses of protected horticulture farms, which acts as the factor of financial difficulty of farms and farm prices rise (RDA, 2008).

A greenhouse is a simple frame structure covered with plastic or glass, and particularly, 98.8% of domestic greenhouses is vinyl houses which have low heat insulation property compared with general structures and are liable to the occurrence of vulnerable points of heat loss due

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to deterioration, damage, poor construction, etc. Though it is important to reduce energy input by using efficient air conditioners like heat pumps to save energy costs of protected horticulture farms, it can be a more realistic energy saving means to correctly audit vulnerable points of heat loss which occur by the above-mentioned causes and appropriately respond to them to minimize the loss of input energy. For general structures over a certain scale, standard of heat insulator for the prevention of heat loss, etc. is specified according to the 'Energy Saving Design Standards of Buildings', and energy-guzzling business operators which have more than 2,000 toe of annual energy consumptions should perform energy audit at five-year intervals according to 'Energy Use Rationalization Act'. A different energy audit method is required, however, as greenhouses are greatly different from general structures in structure, materials, air conditioner, etc. and are differentiated from other industries in energy consumptions and consuming form. As the research on the audit of heat loss in agricultural facilities, domestic researches were performed which audited vulnerable points of heat loss occurring in greenhouses by using the infrared thermal camera (RDA, 2009; Moon et al., 2010; Im et al., 2013) which has been mainly used for identifying defects of insulation, facilities, etc. in architecture (Jeong et al., 2003; Choi et al., 2004; Choi et al., 2007; Chang et al., 2010).

While heating load becomes an important standard of decision making when horticulture farmers establish the management plan like crop conversion and facility improvement, they have difficulty in establishing reasonable farming plan as they generally depend upon others' experiences. Therefore, a tool is to be developed which can be used for management decision making by inputting information on the greenhouse type, covering, crop, heater, etc. and predicting necessary heating energy of greenhouses. Though a variety of energy saving technologies are being developed and provided for improving the management balance of protected horticulture farmers, farmers have much difficulty in applying them to real farming as they cannot easily access the information like technical characteristics or economical efficiency (RDA, 2010).

This research aimed at developing an on-site heat loss audit and energy consulting system by which it is possible to consult farmers to improve energy efficiency of the corresponding greenhouses on the farming field by using heat loss audit of farming greenhouse, trial calculation program of heating energy consumption and database of horticultural energy saving technologies.

Materials and Methods

On-site heat loss audit system

The on-site heat loss audit system was equipped with the infrared thermal camera and visual image camera to correctly and rapidly detect vulnerable points of heat loss of the greenhouse. An infrared thermal camera is a measuring instrument which detects infrared rays emitted from of a body surface in proportion to its temperature and converts the infrared energy into an electric signal. Then it is processed to produce a thermal image on a monitor display and calculate temperature value. Generally, it is possible to easily detect points with relatively greater heat loss by measuring temperature distribution of inner or outer surface of the greenhouse cover, as the outer and inner surface temperatures of the wall are similar to the outdoor and indoor temperatures, respectively. The infrared thermal camera is recognized as an efficient energy audit and consulting method as it is a non-contact type measurement method. It can

Table 1. Hardware configuration of the on-site heat loss audit system

Elements	Specifications	Manufacturers
Infrared thermal camera	Detector spectrum length : 8~14 μm Measurement range : -20~120℃	COX, Korea
Visible camera	1/3 inch CCD, 580 TV lines Lowlight performance : 0.07 lx	Honeywell, USA
Frame grabber	NTSC, PAL, RS-170 video sources	Matrox, Canada
Lens	Variable focal length : 5~85 mm	Computar, Japan
Power supply	Rechargeable Ni-MH battery 13000mAh, DC 12V, 6A	Everwin, China
LCD Monitor	15 inch, resolution 1024 x 768	NI, USA

fast obtain the information on the wide scope of measurement, and has excellent visual effect (Allgaier et al., 1993; KICT, 2003). Table 1 shows the hardware configuration and its specifications of the on-site heat loss audit system. The system has been set up so that the infrared thermal camera and visual image camera simultaneously shoot the same point and both cameras display the results on the monitors, and the real position of vulnerable points of heat loss confirmed in the infrared thermal image display can be also viewed in the visual image display. The measurement of heat loss is mainly performed right before sunrise or sunset or in the night as it should be targeted for the greenhouse being heated and exclude the effect of sun light for accurate audit, which requires the visual image camera to have the night shooting function. Rechargeable Ni-MH battery was used as a power supply and if fully charged, it could operate the system for about four hours with one battery. A touch screen type 15 inch monitor was used when performing on-site audit and consulting for efficient communication with the farmer.

Trial calculation program of greenhouse period heat load

Trial calculation program of greenhouse period heat load installed in the on-site heat loss audit system for use in the energy consulting was based on the following equation generally used in greenhouse heating load calculation (RDC, 1997; Kim et al., 2000).

$$Q_g = [A_g\{H_t(1-F_r)+H_v\}(T_s - T_d) + A_s \cdot q_s] \cdot F_w \qquad (1)$$

where, Q_g : Heating load (W)
A_g : Greenhouse covering area (m^2)
A_s : Greenhouse floor area (m^2)
H_t : Overall heat transfer coefficient of covering ($W/m^2 \cdot ℃$)
H_v : Equivalent heat transfer coefficient due to ventilation ($W/m^2 \cdot ℃$)
T_s : Greenhouse heating setup temperature (℃)
T_d : Outside temperature, dry bulb temperature of standard weather data (℃)
F_r : Saving ratio of heat loss of covering
F_w : Correction factor for outside wind velocity
q_s : Ground heat transfer load per unit floor area (W/m^2)

The period heating load of the greenhouse was calculated by integrating, for the entire heating period, hourly heating load calculated by use of equation (1) based on the difference of the greenhouse outside temperature and heating setup temperature. Heating time was set from 18:00 on a day to 08:00 on the next day, considering nighttime heating only. Table 2 shows a database inputted in the program for the calculation of heating load. For regional greenhouse outside temperatures, hourly dry bulb temperatures were extracted among 30 years reference standard weather data for 7 regions in Korea during 1981 to 2010 provided by The Korean Solar Energy Society (KSES, 2013). For the greenhouse type, 7 types of greenhouse were considered according to roof shapes, and if width, heights of eaves and ridge, length and number of spans were input, the area of each part of the greenhouse was calculated. For correction factor, heat transfer coefficients, heat loss saving ratio, ground heat transfer load used in the calculation, the values generally used in heating load calculation were applied (RDC, 1997; Kim et al., 2000). For the heating setup temperature of the greenhouse, crop-specific recommended temperatures were prepared as a database and inputted, or the temperatures were also made to be directly inputted. The fuel consumption and fuel cost during the heating period were calculated by using equations (2) and (3), respectively.

$$V = Q_p / (H \times \eta) \qquad (2)$$

$$C = V \times B \qquad (3)$$

where, V = Fuel Consumption (m^3 for oil), (kg for LPG), (Wh for electricity)
Q_p = Period heating load (J)
H = Higher heating value of fuel (J/m^3 for oil), (J/kg for LPG), (J/Wh for electricity)
η = Heater thermal efficiency
C = Fuel cost (Won)
B = Fuel price (Won/m^3 for oil), (Won/kg for LPG), (Won/Wh for electricity)

For on-site energy consulting, the trial calculation program of greenhouse period heat load had, as a sub-menu, a database of 13 horticultural energy saving technologies developed by Korea Rural Development Administration (RDA, 2010). The database included the

Table 2. Database used in the trial calculation program of greenhouse period heat load (RDC, 1997; Kim et al., 2000)

Parameter		Database
Outside dry bulb temperature of standard weather data (T_s)		Seoul, Daejeon, Daegu, Busan, Gangju, Inchon, Ulsan
Greenhouse type		Tunnel, arch, monoslope, three quarter, wide span, Dutch light, Venlo
Correction factor for outside wind velocity (F_w)		Strong wind region (Busan, Inchon), general wind region (the rest)
Equivalent heat transfer coefficient due to ventilation (H_v)		Glass greenhouse, vinyl house/plastic board greenhouse, greenhouse with thermal screen
Overall heat transfer coefficient of covering (H_t)	Single covering	Glass, PE film, PVC film, plastic board(FRP, FRA, MMA), pair glass(12, 14, 24 mm)
	Double covering	Glass + glass, PE film + PE film, PVC film + PVC film, glass + PVC film, acrylic board + acrylic board
Saving ratio of heat loss of covering (F_r)	Single thermal screen	PE film, PVC film, non-woven fabric, aluminum mix film, aluminum deposition film, multifold thermal screen
	Double thermal screen	PE film + PE film, PE film + non-woven fabric, PVC film + PE film, PVC film + non-woven fabric, PVC film + PVC film, PVC film + aluminum deposition film, PE film + aluminum deposition film, multifold thermal screen + non-woven fabric(or PE film)
	External covering	multifold thermal screen
Greenhouse heating setup temperature (T_d)		Vegetables 16 (leaf vegetable 5, fruit vegetables 11), Ornamental crop 26
Heater thermal efficiency (η)		Hot air heater, hot water boiler, electric heater
Higher heating value of fuel (H)		Kerosene, Light oil, heavy oil, LPG, electric power
Fuel price (B)		Tax exemption oil for agriculture, electric power for agriculture

structure, performance, energy saving effect, information of government subsidies, cases of application to farms, etc. of each technology. It also included a simple economic analysis sub-program which can calculate the amount of heating cost saving and payback period of each energy saving technology.

Results and Discussion

On-site heat loss audit system

Figure 1 shows the external view of the developed on-site heat loss audit and energy consulting system. The infrared thermal camera and visual camera could be manually adjusted to point at the subject of heat loss audit, and both cameras were set up to always shoot the same position. Taken images were displayed on the analyzing monitor in real time, and the wireless keyboard and mouse were equipped for the temperature distribution analysis and the preparation of heat loss audit report. The analysis results could be output via the USB port, or it was possible to print the heat loss audit report on site by connecting a printer.

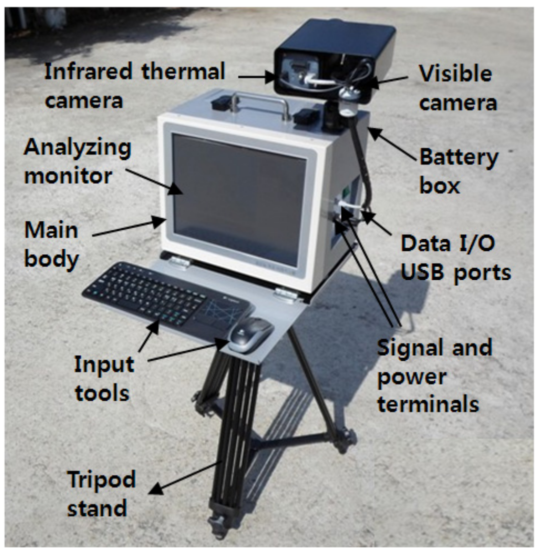
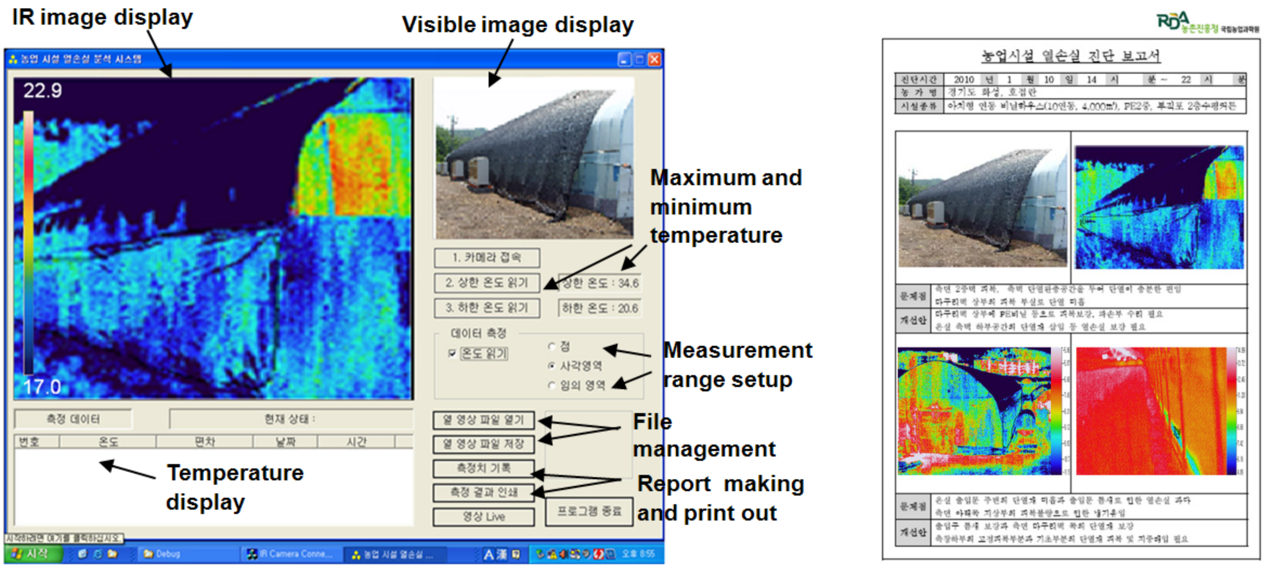


Figure 1. External view of heat loss audit and energy consulting system.

Figure 2 shows the display screen on the heat loss analyzing monitor and heat loss audit report made up by operator and provided to farmer. The infrared thermal image was displayed on the left, big screen and the visible image for confirming the real position of vulnerable points of heat loss was displayed on the right, small screen. Maximum and minimum temperatures of the



(a) Heat loss analyzing monitor display

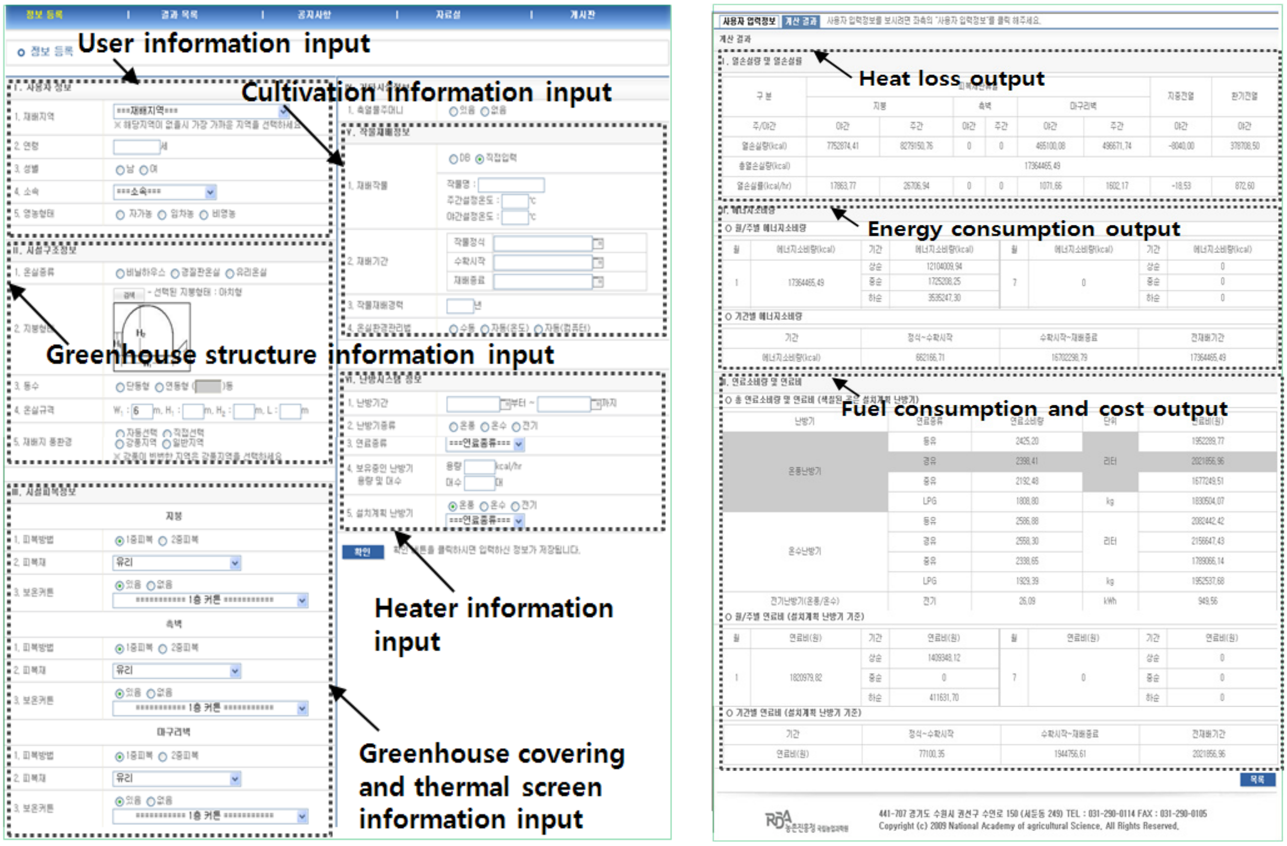
(b) Heat loss audit report

Figure 2. Heat loss analysis on greenhouse and heat loss audit report provided to farmer.

taken area were automatically displayed, and it was possible to perform the temperature analysis on the infrared thermal image by measuring the spot temperature and mean temperatures of rectangular zone or any closed curve zone by using the mouse. Measured temperatures were recorded on the infrared thermal image, and the temperature-recorded infrared thermal image and visual image could be saved as a JPEG file for use in the preparation of the heat loss audit report or be called again to the display monitor for re-analysis. As shown in figure 2 (b), the saved infrared thermal image and visual image could be inserted as a image file in the heat loss audit report. And it was possible to input problems like the position of vulnerable points of heat loss of the audited greenhouse and its causes and improvement methods like repair of facility and insulation reinforcement in problem field and improvement method field of the report, respectively. The prepared heat loss audit report could be output by connecting the printer and provided to the farmer in the field.

Trial calculation program of greenhouse period heat load

Figure 3 shows the information input window and calculation result output window of the trial calculation program of greenhouse period heat load installed in the on-site heat loss audit system. The input window consisted of user information section, greenhouse structure section, covering and thermal screen section, cultivation section and heater section. In User information section, greenhouse installation region and general farm information were entered for establishing statistics of energy consulting-performed farms. For the greenhouse installation region, one of 7 regions was selected from the pop-up menu of the regions shown in table 2 where standard weather data is made as a database. If the corresponding region did not exist, the nearest region was selected. In greenhouse structure section, roof type, number of spans, width, heights of eaves and ridge, length of the cultivating greenhouse were entered. In covering section, material and number of layers of the covering and thermal screen at the roof, side wall and end pieces of the greenhouse were entered, and the covering material and thermal screen are selected from the pop-up menu. In cultivation section, heating setup temperature and cultivating period were entered. For the heating setup temperature, a crop could be selected from the pop-up menu or temperature could be directly inputted. In heater section, heating period of greenhouse and kinds of heater and fuel were selected from the pop-up menu. It was possible to view the calculation results shown in Figure 3 (b) in the list of result menu by clicking the confirm button when information input has been completed. In heat loss output section, it is possible to view the heat loss rate on each part of the greenhouse. In energy consumption section, it was possible to view monthly and per-ten days energy consumptions



(a) Information input (b) Calculation result output

Figure 3. Trial calculation program of greenhouse period heat load.

(a) Horticultural energy saving technologies (b) Information provided to farmer

Figure 4. Database of the horticultural energy saving technologies.

during cultivation period and energy consumptions during planting to harvest start and harvest start to cultivation end. In fuel consumption and cost section, it was possible to view the amount of fuel consumption and necessary fuel costs according to periods and fuel types. The results of the trial calculation could be output by connecting the printer and provided to the farmer at the time of energy consulting in the field.

Figure 4 shows a database of 13 horticultural energy saving technologies developed by Korea Rural Development

Administration as a sub-menu of the trial calculation program of greenhouse heat load. It was possible to view detailed information on the energy saving technology as shown in the left of figure 4 (b) by clicking the technology image in figure 4 (a). It was also possible to view detailed information on the government subsidies of each technology shown in the left of Figure 4 (b) by clicking the right, blue button in the lower left side of Figure 4 (a).

It was possible to open the simple economic analysis sub-program for energy saving technologies shown in Figure 5 by clicking the left, blue button in the lower, left side of Figure 4 (a). The initial investment cost was calculated in real time by using the per-unit area installation price of each technology inputted in the database and entered greenhouse area for each energy-saving technology. The amount of heating cost saving was calculated in real time by using the heating energy saving rate of each technology inputted in the database also and entered heating cost of last year. And the payback period of each technology was calculated and displayed in real time by using the initial investment cost and amount of heating cost saving. As the heat loss audit report, the above results of trial calculation of greenhouse period heating load, fuel cost prediction and information of energy saving technologies could be output by connecting a printer and provided to the farmer at the time of on-site energy consulting.

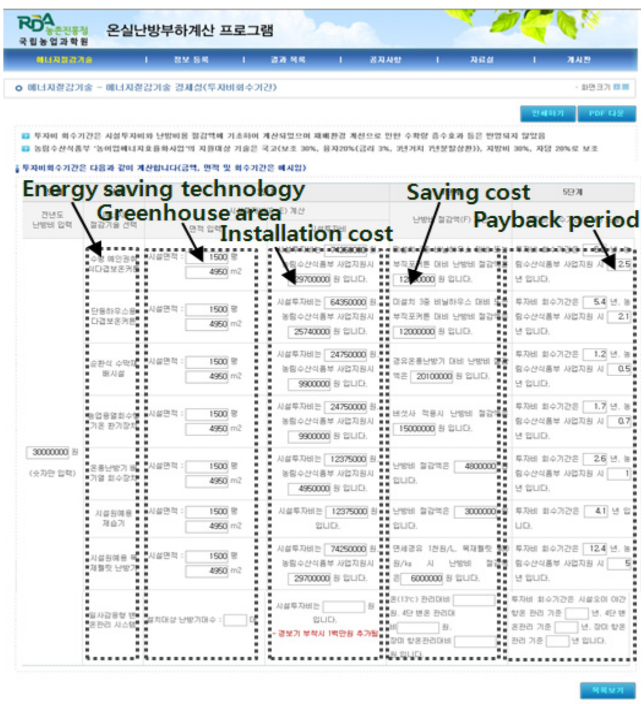


Figure 5. Economic analysis sub-program for energy saving technologies.

Conclusions

In this study, an on-site heat loss audit and energy consulting system was developed for performing energy consulting targeted for greenhouses with low energy efficiency. The developed system could quickly and exactly detect the vulnerable points of heat loss which could occur by a variety of causes like deterioration, damage and poor construction by using the infrared thermal camera and visual camera, and prepare and provide to the farmer the heat loss audit report which includes the locations and causes of vulnerable points of heat loss, and improvement methods like repair of facility and insulation reinforcement. The trial calculation program of period heat load of greenhouse installed in the heat loss audit system could be used for providing information on heating cost of greenhouse to farmers. In addition it can be used for examining energy saving effects of reinforcement of covering, installation of thermal screen, change of heating set up temperature, etc. Also, the database of the information on horticultural energy saving technologies developed by Korea Rural Development Administration and the simple economic analysis sub-program to predict the payback period of the energy saving technologies could provide useful information which could be used by the farmers who consider the introduction of energy-saving technologies in management decision making. The developed system was expected to be used as the basic equipment for instructors of district Agricultural Technology and Extension Centers to conduct the energy consulting for greenhouses within the jurisdiction.

Conflict of Interest

The authors have no conflicting financial or other interests.

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References

Allgaier, M. W., S. Ness, P. McIntire and P. O. Moore. 1993. Nondestructive testing handbook, Vol 8. 2nd ed. Ohio: American Society for Nondestructive Testing.

Chang, Y. S., C. D. Eom, J. H. Park, J. J. Lee, J. S. Park, M. J. Park and H. M. Yeo. 2010. Thermal environment evaluation of wooden house using Infra-red thermal image and temperature difference ratio (TDR). Mokchae Konghak 38(6):518-525 (in Korean).

Choi, G. S., K. W. Kim, J. S. Kang and S. E. Lee. 2007. Evaluation on thermal performance combined with measurement and simulation for development of on-site evaluation method. *Proceeding: Building Simulation 2007*, pp. 175-182.

Choi, G. S., Y. S. Jeong, J. S. Kang and S. E. Lee. 2004. Development of on-site evaluation method for building insulation performance using infra-red camera', *Proceedings of the SAREK SummerAnnual Conference*, pp. 589-594 (in Korean).

Im, J. U., S. W. Yun, H. T. Kim and Y. C. Yoon. 2013. Current on the heat loss in greenhouse during winter season. Protected Horticulture and Plant Factory 22(1):73-79 (in Korean).

Jeong, Y. S., G. S. Choi, J. S. Kang and S. E. Lee. 2003. A study on estimate of surface temperature in corners of building envelope. *Proceeding of Architectural Institute of Korea* 23(2):841-844 (in Korean).

Kim, M. K., S. W. Nam, W. M. Suh, Y. C. Yoon, S. G. Lee and H. W. Lee. 2000. Agricultural Structures Engineering. Seoul, Korea: Hyangmoonsa (In Korean).

Korea Institute of Construction Technology (KICT). 2003. A study on development of the technology for standardizing IR-method-based building insulation evaluation methods. Gwacheon, Korea: Ministry of Commerce, Industry and Energy (in Korean).

KSES. 2013. Standard weather data. Seoul, Korea : The Korean Solar Energy Society. Available at: www.kses.re.kr.

Ministry of Agriculture, Food and Rural Affairs (MAFRA). 2012a. Greenhouse status for the vegetable grown in facilities and the vegetable productions in 2011. Gwacheon, Korea: MAFRA (in Korean).

Ministry of Agriculture, Food and Rural Affairs (MAFRA). 2012b. Cultivation status of floricultural crop in 2011. Gwacheon, Korea: MAFRA (in Korean).

Moon, J. P., N. K. Yun, S. H. Lee, H. J. Kim, S. J. Lee and Y. H. Kim. 2010. Heat loss audit and assessment of the greenhouse using infrared thermal image analysis. Journal of the Korean Society of Agricultural Engineering 52(2):67-73 (in Korean).

Rural Development Administration (RDA). 2008. Protected cultivation energy saving guidebook for overcoming high oil price. Suwon, Korea: RDA (in Korean).

Rural Development Administration (RDA). 2009. Case collection of heat loss audit for agricultural facilities. Suwon, Korea: RDA (in Korean).

Rural Development Administration (RDA). 2010. New agricultural energy saving technologies for improvement of farm management balance. Suwon, Korea: RDA (in Korean).

Rural Development Corporation (RDC). 1997. Design Standards for Greenhouse Environment. Uiwang, Korea: RDC (in Korean).