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# Classification Index and Grade Levels for Energy Efficiency Classification of Agricultural Heaters in Korea

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## Abstract

**Purpose:** This study was carried out to develop a classification index and grade levels to rate agricultural heaters for energy efficiency classification. **Methods:** The classification index was developed mainly by taking simplicity of calculation and easy access to relevant data into consideration. The grade levels were developed on the basis of a 5-grade classification system in which graded heaters are to be normally distributed over the grades. The value of each grade level were determined in terms of the classification index values calculated using the published performance data of agricultural heaters tested at the FACT in Korea over the past 12 years. **Results:** The thermal efficiency of agricultural heaters based on the enthalpy method was proposed as a reasonable classification index. The grade levels were proposed in equation form for three types of agricultural heaters: fossil fuel heaters, wood pellet heaters and wood pellet boilers. A reasonable energy efficiency classification of agricultural heaters could be performed using the proposed classification index and grade levels. **Conclusions:** It is expected that energy saving programs will be extended to agricultural machines in the near future. The classification index and grade levels to rate agricultural heaters for energy efficiency classification were developed and proposed for such near future to come.

**Keywords:** Agricultural heaters, Classification index, Energy efficiency classification, Grade levels

## Introduction

As energy prices increase, national and personal interests have been growing in saving and efficient use of energy. In Korea, there are three energy efficiency programs which are being conducted by the government: Energy Efficiency Rating System, High Energy Efficiency Certification System and Standby Power Reducing Program. Among them, Energy Efficiency Rating Program has been carried out since 1992 and currently 35 energy-related products are subjected to this program. The products include electric refrigerator, electric rice cooker, household gas boiler, gas water heater, and others (MKE, 2012). However, none of agricultural machines have been included although they are consuming a large amount of tax-free fuels. Therefore, it is expected that the energy efficiency programs will be extended to agricultural machines, particularly those machines that consume large portions of tax-free fuels in the near future.

Korea has supplied tax-free fuels to 42 kinds of agricultural machines including agricultural tractors, grain driers, agricultural products driers and agricultural heaters (RDA, 2010). The annual consumption of the tax-free fuels has been estimated to be about 1 trillion Korean Won in value. Of that more than 60% has been used for agricultural heaters mainly for heating greenhouses (NACF, 2011). Demand for agricultural heaters is still high and supply of tax-free fuels is also expected to increase accordingly.

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Among agricultural machines, tractor was the first one considered in Korea that needs energy efficiency classification. Shin and Kim (2012) has proposed the index and method for the classification of tractors using the performance data of 131 tractor models tested from 2006 to 2010 in Korea.

Since agricultural heaters consume the largest portion of the tax-free fuels, it may be rational to consider them following the tractors as the machine that needs energy efficiency rating. The first attempt for the rating was made with 18 models of hot-air type of agricultural heaters in 2012. They were classified into 5 grade levels on the basis of the energy efficiency classification method used for household gas boilers (Kim et al., 2012). Since agricultural heaters have many different types, the method was not proper to other types and more reasonable method applicable to various types is required. The method also must be acceptable to different stakeholders of manufacturers, consumers and government officials when the classification is to be used as regulation purposes. In this study, it was intended to develop a reasonable classification index and the grade levels to rate various types of agricultural heaters for energy efficiency classification.

# Materials and Methods

## Agricultural heaters for efficiency rating

In general, diesel, kerosene, heavy oil, wood pellet, coal, liquefied petroleum gas (LPG) and electricity are those energy sources that can be used to heat greenhouse in Korea. LPG heaters are not widely used due to a requirement of extra storage facilities and a danger of explosion when they are heated. Coals are no longer used owing to inconvenience in handling. Use of electrical heaters has increased recently due to cheap agricultural electricity rates. Since electrical heaters have high energy efficiency of 96-99%, the rating may produce no meaningful classification for them. Supply of wood pellet heaters and boilers has also increased recently because the government has provided farmers with purchase subsidy.

In this study, it was assumed that energy efficiency classification will be performed on agricultural heaters utilizing fossil fuels, mainly kerosene and diesel, and wood pellet. No distinction was made between the kerosene and diesel heaters because they are the same in their structures, heating principles and testing methods. Wood pellet heaters were divided further into two types: heater and boiler, of which energy efficiency classifications are to be conducted separately.

## Performance data of heaters

FACT (Foundation of Agricultural Technology Commercialization and Transfer) has conducted performance test for agricultural heaters and published the test report which contains the data on heating capacity, type of fuel, fuel consumption, power consumption and thermal efficiency. The FACT test code can be referred to as a test method (FACT, 2012). Before 2011, the heating capacity was estimated by the heat loss method which can be expressed by

$$Q=(H_l+Q_f-L)m \tag{1}$$

Where, $Q$ = *Heating capacity, kcal/h*
$H_l$ = *lower heating value of the fuel, kcal/kg*
$Q_f$ = *heat required to preheat the fuel, kcal/kg*
$L$ = *Heat loss by exhaust gas, kcal/kg*
$m$ = *Fuel consumption, kg/h*

for fossil fuel and wood pellet heaters and by

$$Q=G_w\times C_p\frac{\sum_{i=1}^{n}(t_{2i}-t_{1i})}{n} \tag{2}$$

Where, $Q$ = *heating capacity, kcal/h*
$G_w$ = *water flow, kg/h*
$C_p$ = *average specific heat of water, kcal/kg* ℃
$t_{2i}$ = *temperature of outlet water,* ℃
$t_{1i}$ = *temperature of inlet water,* ℃
$n$ = *number of temperature measurement*

for wood pellet boilers. Estimation of heating capacity has been changed by the enthalpy method since 2011, from which the heating capacity was estimated as follows:

$$Q=3600\times\rho\times A\times V\times C_p\times(t_2-t_1) \tag{3}$$

Where, $Q$ = *heating capacity, kcal/h*
$\rho$ = *air density, kg/m*$^3$
$A$ = *cross sectional area of outlet port, m*$^2$
$V$ = *air velocity at outlet port, m/s*
$C_p$ = *specific heat of air under constant pressure, kcal/kg* ℃
$t_2$ = *temperature of outlet air,* ℃
$t_1$ = *temperature of inlet air,* ℃

The thermal efficiency was then calculated by using equation (4).

$$\eta_{th} = \frac{100 \times Q}{m \times H_g} \quad (4)$$

Where, $\eta_{th}$ = *thermal efficiency, %*
$Q$ = *heating capacity, kcal/h*
$m$ = *fuel consumption, kg/h*
$H_g$ = *gross calorific power of the fuel, kcal/kg*

## Classification index

The thermal efficiency estimated by equation (4) and given in the test report was taken as a classification index to rate the energy efficiency of agricultural heaters on account of simplicity of calculation and easy access to relevant data. However, it should be noted that the heating capacity in equation (4) is that estimated by the recently-adopted enthalpy method. Conversion of the thermal efficiency estimated by the heat loss method was done by using equation (5) which was developed from 6 kerosene heaters experimentally by FACT.

$$\eta_{enthalpy} = 1.1777\eta_{heatloss} - 26.75\,(R^2 = 0.823) \quad (5)$$

Where, $\eta_{enthalpy}$ = *thermal efficiency based on enthalpy method, %*
$\eta_{heatloss}$ = *Thermal efficiency based on heat loss method, %*

The classification index, $\eta_i$, of an agricultural heater, $i$, is then obtained directly from its test report if the thermal efficiency was determined by the enthalpy method or by using equation (5) if the thermal efficiency was determined by the heat loss method.

## Number of grades and grade levels

The number of grades for the classification was determined as 5 in compatible with current energy labeling system in Korea. In other words, the number of grades needs to be harmonized with those of other energy-related products which have already adopted a 5-grade system.

To determine the levels of 5 grades reflecting the state of art technology in energy efficiency of agricultural heaters, thermal efficiency data were taken from the test reports published over the past 12 years from 2001 to 2012. Table 1 shows the number of agricultural heater models tested in that period and used to determine the grade levels.

The grade system was designed for the graded heaters to be distributed normally over the grades, resulting in the 1st grade for upper 15%, the 2nd grade for the next 20%, the 3rd grade for the next 30%, the 4th grade for the next 20% and the 5th grade for lower 15%. The statistical method to implement the designed grade system was developed by Shin and Kim (2012) and given in equation form as follows:

$$\begin{aligned}
&1^{st}\ \text{grade}: \eta_{mi} + \triangle_m + 1.0364\sigma_\triangle \le \eta_i \quad (6)\\
&2^{nd}\ \text{grade}:\\
&\quad \eta_{mi} + \triangle_m + 0.3853\sigma_\triangle \le \eta_i < \eta_{mi} + \triangle_m + 1.0364\sigma_\triangle\\
&3^{rd}\ \text{grade}:\\
&\quad \eta_{mi} + \triangle_m - 0.3853\sigma_\triangle \le \eta_i < \eta_{mi} + \triangle_m + 0.3853\sigma_\triangle\\
&4^{th}\ \text{grade}:\\
&\quad \eta_{mi} + \triangle_m - 1.0364\sigma_\triangle \le \eta_i < \eta_{mi} + \triangle_m - 0.3853\sigma_\triangle\\
&5^{th}\ \text{grade}: \quad \eta_i < \eta_{mi} + \triangle_m - 1.0364\sigma_\triangle
\end{aligned}$$

Where, $\triangle_m = \frac{1}{N}\sum_{i=1}^{N}(\eta_i - \eta_{mi})$

$\sigma_\triangle = \frac{1}{\sqrt{N-1}}\sum_{i=1}^{N}(\eta_i - \eta_{mi})^2$

$\eta_i$ = *classification index value of agricultural heater model, $i$*

$\eta_{mi}$ = *average classification index value of agricultural heaters of which heating capacity is equal to that of the heater model, $i$*

$N$ = *number of models used to determine grade levels*

**Table 1.** Number of models for 3 types of agricultural heaters by heat capacity

| Heat capacity, kcal/h | Below 100,000 | 100,000 ~200,000 | 200,000 ~300,000 | 300,000 ~400,000 | 400,000 ~500,000 | Above 500,000 | Sum |
|---|---|---|---|---|---|---|---|
| Fossil fuel air heater | 17 | 30 | 10 | 2 | - | - | 59 |
| Wood pellet air heater | 10 | 28 | 5 | - | - | - | 43 |
| Wood pellet boiler | 4 | 28 | 36 | 30 | 9 | 16 | 123 |

# Results and Discussion

## Classification index value

Classification index values of the 59 models of the fossil fuel heaters were determined and plotted as shown in figure 1. They are scattered within a wide range but increased slightly with the heating capacity, which means thermal efficiency of the fossil fuel heater becomes better as the heating capacity increases. Average classification index value, $\eta_m$ can be represented as a linear regression between the heating capacity and classification index, and is expressed as a function of heating capacity as shown in equation (7).

$$\eta_m = 2\times10^{-6}\times Q + 77.018 \quad (7)$$

The average and standard deviation of the differences between the classification index value $\eta_i$ and the mean $\eta_m$ were estimated respectively to be $\triangle_m = 0.01$ and $\sigma_\triangle = 3.923$. The same work was done for 43 models of the wood pellet heaters and 123 models of the wood pellet boilers. Figures 2 and 3 show the scatter diagrams of the classification index values for the two types of heaters and table 2 shows their statistical values.

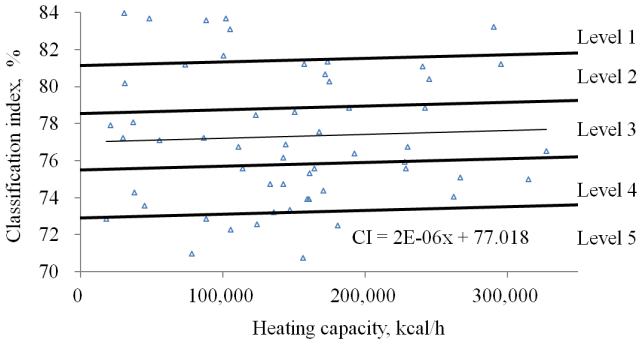


**Figure 1.** Scatter diagram of classification index values for fossil fuel heaters used for grade levels.

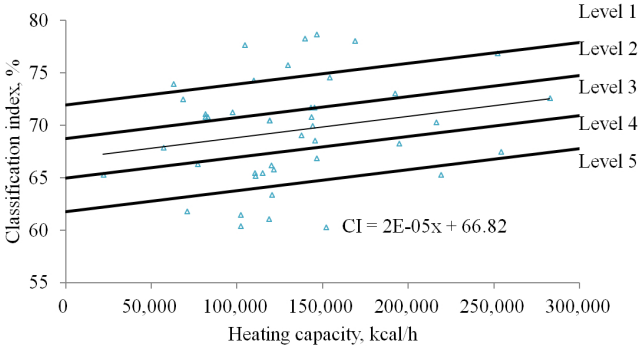


**Figure 2.** Scatter diagram of classification index values for wood pellet heaters used for grade levels.

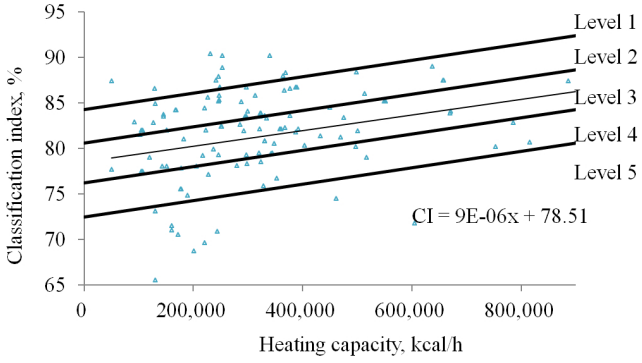


**Figure 3.** Scatter diagram of classification index values for wood pellet boilers used for grade levels.

## Grade levels for energy efficiency rating

Grade levels to rate the energy efficiency of the agricultural heaters were calculated by using equation (6) and the statistical values given in table 2. The boundary values of classification index for each level of grades can be expressed in equation form as follows:

For fossil fuel heaters

1st grade :
$$2\times10^{-6}\times Q_i + 81.13 \le \eta_i, \%$$

2nd grade :
$$2\times10^{-6}\times Q_i + 78.55 \le \eta_i < 2\times10^{-6}\times Q_i + 81.13, \%$$

3rd grade :
$$2\times10^{-6}\times Q_i + 75.50 \le \eta_i < 2\times10^{-6}\times Q_i + 78.55, \%$$

4th grade :
$$2\times10^{-6}\times Q_i + 72.92 \le \eta_i < 2\times10^{-6}\times Q_i + 75.50, \%$$

5th grade :
$$\eta_i < 2\times10^{-6}\times Q_i + 72.92, \%$$

For wood pellet heaters

1st grade :
$$2\times10^{-5}\times Q_i + 71.92 \le \eta_i, \%$$

2nd grade :
$$2\times10^{-5}\times Q_i + 68.73 \le \eta_i < 2\times10^{-5}\times Q_i + 71.92, \%$$

3rd grade :
$$2\times10^{-5}\times Q_i + 64.96 \le \eta_i < 2\times10^{-5}\times Q_i + 68.73, \%$$

4th grade :
$$2\times10^{-5}\times Q_i + 61.78 \le \eta_i < 2\times10^{-5}\times Q_i + 64.96, \%$$

5th grade :
$$\eta_i < 2\times10^{-5}\times Q_i + 61.78, \%$$

**Table 2.** Statistical values for development of grade levels

| Type of heater | Mean classification index | Mean, $\Delta_m$ | Standard deviation, $\sigma_\Delta$ |
|---|---|---|---|
| Fossil fuel heater | $\eta_m = 2\times10^{-6}\times Q_i + 77.018$ | 0.01 | 3.962 |
| Wood pellet heater | $\eta_m = 2\times10^{-5}\times Q_i + 66.82$ | 0.03 | 4.894 |
| Wood pellet boiler | $\eta_m = 9\times10^{-6}\times Q_i + 78.51$ | -0.11 | 5.708 |

For wood pellet boilers

1st grade :

$$9\times10^{-6}\times Q_i + 84.32 \le \eta_i, \%$$

2nd grade :

$$9\times10^{-6}\times Q_i + 80.60 \le \eta_i < 9\times10^{-6}\times Q_i + 84.32, \%$$

3rd grade :

$$9\times10^{-6}\times Q_i + 76.20 \le \eta_i < 9\times10^{-6}\times Q_i + 80.60, \%$$

4th grade :

$$9\times10^{-6}\times Q_i + 72.49 \le \eta_i < 9\times10^{-6}\times Q_i + 76.20, \%$$

5th grade :

$$\eta_i < 9\times10^{-6}\times Q_i + 72.49, \%$$

If an agricultural heater of heating capacity, $Q_i$, has a thermal efficiency, $\eta_i$ based on the enthalpy method, its grade in energy efficiency classification can be determined according to the grade levels proposed. These levels can be used for some time. However, it must be noted that the grade levels should not remain unchanged but should be adjusted accordingly as technology advances.

The grade levels were applied to rate the agricultural heaters that were used for the development of classification index and grade levels. Figure 4, 5 and 6 shows the grade distributions of the fossil fuel heaters, wood pellet heaters and wood pellet boilers respectively. Although the distribution differs slightly from the intended normal distribution, it seems reasonable from a statistical point of view when considering the limited number of models subjected to the classification.

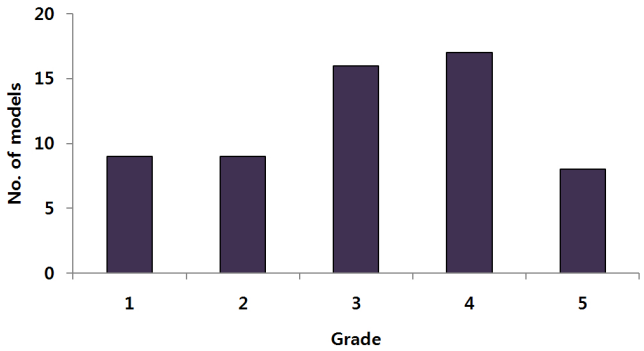


**Figure 4.** Grade distribution of fossil fuel heaters used for the classification index and grade levels.

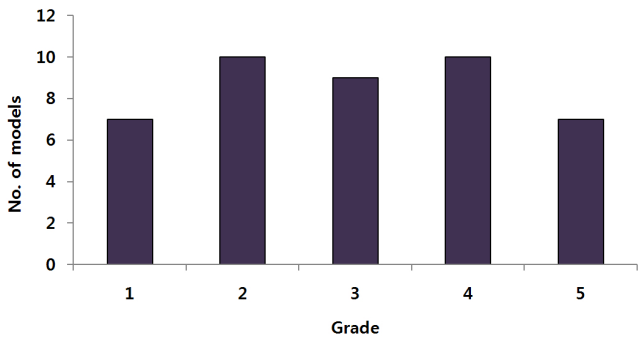


**Figure 5.** Grade distribution of wood pellet heaters used for the classification index and grade levels.

## Summary and Conclusions

As energy prices continue to rise, energy-saving programs are expected to extend to agricultural machinery. Tractors, heaters and dryers for agricultural use are those machines that may primarily be subjected to energy efficiency classification in the near future. To prepare for such future, this study was conducted to develop a reasonable classification index and the grade levels to rate agricultural heaters for energy efficiency classification.

Three types of agricultural heaters, fossil fuel heaters,

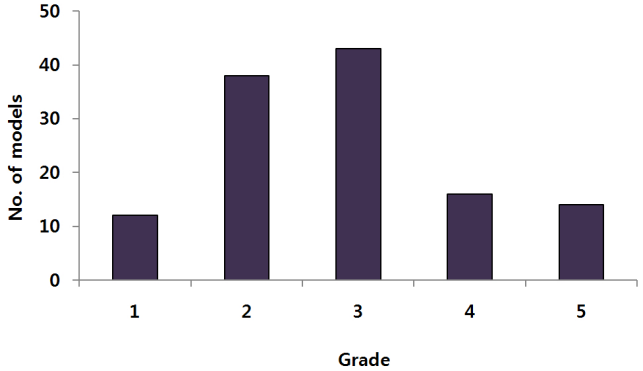


**Figure 6.** Grade distribution of wood pellet heaters used for the classification index and grade levels.

wood pellet heaters and wood pellet boilers, were considered and a 5-grade system was adopted for energy efficiency classification. The grade levels were designed to have the rated heaters distributed normally over the grade levels. The thermal efficiency based on the enthalpy method was proposed as a classification index. The values of each grade level were then determined in terms of the classification index value using the published performance data of agricultural heaters tested at the FACT over the past 12 years from 2001 to 2012. It was recognized that the energy efficiency classification can be conducted reasonably with the proposed classification index and the grade levels. However, it should be noted that the grade levels need to be reviewed and upgraded to adapt the technology developments periodically. Followings are summaries of this study:

(1) The thermal efficiency based on the enthalpy method was proposed as a reasonable classification index for energy efficiency classification of agricultural heaters.
(2) The grade levels of a 5-grade classification system were proposed for three types of agricultural heaters in terms of the classification index values calculated using the published performance data of agricultural heaters tested over the past 12 years.
(3) A reasonable classification of energy efficiency was able to be carried out using the proposed classification index and grade levels for some time until they need to be adjusted to reflect the advances in technology.

## Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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