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A NOVEL INTEGRATED ENERGY SYSTEM OF SOLAR POWER, HEAT PUMPS AND AI-EV (AIR-CONDITIONER ELECTRIC VEHICLE)

Tsuguhiko N.*
*Author for correspondence
Department of System Engineering,
Graduate school of Okayama Prefectural University,
111 Kuboki, Soja, Okayama 719-1197
Japan,
E-mail: nakagawa@cse.oka-pu.ac.jp

ABSTRACT

In order to reduce CO_2 emissions economically, it is important to construct a Smart Community which is expected to be one of the solutions. In a Smart Community, energy supply and demand will be managed by some mathematical models to consume energy efficiently and increase the introducing of renewable energy. In one of the systems, "Photovoltaic power generator (hereinafter referred to as PV) combined Electric Vehicle (hereinafter referred to as EV) Smart System" has been developed.[1]

In the "PV combined EV Smart System", PV power is charged directly to the EV battery, and then the charged PV power is consumed by running and air-conditioning energy of a car and the surplus electricity is supplied to a home. This system is able to reduce CO_2 emissions economically. In order to expand the system, it is necessary to spread EV and clarify the effects. At first, it should solve the issues of short cruising distance, the high cost of storage battery and the risk of dead battery. Therefore, the authors have proposed an advanced EV such as AI-EV (Air-conditioner Integrated Electric Vehicle).[2] AI-EV has a novel hybrid system which drives the air-conditioning system and generates electric power in the case of a low air-conditioning load through the use of a small-engine. If PV power can not only reduce car fuels but also replace with gas and liquid fuels which are consumed at a home, huge effect of CO_2 reduction is obtained as the whole of the system.

In this paper, a novel energy system which is combined and integrated with solar power, AI-EV and home heat pumps has been proposed. Heat pumps are car air-conditioner and CO_2 heat pump water heater for home use. A mathematical simulation model which is integrated with AI-EV model, CO_2 heat pump model and HEX model based on some experiments has been developed to evaluate a smart community which is constructed at an office and a home. And then, CO_2 emissions and economic efficiency are calculated and compared with those of the conventional system.

As the result, the novel energy system is able to reduce more than 40% of CO_2 emissions in comparison with the conventional system as the whole system, and the system can reduce more than 65% of CO_2 emissions in comparison with the conventional home. The economic efficiency is evaluated by more than 5.0% of Internal Rate of Return without some subsidies when the legal service life of the depreciation equipment is assumed 14 years. Therefore, the novel energy system can be widely spread in the future. Additionally, it is clarified that the integrated smart system can reduce the fluctuations which are caused by the PV power generation.

NOMENCLATURE

A_1	[m^2]	Cross section area of air-conditioner blowing port
A_2	[m^2]	Surface area of the vehicle cabin
A_3	[m^2]	Surface area of the vehicle cabin materials
A_4	[m^2]	Exhaust gap area
A_{CU}	[m^2]	Solar radiation area of vehicle
$A_{c,a}$	[m^2]	Heat transfer area of air-conditioner condenser
A_c	[m^2]	Heat transfer project area of air-conditioner condenser
$A_{e,a}$	[m^2]	Heat transfer area of air-conditioner evaporator
$A_{c,wi}$	[m^2]	Heat transfer area of water heater condenser
$A_{e,wi}$	[m^2]	Heat transfer area of water heater evaporator
c_{pa}	[$kJ.kg^{-1}.K^{-1}$]	Specific heat of the air
c_{pl}	[$kJ.kg^{-1}.K^{-1}$]	Specific heat of the vehicle cabin materials
C_m	[-]	Energy conversion factors from each fuel to other energy sources
COP_C	[-]	Coefficient of Performance of cooling
COP_H	[-]	Coefficient of Performance of heating
E	[kWh]	The total amount of energy variation
EF	[kWh]	Energy variation of HEX with Outflow, Inflow energy
ES	[kWh]	Energy variation of HEX with generating energy, consumption and storage
h_1	[kJ/kg]	Refrigerant enthalpy of compressor inlet
h_2	[kJ/kg]	Refrigerant enthalpy of condenser inlet
h_3	[kJ/kg]	Refrigerant enthalpy of condenser outlet
h_4	[kJ/kg]	Refrigerant enthalpy of evaporator inlet

J	[-]	Colburn's j-factor
M_3	[kg]	Weight of the vehicle cabin materials
mf_r	[kg/s]	Refrigerant mass flow rate
$mf_{c,a}$	[kg/s]	Air mass flow rate of condenser
$mf_{e,a}$	[kg/s]	Air mass flow rate of evaporator
Pr	[-]	Prandtl number
q_0	[kJ]	Enthalpy of outside air
q_1	[kJ]	Enthalpy of air-conditioner blow off air
q_2	[kJ]	Heat transfer quantity from outside
q_3	[kJ]	Enthalpy of cabin materials
q_4	[kJ]	Enthalpy of cabin air,
q_5	[kJ]	Enthalpy of discharged air to outside
q_n	[kJ]	Required capacity of air-conditioner
$Q_{S\gamma}$	[W/m^2]	Solar radiation based on an annual weather at time T_t
Q_P	[W/(person)]	Calorific value from person
t	[s]	Elapsed time
T_1	[K]	Air-conditioner blow off air temperature
T_2	[K]	Outside air temperature
T_3	[K]	Temperature of cabin materials
T_4	[K]	Cabin air temperature
T_5	[K]	Discharged air temperature to outside
ΔT_{LMTD}	[K]	Logarithmic mean temperature difference
T_a	[K]	Outside air temperature
$T_{cr,ave}$	[K]	Refrigerant average temperature at condenser
$T_{er,ave}$	[K]	Refrigerant average temperature at evaporator
$T_{cw,ave}$	[K]	Heated water average temperature
u_1	[m.s^{-1}]	Air blowing velocity from air-conditioner blowing port
u_5	[m.s^{-1}]	Velocity of discharged air to outside
V_4	[m^3]	Volume of the vehicle cabin
α_2	[W/(m^2·K)]	Overall heat transfer coefficient between cabin and outside air
α_3	[W/(m^2·K)]	Overall heat transfer coefficient of the vehicle cabin materials
$\alpha_{c,a}$	[W/(m^2·K)]	Heat transfer coefficient of air-conditioner condenser
$\alpha_{e,a}$	[W/(m^2·K)]	Heat transfer coefficient of air-conditioner evaporator
α_{ct}	[W/(m^2·K)]	Overall heat transfer coefficient of water heater condenser
α_{et}	[W/(m^2·K)]	Overall heat transfer coefficient of water heater evaporator
β	[-]	Correction coefficient of solar radiation
δ	[-]	The channel change coefficient
ρ_a		Air density
η_α	[-]	The efficiency of mechanical
η_β	[-]	The efficiency of adiabatic compression of the gas

Subscripts

Area	[-]	The area that is expressed in HEX
i	[-]	Position of study area in a x-axis direction
j	[-]	Position of study area in a y-axis direction
k	[-]	Boundaries of HEXs
m	[-]	Kind of energy source
n	[person]	The number of riding persons
n1	[-]	The number of HEXs in a x-axis direction
n2	[-]	The number of HEXs in a y-axis direction
n4	[-]	The number of kinds of energy source
r	[-]	Refrigerant

INTRODUCTION

In order to reduce CO_2 emissions economically, it is important to construct a Smart Community which is expected to be one of the solutions. In a Smart Community, energy supply and demand system will be managed by some mathematical models to consume energy efficiently and increase the introducing of renewable energy. In one of the systems, PV combined EV Smart System" has been developed.[1]

In the “PV combined EV Smart System”, PV power is charged directly to the EV battery, and then the charged PV power is consumed by running and air-conditioning energy of a car and the surplus electricity is supplied to a home. This system is able to reduce CO_2 emissions economically. In order to expand the system, it is necessary to spread EV and clarify the effects. At first, it should solve the issues of short cruising distance, the high cost of storage battery and the risk of dead battery. Therefore, the authors have proposed an advanced EV such as AI-EV (Air-conditioner Integrated Electric Vehicle).[2] AI-EV has a novel hybrid system which drives the air-conditioning system and generates electric power in the case of a low air-conditioning load through the use of a small-engine. If PV power can not only reduce car fuels but also replace with gas and liquid fuels which are consumed at a home, huge effect of CO_2 reduction is obtained as the whole of the system.

In this paper, a novel energy system which is combined and integrated with solar power, AI-EV and home heat pumps has been proposed. Heat pumps are car air-conditioner and CO_2 heat pump water heater for home use. A mathematical simulation model which is integrated with AI-EV model, CO_2 heat pump model and HEX model based on some experiments has been developed to evaluate a smart community which is constructed at an office and a home. And then, CO_2 emissions and economic efficiency are calculated and compared with those of the conventional system.

1. INNOVATIVE CHANGES OF THE ENERGY SYSTEM

1-1. INTEGRATED TWO-WAY ENERGY SYSTEM

In the conventional system, energy flow is one direction from supplier to consumer. In the future energy system, anyone can build PV and wind power generation apparatus anywhere. Therefore, many energy flows are two-way. For example, consumer can supply energy such as “PV combined EV smart system”.

1-2. ADVANCED PV COMBINED EV SMART SYSTEM

The advanced PV combined EV smart system which is considered one of the future systems is shown in Figure 1.

In the system, PV power is charged directly to the EV battery as DC. In the new system, it is considered to combine with a commuter EV and a second EV.

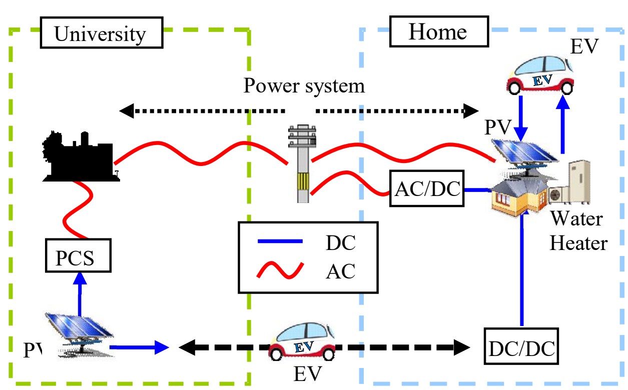

Figure 1 Advanced PV combined EV smart system

The commuter EV runs in morning and evening. In addition, it is parked by an office or a factory during the daytime on weekdays. So, PV is installed in the office or the factory because PV power is generated in daytime. On the other hand, the second EV is parked at a home at almost time without using. So, hot water heater is installed in the home because surplus PV power is consumed efficiently. The generated PV power charges the both of EV batteries directly by DC. When each EV battery level is full, generated PV power is supplied into the power source for the workplace or the home after being converted from DC to AC. And, if the charging level of each EV battery has some surplus power which is not included the necessary power for the next driving, the surplus power can be supplied directly to the home. So, this system is possible to be minimized the number of conversions between DC and AC involving energy losses.

In the novel energy system such as the advanced PV combined EV smart system, it is important to spread and utilize EV effectively. In order to spread and expand EV, it should solve the issues that of short cruising distance, high cost of storage battery and the risk of dead battery. For solving these issues, the new concept vehicle such as AI-EV is necessary.[2]

2. AIR-CONDITIONER INTEGRATED ELECTRIC VEHICLE (AI-EV)

2-1. BASIC DESIGN OF AI-EV

AI-EV is utilized as not only an apparatus for locomotion, but also electricity transportation and a storage medium of electricity. AI-EV is integrated with car driving power system, power storage system, power generation system and air-conditioning power system. A simplified image of AI-EV is shown in Figure 2. An example of operating image is shown Figure 3.[3]

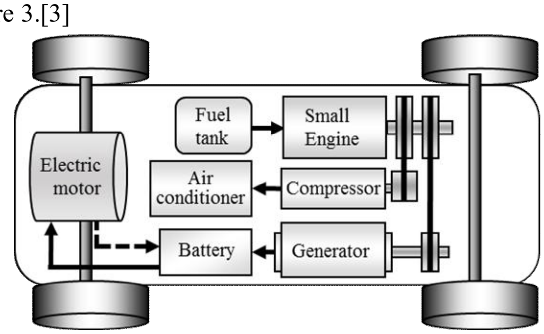

Figure 2 The Simplified image of AI-EV

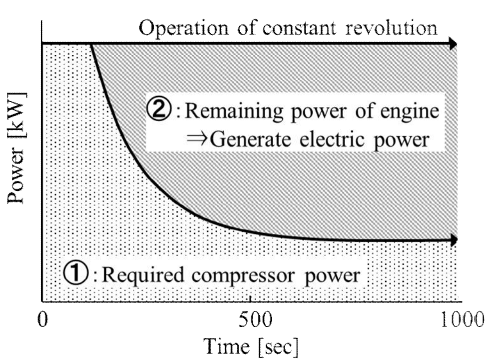

Figure 3 Operation image of AI-EV

As shown in Figure 2 and Figure 3, a small-engine is driven by a constant rotation that is added up a air-conditioner compressor load ① and generator load which is changed by air-conditioning load ②. The operation of constant rotation can be obtained a high efficiency because it can be decreased the energy losses of acceleration and deceleration. Therefore, AI-EV can decrease the power consumption compared with a conventional system. In addition, AI-EV is able to gain cruising distance by generated electricity which is charged to the AI-EV battery. So, AI-EV can solve three issues of conventional EV.

2-2. MATHEMATICAL MODEL OF AI-EV

2-2-1. HEAT BALANCE OF THE CAR

A car air-conditioner capacity is determined based on the heat balance model between the inside and outside of the car. As shown in Figure 4, the inside of the car is heated or cooled depending on the weather conditions outside. This is shown by the heat balance equation from Eq. (1) to Eq. (7).[4]

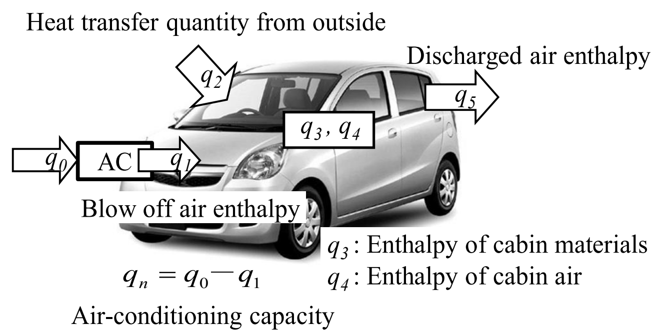

Figure 4 Heat balance model for air-conditioning

$$0 = \sum_{k=1}^{5} q_k \qquad (1)$$

$$\frac{\partial q_1}{\partial t} = u_1 \cdot A_1 \cdot \rho_a \cdot c_{pa} \cdot T_1 \qquad (2)$$

$$\frac{\partial q_2}{\partial t} = \alpha_2 \cdot A_2 \cdot (T_2 - T_4) \qquad (3)$$

$$\frac{\partial q_3}{\partial t} = M_3 \cdot c_{pl} \cdot \frac{\partial T_3}{\partial t} \qquad (4)$$

$$\frac{\partial q_3}{\partial t} = \alpha_3 \cdot A_3 \cdot (T_3 - T_4) + \beta \cdot Q_{S\gamma} A_{CU} + nQ_p \qquad (5)$$

$$\frac{\partial q_4}{\partial t} = -V_4 \cdot \rho_a \cdot c_{pa} \cdot \frac{\partial T_4}{\partial t} \qquad (6)$$

$$\frac{\partial q_5}{\partial t} = -u_5 \cdot A_5 \cdot \rho_a \cdot c_{pa} \cdot T_5 \qquad (7)$$

In order to calculate the heat transfer rate due to the temperature difference between the inside and the outside, Eq. (3) can be used. For that, it is necessary to know the total heat transfer coefficient α_2 which is obtained through the experiment.

2-2-2. CAR AIR-CONDITIONER MODEL

P-h chart of a car air-conditioner refrigerating cycle is shown Figure 5.

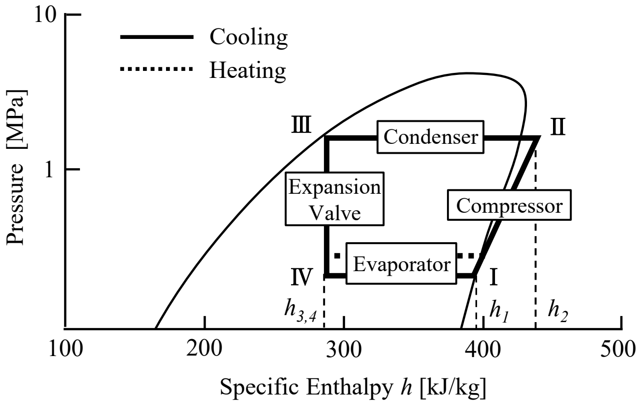

Figure 5 *P-h* chart of a car air-conditioner refrigerating cycle

A condenser and an evaporator are multi-layer structure and complicated shape. Those heat transfer quantities are expressed by the following formula.[5] Equations of the condenser are shown Eq. (8) and Eq. (9). Equations of the evaporator are shown Eq. (10) and Eq. (11).

$$mf_r \cdot (h_2 - h_3) = \delta \cdot \alpha_{c,a} \cdot A_{c,a} \cdot \Delta T_{LMTD} \quad \cdots\cdots\cdots\cdots (8)$$

$$\alpha_{c,a} = J \cdot \left(\frac{mf_{c,a}}{A_c} \cdot C_{pa} \right) \cdot \mathrm{Pr}^{-\frac{2}{3}} \quad \cdots\cdots\cdots\cdots (9)$$

$$mf_r \cdot (h_1 - h_4) = \alpha_{e,a} \cdot A_{e,a} \cdot \left\{ \Delta T_{LMTD,e} + \frac{h_g \cdot (w_{e,ave} - w_{e,s})}{Le^{2/3} \cdot C_p} \right\} \cdot\cdot (10)$$

$$\alpha_{e,a} = J \cdot \left(\frac{mf_{e,a}}{A_e} \cdot C_{pa} \right) \cdot \mathrm{Pr}^{-\frac{2}{3}} \quad \cdots\cdots\cdots\cdots (11)$$

The performance of an air-conditioner is evaluated by the coefficient of performance (hereinafter referred to as COP). The cooling COP_C is shown in Eq. (12), heating COP_H is shown in Eq. (13)

$$COP_C = \frac{h_1 \quad h_4}{h_2 \quad h_1} \eta_m \eta_p \quad \cdots\cdots\cdots\cdots (12)$$

$$COP_H = \frac{h_2 \quad h_3}{h_2 \quad h_1} \eta_m \eta_p \quad \cdots\cdots\cdots\cdots (13)$$

3. HOME HEAT PUMPS

In the conventional system, hot water is supplied with gas hot water heater. The advanced PV combined EV smart system can be used the generated PV power more efficiently through the use of EV battery because CO_2 heat pump water heater is driven by electricity.

3-1. CO_2 HEAT PUMP WATER HEATER MODEL

P-h chart of a CO_2 heat pump water heater cycle is shown Figure 6. And, *T-S* chart is shown in Figure 7.

A condenser and an evaporator are multi-layer structure and complicated shape. Those heat transfer quantities are expressed by the following formula. Equations of the condenser are shown Eq. (14) and Eq. (15), Equations of the evaporator are shown Eq. (16) and Eq. (17). [6]

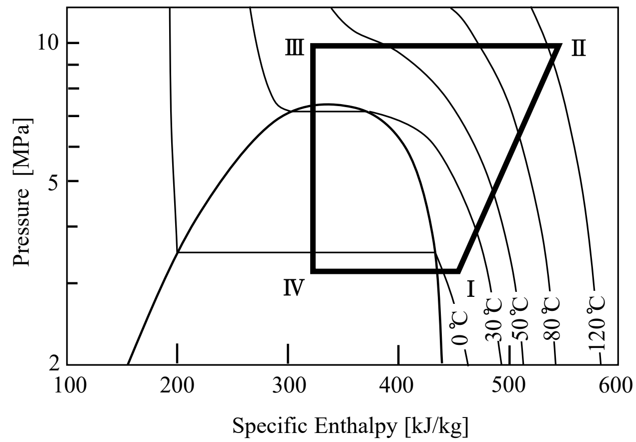

Figure 6 *P-h* chart of a CO_2 heat pump water heater cycle

$$mf_r \cdot (h_2 - h_3) = \alpha_{ct} \cdot A_{c,wi} \cdot (T_{cr,ave} - T_{cw,ave}) \quad \cdots\cdots\cdots\cdots (14)$$

$$\alpha_{ct} = \left(\frac{1}{\alpha_{c,r}} + \frac{A_{c,wi}}{2\pi\lambda L_n} \ln\frac{d_o}{d_i} + \frac{A_{c,wi}}{\alpha_{c,w} \cdot A_{c,wo}} \right)^{-1} \quad \cdots\cdots\cdots\cdots (15)$$

$$mf_r \cdot (h_1 - h_4) = \alpha_{et} \cdot A_{e,wi} \cdot (T_a - T_{er,ave}) \quad \cdots\cdots\cdots\cdots (16)$$

$$\alpha_{et} = \left(\frac{1}{\alpha_{er}} + \frac{1}{\alpha_a \cdot \varepsilon} \right)^{-1} \quad \cdots\cdots\cdots\cdots (17)$$

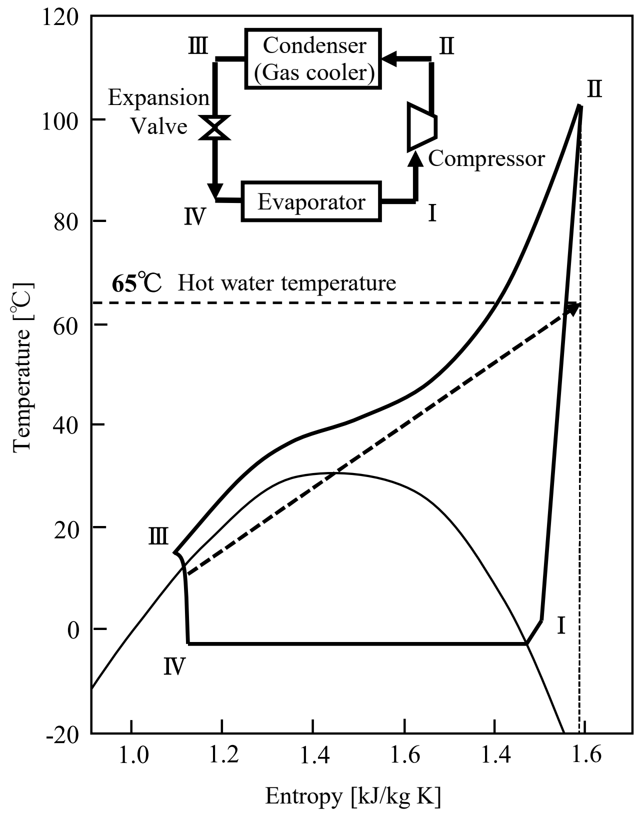

Figure 7 *T-S* chart of a CO_2 heat pump water heater cycle

The performance of a CO_2 heat pump water heater is evaluated by the COP_H. The heating COP_H is shown in Eq. (13) which is evaluated as the same as an air-conditioner.

4. EXPERIMENTS

4-1. HEAT BALANCE OF THE CAR

α_2 can be obtained by Eq. (1) to Eq. (7). In this method, Q_{sy} solar radiation is disturbance factor to calculate the overall heat transfer coefficient α_2. For this reason, the experiments were conducted in the night without solar radiation. Furthermore, Q_p is a fixed value which is using literature data. [7] The required compressor power of a car air-conditioner is able to be calculated based on the obtained air-conditioning load.

Cabin materials average temperature:T_3 and cabin air temperature:T_4 are obtained, if Eq.(1) to (7) are given α_2. Therefore, residual sum of squares (RSS) was calculated from each predicted values and each experimental values. The result is shown in Figure 8. In Figure 8, all results of the average running speed are 30km/h.

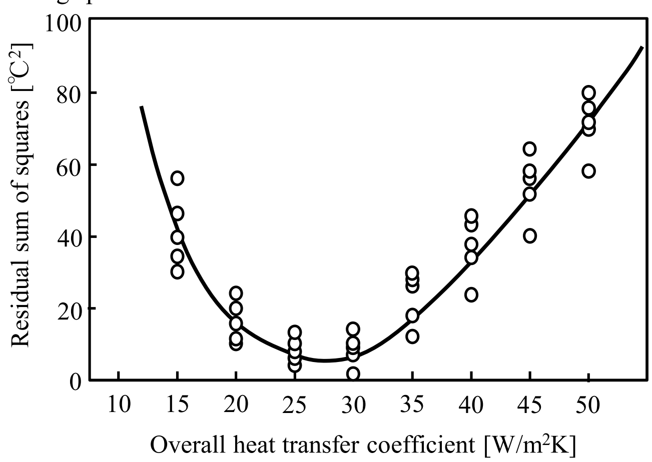

Figure 8 Measured overall heat transfer coefficient $\boldsymbol{\alpha_2}$

From Figure 8, it is obtained that α_2 is 28 W/(m^2·K). Therefore, the required air-conditioning temperature is able to calculate using from Eq. (1) to Eq. (7). Therefore, the required air-conditioning load for cooling is calculated based on the capacity to cool outside air to a target condition of car inside through the use of the air-conditioner model from Eq. (8) to Eq. (11). As the results, necessary compressor power can be calculated by the required air-conditioning load which changes with time to use it.

4-2. CAR AIR CONDITIONER

An experimental device is shown photograph 1 using an air-conditioner which was equipped with Daihatsu MIRA in 2000. Using this experimental device, the mathematical model was verified by the experiments.

4-2-1. EXPERIMENTAL CONDITION

Heat exchanger size of MIRA is shown in Table 1. Fresh air flow quantity of condenser side is 0.4 Nm^3/s and that of evaporator side is 0.1 Nm^3/s. The refrigerant flow quantity is changed it by compressor rotation speed.

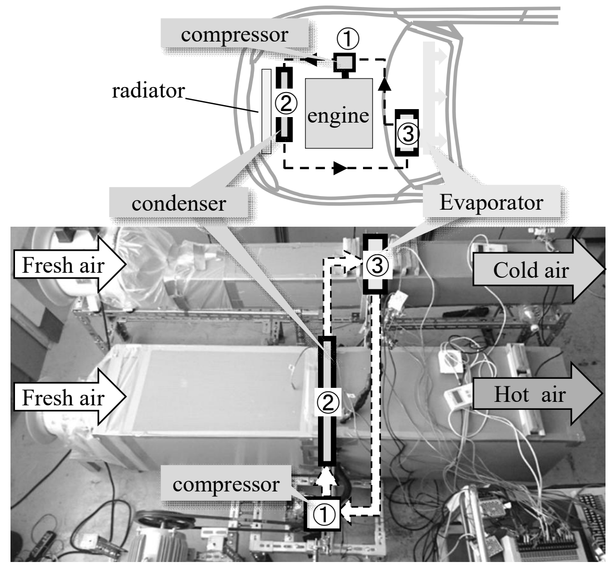

Photo.1 Experimental device of Air-conditioner

Table 1 Size of heat exchanger

		Length × width × depth
Condenser	[mm]	355 × 270 × 15
Evaporator	[mm]	210 × 193 × 55

4-2-1. EXPERIMENT RESULT

Example of the experimental results is shown in Figure 9. The results of the cooling experiment accorded with the calculation result of the model well.

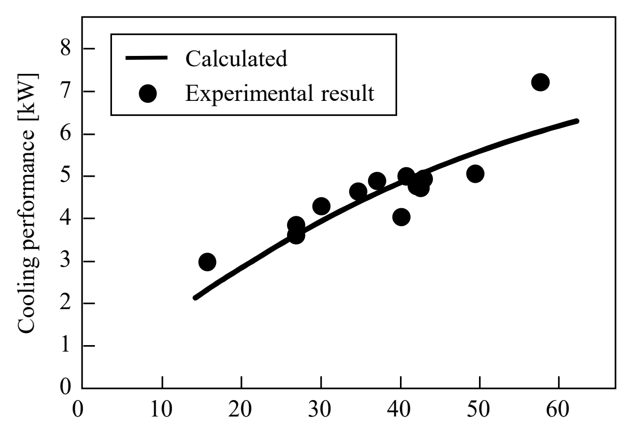

Figure 9 Comparison of calculated values and experimental values

5. EVALUATION OF THE NOVEL ENERGY SYSTEM

5-1. THEORETICAL ENERGY BALANCE MODEL FOR REGIONAL AREA (HEX MODEL)

It is difficult to evaluate the energy system using various kinds of energy source such as the system that fossil fuels, electricity and PV power are mixed in the small area. In the future energy system, PV generates electricity in arbitrary places and electricity is transported and stored by EV. Therefore, it is necessary to consider interconversion of the energy by such a system and cannot obtain the optimum solution using by a network type model because network type model should decide the system structure before the analysis. For this reason, HEX(hexagons) model which is able to evaluate the liquid fuel, gas, electricity, heat and renewable energy unitarily with measurement data has developed. HEX model is shown in Figure 10. [8]

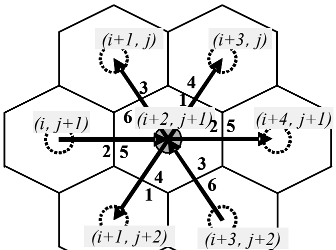

Figure 10 HEX model

The energy balance of each HEX (hexagons) evaluates a total of $\boldsymbol{EF_{ijmt}}$ (the energy variation of HEX with energy outflow and inflow such as EV) and $\boldsymbol{ES_{ijmt}}$ (The energy variation of HEX with generating energy, consumption and storage). Therefore, the total energy variation of HEX (i, j) at time Tt is shown in Eq. (18) and (19). In addition, C_m as shown in Eq. (19) is the electrical conversion factors of each fuel. In the future, when the energy system will be designed within HEX as all energy consumption is substituted by electricity without using fuel, it is possible to calculate energy consumption by Eq. (19).

$$E_{ij\mathrm{mt}} = EF_{ij\mathrm{mt}} + ES_{ij\mathrm{mt}} \qquad (18)$$

$$E_{ij\mathrm{t}} = \sum_{\mathrm{m}=1}^{n4} C_{\mathrm{m}} E_{ij\mathrm{mt}} \qquad (19)$$

A wide area is shown as aggregate of continued plurality of HEX. And, the amount of energy variation with total of object area is shown in Eq. (20).

$$E_{\mathrm{Area\ t}} = \sum_{i=1}^{n1} \sum_{j=1}^{n2} E_{ij\mathrm{t}} \qquad (20)$$

The basic restriction conditions of $\boldsymbol{E_{ijt}}$ and $\boldsymbol{E_{Areat}}$ are shown in Eq. (21). It is necessary to satisfy the balance of energy supply and demand within the object area at all times.

$$E_{ijt} > 0,\ E_{Area\ t} > 0 \qquad (21)$$

5-2. CALCULATED CONDITION

In this case study, four different types of vehicle were simulated, a gasoline engine vehicle and AI-EV. The commuter vehicles has been used for a commuting between a home and Okayama Prefectural University (hereinafter referred to as OPU) once a day. The second vehicle which is used for leisure or going shopping has been moved for an actual data of housewife who has lived in kurashiki city in Japan. The PV data is shown in Table 2. The amount of generated PV power is calculated by using an annual weather database which has hourly solar radiation data and reflected PV power fluctuations caused by the weather, the season and the time. [9] AI-EV data is shown in Table 3.

In this study, all cases are simulated on a condition that all inverse current to a conventional power system is zero.

Table 2 PV date

Maximum power	240.0 W
Output per unit area	190.0 W/m^2
Installed area for commuter AI-EV	12.5 m^2
Installed area for second AI-EV	15.0 m^2
Total power	5.2 kW

Table 3 AI-EV data

Electricity consumption (without air-conditioner)	9.1 km/kWh
Available capacity of battery	20－80 %
The capacity of the battery	24.0 kWh
Commuting distance	28.0 km/day
Commute day	242.0 days/year
Displacement of engine	120.0 CC

As other data, AI-EV uses LPG to drive a small-engine and the average running speed: 30km/h. Additionally, CO_2 emission coefficient of gasoline: 2.62 kg-CO_2/ℓ, CO_2 emission coefficient of electricity: 0.579 kg-CO_2/kWh (Average of the Japanese power companies in 2014), CO_2 emission coefficient of LPG (liquefied petroleum gas): 3.48 kg-CO_2/kg [10]

5-3. RESULTS

5-3-1. CO_2 EMISSIONS

Figure 11 shows the simulated results of annual CO_2 emissions that compare with the conventional system which is used a gasoline and "PV combined AI-EV Smart System".

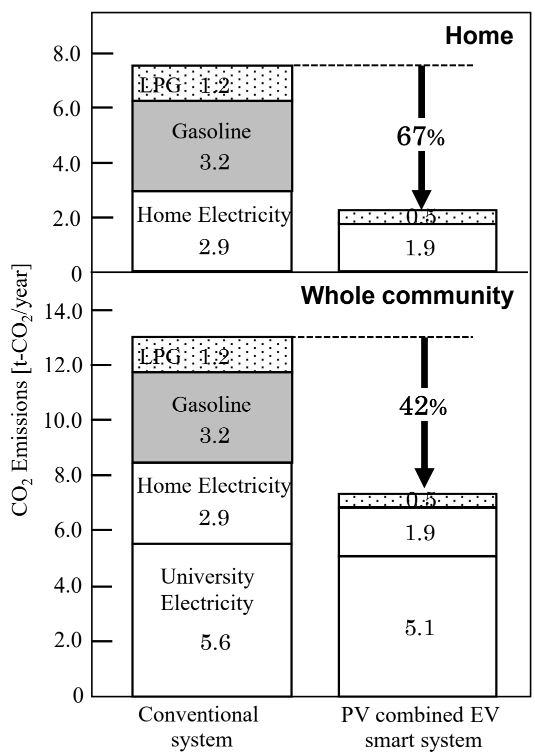

Figure 11 Comparison of annual CO_2 emission

From Figure 11, "PV combined AI-EV Smart System" is able to reduce 68% of CO_2 emissions in comparison with the conventional system as the home energy system because gasoline and gas fuel were replaced with PV power and system electricity was reduced by PV power.

Therefore, "PV combined AI-EV Smart System" is able to reduce 43% of CO_2 emissions in comparison with the conventional system as the whole community. In the new system, the fuel consumption of the vehicle that AI-EV uses is about 15% of the conventional gasoline vehicle. Therefore, if this fuel replaces bio-ethanol, AI-EV can drive all by a natural energy, that will be the first vehicle in the world. In this case, CO_2 emissions can reduce above 75%.

5-3-2. IMPROVEMENT PERFORMANCE OF AI-EV

The performance of AI-EV can be improved by the air-conditioner performance. For example, the effect of increasing heat exchanger area of the air conditioner is shown in Figure 12.

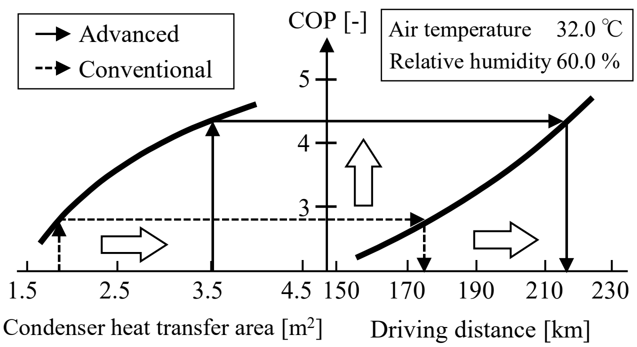

Figure 12 Effect of improving air-conditioner performance

In Figure.12, the limit driving distance of AI-EV which is mounted conventional air-conditioner that is operated a 120cc displacement engine is 175km in the case of driving in a city area (average speed 32km/h, 25miles/h) in summer season.

For example, COP can improve from 2.8 to 4.3 by doubling the heat transfer area of the condenser. Therefore, the power consumption of the air-conditioner decreases and power generation increases. As the result, the driving distance of AI-EV extends by 25% in the same engine displacement. The performance of AI-EV which is mounted advanced air-conditioner is shown in Figure 13.

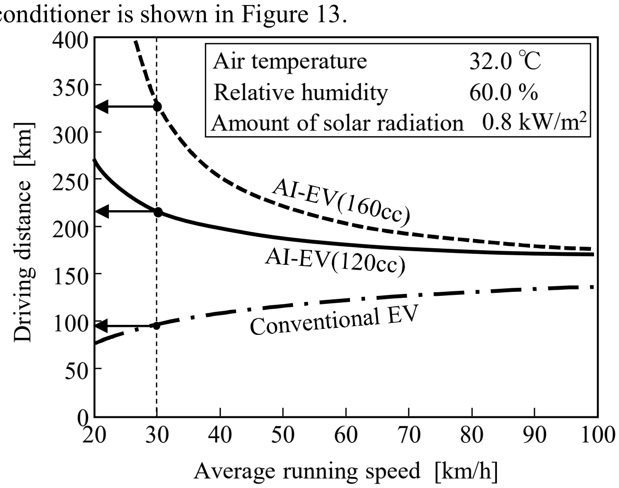

Figure 13 Performance of the advanced AI-EV

5-3-3. ECONOMY

Economic efficiency is evaluated by IRR *(*Internal Rate of Return*)*=5.0% of the new system when the legal service life of the depreciation equipment is assumed 14 years. Therefore, the new system can be widely spread in the future.

6. CONCLUSIONS

A novel energy system which is combined and integrated with solar power, AI-EV and home heat pumps has been proposed. Heat pumps are car air-conditioner and CO_2 heat pump water heater for home use. A mathematical simulation model which is integrated with AI-EV model, CO_2 heat pump model and HEX model based on some experiments has been developed to evaluate a smart community which is constructed at an office and a home. And then, CO_2 emissions and economic efficiency are calculated and compared with those of the conventional system. The results are as follows ;

The novel energy system is able to reduce more than 40% of CO_2 emissions in comparison with the conventional system as the whole system, and the system can reduce more than 65% of CO_2 emissions in comparison with the conventional home.

The driving distance of AI-EV extends by 25% according to the COP improvement from 2.8 of conventional air-conditioner to 4.3 of advanced air-conditioner.

Additionally, it is clarified that the battery can reduce the fluctuations which are caused by the PV power generation. Also heat pumps can effectively utilize for absorbing electric power variations which are caused by supply and demand balance of energy.

The economic efficiency is evaluated more than 5.0% of Internal Rate of Return without some subsidies when the legal service life of the depreciation equipment is assumed 14 years.

Therefore, the novel energy system can be spread widely in the future.

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