B-14.2.3 Technical Assessment of Energy-Intensive Products and Services (Final Report)

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Abstract The purpose of this research was to use case studies to devise a comprehensive method of assessing energy-intensive products used in the household-service sector and energy-conserving technologies for them, as well as to show how to effectively save energy.

We began by analyzing the use of energy in the household-service sector in terms of both macro statistical data and micro product data, and comparing the two types of data. Estimates of per-household energy intensity values generally matched for both micro and macro data. The micro product approach is advantageous in that it is possible to estimate the breakdown for each appliance type, which is necessary to determine for which household-sector products energy consumption should be reduced.

We next performed a case study on beverage vending machines, considered to be one kind of energy-intensive appliance, and analyzed present life cycle energy usage. We proposed to introduce parameters showing the proportions of energy used in processing and assembly in relation to energy for producing materials. The case study was used to examine this method's applicability, and determined the energy consumption entailed by the processes of producing and using vending machines.

In addition, we used estimates based on experimental observations and a model to investigate in detail the present energy consumption of vending machines, and to identify ways of conserving energy and investigate their energy-saving efficacy when used. An energy savings of about 50% per machine seems possible. We also estimated the potential for reducing CO_2 emissions by increasing the use of energy-saving vending machines.

Key Words Energy, Carbon dioxide, Consumer appliances, Vending machines, Life cycle assessment

1. Introduction

Since the first oil shock, carbon dioxide emissions by Japan's industrial sector have held steady or tended to decrease owing to technical innovation, but emissions by the household-service sector have steadily grown since that time. Without effective and quick remedial measures in this area, it is anticipated that the trend toward increasing emissions will continue, which makes it urgent to develop and widely implement technical measures, as well as to devise an accurate and comprehensive method of assessment to underpin those technical measures.

Society must find ways to reduce emissions of CO_2, the major greenhouse gas. The purpose of this research was to devise a comprehensive method of assessing the energy intensity of products in the household-service sector, to develop technologies for improving their energy efficiency, as well as to propose effective technologies for conserving energy. We incorporated life cycle assessment (LCA) into our assessment, which took into consideration the entire life of a product, from the extraction of resources to the discarding of the product.

Specifically, we analyzed the use of energy in the household-service sector in terms of both macro statistical data and micro product data, and compared the two types of data. We also conducted an LCA case study of beverage vending machines, which are said to, in total, consume electricity equal to the output of a large nuclear power plant. In doing so, we proposed a new practical method of conducting LCAs for composite products such as vending machines in a simple manner. We also used estimates based on experimental observations and a model both to investigate, in detail, the present energy consumption of vending machines, as well as to identify ways of conserving energy and investigate their energy-saving efficacy when used. We also estimated the potential for reducing CO_2 emissions by increasing the use of energy-saving vending machines.

2. A Study of Energy Consumption by Household-Service Sector Products

We studied energy consumption in the household-service sector by comparing and examining two types of data: macro statistical data on the amounts of energy used according to type of use and energy source, and micro statistical data accumulated from product diffusion rates.

2.1 Household Sector

The household-service sector can be roughly broken down into the household sector and the service sector. We first used both macro and micro data to calculate single-household energy consumption in the household sector, and compiled the results (Table 1).

Calculations show that the intensities for total energy consumption (i.e., energy consumption intensity per household) according to both data types correspond closely. Reasons for the discrepancy include the fact that the values from macro statistical data for amounts of electricity and kerosene consumed for "space heating" are smaller than their micro counterparts, while the amount of electricity consumption under "other uses" is distinctly larger, more than double the micro value. The table's micro data was calculated on the basis of scenario assumptions about the appliances in the average home and their extent of use. In view of this fact, we surmise there are discrepancies between actual use and the appliance scenarios, which were determined on the basis of each appliance's type of use. That is to say, (1) the average household actually owned and used electric space heaters, *kotatsu* [low, heated tables covered by quilts], and kerosene space heaters to a lesser extent than assumed, while (2) the opposite held true for electric appliances with uses other than space heating. Although the energy efficiency of electric consumer appliances has improved through technological innovation, consumers are using larger and more highly functional products at an accelerating pace, so the scenario probably lacked consideration of this.

Although problems with accuracy still remain, estimates of per-household energy intensity values generally matched for both micro and macro data, which suggests that, in the household sector, one usable method would be estimating total nationwide energy consumption in this sector by aggregating individual household appliances. With this method, accuracy will be considerably affected by the assumed appliance scenario, but it is advantageous in that it is possible to estimate the breakdown for each appliance type, necessary to consider what household-sector products should reduce energy consumption; this breakdown is impossible to determine using macro data alone. Improving accuracy makes it necessary to ascertain well the energy intensities of products, and the extent of ownership and use in households. It is also important to prepare tables such as Table 1 and to check accuracy through comparison with macro statistics.

Table 1 Comparison of Energy Consumption Intensities

Unit: 1,000 kcal/household, Upper cell level: micro, Lower cell level: macro

	Space heating	Space cooling	Water heating	Cooking	Other	Totals
Electricity	Electric heaters: 21 Air conditioners: 22 *Kotatsu:* 358 Total 411	Air conditioners: 136 Total 136	Electric water heaters: 258 Total 258	Electric rice cookers: 77 Electric tea water heater/keepers: 20 Other electric appliances: 86 Total 183	Refrigerators: 574 Color TVs: 254 Washing machines: 15 Vacuum cleaners: 71 Clothes dryers: 37 Lighting: 418 Other: 134 Total 1503	2491
	264	193	271	146		4149
Gas	Gas heaters: 190 Gas central heating: 240 Total 430		Gas water heaters: 900 Gas boilers/ bath water heaters: 1430 Total 2330	Gas ranges: 820 Gas rice cookers: 100 Total 920		3680
	618		2269	770		3659
Kerosene	Kerosene heaters: 2750 Total 2750		Kerosene boilers/ bath water heaters: 501 Total 501			3251
	1959		798	32		2790
Other			(Solar thermal water heaters: 150)			(150)
	8		275	8		292
Totals	3591	136	3089	1103	1503	9420
	2850	193	3613	956	3274	10886

2.2 Service Sector

Service sector energy consumption varies greatly with industry, and there is no average. It would therefore be very difficult, within the range of currently available data, to compare analyses based on macro statistical data with aggregates of micro data on individual products.

For example, it is possible to use existing macro statistical data in estimating energy consumption intensity according to industry, type of use, and energy source, but one cannot make assumptions about an average that would correspond to such estimates. That is to say, because one cannot determine the extent of the ownership and use of each industry's average product, comparisons are impossible. For personal computers and a few other kinds of office equipment, there are published figures on total domestic energy consumption for each product type, but the bases for calculation are unclear, which leaves questions about their reliability.

For these reasons the service sector lacks sufficient micro data to make comparisons with macro statistical data, making it necessary to acquire data including that on product energy intensity, state of use, and product lifetime.

3. LCA Case Study on Vending Machines

We performed a life cycle energy analysis on beverage vending machines, one kind of energy-intensive consumer appliance. As of 1995 about 340,000 beverage (soft drinks, dairy drinks, coffee, sake, and beer) vending machines were being shipped annually, making for a total of about 2,540,000 machines in the country, or about one for every 50 Japanese. Their annual electric power consumption is estimated at 1.07% of total domestic consumption; in mid-summer when their electricity use peaks, their total consumption reaches 1,270 MW, equal to the output of a large nuclear power plant.

Figure 1 is the life cycle of a vending machine. Our research scrutinized the stages of assembly/manufacture and use, which are thought to be particularly important in regard to energy consumption. For assembly/manufacture, we calculated energy consumption mainly by aggregating the consumption for the parts, while for use, we performed observations while running vending machines under a wide variety of conditions. Energy consumption in assembly/manufacture includes that for the manufacture of materials.

Fig. 1 Vending Machine Life Cycle

3.1 Assembly/Manufacture Stage

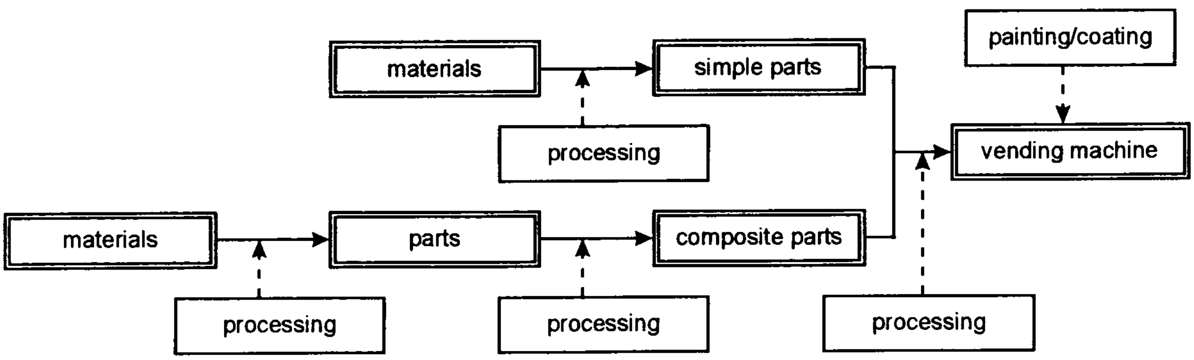

Fig. 2 Process Flow Leading to Vending Machine Assembly/Manufacture

Vending machines comprise nearly 700 components, most of which are produced by subcontractors. Roughly, these parts are those consisting only of processed materials (simple parts), and those composed of other parts (composite parts). This process is outlined in Fig. 2. Composite parts in vending machines include compressors, evaporators, motors, circuit boards, and fluorescent tubes.

3.1.1 Energy Consumption for Manufacture of Materials, and CO_2 Emissions

We determined the materials used in vending machines by actually dismantling a machine and weighing the various materials. For the categorization of materials we chose the level at which the energy consumption intensity and CO_2 emission intensity have been determined in existing research that has applied LCA. Compressors, motors, and other composite parts were considered parts by themselves, and their intensities were determined by finding their weight as a whole.

We calculated the energy consumed and the CO_2 emitted when manufacturing materials by the following procedure: From the manufacturing intensities for steel, plastics, and other materials as found in existing research applying LCA, we located and interpreted the energy consumption intensities and CO_2 emission intensities for material manufacture, while taking the assumptions of that research into consideration, and then multiplied the values obtain by material weights. Calculations for materials whose intensities were unknown, or for parts whose constituent materials were unknown, were performed by using material data that appeared to be similar, or combinations thereof.

The order of materials in terms of energy consumption is hot-dipped steel, coated steel, rigid urethane foam, circuit boards, PMMA, shaped steel, PC, ABS, and so on, while the order in terms of CO_2 emissions is hot-dipped steel, coated steel, circuit boards, rigid urethane foam, copper products, shaped steel, wire rod, PC, and so on. Steel parts account for a considerable portion of their weight. One thing to be noted, however, is that while circuit boards account for only about 0.45% of total weight, they account for as much as 3.58% of energy consumption and 5.63% of CO_2 emissions, making them energy-intensive parts.

3.1.2 Energy Consumption and CO_2 Emissions of Processing and Assembly

Composite products like vending machines contain many parts of varying sizes; each and every one of those parts must be followed through the life cycle when performing rigorous LCA by aggregation. Energy consumption for parts can be estimated as the sum of energy needed to produce materials composing the parts, and the energy required for part assembly and processing (including transport and the like). The energy needed by material production can be calculated with comparative ease, as noted above, from the weight of that material as a percentage of the final product, and from existing energy intensity data, but in determining processing and assembly energy, methods that study each individual part are generally employed. Researching composite products necessitates a large number of such studies, which further necessitates detailed investigation of production methods of suppliers and other businesses, which is in reality nearly impossible. For this reason, in the present research we proposed and applied a practical method that estimates processing/assembly energy from the weights of materials as percentages of a product.

Some of the parts making up vending machines are themselves composite products, and in their manufacture pass through a number of processing and assembly stages. The processing/assembly process flow for such composite products is shown below (Fig. 3).

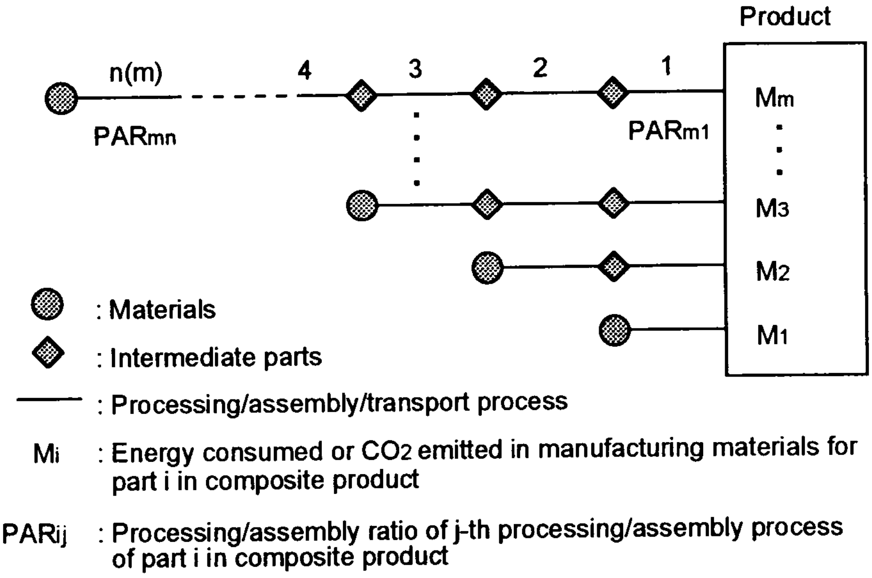

Fig. 3 Processing/Assembly Flow of Composite Products

This figure shows how part i, which helps make up a composite product, starts out as materials and becomes a final product via a number (j) of processing/assembly/transport processes. "Processing/assembly ratio: PAR" in the figure is the value obtained when dividing the energy consumed or CO_2 emitted in the j-th processing/assembly process of part i in a composite product by the energy consumed or CO_2 emitted in all the previous processes including a process of material manufacture. It is defined more specifically by the following formula.

PAR = {"energy consumed or CO_2 emitted in the processing/assembly processes for parts and intermediate parts" + "energy consumed or CO_2 emitted when manufacturing the materials of wastes (such as machining scrap) generated by the processing/assembly of parts and intermediate parts} / "energy consumed or CO_2 emitted in all the previous processes including a manufacturing process of the materials making up parts or intermediate parts"

If the energy consumed or CO_2 emitted when manufacturing the materials of part i going into a composite product is said to be M_i, then the energy consumed or CO_2 emitted when manufacturing the composite product (P) is defined by the following formula. But because composite products like vending machines are manufactured via many manufacturing, processing, and assembly processes, it is impossible to find PAR for all those processes.

$$P = \sum_{i=1}^{m} M_i \prod_{j=1}^{n(m)} (1 + PAR_{ij})$$

where n(m) indicates that n depends on m.

For this reason, this research presupposed that PAR in the process/assembly processes (excluding painting) of vending machine parts is a constant (K), and used the following formula to calculate the energy consumed or CO_2 emitted when manufacturing composite products (P).

$$P = \sum_{i=1}^{m} (M_i \times K^{n(m)})$$

where n(m) indicates that n depends on m.

In order to calculate PAR we obtained the cooperation of subcontractors' part factories and manufacturers' assembly plants to collect data on the utilities for processing and assembly and waste amounts for representative processes. These are compiled below (Table 2).

Table 2 Energy consumed and CO2 emitted in processing/assembly stages, and PAR

Upper cell level: Mcal/machine, Lower cell level: kg-C/machine

	Product Materials	Processing/Assembly	Transport	Waste	PAR
Painting	0.0 (Painting)	307.5 (Painting)	0.0	-	12708
Company A	0.0	17.5	0.0	-	13952
Sheet metal	347.0 (Steel plate)	49.3 (Sheet metal)	2.1	-	0.1
Company B	26.2	2.6	0.2	-	0.1
Plastic molding	122.1 (Plastic)	0.5 (Molding)	0.4	-	0.0
Company C	9.2	0.0	0.0	-	0.0
Wiring	46.2	5.1 (Processing)	0.1	0.1	0.1
Company D	9.3	0.2	0.0	0.0	0.0
Product assembly	-	64.2 (Assembly)	5.4	0.6	-
Company E	-	3.2	0.4	0.1	-

Note: For transport our calculations assumed a truck traveling 100 km with a 10-ton load, fueled with gasoline and getting 5 km/l.

Excluding painting, the processing/assembly ratios are about the same (1.0-1.1), so our research used values in Table 2 as is for painting and product assembly. The processing/assembly ratios for the processing and assembly of other parts were set at 1.1, which was used to calculate the energy consumption and CO_2 emissions involved in manufacturing vending machines.

Here we assumed that simple parts go through one processing stage beginning as raw materials and that composite parts go through two processing/assembly stages beginning as raw materials. The results are as follows (Table 3).

Table 3 Energy Consumed and CO_2 Emitted in Product Assembly and Manufacturing Stages

		Energy consumed Mcal/machine	CO2 emitted kg-C/machine	Note
Simple parts	Materials	2227	166	
	Processing	223	17	0.1 times materials
Composite parts	Materials	249	23	
	Processing/assembly	52	5	0.21 times materials
Painting	Materials	0	0	Table 2, Painting
	Processing/assembly	308	18	
Product assembly		70	4	Table 2, Assembly
Totals		3128	232	
	Materials	2476	189	
	Processing/assembly	653	43	

The overall processing/assembly ratio of vending machines was 1.26 for energy consumption and 1.23 for CO_2 emissions. In a similar study the authors performed on a waste incineration plant, the processing/assembly ratio averaged 1.5. Processing/assembly ratios conceivably differ from one industry to another. If in the future there is a database of processing/assembly ratios for different industries, it will become even easier to apply the method employed here, further facilitating various kinds of LCAs.

3.2 Vending Machine Use

Energy consumed during vending machine use is electricity only, and it is possible to infer generally how much energy is consumed from the machine's lifetime and the specifications of parts such as the compressor unit. The vending machine evaluated in this research was one of the types in most widespread use in 1995. It has the specification given below (Table 4), and three refrigeration compartments; average power consumption and the compressor's operating rate are observed values.

Table 4 Specifications of Assessed Vending Machine

Installation location	Indoors	Total rated power consumption	603 W
Ambient temperature	24°C	Rated compressor input	361 W
Refrigeration compartment temperature	5°C	Operating rate	40%
Compartment configuration	C－C－C	Condenser fan motor	39 W
Power requirement	100 V 50 Hz	Evaporator fan motor	53 W
Total rated current	8.2 A	Fluorescent tubes: three 29 W tubes, one 42 W tube	129 W
Average power consumption	340 W	DC power supply (coin mechanism, etc.)	21 W

Industry statistics say that vending machines have an average service lifetime of seven-plus years, but in urban areas they are replaced with new machines every three to five years. Assuming that the lifetime is 7.5 years, power consumption during use is given as:

$$\text{Power consumption} = 40\text{ W} \times 24\text{ hrs/day} \times 365\text{ days/yr} \times 7.5\text{ yrs}$$
$$= 22{,}338\text{ kWh}$$

Taking energy supply mix and generating efficiency into consideration, average primary energy use per kWh (2.25 Mcal/kWh) and CO_2 emission intensity (0.118 kg-C/Mcal) are multiplied by power consumed, which yields 50,261 Mcal and 2,636 kg-C for energy consumed and CO_2 emitted, respectively.

3.3 Comparison of Assembly/Manufacturing Stage and Use Stage

Table 5 presents the energy consumption and CO_2 emissions of the various stages: manufacture of materials, product assembly and manufacture, and product use. Because vending machines have a long lifetime of 7.5 years, their energy consumption and CO_2 emissions during use account for a larger proportion of the totals.

The energy consumption ratio between assembly/manufacture, including manufacture of materials, and product use is about 1:16, while the ratio for CO_2 emissions is about 1:11.5. This shows the importance of energy conservation measures during use. Of incidental interest is that the ratio between vending machine cost and the electricity cost over 7.5 years is 1:1.0-1.2.

Table 5 Comparison of Energy Consumption and CO_2 Emissions in All Stages

	Units	Manufacture of materials	Product assembly and manufacture	Product use	Totals
Energy consumption	Mcal	2,476	653	50,261	53,390
	(%)	(4.6)	(1.2)	(94.1)	(100)
CO2 emissions	kg-C	189	43	2,636	2,868
	(%)	(6.6)	(1.5)	(92.0)	(100)

4. Energy Conservation Measures for Vending Machines, and Their Effectiveness

4.1 Energy Breakdown During Vending Machine Use

The discussion in the previous section showed that energy conservation measures exercised during use are effective in reducing CO_2 emissions by vending machines. As an aid in considering such measures, therefore, we estimated the energy consumption breakdown from test operation (measurements) under a variety of conditions, and from vending machine design specifications.

When vending machines are in operation, power is consumed roughly in two ways: by the compressor for refrigeration, and by ancillary devices such as lighting and the coin mechanism. The compressor runs in order to eliminate heat from the internal motor, as well as heat that makes its way in through heat transfer or air leaks. We used the following method to estimate electricity consumption according to factor.

(1) Internal motor: Measured amount of time motor ran.
(2) Heat transfer: Calculated according to physical properties of insulation, etc.
(3) Airtightness: Measured when using plastic sheets and other means to assure airtightness.
(4) Ancillary devices: Calculated from devices' specifications.

Table 6 Breakdown of Vending Machine Electricity Consumption During Use

Consumption factor	Elimination of internal heat by compressor			Ancillary devices
	Internal motor	Heat transfer	Airtightness	
Proportion of electricity consumption	15%	22%	27%	36%

Table 7 Energy Conservation Measures for Vending Machines, and their Estimated Effectiveness

Item	Remedial Measures	Estimated effectiveness
Internal motor	◎ When the compressor stops, the internal motor should also stop.	9%
	○ Move present internal motor to external location.	15%
Heat transfer	◎ Blow insulation on site.	5%
	△ Use vacuum panels for insulation.	15%
Airtightness	◎ Form inner compartment as integral unit.	3%
	○ Airtight design for front panel and receiving door.	18%
Lighting, etc.	◎ Eliminate excess lighting.	8%
	○ Innovate front panel design and materials.	3%
Other	◎ Use high-performance compressor.	13%

Note: Degree of ease with which measures can be implemented: ◎ > ○ > △

The estimate results appear in Table 6. Ancillary devices use the most electricity, with most of that going to lighting. There are no exceptionally large heat sources causing the compressor to operate, which means that energy conservation requires a combination of various measures implemented together. Based on these results and on interviews with vending machine manufacturers, we came up with possible measures and their presumed effectiveness (Table 7). Note, however, that estimated effectiveness is not the result of precise calculations; instead the values were inferred from Table 6.

4.2 Scenario for Introduction of Energy-Conserving Vending Machines, and Effectiveness of Their Widespread Use

As of 1995 there were about 2,540,000 beverage vending machines in Japan, and assuming their average power consumption to be 8.2 kWh/day/machine (corresponding to 342 W), which is actual consumption, total annual power consumption comes to 7.6 x 10^9 kWh/yr, corresponding to 1.07% of Japan's electricity consumption. The resulting CO_2 emissions are 0.897 Mt-C/yr, which accounts for 0.28% of Japan's total CO_2 emissions of approximately 320 Mt-C/yr.

On the assumptions of the current technical level and that significant cost increases will be avoided, we hypothesized two types of vending machines that incorporated energy-saving measures such as those shown below (Table 8). However, as the benefit of a high-performance compressor would overlap those of other measures, we set its value lower than in the previous section.

Table 8 Hypothesized Energy-Saving Beverage Vending Machines

Case 1		Case 2	
Measures Incorporated	Energy Savings	Measures Incorporated	Energy Savings
Motor stops at ordinary times.	9%	Move motor to external location.	15%
Blow insulation on site.	5%	Blow insulation on site.	5%
Form inner compartment as integral unit.	3%	Form inner compartment as integral unit.	3%
		Airtight design for front panel and receiving door.	15%
Eliminate excess lighting.	8%	Eliminate excess lighting.	8%
Use high-performance compressor.	8%	Use high-performance compressor.	8%
Total	33%	Total	54%

Our scenario for the introduction of energy-saving vending machines assumed that beginning in 1997 all of the 340,000 vending machines shipped annually would be case 1 machines, and that they would be case 2 machines beginning in 2000, which provided the following calculation results (Fig. 4).

Calculations show that all vending machines will have been replaced with case 2 machines by 2008, but it will probably take a bit more time when one considers the spread in service lifetimes. According to the results, beverage vending machines as a whole will attain energy savings of approximately 20% by about the year 2000, while conservation of 54% can be counted on for around 2000 when all vending machines have been replaced with the new types. This promises a 0.15% reduction in Japan's total CO_2 emissions, corresponding to 0.48 Mt-C/yr.

Although the use of high-performance compressors would likely mean a slight increase in energy consumption when machines are manufactured, this would not cripple the effectiveness of energy conservation measures because, as explained above, vending machines consume far more energy during use than during manufacture.

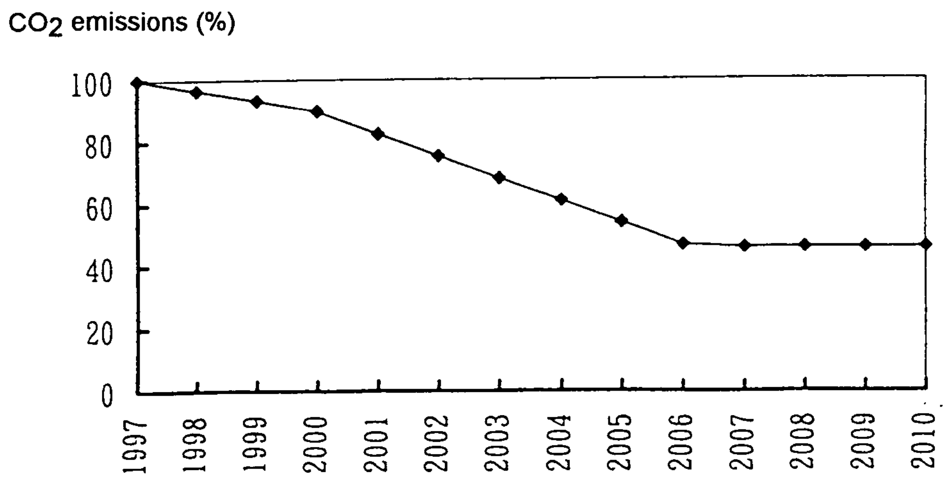

Fig. 4 Carbon Dioxide Emission Reduction Benefit Accrued by Using Energy-Saving Vending Machines

4.3 Challenges of Introducing New Vending Machines

There are no significant technical challenges to surmount when incorporating the energy conservation measures proposed here. Economic considerations present bigger problems to be solved.

The ratio of electricity cost for machine use to the cost of a vending machine is not as great as the ratio of energy consumption for machine use to that required in the processing/assembly stage. However, electricity cost nevertheless accounts for a large proportion, so that investment in electricity-saving measures at the manufacturing stage will no doubt be fully offset over a machine's life. That is to say, vending machines are an example in which reducing overall costs will lead directly to energy savings and a cut in CO_2 emissions. In spite of this fact, even comparatively easy measures are not implemented at this time.

Companies that maintain and manage vending machines (they are also beverage sales companies) conduct their businesses by placing orders for and purchasing machines from manufacturers, paying people to allow the installation of vending machines on their premises, and selling the beverages there. Usually, however, it is the property owners hosting the machines who pay the electricity bill. Thus the entities who buy the machines are not the same as those who pay maintenance fees during their use, and at present there is no mechanism for optimizing the two kinds of costs in totality. If manufacturers institute electricity-saving measures accompanied by increases in machine sale price, that will adversely affect the direct benefit enjoyed by the vending machine management companies that buy the machines, and the consequences will be felt by property owners providing installation space, who are not customers of the vending machine manufacturers. This problem could be easily solved if maintenance companies and property owners would cooperate in making some innovative changes. It is hoped that henceforth such energy conservation measures will be actively implemented.

5. Conclusion

We conducted an analysis and comparison, using both macro statistical data and micro product data, of energy use in the household-service sector. In the household sector we found that micro data can be used to estimate the breakdown of energy consumption data, which cannot be obtained from macro statistical data. Micro data were insufficient, however, to perform such an estimate for the service sector.

We carried out an analysis of energy consumption during both the manufacturing and use stages of vending machines, which are energy-intensive composite products. In the analysis for the manufacturing stage we proposed the implementation of the processing/assembly ratio, and applied it. Heretofore, analyses have ignored the energy consumption and CO_2 emissions of processing and assembly, or they have calculated them by multiplying energy for materials or total CO_2 by a fixed ratio; in these and other ways they have been accorded inadequate consideration. Our proposal, however, makes it possible to perform comparatively simple estimates that do a better job of taking product characteristics into account.

For the use stage, we estimated electricity consumption and the breakdown of consumption factors on the basis of experimental operation and design specifications. This confirmed that it is far more important to reduce electricity consumption during vending machine use than when they are manufactured. An examination of consumption factors showed that most power is consumed by lighting and other ancillary devices, but as there are no exceptionally large factors that account for a major share of consumption, there is no one decisive energy conservation measure. Nevertheless, we found that combining measures that deal with individual factors can effect energy savings of over 50%.

Finally, we examined energy-saving measures for vending machines, and their efficacy. CO_2 emissions arising from beverage vending machines presently account for an estimated 0.28% of Japan's total emissions, but the use of energy-saving vending machines could reduce this to 0.13%. Additionally, the introduction of energy-saving machines is consonant with the trend toward reducing total cost, and should therefore be promoted from an economic perspective as well. Our paper also comments on this matter.

The analysis methods developed or applied in this research can be applied as is to analyses of other energy-intensive products.

[International Joint Research]

We are conducting joint research with the Environmental Sciences Center (Prof. Udo de Haes) of Leiden University in the Netherlands on life cycle assessments, which constitute the nucleus of this research.

[Research Publication]

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