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ENERGY AND MATERIAL USE IN THE PRODUCTION OF ARCHITECTURAL WINDOWS FOR PASSIVE SOLAR HEATING

Masaya Saito and Masanori Shukuya
Laboratory of Building Environment, Musashi Institute of Technology
28 - 1, Tamazutsumi 1-chome, Setagaya-ku, Tokyo 158, Japan

Abstract - Waste heat, waste material, and waste water are estimated for the production of glass sheets and aluminum frames for architectural window systems. The purpose is to compare the wasted energy and materials in the production process with heat loss through window systems in situ. Raw materials, fossil fuels, and fresh water are inputs while waste heat, waste material, and waste water in addition to the products are outputs. Waste heat of 16.9MJ versus 502.5MJ, waste materials of 0.7kg versus 5.4kg, and waste water of $0.05m^3$ versus $0.37m^3$ are given off in the production of glass sheet of one kilogram versus aluminum frame of one kilogram. A comparison of a single glazed and a double glazed windows was made in terms of the waste heat at the stages of production and of use. It was found that the accumulated waste heat, the sum of the waste heat in the production process and the waste heat in situ, of a double glazed window is smaller than that of a single glazed window within the first winter season in Tokyo.

1. INTRODUCTION

The luminous and thermal performance of architectural windows affects electric power consumption for lighting, heating, and cooling systems in buildings. Therefore, new window glazing materials have been developed extensively over the last ten years. Computer simulation with regard to room air temperature and space heating load has confirmed that these newly developed materials are promising (Wilke et al., 1991; Wakabayashi et al., 1993).

Nevertheless, the use of thermally well-insulated glazing materials in newly built homes in Japan is not matured yet except Hokkaido, the northernmost island (JFGMA, 1994). One reason for this is that double-glazed windows, whether with low-emissivity coating or not, are still very much expensive in Japan and some consider that the pay-back period is too long. From the viewpoint of energy and environmental issues, however, it is necessary to consider the pay-back period in terms of the total use of energy and matter during the whole period of production and use even including disposal. Such consideration should reflect the cost of insulated windows.

The purpose of this paper is to reveal how the production systems of window glazing materials such as glass sheets and aluminum frames work. This is done from the viewpoint of thermodynamics, for the thermodynamic view makes it possible for us to let the waste heat and waste materials, which are usually ignored in so-called energy evaluation, come into our view. Finally, we make a comparison of the total waste heat of a single glazed window with that of a double glazed window.

2. PRODUCTION PROCESS

In a production system, as illustrated in Figure 1, not only raw materials are supplied, but also fossil fuels and fresh water are supplied to treat with raw materials for the purpose of producing a product. A certain amount of raw materials become a part of product such as a glass sheet or an aluminium frame, while at the same time the rest is dumped as waste materials. There may be a case in which energy as input fossil fuels is fixed as a part of product, but in most cases it is dumped into the environment as waste heat. Fresh water is usually required for dumping waste heat and waste materials efficiently since the water is a substance that can deliver a large amount of heat when evaporating and that can solve various substances when mixed.

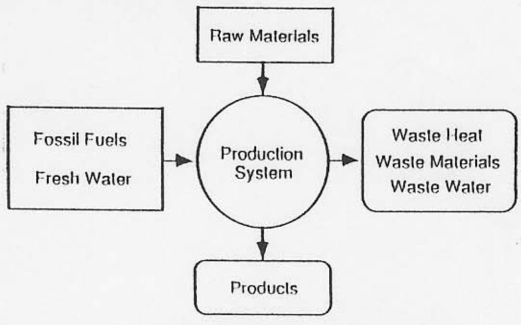

Fig. 1. Flows of energy, materials, and water through a production system.

We tend to take a look only at the relation of input fossil fuels to the final product, but it is also very important for us to take a look at the relation of input fresh water and raw materials to the waste heat, the waste materials, and waste water.

Taking the first and the second laws of thermodynamics into account, the sum of the entropy associated with the raw materials, fossil fuels, and fresh water must be smaller than that of the entropy associated with the product, waste heat, waste materials, and waste water. Even if the entropy of the product is smaller than that of the raw materials, it is possible for the production system to proceed the producing process provided that the waste heat and the waste water can carry away the entropy, an amount of which is large enough, into the environment (Tsuchida, 1982) .

We collected the data of the amounts of silica, dolomite, waste glass as raw materials in mass on annual basis to be supplied to the production systems of glass sheets from the yearbook published by JFGMA (1992). The number of glass sheets produced was also obtained from the yearbook of JFGMA (1992). We also collected the data of the amounts of light oil, heavy oils of class A, B, and C, coal, liquified natural gas (LNG), liquified propane gas (LPG), steam, and the electricity used for production of glass sheets in Japan from the yearbook published by MITI (1992). Each of energy sources is expressed in its own unique unit so that we converted it into the unit of Joule using the respective conversion factor and calculated the total. The steam was assumed to be produced by boilers having the thermal efficiency of 80% and the electricity by oil-fired power plants having the thermal efficiency of 35% including transmission loss. The data of the used water was also obtained from MITI's yearbook.

In a similar manner to what we did with regard to glass sheets, we collected the data with regard to aluminum frames as final product from the yearbook published by JAMA (1992). The data of fossil fuel and fresh water uses associated with the production of aluminum frames was obtained from MITI's yearbook.

Using the collected data, we calculated the mass of raw materials per each kilogram of glass sheets and aluminum frames. The amount of waste materials was assumed to be the difference in the mass between the raw materials and the products. The amounts of waste heat and waste water were assumed to be exactly the same as those of fossil fuels and fresh water supplied to the production system.

We did not calculate the actual amounts of entropy of raw materials, fossil fuels, and others, but as described above, the sum of the entropy of waste heat, waste materials, waste water, and the product must be greater than that of the fossil fuels, fresh water, and the raw materials supplied.

3. RESULTS AND DISCUSSION

3.1 *Production system of glass sheets*

Figure 2 shows the flows of estimated energy, materials, and water through a production system of one kilogram of glass sheets. The whole production system of glass sheets is considered to consist of three processes: melting, plating, and cutting. Raw materials such as silicate materials are first mixed and molten in a fireplace. Glass sheets are made by pouring liquid glass onto a flat table made of metal such as tin and by rolling it into the sheets. The sheets are ground flat and polished on both sides (Pauling, 1970). The final process is cutting the glass sheets.

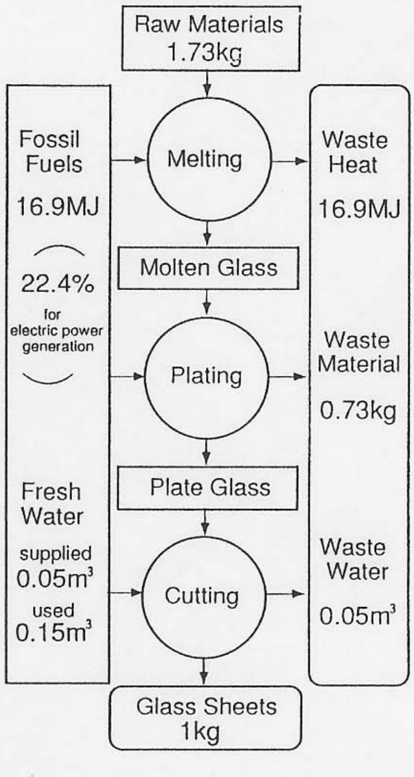

Fig. 2. Production of one kilogram of glass sheets.

The fossil fuels of 16.9 MJ is required for producing one kilogram of glass sheets. The waste heat, the amount of which is equal to the fossil fuels of 16.9 MJ is dumped into the environment. A portion, 22% of the fossil fuels supplied, is used to generate electric power to be used by the production system. The amount of supplied water, 0.05 m^3 for the product of one kilogram, is equal to that of waste water. The total of the used water is 0.15 m^3 so that 0.1 m^3 of water is recycled within the production system. The difference between the raw materials of 1.73 kg and the glass sheets of 1 kg as final product is dumped as waste materials of 0.73

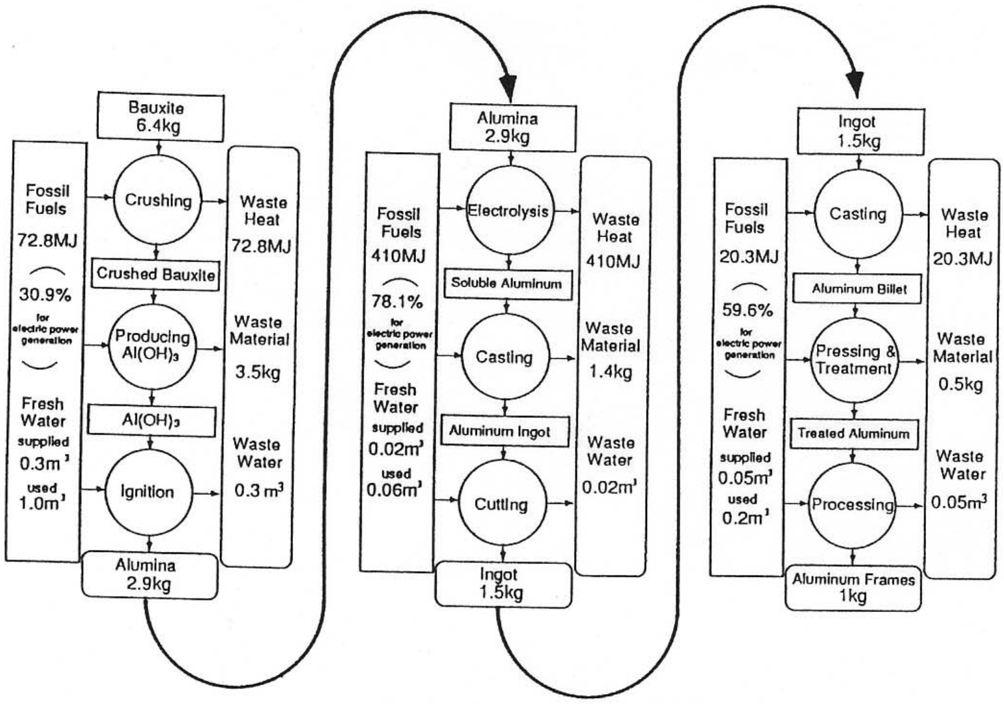

Fig. 3. Production of one kilogram of aluminum frames.

kg into the environment. Most of the waste glass among the waste materials is used again as a recycled raw material.

3.2 *Production system of aluminum frames*

Figure 3 shows the flows of the estimated energy, materials, and water through the production system of one kilogram of aluminum frames. The production system is considered to consist of nine processes from bauxite to final product: crushing, ignition, electrolysis, casting, treatment, and so on. Alumina and ingot are the middle products from bauxite to aluminum frames as final product. The alumina of 2.9 kg requires the bauxite of 6.4 kg; the ingot of 1.5 kg requires the alumina of 2.9 kg; and the aluminum frame of 1 kg requires the ingot of 1.5 kg. Their differences, 3.5 kg from bauxite to alumina, 1.4 kg from alumina to ingot, and 0.5 kg from ingot to the frame are dumped as waste materials. The total of the waste materials is 5.4 kg.

Electric power is consumed most in the process of producing the ingot from alumina, namely electrolysis, among the nine processes. In Japan, there exists only one factory that refines aluminum; it uses the hydro-electric power generated within its own site (JAMA, 1992). The reason is expensive electric power from the grid. The total waste heat of 503 MJ is given off during the production process of aluminum frames of one kilogram; this is thirty times the total waste heat in the production process of glass sheets of one kilogram.

There are usually two casting processes in the production system of aluminum frames: the first is for aluminum ingots and the second for frames. This is because the casting factories usually exist separately.

3.3 *Production of a window system*

We assumed a window system of 1.2 m^2 including both glass and frame. Glass part is 1.02 m^2 and frame part is 0.18 m^2. Comparison was made for three types of window. The first type is single glazed with aluminum frame; the second is double glazed with aluminum frame; and the third is double glazed with wooden frame. A glass sheet was assumed to be 3 mm thick. Therefore, a single pane weighs 7.6 kg and double panes 15.2 kg. The mass of aluminum frame was determined to be 4.1 kg, assuming the sectional shape of a typical aluminum frame commercially available.

Table 1 shows the estimated amounts of the waste heat, waste material, and waste water when the three types of window system are produced. We assumed that the waste heat in the case of wooden frame is one tenth of that of the aluminum frame although there is a study claiming that the wooden frame requires only 0.3~0.8% of fossil fuels for producing the aluminum frame (Arima, 1994). We neglected the waste material and

Table 1. Waste heat, waste material, and waste water by-produced when three types of window system of 1.2 m² are produced.

	Heat [MJ]	Material [kg]	Water [m³]
Type 1	2192	27.6	1.9
Type 2	2321	33.1	2.3
Type 3	464	*	*

Type 1 is single glazed with aluminum frame; Type 2 is double glazed with aluminum frame; Type 3 is double glazed with wooden frame. Glass part is 1.02 m² and frame part is 0.18 m².

Table 2. U-values of three types of window systems

Type 1	7.2 W/m²K (8.6 W/K)
Type 2	4.2 W/m²K (5.0 W/K)
Type 3	2.9 W/m²K (3.5 W/K)

The figures in the brackets are the heat loss coefficient of the whole window area of 1.2 m². The U-values of single pane and double panes are assumed to be 6.5 W/m²K and 3.0 W/m²K, respectively. The U-value of the frame is assumed to 10.8 W/m²K in the case of aluminum and 2.3 W/m²K in the case of wood (ASHRAE, 1989).

waste water when the wooden frame is produced.

The waste heat in the case of Type 2 is larger than Type 1 by 9%. The waste material and waste water in the case of Type 2 is larger than Type 1 by 20%. The reason for a smaller percentage of difference in waste heat is that the waste heat caused by the production of one kilogram of aluminum frames is much greater than that of glass sheets as described above, although the glass sheets weigh more than three times the aluminum frame does. On the other hand, the mass of two glass sheets weighing more than three times that of the aluminum frame causes a larger percentage of difference in waste material and waste water.

Accordingly replacing single glazed window systems with double glazed window systems results in only a small increase in waste heat. The difference in waste heat between Type 2 and 3 is very large, since we assumed the small amounts of waste heat in the case of producing wooden frames.

3.4 *Waste heat from window systems in situ*

We investigated how much of waste heat is released from each of the above three types of window systems in situ. The waste heat in situ is equal to the heat loss through the window systems. We estimated the values of the heat loss by using the overall heat transmission coefficient (U-value) of the glazing and the frame and the degree-days in Tokyo. Table 2 shows the U-values of the three types of window systems. The degree-days of Tokyo is 1800 °C·days, assuming that heating is required when the daily average of outdoor air temperature is below 18 °C and desired room air temperature be 18 °C.

Figure 4 shows the accumulated amounts of waste heat among the above three types of window systems. The accumulated waste heat is the sum of the waste heat dumped in the production process and the waste heat dumped through the window systems during the heating seasons. As described in Art. 3.3, Type 2 must dump a little more waste heat than Type 1 does as far as the production process is concerned, because the total area of the glass sheet doubles. But the heat loss coefficient of Type 2 is much smaller than that of Type 1 as shown in Table 2 so that the total amount of waste heat of Type 2 becomes smaller than that of Type 1 within the first winter season. This suggests that taking the environmental issues into consideration, the cost of double glazed windows in Japan should be much more lowered. The accumulated waste heat over three winter seasons in the case of Type 3 is almost the same as the waste heat in the production process in the case of Type 1 and

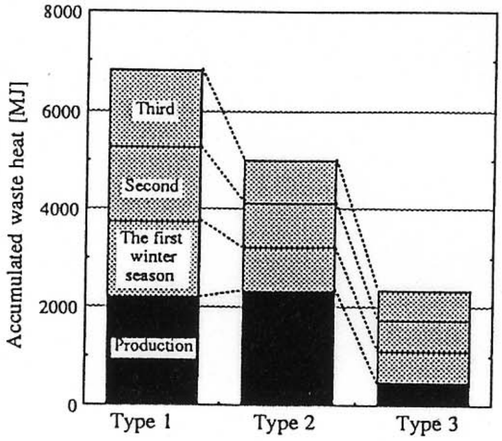

Fig. 4. Comparison of accumulated waste heat among three types of window system.

2, since the wooden frame was assumed to dump a smaller amount of waste heat than the aluminum frame does and it contributes to reducing the heat loss because of the low thermal conductivity. Although the use of wooden frames is basically considered to be welcomed, we should also concern about where and at what rate we may get wooden materials so that we do not help accelerate deforestation.

4. CONCLUSION

We have investigated the production systems of a glass sheet and an aluminum frame in terms of inflows and outflows of energy and matter. The amounts of waste heat, waste materials, and waste water in producing one kilogram of aluminum frames is much greater than those in producing one kilogram of glass sheets. The accumulated waste heat, the sum of the waste heat in production process and the waste heat in situ, of a double glazed window is smaller than that of a single glazed window within the first winter season.

REFERENCES

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) (1989) ASHRAE Handbook of Fundamentals, SI edition. 27.15-27.16.

Arima T (1994) Wood as an eco-material. Japanese Institute of Licensed Architects pp 17-19 (in Japanese).

Japan Aluminium Manufacturers Association (JAMA) (1992) Light Metal Statistics in Japan, pp 1-11.

Japan Flat Glass Manufacturers Association (JFGMA) (1992) Ceramic Industry & Building Statistics in Japan. pp 38-79 (in Japanese).

Japan Flat Glass Manufacturers Association (JFGMA) (1994) The Report on Flat Glass Use In Japan. p 8 (in Japanese).

Ministry of International Trade and Industry (MITI) (1992) Yearbook of The Current Survey of Energy Consumption in Manufacturing. pp 242-254 (in Japanese).

Pauling L (1970) General Chemistry, Third edition. Dover Publications, New York, pp 643-644.

Tsuchida A (1982) Introduction to Resource Physics. NHK Books, pp 41-66 (in Japanese).

Wilke WS, Schmid J (1991) Modelling and Simulation of Elements for Solar Heating and Daylighting. Solar Energy 46(5): 295-304.

Wakabayashi H, Komuro D, Shukuya M (1993) Sensitivity Analysis of Thermal Performance of Highly Insulated Windows. Annual Meeting of Architectural Institute of Japan, Environmental Engineering Section. pp 37-38 (in Japanese).