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Life cycle analysis of retrofitting with high energy efficiency air-conditioner and fluorescent lamp in existing buildings

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ABSTRACT

Life cycle analysis of mercury in discarded low energy efficiency fluorescent lamps (36 W) and of HCFC in air-conditioners (12,000 Btu) removed from service has been conducted in this study. The objective was to find out the environmental impact (EDIP 1997 category, waste evaluation) of the products that appear in the waste stream as a result of facility upgrades. The scope of the study starts from retrofitting of the lamps and air-conditioners through recycling and disposal. For a 36 W fluorescent lamp, the bulk waste 1.64E−5 kg, hazardous waste 1.11E−4 kg, radioactive waste 1.09E−9 kg, and slag–ash 6.02E−7 kg occurred at the end of life of the retrofitting cycle. For a 12,000 Btu air-conditioner, the bulk waste 0.58 kg, hazardous waste 0.11 kg, radioactive waste 0.0002 kg, and slag–ash 0.01 kg also occurred at the end of life of the retrofitting cycle. These small amounts become important when viewed at the country level. These quantities imply that the policy makers who deal with hazardous waste should be aware of this waste-generating characteristic before issuing any pertinent policy. Consideration of this characteristic and planning for appropriate waste management methods at the beginning stage will reduce any future problem of contamination by the hazardous waste.

1. Introduction

This paper reports the life cycle analysis conducted to find out the environmental impacts resulting from some energy conservation measures that produce hazardous waste. The hazardous waste considered for this study is mercury in discarded low energy efficiency fluorescent lamps and HCFC in air-conditioners removed during building upgrades for improved energy efficiency. A 36 W fluorescent lamp and a 12,000 Btu air-conditioner are the reference flows for this study.

1.1. Retrofitting of air-conditioners and fluorescent lamps and their wastes

The term "designated building" in Thailand means a building that consumes energy at a level higher than 20 million MJ/year or has transformers installed with a capacity of more than 1000 kW or 1175 kVA (DEDP, 2000). Energy conservation in designated buildings is an important task as its potential result in terms of energy savings can directly reduce the expenses of the building owners. The estimated Thai government of budget 154 million USD to encourage such energy savings had to be used during 1995–2003 and was projected to save 56.3 million USD in 1234 designated buildings over the first 5 years after the retrofit (WEC, 2005). Retrofitting the buildings by replacing the low energy efficiency air-conditioners and fluorescent lamps are two typical measures from 366 measures recommended by the Department of Alternative Energy Development and Efficiency (DEDE, 2005). The savings from the evaluation of 139 state-owned buildings show that the average total saving ranges around 20–45% (Table 1).

The Thai Bureau of Energy Regulation and Conservation, in 2002, followed up the management of waste removed during retrofitting. It was found that from 139 selected buildings, 59% of the removed air-conditioners were destroyed as specified by the rules of the Treasury Division, 21% were donated to other organizations, 18% were re-used, and the fate of 4% was unclassified. From the same study, 35% of the lighting fixtures were destroyed as specified by the rules of the Treasury Division, 18% were donated to other organizations, and the fate of 47% was unclassified (TU-Thammasat University, 2001). The re-use of the removed air-conditioners or fluorescent lamps will increase the

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Table 1
Average savings from 139 retrofitted state-owned buildings in Thailand 2001

Building type	Savings from air-conditioning system (%)	Savings from lighting system (%)	Total savings (%)	Internal rate of return: IRR (%)	Simple payback period: SPB (year)
Academic	18	21	39	9.2	4.0
Retail store	10	11	21	17.3	7.0
Office	19	14	33	18.0	7.9
Hospital	11	11	22	13.2	5.8
Enterprise	13	15	28	16.4	7.2
Municipal	28	15	43	12.5	5.5

TU Energy Conservation and Management Center (2001).

total load of the country's electricity consumption as compared to the Government plan that all new installations will use low energy consuming devices. From these data, it is clear that there was improper waste management at the end of the retrofitting activity. The problem likely will become worse because the increasing promotion of energy conservation in buildings will lead to higher levels of retrofitting of air-conditioners and fluorescent lamps. It will be even worse if the hazardous waste, e.g. mercury from fluorescent lamps or refrigerant from air-conditioners, leak and lead to contamination in the environment. Suitable recycling and disposal strategies for the removed air-conditioners and fluorescent lamps must be developed and implemented to avoid negative environmental impact.

1.2. *Recycle of air-conditioners and recovery of refrigerant*

The split-type air-conditioner is composed of two separate appliances: the fan coil unit and the condensing unit. These two devices are disassembled for recycle on separate lines. The first stage for the fan coil unit is the disassembling process. The screws are manually removed and the external casing, fan, and internal components are taken out. The coil or heat exchanger contains a high proportion of copper and aluminum. This component is placed on a conveyor belt so that it does not mix with other internal components and is then sent to a crushing machine. For the condensing unit of the air-conditioner, the first stage is also manual dismantling, and the heat exchangers as well as the compressors are removed. The refrigerant and oil used in the refrigeration cycle are recovered. The recovered refrigerant is sealed and sent to a treatment company that specializes in the appropriate processing of these types of gases. In some instances, the refrigerant has already escaped from very old air-conditioners before they come to the recycling facility. In such a case, the used oil cannot be extracted easily from the appliance. The heat exchangers taken out of both the fan coil unit and the condensing unit are crushed into pieces of mixed metals. Next, the pieces travel under a magnet to separate the steel. Later, the remaining pieces are vibrated until they are separated into aluminum and copper by the differences in the specific densities of the materials. The compressor is crushed and the material is recovered by using magnetic force for steel separation. Next, the remaining parts of the compressor are put into a device called an ''eddy current separator''. Inside such a device, the pieces of copper repel the electric current and fly out of the machine, facilitating copper recovery. Then, the pile is again placed under a magnet to recover the small thin metal pieces. By making the effort to utilize such methodical processes, the amount of material recovered is maximized. The crushing and separating room is sealed so that noise pollution from the recycling facility is minimized. The materials recovered from the compressor emerge in separated piles from the line outlet. There are two types of steel material that are recovered: large pieces and small pieces. Unfortunately, the small pieces by themselves are not suitable for cast metal so they are packed into press molds before being sent to a foundry. Moreover, the recovered aluminum is also pressed before being sent to a non-steel smelting plant because it is easier to transport in that form. It is sent along with the recovered copper (Panasonic, 2005).

1.3. *Recycle of fluorescent lamps and recovery of mercury*

Mercury-containing fluorescent lamps that fail the Toxicity Characteristic Leaching Procedure must be managed as a hazardous waste with full requirements for final recycling, treatment, or disposal. This approach helps remove these wastes from municipal landfills and incinerators, providing stronger safeguards for public health and the environment (NYSDEC, 2005).

Recycling of fluorescent lamps begins by keeping the end caps in place during transportation to the recycling facility. After temporary storage at the facility, the lamps will be processed in the crusher, separator, particle and vapor filtration systems, and material handling systems. The materials generated from this activity are end caps, glass, and phosphor powder. End caps are collected, sampled, analyzed for mercury content, and shipped to an off-site metals recycling facility for their aluminum content. Glass is sampled and analyzed for mercury and sent for recycling or disposal, depending on the current market. The phosphor powder is separated and collected in containers and shipped off-site for retort. The ferrous filaments of the lamps are removed by a magnetic separator and sent for retort. The mercury recovered from the retorted co-products is triple distilled and sold on the domestic market as technically pure mercury. An industrial blower maintains negative pressure across the entire lamp processing system, drawing air through the system to clean off residual dust and powder with a series of nine bag house cartridge filters. These filters are automatically flushed to prevent powder build-up, and exiting air passes through a carbon filtration system prior to discharge. The powder is fed into the retort unit where, through the application of heat, the mercury vaporizes, and then condenses in liquid form. This commodity-grade mercury is collected for the triple distillation process. Retorted mercury is distilled three times to remove impurities. When the triple distillation process is complete, an independent metallurgical laboratory analyzes the mercury for appearance and purity and provides certification that it is at least 99.99% pure. Upon verification of purity, the technically pure mercury product is packaged according to individual customer specifications and sold to companies that manufacture mercury salts, mercury-containing devices, or utilize mercury in electronics and various research and development applications (AERC, 2006).