Life Cycle Energy Analysis of Thermal Insulation:
Agricultural waste materials in Thailand

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ABSTRACT: This study evaluates the life cycle energy of insulation boards made from agricultural waste in Thailand, compared with conventional insulation. The evaluation was determined using Life Cycle Energy Analysis methodology which identified the embodied energy of insulation materials over their pre-use phase – manufacture and transportation. Three waste materials were chosen according to their availability and thermal properties for thermal insulation: bagasse, coconut coir and rice hulls. The conventional insulation materials for comparison are cellulose, fibreglass and rock wool. The results from LCEA show that the currently available agricultural waste insulation boards have higher embodied energy than conventional thermal insulation. Only the insulation board made from coconut coir has lower embodied energy than rock wool insulation whilst the embodied energy of bagasse board is almost eight times higher than that of rock wool insulation.
Keywords: agricultural waste, thermal insulation, life cycle energy analysis

INTRODUCTION

Buildings are responsible for significant proportions of global energy consumption and CO_2 emissions and hence have a significant effect on environmental quality. In addition to the energy required for building operation, research of building energy efficiency now focuses also on the embodied energy of construction materials.

Modern dwellings in Thailand are not designed with consideration to the hot and humid climate and therefore frequently demand the installation of air conditioning to achieve comfortable conditions. This is exacerbated in cities like Bangkok where the high density of buildings and atmospheric pollution limits the effectiveness of natural ventilation. Thermal insulation is applied to the building envelope to reduce heat transfer from outside in order to reduce the energy consumption of air-conditioning.

Most of the thermal insulation materials available in Thailand (fibreglass, mineral wool and polyurethane foams) are imported, which increases the transportation element of their embodied energy. This research is exploring the use of the waste materials from Thai agriculture – local materials – for thermal insulation. These materials include bagasse (the waste from sugar production), coconut coir and rice hulls, chosen according to their availability and thermal properties [1].

LIFE CYCLE ENERGY ANALYSIS

This paper evaluates the life cycle energy of insulation boards made from the agricultural waste materials in comparison with conventional insulation materials. The evaluation is based on the Life Cycle Energy Analysis (LCEA) methodology [2, 3] which identifies the embodied energy and environmental impact of insulation materials over the pre-use phase – production process and transportation. The methodological stages of the LCEA are definition of goal and scope, life cycle inventory, impact assessment and interpretation [4]. The critical stages here are the life cycle inventory, in which the energy use in the pre-use phase of insulation materials is quantified, and the impact assessment in which energy consumption is converted into observable impacts – CO_2 emissions, a prime indicator of environmental impact due to its role in global warming [5, 6].

The life cycle inventory demands input data including insulation properties such as density, thermal conductivity and thickness. For equitable comparison, these properties are chosen so that all materials give a thermal resistance of 1.0 m^2K/W. Some thermal insulation materials manufactured from agricultural waste are already commercially available. However, the thermal conductivities of these tend to be higher than for conventional materials; bagasse for example is the most abundant agricultural waste and currently available insulation boards have a thermal conductivity of 0.070 W/mK [7], almost twice that of conventional thermal insulation materials. The higher conductivity demands that a thicker section of insulation is needed, i.e. a greater amount of material, and this increases the pre-use embodied energy for a given thermal insulation performance.

Therefore, two sets of input data for agricultural waste materials have been used; the first set comprises the properties of insulation boards currently available on the market, and the second set comprises the tentative properties of thermal insulation boards currently under development, designed to have a thermal conductivity similar to that of conventional insulation materials. A further aim of these prototype materials is to reduce their density which also contributes to reducing embodied energy. Both sets of input data provide the different energy profiles for comparison with conventional insulation materials.

The main goal of the study is to define the energy profile of insulation boards made from agricultural waste materials. The analysis is carried out according to the Life Cycle Assessment (LCA) standard of ISO 14040. The goal of LCA is to compare the environmental performance of products in order to choose the least burdensome [8].

FUNCTIONAL UNIT

According to ISO 14040 the functional unit (f.u.) is defined as the reference unit through which a system performance is quantified in a LCA. In this study, f.u. is defined as the mass (kg) of insulating board which produces a thermal resistance of 1.0 m^{2}K/W, as proposed by the Council for European Producers of Materials for Construction [9]:

f.u.= $R\lambda\rho A$………………………………………..(1)

Where R is the thermal resistance (1 m^{2}K/W); λ is the thermal conductivity (W/mk); ρ is the density of insulation board (Kg/m^3); and A is the area (1 m^2).

Such a functional unit gives information about the amount of insulation material required to perform a given thermal resistance during the insulation lifetime, focusing only on the environmental and insulating properties of the assessed materials. According to the Eq. (1), input data including insulation properties such as density, thermal conductivity, thickness and the f.u. corresponds to the weight of insulation boards showed in Table 1 and 2.

Table 1: Properties of insulation boards available on the market

Raw Materials	Density (Kg/m^3)	Thermal conductivity (W/mK)	Thickness (mm)	Weight (per f.u.) (kg)
Bagasse	600	0.070	70	42
Coconut coir	200	0.045	45	9
Rice hull	400	0.041	41	16.4
Cellulose[a]	35.3	0.039	39	1.37
Fiberglass[a]	12.1	0.039	39	0.47
Rock wool[a]	64.1	0.039	39	2.49

a = Information from BEES 4.0 [10]

Table 2: Tentative properties of insulation boards currently under development

Raw Materials	Density (Kg/m^3)	Thermal conductivity (W/mK)	Thickness (mm)	Weight (per f.u.) (kg)
Bagasse	18	0.039	39	0.70
Coconut coir	45	0.039	39	1.75
Rice hull	34	0.039	39	1.32

SYSTEM BOUNDARIES

In this study energy and mass flows and environmental impacts have been assessed from the production of raw materials to manufacture of the end-product, following the “cradle to gate” approach. The following life-cycle steps have been analyzed: (See figure 1)

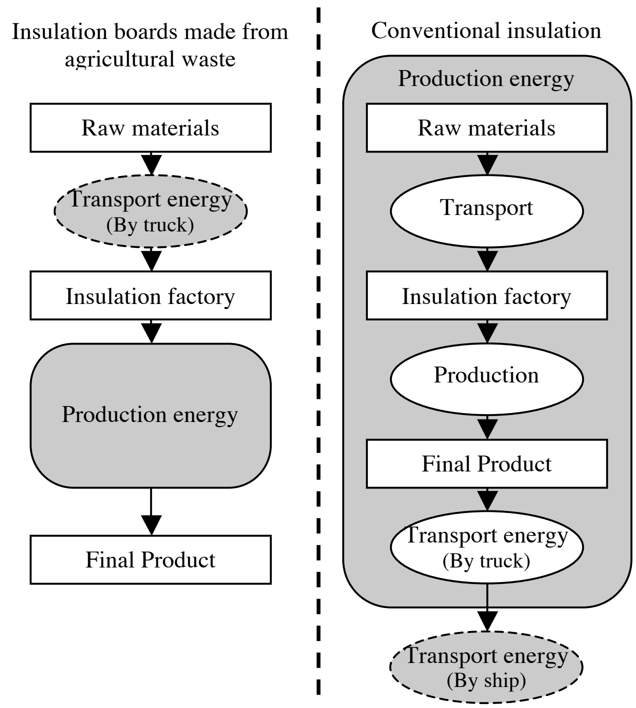


Figure 1: Flow chart identifying transportation and manufacture stages in the production of insulation boards made from agricultural waste in comparison with the production of conventional insulations.

1. Raw materials: the chosen agricultural waste materials are from the Thai food production factory. The conventional insulation materials are imported from USA.

2. Transportation: It has been assumed that agricultural waste materials are transported by diesel truck from the exit gate of the food production plant to

the insulation factory in Bangkok. The transportation distances are estimated as the distance between the Thai province with highest production of the chosen material and Bangkok (Figure 2). The conventional insulation materials are transported by cargo ships from Los Angeles, USA to Bangkok, Thailand (Figure 3).

3. Manufacturing of thermal insulation: A typical production of insulation boards from a factory has been monitored.

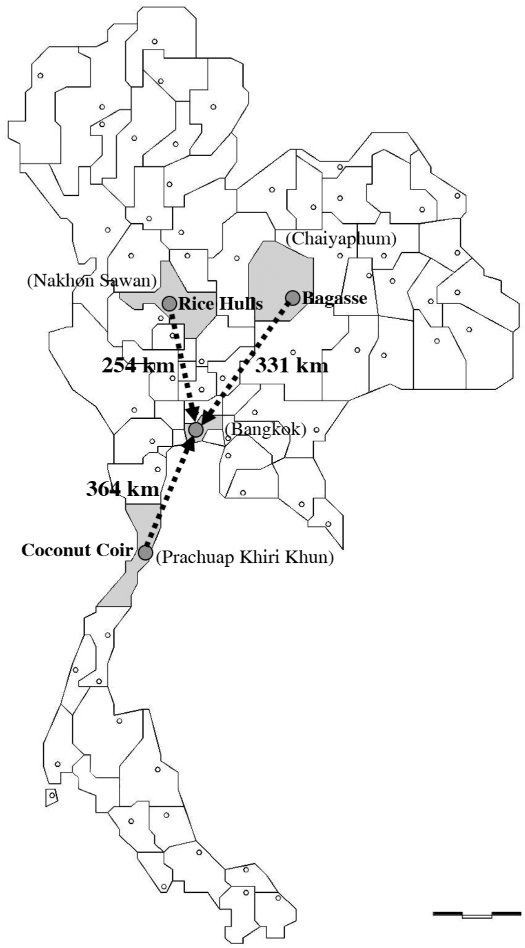


Figure 2: Map of Thailand shows the transport distances of agricultural waste materials to insulation factory.

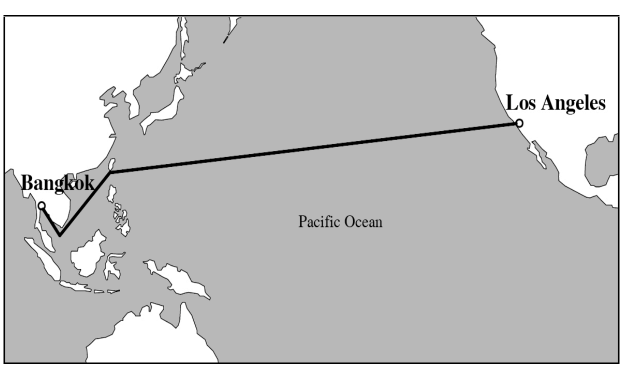


Figure 3: Map shows the transport distance of conventional insulation from Los Angeles to Bangkok. [11]

INVENTORY PHASE

The inventory phase started from the analysis of the production process of insulation boards. The analysis has focused only on the production process and transportation. All data have been established from literature. From investigation the following data were obtained:

1. Energy consumption in the transportation steps are estimated, depending on the transportation modes and the distance among sites. In detail, the following modes are assumed:

Road transport by diesel truck with maximum capacity of 16 tons. Table 3 shows the energy required to transport agricultural waste materials from the food production waste gate to the insulation factory.

Sea freight by cargo ship with maximum capacity of 10000 tons. Table 4 shows the energy required to transport conventional insulations from Los Angeles to Bangkok.

Table 3: The energy required for transport 1 kg of agricultural waste materials to manufacture site

Raw material	Distance (km)	Fuel consumption (MJ/km)	Energy Use (MJ)
Bagasse	331[b]	0.0028[c]	0.927
Coconut coir	364[b]	0.0028[c]	1.020
Rice hull	254[b]	0.0028[c]	0.713

b = Department of highway, Thailand [12]
c = SimaPro 7: fuel consumption of truck (16 tons) [13]

Table 4: transport 1 kg of final products (conventional insulation) from Los Angeles to Bangkok

Final Product	Distance (km)	Fuel consumption (MJ/km)	Energy Use (MJ)
Imported boards	14275[d]	0.0000931[c]	1.329

c = SimaPro 7: fuel consumption of cargo ship (10000 tons) [13]
d = http://www.searates.com/ [11]

Table 5 shows the total transportation energy of insulation boards per functional unit.

Table 5: Total transportation energy of insulation boards

Raw materials	Energy Use (MJ/kg)	Weight (per f.u.) (kg)	Total Energy Use (MJ)
Currently available			
Bagasse	0.927	42	38.93
Coconut coir	1.020	9	9.180
Rice hull	0.713	16.4	11.69
Cellulose	1.329	1.37	1.820
Fiberglass	1.329	0.47	0.624
Rock wool	1.329	2.49	3.309
Tentative boards			
Bagasse	0.927	0.70	0.648
Coconut coir	1.020	1.75	1.785
Rice hull	0.713	1.32	0.941

2. Energy Use in the process of insulating boards production. Table 6 show the energy required for the production process of insulation boards.

Table 6: Total energy use in the production process of 1 m² of insulation boards

Raw materials	Energy Use (MJ/kg)	Weight (per f.u.) (kg)	Total Energy Use (MJ)
Currently available			
Bagasse	2.96[e]	42	124.32
Coconut coir	0.55[f]	9	4.95
Rice hull	1.36[g]	16.4	22.30
Cellulose	0.80[h]	1.37	1.09
Fiberglass	4.21[h]	0.47	2.16
Rock wool	7.83[h]	2.49	19.49
Tentative boards			
Bagasse	2.96[e]	0.70	2.07
Coconut coir	0.55[f]	1.75	0.96
Rice hull	1.36[g]	1.32	1.79

e = Data from factory in China (Production of bagasse particleboard of 600 kg/m³) [14]
f = Data from research of UC Berkeley (Production of coconut board of 1356 kg/m³) [15]
g = Data form factory in Sweden (Production of MDF board of 660 kg/m³) [16]
h = BEES 4.0 (May 2007) [10]

RESULTS

LCEA analysis using the properties of agricultural-waste thermal insulation currently available reveals that these have higher embodied energy than conventional thermal insulation materials (Table 7, Figures 3). Cellulose and fibreglass based insulation materials have the lowest embodied energy; only the insulation board made from coconut coir has lower embodied energy than rock wool insulation and the embodied energy of bagasse board is almost eight times higher than that of rock wool insulation. When the prototype low-conductivity agricultural-waste materials are analysed, all have an embodied energy equivalent to, or lower than, the conventional insulation materials (Figure 4).

Table 7: Inventory results per functional unit of insulation boards (1 m²)

Raw materials	Transport Energy (MJ)	Production Energy (MJ)	Total Energy (MJ)
Currently available			
Bagasse	38.93	124.32	163.25
Coconut coir	9.180	4.95	14.75
Rice hull	11.69	22.30	33.99
Cellulose	1.820	1.09	2.91
Fiberglass	0.624	2.16	2.78
Rock wool	3.309	19.49	22.79
Tentative boards			
Bagasse	0.648	2.07	2.71
Coconut coir	1.785	0.96	2.74
Rice hull	0.941	1.79	2.73

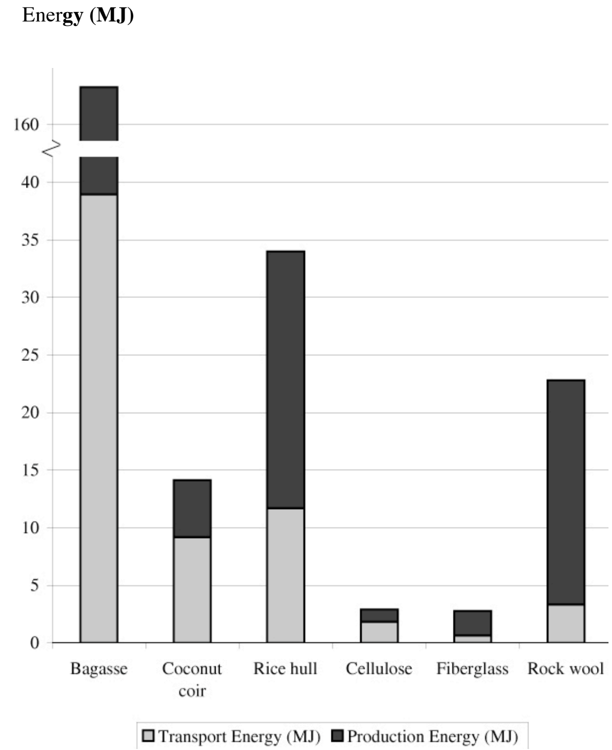
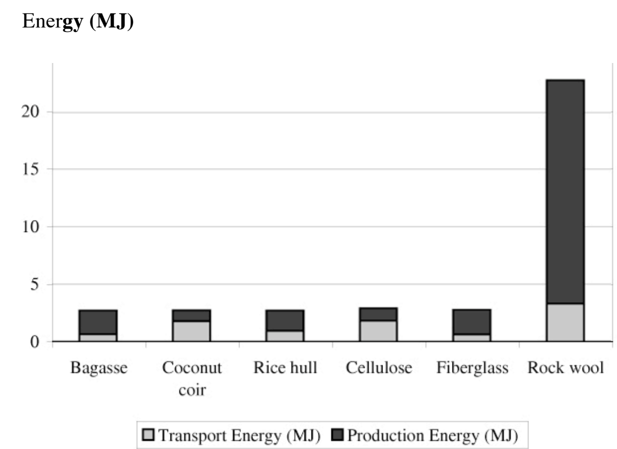


Figure 3: comparison of energy profile of current insulation boards.



DISCUSSION

This analysis shows that currently available thermal insulation boards made from agricultural waste tend to have higher embodied energy and more environmental impact than conventional insulation materials. This is because they demand a higher mass for the same functional unit. To compete with conventional insulation, agricultural-waste insulation boards need to be made with lower thermal conductivity and lower density – the production of these is currently being investigated.

This analysis of pre-use energy represents one component of the overall life-cycle energy analysis, the other elements including in-use energy and energy involved in post-use recycling and/or disposal. Life cycle energy is itself just one component of the Life Cycle Analysis (LCA) which also examines the health implications of different materials in production, use, and post-use.

FURTHER WORK

The insulation properties and energy consumption data presented in this paper have been established from literature and therefore may be subject to errors. The ongoing work includes direct data collection from local factories by means of on-site enquiry and measurement. This will provide data which are more accurate and specific to the system being investigated. Nevertheless these private data are typically confidential which adds the difficulty to get access to the data for researchers.

The next stages of work will also consider agricultural-waste thermal insulation comparison with conventional insulation using LCA methodology. The evaluation will use IMPACT 2002+ method for impact assessment which focuses on human toxicity (calculated for carcinogens) and indoor air quality [17]. The research outcome will encourage architects and builders to consider alternative ways of creating ecological buildings to reduce their energy consumption and environmental impact. The results will add usefulness and market value to agricultural waste materials, a financial benefit to the farmers in developing country like Thailand.

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