Life Cycle Assessment using input-output analysis of CO_2 emissions from housing in Malaysia

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ABSTRACT: In order to develop a sustainable society; it is necessary to assess environmental loads such as CO_2 and NO_X emissions, and the use of natural resources. The Life Cycle Assessment (LCA) can provide useful information for decision-making purposes in order to solve this problem. In this paper, we focus on the analysis only, using an input-output table. The housing types assessed were apartments, terraced houses, semidetached houses, detached houses and so on. We found that the main source of CO_2 emissions during the construction phase came from building structures, foundations or finishes. Finally, methods for the reduction of CO_2 emissions during the construction phase and operation phase were discussed.

Keywords; HOUSING, MALAYSIA, LIFE CYCLE ASSESSMENT, INPUT-OUTPUT ANALYSIS

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1. Introduction

In the IPCC 4th assessment report, it has been pointed out that carbon dioxide (CO_2) emissions come from anthropogenic activity. Developing a low-carbon society is a task we should undertake immediately. Conversely, CO_2 from the housing industries in Asia and Africa will increase. This is because housing demands which correspond to rapid population growth are also increasing. When comparing housing stock in Malaysia in 2001 with that in 2007, a 38% increase in the unit number of the housing stock is observed as shown in Figure 1. It is also increasingly more common to use concrete as a structural material. Subsequently, the fact that CO_2 emissions will increase rapidly, if the present conditions related to the housing in Malaysia persist, has become obviously clear. Generally speaking, timber housing creates less CO_2 emissions than reinforced-concrete housing because CO_2 emissions are generated from the production of cement which uses calcium carbonate as a material. Regarding housing in Japan, the reinforced-concrete housing emits an estimated 23% higher CO_2 content compared to wooden housing [2]. Hence, it is expected that changing the structural materials from reinforced concrete to timber can reduce CO_2 emission. In this paper, the authors assess CO_2 emissions from housing construction in Malaysia by differentiating between housing types and structural materials. The impact on forest resources from increased timber housing construction was also assessed.

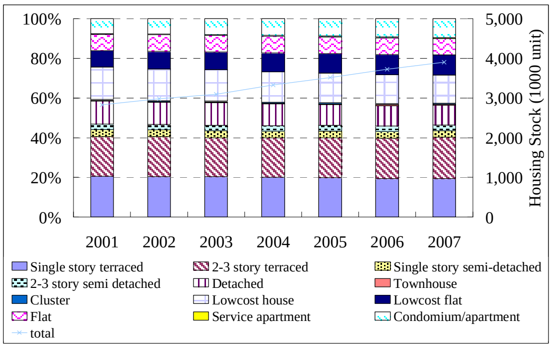

Figure 1: Housing stock in Malaysia and distribution by housing types.[1]

2. Method

2.1. Life-Cycle Assessment (LCA) data

Generally speaking, CO_2 is mainly emitted from fuel combustion and cement production processes. The authors assume that CO_2 is only generated from fuel combustion and cement production processes. In order to estimate CO_2 emissions in Malaysia, a published I-O table of Malaysia- year 2000 [3] was used. Energy consumption data was obtained from the *National Balance of Energy Malaysia 2000*[4]. The other source of CO_2 emission factors excluding fuel consumption was obtained from cement production processes (WBC, 2001 and Yearbook of Statistics Malaysia 2001) [5, 6]. The *equilibrium-output model in consideration of import commodity endogenously expressed as an equation* (1) was used for computing CO_2 emissions**:**

$$\Delta E = \varepsilon[I - (I - \hat{M})A]^{-1}[(I - \hat{M})\Delta F + \Delta EX] \qquad (1)$$

The variables are as follows:

E: Total CO_2 *emission,* ε*: Diagonal matrix of directly* CO_2 *emission, I: Identity matrix, M: Coefficient of import, A: Coefficient of supply, F: Final demand, EX: export*

2.2. Analysis of CO_2 emissions from housing construction

The analysis of CO_2 emissions from housing construction was carried out using LCA data, housing plans and estimated prices of building materials. These data were obtained from the "Building Cost Information Centre" at *Universiti Teknologi Malaysia*. Timber houses were also assessed. Those data were referred to as the *"Feasibility study on the manufacture of prefabricated timber houses in west Malaysia"* [7] by *FIDA* and the *"Construction manual of prefabricated timber house"* [8] by Mohd Shukari Midon et al. The analysis of CO_2 emissions based on building elements such as substructures, super-structures, finishes, sundries/fitting and furnishings, services and external works was done.

The CO_2 emissions from housing construction were calculated by multiplying the material cost by CO_2 emission per 1000 RM as shown in Equation (2):

$$CO2_C = \sum_{i=1} m_i E_i \qquad (2)$$

The variables are as follows:

$CO2_C$: CO_2 emission on construction phase ($t\text{-}CO_2$), m_i : cost of the i-th material ('000RM)

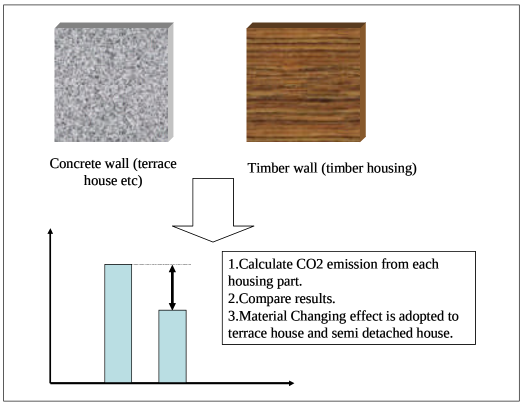

Figure 2: Approach using changed-material effect

It was difficult to obtain the information for computing CO_2 reduction effects through changing the structural material of reinforced concrete to timber. Because of this, the effects of changing the structural materials were investigated as shown in Figure 2. First, CO_2 emissions from the wall construction, per wall area, were computed. This analysis was done for both timber and reinforced-concrete houses. The emissions from the floor were also computed. These results were compared and analyzed. These steps are shown in Figure 2. The analysis was also adopted to terrace houses, semi detached houses, low cost houses and detached houses.

2.3. Analysis of CO_2 emissions from the operation phase

CO_2 emissions from the operation phase were calculated using the same approach that was done for the construction phase. That is to say, they were calculated by multiplying Wj by U and El, as is expressed as Equation (3):

$$CO2_O = \sum_{j=1} W_j U_j El + G \quad (3)$$

The variables are as follows:

$CO2o$: CO_2 emissions during operation phase (t-CO_2), W_j : electric power (W), U_j : Usage time (hrs), El : CO_2 emission per electricity generation (t-CO_2/kWh), G : CO_2 emission by gas usage(t-CO_2)

Table I: Energy saving ways

Home appliances	Energy saving way
Air-conditioner	Using a 1 hp air conditioner with a load rating of 850 W instead of one with a rating of 950 W for 6 hours a
Lightning	Using Compact fluorescent lamps instead of incandescent lamps.
Washing machine	If daily part load wash is reduced to three full load wash per week.
Refrigerator	Using more energy saving type reregister.
Freezer	Temperature is set at –18℃ instead of –21℃.
	Choosing an chest freezer as instead of an upright freezer.
TV&PC	The electricity consumption for standby can easily run up to 100 kWh per year equivalent to RM 22.

The data for estimating electricity consumption was obtained from the *Centre for Education and Training in Renewable Energy and Energy Efficiency* [9]. Gas consumption data was quoted from research by Ho, et al [10]. Furthermore, CO2 emissions from household appliance operations such as gas consumption for cooking which utilize energy-saving practices were also estimated by Equation (3). The hypothesis for this estimation is shown in Table I.

2.4. Environmental impact on forest resources.

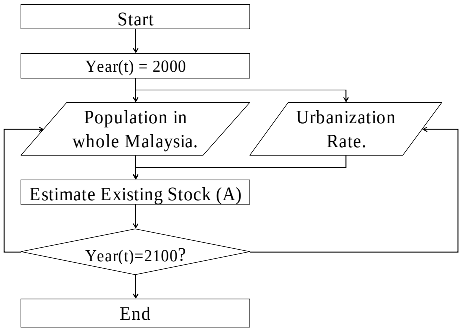

Figure 3: Flow chart of housing stock estimation.

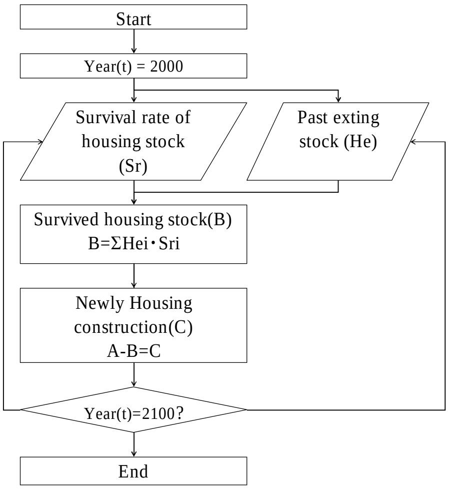

Figure 4: Flow chart of new housing construction.

The environmental impact on forest resources from the effects of changing the structural materials was computed using a statistic model. This estimation was carried out from 2000 to 2001 based on new housing construction and forest productivity. Figure 3 shows the statistical model for estimation of existing housing stock. The estimation for new housing construction was done with the survival rate and existing housing stock as shown in Figure 4.

2.4.1. Estimation of a population

The *cohort survival method* was used to estimate the population. The data for predictions was quoted from the United Nation's population division [11]. Population data predicted by United Nation up to the year 2050 was used.

The population data after 2055 was predicted by the cohort method based on several parameters as shown in Tables II and III.

Table II: Total fertility rate after 2055.

Age/Parameters	Medium	High	Low
15-19	0.04	0.05	0.03
20-24	0.43	0.54	0.31
25-29	0.75	0.95	0.54
30-34	0.45	0.57	0.33
35-39	0.16	0.20	0.12
40-44	0.03	0.04	0.02
45-49	0.00	0.00	0.00
TFR	1.85	2.35	1.35

Table III: Mortality rate by each cohort and assumptions after 2055.

Age/sex	medium		high		low	
	female	male	female	male	female	male
0-4	0.0%	0.0%	0.1%	0.1%	0.0%	0.0%
5-9	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
10-14	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
15-19	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
20-24	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
25-29	0.2%	0.0%	0.1%	0.0%	0.1%	0.0%
30-34	0.1%	0.1%	0.3%	0.1%	0.2%	0.1%
35-39	0.3%	0.4%	0.3%	0.3%	0.2%	0.4%
40-44	0.5%	0.7%	0.5%	0.7%	0.5%	0.7%
45-49	0.9%	1.4%	0.9%	1.4%	0.9%	1.4%
50-54	1.5%	2.5%	1.5%	2.5%	1.5%	2.5%
55-59	2.5%	4.4%	2.5%	4.4%	2.5%	4.4%
60-64	4.4%	7.6%	4.4%	7.6%	4.4%	7.6%
65-69	7.6%	12.5%	7.6%	12.5%	7.6%	12.5%
70-74	12.5%	19.5%	12.5%	19.5%	12.5%	19.5%
75-79	19.9%	29.3%	19.9%	29.3%	19.9%	29.3%
80-84	31.3%	42.7%	31.3%	42.7%	31.3%	42.7%
85-89	45.8%	57.9%	45.8%	57.9%	45.8%	57.9%
90-94	61.6%	72.1%	61.6%	72.1%	61.6%	72.1%
95-99	76.0%	87.5%	76.0%	87.5%	76.0%	87.5%
100+	78.6%	88.9%	78.6%	88.9%	78.6%	88.9%

2.4.2. Estimation of the urbanization rate

The urbanization rate was estimated with a logistic curve as shown in Equation (4). The data for deciding a coefficient was referred from United Nation's population division [11] as shown below:

$$Ur(t)=\frac{K}{1+A\exp(-Bt)} \qquad (4)$$

The variables are as follows:
A and B: Coefficient, t: year,
$Ur(t)$: Urbanization rate

2.4.3. Estimation of the survival rate of housing

The survival rate was also estimated with a logistic curve. The data was referred from the *Housing Census by Malaysian Statistics Bureau* [12], [13]. In general, the survival rate should be estimated based on each construction year, housing type and structural material. However, the authors had to estimate the rate based on assertive assumptions, due to the limitation of the data. The assumptions are as follows.

A) All houses have similar durability regardless of the construction year, structural material or housing types.

B) All houses eventually deteriorate after a long enough period of time.

These assumptions are discussed in Section 4. The survival rate of housing is estimated by the following steps and data scheme in Table IV:

i. Calculate relative demolition rate (r).
ii. Calculate cumulative demolition rate.
$$R(t)=\Sigma r_i$$
iii. Estimate coefficients by linear regression.

Table IV: data scheme

Construction year	Observed year		Demolition rate r=(A-B)/A
	1980	1991	
1980-91	-	B0	
1970-79	A1	B1	r1
1960-69	A2	B2	r2
1950-59	A3	B3	r3
Before1949	A4	B4	r4

2.4.4. The impact on forest resources.

The impact on forest resources was estimated by the following procedures:

A) The entire floor area of new construction housing is calculated by multiplying the housing unit by the floor area per unit.

B) Timber usage is estimated by multiplying the floor area by timber usage per floor by each housing type.

C) Amount of forest areas needed for the building of new housing are predicted based on forest productivity.

Table V shows forest productivity in Malaysia and Table VI shows timber use for housing construction. Timber usage in the low-cost model, per floor area, was estimated for low-cost housing and single-storey terrace housing. Timber usage in the quality model, per floor area, was estimated for 2-3 storey terrace housing, semi-detached housing, and detached housing.

Table V: log productivity [14]

Year	Forest Area (kha)	log (kcu m)	Productivity (cu.m/ha)
2000	18,609	23,074	
2001	18,459	18,922	126
2002	18,411	20,649	427
2003	18,376	21,531	615
2004	18,338	22,039	578
2005	18,065	22,087	81
		Ave.	365

Table VI: timber usage

	Low cost model	Quality model
Log usage (cu.m)	20.84	30.44
Floor area(sq.m)	71.35	225.94
Log usage per floor area (cu.m/sq.m)	0.29	0.13

The following assumptions were used for simulation:

A) After deforestation, replanting is done immediately.

B) Replanted forest cannot be utilized for a period of 30 years.

C) Deforestation areas are permitted only in plantation forests.

Simulations were also done for the following cases:

- Standard
- Higher population growth
- Lower population growth
- Higher Urbanization rate
- Lower Urbanization rate
- Extended housing durability of 20 years
- Extended housing durability of 40 years

3. Results

3.1. The CO_2 emissions from housing construction by each housing type

The results regarding CO_2 emissions from reinforced concrete housing construction are indicated in Figure 5.

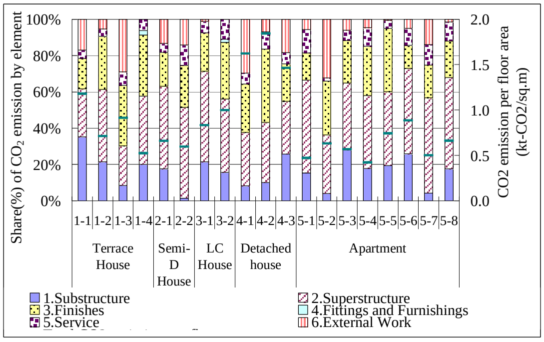

Figure 5: Sharing of CO_2 emissions from housing construction by elements

We obtained the following findings from these results:

A) Figure 5 shows the share of CO_2 emissions from reinforced concrete housing construction. The superstructure emits 20 to 50%, due to cement usage. The secondary CO_2 emission source is the substructure, and finally, finishing.

B) From comparisons between housing with piles and housing without piles (i.e.1-1 and 1-3), it is noted that if the housing weight becomes lighter, then CO_2 emissions from the pile can be reduced or even avoided altogether.

C) CO_2 emissions from finishes are mainly caused by the usage of tiles, because the tile production process requires combustion for producing hard tile.

D) Housing types that have more units such as apartments or terrace housing also have less CO_2 emissions per floor area. This is caused by the sharing of boundaries such as the wall and floor.

3.2. The comparison of CO_2 emissions from housing made of timber and reinforced concrete

We obtained the differences between the CO_2 emissions of timber housing and reinforced-concrete housing with an analysis of elements as shown in Figure 6. CO_2 reduction effects were 31% to 9%.

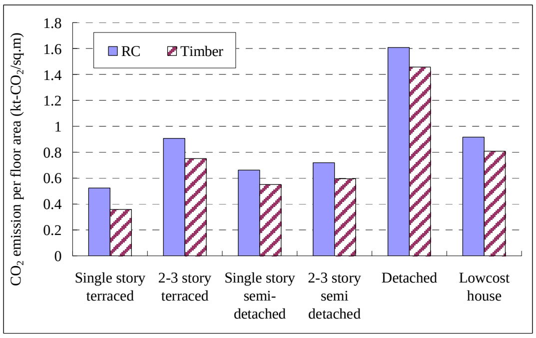

Figure 6: CO_2 reduction effects from changing the structural materials

3.3. CO2 emissions from housing operations for each housing type

Figure 7 shows the CO_2 emissions from housing during the operation phase.

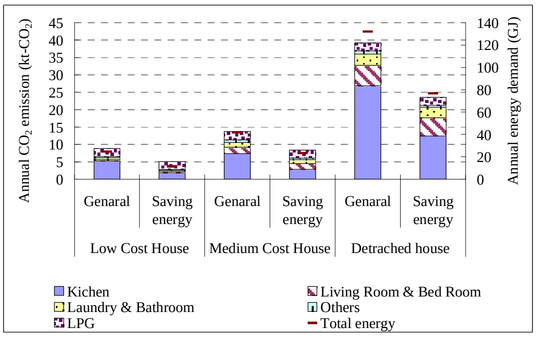

Figure 7: CO_2 emissions from housing operations for each housing type

Based on this analysis, the following findings can be seen.

A) CO2 emissions can be reduced by about 30% when practicing energy conservation in the home.

B) CO_2 emissions from the kitchen consist of more than 50% of the total because of electricity consumption from the refrigerator.

3.4. Environmental impact on forest resources

The regression formulas for existing housing stock are shown in Table VII. Every formula in table VII is acceptable for use with a simulation because statistic tests such as the T-test, F-test and adjusted R-Square test are satisfied. However, the mean average percentage error is indicated to be as much as 8.4%. Figure 8 to 10 shows the results of existing housing units and newly constructed units, based on simulation cases. Based on these results the following findings have been discovered:

A) Population control is the most reductive way to decrease housing construction.

B) More urbanization can encourage housing construction, such as apartment and terrace housing. Nevertheless, all housing construction should be controlled. By contrast, more housing construction, especially detached housing, is considered necessary in the case of urbanization control.

C) Housing construction can be reduced by increasing housing durability. However, the difference between a 40-year increase and 20-year increase is less than between the standard case and a 20-year increase.

Table VII: Regression formula

Housing type	Regression formula							F-test	Adjusted R-square	MAPE
Single story terraced	S_1=	63	Pu+	67	Pr+	-9.8E+05		**	0.996	1.1%
t-value		<48.40>	**	<3.07>	**	<-4.80>	**			
2-3 story terraced	$S_{2=}$	68.76	Pu+			-4.9E+05		**	0.992	2.0%
t-value		<47.62>	**			<-24.67>	**			
Single story semi-detached	$S_{3=}$	12.88	Pu+			-9.4E+04		**	0.953	8.4%
t-value		<19.16>	**			<-10.19>	**			
2-3 story semi detached	$S_{4=}$	9.31	Pu+			-6.9E+04		**	0.958	3.6%
t-value		<20.41>	**			<-10.97>	**			
Detached	$S_{5=}$	144.20	Pu+	658.31	Pr+	-7.7E+06		**	0.951	2.7%
t-value		<6.35>	**	<8.19>	**	<-6.53>	**			
Lowcost house	$S_{6=}$	49.64	Pu+	134.06	Pr+	-1.5E+06		**	0.964	1.7%
t-value		<2.79>	*	<17.48>	**	<-3.31>	**			
Lowcost flat	$S_{7=}$	36.52	Pu+			-3.13E+05		**	0.967	5.1%
t-value		<23.09>	**			<-14.44>	**			
Apartment	$S_{8=}$	69.54	Pu+			-6.11E+05		**	0.990	1.7%
t-value		<42.18>	**			<-27.03>	**			

**1%
*5%

Forest areas required to build houses for each simulation case is shown in Figure 11. Moreover, integrated assessments that consider CO_2 emissions and forest usage are shown in Figure 12.

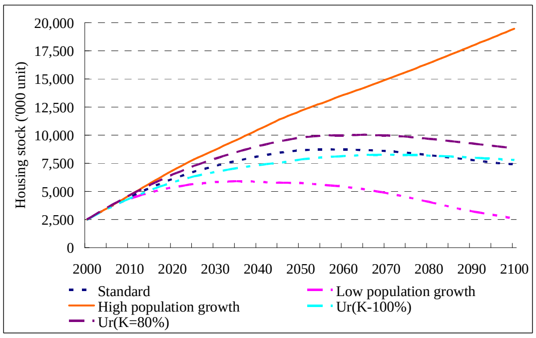

Figure 8: Existing housing units for each simulation case.

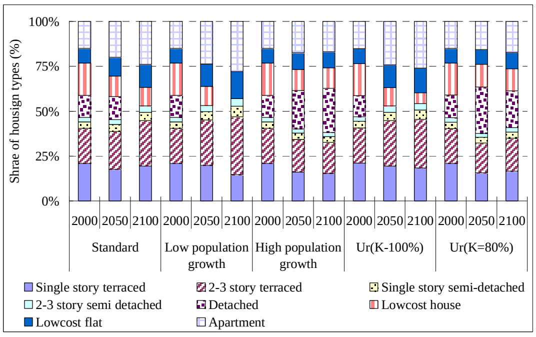

Figure 9: Share of housing types by simulation case.

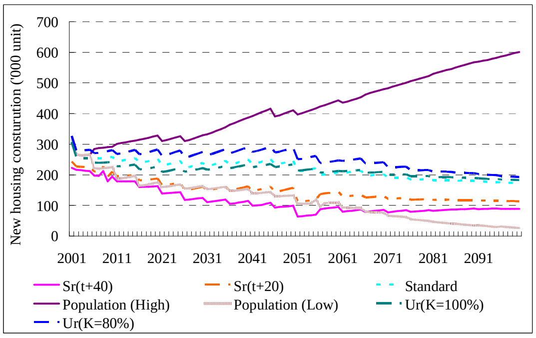

Figure 10: New housing construction

The cumulative CO_2 emissions for a standard case of 100 years were compared to other cases using the ratio of CO_2 emission for reinforced concrete to the standard case. The impact on forest resources for 100 years are represented by the ratio of CO_2 emissions from the total forest area for new housing construction, to the standard case that all housing structures use timber.

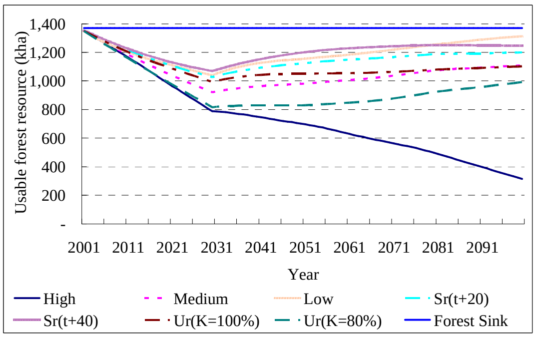

Figure 11: Usable Forest Area

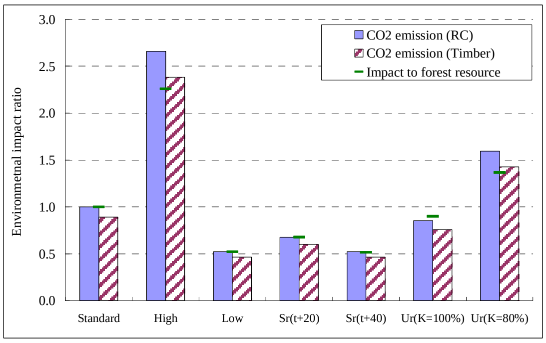

Figure 12: Environmental impact ratio of standard cases compared to other cases.

The following findings have been discovered from the simulation results.

A) Regarding rapid population growth cases, sustainable forest resource use is impossible, due to a greater demand on such resources than is productively possible.

B) Cases for the increase of housing durability up to 40 years appears to have the lowest impact on forest resource, followed by low population growth and encouraged urbanization.

C) Population growth control has the lowest CO_2 emission for 100 years, among all the simulation cases, followed by the increase of housing durability up to 20 years and encouragement of urbanization.

4. Discussion

4.4. CO_2 emissions from housing construction

Countermeasures against CO_2 emissions are as follows:

A) If you build lower housing such as terrace housing, reduce structural weight by changing structural material to timber, a reduction of emissions can be expected.

B) Abstain from using tile for finishes. However, because the relationship between housing durability and finishing materials hasn't been studied yet, this idea must be considered carefully.

In this study, the authors did not show how to increase housing durability. According to Komatsu et al [15], changing the life-style may be a main factor in housing durability in Japan. In the Malaysian case, this hypothesis also might be useful for the consideration of housing durability. A study for clarifying the factors that affect housing durability in Malaysia must be conducted.

4.5. CO_2 emission in the operation phase

The following countermeasures might be effective in reducing CO_2 emissions in the operation phase;

A) Encouraging consumers to buy refrigerators that consume less energy.

B) Establishing “energy-saving” labels for home appliances.

To clarify the differences between timber housing and reinforced concrete housing in lifestyle and energy usage, a questionnaire survey should be administered.

4.6. Impact on forest resources

The results show that changing the structural material to timber has less of a CO_2 reduction effect than do population control, the extension of housing durability, and urbanization. Therefore, these countermeasures must be adopted before structural materials are changed. Furthermore, these measures are also expected to reduce the impact of building on forest resources. In particular, we believe the extension of housing durability to be the most effective countermeasure against CO_2 emission because population control has poor effects on the economy and social welfare. Additionally, a limit on the extent to which urbanization can be encouraged will soon be reached.

Acknowledgments

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