Energy consumption of RC buildings during their life cycle

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ABSTRACT: Studies on the total energy use during the life cycle of reinforced concrete buildings are desirable, considering the urgent necessity to save energy. Life cycle of buildings includes different phases which are the manufacture of the building materials, transportation, construction of the building, occupancy, renovation, demolition and removal of the materials from debris. However, there have been few studies are on the total energy use during the life cycle of buildings. Researches are mainly focused on the energy use for buildings during their period of use. In the present study, the total energy use of ordinary reinforced concrete buildings in Izmir during their life cycle is investigated and their energy consumptions are calculated for all temporal phases separately.

1 INTRODUCTION

The optimum use of limited energy sources is one of the most vital issues for the modern countries. The increase in global warming, energy resource depletion, and local and regional pollution have detrimental effects on the ecological system since the late 1980s. Buildings have a great role in global and local energy consumption of the world and energy savings in buildings has gain importance in last decades.

Energy used during the lifespan of buildings consists of consumed energy in production, management and destruction phases (Fig. 1). Production energy may be divided into three parts: material manufacturing, transportation and erection energy. Management energy is the energy used during occupation and renovation of building. Occupation energy mainly includes the energy used for heating, ventilation and household electricity. Obsolescence, natural or man-made catastrophe and out-of-fashion facilities causes the renovation of building. Destruction energy is the energy use for the demolition and removal of debris processes at the end of the lifespan of buildings.

There have been few studies are on the total energy use during the life cycle of buildings. Researches on the energy use for buildings are mainly focused on management phase. In the present study, the total energy use of three ordinary reinforced concrete buildings in Izmir during their life cycle is investigated and their energy consumptions are calculated for all temporal phases separately. Therefore, it is often useful for a designer to have a tool, which will allow a building to be assessed at the design stage, so that various design options and strategies can be compared with one another based on the performance over their useful lifetime.

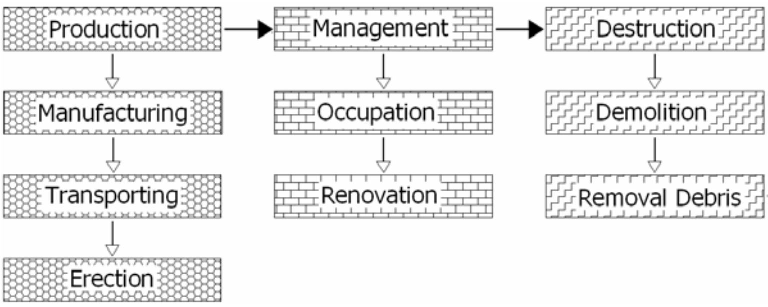


Figure 1. Life cycle phases of a building

2 METHOD

Life cycle of building includes the manufacture of building materials, transportation of building materials to construction site, erection of building, occupancy, renovation, demolition and removal phases. Energy demand during the life cycle of the building $Q_{life\ cycle}$ (kWh), is the sum of the different energy demands during the different phases and calculated as below.

$$Q_{life\ cycle} = Q_{manufacture} + Q_{transportation,\ production} + Q_{erection} + Q_{occupation} + Q_{renovation} + Q_{transportation,\ renovation} + Q_{demolution} + Q_{transportation,\ removal} \quad (1)$$

Since there is not enough data about the energy gained by reuse, recycling or combustion, the value of the left over products are neglected. The procedure used for calculating energy consumption in all these phases is described below.

2.1 *Energy consumption in production phase*

Energy is required for manufacturing any construction material. The manufacturing energy requirements of some construction materials are presented in Table 1. The waste of each material produced during the erection of the building is also shown in the same table. The waste is expressed as a waste factor w_i. The energy requirement for manufacturing any the building material $Q_{manufacture}$ (kWh) can be calculated as follows (Adalberth, 1997):

$$Q_{manufactur} = \sum_{i=1}^{n} m_i \left(1 \pm w_i/100\right) M_i \quad (2)$$

where n = number of materials, *i* = the material of concern, m_i = amount of the building material *i* (ton), w_i = the factor for waste of the building material *i* produced in erection (%), and M_i = energy required for manufacturing the building material *i* (kWh/ton).

Table 1. Energy use for building materials

Materials	M_i (kWh/ton)*	w_i (%)**
Reinforced Concrete	560	20
Plain Concrete	210	10
Tiles and clinkers	2000	10
Glass	7230	0
PVC	24650	5
Polystyrene	29650	10
Coatings: Paints and lacquers	7000	5
Steel	8890	5
Electric wires, copper	19780	5
White goods, 1110 kWh/per item	-	-

* Source: Andersen et al., 1993
** Source: Larsson, 1983

Energy is required for moving construction materials from one place to another. Transport takes place from the manufacturer to the building site, when the building is being erected or renovated. The transportation of raw and semi-manufactured materials is included to the manufacturing energy. Various energy uses associated with different kinds of transportation is shown in Table 2.

Table 2. Energy use for transportation of building materials

Transportation	T_c (kWh/ton km)*
Long Distance Road (distances > 50 km)	0.28
Long Distance Road (distances ≤ 50 km)	0.75

* Tillman et al., 1991

The energy use for transporting the building materials $Q_{transportation,erection}$ (kWh) to and from the building site in erection can be calculated as follows (Adalberth, 1997):

$$Q_{transportation,erection} = \sum_{i=1}^{n} m_i (1 + w_i/100) d_i \; T_c \tag{3}$$

where n = number of materials; i = the material concerned; m_i = amount of the building material i (ton); w_i = factor for waste of the material i produced during erection of the building (%); d_i = distance from the manufacturer of material i to the building site (km) and T_c = energy required for the conveyance concerned (kWh/ton km).

Energy is needed for many erection stages of a building such as for instance drying and drainage, the heating of sheds and of the building itself, electricity for lighting purposes and for machinery, and so on. The energy pertaining to the various processes are given in Table 3.

Table 3. Energy consumption for various processes

Materials	P_i *
Drying of standard concrete on building site	44 kWh/ton
Drying of concrete element	25 kWh/ton
Excavation and removal of soil	32 kWh/m^3
Smoothing of soil	3 kWh/ton
Lighting of construction object	26 kWh/m^2 usable floor area

* Source: Andersen et al., 1993

The energy use for different processes in erection of a building $Q_{erection}$ (kWh) is estimated as follows (Adalberth, 1997):

$$Q_{erection} = \sum_{k=1}^{m} p_k P_k \tag{4}$$

where m = number of processes; j = the type of process; p_i = the amount of the process j (ton, m^3 or m^2 usable floor area); and P_j = energy required for the process j (kWh/ton, kWh/m^3 or kWh/m^2 usable floor area).

2.2 *Energy consumption in management phase*

Management includes occupation and renovation phase of a structure. Energy used in occupation has many components but in the present study only heating and electricity energy are considered. The heating energy demand of buildings is calculated according to Turkish Standard TS825-Thermal Insulation of Buildings (1999). Due to there is no detailed investigation on electricity consumption for example buildings, general consumption values are used.

According to Turkish Republic Prime Ministry State Planning Organization (2003), annual electricity consumption is 3000 kWh/person for Izmir region. The energy needed during the occupation phase, $Q_{occupation}$(kWh), is obtained by multiplying the energy use per year, $Q_{occupation}$ (kWh/year), by the life-span of the building concerned, in this case 50 years:

$$Q_{occupation} = 50.Q_{occupation,annual} \tag{5}$$

When the energy use during the renovation of a building is calculated, some assumptions regarding the life-span of the various construction materials have to be made. Life-spans of some materials are given in Table 4.

Table 4. The life spans of construction materials

Life span of building	Life span (annual)*
Life span of building	50
Frame (External walls, internal walls, insulation)	50
Parquet flooring	50
Water pipes and electric wires	50
Ventilating channels	50
Facing: wooden paneling	30
Windows and doors	30
Wardrobes and cupboards	30
Roofing tiles and drainpipes	30
Plastic carpeting	17
Water heater	16
White goods	12
Painting and wallpapering	10

* Source: SABO, 1992

The energy use for producing the building materials during the renovation, $Q_{renovation}$ (kWh), is estimated as follows (Adalberth, 1997):

$$Q_{renovation} = \sum_{i=1}^{n} m_i (1 + w_i/100) M_i \left(\frac{\text{life span of a building}}{\text{life span of material}_i} - 1 \right) \tag{6}$$

The energy use, $Q_{transportation,renovation}$ (kWh), for transporting the building in renovation is estimated as follows (Adalberth, 1997):

$$Q_{transportation,renovation} = \sum_{i=1}^{n} m_i (1 + w_i/100) \left(\frac{\text{life span of a building}}{\text{life span of material}_i} - 1 \right) (d_i + 20) T_c \tag{7}$$

2.3 *Energy consumption in destruction phase*

Destruction phase includes demolishing and removing debris from the building site. The energy use for demolishing the building $Q_{demolition}$, (kWh), is estimated as follows (Adalberth, 1997):

$$Q_{demolition} = \sum_{k=1}^{m} p_k P_k \tag{8}$$

where m = number of processes; j = the type of process; p_i = the amount of the process j (ton, m^3 or m^2 usable floor area); and P_j = energy required for the process j (kWh/ton, kWh/m^3 or kWh/m^2 usable floor area).

The energy use, $Q_{transportation,\ demolition}$ (kWh), for transporting the building in renovation is calculated as follows:

$$Q_{transportation,\, demolition} = \sum_{i=1}^{n} m_i \left(1 + w_i/100\right) 20\ T_c \qquad (9)$$

20= the assumed distance from the building site to the waste disposal site (km); and T, = energy required for the conveyance concerned (kWh/ton km).

3 NUMERICAL EXAMPLE

In the present study, the energy use of three reinforced concrete dwelling buildings during their lifespan is investigated. Floor plans of these buildings are shown in Figure 2, Figure 3 and Figure 4.

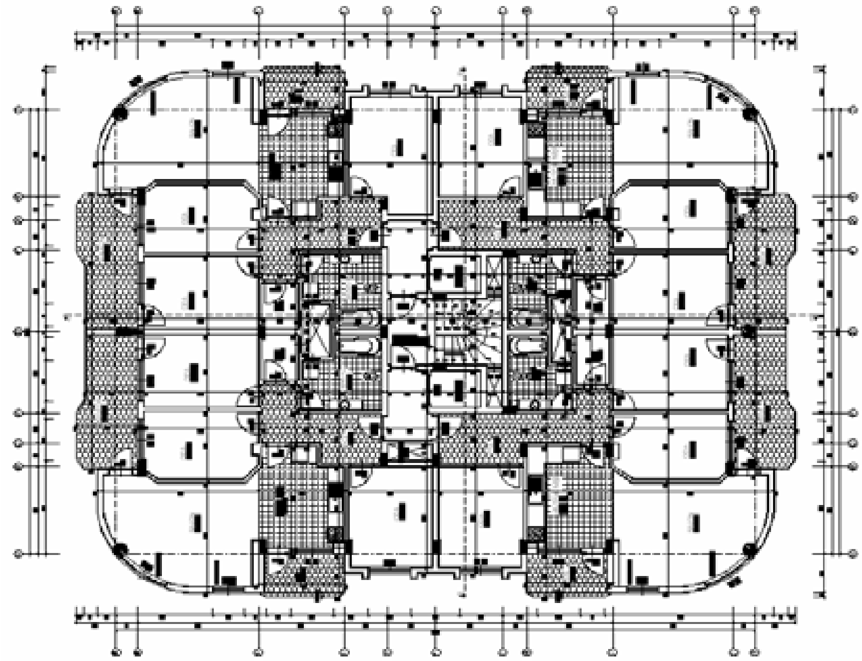


Figure 2. Building Plan 1

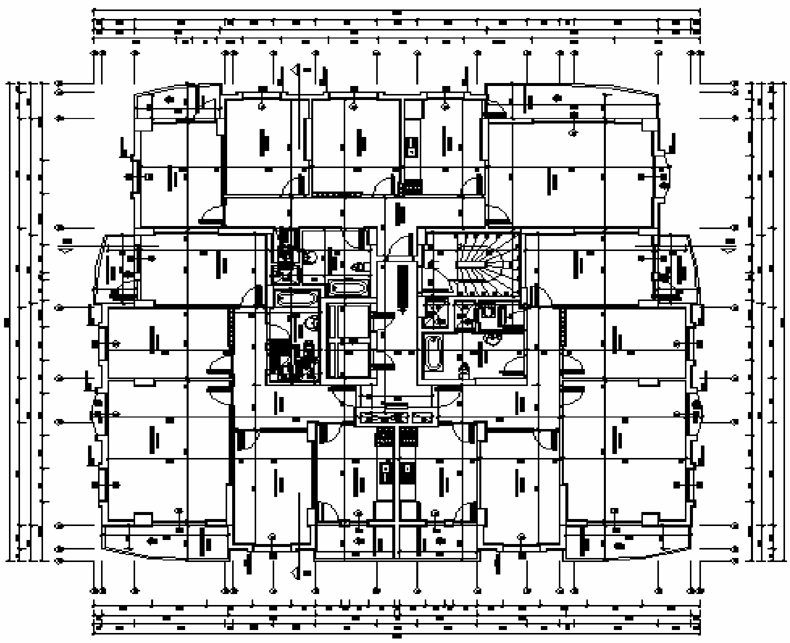


Figure 3. Building Plan 2

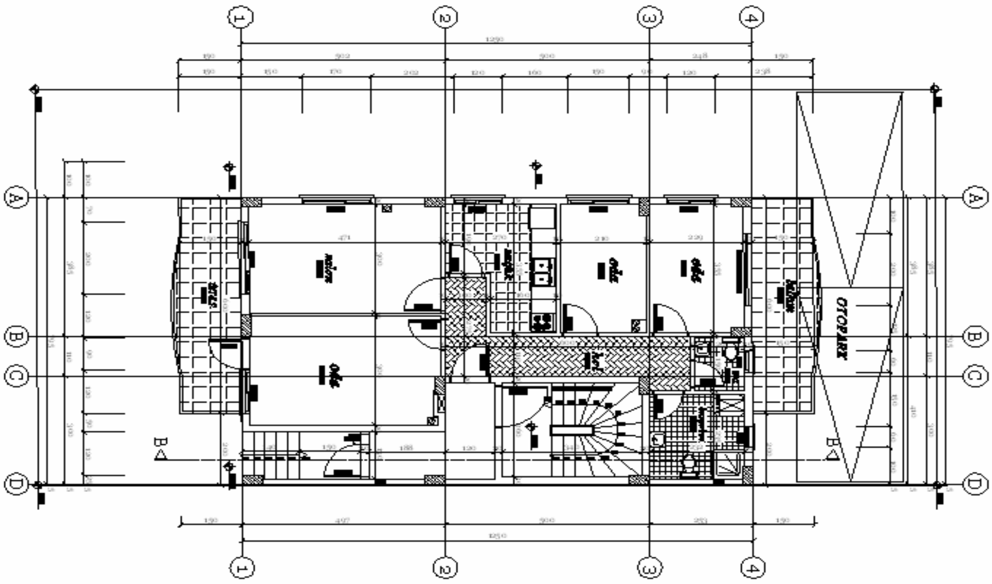


Figure 4. Building Plan 3

All buildings are in Izmir region. Some characteristic properties of buildings are summarized in Table 5.

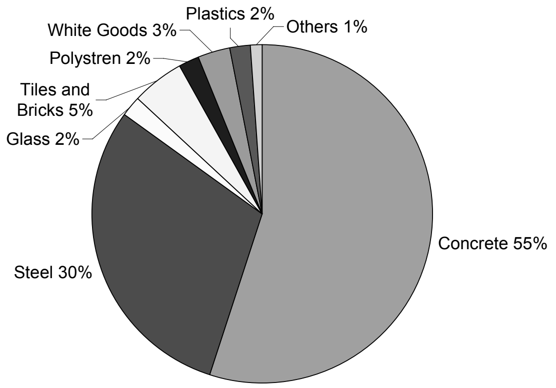
Table 5. Properties of buildings

	Building 1	Building 2	Building 3
Floor Area (m^2)	410	450	100
Number of floors	10	6	5
Number of apartments	40	24	5
Number of residents*	144	86	16
Source of heat	District Heating	District Heating	District Heating
Heating system	Radiators	Radiators	Radiators

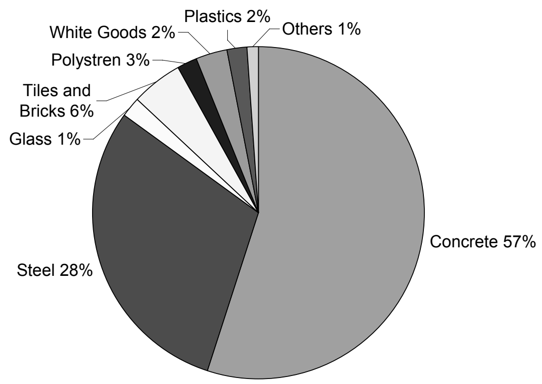
* The number of residents is estimated according to Turkish Prime Ministry State Planning Organization Reports (2003). In the city of Izmir, approximately 3.6 person living in each apartment.

The amounts of materials consumed for erection of each building was calculated. The quantities of the building materials are substituted into Equation 2 in order to determine manufacture energy of materials for each building and calculated energies for materials are presented in Figure 5.

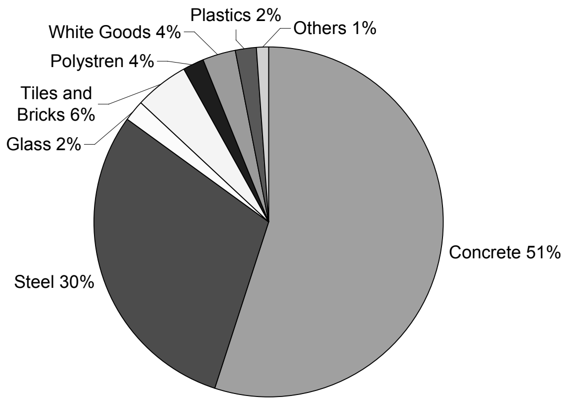
Only heating and electricity energies are considered in calculating occupation energy of buildings. The heating energy demand of buildings was calculated according to Turkish Standard TS825 (1999). There is no detailed investigation on electricity consumption for buildings. For this reason, the approximate energy consumption value published by Turkish Republic Prime Ministry State Planning Organization is used. According to this organization report, electricity consumption is 3000 kWh per person for Izmir region. This value is multiplied by number of residents and annual electricity consumption of each building is calculated.



Building 1 : $Q_{manifacture}$= 1066 kWh/m^2 for 50 years



Building 2 : $Q_{manifacture}$= 1202 kWh/m^2 for 50 years



Building 3: $Q_{manifacture}$= 1396 kWh/m^2 for 50 years

Figure 5. Energy used for manufacture the construction materials for life cycle of buildings

The energy used in production, management and destruction phases are calculated and summarized in Table 6. It is seen from this table that the most energy is consumed in management phase for all buildings. Results also show that the total energy consumption of each building is 162, 157 and 182 kWh/(m^2 .year) respectively.

Table 6. Energy use during life cycle of buildings

	Building 1		Building 2		Building 3	
Phases	kWh/m^2	%	kWh/m^2	%	kWh/m^2	%
Production						
Manufacture	1066	13.2	1202	15.4	1071	11.8
Transportation	31	0.4	34	0.4	28	0.3
Erection	148	1.8	159	2.0	143	1.6
Management						
Occupancy, 50 years	6470	80.0	6086	77.8	7098	78.2
Renovation	341	4.2	313	4.0	707	7.8
Destruction						
Demolition	10	0.1	11	0.1	9	0.1
Removal	21	0.3	23	0.3	19	0.2
Total kWh/(m^2.50 years)	8088	100	7827	100	9075	100
Total kWh/(m^2.year)	162		157		182	

4. CONCLUSIONS

In this paper, the total energy use during the life cycle of the three buildings in Izmir region is investigated. The purpose is to gain an insight into total energy use for buildings during its life cycle. The energy used for concrete and steel is 85%, 85% and 81% of the buildings and these are composing the main part of the manufacturing phase. The results show that management phase is the highest energy consumption phase for all buildings. For this reason, using less heating and electricity energy is very important for minimizing life cycle energy. It is also obtained that total energy use of buildings are 162, 157 and 182 kWh/(m^2.year) and energy use is increasing when the total useful area of building is decreasing .

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