Renewable Energy 84 (2015) 124–129

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

An investigation on life-cycle energy consumption and carbon emissions of building space heating and cooling systems

Li Xiang-Li*, Ren Zhi-Yong, Duanmu Lin

School of Civil Engineering, Dalian University of Technology, Dalian 116024, China

A R T I C L E I N F O

Article history:
Received 15 March 2015
Received in revised form
1 June 2015
Accepted 11 June 2015

Keywords:
Building energy systems
Carbon emission
Mathematical model
Life cycle

A B S T R A C T

Building space heating and cooling system built-in the town's infrastructure is an important factors for building energy consumption and carbon emission source. In order to understand the roles of building energy system in the global warming, this paper established a mathematical model of energy consumption and carbon emission for the building energy system. Two district heating systems for residential buildings and nine space heating and cooling systems for public buildings were selected to analyze their energy consumption, carbon emission and economy based on a calculating model. The results showed that the two residential building cases B_{01} and B_{02} of life-cycle carbon emissions are 743.60 kg/m^2 and 620.98 kg/m^2, the public building cases B_{03}~b_{l1} of life-cycle carbon emissions are 800.15–1377.85 kg/m^2. Equipment materials production, installation and maintenance phase embodied energy and carbon emissions proportion reached up to 6%~14%, energy conservation and emissions reduction potential should not be neglected. The application of some renewable energy reaches a certain effect of energy conservation and emissions reduction in building, but the life cycle cost of emission reduction is much higher than carbon tax in China.

1. Introduction

The critical environment challenge for the human being is of great climate warm effects due to the increasing global carbon dioxide emission. To greatly cut down the emission has been considered as an important national development policy. At the Copenhagen climate conference in 2009, China government has issued an obligatory target, that is, to reduce the carbon dioxide emission per unit of gross domestic product (GDP) by 40%–45% between 2005 and 2020.

Construction industry has become a major aspect of global energy consumption and greenhouse gas emissions. United Nations Environment Programme(UNEP) revealed that the building energy consumption has a ratio of 30%~40% to the total energy consumption and its greenhouse gas emissions will reach up to around 30% by 2030 [1]. Urban building energy consumption in China consists of the building materials production, the building energy consumption, the life consumption, the space heating energy consumption, and the air-conditioning energy consumption, etc., which account for around 46.7% of the total energy consumption.

The biggest consumption produces from the space heating and air conditioning systems is a proportional to 20% of total consumption and the energy consumption during building materials manufacture accounts for16.7%. In regarding to the energy structure, China government has made a coal-leading policy for the present and the future development plan. As well known that the high energy consumption will generate the high emissions. Thus, to save energy and reduce gas emission by means of optimal design of the building energy system, reducing energy consumption and the environment impact caused by the building and its affiliated energy systems is an urgent and ongoing target.

Life cycle assessment is one of the well-know methods to evaluate the environment load [2]. The preliminary explorations of building life cycle energy consumption and environmental impact of carbon emissions have been investigated in recent years [3–6]. Effects of energy consumption and carbon emissions of traditional building energy consumption are confined by the statistic data and simulation approach during system operation stage [7,8] or limited by qualitative evaluations for smaller system life cycle [9]. Especially for renewable energy systems, such as photovoltaic power generation system, solar hot water system, etc. The guidance of building energy system design, energy conservation and emissions

* Corresponding author.
E-mail address: lxl@dlut.edu.cn (L. Xiang-Li).

http://dx.doi.org/10.1016/j.renene.2015.06.024
0960-1481/

reduction in the construction field design should obey the integrated and regional principle of the system evaluation.

In this work, we divided the life cycle of the building energy system into four stages based on the division building life cycle method, which are the pipeline comprehensive production, the installation, the operation maintenance and the dismantle disposal [10]. In order to disclose the distribution of energy consumption and the carbon emissions at corresponding four stages and provide strategy for energy conservation and emissions reduction of building energy systems, we proposed a energy consumption and carbon emissions life cycle calculation model in terms of the actual situation of China. The validation of proposed model operability is conducted by two district heating systems and nine large public buildings heating and cooling system life cycle energy consumption and carbon emissions were analyzed in detail.

2. Energy and carbon emissions calculating model

The proposed mathematical model can visually express calculating data what we need about the energy consumption and carbon emissions of urban building energy system. All kinds of energy consumption can be convert to the equivalent heat value while energy consumption are calculated and compared within different energy source. Different kinds of greenhouse gases caused by the greenhouse effect intensity difference is quite larger. Generally, the international unified practice is to use carbon emission equivalent as a benchmark. This paper adopts carbon emission equivalent to represent all kinds of greenhouse gas emissions according to the global warming potential (GWP). The carbon emission equivalent including CO_2, CO, NO_2, O^3, etc.

2.1. Comprehensive production of equipment phase

Most energy consumptions and carbon emissions during this phase are all originated from the production of material and equipment processing in which the energy consumption comes from the process of raw materials extracting, transportation and production. Considering the loss of material production process and regeneration of recyclable materials, energy consumption in this phase can be expressed as [3]:

$$E_{production} = \sum_j \sum_i (1+\varepsilon_i)\left[M_i\omega_{ei}(1-\delta_i) + M_i\omega_{ei}^r\delta_i\right] + \sum_j M_j E_j \omega_e \tag{1}$$

where $E_{production}$ is energy consumption from equipment comprehensive production, MJ, ε_i is waste coefficient caused by production process of the ith composition material at jth equipment, M_i is the mass or volume of the ith composition material at jth equipment, and the units are kg or m^3, ω_{ei} and $\omega r\ ei$ are the unit mass or the volume energy consumption by original production process and recycling of the ith composition material of jth equipment, and units are MJ/kg or MJ/m^3, M_j is the mass of jth equipment, kg, E_j is unit mass electricity consumed by secondary processing of jth equipment, kWh/kg, ω_e is conversion coefficient of the power, MJ/kWh.

Carbon emission of this phase can be calculated based on the carbon emission intensity of unit building materials production [11], it is

$$C_{production} = \sum_j \sum_i (1+\varepsilon_i)\left[M_i\omega_{ci}(1-\delta_i) + M_i\omega_{ci}^r\delta_i\right] + \sum_j M_j E_j \omega_c \tag{2}$$

where $C_{production}$ is the carbon emissions from the equipment comprehensive production, kg, ω_{ci} and $\omega r\ ci$ are unit mass or volume carbon emissions from original production process and recycling of the ith composition material at jth equipment, kg/kg or kg/m^3, ω_c is carbon emission factor of power, kg/kWh. δ_i, ε_i, M_i, M_j and E_j have the similar terms as Equation (1).

Energy consumption and carbon emissions data of per unit building materials production are indispensable when calculate the energy consumption and carbon emissions. Some data belongs to the research of china building materials [12–18]. Some data are extracted from the extrapolation of foreign research data [3]. Energy consumption data of primary metal material comes from the China's National Development and Reform Commission (CNRC), including energy consumption from mining to ingot casting, main production process and auxiliary production systems. Based on the influence of material reuse rate and yield [13], the optimized results are as shown in Table 1.

2.2. Installation phase

The energy consumption and carbon emissions of installation phase are referred as literature [19,20], which generated by the transport machine energy consumption E_{ct} and the carbon emissions C_{ct} transferring from the factory equipment – to construction site, construction machinery energy consumption E_{cp}, carbon emissions C_{cp}, heat station, direct-buried insulation pipe construction, additional material consumption energy consumption E_{cm} and carbon emissions C_{cm} during the construction.

Three kinds of power energy are called by the diesel, the petrol and the electric power in this phase, the energy consumption E_{cm} of material consumption of direct-buried insulation pipe construction is calculated by as Equation (1) and the rest of parameters are as the Equation (3) and Equation (4).

$$E_{ct} = \sum_j \sum_i M_i L_{ij} \mu_1 \omega_{tj} (1+\alpha_n) \tag{3}$$

Table 1
Energy consumption and carbon emissions per unit building materials production.

Materials	Energy consumption (MJ/kg)	Carbon emissions (g/kg)	Materials	Energy consumption (MJ/kg)	Carbon emissions (g/kg)
Steel	41.5	3910	Bitumen	51.2	5100
Recycling steel	15.2	2230	Facing brick	3.0	132
Aluminum	217.4	12630	Sand	0.8	20
Recycling aluminum	137.6	8146	Scree	0.4	50
Recycling copper	90.2	7580	PVC	46.2	3880
Cement	6.2	1180	PU	55.2	21153
Concrete	1.7	485	PE	51.1	9120