Life cycle carbon assessment of buildings based on the national standard - GB/T51366: the pros and cons

Supplementary Material II

S.1 Calculation of construction materials

The calculation of carbon emissions from the production of building materials is based on the emission factor method, which is calculated by multiplying the consumption of building materials with their carbon emission factors. GB/T51366 requires that the total weight of building materials to be calculated should be no less than 95% of the total weight of the building materials consumed, and building materials with a weight ratio of less than 0.1% can be excluded from the calculation if they meet the requirement of no less than 95%. For recyclable materials, the calculation is based on 50% of the carbon emissions of the main raw materials replaced. Carbon emission factors that have been verified by third-party organizations are preferred. If no third party verification is available, the carbon emission factors provided by the standard can be used. The carbon emission factors should include the direct carbon emissions from the extraction, transportation and production processes of the raw materials used in building materials. MI and MII are consistent when calculating carbon emissions for the production phase of building materials, and the equation is given below (MOHURD, 2019):

$$C_{SC}=\sum_{i=1}^{n} M_i F_i \quad (1)$$

where C_{sc}- carbon emission in the production stage of building materials ($kgCO_2e$);

M_i- the consumption of the *i*th main building material; and

F_i- the carbon emission factor of the *i*th main building material ($kgCO_2e$/unit building material quantity).

S.2 Material transportation

The transportation stage includes direct carbon emissions from the transport processes, as well as carbon emissions from the energy consumption. It is calculated based on the emission factor method. The carbon emission factor is required to include the direct carbon emissions during the transportation of construction materials from the place of production to the place of construction as well as the carbon emissions from the energy consumed during production and transportation. For the transport distance of major construction materials, GB/T51366 requires that the actual transport distance of the construction material is preferred. However, when the actual transport distance of the building material is unknown, the transport distance is assumed to be 50 km for concrete and 500 km for other building materials, and MI and MII are the same for this stage of the calculation. The calculation equation is as follows (MOHURD, 2019):

$$C_{ys}=\sum_{i=1}^{n} M_i D_i T_i \quad (2)$$

where C_{ys}- carbon emission of building materials transportation process ($kgCO_2e$);

M_i- the consumption of the ith main building material (t);

D_i- the average transportation distance of the ith building material (km); and

T_i- the carbon emission factor [$kgCO_2e/(tkm)$] per unit weight of transportation distance under the transportation mode of the ith building material.

S.3 Operation

The scope operation stage includes carbon emissions generated from energy consumption in HVAC, domestic hot water, lighting and lifts, as well as carbon reduction due to renewable energy and carbon sinks. GB/T51366 requires detailed design parameters to calculate the energy consumption of the building (MI), and when these parameters are not available, MII is used, based on a building's energy consumption data or energy simulation reports issued by third party companies. When the life span of the studied building is not available, 50 years is assumed. The carbon emissions (C_M) of the operational phase of the building are determined according to the different types of energy consumption and their carbon emission factors. Table 2 shows the average carbon emission factors for regional electricity grids in China. Both methods are calculated according to CB/T51366, with the following formula (MOHURD, 2019):

$$C_M=(\sum_{i=1}^{n} E_i\, EF_i - C_p)y \quad (3)$$

$$E_i=\sum_{j=1}^{n}(E_{i,j} - ER_{i,j}) \quad (4)$$

where C_M- carbon emission per unit of building area during the operation phase of the building ($kgCO_2e/m^2$);

E_i- the annual consumption of the ith type of energy in the building (unit/a);

EF_i- the carbon emission factor of the ith type of energy, taken according to Appendix A of this standard;

$E_{i,j}$- the ith type of energy consumption of jth type of system (unit/a);

$ER_{i,j}$- the amount of type i energy consumed by the renewable energy system in type j system (unit/a);

i- building consumption of end energy types, including electricity, gas, oil, municipal heat, etc.; and

j- building energy system type, including heating and air conditioning, lighting, domestic hot water system, etc.;

C_p-the annual carbon reduction of building green space carbon sink system ($kgCO_2e/a$);

y-building design life (a).

Table S1: Average carbon emission factors for electricity in different provinces in China (NMC, 2014)

Grid	Emission factor ($kgCO_2/kWh$)	Geographical scope
North China Regional Grid	0.8843	Beijing, Tianjin, Hebei Province, Shanxi Province, Shandong Province, western Inner Mongolia Autonomous Region (except Chifeng, Tongliao, Hulunbeier and Xing'an Meng outside the Inner Mongolia region)
Northeast Regional Grid	0.7769	Liaoning Province, Jilin Province, Heilongjiang Province, eastern Inner Mongolia Autonomous Region (Chifeng, Tongliao, Hulunbeier and Xing'an Meng)
East China Regional Grid	0.7035	Shanghai, Jiangsu Province, Zhejiang Province, Anhui Province, Fujian Province
Central China Regional Grid	0.5257	Henan Province, Hubei Province, Hunan Province, Jiangxi Province, Sichuan Province, Chongqing City
Northwest Regional Grid	0.6671	Shaanxi Province, Gansu Province, Qinghai Province, Ningxia Hui Autonomous Region, Xinjiang Uygur Autonomous Region
Southern Regional Grid	0.5271	Guangdong Province, Guangxi Zhuang Autonomous Region, Yunnan Province, Guizhou Province, Qinghai Province

GB/T51366 involves carbon sinks (e.g., trees, shrubs and grass) in vegetation areas of the studied building project. The carbon reduction effect should be deducted from the carbon emission calculation results. However, the calculation of carbon sink by vegetation is only available with respect to agroforestry, while no standard methodology has been published for green space of a building project. In the calculation tool, the estimating approach of biomass in IPCC 2006 and Volume IV of the forest land in IPCC 2019 are referred (IPCC, 2006; IPCC, 2019). Annual increase of biomass carbon storage is caused by growth of biomass in land. The calculation equations are given below, and the relevant parameters are provided in Table 3.

$$\Delta C_G=\sum_{i,j}(A_{i,j}\, G_{\mathrm{All}_{i,j}} CF_{i,j})*44/12 \tag{5}$$

$$G_{\mathrm{All}}=\sum\{G_W*(1+R)\} \tag{6}$$

where ΔC_G-the annual increase in biomass carbon pool (ton of carbon/year) caused by biomass growth in land maintaining the same land use category (by vegetation type and climate zone);

A-the area of land maintained in the same land use category (ha);

G_{All} - the average annual biomass growth (ton dry matter/ha/year);

G_W - the average annual above-ground biomass growth (ton dry matter/ha/year) for a given woody vegetation type;

R- the ratio of below-ground biomass to above-ground biomass for a given vegetation type (ton of dry matter below-ground biomass/ton of dry matter above-ground biomass);

i - the ecotone;

j - the climatic region; and

CF - the ratio of carbon to dry matter (ton of carbon / ton of dry matter).

Table S2: Parameters required for carbon sink accounting in tree forests and unestablished forests in the study area (IPCC, 2006; IPCC, 2019).

Parameter	Amount	Unit	Data source
C_F	0.47	ton carbon / ton dry matter	IPCC2006 Volume IV, Chapter 4, Table 4.3
G_W	4	ton dry matter/ha/year	IPCC2019 Volume IV, Chapter 4, Table 4.12
R	0.224	ton of dry matter below ground biomass/ton dry matter above ground biomass	IPCC2019 Volume IV, Chapter 4, Table 4.4

S.4 Construction and demolition

In GB/T51366, carbon emissions of construction stage include emissions generated from the construction processes and equipment. The total energy consumption can be obtained by calculating the quantity of individual processes, the energy consumption of construction machinery shifts. When the above data are not available, MII is adopted. The data required by MII can be obtained from a third-party report. MI and MII share same method to convert the on-site energy consumption to carbon emissions. Carbon emissions from the demolition stage include carbon emissions from manual demolition and the small machinery and equipment. For demolition energy consumption, the same method to construction stage is used to estimate process energy consumption. The difference between MI and MII is analogue to the construction stage. The equations for calculating carbon emissions are given below. (MOHURD, 2019).

$$\text{Construction:}\quad C_{JZ}=\sum_{i=1}^{n} E_{jz,i}\, EF_i \tag{7}$$

$$\text{Demolition:}\quad C_{CC}=\sum_{i=1}^{n} E_{cc,i}\, EF_i \tag{8}$$

where C_{JZ} - the carbon emission per unit of building area in the construction phase ($kgCO_2e/m^2$);

$E_{jz,i}$- the total energy consumption of the ith building construction phase (kWh or kg);

C_{CC}- carbon emission per unit of floor area in the demolition phase of the building ($kgCO_2e/m^2$);

$E_{cc,i}$- total energy use of the ith type of energy in the building demolition phase (kWh or kg); and

EF_i- carbon emission factor of the ith type of energy ($kgCO_2e$/kWh or $kgCO_2e$/kg).

For the calculation of carbon emissions from non-electricity energy, emission factors provided in GB/T51366 are used. Emission factors of gasoline and diesel are calculated based on the carbon content per unit calorific value of the energy source. As the relevant calorific value data is not provided in the standard, the calculation is based on the energy-related parameters provided in the General Guidelines for Calculating Integrated Energy Consumption GB/T2589-2020, as shown in Table 4. The formula for calculating its carbon emissions is as follows (NMSC, 2020)

$$C_{nh}=E_i*Q_i*K_i \tag{9}$$

where C_{nh}- building other energy consumption carbon emissions;

E_i- the ith energy consumption;

Q_i- the low level heating value of the ith energy source; and

K-CO_2 emission factor per unit calorific value of the *i*th energy source.

Table S3: Calculation parameters of carbon emissions for different energy types (NMSC, 2020)

Fuel Type	Carbon content per unit calorific value（tC/TJ）	Carbon oxidation rate（%）	CO_2 emission factor per unit calorific value（tCO_2/TJ）	Low level heat generation (TJ/kg)	Resource
Gasoline	18.9	0.98	67.91	4.3124E-5	Comprehensive energy consumption calculation-General regulations (2020)
Diesel	20.2	0.98	72.59	4.2705E-5	Comprehensive energy consumption calculation-General regulations (2020)