

Supplementary Materials

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Title: Passive Energy-Saving and Carbon Reduction Strategies for Substation Buildings in Cold Regions: A Case Study of Shijiazhuang

Table S1. Material inventory used in the A1-A3 accounting (reproduced from the YJK carbon-accounting inventory).

Material	Quantity	Unit	Production factor (kgCO ₂ /unit)	Factor source	Carbon emission (kgCO ₂)
XPS (extruded polystyrene foam, with skin)	111.25	m ³	175.70	module default	684.11
Steel-mesh fine-stone concrete	58.37	m ³	295.00	module default	43049.52
Gravel/pebble concrete (rho = 2300 kg/m ³)	116.74	m ³	304.78	module default	81837.18
Aerated/foam concrete (rho = 700 kg/m ³)	396.00	m ³	336.00	module default	93139.20
Concrete (C30)	401.82	m ³	295.00	Carbon Footprint of Buildings, p.103	178988.67
Polyethylene pipe	57.38	t	3600.00	module default	206551.38
High-density polyethylene	2.87	t	2620.00	module default	7516.18
Construction steel	65.00	t	2050.00	module default	1046005.26
Window 735	6.48	m ²	254.00	Carbon Footprint of Buildings, p.103	53.82
Energy-saving door 1	24.43	m ²	147.00	module default	117.43
Window 836	9.72	m ²	254.00	Carbon Footprint of Buildings, p.103	80.73
Concrete hollow block (rho = 900 kg/m ³)	181.69	m ³	292.00	module default	47747.79
Cement mortar M5.0	35.02	m ³	162.88	module default	9697.82
Lime-gypsum	87.89	m ³	867.59	module	114380.41

mortar				default	
Cement mortar finish	67.39	m ³	290.52	module default	35242.09
Rammed clay (rho = 2000 kg/m ³)	166.75	m ³	2.51	module default	837.06
Total (A1-A3)					1 865 930

Note: The inventory is reproduced from the material-production table of the YJK carbon-accounting report for the baseline working condition (16 items). The inventory total is 1865.93 tCO₂ (A1-A3), i.e. 37.32 tCO₂/year when amortized over the 50-year design service life. Material transport to site (A4) adds 79.34 tCO₂ (500 km road transport), construction and installation (A5) 33.5 tCO₂, demolition and disposal (C1-C4) 5.5 tCO₂, recycling benefits (D) -45.49 tCO₂ and the greening carbon sink -17.73 tCO₂, giving a combined non-B6 contribution of about 1921 tCO₂ over the 50-year assessment period, i.e. 38.4 tCO₂/year, which is consistent with Table S6. The carbon-emission column reports the values adopted in the accounting (the values reported by the YJK carbon-accounting module for the baseline working condition), and these values sum to the A1–A3 total given above. The quantity and production-factor columns are provided for reference only: because the compliance module derives the carbon emission of each entry from its own component-level material-conversion rules and factor database, the carbon-emission value is not in all cases equal to the product of the listed quantity and production factor, and the largest differences occur for construction steel, C30 concrete and the XPS insulation. Reproducing the calculation therefore requires the carbon-emission column together with the factor database of the compliance module; the production factors of the main materials are listed in Table S2.

Table S2. Carbon emission factors and sources.

Category	Factor	Value	Unit	Source
Building material	Ready-mix concrete (C30)	295	kgCO ₂ /m ³	GB/T 51366-2019 Appendix D
Building material	Cement mortar	290.52	kgCO ₂ /m ³	GB/T 51366-2019 Appendix D
Building material	Reinforcing/construction steel	2050	kgCO ₂ /t	GB/T 51366-2019 Appendix D
Building material	Masonry / insulation / finishing	292 / 336 / 175.70	kgCO ₂ /m ³	GB/T 51366-2019 Appendix D
Energy	North China grid electricity	0.8843	kgCO ₂ /kWh	North China regional grid (YJK database)
Energy	District heating	0.11	tCO ₂ /GJ	GB/T 51366-2019 Appendix D

Table S3. Simulation input parameters.

Item	Value	Source
Floor area	1181.81 m ²	Construction drawings / model
Storeys	1 above ground, 0	Construction drawings

	underground	
Building volume	3545.43 m ³	Model
External surface area	2088.50 m ²	Model
Shape coefficient	0.59	Model
Structure type	Frame structure	Construction drawings
Climate zone	Cold B	GB 50176 / project data
Weather data	Shijiazhuang typical meteorological year	DeST
Heating period	121 days (plausible range 116–126 days)	Actual heating period
Exterior wall U-value	0.50 W/(m ² K)	Table 2
Interior wall U-value	0.96 W/(m ² K)	Table 2
Roof U-value	0.50 W/(m ² K)	Table 2
External window U-value	1.8 W/(m ² K)	Table 2
Heating setpoint	20 °C (plausible range 18–20 °C)	Field investigation
Cooling setpoint	28 °C (plausible range 26–28 °C)	Field investigation
SEER / HSPF	3.60 / 2.60 (plausible range 3.06–3.60 / 2.21–2.60)	Equipment specifications
Ventilation / infiltration	Not explicitly included in the model (no fresh-air or air-change rate specified as a simulation input; split air conditioners only) The plausible range considered is 0–0.5 h ⁻¹ , since doors remain closed except during the one or two weekly inspection tours.	YJK renewable-energy report / design documents
Internal gains	Table 3 (equipment, lighting); plausible range $\pm 20\%$	Field investigation

Note: The plausible ranges given for the operational inputs are based on the design documents, the equipment specifications, the applicable standards and the ranges reported in the literature for uncalibrated building energy models. Because the station is neither submetered nor continuously monitored, these ranges are used for the bounding perturbation reported in Section 2.2 of the main text and are not treated as probability distributions.

Table S4. Orientation-specific facade areas and window-to-wall-ratio scanning range.

Orientation	Facade area (m ²)	Window-to-wall ratio range scanned
South	206.00	0.05–0.50
West	230.36	0.05–0.50
East	159.17	0.05–0.50
North	354.55	0.05–0.50

Note: The window-to-wall ratio of each orientation was treated as a free design parameter and varied parametrically from 0.05 to 0.50 in the carbon simulations; no single baseline window-to-wall ratio is therefore reported in the orientation-specific WWR scan, and the reported trends are comparisons among the tested conditions. The facade areas are taken from the construction drawings. In all other single-parameter scans (building height and envelope heat-transfer coefficients), the WWR of each orientation was held constant at the as-built value, so that the control-variable comparison is preserved.

Table S5. Equipment heat dissipation and air-conditioning operating schedules (summarized from Table 3).

Room	Equipment	Qty	Rated power (kW)	Operating power (kW)	Setpoint (°C)	Operating period
Main transformer room	AC power supply for intelligent control cabinet	2	3	1	N/A	All day
Main transformer room	Main transformer protection	2	0.08	0.096	20	All day
Main transformer room	Main transformer measurement and control	4	0.08	0.256	20	All day
10 kV power distribution room	AC power supply for 10 kV distribution equipment	1	9.6	4.8	28	All day
10 kV power distribution room	Heating power supply	1	20	20	N/A	All day (seasonal)
10 kV power distribution room	Lighting	1	1.2	1.2	N/A	Intermittent
10 kV power distribution room	Protection and control device	1	0.05	0.04	N/A	All day
10 kV power distribution room	Sectional automatic bus transfer	1	0.05	0.03	N/A	All day
110 kV GIS power distribution room	AC power supply for 110 kV distribution equipment	1	8	3	N/A	All day
110 kV GIS power distribution room	Heating power supply	1	16.5	16.5	N/A	All day (seasonal)
110 kV GIS power distribution room	Lighting	1	0.6	0.6	N/A	Intermittent
110 kV GIS power distribution	Protection and control device	1	0.05	0.04	N/A	All day

room						
110 kV GIS power distribution room	Sectional automatic bus transfer	1	0.05	0.03	N/A	All day
Capacitor room	Lighting	1	0.3	0.3	N/A	Intermittent
Secondary equipment room	UPS load	10	1	7.5	N/A	All day
Secondary equipment room	Protection and control equipment	300	0.08	23.1	20	All day
Pump room	Pump room power distribution box	1	1.5	1.5	N/A	All day
Pump room	Lighting	1	0.3	0.3	N/A	Intermittent
Guard room	Lighting	1	0.3	0.3	N/A	Intermittent
Safety tool room	Lighting	1	0.2	0.2	N/A	Intermittent
Restroom	Lighting	1	0.2	0.2	N/A	Intermittent
Restroom	Electric heater	1	2.5	2.5	N/A	Intermittent
Corridor	Lighting	1	0.5	0.5	N/A	Intermittent

Note: Continuous equipment operates 24 h/day; the lighting rows operate intermittently; the heating power supplies and the electric heater operate only during the heating period. This table summarizes the operating power and the operating-period assumptions adopted for each equipment heat source, which are used to define the internal heat gains of the corresponding functional rooms in the DeST model. N/A in the 'Set A/C Temp. (°C)' column indicates that no air-conditioning set temperature is specified for that equipment item.

Table S6. Stage-by-stage composition of the assessed carbon emissions under the baseline working condition (reproduced from the stage summary of the YJK carbon-accounting report).

Module	Item	Carbon emission (tCO ₂ /year)	Share of the total (%)
A1–A4	Material production and transport	38.91	65.1
A5	Construction and installation	0.67	1.1
B6	Operational energy (heating, cooling, ventilation, lighting, elevator, domestic hot water)	21.34	35.7
C1–C4	Demolition and disposal	0.11	0.2
D	Recycling benefits (netted in the material stage)	–0.91	–1.5
–	Greening carbon sink	–0.35	–0.6
Total	Assessed total (partial	59.77	100

	life-cycle accounting)		
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Note: The non-B6 contribution (A1–A5, C1–C4, D and the greening carbon sink) is 38.42 tCO₂/year (64.3%) and the operational stage (B6) is 21.34 tCO₂/year (35.7%); totals may not sum exactly due to rounding. The use, maintenance, repair, replacement, refurbishment and operational-water modules (B1–B5, B7) are not resolved by the compliance model and are therefore not included; the B4 replacement module is provided as a sensitivity case in Section 3.5 of the main text.