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Comparison of Building Codes and Insulation in China and Iceland

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ABSTRACT

Heat load for a sample building with and without insulation using Chinese and Icelandic building codes was calculated in this paper. The results show that the calculated heat load in Icelandic codes is bigger than that of in Chinese for the un-insulated building. However, when insulation is added to the building envelope, heat load decreases 45.4% in Chinese codes. If the thermal insulation property is improved to satisfy the Icelandic standard, which was valid at the time of construction for the sample building, the heat load decreases 70.4%, which indicates that improving thermal insulation and insulation properties could reduce energy consumption significantly.

1. INTRODUCTION

Heat load of a building is dependent on the building's structure, its insulation and its characteristics, volume, and local climate. Following the reference from the China Heating Design Handbook (Tang and Fan,1992), the design heat load per unit area of 46-70 W/m^2 in typical residential buildings can be used to estimate the heating load. The method of the building standards has to be followed to obtain the design heat load.

1.1 Building Heat Load

Building heat load consists of following components:

1. Heat loss through building envelope;
2. Heat loss by infiltration;
3. Heat load of inrush air;
4. Heat gain by radiation through building envelope.

In addition, other heat load factors, such as illumination, human body heat and other addition heat load factors. These are neglected in the heat load calculation because they are insufficient and unstable.

1.2 Sample Building

Figure 1: Sample building in Tianjin

The sample residential building exemplified in this paper in Tianjin, China contains four flats of three types. A floor layout of the building is shown in Figure 1, and the building area is presented in Table 1.

Table 1: Areas of the building envelope

Type	A (m^2)	B (m^2)	C (m^2)	Total area (m^2)
Roof	276.30	149.24	125.92	551.46
Floor	276.30	149.24	125.92	551.46
Outer wall	262.10	144.59	121.27	527.96
Inner wall	137.36	132.72	113.40	383.48
Window	14.20	4.65	4.65	23.50

2. CALCULATION OF BUILDING HEAT LOAD

The characteristics of the building construction materials need to be identified to evaluate the building parameters, which are given by Emeish (2001) in Table 2. The heat transfer coefficients for door and windows of different materials are given in Table 3.

The following calculations are based on a steady state energy balance by Chinese and Icelandic building codes for the sample building with and without insulation respectively.

Table 2 Construction material's properties

Constructions material	Density ρ ((kg/m^3))	Thermal conductivity λ (W/(m °C))	Heat capacity (kJ/(kg °C))
Concrete	2088	1.21	1.08
Brick	1800	0.60	1.80
Plaster	2710	1.00	0.86
Asphalt mix	2000	0.70	-
Roof brick	1400	0.95	1.08
Sand	1450	0.38	0.92
Cement tiles	2145	1.35	0.96

Table 3: Overall heat transfer coefficients of the door and window

		K(W/(m^2°C))	structure
Window		2.70	Steel (12 mm air layer)
Stair	Wall	1.50	360 mm brick
	Door	1.50	Compound insulation
Balcony door		1.50	

2.1 Heat Loss Calculated (Un-insulated Building)

The total heat transfer coefficient is indispensable to heat load calculations. Heat transfer coefficient, K is a constant that describes the heat transfer between the building and its environment due to conduction, convection and radiation, K_{total} can be calculated according to Eq. 1

$$K_{tatal} = \frac{K_1 A_1 + K_2 A_2 + \ldots}{A_{tatal}} \quad \text{(W/(m}^2\text{ °C))} \qquad (1)$$

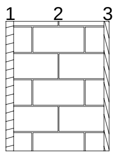
Where K_n, A_n, A_{total}, R_n, R_o are the Heat transfer coefficient of different components of building, surface area of components, total surface area of the building, the thermal resistance of heat transfer, total thermal resistance of heat transfer, respectively.

2.1.1 Heat losses through the building envelope

1) Wall heat transfer coefficient

The walls heat transfer coefficient is given in Table 4.

Table 4: Outer wall heat transfer coefficient

Outer wall	Construction material	x (m)	λ (W/(m °C))	R (m °C /W)
	1.Concrete	0.03	1.21	0.02
	2.Brick	0.35	0.60	0.58
	3.Plaster	0.02	1.00	0.02
	R_i			0.12
	R_e			0.04
	R_o			0.78

$$K_{wall} = 1/R_o = 1/0.78 = 1.27 \quad \text{(W/(m}^2\text{ °C))}$$

2) Roof heat transfer coefficient

The construction materials consist of concrete and roof bricks, concrete. Two different heat transfer coefficients need to be calculated. The results are shown in Table 5 and 6.

Table 5: Roof heat transfer coefficient using with brick

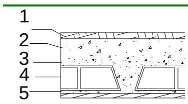
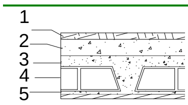
Roof	Construction material	x (m)	λ (W/(m °C))	R (m °C /W)
	1.Asphalt	0.02	0.70	0.03
	2.Concrete	0.05	1.21	0.04
	3.Reinforced concrete	0.06	1.75	0.03
	4.Roof brick	0.18	0.95	0.19
	5.Plaster	0.02	1.00	0.02
	R_i			0.10
	R_e			0.04
	R_o			0.46

Table 6: Roof heat transfer coefficient without brick

Roof	Construction material	x (m)	λ (W/(m °C))	R (m °C /W)
	1.Asphalt	0.02	0.70	0.03
	2.Concrete	0.05	1.21	0.04
	3 concrete	0.24	1.75	0.14
	4.Plaster	0.02	1.00	0.02
	R_i			0.10
	R_e			0.04
	R_o			0.37

$$K_1 = 1/R_o = 1/0.46 = 2.17 \quad \text{(W/(m}^2\text{ °C))}$$

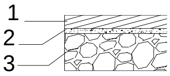
$$K_2 = 1/R_o = 1/0.37 = 2.70 \quad \text{(W/(m}^2\text{ °C))}$$

$$K_{roof} = \frac{K_1 A_1 + K_2 A_2}{A_{total}} = 2.28 \quad \text{(W/(m}^2\text{ °C))}$$

3）Floor heat transfer coefficient

Floor heat transfer coefficient is given in Table 7.

Table 7: Floor heat transfer coefficient

Floor	Construction material	x (m)	λ (W/(m °C))	R (m °C /W)
	1.Tiles	0.03	1.35	0.02
	2.Concrete	0.01	1.21	0.01
	3.Sand	0.07	0.38	0.18
	R_i			0.15
	R_e			0.09

R$_o$	0.45

$K_{floor} = 1/R_o = 1/0.45 = 2.22$ (W/(m^2 °C))

4) Windows

The type commonly used in Tianjin is single glazing with a K value of 6.40 W/(m^2 °C).

5) Heat loss in the unheated stair area

The stairs of the building are not heated. The equilibrium temperature in the stair area has thus to be calculated. Heat flow from the heated areas of the building into the stair area is equal to the heat lost. Calculation of the stairs temperature is, according to Eq. 2, based on energy balance and the area of each element (Table 8).

$$\sum K_i A_i (T_i - T_{stair}) = \sum K_o A_o (T_{stair} - T_o) \quad (2)$$

Table 8: Stair heat transfer coefficient

Element	A (m^2)	K (W/(m^2 °C))
Inner wall	94.30	1.21
Outer wall	29.40	1.31
Door in inner wall	2.44	1.50
Window in outer wall	3.42	2.70

Eq. 2 gives $T_{stair} = 15.87$ °C

Heat loss from the stairs is then $Q_s = 1.19$ (KW)

2.1.2 Building total heat transfer coefficient

On the basis of the above calculation, the total heat transfer coefficient of a building can be summarized as in Table 9.

Table 9:Heat transfer coefficient of a sample building

Element	K (W/(m^2 °C))	A (m^2)	KA (W/°C)
Roof	2.28	551.46	1257.33
Floor	2.22	551.46	1224.24
Outer wall	1.29	527.96	681.07
Window	6.40	23.50	150.40
Door	2.30	13.67	31.44
Total			3344.48

$Q_1 = KA(T_i - T_o) = 96.99$ (KW)

2.1.3 Heat loss by infiltration

Infiltration is the leakage of outside air into the house through cracks around the windows and doors, which depends mainly on the tightness of windows and doors, as well as the wind velocity (the pressure difference between the outside and inside of the envelope). The air change method is used here to estimate the volume of flow of infiltration air into the heating area, which is based on the air volume in a space being replaced by outside air a certain times per hour. Chinese building codes recommend。0.5-1.0 air changes per hour for residential buildings, 0.8 is used in Eq. 3 (He and Sun, 1993):

$$Q_2 = 0.278 n_k V_n c_p \rho_w (T_i - T_o) \text{ (W)} \quad (3)$$

Where c_p, n, V_n, ρ_d are the specific heat of air, air change rate, room volume, airflow rate, air density when temperature is T_o,, respectively.

Using air change method to determine V (m^3/h), gives:

$$V = nV_h \text{ (m}^3\text{/h)} \quad (4)$$

Where n, V_h are the air change rate, room volume, respectively.

From Eq. 3 $Q_2 = 8.53$ (KW)

2.1.4 Additional heat due to building direction

$Q_3 = 0.22$ (KW)

2.1.5 Total heat load

$Q_{total} = Q_1 + Q_t + Q_3 + Q_4 + Q_s = 106.93$ (KW)

2.2 Heat Loss Calculated by Chinese Codes (Un-insulated Building)

2.2.1 Heat losses through the building envelope

As for state heat transfer, the formula has been given as follows:

$$Q_1 = KA(T_i - T_o) \text{ (W)} \quad (5)$$

Where Q_1, K, A, T_i, T_o are the heat loss through building envelope, heat transfer coefficient through building envelope areas of building envelope, indoor temperature, outdoor temperature, respectively.

Table 10: Heat transfer coefficient of building envelope

Element	K (W/(m^2 °C))	A (m^2)	KA (W/°C)
Roof	0.93	551.46	512.86
Floor	0.47	551.46	220.58
Outer wall	1.57	527.96	828.90
Window	6.40	23.50	150.40
Stair	1.83	53.58	98.05
Door	4.65	13.67	63.57
Total			1874.36

$$Q_1 = \sum K_i A_i (T_i - T_o) = 54.36 \text{ (KW)}$$

2.2.2 Infiltration

From Eq. 3, $Q_2 = 8.53$ (KW)

2.2.3 Heat load of inrush air due to opening the doors and windows

Heat loss of external door is 1.84 KW, So additional heat load of inrush air is:

$$Q_3 = 65N\% \times 1.84 = 1.20 \quad \text{(KW)}$$

Where N is the number of stories

2.2.4 Additional heat due to building direction

$$Q_4 = -0.63 \text{ (KW)}$$

2.2.5 Total heat load

$$Q_{total} = Q_1 + Q_t + Q_3 + Q_4 + Q_s = 64.65 \text{ (KW)}$$

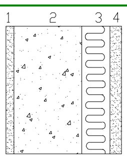
2.3 Building Calculation (with insulation) by Icelandic codes

2.3.1 Heat load of building envelope (Iceland standards UDC 699.86)

1) Wall heat transfer coefficient

The outer wall heat transfer coefficient is given in Table 11.

Table 11: Outer wall heat transfer coefficient

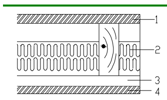
Outer wall	Construction material	x (m)	λ (W/(m °C))	R (m °C /W)
	1.Plaster	0.015	1.20	0.01
	2.Concrete	0.20	1.70	0.12
	3. Insulation	0.07	0.07	1.75
	4. Plaster	0.02	0.02	0.02
	R_i+ R_e			0.17
	R_o			2.07

$$K_{wall} = 1/R_o = 1/2.07 = 0.48 \text{ (W/(m}^2\text{ °C))}$$

2) Roof heat transfer coefficient

The heat transfer coefficient of the roof is given in Table 12.

Table 12: Roof heat transfer coefficient

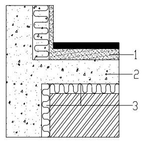
Roof	Construction material	x (m)	λ (W/(m °C))	R (m °C /W)
	1.Wooden panel			0.40
	2. Rock Wool	0.12	0.05	2.31
	3. Wood			0.13
	4. Planking	0.02	0.15	0.13
	R_i+ R_e			0.17
	R_o			3.14

$$K_{roof} = 1/R_o = 1/3.14 = 0.32 \text{ (W/(m}^2\text{ °C))}$$

3) Floor heat transfer coefficient

The total heat transfer coefficient of the floor is given in Table 13.

Table 13: Floor heat transfer coefficient

Floor	Construction material	x (m)	λ (W/(m °C))	R (m °C /W)
	1.Floor layer	0.04	1.20	0.03
	2.Concrete	0.12	1.70	0.07
	3.Insulation	0.03	0.07	0.43
	R_i			0.13
	R_j			0.70
	R_o			2.55

$$K_{floor} = 1/R_o = 1/2.55 = 0.39 \text{ (W/(m}^2\text{ °C))}$$

Heat transfer coefficient of building envelope is summarized in Table 14. Accordingly, Heat load of building envelope is calculated.

Table 14: Heat transfer coefficient of building envelope

Element	K (W/(m² °C))	A (m²)	KA (W/°C)
Roof	0.32	551.46	176.47
Floor	0.39	551.46	215.07
Outer wall	0.48	527.96	253.42
Window	1.30	23.50	30.55
Stair	0.80	53.58	42.86
Door	2.30	13.67	31.44
Total			749.81

$$Q_1 = \sum K_i A_i (T_i - T_o) = 21.74 \text{ (KW)}$$

2.3.2 Infiltration

From Eq. 3, $Q_2 = 8.53$ (KW)

2.3.3 Heat load of inrush air due to direction

From Eq. 5 , $Q_3 = 0.22$ (KW)

2.3.4 Additional heat load due to building height

$Q_4 = 74.95$ (KW)

2.3.5 Total heat load

$$Q_{total} = Q_1 + Q_t + Q_3 + Q_s = 31.68 \text{ (KW)}$$

2.4 Building Calculation (with Insulation) by Chinese Codes (Zhang and Zhou, 2003)

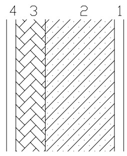
The following calculations are according to China codes and given for comparison.

2.4.1 Heat load of building envelope

1) Wall heat transfer coefficient

The wall total transfer coefficient is given in Table 15.

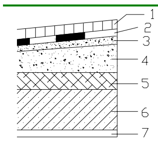
Table 15: Outer wall heat transfer coefficient

Outer wall	Construction material	x (m)	λ (W/(m °C))	α	R (m °C /W)
	1.lime mortar	0.02	0.81	1.0	0.03
	2.Concrete	0.20	1.74	1.0	0.12
	3.Insulation	0.05	0.03	1.1	1.81
	4.Tile	0.02	1.35	1.0	0.02
	R_i				0.12
	R_e				0.04
	R_o				2.14

$K_{wall} = 1/R_o = 1/2.14 = 0.46$ (W/(m^2 °C))

2) Roof heat transfer coefficient

Table 16: Roof heat transfer coefficient

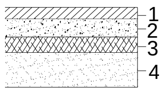
Roof	Construction material	x (m)	λ (W/(m °C))	α	R (m °C /W)
	1.Cement mortar	0.04	0.93	1.0	0.04
	2.Waterproof material	0.01	0.17	1.0	0.06
	3.Same as 1	0.02	0.93	1.0	0.02
	4. Plaster	0.07	0.29	1.5	0.16
	5.Insulation	0.06	0.04	1.3	1.54
	6. concrete	0.11	1.74	1.0	0.06
	7.Plaster	0.02	0.81	1.0	0.03
	R_i				0.12
	R_e				0.04
	R_o				2.07

$K_{roof} = 1/R_o = 1/2.07 = 0.48$ (W/(m^2 °C))

3) Floor heat transfer coefficient

The total heat transfer coefficient of the floor is given in Table 17.

Table 17: Floor heat transfer coefficient

Floor	Construction material	x (m)	λ (W/(m °C))	α	R (m °C /W)
	1.Tile	0.03	1.35	1.0	0.02
	2.Concrete	0.10	1.74	1.0	0.06
	3. Insulation	0.06	0.04	1.5	1.00
	4. Lime & soil mixture	0.15	0.29	1.5	0.35
	Ri				0.12
	Ro				3.22

$K_{floor} = 1/R_o = 1/3.22 = 0.31$ (W/(m^2 °C))

The heat transfer coefficient of the building envelope is summarized in Table 18. Accordingly, heat load of the building envelope is calculated.

Table 18: Heat transfer coefficient of building envelope

Element	K (W/(m^2.°C))	A (m^2)	KA (W/°C)
Roof	0.48	551.46	264.70
Floor	0.31	551.46	170.95
Outer wall	0.46	527.96	242.86
Window	2.70	23.50	63.45
Stair	1.50	53.58	80.37
Door	2.91	13.67	39.78
Total			862.11

$$Q_1 = \sum K_i A_i (T_i - T_o) = 25.00 \text{ (KW)}$$

2.4.2 Infiltration

From Eq. 3, $Q_2 = 8.53$ (KW)

2.4.3 Heat load of inrush air

From Eq. 5 , $Q_3 = 1.20$ (KW)

2.4.4 Additional heat load due to building direction

$Q_4 = -0.63$ (KW)

2.4.5 Total heat load

$$Q_{total} = Q_1 + Q_2 + Q_3 + Q_4 + Q_s = 35.29 \text{ (KW)}$$

3. CONCLUSIONS

Tab. 19 shows the comparison of building calculation with and without insulation by China and Iceland codes.

Table 19: Comparison of heat load calculation for sample building

Heat load (KW)	Without insulation		With insulation	
	Iceland codes	China codes	Iceland codes	China codes
	106.93	64.65	31.68	35.29

Thermal insulation is one of the most effective energy-conservation measures in buildings. According to comparison of heat load calculations, the following conclusions for a sample building in Tianjin are obtained.

1) Heat load is calculated by Icelandic and Chinese building codes, the results of former is bigger than that of latter are similar.

2) The results of heat load calculations indicate that thermal insulation is an effective way to reduce energy consumption. Heat load decreases 45.4% when insulation is added to the building envelope.

3) When the thermal insulation property is improved to Icelandic standard, the heat load decreases to 70.4%. This is a better way to improve the thermal insulation property of the building envelope for energy saving.

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