Article:

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Supplementary material: calculation procedure of refrigeration load

Take total refrigeration load in 40°C ambient temperature as an example:

- Transmission load

The heat gain transferred through walls, floor and ceiling is calculated as:

$$Q_1 = \frac{UA\Delta T}{1000} \quad (1)$$

Where

Q_1 = transmission load, kW

U = overall heat transfer coefficient, W/(m^2·K)

A = outer area of surface, m^2

ΔT = difference between outdoor air temperature and setting temperature of refrigerated box, K

The heat transfer coefficient for a wall with n flat parallel surfaces of materials is given by:

$$U = \frac{1}{\sum_{i=1}^{n} \frac{x_i}{k_i}} \quad (2)$$

Where

x_i = wall thickness of material i, m

k_i = thermal conductivity of wall material i, W/(m·K)

When calculating the temperature difference ΔT, solar heat is considered.

Table 1 Temperature difference of every outer surface of frozen compartment

	Sun effect [c], K	Surface temperature [d], K	ΔT_{frozen} [e], K
Roof [a]	9	322.15	67
Floor	0	313.15	58
Door	4	317.15	62
Wall, Front	0	313.15	58

Rear [b]	0	275.15	20
Right side	4	317.15	62

[a] schematic diagram of the insulated box is showed in **Error! Reference source not found.**

[b] adjacent to chilled compartment held at 2°C (275.15 K)

[c] sun effect parameters can be found from table 3, chapter 24 in Handbook – Refrigeration (ASHRAE, 2018)

[d] ambient temperature is set to 40°C (313.15 K)

[e] frozen compartment setting temperature: -18°C (255.15 K)

Table 2 Heat transmission in frozen compartment per hour

		U, W/(m²·K)	A, m²	ΔT, K	Load*10⁻³, kW
Roof		0.38	0.6	67	15.28
Floor		0.38	0.6	58	13.22
Door		0.38	1.08	62	25.44
Wall,	Front	0.38	1.8	58	39.67
	Rear	0.38	1.8	20	13.68
	Right side	0.38	1.08	62	25.44
Safety factor, 20% [a]					26.55
Total transmission load $Q_{1\,frozen}$ *10⁻³, kW					159.29

[a] a safety factor of 20% is often used to allow for possible difference between design criteria and practical situation (ASHRAE, 2018)

Table 3 Temperature difference of every outer surface of chilled compartment

	Sun effect [b], K	Surface temperature [c], K	$\Delta T_{chilled}$, K [d]
Roof	9	322.15	47

Floor		0	313.15	38
Door		4	317.15	42
Wall,	Front [a]	0	-255.15	-20
	Rear	3	316.15	41
	Right side	4	317.15	42

[a] adjacent to frozen compartment held at -18°C (255.15 K)

[b] sun effect parameters can be found from table 3, chapter 24 in Handbook – Refrigeration (ASHRAE, 2018)

[c] ambient temperature is set to 40°C (313.15 K)

[d] chilled compartment setting temperature: 2°C (275.15 K)

Table 4 Heat transmission in chilled compartment per hour

		U, W/(m²·K)	A, m²	ΔT , K	Load*10⁻³, kW
Roof		0.38	1.2	47	21.43
Floor		0.38	1.2	38	17.33
Door		0.38	2.16	42	34.47
Wall,	Front	0.38	1.8	-20	-13.68
	Rear	0.38	1.8	41	28.04
	Right side	0.38	2.16	42	34.47
Safety, 20%					24.41
Total transmission load $Q_{1chilled}$ *10⁻³, kW					146.49

$$Q_1 = Q_{1frozen} + Q_{1chilled} = 0.31 \text{ kW}$$

- Product load

We consider that groceries are moved into the box in setting temperature, so product load is not considered.

- Infiltration air load

The heat gain from air infiltration is considerable when the vehicle is used for short delivery rounds and has to open doors frequently. A simplification of the equation is given by ASHRAE (2018):

$$Q_3 = \frac{t_o}{3600} q_3 \tag{3}$$

Where

Q_3 = infiltration air load, kW

t_0 = door opening time, s

q_3 = heat gain during door openings, kW

$$q_3 = 0.577 W H^{1.5} \left(\frac{q_s}{A}\right)\left(\frac{1}{R_S}\right) \tag{4}$$

Where

W = doorway width, m

H = doorway height, m

$\frac{q_s}{A}$ = sensible heat load of infiltration air per square metre of doorway opening, kW/m^2

R_s = sensible heat ratio for infiltration from outdoors to refrigerated space

Table 5 Infiltration air load of both frozen and chilled compartments

	Frozen compartment	Chilled compartment
Door width W [a], m	0.5	0.5
Door height H [a], m	1.5	1.5
sensible heat load per square metre $\frac{q_s}{A}$ [b], kW/m^2	37	18
sensible heat ratio R_s [b]	0.74	0.74
Door opening time per hour t_0 [c], s	240	240
Infiltration air load $Q_{3frozen}$, $Q_{3chilled}$, kW	1.77	0.86

Total infiltration air load Q_3 ,kW	2.63

[a] the dimension of door is smaller than the dimension of body box and it's set to be 0.5m wide and 1.5m high

[b] sensible heat load per square metre and sensible heat ratio can be found in fig.9, table 9 and table 10, chapter 24 in Handbook – Refrigeration (ASHRAE, 2018)

[c] we assume that the driver will keep the frozen compartment door and one of the chilled compartments door open for 1 minute per customer. So the door opening time is 240s per door per hour

- Precooling load

The precooling load is the heat that must be removed from the vehicle box body to bring its interior surfaces to the planned setting temperature before loading product. Precooling load is not considered because our focus is emissions on the delivery route.

- Total refrigeration load

$Q = Q_1 + Q_3 = 2.93\ \mathrm{kW}$