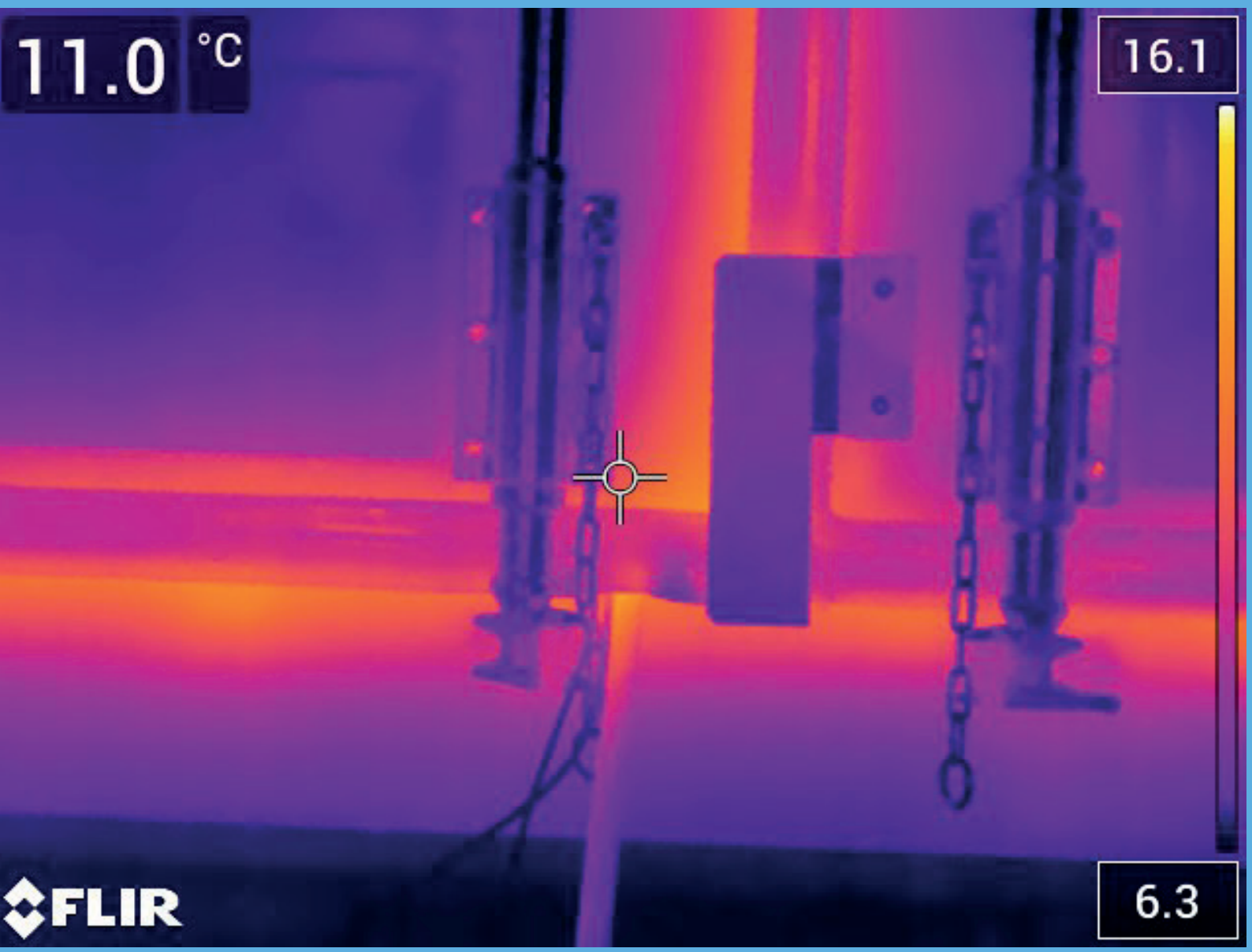

K-value of BODU2000233

measurement and analysis

L. J. S. Lukasse, M. G. Staal

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Contents

1 Introduction

The measured K-value of light weight container PVDU3850116 is 0.486 $W.m^{-2}.°C^{-1}$, which disappoints (Lukasse et al., 2021). Jan Nouwen (unit45) suspects this is due to wall construction. Therefore it was decided to measure the K-value of a second container with virtual identical dimensions, but without light weight wall construction. The measurement was done according to ATP procedures (ATP, 2020) by following the relevant steps in WFBR internal Standard Operating Procedure T-10006. This report covers that K-value measurement. For further analysis a theoretical K-value calculation is added. Infrared photos are taken to analyze the insulated enclosure for thermal bridges, i.e. locations where the insulation is worse.

For additional information about this report, see the colophon.

2 Equipment specifications

2.1 Reefer container

Container identification number	BODU2000233
Tare weight	7,195 kg
Max. gross weight	34,000 kg

2.1.1 Insulated body

Figure 1 box type plate.

Description	**Value**
Container box identification number	TF003604
Date of construction insulated body	08/2020
Box manufacturer	Guangdong Fuwa Equipment Manufacturing Co. Ltd.
Box type	LT4596PLD-00003
External dimension of insulated enclosure	LxWxH = 1344.2 x 259.7 x 282.1 cm
External height of container (from roof till lower rim of I-profile beam at bottom)	H = 286.6 cm
Inside dimensions of insulated enclosure	L(@floor, without return air duct)xWxH = 1331.6 x 248.6 x 257.0 cm
Internal width in corrugations	250.8 m (= 25% of wall area)
Thickness of doors	45 mm in thin areas, 70 mm in thick areas. The thick areas cover ± 40 % of the doors.
Thickness of walls	55 mm
Thickness of roof	100 mm (measured)
Thickness of floor	151 mm (calculated: external H – inside H – roof thickness)
Thickness of front wall	65 mm (calculated as L_{extern} – L_{intern} – door thickness)

Gooseneck dimensions (position, L,W, recess)	@ unit-end in centre of container, L = 3.77 m, W = 1.027 m, recess = 12 cm from lower rim I-profile (i.e. in this area the floor is 7.5 cm thinner than in rest of floor, leaving 7.6 cm thickness)

Description / dimension of accessories and constructions that may weaken the insulation:
Drain holes and lashing points are in a four gutters, that are 27 mm deep in floor and run across complete length of container floor.
Outer cladding of floor is corrugated. 50% deep, 50% shallow. Recesses from lower side I profile: 3 cm and 6 cm. Around square cross bars (8 after gooseneck tunnel, 3 next to gooseneck tunnel) the recess is 10 cm deep over a length of 42 cm.
Recess at door-end between 40 ft and 45 ft corner castings: 7 cm.

Table 1 calculated surface areas and internal volume.

Description	Value
Total floor area	33.14 m^2
Usable internal volume	85.18 m^3
Total internal surface area S_i of body	147.59 m^2
Total external surface area S_e of body	160.31 m^2
Mean surface are S = $\sqrt{S_i \times S_e}$	153.82 m^2

2.1.2 Refrigeration unit type

Description	**Value**
Manufacturer	Thermo King
Type	Advancer A-500

Figure 2 TK unit type plate.

3 Results

3.1 Measured K-value

This section reports the K-value measured according to ATP procedures.

Testing method	:	inside heating
Start of inner heating (yyyy-mm-dd hh:mm:ss)	:	2021-02-01 17:20:24
Start time of steady state conditions (yyyy-mm-dd hh:mm:ss)	:	2021-02-03 00:40:24
End time of steady state conditions (yyyy-mm-dd hh:mm:ss)	:	2021-02-03 12:40:24
Total duration of test (yyyy-mm-dd hh:mm:ss)	:	0000-00-01 19:20:00
Duration of steady state conditions (yyyy-mm-dd hh:mm:ss)	:	0000-00-00 12:00:00

3.1.1 Measuring results

Outside

Mean outside temperature of body (θ_e)	:	7.33	°C
Max. difference between two mean outside temperatures	:	0.18	°C
Max. difference between two outside measurement locations	:	1.00	°C

Inside

Mean inside temperature of body (θ_i)	:	32.50	°C
Max. difference between two mean inside temperatures	:	0.06	°C
Max. difference between two inside measurement locations	:	1.43	°C
Mean temperature difference achieved ($\Delta\theta = \theta_i - \theta_e$)	:	25.17	°C
Mean temperature of walls of the body achieved ($\frac{\theta_e + \theta_i}{2}$)	:	19.91	°C
Electric power consumption (heaters + fans) , Q =		1970.24	W
Total heat leakage rate ($Q/\Delta\theta$), U =		78.27	W/°C
Total heat transfer coefficient $\left(K = \frac{Q}{\Delta\theta * S}\right)$, **K =**		**0.509**	$W.m^{-2}.°C^{-1}$
Max. error in measured K in this test, : ±		5	%

3.2 Calculated K-value

row	description of panel	no. per insulated body	length (mm)	width (mm)	hickness (mm)	λ (W/m.°C)	A (m^2)	U (W/°C)
1	FLOOR	1	13332	2486	147	0.024	33.14	5.15
2	ROOF	1	13332	2486	96	0.024	33.14	7.69
3	FRONT WALL	1	2570	2486	61	0.024	6.39	2.24
4	DOORS	1	2570	2486	51	0.024	6.39	2.62
5	SIDE WALLS	2	13332	2570	50	0.024	68.53	28.62
6							0.00	0.00
7							0.00	0.00
8							0.00	0.00
9						**TOTAL:**	**147.59**	**46.32**
10	α_{intern} (W/m2.°C):	9						
11	α_{extern} (W/m2.°C):	5						
12								
13	**U-value (W/°C):**	46.3						
14	**K-value (W/m2.°C):**	0.314						

The above calculation is based on an assumed heat conduction coefficient of 0.024 W/m.°C for PUR, which was used as insulation material in this container.
For convenience the calculation above uses internal length, width and height. This results in a calculated total surface area of 147.59 m^2, where the ATP measurement in section 3.1.1 uses the mean surface area 153.82 m^2 reported in Table 1. The use of a slightly smaller surface area in this calculation results in a slightly larger calculated K-value.
The panel thicknesses used in the calculation above only cover the thicknesses of the insulation layer. The used thicknesses are the measured panel thickness minus the thicknesses of inner and outer cladding. The thicknesses of inner and outer cladding were assessed using design drawings provided by unit45.

3.3 IR photos

IR photos were taken in the K-value test condition, where Toutside = 7.5°C and Tinside = 32.5°C. On these photos thermal bridges, i.e. spots where the insulation is worse, show up like warm locations on the outer cladding, or cold locations on the inner cladding. Some thermal bridges were observed (Figure 3 till Figure 12). The roof was inspected with the IR camera, but no thermal bridges were observed. Therefore no IR photo of the roof is shown.

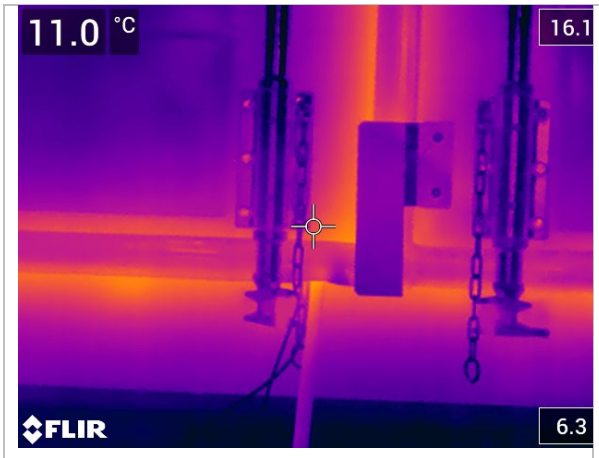

Figure 3 IR photo of lower half of container doors.

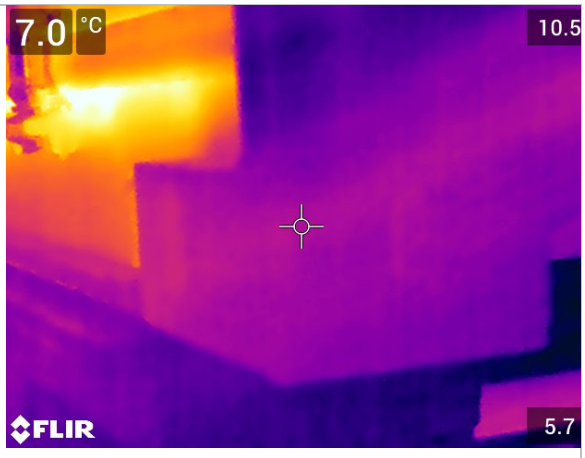

Figure 4 IR photo of corner casting + lower rim of doors.

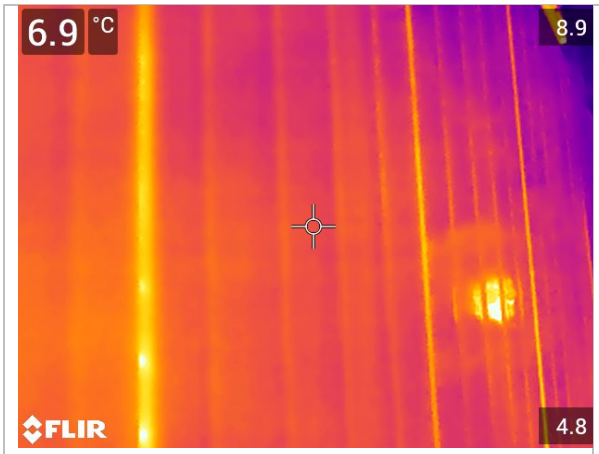

Figure 5 vertical strips in side wall (note that the circular apparent hot spot is a misleading reflection)

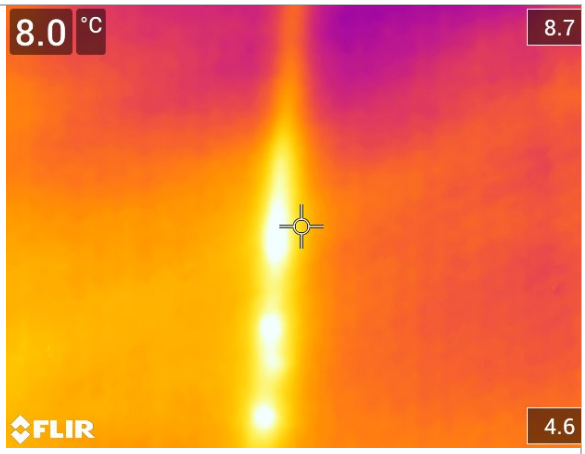

Figure 6 close-up of vertical strip in side walls.

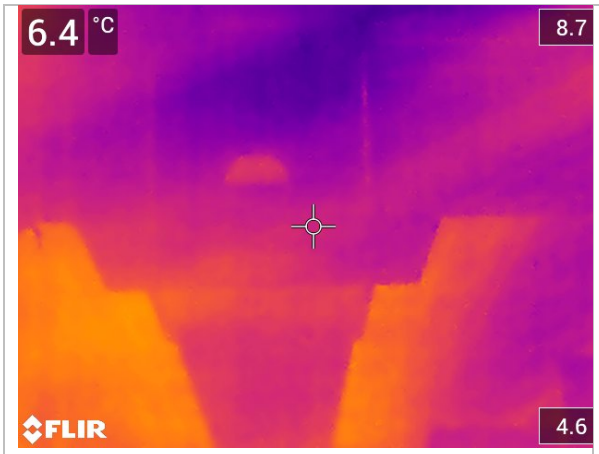

Figure 7 IR photo of thinner floor around cross bar under floor.

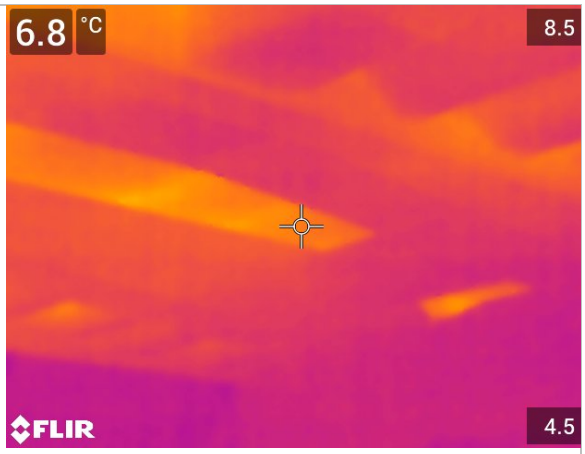

Figure 8 gooseneck area in floor.

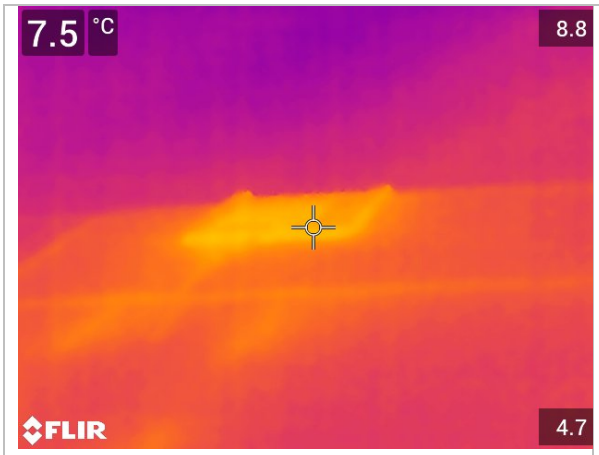

Figure 9 the 40 ft corner casting on the roof.

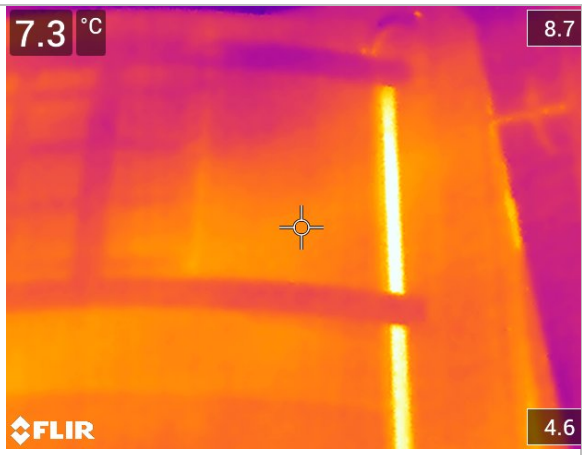

Figure 10 reefer unit mounting.

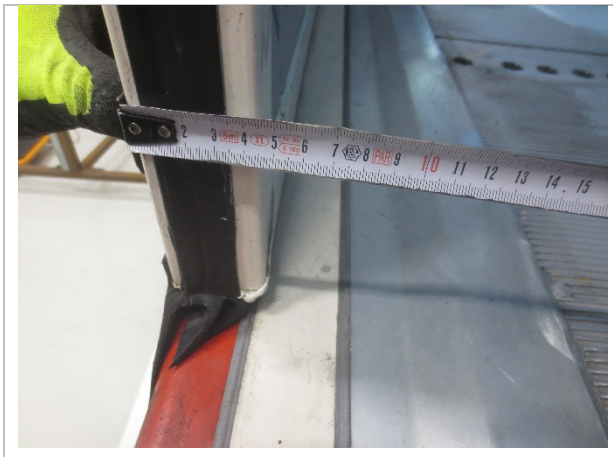

Figure 11 metal (red) connects inside and outside on the floor. White material is synthetic (± plastic), which should interrupt the metal floor underneath the door, but the door is too thin.

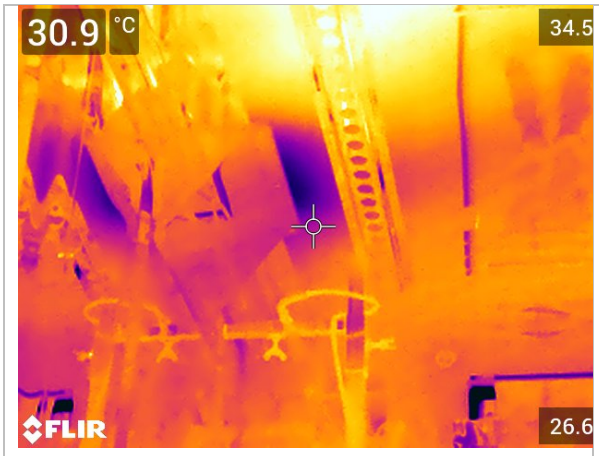

Figure 12 unit-end 40 ft corner casting from inside. A lot of disturbing reflections, but also blue areas (thermal bridge) around the corner casting.

Figure 13 strong reflection on shiny metal internal cladding makes photos from the inside hard to interpret.

Also from the container's inside IR photos were taken (Figure 12). These revealed no new thermal bridges and are much more difficult to interpret due to the strong reflection of the shiny internal cladding (Figure 13).
All in all the photos reveal multiple spots where thermal bridges occur. Many of these spots (40 ft corner castings, door seals, reefer unit mounting) seem ± unavoidable. Though these thermal bridges are hard to quantify, the impression is that the observed thermal bridges are not the explanation for the high measured K-value.

4 Conclusion

Measured K = 0.509 $W.m^{-2}.°C^{-1}$.
Calculated K = 0.314 $W.m^{-2}.°C^{-1}$.
The measured K-value is 60% larger than the calculated K-value. This is distinctly higher than expected, and a good explanation is lacking.

Literature

ATP (2020). Agreement on the international carriage of perishable foodstuffs and the special equipment to be used for such carriage. Available from https://www.unece.org/trans/main/wp11/atp.html.

Lukasse, L. .J.S.; Staal, M.G.; Wildschut, J. (2021). Temperature uniformity, air flow and fuel efficiency in a 45ft reefer container - Climate chamber tests on 45ft intermodal refrigerated container PVDU385011[6]. Wageningen UR Food & Biobased Research report no. 2179.

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To explore the potential of nature to improve the quality of life

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