Contra Vision Bus Window Wraps

A case study of how the energy consumption of air conditioning (HVAC) units is reduced contrAvision®

- A Contra Vision bus wrap is estimated to reduce the air-conditioning load by up to 23% on a warm day (17-20oC), equivalent to a daily saving of 0.5 litres of diesel (180 litres pa).
- There is also a net CO_2 reduction of 3.76kg for each m2 of Contra Vision® Performance™ over the entire product lifecycle.

What is a bus wrap?

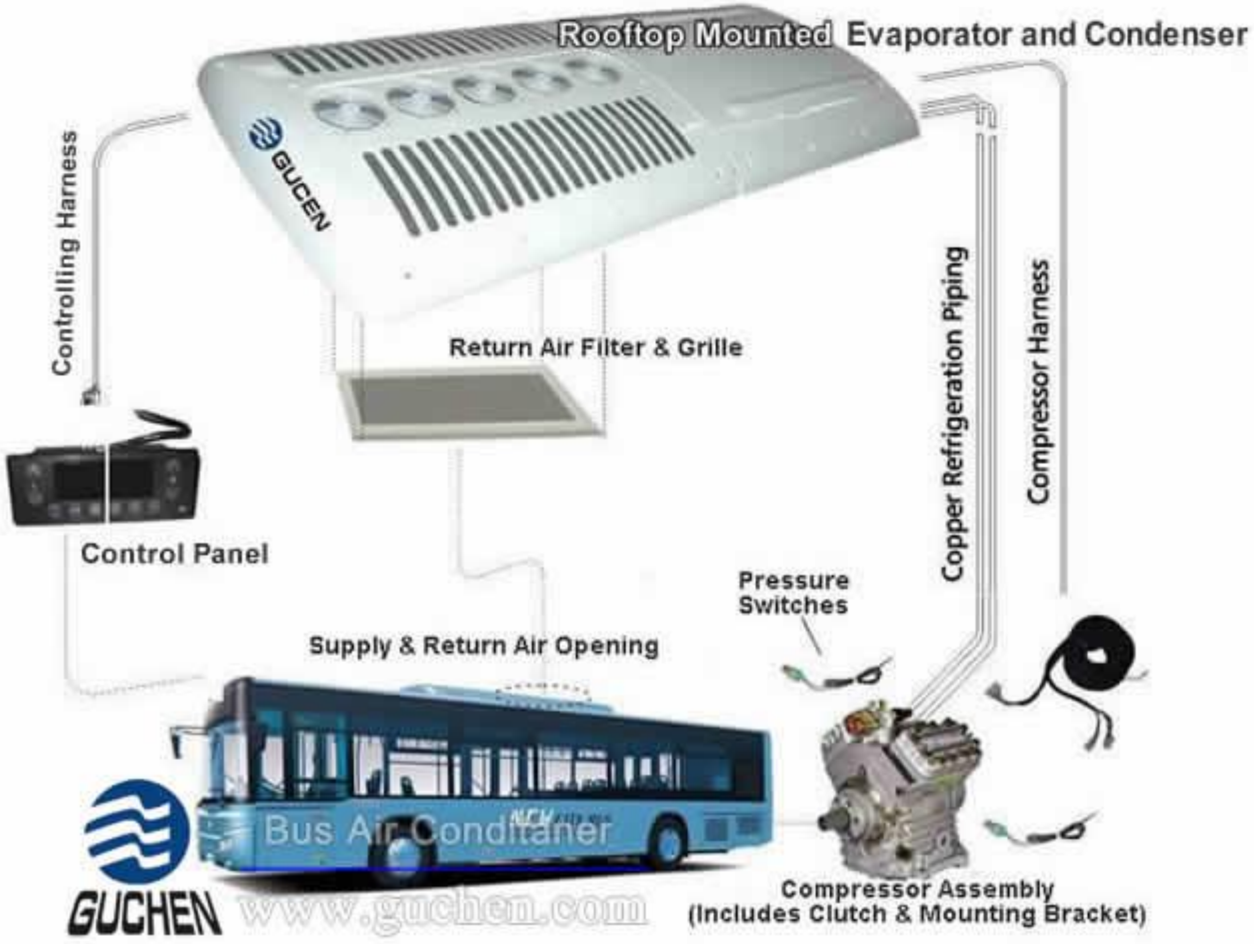
The world's first total bus wrap was produced in 1991 by Contra Vision for the Pan Pacific Hotel (New Zealand). One-way vision window graphics were applied to the glass, transforming the bus into a mobile billboard, while passengers continued to have an excellent view out.

It wasn't long before bus wrap advertising was everywhere using digitally printed perforated window film (PWF).

Air conditioning inside buses

The temperature inside buses is controlled to ensure passenger comfort. On warmer days, this temperature can spiral as solar heat energy is transmitted through windows and bodywork and trapped inside. Engine heat and passenger metabolism will also contribute.

Modern buses are equipped with HVAC (Heating, Ventilation and Air Conditioning) units which heat or cool the inside of the bus to maintain a target temperature. However, additional fuel is consumed to power the HVAC units and there is leakage of refrigerant gasses which contribute to the greenhouse effect.



Reduction in solar heat gain

PWF helps to reduce solar heat transmittance through windows because the solid area acts as a barrier which reflects or absorbs heat before it reaches the glass.

Contra Vision conducted two separate analyses to estimate the reduction of solar heat gain inside buses:

1. Theseus-FE simulation modelling
2. Theoretical "bottom-up" calculation using thermal engineering methodology

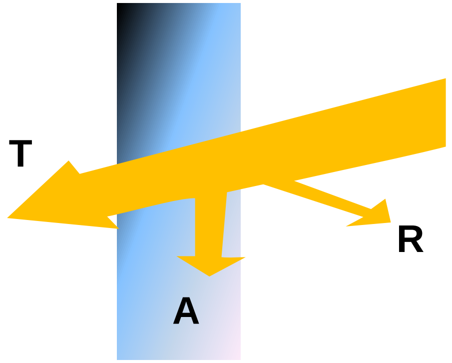
PWF solar energy transmission parameters

The solar energy transmission properties of PWF depend on 2 main factors:

- The transparency level of the PWF (the percentage of the area which is perforated);
- The average reflectance of the printed graphic (unprinted white is highly reflective whereas darker colors absorb more solar energy).

The table below shows some assumptions on the average solar properties of Contra Vision 40% transparency PWF.

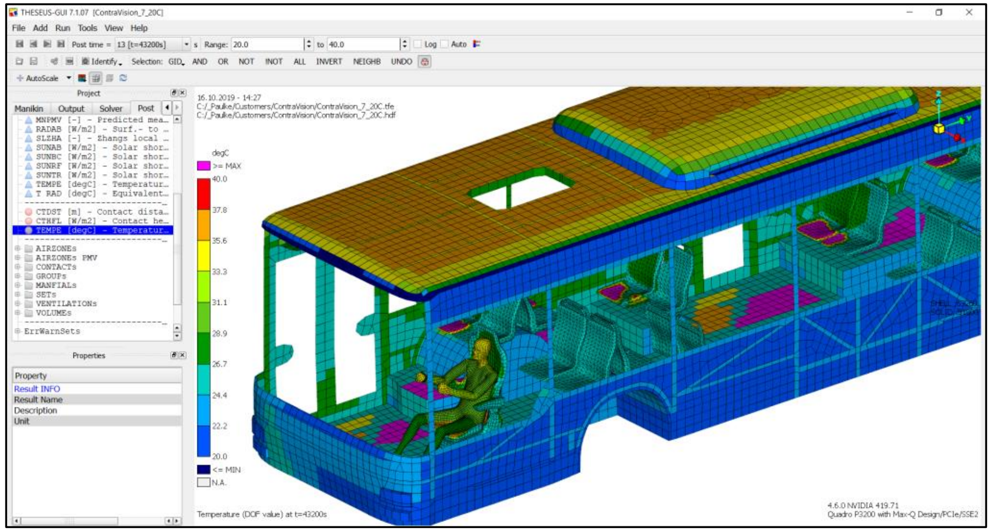
	Transmission T	Reflectance R	Absorption A
Standard glass	59%	19%	22%
Contra Vision unprinted	33%	55%	16%
Contra Vision average print	41%	37%	22%



THESEUS-FE Simulation Model

The first study used a simulation model built by Theseus-FE, a German engineering company based in Munich
https://www.theseus-fe.com/application-areas/transportation

The model simulates a full day of activity from 6am to 8pm, calculating the power requirement of the HVAC unit at each point of the day to maintain the target temperature.



Key input parameters	Values
Make of bus	MAN Bus A37
Average bus velocity	20 kmh
Outside temperature	20°C
Target inside temp	25°C
# passengers (average)	33 (87W metabolism each)
Engine heating	35°C wall temp

Results: Average Contra Vision print,T=41%

- HVAC load is reduced by 23%
- Saving of 0.4KW at 3pm
- 5KWH saving over average day
- Reduced daily fuel consumption = 0.5 litres
- 1.5kg reduction in CO_2 emissions

See Annex A for extended results

Theoretical calculation

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A second study was conducted to verify the results of the simulation modelling, using "bottom-up" thermal engineering calculations and assumptions of heat load.

The calculations included the following components:

- Outside air temperature = 17.5oC
- Passenger metabolic heat (assume 36, 75W each)
- Air infiltration heat load which is a function of vehicle speed, air density and enthalpy of infiltrated/cabin air
- Blower Motor Heat Load
- Bodywork Heat Load
- Glass Heat Load
- HVAC unit consumes 3litres of diesel per day (100km)

Results

- The HVAC load is reduced by 2KW or 14%
- Reduced daily fuel consumption = 0.4 litres
- 1.2kg reduction in CO_2 emissions

Ambient 17.5ºC (Solar Load 1000 W/m2)							
Heat Load Calculation with normal glass				**Heat Load Calculation with glass (Transmitivity 40%)**			
S/n	**Parameter**	**Value**	**Unit**	**S/n**	**Parameter**	**Value**	**Unit**
Metabolic Heat Load				**Metabolic Heat Load**			
1	Number of passingers	36	Nos	1	Number of passingers	36	Nos
2	Metabolic Load/Person	75	W	2	Metabolic Load/Person	75	W
3	Total Metabolic Load	**2700**	W	3	Total Metabolic Load	**2700**	W
Air Infiltration Heat Load				**Air Infiltration Heat Load**			
4	Vehicle Speed	50	Km/h	4	Vehicle Speed	50	Km/h
5	Air Density	1.11	kg/m3	5	Air Density	1.11	kg/m3
6	Enthalpy of infiltrated air	109	J/kg	6	Enthalpy of infiltrated air	109	J/kg
7	Enthalpty of cabin air	35	J/kg	7	Enthalpty of cabin air	35	J/kg
8	Air Infilteration Load	**570**	W	8	Air Infilteration Load	**570**	W
Blower Motor Heat Load				**Blower Motor Heat Load**			
9	Blower wattage	240	W	9	Blower wattage	240	W
10	Load Factor	0.8		10	Load Factor	0.8	
11	Efficiency	1.0		11	Efficiency	1.0	
12	Blower Motor Load	**202**	W	12	Blower Motor Load	**202**	W
Sheet Metal Heat Load				**Sheet Metal Heat Load**			
13	Over all heat transfer coefficient	2	J/m2/ºC	13	Over all heat transfer coefficient	2	J/m2/ºC
14	Area	45	m2	14	Area	45	m2
15	Surface Temperature	65	ºC	15	Surface Temperature	65	ºC
16	Cabin Temperature	18	ºC	16	Cabin Temperature	18	ºC
17	Sheet Metal Heat Load	**3557**	W	17	Sheet Metal Heat Load	**3557**	W
Glass Heat Load				**Glass Heat Load**			
18	Heat transfer coefficient for conduction	5	J/m2/ºC	18	Heat transfer coefficient for conduction	5	J/m2/ºC
19	Glass area	18	m2	19	Glass area	18	m2
20	Glass surface temperature	45	ºC	20	Glass surface temperature	45	ºC
21	Cabin Temperature	18	ºC	21	Cabin Temperature	18	ºC
22	Glass conduction heat transfer	**2430**	W	22	Glass conduction heat transfer	**2430**	W
23	Diffused fraction	0.28		23	Diffused fraction	0.28	
24	Solar Load	1000	W/m2	24	Solar Load	1000	W/m2
25	Transmissivity	0.84		25	Transmissivity	0.50	
26	Glass Diffused Heat Load	**4233**	W	26	Glass Diffused Heat Load	**2540**	W
27	Transmitted fraction	0.72		27	Transmitted fraction	0.72	
28	Incidant angle	84	º	28	Incidant angle	84	º
29	Glass Transmitted Heat Load	**569**	W	29	Glass Transmitted Heat Load	**341**	W
30	Total Glass Heat Load	**7232**	W	30	Total Glass Heat Load	**5311**	W
Total Vehicle Heat Load				**Total Vehicle Heat Load**			
31	Total Vehicle Heat Load	**14.3**	Kw	31	Total Vehicle Heat Load	**12.3**	Kw

Conclusions

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- The results are aligned.
- A bus wrap saves 0.4-0.5 litres of diesel per day in temperature of 17-20oC
- Equivalent to 0.8 litre saving per m2 of PWF for every month it is posted on a bus
- This corresponds to an average clear day (*) in Sydney, Florida and California cities.
- Estimated reduction in refrigerant gas leakage = 0.05 kg CO_2 equivalent
- A 3 month bus wrap campaign results in a net reduction in CO_2 of 3.76kg per m2
    - PWF lifecycle impact (excluding on window) = 3.43kg per m2 CO_2 eq
    - HVAC benefit = 7.18 kg CO_2 per m2

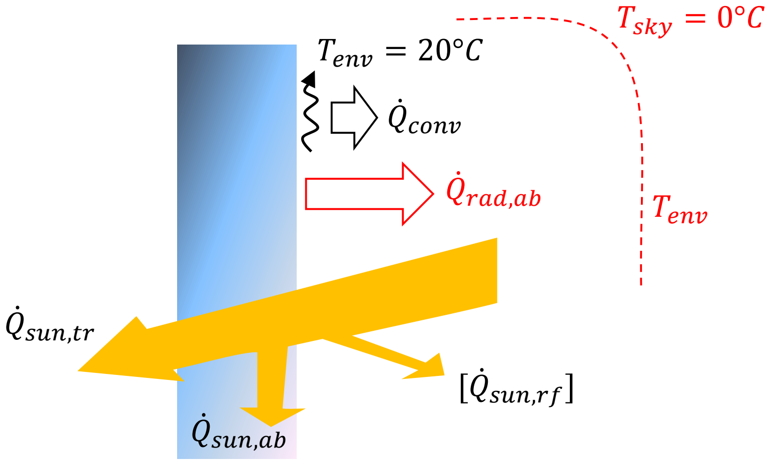
(*) The benefits are proportional to the amount of solar energy which reaches the glass. The benefits are reduced on overcast days even if the air temperature is 17-20^{o}C

THESEUS-FE Simulation Model

RESULTS

The diagram shows the heat fluxes acting on the outer surface of the bus for load case LC1. Positive values show heating fluxes. Negative values show cooling fluxes:

- $\dot{Q}_{conv}$ is the convective heat flux between the environmental air temperature 20°C. This is a cooling flux because the outer surface temperature of the bus is > 20°C.
- $\dot{Q}_{sun,ab}$ is the solar absorbed heat flux from the sun.
- $\dot{Q}_{sun,tr}$ is the solar transmitted heat flux (through windows).
- $\dot{Q}_{rad,ab}$ is the long wave radiation heat flux between the environment/sky and the outer surface of the bus.



$\dot{Q}_{sun,rf}$ (the reflected solar heat) remains unconsidered in the simulated energy balance because this heat flux does not heat up (or cool) the outer surface of the bus.

Adding all the outer heat fluxes leads to:

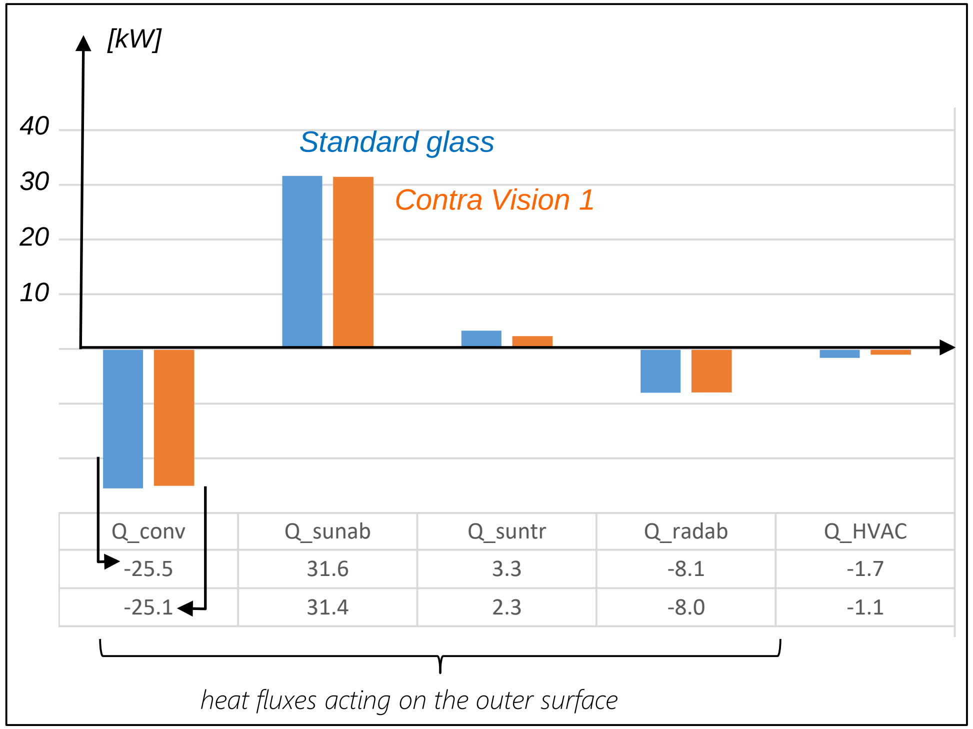
$$\sum \dot{Q}_{outside} = \dot{Q}_{conv} + \dot{Q}_{sun,ab} + \dot{Q}_{sun,tr} + \dot{Q}_{rad,ab} = 1.7kW$$

for standard glass.

This is the net HVAC cooling power consumed to fix the cabin air at 25°C inside: $\dot{Q}_{HVAC} = -1.7kW$ for standard glass.

For the Contra Vision 1 variant the HVAC cooling power is only -1.1kW because of less solar transmission through side windows.

Load case LC1: environmental air temperature 20°C



Comparing the cooling power from standard glass $\dot{Q}_{HVAC} = -1.7kW$ with $-1.1kW$ from Contra Vision 1 we can derive the efficiency:

$$\eta = \frac{\dot{Q}_{HVAC,standard} - \dot{Q}_{HVAC,CV}}{\dot{Q}_{HVAC,standard}} 100\%$$

$$\eta = \frac{-1.7kW - (-1.1kW)}{-1.7kW} 100\% = 35\%$$

Contra Vision efficiencies for all simulations:

	LC1
Contra Vision 1: T=29%	35%
Contra Vision 2: T=41%	23%