Environmental Lifecycle Impact

James Trevelyan

CEO Close Comfort Pty Ltd, Suite 6, 18 Stirling Highway, Nedlands 6009, Western Australia

Emeritus Professor, The University of Western Australia, Crawley 6009, Western Australia

July 2023

Summary

In this document, we estimate the environmental impacts from:

a) Manufacturing and transporting Coolzys to customers,
b) Using Coolzys already in service, and
c) CO_2 emission reductions potentially achievable from 2024 till 2080 with global adoption of Coolzys or a similar low-energy cooling technology.

Briefly, manufacture and transport has a global footprint of 0.014 hectares (140 square metres), with equivalent carbon emission of about 60 kg. As more material recycling becomes attractive, a greater proportion of the materials can be sourced from recycling old air-conditioners.

The annual CO_2 emissions from each Coolzy across all countries average 201 kg, compared with 1,326 kg for a split air-conditioner. This includes the effect of refrigerant losses from a split air-conditioner which, according to Australian data, account for 20% of the refrigerant volume annually, including the unfortunate likelihood that none of the refrigerant is retained for recycling at the end of the air-conditioner's life.

Counting the number of trees needed to offset the CO_2 emissions is a useful way to visualize these figures. Using a conservative average, a tree absorbs 750 kg of CO_2 in a 50-year life. Therefore, planting a tree every 4 years offsets a Coolzy's emissions, whereas nearly two trees have to be planted every year to offset emissions from a split air-conditioner.

On a global scale, with climate warming and urban heat island effects, air-conditioning will be needed for many months each year by many billions of people.

The challenge is to eliminate all CO_2 emissions by about 2050.

Realistically, we must expect that low-income countries and large users of air-conditioners like China and India will not achieve net zero until a decade or two later. Therefore, night-time use of air-conditioners almost certainly will still require some fossil fuel electricity generation.

There are two hugely significant measures already in place that will progressively reduce emissions caused by air-conditioners.

First, thanks to the 2016 Kigali amendment to the 1972 Montreal protocol, the international community has agreed to phase out refrigerant gases that damage the ozone layer, and also gases that cause significant climate warming. Some of the latter gases cause thousands of times more warming than an equivalent amount of CO_2 – the value for any particular gas is its "global warming potential" (GWP).

Second, with the large-scale change from using fossil fuel to generate electricity to renewables such as solar, wind, geothermal, and hydro-electric power, also to nuclear power generation, the emissions of CO_2 associated with electricity generation will fall significantly over time.

As a result, emissions from air-conditioners will fall from about 2035 onwards.

In estimating the environmental impacts from broad global adoption of Coolzys, we see an additional large reduction in emissions, but only when the number of Coolzys in use has significantly eliminated the use of split air-conditioners, from about 2040 onwards.

Using the estimates explained later, broad adoption of Coolzys can reduce overall global emissions by 17 $GtCO_2$, about half the current annual global emissions, about 35 times Australia's current emissions. There is considerably uncertainty, of course. However, that is still a very large and helpful reduction in the context of all the other measures available.

The following sections present the calculations in more detail.

Even if the use of conventional air-conditioners does not increase as the Rock Mountains Institute model and others have predicted (Campbell, Kalanki, & Sachar, 2018), Coolzys would significantly increase human health, well-being and capacity for productive work, enabling faster progress towards achieving the Sustainable Development Goals (SDGs).

Manufacturing and Transport Impact

Coolzy is made from steel, copper (mostly in the refrigeration compressor), aluminium (heat exchangers), PVC plastics and cardboard for the packaging. The following table sets out the environmental impact of one personal air conditioner in terms of kilograms of carbon dioxide equivalent ($kgCO_2e$) and global hectare average (gha).

Material	Mass (kg)	$kgCO_2e$/tonne	$kgCO_2e$	gha/tonne	gha
Steel	7.0	2,530	17.7	0.61	0.004
Aluminium	0.4	10,840	4.3	2.42	0.001
PVC	5.2	1,920	10.0	0.41	0.002
Polystyrene	0.3	2,970	0.9	0.66	0.000
Copper	1.5	7,000	10.5	2.5	0.004
Cardboard	1.0	890	0.9	2.76	0.003
Total	15.4		44.3		0.014

Material data taken from (Kissinger, Sussman, Moore, & Rees, 2013)

The data in the table assume that all the materials are sourced from fresh mineral resources. As more material recycling becomes attractive, a greater proportion of the materials can be sourced from recycling old air-conditioners, reducing the emissions and footprint estimates shown in the table.

A factory in China makes Coolzys. They reach your country on a container ship and then by road transport to your home causing 2 $kgCO_2e$ emissions if you're in Australia, or about 6 $kgCO_2e$ if you're in Europe or the USA.

So, in summary, making a Coolzy and transporting it to a home generates less than 60 $kgCO_2e$. A small car generates about 22 kg over a distance of 100 km, so the emissions associated with making a Coolzy and delivering it to your home are approximately the same as driving a car for about 300 km.

Refrigerant emissions

The refrigerant gas inside Coolzy also affects the climate if it is released into the atmosphere. Coolzy uses permanently welded refrigeration tubes so no gas can escape in normal operation. We recommend taking Coolzy to a recycling organisation at the end of its life to recover and process the refrigerant gas with minimal climate impact. However, this is not always possible. If the refrigerant gas is accidentally released there will be some climate impact.

From 2022 we have used the natural refrigerant R290 (Propane) equivalent to just 0.240 kgCO_2e. In the USA, regulations require us to use R134a refrigerant equivalent to about 400 kgCO_2e, eight times the emissions associated with making a Coolzy.

R290: 80g, 3 GWP, equivalence 240g kgCO_2e (negligible).

R134a: 280g refrigerant, 1430 GWP, equivalence 400 kgCO_2e.

This should be compared with the refrigerant in a typical split air-conditioner sold in Australia today, containing 1.4 kg R32 refrigerant with GWP value 677. This is equivalent to almost one tonne CO_2e, 4,000 times more than the Coolzy refrigerant. According to analysis of Australian data, split air-conditioner leaks through a typical 10 year air-conditioner life add as much emissions again, bringing the total to two tonnes CO_2e, or 8,000 times the impact of the Coolzy refrigerant charge. Coolzy uses permanently welded pipes so there is no in-service leakage.

We have used widely accepted GWP estimates for refrigerant gases. However, the real situation is a little more complex because refrigerant gases break down in the atmosphere at different rates, most faster than CO_2. CO_2 is one of the slowest gases to dissipate from the atmosphere. Therefore, with wide agreement, we consider the equivalent effect of a gas over the first 100 years from its release.

Calculation of in-service environmental impact for units in service

The manufacturing impact is small compared with the impact in use through an estimated service life of 10 years, as shown in the following table.

The main environmental impact comes from generating electricity to provide power for a Coolzy. If the electricity comes from wind generators or solar panels, there is little impact. However, many people will be using Coolzy at night when electricity generation still requires burning fossil fuels like coal, oil and gas.

We can calculate the average emissions from data revealing the 'carbon intensity' of electricity generation. This data is available from sites such as https://ourworldindata.org/grapher/carbon-intensity-electricity.

Country (2021 data)	kg CO_2/kwh
Pakistan	0.296
Australia	0.486
Indonesia	0.625
Singapore	0.464
Europe (average in Spain, France, Italy, Greece)	0.2
USA	0.357

Data from countries like Australia provides the average number of hours people use air conditioners each year, and the average power (Brodribb & McCann, 2018). In other countries, we ask representative customers about their electricity bills and energy usage. We estimate the average power used by Coolzy and room air conditioners from data on the types of model in use and the usage of Igloo tents for additional energy savings.

Country	hours used in 1 year	Average Coolzy power	Traditional aircon power
Pakistan	1800	270	1800
Australia	525	330	1700
Indonesia	2000	330	1200
Singapore	2000	330	1200

Europe	400	340	1700
USA	700	340	1700
Total			

This next table estimates the average annual electricity savings assuming that a personal air conditioner is used for the stated number of hours each year in place of a traditional room air conditioner. The number of hours estimate is based on a combination of regulatory publications (Australia and Singapore) and feedback from users (Indonesia, Pakistan). Average power and traditional power refer to the average power used by a personal air conditioner and average power used by a traditional room air conditioner (Watts).

The following table is based on data collected till the end of 2022. We assume that 30% of low-income country customers use their Coolzys instead of a split air-conditioner, and 50% of customers in high-income countries do likewise.

Country	Units in use	hours	Average power	Conv. AC power	kWh saved/unit	kWh saved total
Pakistan	1720	1800	270	1800	2,754	4,736,880
Australia	5600	525	330	1700	719	4,027,800
Indonesia	2400	2000	330	1200	1,740	4,176,000
Singapore	2600	2000	330	1200	1,740	4,524,000
Europe	50	400	340	1700	544	27,200
USA	150	700	340	1700	952	142,800
Total	12520				1409	17,634,680

The following table estimates the average annual saving in electricity cost from using personal air conditioners (Australian dollars).

Country	kWh saved total	Electricity cost/unit (AUD)	Electricity Cost Saved
Pakistan	4,736,880	0.12	559,254
Australia	4,027,800	0.35	1,409,730
Indonesia	4,176,000	0.13	536,914
Singapore	4,524,000	0.25	1,131,000
Europe	27,200	0.50	13,600
USA	142,800	0.24	34,680
Total	17,634,680		3,685,178

On 12,500 units in service this amounts to an average of $300 saving.

The final table estimates the total CO_2 equivalent saving for these units.

Country	Total CO_2e saving (tonne)
Pakistan	2,221
Australia	4,623
Indonesia	3,752
Singapore	3,337
Europe	29
USA	122
Total	14,085

On average, each unit saves about 1.12 tonne CO_2e, while each unit saves its owners $300 off their electricity costs in doing so.

This should be compared with the recent European carbon price of 80 € ($110) per tonne. With personal air conditioners used instead of traditional room air conditioners, users save $300 for every tonne of CO_2e reduced, instead of being expected to pay $110 per tonne embedded in the price of products they purchase.

Modelling Global Adoption of Coolzy Technology

We have modelled the global adoption of Coolzy technology to estimate the potential reduction in global greenhouse emissions over the period 2025 – 2080. We only model room air-conditioners (RACs) and Coolzys.

We expect that emissions from large air-conditioning installations will fall more rapidly, for example in hotels, office buildings and factories. Decisions on these installations typically rely on life-cycle cost assessment and the advantages of low energy consumption technologies and incentives to move to net zero emissions will drive this more rapid transition. Therefore, we have not included these installations in our assessment.

The Rocky Mountains Institute (RMI) developed a more comprehensive model (Campbell et al., 2018). We adopted their reference case with the following modifications to predict business-as-usual emissions if world continues to use and improve conventional room air-conditioning technology.

i) We used a lower forecast for the number of room air-conditioners (RACs) in 2024, the first year of our forecast (1,250 million compared with 1,750 million forecast by RMI). Growth in RAC adoption slowed significantly through the Covid-19 pandemic and discretionary spending in low-income country economies and is still significantly lower than it would have been otherwise. We base this on observations and data from India, Pakistan and Indonesia.

ii) We have also forecast a lower rate of growth in the number of RACs in use over time. Even today, the number of RACs used routinely in low-income countries is much less than the number installed because people struggle to afford the cost of electricity. In small shops, for example, RACs and display lights are only turned on when customers are in the shop. Our reference case predicts 2,300 million RACs in use in 2050 compared with 4,500 million units in the RMI forecast.

iii) We used a lower rate of improvement in RAC efficiency and housing thermal insulation because we have not seen improvements in low-income countries aligning with the 2018 RMI forecast. By 2050, we forecast that the average power used by RACs globally falls from 1,700 Watts in 2024 to about 1,300 Watts in 2050.

iv) We have assumed greater reductions in the carbon intensity of electricity generation as the world adopts renewables, geothermal and nuclear generation, falling from an average of 0.5 in 2024 to 0.13 in 2050. China and India are expected to reach net zero emissions well after 2050.

v) We have forecast a reduction in the average global warming potential (GWP) of refrigerants used in RACs from 1700 in 2024 to 770 in 2050 as with adoption of lower GWP refrigerants under the Kigali amendments to the Montreal protocol. However, progress in low-income countries is slow because older RACs stay in use for up to 30 years and low-income countries only start adopting lower GWP refrigerants in 2028.

We have assumed that the market for Coolzy (or equivalent low-energy cooling technology) saturates by about 2050 with rapid adoption in low-income countries because of affordability. As Coolzys become more widespread, people use RACs less, but they are still used for about 10% of the original number of hours in 2050. The total number of RACs in use falls as more people dispense with RACs, but is still 60% above the 2024 level in 2050. This significantly reduces direct emissions caused by leaks from RACs.

The total calculated emissions saving from introducing Coolzys or another low-energy alternative between 2024 and 2080 is 17 $GtCO_2$, about 35 times Australia's entire emissions in 2021. CSIRO have forecasted global emissions in 2022 at 37 $GtCO_2$.

Model Details

There are large uncertainties in outcomes over the next 50 years. Therefore a relatively simple model is as useful as a complex model because a complex model is equally subject to the large uncertainties.

1. The model calculations are performed year by year from 2024 till 2080.

2. The number of Coolzys commences at 25,000 in 2024 and increases at an initial growth rate of 75% annually till saturation is reached at 2.9 billion units. The assumption is that, once large air-conditioning companies realise the market potential, they will enter the market and expand rapidly, licencing technology or developing their own.

   $n_{i+1} = n_i + n_i*g*(m-n_i)/m$

   Where

   n_i is the number of Coolzys in year i,

   g is the annual growth (75%),

   m is the ultimate market size (2.9 billion).

3. Coolzy power is set at 340 Watts. In fact, the average power can be significantly less, as little as 200 Watts when using a bed tent with ambient temperature typical of monsoon / tropical heat with 33 °C indoor temperature. When used without a tent in ambient temperatures around 40 °C, the power can be as high as 400 Watts.

   Pc = 340 Watts (Coolzy power)

4. The power used by a conventional air-conditioner is set to the Australian average of 1,700 Watts in 2024 (Brodribb & McCann, 2018), but reduces annually:

   $Ps_{i+1} = Ps_i * 0.99$

   The reduction, following the RMI study prediction, but more conservatively, is that improved building construction and improved air-conditioner design and performance gradually reduces the average power consumption to around 970 Watts by 2080.

5. The refrigerant charge in a conventional split air-conditioner is constant at 1.1 kg.

6. The conventional split air-conditioner has refrigerant gas with average GWP which reduces annually at 3% because of the Kigali amendment forcing the adoption of lower GWP refrigerants, reducing to 400 by 2080. We should note that low-income countries are required start restricting the use of HFC gases in 2028, and typical air-conditioners last up to 20 years.

   $GWP_{i+1} = GWP_i * 0.975$

7. In the absence a significant population of Coolzys, increasing incomes and improved cost-reduction in manufacture increases the number of conventional air-conditioners, nb, by 5% annually, with market saturation at 2.7 Billion units, using the same computation method as item 2 above.

8. With Coolzy in the market, the number of conventional air conditioners, ns, still grows initially at the same annual rate. However, as the number of Coolzys increases, the growth in ns slows, and then becomes negative as the popularity and effectiveness of Coolzys increases. The 2024 value for ns is 1250 million, whereas the RMI study assumed 1750 million. Our data reveals that a significant proportion of air-conditioners are not used for much of the time. Therefore, our population is considered to be the actual number of air-conditioners in use for the estimated number of annual hours.

   $ns_{i+1} = ns_i + (ms - ns_i - n_i*a)*gs$

   Where

   ns_i is the number of split air conditioners in year i,

   gs is the annual growth (5%),

   ms is the ultimate market size (2.7 billion),

   a is a factor 0.7 that modifies the growth rate such that as the number of Coolzys increases, the growth in the number splits, ns, gradually decreases, becoming negative in 2043 when the number of Coolzys has reached about 1 billion units.

   Note that there is a risk that we may underestimate refrigerant leakage as a result of using a smaller number of air-conditioners. One should also note that there is considerable uncertainty in the actual leakage rates from air-conditioners.

9. We calculate direct emissions caused by refrigerant leaks from the total number of split air-conditioners (with Coolzy in the market), ec, as

   $ec_i = 0.15\ c\ gwp_i\ ns_i$

   on the assumption that 15% of the charge leaks every year. Data provided by Brodribb (2018) for Australia suggests that a figure closer to 20% should be more appropriate, with an average 10 year life span over which top-up charging amounts to 100% of the charge, and no refrigerant is recovered at end of life.

   The result is calculated in Gt (Gigatonnes, 10^9 tonnes)

10. We calculate the global average number of cooling hours annually starting at 1200, growing at 4% annually due to climate warming and urban heating (the latter is more rapid), and improved living standards increasing the capacity to pay for electricity. We used the same computation as in 2 above, with a saturation value of 4,000 hours, but that is not reached by 2080. The number of hours in use reaches 3200 in 2080.

11. As more and more Coolzys appear, and more people have both a Coolzy and a split air-conditioner, the average proportion of time, hc, (during cooling hours) that the split air-conditioner is used decreases over time.

    $hc_i = 1 – nc_i/(m(1 + r))$

    Where r = 0.1,

    m is the market size for Coolzys.

    As the number of Coolzys in the market rapidly rises from 2040 onwards, this proportion decreases from 1 to about 0.09 by 2050.

12. We calculate the total kWh used by the entire Coolzy population, n_i, using the number of cooling hours at step 10, and the power consumption.

13. We calculate the total kWh used by conventional split air-conditioner population, ns_i, using the average cooling hours from step 10, the proportion of hours in use from step 11, and the average power consumption from step 4.

14. We calculate the average global carbon intensity for electricity generation, initially 0.5 at 2024, reducing by 5% annually to about 0.13 by 2050. We assume that the day-time figure should be zero by then, however a proportion of night-time electricity will still be generated with some carbon emissions.

15. We calculate the indirect emissions from electricity generation from the population of Coolzys and split air-conditioners, and add the direct emissions from step 9.

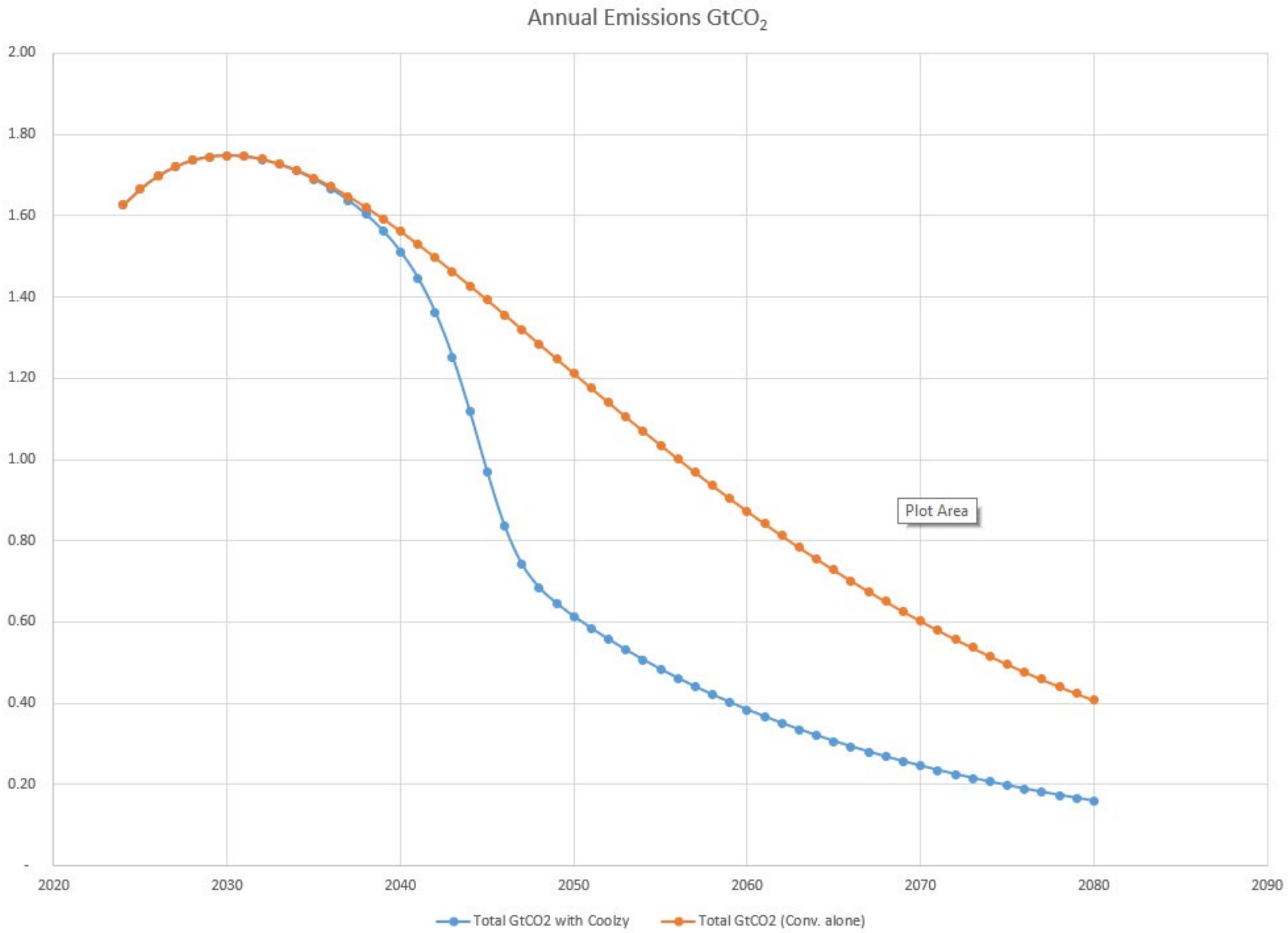
16. We calculated the indirect and direct emissions from the population of split air-conditioners using the same relationships, but with the population nb_i from step 7 in the case that the Coolzy population n_i is insignificant.

We should note that there are many assumptions in this model, all of which influence the final calculated results.

Model Results

The model with the stated assumptions calculates the total emissions from Coolzys and the number of conventional split air-conditioners in use at 47.9 $GtCO_2e$ (Gigatonnes carbon dioxide equivalent), and 64.7 $GtCO_2e$ from conventional air-conditioners if no Coolzys or other energy-efficient technologies appear. The reduction is 16.7 $GtCO_2e$ between 2024 and 2080.

The following graph summarises the model result:



Adopting Coolzy technology enables a rapid reduction in emissions from 2045 onwards. Emissions do not fall to zero, even with Coolzy technology. However, after 2050, the overall level of air-conditioning emissions is small compared with today's global emissions total.

We should note the argument presented in attachment 3, that a large proportion of people in low-income countries who own air-conditioners (typically 60 – 80%) cannot afford to pay for the electricity to run them except in extreme heat and for special occasions. Additionally, in 2019, the number of homes in India with air-conditioners was less than 10%.

Therefore, one might argue that the predictions for growth in the number of air-conditioners, to the point where almost the entire global population have one, is unrealistic. Therefore, emissions from these air-conditioners will not reach the levels predicted by RMI and other models.

Following this line of reasoning, one might also argue that the emissions from Coolzys will *increase* global emissions above the level that would otherwise have occurred, because far more people will feel they can afford the much smaller amount of electricity they need to run their Coolzys.

We assert that the use of Coolzys in these circumstances will improve health, well-being and global productivity, particularly in low-income countries, accelerating progress towards achieving the SDGs. This, in turn, will enable far more significant improvements that help to reduce overall emissions by much larger amounts than otherwise. Therefore, the small increase in emissions caused by using Coolzys will be offset by much larger reductions in emissions from other sources. For example, trials have shown that the productivity of irrigated agricultural land in Pakistan could be five times higher than it is today, with improved farming practices and reduced water consumption (personal communications from Pakistan government sources). Therefore, as the area of agricultural land needed for food production decreases with improved farming practices, land can be released for growing forests to capture more carbon from the atmosphere.

If farmers sleep in comfort with Coolzy, they can then think more clearly about improving productivity. Without healthy sleep, it is simply unrealistic to expect that anyone can think clearly.

References

Brodribb, P., & McCann, M. (2018). Cold Hard Facts 3. Retrieved from https://www.environment.gov.au/protection/ozone/publications/cold-hard-facts-3

Campbell, I., Kalanki, A., & Sachar, S. (2018). Global Cooling Prize: Solving the Global Cooling Challenge - how to counter the climate threat from room air conditioners. Retrieved from http://rmi.org/wp-content/uploads/2018/11/Global_Cooling_Challenge_Report_2018.pdf

Kissinger, M., Sussman, C., Moore, J., & Rees, W. (2013). Accounting for the Ecological Footprint of Materials in Consumer Goods at the Urban Scale. *Sustainability, 2013*(5), 1960-1973. doi:10.3390/su5051960