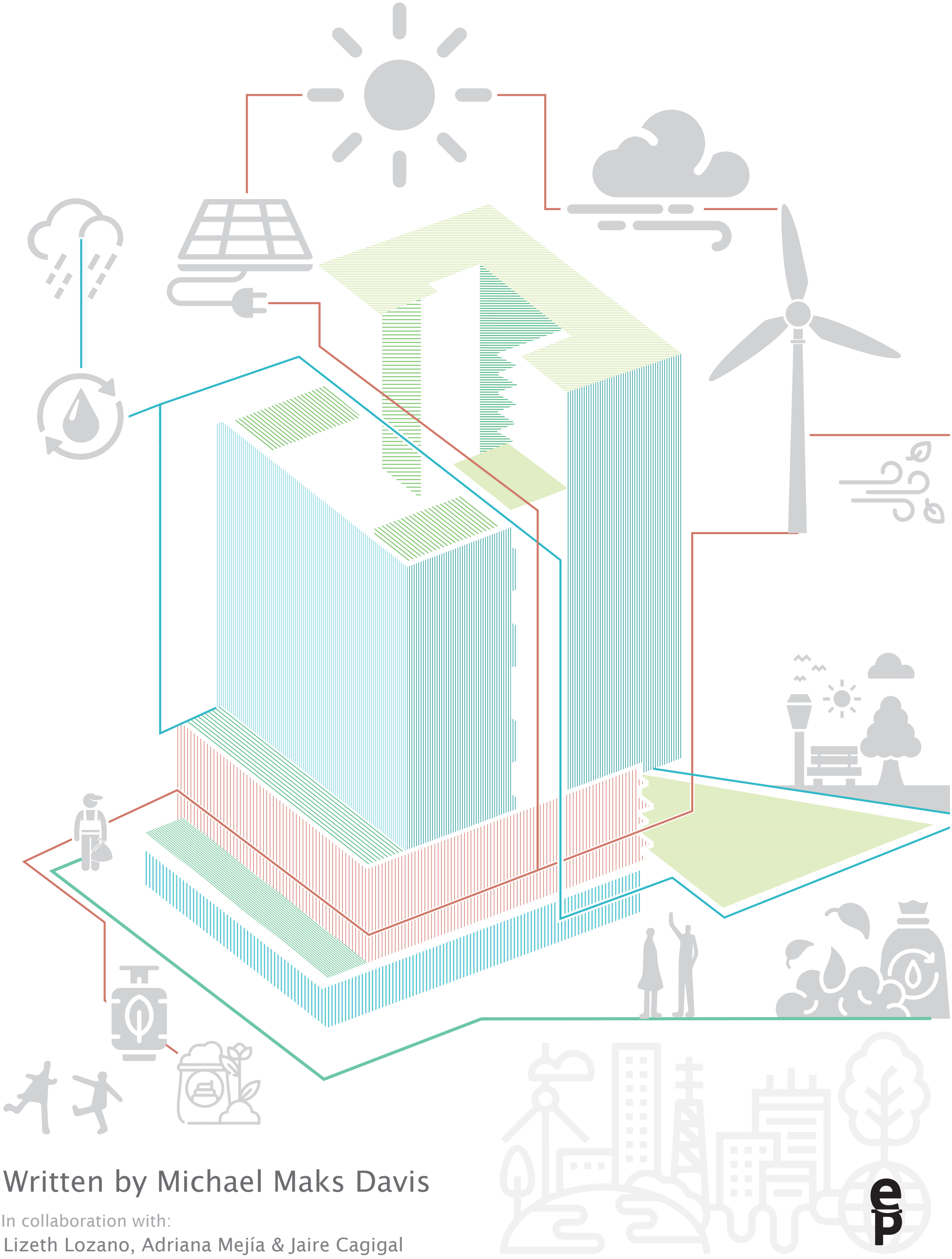
# Design in the Anthropocene

## Sun, Water & Soil




Written by Michael Maks Davis

In collaboration with:
Lizeth Lozano, Adriana Mejía & Jaire Cagigal

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Written by Michael Maks Davis

In collaboration with:

Lizeth Lozano for the architectural design, water calculations and green infrastructure of the Case Study, plus her work for the Green Infrastructure Annex.

Adriana Mejía for the energy and waste management calculations of the Case Study.

Jaire Cagigal for the design, graphics, layout and 'feel' of the book.

Dedication:

To David Mackay, thanks for your work in sustainable energies in the UK that simplified so much for so many of us.
To my wife, Luz and our two amazing kids, Julia, and Elliot, who put up with many late nights and subsequent grumpy mornings.
To my mother, Antonia Maks, who is a permanent source of positive energy.
To my brother, Gully, who taught me of life the incredible power of narratives in the way we see the world.

Acknowledgements:

My gratitude is extended to the Task Force Groups: students who were given the challenge of reviewing the book in its raw, text form. They told me about sections they found read well, those that needed improvement, how this could be made and most importantly, checking all the calculations (where a couple of hiccups were brought to light!). Thanks therefore to: Adrián Enríquez, Daniel Dávila, Diego Tipán, Camila Rosero, Sarahí Tinoco, Kevin Akoa Akoa, Marie Magloire Carelle Nnomo Kamdem, Michel Yvan Nzwessa Lamingwa, Pierre Marie Chancel Nya'abe. In particular, I am grateful to Jorge Salazar for going the extra mile to wheedle out all of the hard-to-find 'blips'.

Additionally, this book makes some references to articles that I had the pleasure of working on with colleagues from all over the world: David Jácome-Pólit, Mathieu Lamour, Andrea Cecchin, Andrea Vallejo, Paulina Criollo and Teresa Domenech.

Finally, my sincere thanks to the people who reviewed the final draft of this book, Francesco Alberti and Goffredo Serrini, both from the Department of Architecture (DIDA) of the University of Florence, plus Eleonora Giannini, now at the School of Geography and Planning of the University of Sheffield.

# Table of Contents

# Introduction

Design in the Anthropocene. Who is this book for? Chances are, if you have picked it up and got this far, it has been written for you.

I have tried to divide the work in a way that makes it accessible to a wide variety of readers. It puts the different units found in renewable energies, water systems and waste management into one, simple and common metric, namely, space. Space that can be discussed throughout a range of different specialities, space that can be designed.

The mini-intros and graphics provide you with an overview of what the chapter holds. They offer just about enough information for high school projects and to impress your colleagues at the office over coffee. They give a taste of what is further to come. Each chapter then gives you the information in more detail, useful for engineers, architects and urban planners, who might be experienced in one field but wish to know more about the others presented in this book. The case study then puts the tools presented into practice, using a hypothetical high-rise, mixed-use building that was developed for this book and is based on nearly two decades of sustainable building design consulting experience. It is here that practitioners in the field of sustainable design can find a practical application of the theories described to really get their teeth into. Finally, the Annexes were written for more experienced professionals who want to learn about fieldwork research, or might wish to see exactly how the rules of thumb presented in the book were reached and to explore certain aspects in more detail.

This book is titled 'Design in the Anthropocene: Sun, Water, Soil'. The reason is that it has become increasingly clear that we have entered the Anthropocene Age, where global climate systems begin to be dictated to a great extent by human activity over anything else[1]. Furthermore, everything in the world is dependent on the Sun, it is the main energy source for everything, everywhere. Thanks to this energy source, add a few billion years of ice entering the Earth (probably from meteorites) and the development of atmospheric cycles, we have water on our planet. Water is the source of life, life developed thanks to water and continues thanks to water. Should water ever end, so will life as we can ever know it. Finally, we have soil. Soil is where plants, trees and food grow. Perhaps more importantly, it is where valuable ecosystems occur that are a vital part of the food chain. In short, the Sun powers everything, water is essential for life and soil is vital for both ecosystems and nutrition cycles. This book is about using the Sun (through renewable energies), harnessing water (in management systems) and seeking to have soil as the end product of our designs (through waste management). Hence, the title.

[1] First coined by Paul J. Crutzen and Eugene F. Stoermer (2000). The 'Anthropocene.' Global Change Newsletter (41): 17–18., and which has gained weight ever since.

You can read this book much as I wrote it, not from cover to cover but more like a paddling pool, dipping in when fancy takes it. Some days I would feel energy-like and write in that chapter. At moments I would be inspired by water and soil, and so set myself to work there. Don't feel that you need to study the book in depth, only do that if you have the desire to do so. Otherwise, have it lying around (in digital or print form), pick it up as the whim grabs you and put it down as soon as you get bored. No problem if you start reading about circular economy design in practice, and then jump to rainwater harvesting. The book could be written in such a liberal manner because it was basically already 'all in my head', a head that had been pumped with nearly two decades of experience in the sustainable design sector both as an academic and as a professional. My work and research have spanned everything from crazy ideas, such as active vertical gardens for building climate control, to applied sustainability consulting for mixed-use construction projects, to urban planning and transport policies. I have had the particular luxury of being able to explore new, exciting concepts with my students and in academic research, and then see how these could be moulded, adapted and costed in my professional work. However, it would be a lie to say that this book only comes from my head, as the decades of experience is thanks to students, clients and in particular to my colleagues who collaborated on this book.

Why take a high-rise, mixed-use building as the case study? In the ancient past a human being would have a dream: to eat well (and not die of famine), be healthy (to not die of a virulent disease) and live long (not be violently killed through war, fights or murder)[2]. But come the 20th century and this all changed. In the capitalist, developed countries that had rocketed through the industrial age, humans found themselves above and over the restraints usually supplied by nature. Ending the 20th century and leaping into the 21st, humans switched from being mainly rural inhabitants to being urban dwellers (by 2007 more than 50% of the world population had switched to urban life, according to the UN estimates). Finally, through the UN Sustainable Development Goals and in the New Urban Agenda declared at the UN Habitat III conference, cities were recognised as the main driving force in the Age of the Anthropocene:

> 'Cities account for between 60 and 80 per cent of energy consumption and generate as much as 70 per cent of human-induced greenhouse gas emissions'[3]

And then we get the proposed way forward: Compact Cities. These are based around the idea that for cities to be in balance with Mother Nature, they had to stop spreading out in an urban sprawl and remain compact in a manner that our daily needs could be met through walking, cycling or at most public transport. This could be interpreted as the adaptation of a preceding concept known as Transit Oriented

[2] Harari, Y. N. (2016). Homo Deus: A brief history of tomorrow. Random House.

[3] UN Goal 11: Sustainable Cities and Communities. https://www.un.org/sustainabledevelopment/cities/

Development, which to all extents and purposes points to the same thing. Additionally, the 15-minute city has given this concept a new breath of life. It is very controversial as to whether this is the only way forward or not. Some of the greatest civilisations the world had known before the Industrial Revolution were to be found in the Amazon, something that is now becoming clear to us with the introduction of lidar scanning in archaeology. But, these were sprawling cities that survived for many millennia in some estimates, where decentralised, urban agriculture might have formed a strong part of the urban infrastructure. Additionally, the Covid-19 crisis taught us that we can carry out a lot of our work, shopping and social activities from home only armed with a decent internet connection, no matter where we are, be it a high-rise skyscraper in Hong Kong or a leafy suburb in Brisbane.

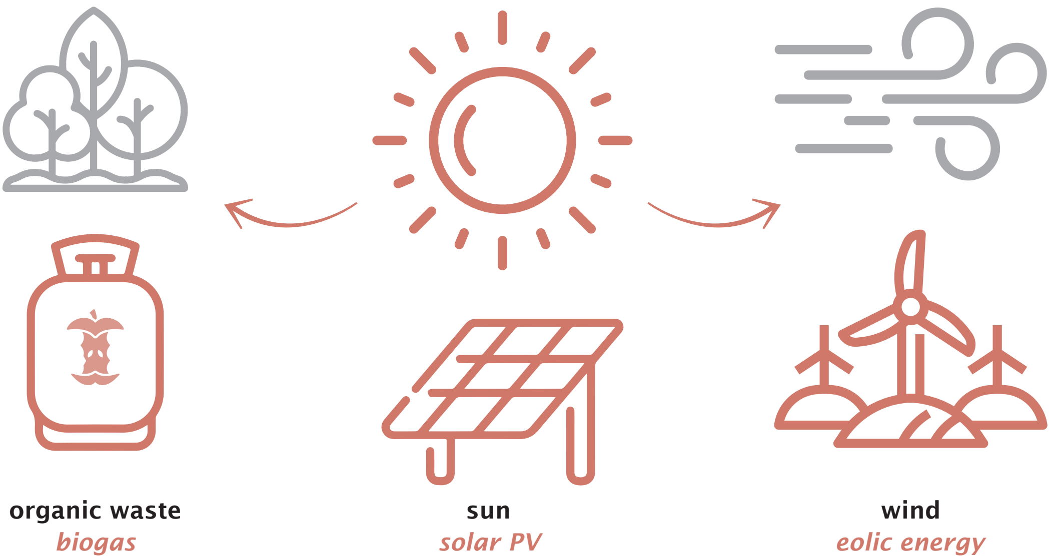
However, that discussion is for another book. For this one we will assume that the future of cities is compact, where there is a tendency towards living in dense, mixed-use urban environments. For that reason, for the case study a hypothetical, mixed-use high-rise building has been developed, consisting of residential flats, office space and restaurants/cafés on the ground floor.

So, let us begin.

# SUN: GIVE YOURSELF SOME SPACE

## Mini Intro

In this chapter we will be looking at three forms of renewable energies, which are all ultimately derived from the Sun. The first is directly captured solar radiation through photovoltaics (solar PV) using solar panels. The second is wind energy, where the energy from the Sun drives air expansion that sets up pressure curves the wind rides[1]. The wind can be harnessed by turbines and converted into electricity. The third is biogas, produced from the leftovers of edible plants and fruit that had previously grown thanks to their daily input of sunlight. If these are composted in anaerobic conditions[2] gas can form, which can burn in an internal combustion engine to produce electricity.



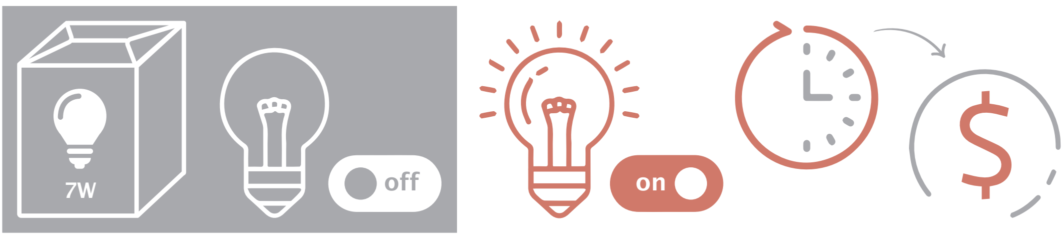

[1] The air flows from high-pressure areas to low-pressure ones.

[2] Composted in the absence of Oxygen.

Additionally, the bold assumption is made here that electricity is the energy of the near future. Kitchens become electric, water and space are heated with electric appliances, cars and transport transition to being completely electric. Is my assumption far-fetched? Time will tell if I am barking up the wrong tree or not.

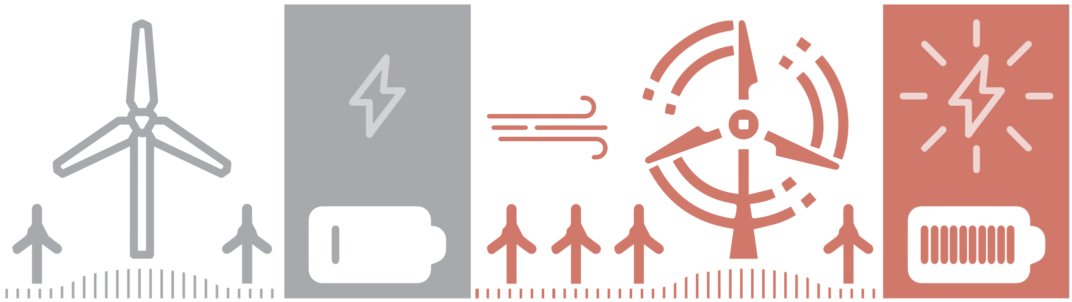
First and foremost, it is important to understand the difference between *potential, demand and production* if we are talking about electricity.

For example, if you buy a light bulb that says 7-Watt on the box, this means that it has the potential of 7 W, but does not consume anything while it is in the box. You then install the light bulb, but it still doesn't consume any electricity. It is only when you switch the light on that it starts to consume electricity that will add to your monthly bill. If you leave the 7-Watt light on for an hour, it means that 7 Watt hours will be added to your electricity bill (written as 7 Wh). Divide this by 1000 to get the number in kWh (0.007 kWh). Leave it on for 2 hours and you will consume 0.014 kWh, 3 hours will be 0.021 kWh, and so on. If you leave the light on for 2 hours, then switch it off for an hour, and then switch it on again for another hour, what would the overall consumption be?[3].




The same is true for electricity production. A wind farm might have the potential to produce many gigawatts (GW) of electricity. But if there is no wind, nothing is produced, whereas a good, steady, constant wind will mean the farm will produce many GWh each hour for the national grid.

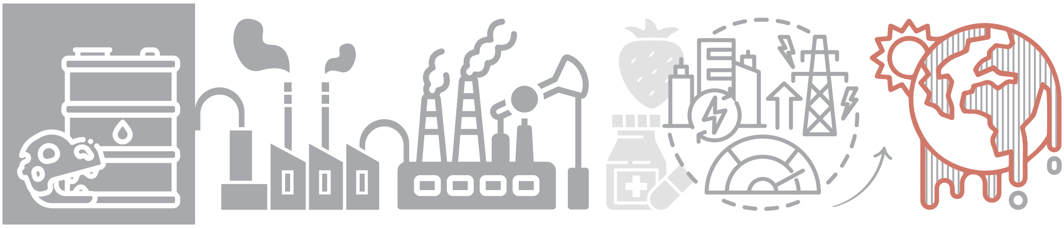
[3] 0.021 kWh: you only had the light switched on for a total of 3 hours.



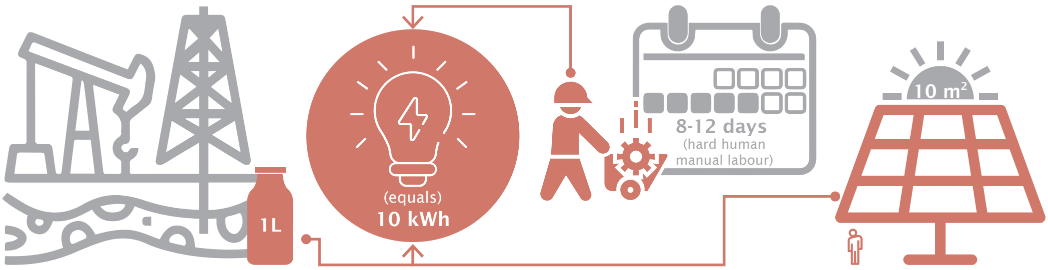
Typically, one will read that the amount of energy from the Sun that brushes the Earth's surface every day far exceeds our current energy demands (enough in a day for up to a year). This is even true for our energy-hungry predictions of the future. Solar energy takes many forms. It radiates directly onto surfaces, it stirs up the wind, and it is absorbed by vegetation in processes of photosynthesis. It is also the ultimate source of fossil fuels, which are basically very old biological matter that got its energy from the Sun, then became squeezed, squashed and concentrated over time into the most powerful fuel source we could have ever imagined[4].

Humankind has made unprecedented leaps and bounds over the last century thanks to fossil fuels. We have grown more food, made more medicines, and built more infrastructure than could have been thought possible before the 20th century. But this has all come at a great price, we have converted carbon that was stored deep in the ground into greenhouse gases (GHGs) floating in the atmosphere. The result is Climate change, where in a very short time indeed we find that we are the cause of an accelerated heating of the planet we live on (and are confined to). The result is the Anthropocene Age. However, being the ultimate in concentrated energy, fossil fuels are pretty hard to compete with.

[4] Until the 20th century, when the embodied energy in Uranium was harnessed in nuclear power.



For example, 1 litre of petrol has the energy equivalent of around 10 kWh[5], approximately 8 to 12 days of hard human manual labour[6], or the daily output of around 10 $m^2$ of expensive monocrystalline solar PV in an incredibly sunny area such as the Andes at the Equator in ideal conditions. This means that to successfully compete with fossil fuels using renewables, we will need space… lots and lots of space.




I can feel at least a few readers out there waving a finger and asking why I am not getting into solar thermal energy for hot water demands. The answer is simply that I haven't found them to work very well in practice for large-scale, mixed-use buildings, and are more suited to projects for ecologically minded private clients building their own, detached house. The reason is that *a) we generally want hot water on demand*, and *b) we use most of our daily hot water when it isn't sunny.* I don't want to bog down to the ins and outs of why/why not in this chapter, so I have dedicated the details to the Annex on ''Solar Thermal''.

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[5] MacKay, D. J. (2016). Sustainable Energy-without the hot air. Bloomsbury Publishing., pg. 9

[6] Taking into account the diesel fuel used in the vehicles that replace human labour, and the calorific value for a human carrying out heavy work compared to being in a sedentary state.

# Bringing the house down

The Annexes offer more detail as to how some of the easy numbers in the quick calculation tools in this chapter came about, and the case studies show the realities of this for our theoretical tall, mixed-use building. But for a quick idea of the spaces required I'll be presenting a hypothetical house in a temperate climate of the UK, with two adults and two children, which has been retrofitted to become more energy efficient and where the family drive a 100% electric car.

First, there are lights, plus the electrical appliances and 'things' that we plug in and use. We'll draw on information from over a decade of research and consulting, using similar numbers as for the hypothetical Verticapolis case study found later on in the book. Therefore, *note that this is a hypothetical house that draws on information from around the world.* It therefore cannot be cited nor used as a basis for your Anthropocene Design! You will have to get out of your chair and do your research into the energy demands for your particular project.

7.5 kWh per day for electrical appliances and lighting[7].

Now let's make the cooker and oven electric, where again we'll draw on the same numbers as were concluded in ''Verticapolis''.

[7] Efficient, LED lights are assumed.

6.5 kWh per day for cooking food.

Also, we need hot water. For now, let's use the numbers from the Annex titled ''Let's start with water'', which gives us 3.13 kWh per person per day, and we'll round to: 12.5 kWh per day for showering.

Additionally, for houses in the UK there is a big heating demand. We'll make reference to a case study offered by Cambridge Professor David Mackay (''Sustainable Energy Without the Hot Air'') to begin[8], which was a semi-detached, three-bedroom house, built in the 1940s. It was and retrofitted with double glazing on all the windows and doors, cavity wall insulation and additional insulation in the roof. He found that with these interventions the gas consumption for heating his family home was reduced by 67%, giving a total of: 13 kWh per day for heating space[9].

This is of course for the cold, winter months only, but we'll take it as the peak load that would need to be resolved for this Anthropocene Design exercise.

Finally, these last two energy demands for heating water and space are usually satisfied via a condensing gas boiler. In this case, we need to convert everything to an electrical demand, but it would be crazy

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[8] MacKay again, pg. 293 – 296. Whilst his work was first published a while ago (around 2009), let's face it: family homes haven't changed all that much and the main task at hand is to retrofit those that have already been built, instead of knocking them all down and starting anew.

[9] Sort of … in reality we need to take the efficiency of the condensing boiler into consideration as well. This is carried out in further detail in the Annex titled ''Water and space heating: having the capacity and not losing it''. But we'll simplify things and leave them as they are for this bit of the book.

to replace the gas boiler with an electric one and then to satisfy the electricity demands. *Why?* It becomes incredibly inefficient: first you convert solar irradiation into electricity, then you convert electricity into heat. We could look at solar thermal, but as I mentioned before this can have some issues if we are not prepared to live in accordance with the rise and fall of the Sun. So, heat pumps are going to be installed in this hypothetical house for heating water and spaces. They basically give you more 'bang for your buck', as for every kWh of electricity you put into the heat pump, they draw a greater amount of thermal energy from the outside air (if you want to know more about this, have a look at the "Sun Annex"). For now, we'll use the heat pump efficiency given by British Gas of 350%, which means for every kWh of electricity we get 3.5 kWh of thermal energy (heat). Overall, for the 25.5 kWh needed for water and space heating (12.5 kWh and 13 kWh), we will need to supply our heat pump with 7.3 kWh of electricity. Let's round this up to:

7.5 kWh per day for water and space heating

This gives a total of:

21.5 kWh per day for the house.

Now let's add the electric car.

The average car consumption per person per day is 40 kWh[10]. However, we know that electric cars are more efficient than their hydrocarbon-fed counterparts. In some research I published, I reached the conclusion that in the worst-case scenario, a 62% reduction in energy demands from a transition to electric private vehicles was reasonable to assume[11]. So, let's use this here, bringing the energy consumption for the electric car in our hypothetical household to:

40 x (1-0.62) = 15.2 kWh per day, which we can round up to:

15.5 kWh per day

This gives us a total of:

37 kWh per day for the hypothetical household for this chapter.

*Note that this is not correct! Nor should it be quoted by any means for any work*, where it can vary hugely depending on the whereabouts

[10] Thanks again MacKay....

[11] Davis, M.J.M., An Electrifying Change: The Need to Introduce Electric Vehicles in Ecuador, And Its Potential Impact on the Energy Sector, First International Conference on Urban Physics (Quito – Galapagos, 2016, Sept. 26–30). And,
Davis, M. M. (2017). Más allá del petróleo: Una mirada al impacto de los autos eléctricos en las tres principales ciudades del Ecuador. Estoa. Revista de la Facultad de Arquitectura y Urbanismo de la Universidad de Cuenca, 6 (10), 149–156.

of your project and household profile[12], it is merely a hypothetical number that seems reasonable enough to use here as an illustration to demonstrate the types of areas required for renewables to replace fossil fuels.

## How much are we actually talking about (in kWh)?

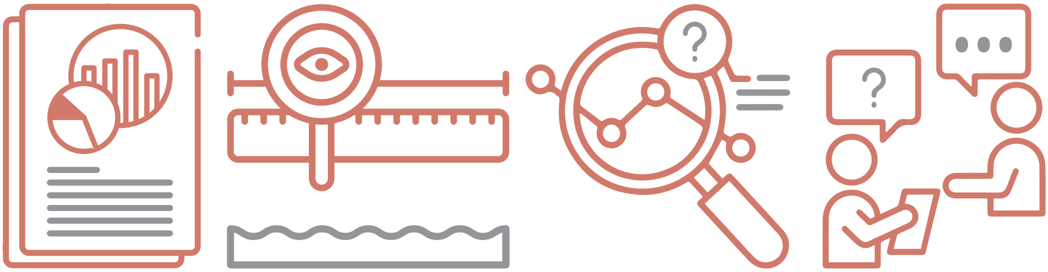
There is an art to Design in the Anthropocene. You determine demands in a baseline unit, you manage these in terms of space, and you do so in a manner that results in beautiful design.

However, it is easy to get it wrong. The output of your design will only be as good as the input of your initial numbers. As such, you run a great risk of getting things wrong, simply because you haven't put enough time and effort into getting the pre-design stage right.

So, how to go about this for energy? The methodology we have found to work well (in research and in consulting) is to determine a baseline demand, see how it might be improved, and then carry on looking at the Anthropocene Design options. The first step is to carry out case studies. If you are designing a residential building, then carry out fieldwork on the energy demands for homes: your home, family members' homes, friends' homes[13]. Office spaces? Then study offices. Commercial spaces? Go to similar projects. Hotels? Carry out fieldwork in hotels. Everything? Divide up the team to cover everything.

[12] Quotes such as *'According to Davis (year this book is published), the hypothetical energy demand for a family home is 36 kWh per day'*, are not allowed. Be warned that one of the student task force groups (see the acknowledgements at the beginning of the book) pointed out that a typical household in parts of Africa could easily have a lower energy demand by an order of magnitude.

[13] Please note, I tell my work colleagues, research staff and students never to go into random strangers' homes.



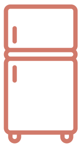
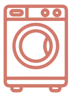
The first stage is observation. What installations can you find in the case studies that need energy? Write it down, find out what the potential in kW is, and make a list of all the items that are present. You now have the list of *potentials* (see the section on the light bulb in the ''Mini Intro'').

Next, you will need to determine the time each item is used. This involves interviewing the end users (or at least people of a similar profile), asking them about their daily routines, what they use and when. For example, you might know how long, on average, a person cooks per day, but will need to determine the level of detail up to how many hobs of the kitchen they use on average when they are cooking.

Finally, once you have carried out the qualitative research described above (observation and interviews) questionnaires can be useful in order to get an idea of the tendencies for the energy demands. Questions such as 'Do you have 1-2 or 3-5 lights in your kitchen?' (and similar for other rooms) can be useful.

Fieldwork research is both necessary and extensive, so I have added a whole ''Annex'' to the book to explain the techniques mentioned above in more detail. You'll see me make reference to these throughout the book, and remind you again (and again, and again) that you need to get out there, speak to people, study and reduce your risk of getting your numbers all muddled and wrong.

After carrying your fieldwork out, you can then draft up the *demands* in kWh in the list. An example of a possible way to organise your case study list is given below:

| Item | Potential (W) | Potential (kW) | Time used (min) | Time used (hr) | Demand = Potential (kW) x Time (hr) (kWh) |
|---|---|---|---|---|---|
|  | | | | | |
|  | | | | | |
|  | | | | | |
|  | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| **Total** | | | | | |

You will then have a list of items, their potentials and the final demands created, giving you a total estimated energy demand for the case study.

However, you will probably need to calibrate your table. This can be done by studying the electricity bills of the case study. You might find that your total is within a few percent of the totals given in the electricity bills, but it is more likely that you will need to adjust and tweak some of the figures until they become reasonably close to the total the bills show in reality. You most likely need to revisit your times. Sometimes we can over- (and under-) estimate the time an item is in use, which will in turn inflate (or reduce) the corresponding energy demand. You might find that you need to iron out some mistakes you made along the way. For example, it can be common to assume a refrigerator works around the clock, when it only really 'runs' for 6 to 8 hours per 24, or that a stove is in use for the hours deduced in the interviews, but where you have to go deeper and find how many cooking rings are used when people are cooking. Once you have your calibrated table of potentials and demands ready, compare it with those of your colleagues. You should have at least a few in order to be able to confidently say you have reached a conclusion suitably robust for your Design in the Anthropocene.

There is the added step of converting fossil fuel demands to their electrical equivalent. You might ask *'What about a gas cooker and condensing boiler?'*. These do use fossil fuels and we need the demands to be electrical in order to satisfy them with renewable energies. In the case of the kitchen it is pretty easy. You know how much time the different cooking hobs and oven are used. You can then replace the cooker and oven with its electrical (highly efficient!) equivalent, and you will get your demand. The really on-the-ball designers out there will now raise their hand to point out that the gas is actually *incredibly efficient*. The condensing boiler is in fact only a few percent short of 100% in its efficiency in drawing the heat from gas combustion[14]. Technically speaking, this is in fact much more efficient than having an electric boiler powered by solar photovoltaic (PV) panels[15].

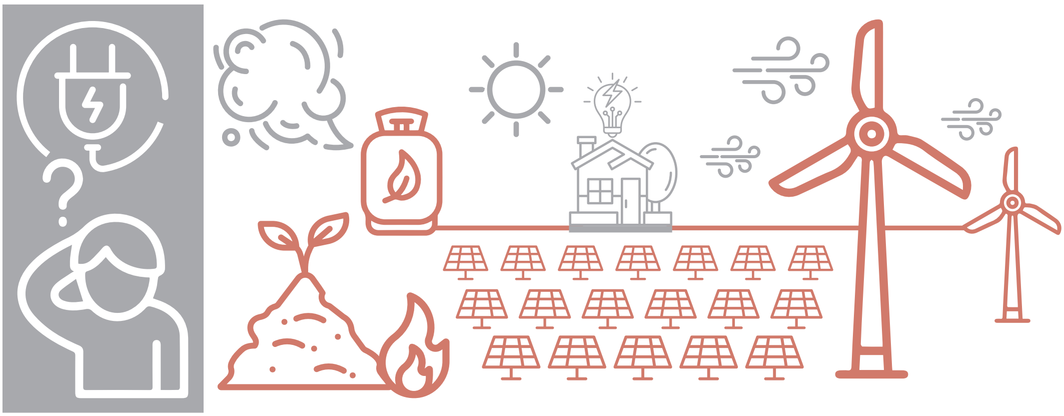
[14] Note the overlap here: a boiler is used to heat water, and you will be carrying out a similar exercise to determine the amount of litres used per person in the ''Water: Refresh yourself'' section of the book when you work on ''How much are we actually talking about (in litres)?''.

[15] And for this reason, in the Case Study Verticapolis building we'll be using heat pumps instead.

However, it is dependent on fossil fuels, and the aim in this book is to convert everything to a form of an energy demand that can be satisfied through solar PV, wind power and biogas[16].

The next step is to think of efficiency. Where can energy be saved? How? What are the biggest wins? For instance, you might assume that eco-friendly end-users will not leave phone chargers plugged in. But, is this really true and does it actually make any real tangible difference? It is far better to have highly efficient refrigerators installed, or a smart meter that says how much more/less electricity you're using 'in your face'[17].

This all having been done, you are ready and can finally say with pride: 'I know how much energy demands there are for the design project I am embarking on!'. Be warned, if you haven't done this, then you probably don't have much idea and your final spaces (which you will see are BIG) might be widely out of proportion with reality.



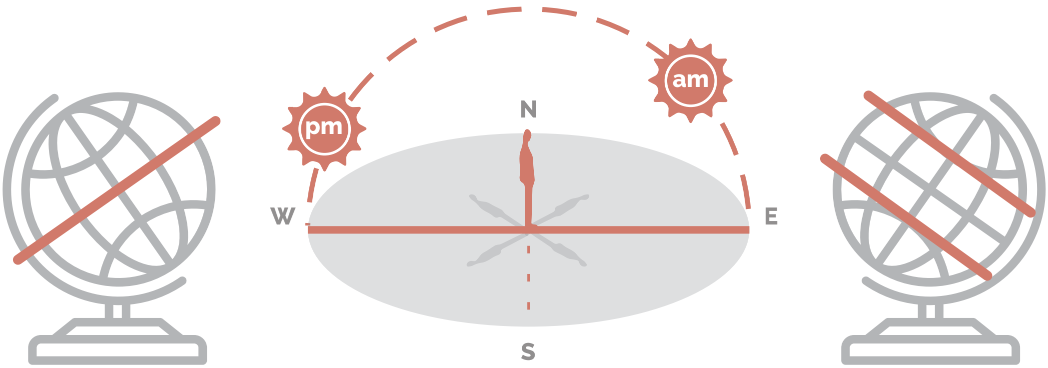
[16] The really on-the-ball renewable-minded readers will (should) at this point say that biogas could be produced that can in turn be used for cooking. This is a possibility, and I have seen it used on some farms.

[17] If you are shown that you are using more energy one week than the previous one, as humans our reaction is to try to reduce our consumption, guaranteed.

# Where to put it all?

## Solar Photovoltaic (PV) Energy

As renewable energies go, the Sun at least can be relied on: it will rise in the morning, shine its peak at the zenith of the day and then settle down to rest in the evening. In a perfect energy setting, there would be no unpredictable cloud cover, and everyone would use electricity in perfect synchronisation with the amount of solar irradiation available.

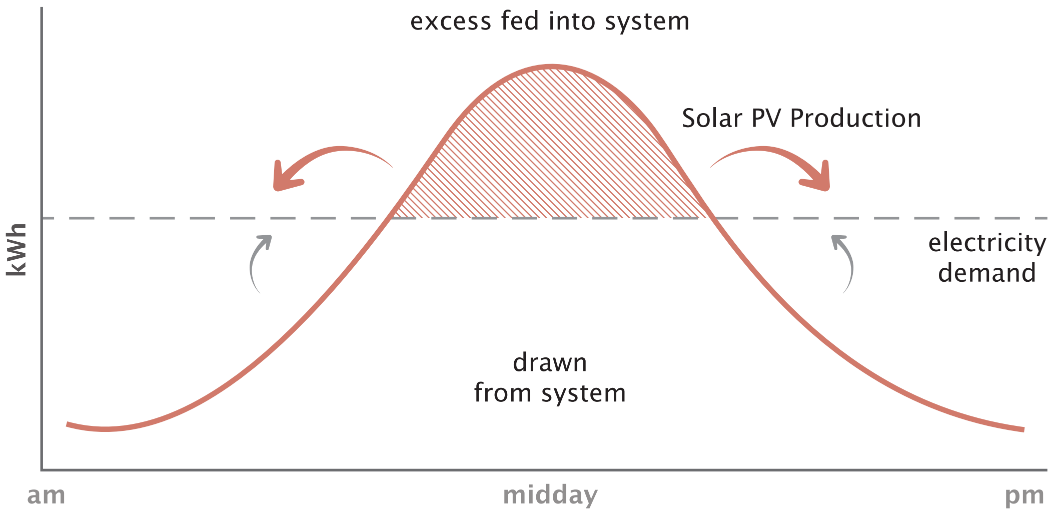



This isn't the case however, which leads us to the bold assumptions we will be making in this section. The first is the existence of an average solar radiation throughout any given day. In the tropics (close to the equatorial line) solar radiation can be pretty constant throughout the year. In the Northern or Southern hemispheres this isn't the case, and it would be better to use the average in the winter months to get an approximate worst-case scenario[18].

The solar radiation simplification means you need to find the average radiation from the Sun in kWh/m²/day. The second assumption for our Design Tool is to say that electricity demands are also an average

[18] Then there is the element of optimal angles etc for your solar panel, which you will need to determine with the solar PV supplier for your project.

on any given day. This is not the case, demands jump, peak, dive and wobble at any given time over any 24-hour period. What these assumptions mean in practice is that we are designing for Net Zero systems. This is to say you assume your Solar Photovoltaic (PV) system exchanges with a backup system, such as batteries or the national grid. When there is little Sun, electricity is drawn from the backup system, and when there is an excess of solar radiation electricity is fed into the system.




We will harness the solar radiation through solar PV panels. These have improved greatly since their first inception in the 19th century and later use in the 1950s by NASA, the USSR and the like to power satellites, spaceships and space stations. They have also greatly decreased in price over the last years at the time of writing this book, where the electricity produced has even begun to compete with some of the pricier fossil fuel powered electricity production (such as petrol and gas). In terms of regular, silicone solar PV panels, these tend to range from around 15% and 20% efficiency[19]. You can find the

[19] 15% for decent, polycrystalline solar PV, around 20% for the pricier monocrystalline panel. Monocrystalline panels are even creeping up to over 20% at the time of writing, with lab research panels hitting nearly a 25% mark. There are also Sun-concentrating technologies that focus the solar irradiation onto a panel surface, increasing the efficiency further still.

efficiency of the panels you are thinking to use on a technical spec sheet (for the purposes of this design tool, there is no need to worry too much about the many other specifications, which are related to laboratory tests, durability, etc.).

Finally, we usually need to convert the electricity produced from Direct Current (DC) to Alternating Current (AC), using an inverter. DC and AC battled it out in Victorian Britain to be the national norm. In the end AC won and has become the standard throughout the world. This is somewhat inconvenient for electricity produced from solar PV, which comes out in DC. There is then all the cabling, connection to the backup system we meant earlier, etc. All of this adds up to a loss in electricity production that has to be taken into account. For this book and the Design Tool the third assumption I am making is that the energy loss is approximately 10%, which means an additional efficiency factor of 90% (0.9). This is based on past experience, but *I strongly suggest you get a more accurate approximation for the specific context and system you are working with for any given project.*

Overall, we get the following Design Tool:

SR x EF x L = Solar PV Electricity Generation

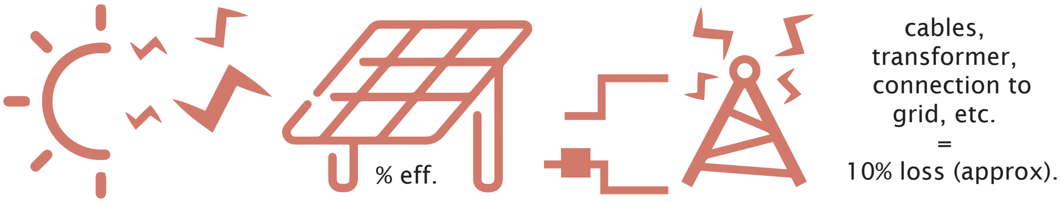
***Where:***

**SR** = average solar irradiation at the project surface ($kWhm^{-2}day^{-1}$).

**EF** = solar PV panel efficiency (%).

**L** = additional factor of losses due to the inverter, cabling, exchange with backup system, etc.

kWh/m$^2$/day x (% eff.) x (% loss) = Solar PV Electricity Generation




In the section on the "Case Study", we'll examine the problem of finding enough roof space on a high-rise, mixed use building. For the purpose of this chapter, we'll refer to the hypothetical detached house described in the mini-introduction, which has an electricity demand of:

37 kWh/day

Optimal solar conditions are found around the Equator, where you are literally closest to the Sun and it rises and falls almost perpendicular throughout the year[20]. In Ecuador, an extensive study was carried out to determine the national solar PV potential, which gave around 5 kWhm$^{-2}$day$^{-1}$ as an annual average in the country's capital (Quito). We mentioned David Mackay's work earlier, where he states that Cambridge, UK, has about 60% of the energy intensity from the Sun compared to the Equator[21] (the angle the Sun shines is less optimal).

This gives us a range for solar irradiation of:

3 (UK) - 5 (Equator) kWh/m$^2$/day

Let's go with 3 kWh/m$^2$/day.

[20] Perpendicular in the Equinoxes (no shadow at midday), a few degrees off in the Solstices.

[21] See Mackay's "Sustainable Energy Without the Hot Air", pg. 38.

Then, let's go with a standard, not too expensive amorphous or multi-crystalline solar panel, with an efficiency of:

| 15% (0.15) |
|---|

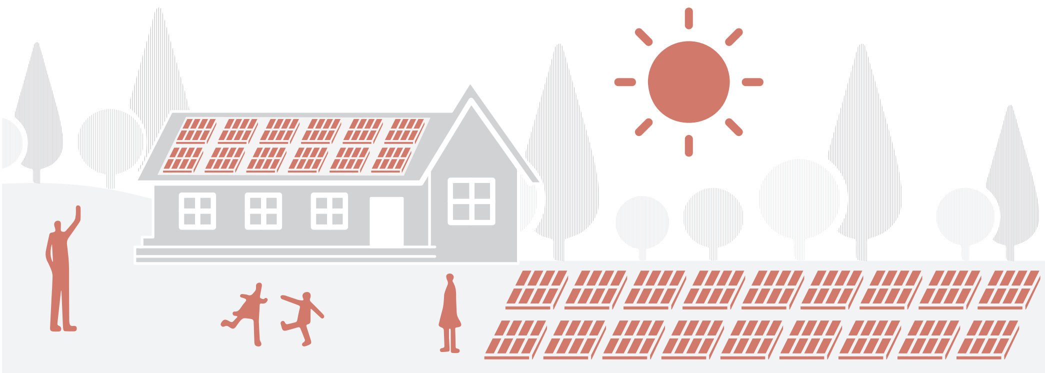
Finally, as mentioned earlier, I'm assuming the losses to be 10%, which translates to an additional factor 0.9:

| 10% (0.9) |
|---|

Plug these numbers in and we find for our detached house with an electric car we need:

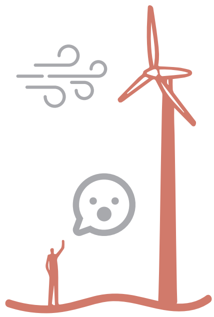
$$37/(3 \times 0.15 \times 0.9) = 91.5 \text{ m}^2 \text{ of solar panels}$$
(91.36 to be exact)

This would fit on the roof space on an optimally oriented roof of the average detached suburban home (these tend to be up to approximately 200 $m^2$ for new homes for space hungry families in Australia and the USA). Or, you have a decent sized garden you are prepared to cover with solar panels. If you get rid of the electric cars, heating water and heating space, the figure goes down to a mere 35 $m^2$. But, this would entail having excellent public transport and an incredibly passive-designed house (or alternatively that you still rely heavily on fossil fuels).

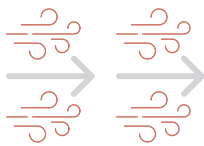


Furthermore, as you can see in the case study, when we move away from large, detached houses and consider Compact Cities, there is little room for solar PV. We therefore need to move to an urban scale, designing solar energy into everyday public infrastructure and space. Bus stops, cycle paths, roads, the roofs of museums and malls: they must all be covered in solar panels.

## Wind power

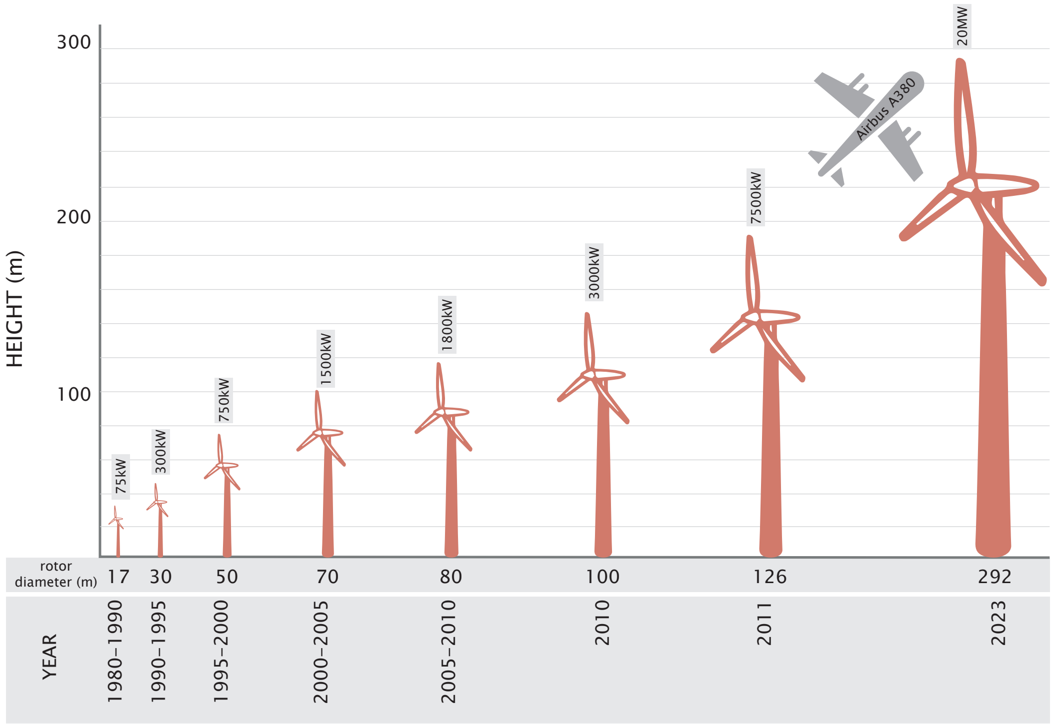


The main takeaway before you read any further: wind power is *big*. We are not talking about a few micro-turbines in the parks or on roofs. Wind power means turbines that dominate the landscape and are bigger than any building in the vicinity. If you're still interested, read on....



Wind can be a funny thing. Sometimes it blows, other times it rests. It lives a hedonistic life, gusting or breezing along as it pleases, with little heed to energy demands, sailing boats or beachgoers. As you get higher up it becomes stronger and more constant. The nearer to ground level you go, the messier and more temperamental it becomes. This is related to a roughness coefficient, which basically says that the wind blows in a stronger, more constant fashion the higher up you go and the further away it is from things that might disturb its flow. This means it is better to have massive turbines bigger than skyscrapers deep out in the sea, than small turbines close to the uneven roofs of buildings in an urban environment.

Wind power is now pretty much a universally accepted source of renewable energy, where wind farms are a profitable enterprise. The rise of the wind turbine has been phenomenal, from being a house-installed concept to having R+D thrown at it similar to that seen in the aeronautics industry (the turbine blades work under the same lines as the wings of an aeroplane). Indeed, today's offshore turbines are far bigger than the biggest aeroplanes in existence.




Actually quantifying how much wind there will be on any given day or night, and matching this up to the expected energy demands that will need to be met, is a phenomenal task. Much research is carried out in this field, big consulting projects paid for and many PhDs slaved over. We aren't able to do this here, and so will be making some audacious leaps and bounds of faith in simplifying matters down to a few basic design tools.

These tools are not correct, there is no differential or integral equations to be solved that is so very common in wind power sizing. However, the tools are close enough in my opinion as to nevertheless be useful. So here we go:

$0.00471\ \rho\ v^3\ d^2\ CF$ = Wind Power Electricity Generation

***Where:***

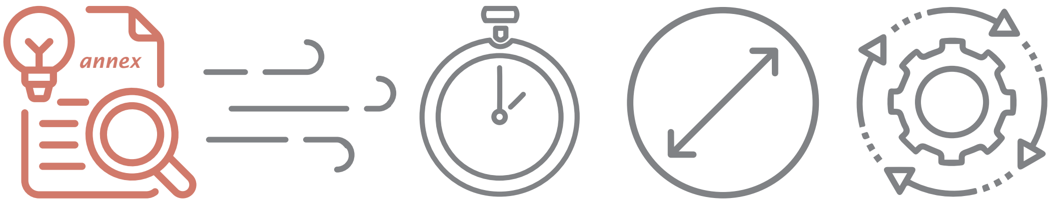
$\rho$ = the density of air at the place you are designing.

**v** = average air velocity at the height of the turbine blades.

**d** = the diameter of the circle drawn by the turbine blades.

**CF** = the capacity factor for the wind turbine(s).

*Where did 0.00471 come from?* Have a look at the technical explanation in the Annexes on ‘‘wind power’’ to know more. What I’d like to highlight here are the other elements.




First, note that $\rho$ does vary from around 1.2 $kg/m^3$ at sea level to 0.85 $kg/m^3$ in the Andes. As you can guess, there is a knock-on effect of multiplying something by a number that is greater than or less than 1 (greater than 1 gets bigger, less than 1 gets smaller).

Second, there is the air velocity. Whilst it is true that wind can rock from high to low, the fact that it is to the power of ‘3’ shows why wind power has such a good rate of return for wind farm investors. We have a steep exponential growth curve here[22]: any increase in velocity leads to a great increase in performance (eg. $2^3 = 8$ m per second vs. $6^3 = 216$ m per second)[23]. You can get average wind

[22] A slope on a graph that curves up, instead of climbing in a straight line. Think of the height you would gain over distance climbing a mountain that curves up, compared to one that slopes up in a straight line.

[23] And you can forget about average air speeds that are less than one (eg. $0.9^3 = 0.73\ m^{s-1}$…. it gets less and less).

speeds from local weather data (although remember to look at what height the measurements were taken!).

Third, we have the diameter of the turbine blades[24]. The fact that we are talking about the diameter raised to the power of '2' (the diameter squared if you like), is similar to the exponential effect we mentioned earlier. Although not quite as steep as for air velocity, the difference here is we can control the diameter our wind turbine has (unlike the rocky air velocity). You might guess that this is a big factor behind the massification of wind turbines and the giants being installed in today's age: the bigger the better.

Finally, let's talk about the capacity factor. The fact that the wind speed varies greatly over any 24-hour period has to be taken into account in some way or another. Moreover, a wind turbine will usually stop rotating if the wind is too low (below 3-5 m/s: not worth the effort) and in gales (above 25 m/s to stop the turbines being blown off). The common way to do this is through a capacity factor, which in layperson's terms means within a 24-hour period, how much of the time are the wind conditions optimal for electricity production? The capacity factor varies from up to 30% in the UK, to around 22% in the Netherlands and between 25% and 30% in the Ecuadorian Andes.

As I mentioned above, wind power is big, very big. In the section on the ''Case Study'' we'll see how big exactly for a high-rise building. For now, let us consider the detached house from the Mini-Intro that needs 37 kWh per day. We'll assume we are in an open space on the outskirts of Greater London, UK, where the air density is 1.2 kg/m$^3$, plus that we can estimate 4 m/s average wind speed and a capacity factor of 30%[25]. Plug this all into our Design Tool and we get:

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[24] This refers to the diameter of the circle drawn by the blades as they swish round in rotation through the air.

[25] Again, Mackay (pg. 266-267).

$$0.11d^2 = 37\ kWh/m^2/day$$

$$d = \sqrt{(37/0.11)}$$

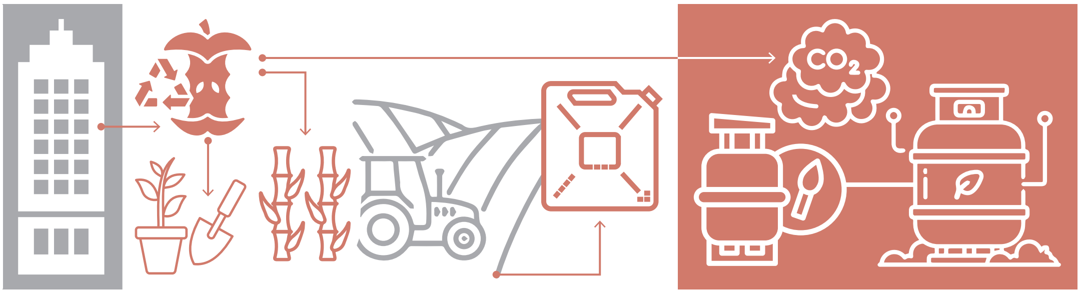
$$d = 18.5\ m^2\ (18.34\ \text{to be exact})$$

Which is a pretty big wind turbine in comparison to a house … and … remember that it will also need to be much higher than the roof to have optimal wind conditions!

## Biogas

There are many biotechs out there: biogas, bioethanol, algae...to name but a few. We will focus on biogas here for a few reasons. It is one of the options for renewables that fits into the concept of the circular economy quite nicely: organic waste from the cities can be transformed into a gas that is turned into heat and electricity in a manner similar to biogas' close cousin, natural gas (a fossil fuel). Additionally, bioethanol is an option that is gaining popularity in the automotive sector and has had a particular push in Brazil (using sugar cane). My main problem, however, is that arable land becomes dedicated to fuel crops instead of producing food. Other fuel sources such as algae are certainly interesting, but I won't even pretend to know enough about them that I can write a book on the matter. So, we are sticking to biogas for now.

For the critical thinkers out there, someone is likely to raise their hand to say something along the lines of *'But burning biogas gives off $CO_2$!'*. You are indeed correct. However, in the sustainability lingo it is considered a closed cycle: the $CO_2$ absorbed by the plant in its growth compensates for the $CO_2$ that is emitted at the energy stage. In addition, it is far more preferable to emit in this case $CO_2$ that has previously been absorbed, than to send the organic waste to landfill. Once in a landfill site the organic waste undergoes anaerobic digestion[26], where it will emit methane, which is a Greenhouse Gas that is over 30 times more effective at global warming than $CO_2$. Finally, biogas brings us into the field of a circular economy (the chapter on ''Soil: Waste not, Want not...'' goes into this in greater detail).




So, debate aside, for this section we give biogas a brief consideration. Additionally, we'll be looking at this from the point of view of burning the gas to create electricity. It is true that the gas can be burnt to produce heat to warm things such as households. But as we said in the ''Mini-Intro'', the assumption is made in this book that in the near future everything will be electric, and so be it.

I was part of a team that wrote an article on potential urban biogas production[27], where we got to the following:

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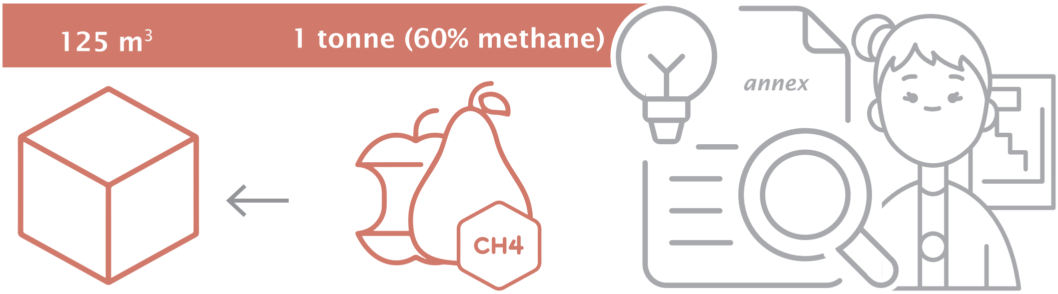
[26] Decomposes in the absence of oxygen.

[27] See the article: Davis, M. J. M., Polit, D. J., & Lamour, M. (2016). Social Urban Metabolism Strategies (SUMS) for Cities. Procedia Environmental Sciences, 34, 309-327.

Electricity produced from biogas = 225 kWh per tonne[28] of organic waste.

It is assumed here that 125 $m^3$ of biogas is obtained per tonne of organic waste, with a 60% methane content that has a specific heat of 10 kWh/$m^3$, which is converted in a generator to electricity at a 30% efficiency.




The Annex titled "Biogas: how did we get to 225 kWh per tonne?" gives some more background to all this if you are interested in knowing the nuts and bolts behind the 225 kWh per tonne figure.

So, where does this take us in terms of our household we have used so far in the solar PV and wind power section? I'll be using the waste produced per household in Quito, Ecuador, as an example here. I'm doing this for two reasons. First, Quito is the city where the collaborators for this book and I have the most accumulated data from many years of consulting and research. Second, it will hopefully encourage you to research into the specific area where your project is taking place, and not just to copy and quote the figures given in this book. You need to get away from your desk and carry out fieldwork studies in order to really know the quantities you are designing for! In the case of Quito, over the years of research and consulting we found a 4-person household would produce 1.28 kg per day. Note: *this figure is not generic in nature*. The quantity differs depending

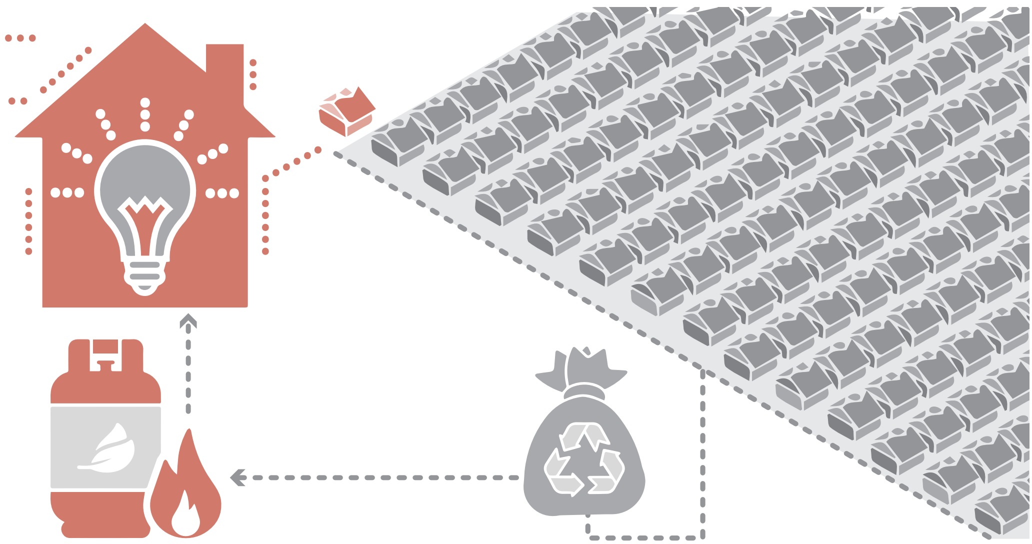
[28] 1000 kg

on the local context, where people in New York produce different amounts of organic kitchen waste than those in Christchurch, Dubai, etc..

Put that in the equation above (225 kWh per tonne of organic waste) and you get 0.288 kWh per day from biogas. And we need 37 kWh per day.... oh dear.

In short, the household would need to ask 128.5 other, additional households to donate their organic waste in order to produce enough electricity, or the household in question would need to be a farmhouse with organic waste to use from crops, cows and pigs[29].

So, we can quickly see that a household cannot be self-sufficient by creating biogas from its own organic waste: we need more, much more. We would also need a biogas plant to get the electricity needed. In the ''Case Study'' we'll look at a high-rise building, where the suggestion is put forward to import waste, for example from city parks, agricultural areas (preferably urban) and the like.



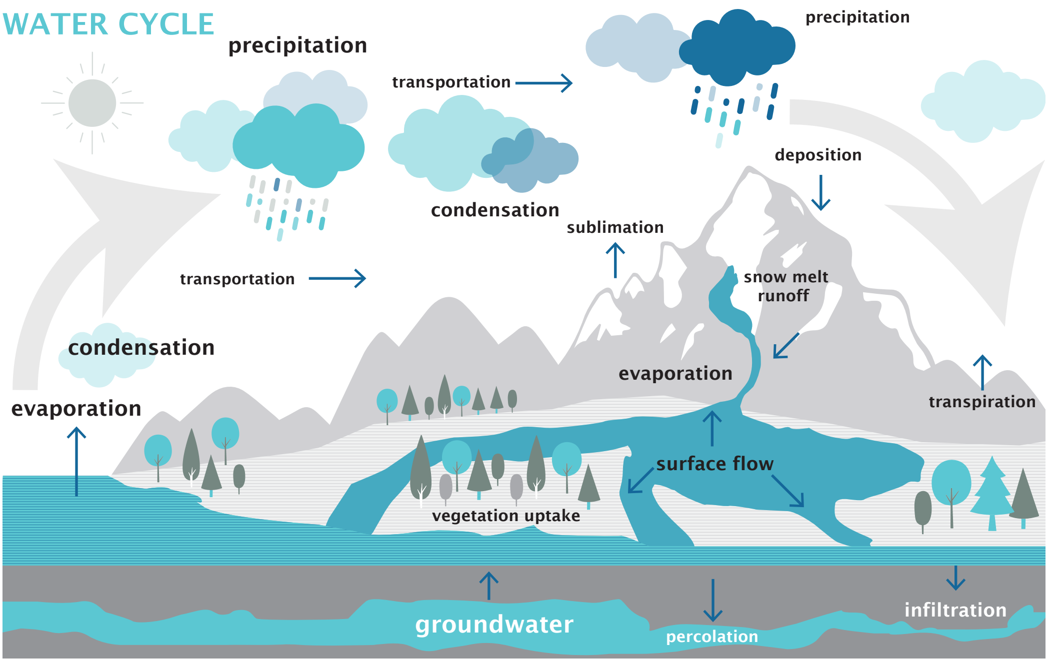
[29] In fact, the dung from a few cows and pigs per house is enough to self-supply energy needs. But then cows produce methane, and it is difficult to keep herds of cows and pigs in a high-rise building.

# WATER: REFRESH YOURSELF

## Mini Intro

We all know about the water cycle; it is taught to us generally in secondary school and comes with a pretty standard picture. Clouds form, they condense, it rains, the rainfall is absorbed into the ground to go to underground aquifers or taken up by vegetation that evaporates it back into the atmosphere as part of the photosynthesis process. Excess runoff flows into rivers, which make their way towards the ocean. Evaporated water or vapour through evapotranspiration[1] is released back into the air, where high up it condenses back into clouds, and so we start the cycle again.

WATER CYCLE




[1] Think of the water vapour coming off vegetation or from saturated soil around the vegetation.

In the urban environment everything changes. The cycle is more of a linear process, where we take clean water, pollute it in various ways, and then discharge it back into the environment in different manners. True, in some cities huge effort is made and expenditure of public funds given out to have drinking water of the highest quality come out of household taps, and wastewater treated in large, expensive industrial plants to have clean water then discharged back into the environment. However, for the majority this is not the case. At the time of writing, the UN estimates that nearly 30% of the world's population lack access to drinking water, whilst over 50% do not have safely managed water sanitation[2].

Let's consider the first step in the water cycle, rain, within the context of an urban enviroment

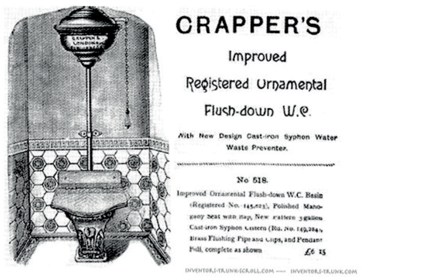
Rain is a funny thing in the city, where we are not really sure what to do with it. Precipitation percolates into concrete and asphalt no more than it would into a rock, and flows in a torrent to the drains dotted around the city to mix with faeces and collapse the sewerage infrastructure. At times of peak rainfall, rainwater mixed with sewage is usually discharged straight into the nearest river. The traditional way to confront this is through a continuous expansion of infrastructure works that are made bigger and bigger: the greater the

[2] UN-Water SDG6 Data Portal: https://www.sdg6data.org/.

urban expansion, the greater the rainwater runoff that is produced and the more massive the respective water infrastructures that are needed.

Take the toilet for example. If I challenged you to design a system that could pollute the greatest amount of clean water, to the greatest extent, in the shortest amount of time; it would be hard to top the design of a toilet. Necessary in the 19th century to stop the spread of disease in increasingly urbanised environments, nowadays the toilets in use are pretty much the same as their 100-year-old counterparts.

Late 19th century




Recovered from the article: La evolución de los baños: Lecciones históricas para aspirar a un futuro con espacios seguros e inclusivos, by Joel Sanders (2020), in Arch Daily

Late 20th / early 21st century

FV catalog, Ecuador, 2024

So, at present we take clean water, pollute it and discharge it. As Anthropocene Designers, how can we do better?

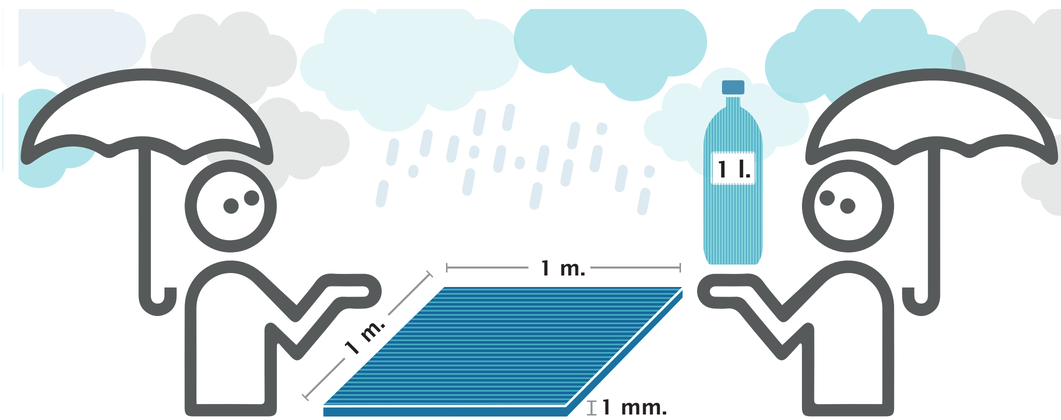
The answer is simply to determine the quantities of water that we need to manage, use the water in a more intelligent manner, and to make the human consumption of water an integral part of the water cycle found in nature.

# It’s raining it’s pouring

It is all very well talking about the importance of determining quantities, but how can we go about handling rain? In Anthropocene Design there are two options really: a) design to absorb, or b) design to harness for further use. Rainfall is generally talked about in millimetres of precipitation, and we will now look at how to translate this into litres of harvesting or absorption.

In terms of quantifying, imagine that you are stuck out in the rain for some reason, looking at the black sky, huddled under an umbrella and wondering when it will stop pouring down around you. Then your eye catches a most strange thing on the ground: a square 1 metre by 1 metre, with a tiny, 1-millimetre ridge. As you look at it you notice how it slowly fills up with rainwater until the 1 $m^2$ by 1 mm becomes full.

In a flash of inspiration, you realise a profound truth:




‘1 mm of rainfall has fallen in 1 $m^2$, which is equal to 1 litre of water collected.’

As you bask in this new-found knowledge, you now see how the structure on the floor has extended by a metre, being 2 m by 1 m by 1 mm. You watch as it slowly fills up with rainwater, and think:

'There are now 2 litres of water'

Finally, the structure morphs into a rectangle that is 2 m by 3 m by 5 mm height. It fills up with rainwater. And....

'30 litres of precipitation have been collected!'

And you get the gist[3].

This is all of course a brazen simplification. Rainfall does not pour in a constant, litre per litre manner, but more begins drizzling, rains heavily and dissipates in a graceful curve. However, our methodology in understanding precipitation is close enough to the truth as to be handy, providing us with a useful tool for Design in the Anthropocene.

The surface in our thought exercise would be the areas you are seeking to use to collect rainwater. However, there is another element we need to take into account before we run off to size our rainwater collection tank: the runoff coefficient. Imagine for example that you have a pretty standard, dual-pitch (truss) roof in your project, but one side is a green roof and the other is tiled. You have two separate gutterings and downpipes, one for each side of the roof. Now, if you specifically wanted to collect as much rainwater as possible, under which side and respective downpipe would you place a rainwater collection tank[4]?

Some roofing materials absorb more rainwater than others, and

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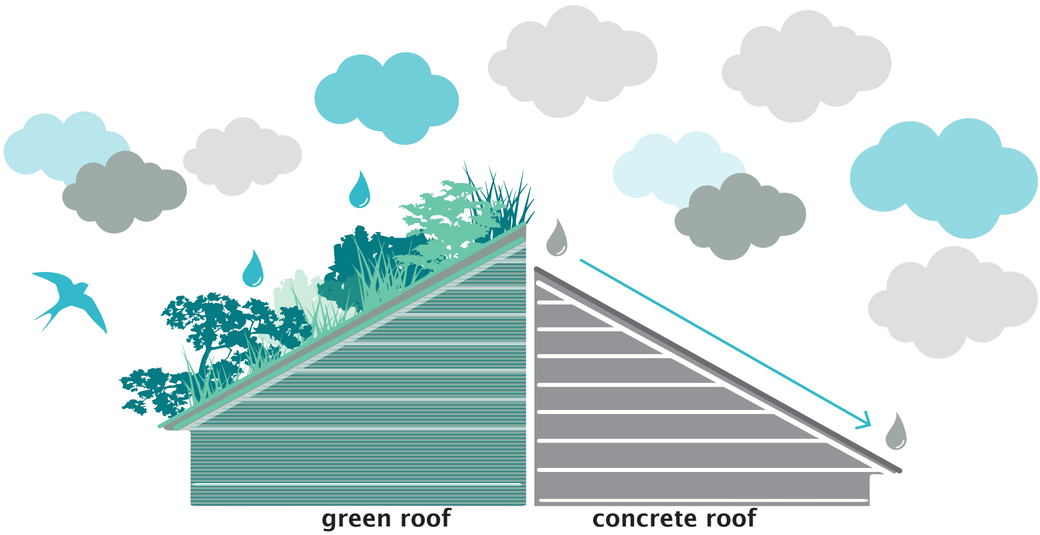
[3] How about this: 2.5 m by 9.2 m and 7 mm of rainfall (answer in the ''$H_2O$ Annex'' if you want to check).

[4] Underneath the downpipe of the tiled roof: more rainwater flows off the tiles into the tank than the green roof, which absorbs most of the rainwater into its substrate.




this is represented by a runoff coefficient. There is an awful lot of research being carried out into *runoff coefficients*; they depend on the material type, the intensity and duration of precipitation etc. Once again though, we are going to simplify things for our design tools and be satisfied if we are close enough to the truth.

A perfectly smooth material that has become completely saturated will have a runoff coefficient of circa 100%. This means that any further rainfall that lands on the surface will become runoff. At the other extreme would be a bottomless hole in the ground. In this case all rainfall that lands on the hole's surface falls inside (in effect, is absorbed), and so the runoff coefficient is 0%. The runoff coefficients are usually between these two extremes[5], and will either be expressed as a percentage or as a decimal number (e.g. 70% or 0.7). A quick search on the internet will usually quickly knock up a reliable table or two of runoff coefficients, otherwise I have put one that can be used in the ''$H_2O$ Annex''. In all therefore, our Design Tool becomes:

[5] Although hard surfaces such as concrete, roofing asphalt and tiles are often given a coefficient of 1 or 100% as a rule for simplicity.

Rainwater collection (litres) = mm of rainfall x $m^2$ collection surfaces[6] x runoff coefficients of those surfaces.

So, there we have it, with a simple excel sheet you can put in the $m^2$ of your surfaces that collect rainfall, their respective runoff coefficients, and 'hey presto!' for any given mm of precipitation, you can easily calculate the rainwater collection. The question remains then: where can I get the rainfall data in mm?

Luckily this is usually readily available from weather data and nearby meteorological stations, which will give the rainfall in mm for any given month. This brings us on to the final element of the Anthropocene Design Tool, which as you will see is useful in making decisions around our water management systems later on. Rainfall data usually comes in a number of forms. If we are in temperate climates there are usually wet and dry seasons, with a graph that much resembles a couple of hilltops. This will mean there are periods of greater/lesser collection, and we seek to reach equilibrium overall. Let's look at this in a bit more detail, using a typical graph from a typical temperate climate[7].

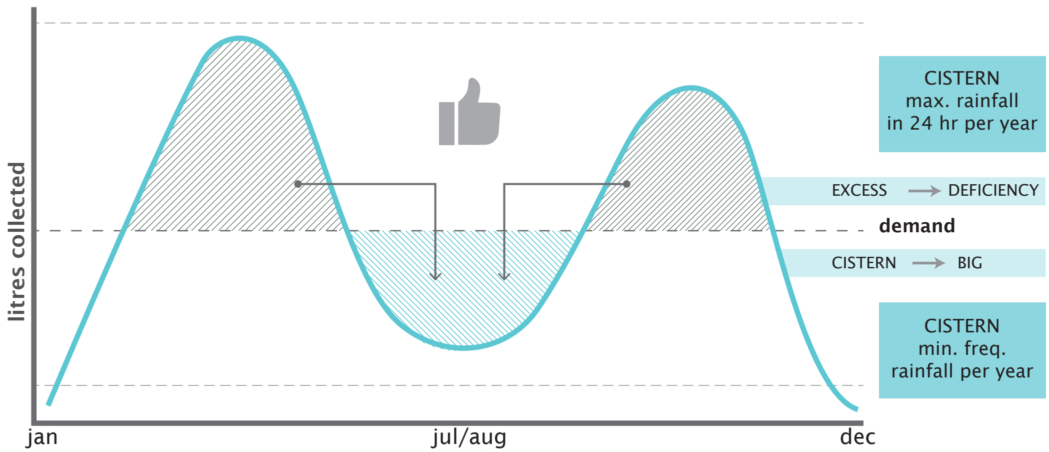
The graph gives the average mm of rainfall for any given month (the importance being that it is an average over the years, and not for a particular year), whereby using the methodology described above the mm can easily be converted into litres collected. We can then plot our water demand for any given month as a line on the same graph. This is an iterative process that goes hand in hand with the next

[6] If for whatever reason you have very inclined roofs take the $m^2$ from a bird's eye view (what the falling rain 'sees' if you like) instead of the actual $m^2$ of the inclined roof. This avoids over estimations of the collection abilities of your design.

[7] The methodology is the same as would be used for the tropics or arid regions.

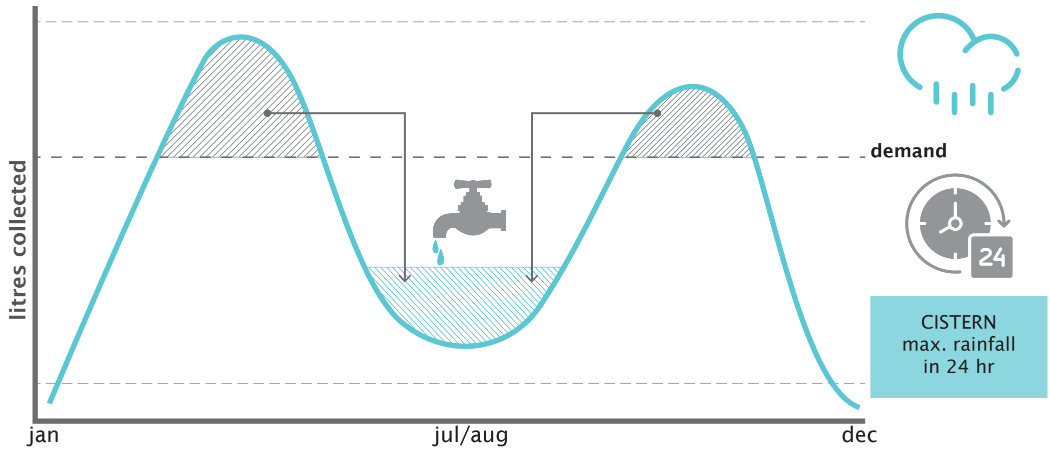
section on quantifying water demands. It is also a process of trial and error in terms of the amount of green vs. hard surfaces that you have (to decrease or increase your rainwater collection). But this is essentially all part of the game, and the graphic tool presented here can help in making those design decisions that you have to face.

The perfect solution would be scenario a) where the demand is equivalent to the annual average of the rainwater collection and excess over the rainy seasons is equal to the deficiency in the drier seasons. This demand could be the project's potable water needs, or water required for flushing toilets, indoor vegetation irrigation, etc. The situation here is that you have the potential in your design to satisfy the demand 100% from rainwater collection. However, the capacity in $m^3$ to store the excess rainfall for drier days can easily become BIG, and so we often incorporate it into landscaping as a water collection reservoir, or have huge underground storage tanks with chlorine, ozone or similar to prevent the water from becoming stagnant.

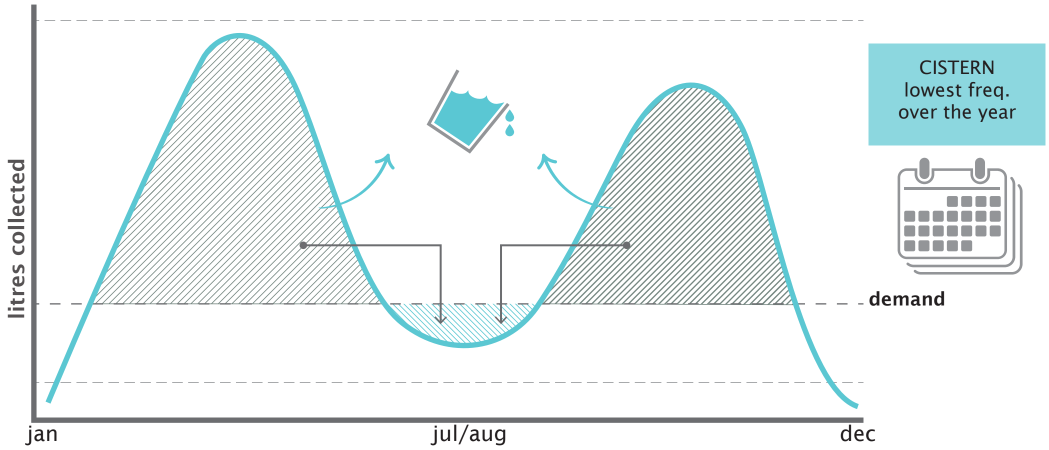



The common scenario is b) where the water demands exceed the rainwater collection in any given month. In this case, the first question to ask is 'Is there any way I can reduce the demand and/or increase the rainwater collection?'. Water recycling, water-efficient installations, and increasing hard surface areas, might all be possibilities here.

Nevertheless, if everything has been tried and no matter what, the water demand exceeds the rainwater collection, then we know that: i) we are talking about an annual water savings percentage, and ii) no matter how much it rains on any particular day, it will get used up over the month. In this case therefore, the water storage cistern will need to be big enough to at least be able to store the *maximum precipitation of 24 hours*. This information is also usually readily available from the meteorological weather data, where it is important to: i) get the average over at least 10 years if possible, and ii) take the maximum mm in 24 hours that occurred in the year.




The final scenario is c), where the water demand is always below the rainwater collection. This can crop up when designing museums, cemeteries, and libraries for example. In this case, the rainwater collection exceeds the water demand every month. The first step here is the inverse of scenario 'b)', where we first ask ourselves 'Is there any way I can bring the demand and rainwater collection more in balance with one another?'. For instance, try to drastically reduce the surface runoff through increasing the amount of green surface area. Again, we can bring this as close as possible to what is feasible in our project, but if the scenario of runoff exceeding water demand persists, then we know that i) every month our water demand will be satisfied by the rainwater collected, ii) we only need to collect and treat the rainwater needed[8]. We know that even if it only rains a little over the month, we shall still gain enough water to meet our needs. As such the rainwater cistern needs to be sized so that it is big enough to store the amount of water needed for the *lowest rainfall frequency over the year*. For example, say July is the driest month of the year and that the frequency of precipitation is once average every 7 days. We know that over the month we will have enough rainwater collection to satisfy our water demands, but that from one rainfall we will need to store 7 days' worth of water demand in order to have enough until the next precipitation occurs.

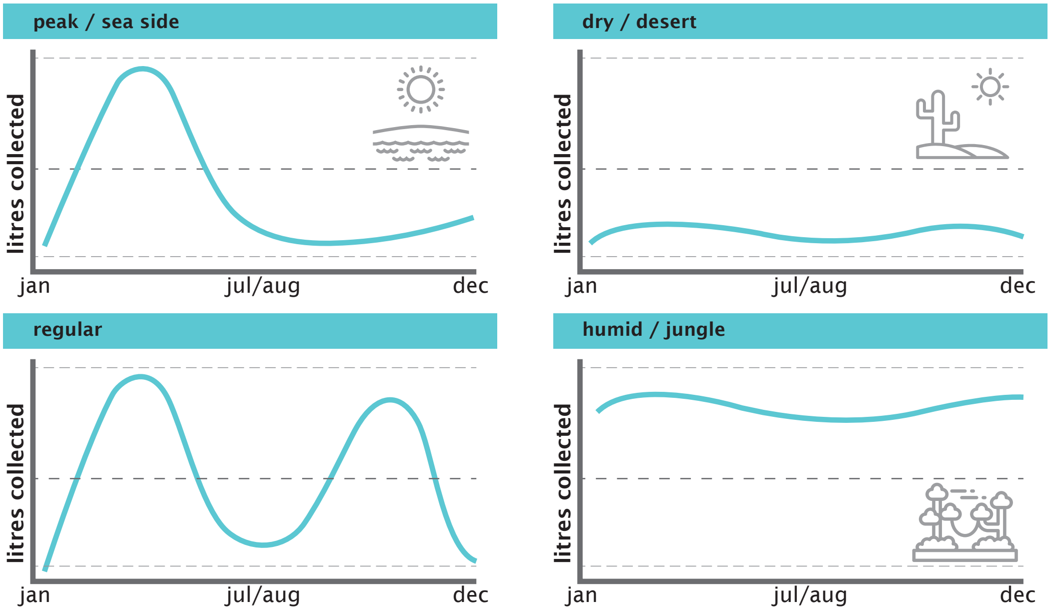



Overall then, we have 3 different lines types that help make decisions as to where, with what and how to use our rainfall. The graph also gives us an indication of how big a water tank/cistern we need to incorporate into our design.

If however you find yourself in the tropics or amazonian regions, there is often a very constant rainfall over the year. Lucky you, it makes life easier. And then there are the arid, drier areas of the world (which are increasing due to climate change!). These usually

[8] The rest will have to be managed, using Sustainable Urban Drainage Systems (SUDS), which we won't go into too much detail here because there are only so many pages a book can comfortably hold. But basically, think of increasing low runoff coefficient and high absorption surfaces, possibly coupled with temporary runoff water storage infrastructure.

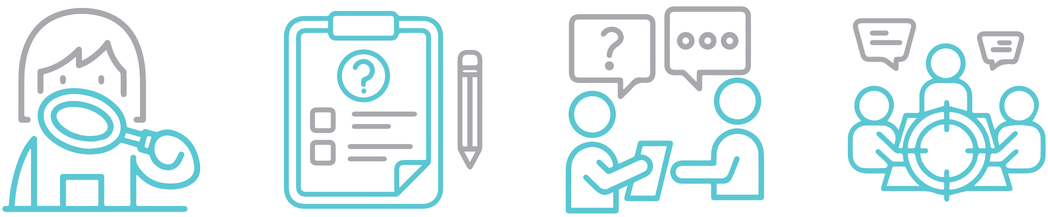
involve vast collection areas and little water usage if you want to incorporate any rainwater collection strategy.




## How much are we actually talking about (in litres)?

The tools described above are only useful insofar as you really have some sort of accurate idea of how much water is needed for any particular activity. For example, the water demands are not the same for showers in London vs. New Delhi, or Johannesburg vs. New York. Nor are they the same for a gym vs. an office (with showers), or a swimming pool vs. a household, nor a coastal region vs. cold climates. So, forget about sitting comfortably behind a computer screen, doing a bit of background research and coming up with any sort of answer that can be considered even remotely accurate. There is also the element of risk to think of here. You are proposing a dramatically innovative method in your Design, that someone will have to take the responsibility for (you yourself or the water engineering team). If you haven't quantified your demands properly, there is a high probability that the design won't work. You'll get blamed, fined, ridiculed and the project inhabitants will bypass your design for a direct connection to the water mains and sewerage systems.

So, how can you confidently quantify your water demands? The answer is by getting out of your chair, ditching the computer screen and doing fieldwork research. Go and find case studies that are in the same area, or are at least representative of your project (people, place), and find out what the *litres per person per day* are. We use this unit as it is easy to adapt later to your particular project[9]. Typical fieldwork research techniques are:



**Observation:** take the time to observe what is going on and write the results in a log (people present over time, number of times a water installation is used per person…). This technique is good for getting a general idea of the water usage for your design.

**Questionnaires:** these can be carried out in person or by using one of the many online tools available nowadays. The data is collected and analysed to find out quantitative tendencies, percentages, amounts, etc.

**Interviews:** prepare a list of questions that incite the interviewee to give in-depth answers, which explore their opinions and views regarding their personal water usage. If questionnaires are useful to determine *what* water usage exists (tendencies, data), interviews are handy for finding out *why* the water is used in such a manner.

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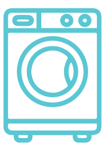
[9] Multiply it by the capacity your project is designed for.

**Focus groups:** these are especially handy for getting an idea of general opinions, and to create new ideas surrounding a particular theme. For example, people may be reluctant to shower in recycled water, but this is made easier if there is a slight chlorine odour to indicate that it has been thoroughly treated[10].

These techniques are important, and are covered in much greater detail in an Annex that has been specially dedicated to them, titled ''Research Techniques''. From past experience I strongly recommend using a mix of the techniques described above, using a questionnaire (quantitative data, the *what*) mixed with one or two of the other techniques (qualitative data, the *why*) to get a complete picture of water usages.

You can carry this out through case studies much in the same way that was explained in the previous chapter on energy, using the results of the research to set up a table along the lines of the ones below and over the page.

| Item | Potential (ltr/use) | Frequency (uses) | Demand = Potential (ltr/use) x Frequency |
|---|---|---|---|
|  | | | |
|  | | | |
| | | | |
| | | | |
| Total | | | |

[10] This is a random example, not to be quoted as evidence to be used in practice and to skip the focus group.

| Item | Potential (ltr/min) | Time used (min) | Frequency (uses) | Demand = Potential (ltr/min) x Time (min) x Frequency |
|---|---|---|---|---|
|  | | | | |
|  | | | | |
|  | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| Total | | | | |

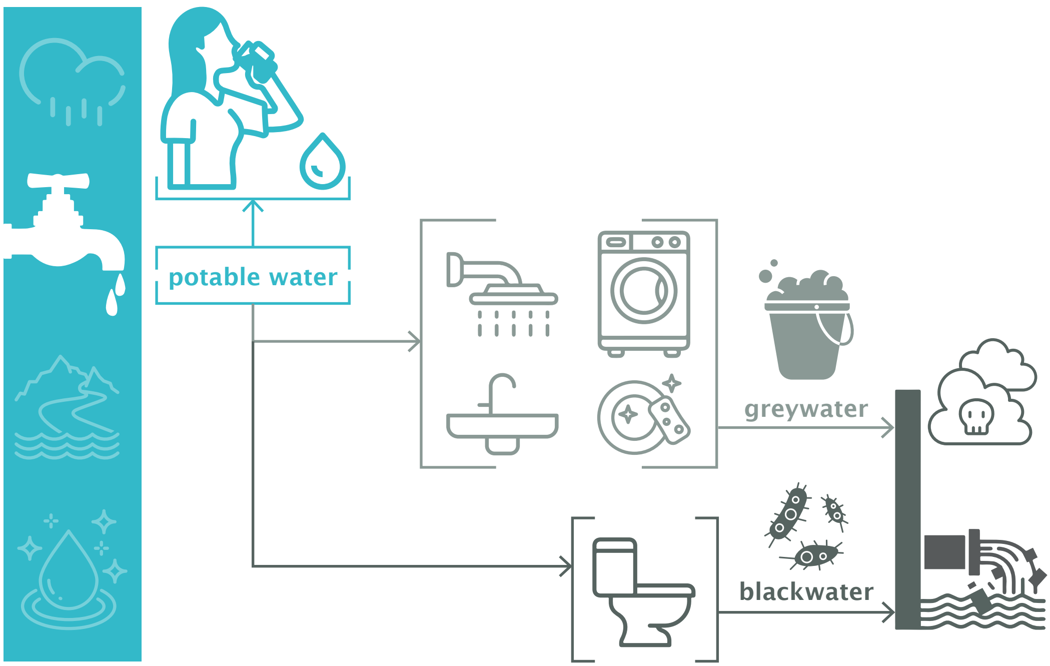
The litre per minute that flows from the installation can be measured in the case studies by using a vessel and stopwatch, or through market research using the technical specifications of the products you are looking to install in your final design.

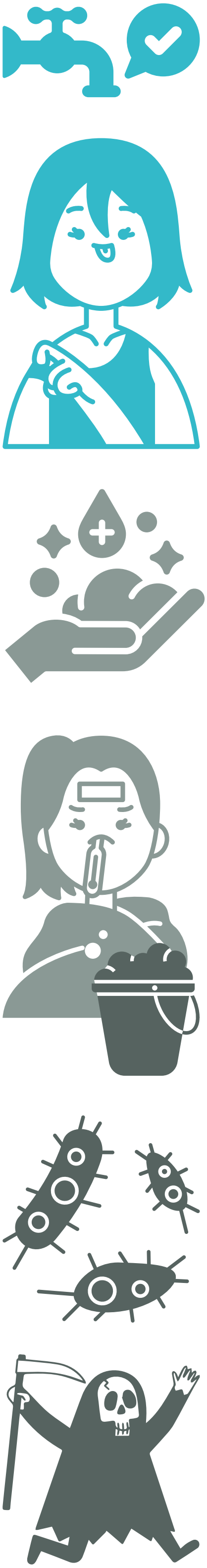
You can check the totals you are getting for litre/person/day by looking at the water bills for the different case studies: they will give you an idea of the total monthly demands. You can then check the total of the different demands for different uses in comparison to the water bills. Note that the water bill totals cannot replace the fieldwork research and quantifying each and every demand: you will need these for your flow diagram and final design.

# Go with the flow

In the ''Mini-Intro'' we mentioned the idiocy of using potable water to flush the toilet, and how in general we get fresh water, pollute it and then discharge it to the environment. As an Anthropocene Designer you would be right to ask 'Surely it is possible to improve this system?', and you would be right. There are many ways in which we can manage our water usage better, releasing it back into the environment in optimal conditions for its reincorporation into Mother Nature.

First, we need to understand the different qualities of water and the level of contamination, which can be done by considering a water cascade. The one presented below is for household water, but we could just as easily do the same exercise for different project types.





At the top end we have potable water, which can be safely ingested by human beings without risk of becoming ill. I also like to refer to this level as ‘dead water’, as by filtration and purification processes every possible living entity (bugs, parasites, bacteria) has been wiped out (through polishing techniques such as the addition of chlorine, UV screening, ozone, etc.).

If we move further down the scale, we reach the greywater sections. I think of greywater as water we could drink, would taste pretty nasty but wouldn’t kill us. Let’s take the shower as an example. Here, potable water is needed (in case it is ingested by the person having a shower), which then gets mixed mainly with hygiene products (such as soap, shampoo, etc) or organic, tiny things (hairs, flakes of skin, etc.)[11]. The same is true for the washbasin, with the addition of toothpaste and oral hygiene products in general. The laundry machine uses more aggressive detergents than soap, shampoo or toothpaste are[12]. Finally, the kitchen sink is where the most contaminants are found mixed in with the clean water (detergent, food particles, fat, oils, etc). Even so, whilst the water would taste pretty bad if we were to drink it out from the siphon below the sink, whilst it might give us a stomach upset, it would unlikely be lethal.

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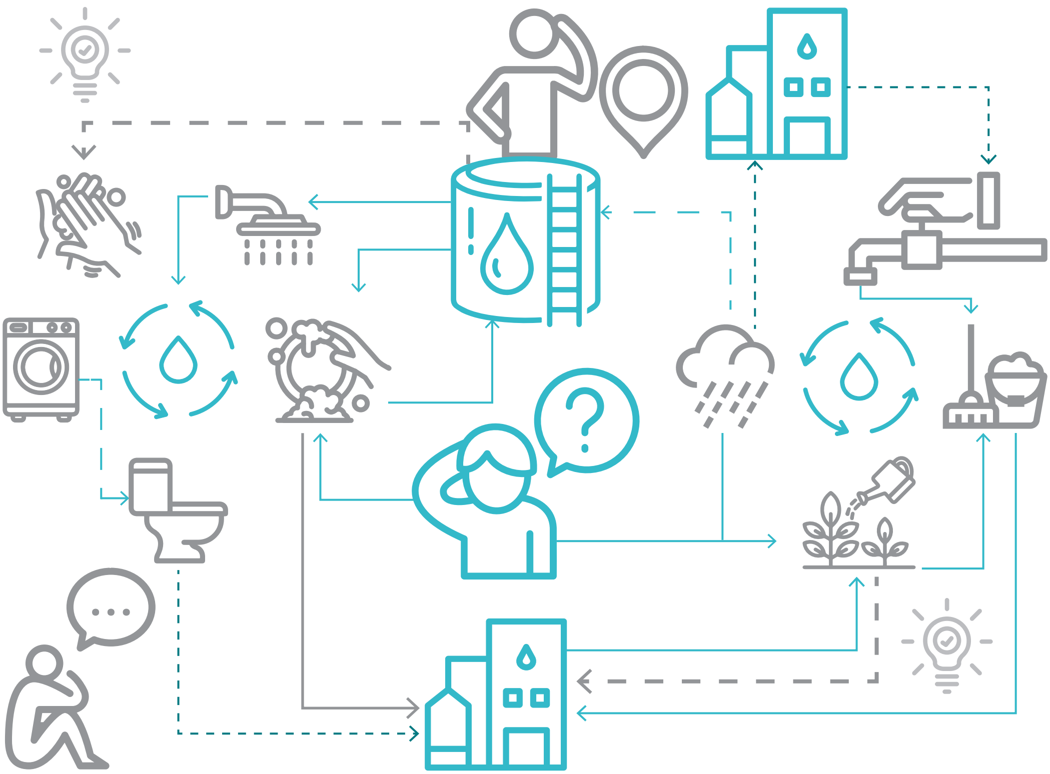
[11] Depending on your activities in the shower.

[12] And might even have the occasional set of nappies or soiled clothes washed. However, note for the next section: there is no real vector between human consumption and the laundry machine (ever attempted sticking your thirsty head to drink from the laundry during the wash cycle?), and so only clean water is needed for the input (not potable, or dead, water).

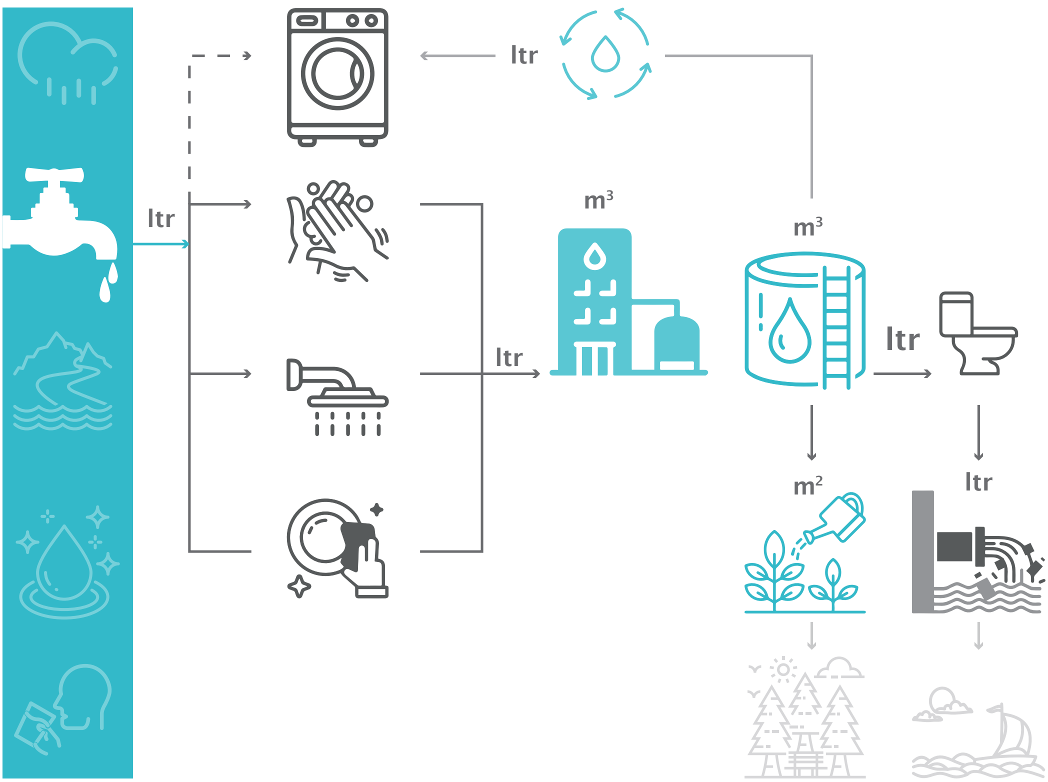
This is not the case for the toilet: potable water is efficiently blended with faeces and urine. The faeces contain a plethora of pathogens, parasites and the like that are a major cause of premature death the world over. Should you be daft enough to drink from the siphon of a toilet, well, you will most likely die.

A common example of Anthropocene Design would be to recycle water from the washbasin to flush the toilet. It is a good idea: freshwater mixed with soap, toothpaste and other benign contaminants is more than good enough to mix with urine and faeces when flushing. But if you have carried out the exercise above, you will notice how the water needed to flush the toilet is not necessarily the same as the water used for the washbasin. So, what do we do? Might we need extra water from another source? Maybe there is an excess that needs to be managed? How long and where will the greywater be stored before it is used to flush the toilet? All of these types of inconsistencies need to be identified and solved.



The easiest way to do this is by using a flow diagram. At every step of the flow diagram (washbasin, toilet, shower, etc.) you can put the total litres per day needed. You can then identify opportunities for water recycling, bringing deficiencies and excess water flows into equilibrium. For every point where the water needs treatment, you should put the type of installation needed and the space taken up. For example, how big are your water treatment plants? How many m$^3$ are needed for the storage cisterns? Where should these be placed? How do they fit into your design?

If possible, the last step in the flow diagram should be irrigation, where the treated water is brought back into Mother Nature and the natural water cycle mentioned in the mini-intro. This should be considered in m$^2$ to be incorporated into your final design. You can see an example of this in the water section of the case study in a hypothetical high-rise building.



# Soil: Waste not, want not...

## Mini Intro

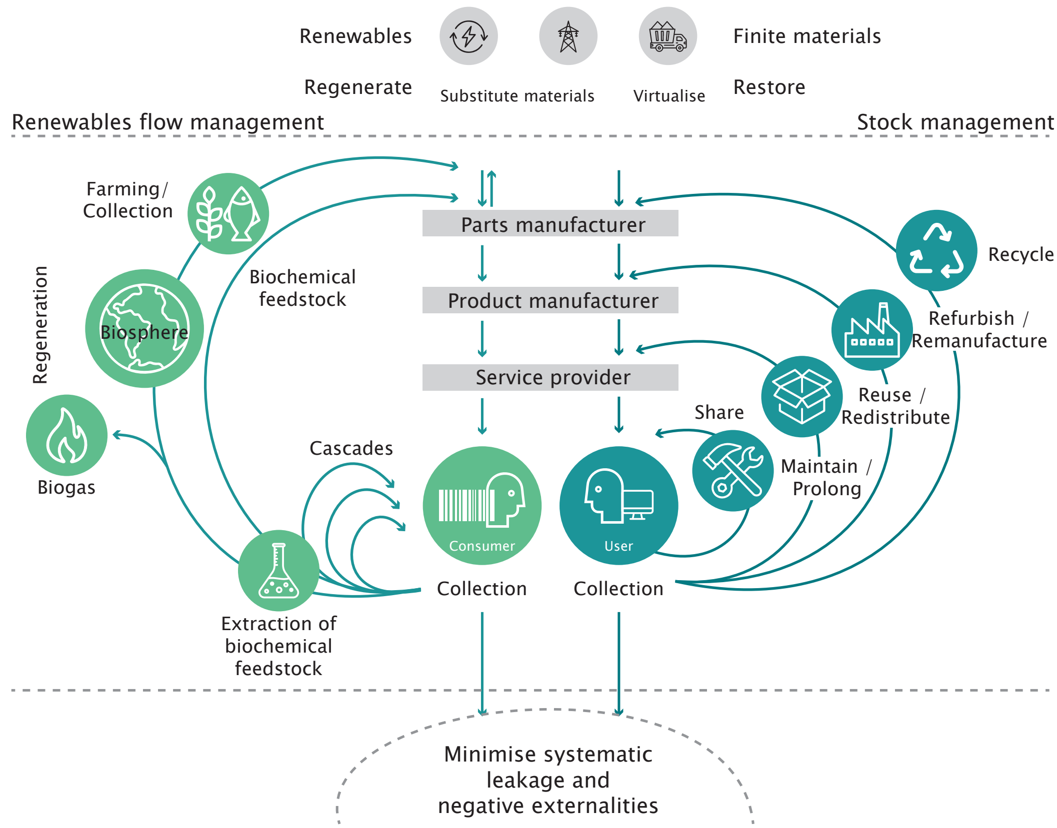
Soil is an incredibly useful end product in the natural world. It comes from breaking down organic matter that is no longer needed by its previous owner, such as leaves that cascade down from trees or the (slightly smelly) deposits of various animals politely placed on the ground. In the natural cycle, everything is ultimately reduced to soil. This wonder-product is a matrix full of nutrients, within which new vegetation can grow that then provides food for insects and animals, who are then food for other beings. In short, soil can be called an initiator of the food cycle.

In the Anthropocene, humans have produced something remarkably new: rubbish. This new type of waste has no use, where burying it, burning it or ignoring it seem to be the only things we can do with it. Unlike soil, it tends to contaminate things in a manner that is ultimately detrimental to the very food cycles we rely on.

The concept of waste being an unnecessary product that is unique to modern society has been put forward by a number of schools of thought. For example, since the 90s the Industrial Ecology movement has sought 'ultimate sustainability' by making industrial systems work more like the ecosystems found in nature. In layperson's terms what this actually means is to design a system so that the waste of one component becomes a resource for another. We see this idea permeate the concept of Biomimicry, which also gained track in the 90s. The founder Janine Benyus calls for humanity to learn from nature, where amongst other things 'Nature Recycles Everything' and sees a future based around closed-loop, feedback systems that are common in the natural world. This was put into a more accessible language by William McDonough and Michael Braungart in 2010, who simply stated: 'Waste equals Food' in their Cradle to Cradle Philosophy. Here they identified two main types of loops: one technological and the other one biological. Nowadays[1], the Circular Economy movement joins this call to arms that 'Waste' has become an outmoded concept that needs to be laid to rest. The Ellen MacArthur Foundation (EMF) has propagated the concept of the Circular Economy in a butterfly diagram, where a continuous flow of technological and biological materials function in a value chain approach.

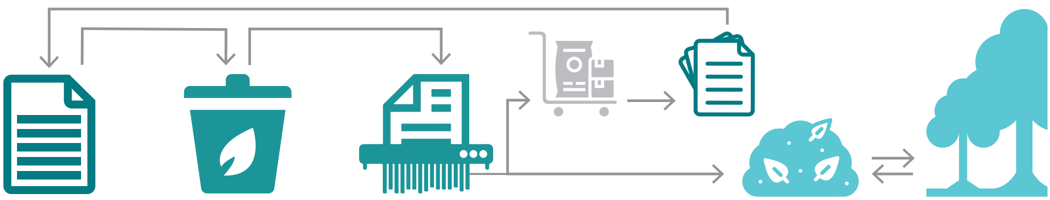
The left side of the butterfly diagram shows a circular flow of biological resources, emphasising the recovery of nutrients and restoration of natural capital. The technosphere on the right-hand side of the diagram describes the stocks and flows, products and services of technical components. In both spheres the aim is to eliminate the production of waste insofar as is possible, promoting an efficient use of resources while preserving or restoring natural capital. In other words, waste is redefined as resources that feed new processes.

[1] Well, at the time of writing this book at least.



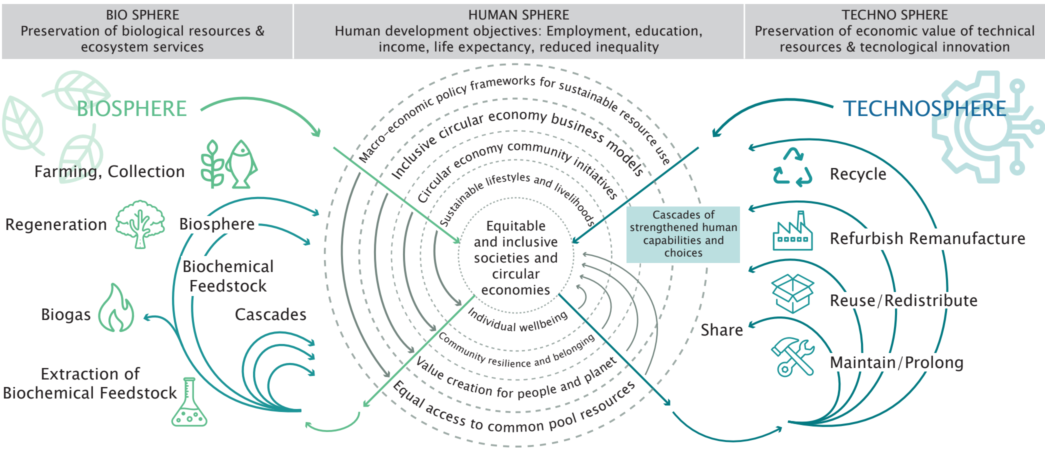

*Adapted for this book from: The Circular Economy Butterfly Diagram.*
*Source: Ellen MacArthur Foundation, 2013*

Let us consider paper for example. Paper use can be maintained in the technological sphere: people use the paper, it is cleaned, shredded and reduced to a raw material; new, fresh paper is made, people use the paper. It can also be fed into the biological sphere: people use the paper (admittedly non-bleached), it is cleaned, shredded and reduced to a compostable material, the paper becomes a nutrient source that is re-incorporated into Mother Nature.



But this then begs the question: 'What is the role of humans?'.

Some scholars[2] have highlighted the lack of clarity regarding the human dimension of the Circular Economy, where people were primarily considered as consumers. In this context, the Human Development Index (HDI)[3] was incorporated into the traditional Circular Economy butterfly diagram where the human sphere interacts with the bio- and the techno- spheres in order to strengthen the objectives of the HDI. Let's go back to the paper example to illustrate this. Paper would be recycled using non-toxic chemicals that would not harm people handling the paper in any way whatsoever (healthy life). Its main use would be for schools and educational purposes (knowledge). Also, the whole industrial process would be carried out in industries that adhere to just wages and working conditions within an environment where all the employees are felt of worth (decent standards of living).




*Adapted for this book from: Framework for a Human Development Focused Circular Economy (Schröder, et al., 2020)*

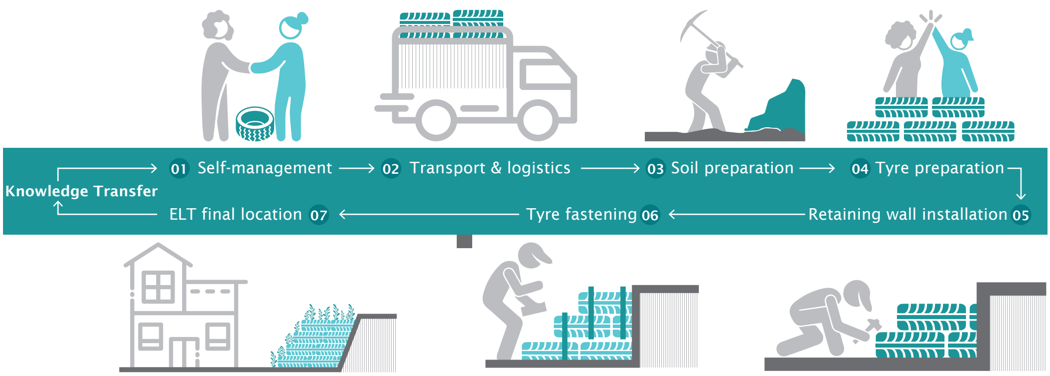
[2] See for example Schröder, P., Lemille, A. and Desmond P. (2020). Making the circular economy work for human development. Resources, Conservation and Recycling, 156, 104686.

[3] The HDI indicators were thought up and developed by the Pakistani economist Mahbub ul Haq in 1990, before being taken on and refined by the United Nations Development Programme. Instead of the brutal, trickle-down economics offered by Gross Domestic Product (GDP) economic indicators, the HDI consists of the people-centred indicators of: a long and healthy life, being knowledgeable and having a decent standard of living.

# Let's get loopy

I'd like to add a couple of further points in this book that builds on the role of humans in the Circular Economy and on the two loops. First, the Circular Economy seems to constantly discuss the transformation of products through mainly industrial processes that break them down into their raw materials, ready to be made into new products or services. But it doesn't necessarily have to be so.

I worked in a number of teams over the years in the realm of End-of-Life Tyres (ELTs), following a series of catastrophic earthquakes that hit Ecuador in 2016. We looked at the reuse of ELTs in civil engineering works, more specifically foundations for semi-detached houses and retaining walls[4]. The inherent properties of ELTs make them particularly suited to such applications, without having to go through any major transformations to reduce them to their core, raw materials. For example, ELTs have excellent friction between each other, are long-lasting and able to absorb impacts without losing their structural integrity. What better qualities could be asked for?



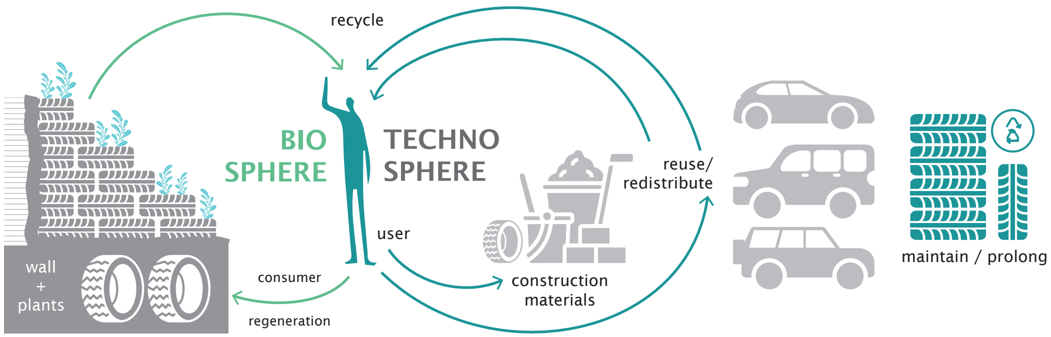

*Adapted for this book from: The 'Human Sphere and the Figure of 8 as the Enabler of Circular Economy in Developing Countries: a Case Study (Davis, et al., 2023)*

[4] Cecchin, A., Lamour, M., Joseph Maks Davis, M., & Jácome Polit, D. (2019). End-of-life product management as a resilience driver for developing countries: A policy experiment for used tires in Ecuador. And, Davis, M. M., Vallejo, A., Criollo, P., & Domenech, T. (2023). The 'Human Sphere and the Figure of 8 as the Enabler of Circular Economy in Developing Countries: a Case Study.

The first thing to note is the ease with which the ELT can be turned from a waste product no one knows what to do with, to a valuable resource that can potentially save lives. This was done in the absence of complex transformation processes: at most, the tyres needed one of their rims cut out to make the process of compacting a soil infill into the tyre hollow easier. So, what happened exactly that changed the ELT from a waste product to a raw construction material without changing the tyre itself?

## Us … We … You.

The transformation of the used tyres into a material that was particularly suited for the construction of a retaining wall, or seismic resistant building foundations, was not due to any complex industrial process or technological processes. It was thanks to that most complex of processes that lurks somewhere in the back of our imagination: human ingenuity. In the case of the ELTs, human ingenuity meant the tyres were seen in a fresh, new perspective regarding their inherent, base mechanical properties.




*Adapted for this book from: The 'Human Sphere and the Figure of 8 as the Enabler of Circular Economy in Developing Countries: a Case Study (Davis, et al., 2023)*

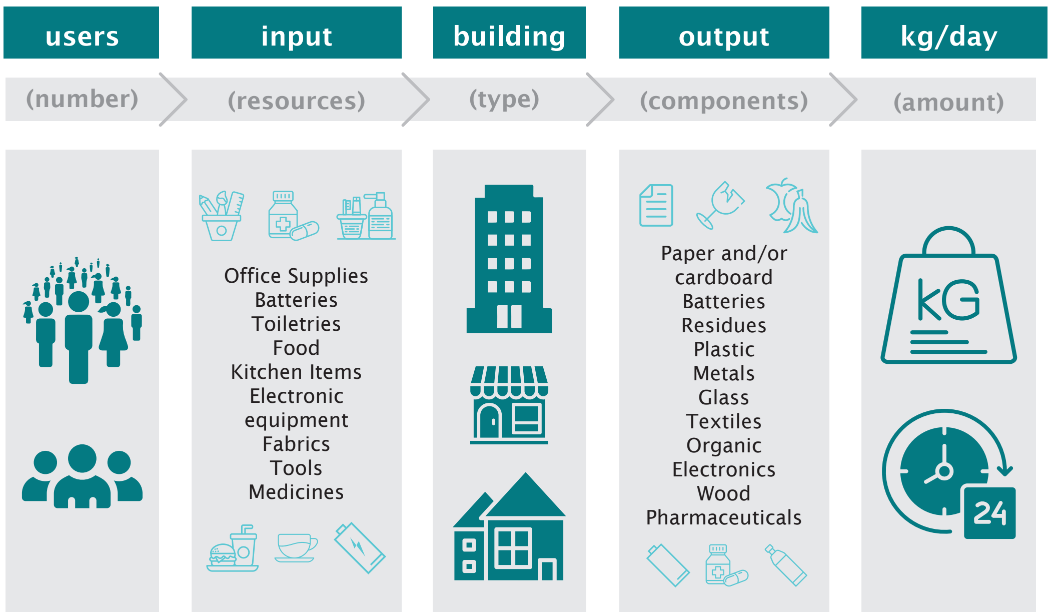
This, in my view, is the true future for applied Circular Economy. I go into this concept in more detail in the Annex titled ''Ceci n'est pas une pipe'', where you can find a discussion on how to consider waste products in terms of the inherent material and mechanical properties. It can make them particularly suited to something completely different than was originally intended. It's quite fun, have a go, try it with someone in the family or a friend.

Finally, there is the distance element of Circular Economy cycles to take into account. For example, let us consider used-coffee grind. It is the used ground coffee after making an espresso, americano, cappuccino or suchlike, which is more often than not binned and thrown away. However, used coffee grind can also be a great skin exfoliant, or is excellent for compost (wormery, compost bin or applied directly to gardens). This is great if you get the used coffee grind from your local café, which is within walking distance. But if you buy used coffee grind that has been flown in from halfway round the world, it somewhat defeats the object[5]. So, not only should we look for Circular Economy opportunities in themselves, we also need to begin with the opportunities that are in the vicinity of the project we are designing. First, identify the opportunities in the immediate area. If needed, the next step is at a neighbourhood, borough, or similar scale. After this the city can be considered, then the city perimeters and if needed move on to a provincial scale. The last step if none of the previous ones have worked is to look at a national level for the waste flows and nutrition sources needed.

[5] The beneficial Circular Economy impact of using the coffee grind is greatly outweighed by the greenhouse gas emissions and the environmental impact of transporting it from the other side of the world.

# How much are we actually talking about (in kg or m³)?

Theory aside, let's now get down to looking at the Design Tools we have at hand. First, we need to quantify the waste flows we are looking to process in the specific project we are working on. We do this by using a technique called Eco-balances, where we determine the quantity of products that enter the project, and the amount of waste coming out of the project. The next step is to change this linear flow into a cycle, by harnessing each waste flow as a resource for a future cycle.




How do you determine the amounts? If you have read any of the previous chapters, the next sentences will come as no surprise:

Get out of your chair, get out there and carry out fieldwork research in order to confidently quantify the waste flows for your project!

The Annex titled ''Research Techniques'' covers some of the methodologies that can be harnessed. In this case, the unit we try to determine is kg or $m^3$ per person per day.


In general, there are different waste flows depending on the project type. In the section on the mixed-use building of the Case Study we'll analyse the spaces needed to store, process and access the different wastes produced (cardboard, plastic, organic etc.).

For this part of the book, we'll focus on composting organic (food) waste in situ.

You might ask 'Why?'. Organic waste tends to be the biggest flow, whichever part of the world you might be working in. Around the globe the perfect consumer cycle has often been reached. Supermarkets are bursting with far more food than they can sell, and a significant amount is thrown away once it reaches its supposed sell-by-date. Not only that, but people then buy far more food than they actually need. This food is taken home, put into fridges and suchlike, and then a massive quantity is thrown away. In fact, I learned in 2011 that a staggering 50% of food sold in the UK ended up in landfill, without having been consumed at all. Once in a landfill, the organic waste undergoes anaerobic digestion, where it produces methane as part of the decomposition process[6]. This is crazy when you really think about it, especially as at the time of writing 343 million people around the world are facing acute hunger[7]!

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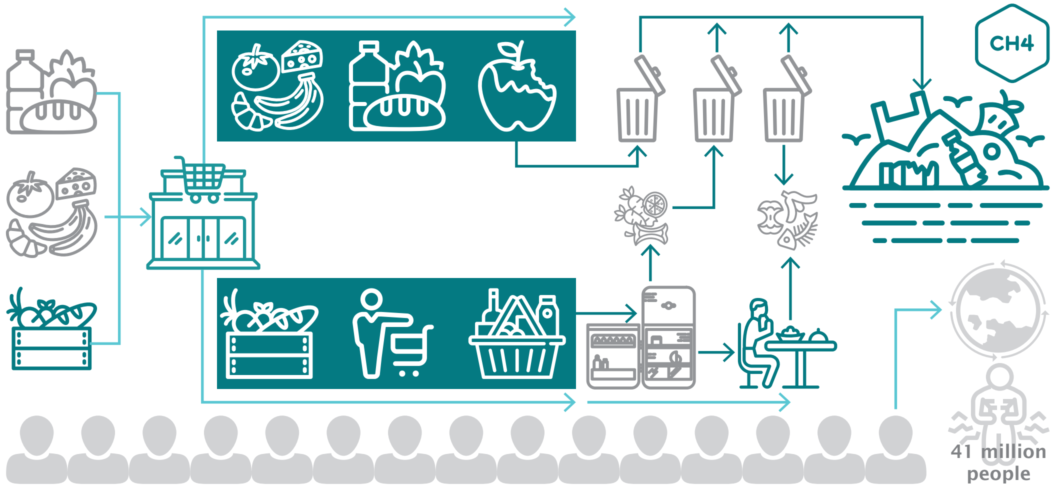
[6] Much the same as described in the previous section on ''Biogas''.

[7] According to the United Nations World Food Programme: https://www.wfp.org/global-hunger-crisis.



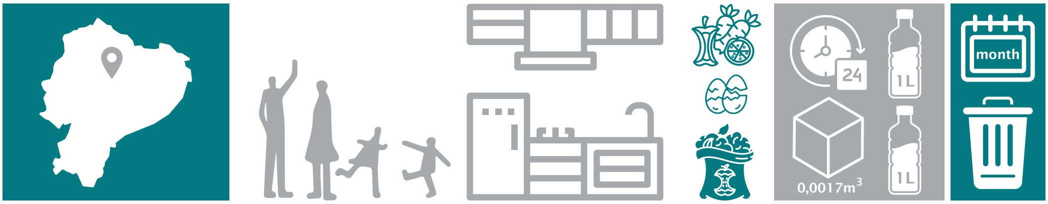

# All in good time

Let us consider waste flows for an average household in Quito, Ecuador. I have specifically chosen Quito because a) through many years of research and consulting there is a decent database of information, and b) unless your Anthropocene Design happens to be in Quito, you will need to get out there and carry out your research.

For those who are reading this after having gone through the section on biogas, you might remember that a 4-person household in Quito (like the one in the ''Mini Intro'') produces 1.28 kg of organic kitchen waste per day. The usual option is for this to be separated and taken away by specific waste collection[8], as unfortunately, people tend to shy away from processing their own food waste (much in the same way as they do from the idea of their own waste in dry toilets).

[8] I found this to be much more efficient and sensible in Quito than 'developed' cities. Instead of having a centralised municipal system that collects and processes organic waste, for our design projects we set up Memorandums of Understanding with grassroots waste collectors, who pick up the food waste and take it straight to be fed to livestock, usually pigs. This bypasses a lot of energy and effort that is spent in processing a lot of waste, and then making a lot of animal feed as two separate activities.

But let's say we can go the whole hog and compost the food waste at home. Food waste is slightly less dense than water (which is 1000 litres or kg per $m^3$), at around 750 kg per $m^3$. This means that our family in Quito produces:




1.28/750 = 0.0017 $m^3$ per day.

You can think of this as a nearly full 2-litre bottle of water, or almost two tetra packs of milk per day, and an average household kitchen dustbin per month[9].

Now, composting is a process that takes time. If well managed, organic food waste can be reduced to compost in around 3 to 6 months[10]. So, in the first month we would fill up the first composting drum (the size of an average household kitchen dustbin). We would then need the same size composting drum for the second month, and another for the third month, and so on. By the end of the sixth month, we could empty out the first compost drum and start the cycle again. However, the important thing to note here is that time is space: we need one more composting drum for every extra month of the composting process, which needs to be taken into account for our Anthropocene Design.

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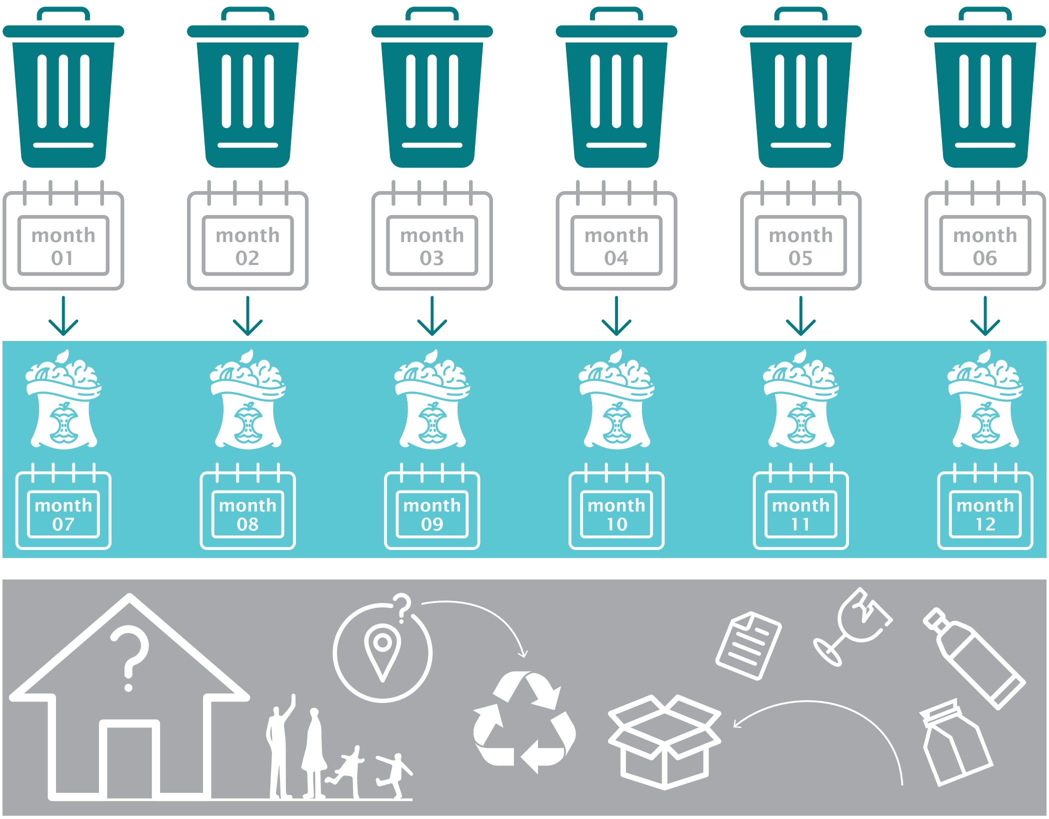
9 7 days x 0.0017 $m^3$/day = 0.012 $m^3$
31 days (in a peak month) x 0.0017 = 0.053 $m^3$

10 Worms are incredible accelerators of the composting process, which can reduce the time taken to under three months in a well-managed vermiculture. They also produce a nutrient-rich liquid, which will have to be incorporated into the management of your compost. If the nutrient is not removed, it can build up in the composting process and become detrimental (smelly and drowns worms). If it is not watered down, it can burn the roots of the plants when applied.

You also need to make sure the compost process is managed well. Compost is an easy, but nevertheless supervised process that transforms organic material into nutrient-rich soil. But, if it is not carried out properly, has meat, bones, too much moisture and not enough air, it can also become a putrid, fly-ridden, disease-spreading sludge. This is why there is a dedicated Annex that tells you all about how to get it right (''Composting: it's an art'').

Time also equates to space for storing recyclable materials until the waste collectors come to pick them up: do they come once a week? A month? This will determine the areas you have to allocate in your project.



# A Toolbox

The previous sections outlined a vast amount of theory with rules of thumb. In the next section of the book a case study is offered, where these tools are put into practice. However, before doing so it might be useful to bring all the rules of thumb together in a sort of Toolbox. Remember that you can see where all these come from in the ''The Annexes'' section! Here you can find all of the deeper theories and calculations that went into developing the tools that have been given in the book up until now and are summarised here.

## Sun

### For photovoltaic solar panels:

**SR x EF x L = Solar PV Electricity generation**

***Where:***

SR = average solar irradiation at the project surface ($kWhm^{-2}day^{-1}$).

EF = solar PV panel efficiency (%).

L = additional factor of losses due to the inverter, cabling, exchange with backup system, etc.

## For wind power:

**$0.00471\ \rho\ v^3\ d^2\ CF$ = Wind Power Electricity Generation**

***Where:***

$\rho$ = the density of air at the place you are designing.
$v$ = average air velocity at the height of the turbine blades.
$d$ = the diameter of the circle drawn by the turbine blades.
$CF$ = the capacity factor for the wind turbine(s).

## For biogas:

**Electricity produced = 225 kWh per tonne (1 000 kg) of organic waste**

## To calculate the energy demands:

**Demand = Potential (kW) x Time (hr) (kWh)**

# Water

## For rainwater collection:

**Rainwater Collection (litres) =**
**mm rainfall x $m^2$ recollection surfaces x runoff coefficients of those surfaces**

If for whatever reason you have very inclined roofs take the $m^2$ from a bird's eye view (what the falling rain 'sees' if you like) instead of the actual $m^2$ of the inclined roof. This avoids over-estimations of the collection abilities of your design.

## For water storage sizing

**1 000 litres = 1 $m^3$ water**

## To calculate the water demands:

**Total demand in litres = Potential (ltr/min) x Time (min) x Frequency**
**or = Potential (ltr/use) x Frequency**

# Soil

## For the organic kitchen waste

Organic waste is slightly less dense than water (which is 1000 litres or kg per $m^3$), at around 750 kg per $m^3$.

It takes approximately 6 months for the organic kitchen waste to compost into soil (unless you use vermiculture).

Never add meat, nor bones.

**Organic waste density: *around* 750 kg per $m^3$**
**Time: 6 months (unless you use vermiculture)**

## To calculate the size of the composting area:

Remember this will be 6 (or 3) separate containers that will be filled each month!

**Capacity needed for the compost =**
**The kg waste per day (from your research) ÷ 750 kg/$m^3$ x 31 days (the longest month) x 6 months *(3 months if it is vermiculture)***

# My Toolbox

Feel free to write down your own data and formulas

# My Toolbox

Feel free to write down your own data and formulas

# Overall: Sun, Water, Soil and Design in the Anthropocene

Having gone through all the steps of renewable energies, water systems, and waste management, let's take a moment and reflect on what's been covered, before launching into the practical case study.

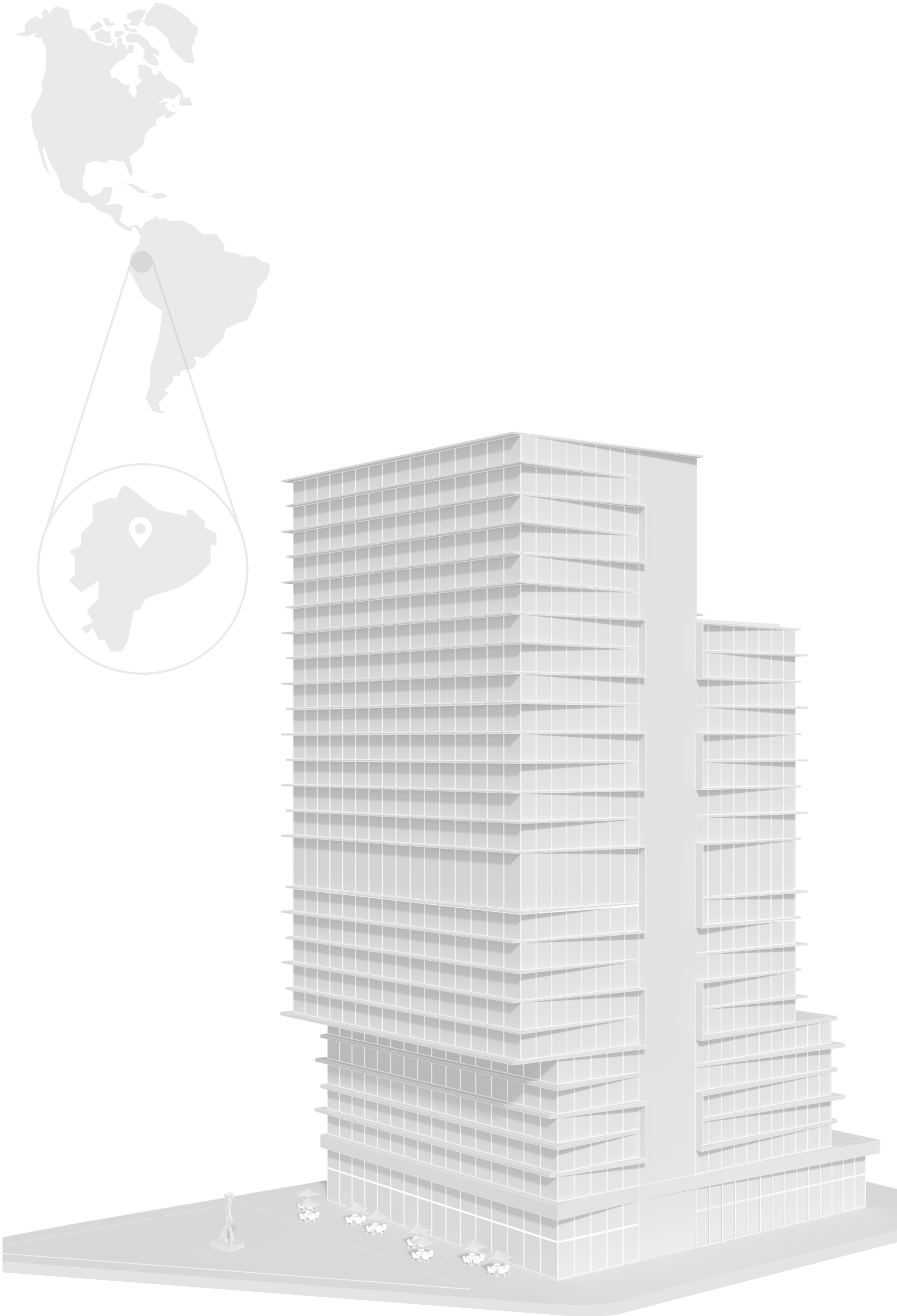
First, we know that renewable energies are big, needing much more space than is usually available. However, this added challenge gives our design process a creative twist. If we are using solar irradiation, we can be inventive and incorporate photovoltaic panels into our everyday lives. If we use wind power, let's make the turbine a powerful statement. It is a turbine that will be seen kilometres away and we can use it to make clear our project runs on renewable energy. Bringing a biodigester into play means that our project brings a service to the city where it processes organic waste, producing energy and fertiliser in return.

Second, water systems are all about balancing demands, green infrastructure, and water recycling. It can be a fun game to play: researching into habits of the people who will live, work, and 'be' in our project, tweaking and seeking the optimal mix of green infrastructure, opportunities to recycle water, and green space that can be irrigated through our project.

Third, producing soil could mean planning for additional waste processing facilities within the project, finding partners who can process our organic waste and recyclable materials, or a mixture of both options.

Finally, as you will see in the case study that now follows, there is no one-size-fits-all solution. Every design will have decisions that need to be made, suited to the people who will become the end-users of the project, and which seem the most ‘elegant’ to you. This is part of the creative design process, which is iterative, sometimes seeming never-ending until finally it ‘clicks’.

Now let’s see some of this theory put into practice by moving on to the hypothetical case study.



# The Case Study: Verticapolis

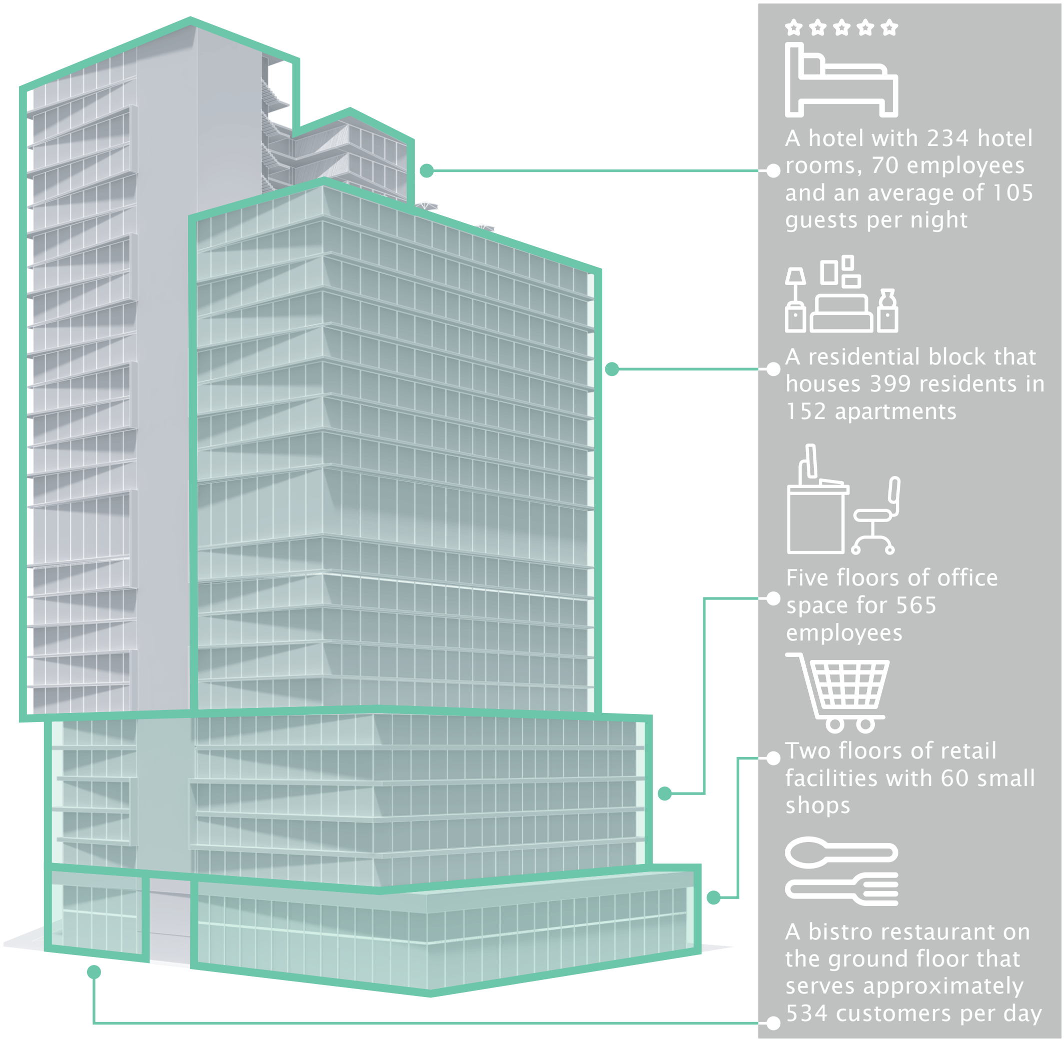
## Mini Intro

In this section we'll take a theoretical, high-rise, mixed-use building for a case study into which we apply the Anthropocene Design Tools presented in this book. The numbers are based on nearly two decades of sustainable building design consultancy, with approximate values that are useful in getting an idea of the spaces required in Compact City design.

In this case, our building has had everything thrown at it: a mix of residential apartments, office space, a hotel, shops and restaurants. It is essentially a mixture of the many projects I have had the pleasure of working on over the years with the collaborators of this book through the consultancy Evolution Engineering, Design and Energy Systems Ltd. So, it is not entirely fictional, but let's say as they do in Hollywood: 'based on a true story'. The project in question was located in Quito, the capital of Ecuador and in the Andes. This has been done on purpose: unless your project is in Quito you will need to get out and into the world to study what the realities of your water, energy and waste demands are. Only then can you be successful in your final projects.

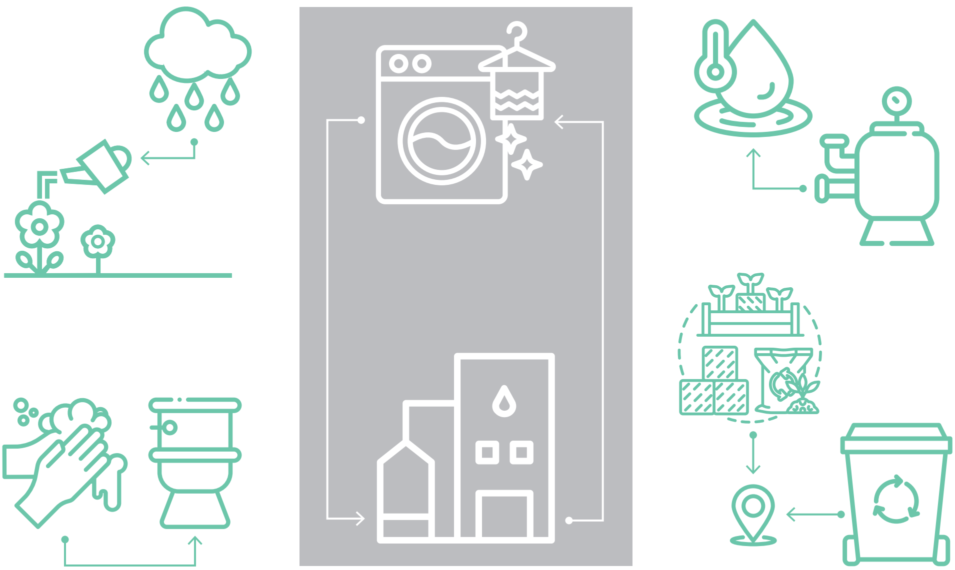
Our high-rise building in this case has a hotel, a block of residential apartments, offices, 2 floors of retail areas and a bistro restaurant on the ground floor. There are only two parking basements, as one of the principal aims of Compact City design is to drastically reduce the use of private vehicles. Maybe this is unrealistic, but it is a theoretical study after all and does not change the methodology of the calculations. We could be criticised for taking a luxury high-rise for our case study, but such are the majority of case studies we had to draw from, and such is life. Remember however, we are merely putting the Design Tools into practice and the methodology would be similar for any type of building project you embark on.

The case study was designed with the Evolution Team, led by the architect Lizeth Lozano. Let's it the Verticapolis Project. Overall, the programme of the building project consists of:



Also, it was given the following characteristics:

1. Rainwater harvesting for green space.
2. Greywater recycling for toilet flushing (absurd to import potable water for this).
3. Laundry services in the hotel are a closed cycle for water: clean water is put in for the laundry process, the wastewater is collected and treated on-site, and then used again (and so on). This means that the water demand for hotel laundry is to all extents and purposes reduced to a minimum.
4. The hotel clients eat in the ground floor restaurant.
5. Hot water is provided via a centralised Heat Pump.
6. All waste management (including composting) is to be carried out on-site[1].



[1] A great leap into the possibilities of a purely hypothetical case study.

# Verticapolis: Sun

## Bringing the energy demands down

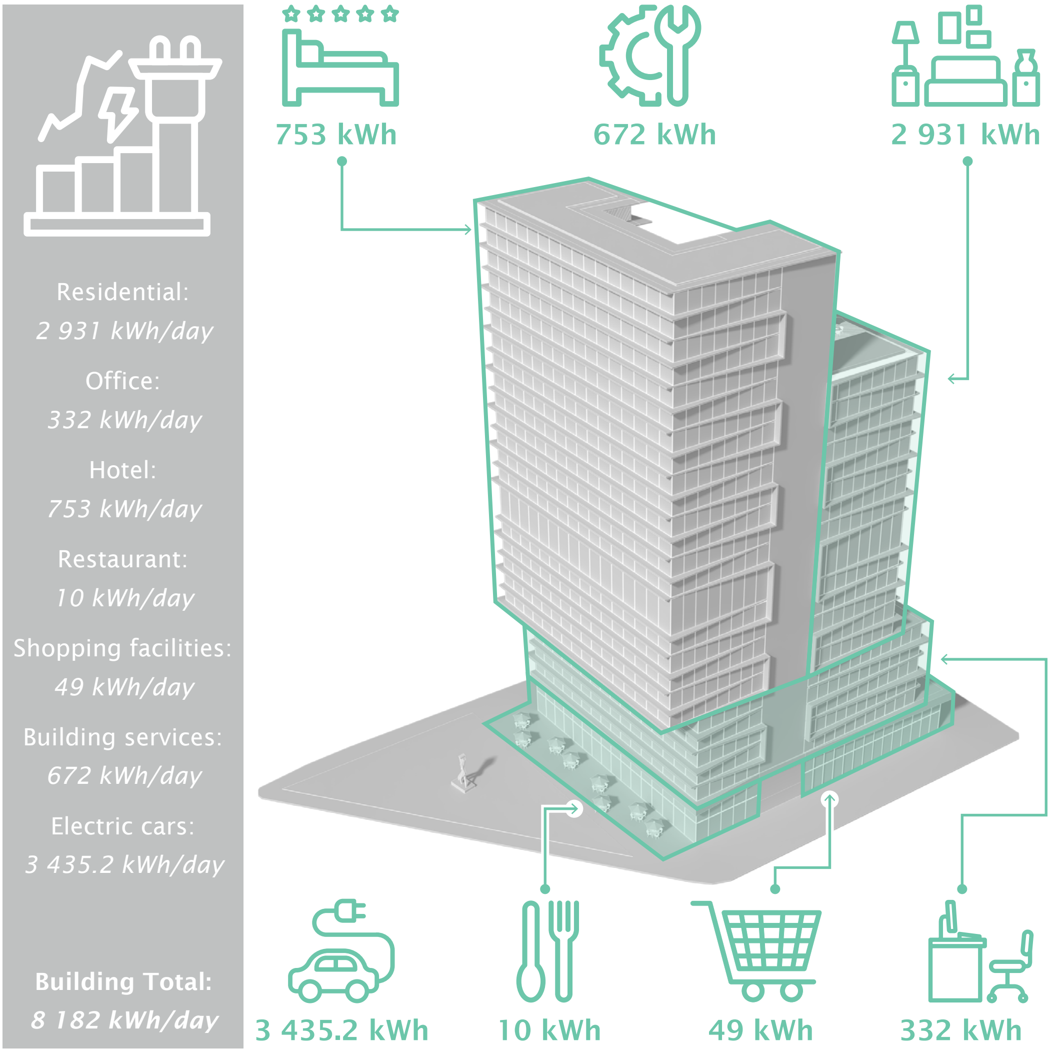
In this particular case, all the installations were made as efficient as possible in their energy demands, a centralised heat pump with a Coefficient of Performance (CoP) of 4.5 was used for all the hot water of the building, and no space heating or cooling was required[2]. Regarding cars, the bold assumption is made that only electric cars will be used and that all their daily energy charging demands will be met by the building, at 15.2 kWh per car per day (see ''Bringing the house down''). Only family apartments with 2 or more bedrooms are permitted a parking space, we allowed a car for every 4 to 5 office employees and threw in a few extra for visitors and as a 'just in case'.

The overall energy demands had to be divided according to the type of use of the building, in this case it meant dividing up what energy was needed for the residential, office, commercial, hotel and restaurant areas, which can be quite distinct from one another. For example, you can't expect the energy required for cooking in a restaurant or residential building to be similar to that of an office. Nor will the water heating demands of a hotel have anything to do with those of a shopping mall.

[2] Remember that the case study is for a climate where little heating or cooling is required, which we translate into passive or bioclimatic design that mitigates heavy heating or cooling loads. However, you could easily include these into your project if needed.

## How many kWh are we talking about?

The first stage of our work is to quantify our energy demands. This takes an awful lot of fieldwork studies and very large excel tables. For this part of the case study, we will handily summarise over a decade of sustainable design consultancy, case studies and research into a few numbers for the Verticapolis project.




Remember, *these are wrong for you to copy and are in general for Quito, Ecuador only. So, get up, get out and get your fieldwork done to quantify your energy demands!*

## Where to put it all?

At this point, the exercise is similar to that which was carried out for the household previously in the book (see ''Where to put it all?''). The difference you'll find here is that whereas for a household we need space, for a high-rise, mixed-use building in a compact city *huge* amounts of space are needed. Let's look at this step by step, going through solar photovoltaic (PV), wind power and biogas.

## Solar Photovoltaic (PV) Energy

So, as previously mentioned Quito has around 5kWh per $m^2$ under optimal conditions, and we will start with this for the Verticapolis project (Note: this is more solar irradiation than we assumed for the detached house in the ''Sun'' chapter).

Let's then add some nice, expensive monocrystalline solar PV panels with an efficiency of 20%.

Finally, we'll assume a net-zero design that is plugged into the national grid, with a total loss of 10%, which translates to 90% efficiency (100% minus 10% loss).

This gives us:

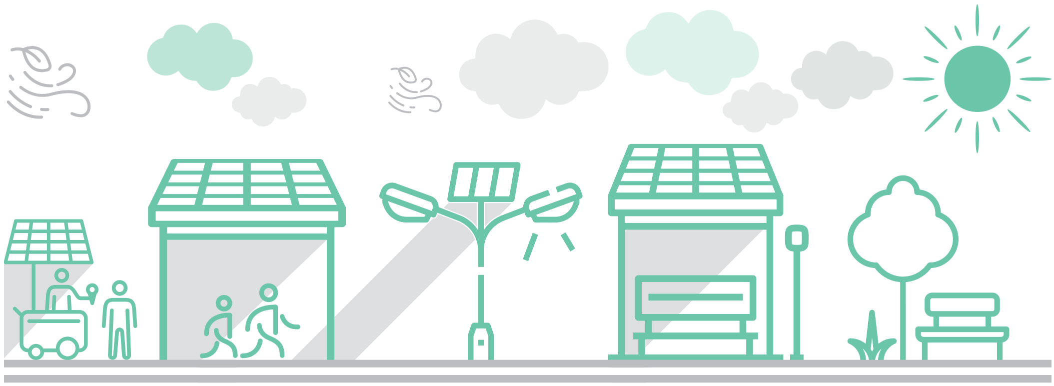
$$8182/(5*0.2*0.9) = 9091 m^2$$

This is far, far bigger than the total roof space of our building of approximately 759 $m^2$, even without taking into account the area required for green space, walkways, the building services equipment and things. Some of you might be raising an eyebrow and thinking 'We can put the solar PV panels on the building facades!'. But no, I'm afraid that won't solve things. First, you have to remember that we are assuming that the panels are at an optimal angle. On the building facades they would be at a very not optimal angle, and would also be in the shade for a greater part of the day[3]. Second, you might have to choose between windows and panels, as solar PV is usually not very translucent (see-through)[4]. Third, remember that you are greatly increasing the number of solar panels needed (as they are at the wrong angle), and these things are expensive.

So, here comes the key:

*The building has to interact with and become part of the wider city.*

Once we have the area of panels, we then need to think creatively about where they can be placed. And I challenge you to go a step further, asking yourself where they could be placed that would be beneficial for society[5]. You will have to enter public space, and in negotiation with the authorities responsible for that space. For example, the very property of PV panels turning solar irradiation into electricity makes them particularly suitable as shading devices, as they diminish the amount of radiation that reaches the surface below. Bus stop shelters, shaded walkways in parks, covered bicycle lanes ... these might all be prospective candidates.



[3] Meaning that they become incredibly inefficient, and basically 'don't work'.

[4] Or, by being more translucent, become even less efficient.

[5] Those of you who, like me, work in tricky cities, will also have to ask yourselves where they won't be stolen.

## Wind power

As I mentioned before, wind power is big, very big. However, for a high-rise building with residential areas, a hotel, shops and restaurants it isn't big at all … it is *massive.*

Let's go through the numbers and see how massive exactly.

In this case study we are in the Andes, where the air is less dense ('thinner') and has a density of 0.85 $kg/m^3$.

The wind velocity averages out at 7.5 m/s, with a Capacity Factor (CF) of approximately 25%[6].

We can then put all these numbers into our design tool, where:

$$0.00471\ \rho\ v^3\ d^2\ CF = 8182\ kWh/day$$

Whereby:

$$0.42224\ d^2 = 8182\ kWh/day$$

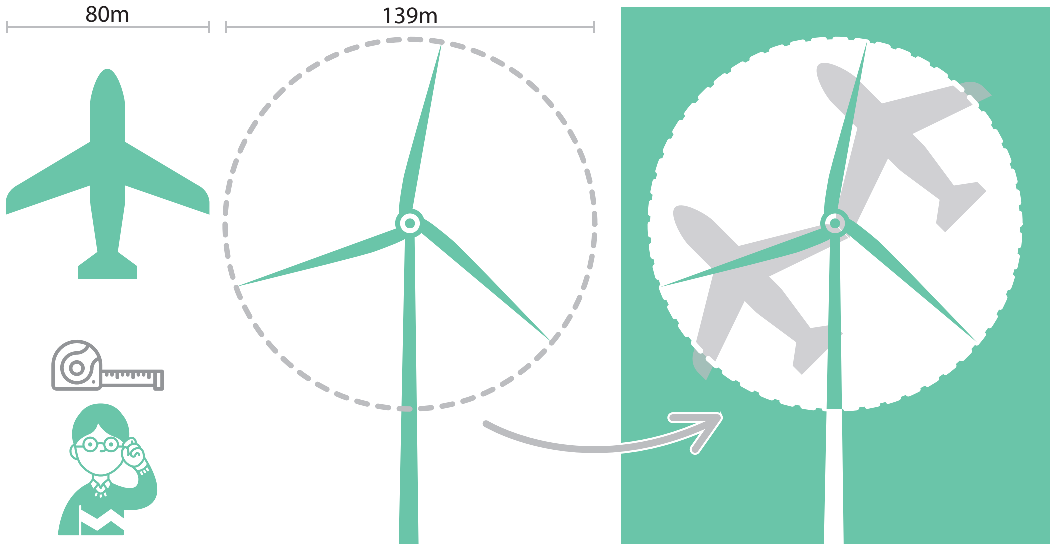
And:

$$d = \sqrt{(8182/0.4224)} = 139\ m\ diameter$$

Now … that's pretty big.

[6] Many thanks to the Ecuadorian Ministry of Electricity and Renewable Energies of 2013 for the Wind Atlas that brings all this data easily to hand.

Let's put this into perspective. The Airbus A380 is one of the biggest aeroplanes in existence: it has a wingspan of 80 m. The wind turbine needed is almost two A380s standing side by side. Then there is the aspect of height. Our turbine would need to be much higher than the top of the Verticapolis, and any surrounding giants, in order to get rid of uneven, 'noisy' wind[7].




In short, it becomes incredibly difficult to include wind power within the footprint of the building. It is most likely that the turbine would be located in an open space, where it could also double as a viewing platform or tourist attraction (a concept you can find far and wide, from the Albany Wind Farm in Western Australia to the Green Britain Centre in England). However, it would only meet the energy demands for the Verticapolis, and none of the other many, many buildings nearby. So, we would have to spread out to the surrounding countryside, which is a completely different story.

[7] Then we also have the inconveniences of flickering shadows, unfortunate passing birds, etc.

## Biogas

Let's get straight to the point.

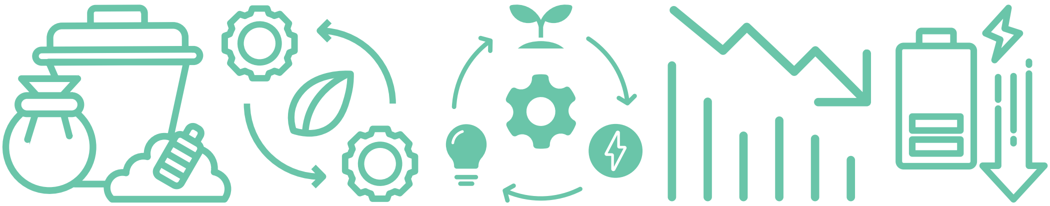
We know that 225 kWh can be produced from every tonne of organic waste.

We need 8182 kWh/day, and so 36.4 daily tonnes of processed organic waste.

We will see in the next section of the case study, ''Verticapolis: Soil'', that the whole project only produces approximately 150 kg of organic waste per day. This means we would need the organic waste of over 242.5 Verticapolis-size projects in order to meet the daily energy demands.

And yet ...

It is surprising how much organic waste is produced and goes to waste (literally) in urban landfills: restaurants put sacks of it out every evening, parks produce lorry loads of it when they are maintained. Maybe, we could add another function of the Verticapolis project: one that offers an organic waste processing service to the city, where it gets free energy in return and produces organic nutrients for agriculture or gardening as a result.



## Overall, think big

In conclusion, we can see that meeting the energy needs of a high-rise building is not merely about putting a few solar panels and a small wind turbine on the roof. We need to change the way we think about energy. Consider renewable energy production becoming an integral, interwoven and interconnected aspect of the city and people's daily lives within it. Envisage solar panels everywhere, with every possible surface available given over to photovoltaic installations. Picture wind turbines on the horizon, over land and sea. Imagine biogas plants nestled between buildings every block or so, eagerly waiting to receive the organic waste produced by the city parks, restaurants, and households.

And there is also the less popular aspect: drastically reducing energy demands…

This might entail limiting the kWh that can be used per day. It could mean following the sensible tendency that most people around the world incorporate into their daily lives: energy rationing. And electric cars? Well, rethinking how to mitigate the need for private car use is nothing new and has been a subject of debate for many decades.

# Verticapolis: Water

## It's raining it's pouring: let's go green

Let's start with the rain. Quito has a temperate climate, where for this case study we will play the design game of trying to reach an equilibrium, where the rainwater runoff is in equilibrium with the water demand. This could be anything from potable water (with the correct treatment plant) to toilet flushing and laundry machines or the irrigation of green spaces. In this case study, we will go with the irrigation of green spaces to illustrate the Design in the Anthropocene methodology in action.

If we consider the roof of our building, we could go to two extremes. At one end of the scale everything could be a hard surface, where over 90% of the rain that falls is transformed into runoff. At the other end of the scale, all of the roofs could be green and absorb a substantial amount of the rainwater, leaving only some as runoff[8].

Now, in order to use all of the rainfall runoff as it flows from the roof we would need a corresponding variable demand, which grows in times of precipitation and reduces drastically in the drier periods. This is difficult and unrealistic[9].

[8] Have a look at the ''It's raining it's pouring'' section to refresh your memory if this is not clear!

[9] As mentioned previously in the book, the only situation I have made monthly runoff equal to demand has been for designs in the Amazon, where there is the luxury of a fairly constant, standard rainfall over the year (when compared to temperate climates).

So, we are seeking a design solution that reaches a perfect equilibrium, where the excess runoff that exceeds the water demands in the wetter months is stored, being equal to the demand that is not met in the drier periods. This demand could be for toilet flushing, clothes washing, or in this case we will design for the irrigation of roof terraces and surrounding green spaces.

The first step is to quantify our rainwater collection (which we will design to match the irrigation demands of the green infrastructure). As we saw in the section on ‘‘It’s raining it’s pouring’’, we will need:

- The mm precipitation per month.
- The $m^2$ of rainwater harvesting area.
- The surface runoff coefficients.

In this case study the average monthly rainfall in mm has been taken from a local weather station and is summarised in Figure 1 below:

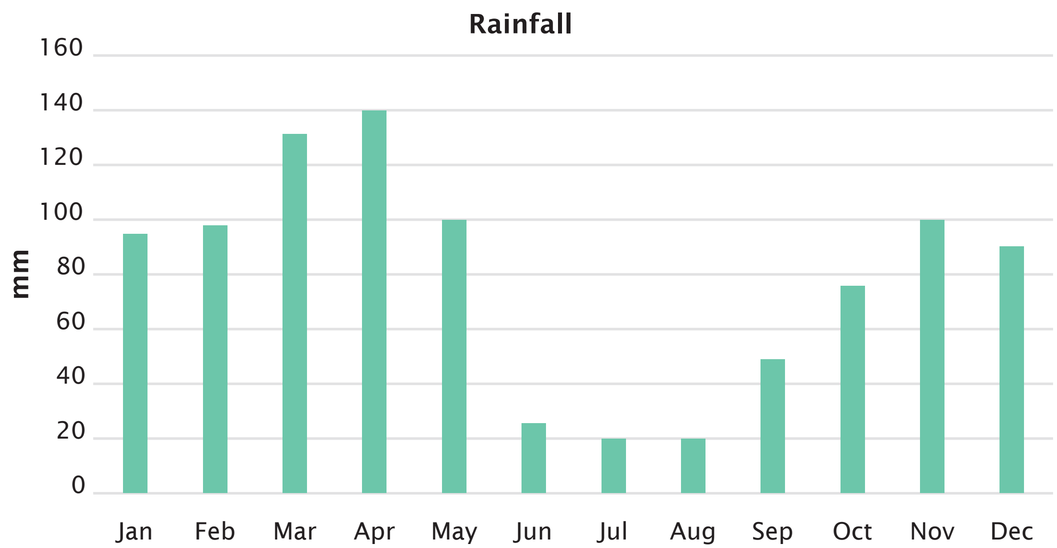
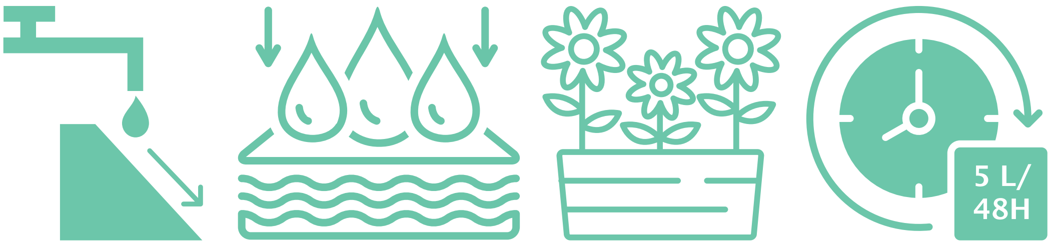



*Figure 1: average monthly rainfall in mm (with an overall average of 78 mm per month)*

We then put these values in mm into a table, adding the columns where the mm of rainfall are multiplied by $m^2$ and runoff coefficients for the green roofs and hard surfaces respectively. We then start to play, knowing that:

- We want the runoff to come from areas that are elevated above the water irrigation demands, which will allow all watering of green space to be carried out by gravity (no need for electric pumps).
- 0.9, 0.3 and 0.6 serve as runoff coefficients for hard surfaces, extensive and intensive[10] green roofs respectively.
- An intensive green roof will need on average 5 litres per square metre irrigation every two days under the beating Sun of the Equator.




And so, the game begins. As Designers in the Anthropocene, you will not only need to reach a point of equilibrium in your technical parameters, but also need to reach an equilibrium between your suggestion for green infrastructure in the project with the

[10] We took the runoff coefficients from a mixture of our experience, those used according to ecological building design legislation in Quito and international references such as the LEED guidelines. Regarding the gardens, extensive green roofs consist of endemic plants sitting on a thin layer of substrate, which don't generally require regular maintenance (or any maintenance at all) and only need minimal irrigation (or if designed well should survive well on rainfall only). They are called green but can actually look pretty barren in the winter. Despite this, they have a very valuable ecological value. In contrast, intensive green roofs are usually accessible, as they are more like lush gardens that require constant irrigation and maintenance. They have a lower runoff coefficient, due to their substrate being thicker (30cm or above). The Annex on ''green infrastructure'' provides some further detail on this.

construction company, the providers of the green roofs and the client who is financing the project. It is easier (and much cheaper!) to build a simple roof with a hard surface, so what will convince the other parties that your design is worth all the effort?[11].

For example, in the Case Study a useful point to begin was to think what could work as a design. Here, we considered the roof types, whether they were accessible or not to enjoy and to maintain, how much hard space was needed (for building services machinery), how much ecological space could be incorporated (for extensive green roofs) and how the design of walkways, etc., through gardens could work (intensive green roofs). Taking all of this into account, the following conclusion was reached (shown in Table 1, Table 2 and Figure 2 below). For those interested in ''green infrastructure'', more information can be found in the Annexes.

| Month | Litre runoff hard surface | Litre runoff extensive green surface | Litre runoff intensive green surface | Total runoff* |
|---|---|---|---|---|
| Jan | 81543 | 22334 | 32127 | 136004 |
| Feb | 84118 | 23040 | 33141 | 140299 |
| Mar | 111585 | 30563 | 43963 | 186111 |
| Apr | 120169 | 32914 | 47345 | 200427 |
| May | 85835 | 23510 | 33818 | 143162 |
| Jun | 21459 | 5877 | 8454 | 35791 |
| Jul | 17167 | 4702 | 6764 | 28632 |
| Aug | 17167 | 4702 | 6764 | 28632 |
| Sep | 41201 | 11285 | 16232 | 68718 |
| Oct | 64376 | 17632 | 25363 | 107372 |
| Nov | 85835 | 23510 | 33818 | 143162 |
| Dec | 77251 | 21159 | 30436 | 128846 |

*Table 1: The rainwater runoff over the year for the case study*
** Total runoff shown in columns of the bar chart of Figure 2.*

[11] In Quito, Ecuador, up until the time of writing this book the building regulations make it a requirement, which helps greatly.

| Total m² roof | 2191 m² |
|---|---|
| m² hard surface | 954 m² |
| m² extensive green | 392 m² |
| m² intensive green | 845 m² |
| Average monthly litres irrigation demand ** | 64317 litres |
| Average monthly litres runoff *** | 112263 litres |
| Average monthly excess sent to sewerage **** | 47946 litres |

*Table 2: A summary of the runoff and water irrigation demands*
*** Shown as the green line in Figure 2 below.*
**** Shown as a red line in Figure 2 below.*
***** The difference between the two numbers and lines.*

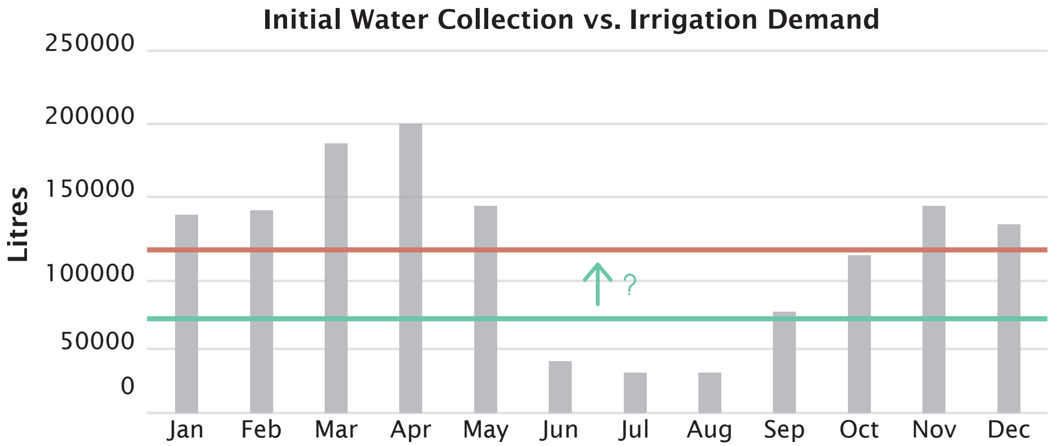


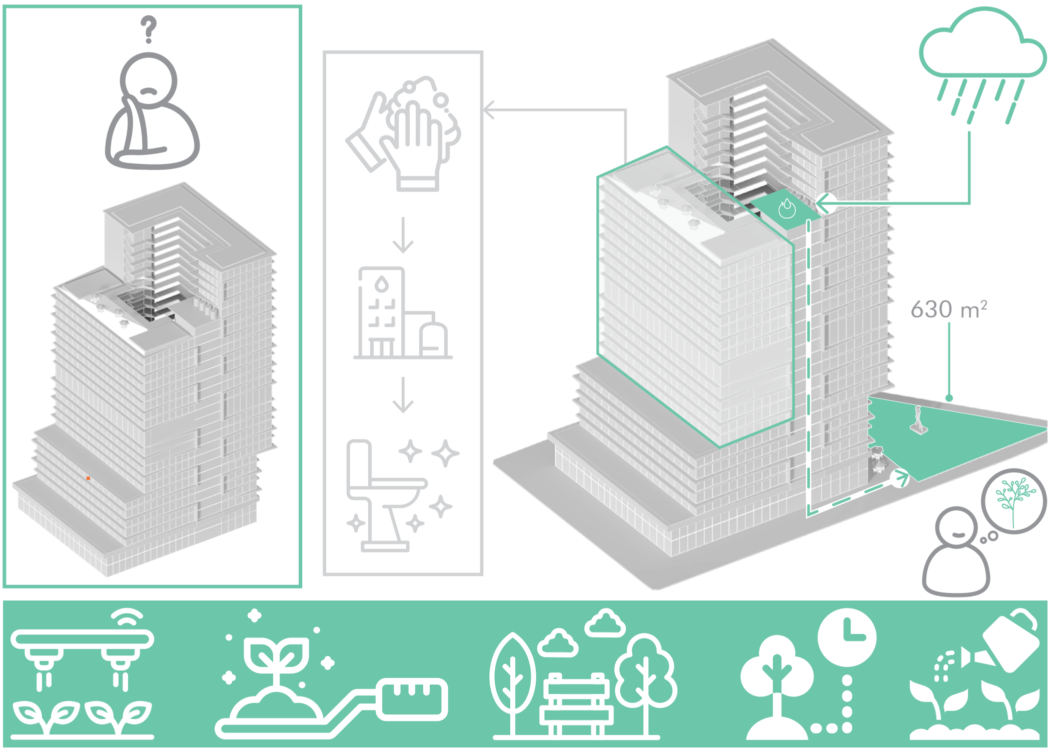

*Figure 2: A summary of the results – we need more green space.*

It quickly becomes clear that the green space is not enough to bring the Anthropocene Design into equilibrium. As it stands, either we need to somehow deal with over 48 thousand litres per month excess (which is still a big reduction over the nearly 113 thousand litres per month average it would otherwise be), or we need to incorporate more green space. In other words, the objective becomes to harness green infrastructure to move the average irrigation demand line up in Figure 2, such that the yearly excess is equal to the deficiency.

In this case, we need a *further 630 square metres of water-hungry intensive green space, needing 5 litres per m² every two days.*

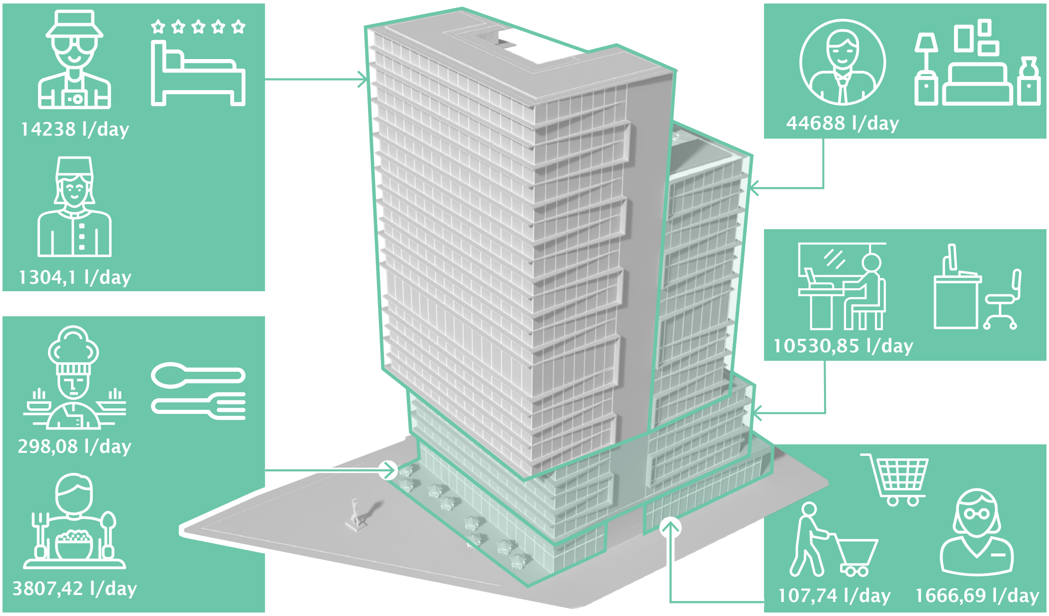
## Where to put it all?

We decided it could be incorporated at a ground level, creating a park surrounding the construction footprint that was within the plot of land of the project. We could have looked at vertical gardens within the building (a design we have used on many occasions), we could have sought more roof space. There is never a fixed, definite answer for Design in the Anthropocene, the possibilities are almost endless!




## How many litres are we talking about?

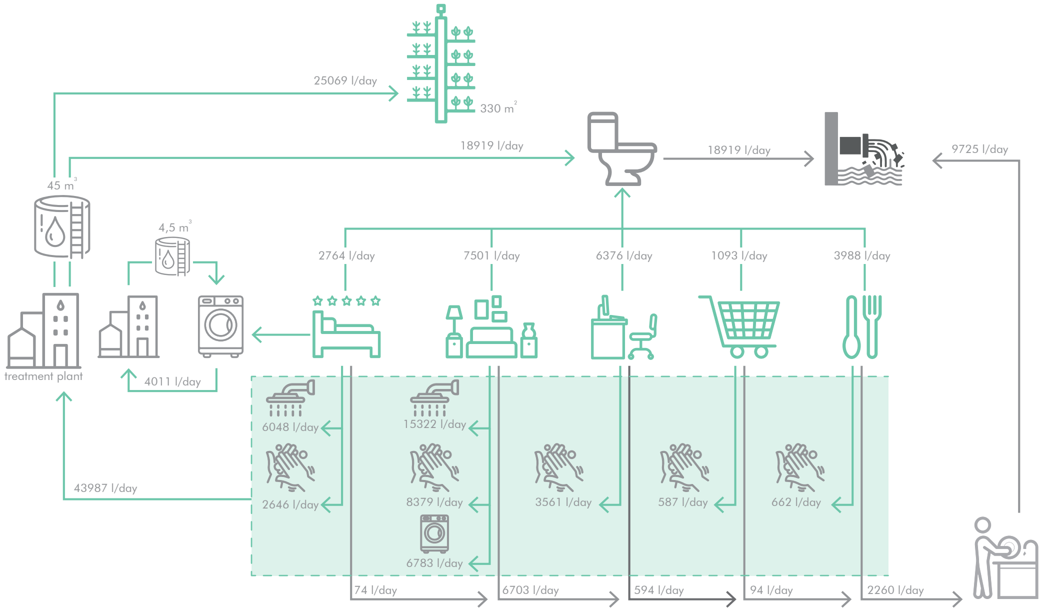
Bring together over a decade of sustainability consultancy work, several research projects and many, many undergraduate student projects, and we get to the numbers that are shown in the flow diagram on the next page.




Just as was said previously: be warned! These numbers are not omnipresent and are for this specific hypothetical case study in Quito, Ecuador only. You need to get up, get out and get your fieldwork done to quantify the number of litres in your particular project.

## Surely we can do better? Let's be savvy with greywater.

Earlier in the book, great attention was given to the ability of a toilet to contaminate water in the most efficient manner possible. It was also mentioned how ludicrous it is to get high-quality drinking water and then to literally flush it down the loo. Finally, it was highlighted that if we wish to do sensible things, such as recycle greywater from the hand wash basin to the toilet cistern, then it is necessary to know if we have too much or too little water from one use to the other. It is here that a flow diagram can be useful to explore, mix, match and play. We chose the following configuration for the Verticapolis project, not because it is *the* correct answer (there are many, many possibilities), but simply because it seemed the most elegant solution for this project at this time and place. The flow diagram materialised as shown overleaf.



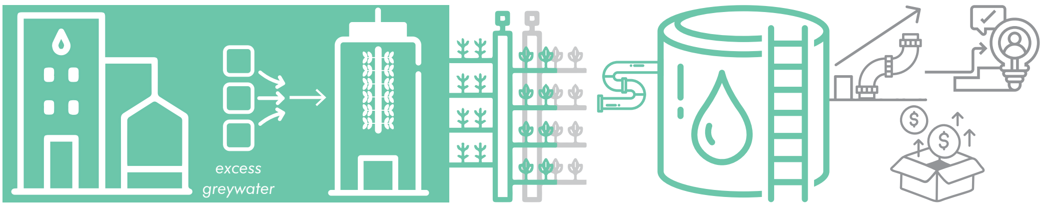

Greywater is harnessed as a resource that can be treated and re-used for other water demands. Toilet flushing is an obvious choice, laundry machines are another. Also, whilst this project has the luxury of being hypothetical in nature (we have more flexibility to do whatever we like), there does need to be a certain sense of reality in place. With laundry and washing clothes, people don't like to use the shower water of their neighbour to wash clothes they put on, treated or not. The opportunity we identified was in the hotel: the greywater from the laundry machines is collected, filtered, cleaned and re-used. It becomes in essence a closed cycle, being relatively easy (and not too expensive) to do so. People are generally happier with treated greywater being used to flush the toilet, as they don't have any personal contact with toilet water. This was the strategy adopted for the Verticapolis project: water is collected from the showers, washbasins and residential laundry machines, sent to an internal water treatment plant and used to flush toilets[12].

[12] Please note that I am oversimplifying what is devilish in the detail. Big, expensive water treatment plants and pumps are needed to recirculate water in a building as massive as the Verticapolis. It might make more sense to decentralise the water infrastructure in reality, with different plants for different areas of the project (hotel, offices, commerce), or to separate by floors in order to mitigate the costs and risks of mega-pumps.

However, this is not enough.

You can see in the flow diagram how an excess of greywater is created, with just over 25 thousand litres per day being left over. We can't just send this to irrigate outdoor space, we don't have any more after the "It's raining it's pouring: let's go green" section. So, let's look inside. We've had much success over the years in using recycled greywater for the irrigation of vertical gardens. Vertical gardens can also be a great addition to a building: they improve air quality, biophilia levels, the general well-being of the occupants and have a cooling effect. They also give the project a positive, green image (see the Annex titled "Incorporating Green Infrastructure"). In this case we could solve the excess greywater problem with just over 330 $m^2$ of vertical green space in the building interior, which was fairly straightforward to incorporate into the design. However, for the astute readers: you will have noticed that dirty dishwashing water is sent straight to the sewer. Remember it's the most contaminated of the greywater bunch, with greases and fats included. We don't think it's a good idea to reuse it for vertical gardens, as they can be quite sensitive to that sort of thing.

Please note, the extra water piping, greywater treatment plants and storage cisterns cost money! In order for this strategy to be financially feasible in practice, you either need the water to be an expensive resource that the client needs to reduce at all costs, or a sustainable certification requiring the infrastructure to be in place (LEED, BREEAM, EDGE, etc), building regulations that give rewards that make the extra investment worthwhile[13], or an extremely environmentally-minded client with a deep pocket.

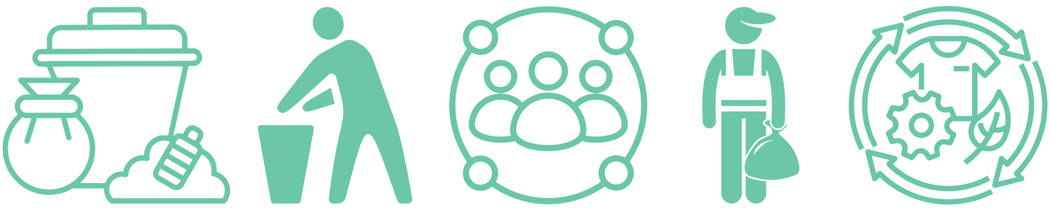



[13] As has been the case in Quito.

# Verticapolis: Soil

## Let’s get loopy: it’s all about people

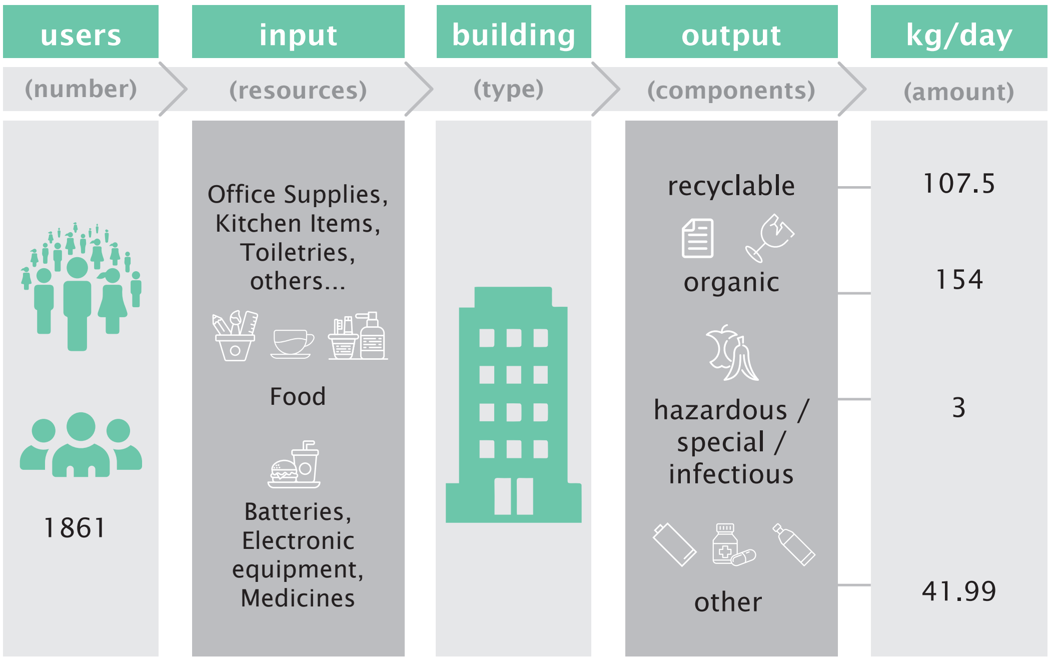
I mentioned in the ‘‘Let’s get loopy’’ section of the book how important it is to think about people, and not just kg and $m^3$. Often in the ‘Global North’, ‘Developed Economies’, etcetera, etcetera, much industry is dedicated to waste collection and transformation. In the rest of the world (the majority) we need to think of much simpler, more efficient processes, where the key is people. I am writing this book from a city where I can proudly say that families and organised cooperatives are effective in sorting waste and ensuring everything recyclable is taken to central facilities to transform it into raw materials. In order for this to happen, however, we need to ensure that our building design facilitates the sorting and waste collection.



For example, there is little use in putting the main bins at the bottom floor of the multi-level underground carpark, if the very location makes it difficult for informal and formal waste collection services to reach the resource. In short, it has to be as easy and convenient as possible to separate the waste at the source (i.e., have the building residents and users divide the rubbish into different bags, collected on distinct days), then have the waste collected through different collection processes (municipal or through families and cooperatives) so that it can become part of the circular economy (via recycling centres, agricultural farms or similar). It is also most important for hazardous waste to be easily separated, as even if a small amount gets mixed into the other waste streams, it has the capacity to contaminate and ruin a great amount of effort put into processing the correct waste flows.

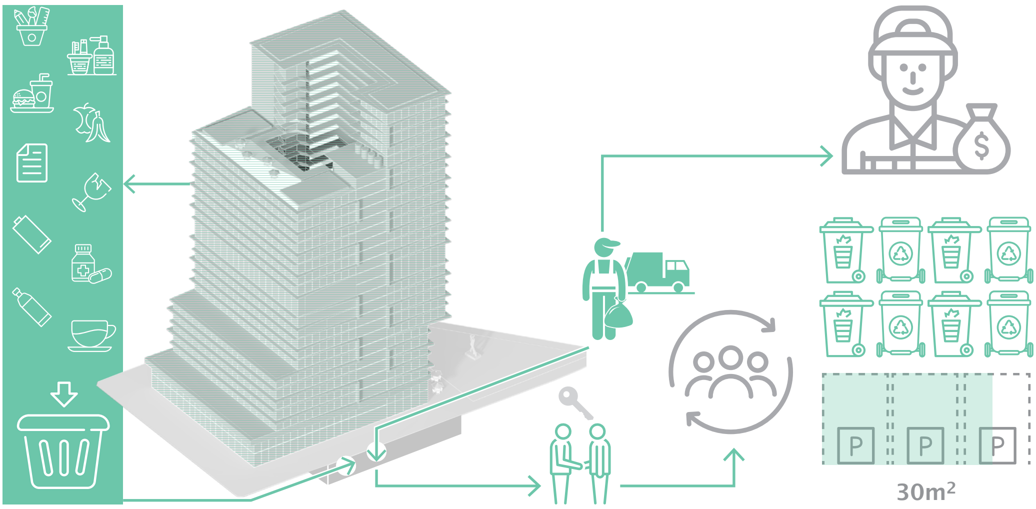
## How many kg are we talking about?

For our case study, the Eco-Balance became as follows:




Once again, *these are wrong for you to copy and are in general for Quito, Ecuador only.* It is distinct for Mumbai, Los Angeles, Christchurch or Edinburgh. You will need to carry out your fieldwork research to quantify the kg for your project!

The total amount of space needed is 30 m². This is not very complicated, being relatively easy to fit into the Verticapolis project in a manner that gives room for sorting and access to the pickup trucks usually used by families and cooperatives to take the recyclable waste away.




## All in good time: space and soil

Now let's move on to the composting exercise. This will be the same process as we saw in the previous section of the book ("All in good time"), but the building is bigger, the quantities are greater, and the space required is larger.

Drawing on the many years of research and experience in the field of one of the collaborators of this book, the enviromental engineer Adriana Mejia, the Ecobalance for the Verticapolis gives the result:

| 154 kg of organic waste per day. |
|---|

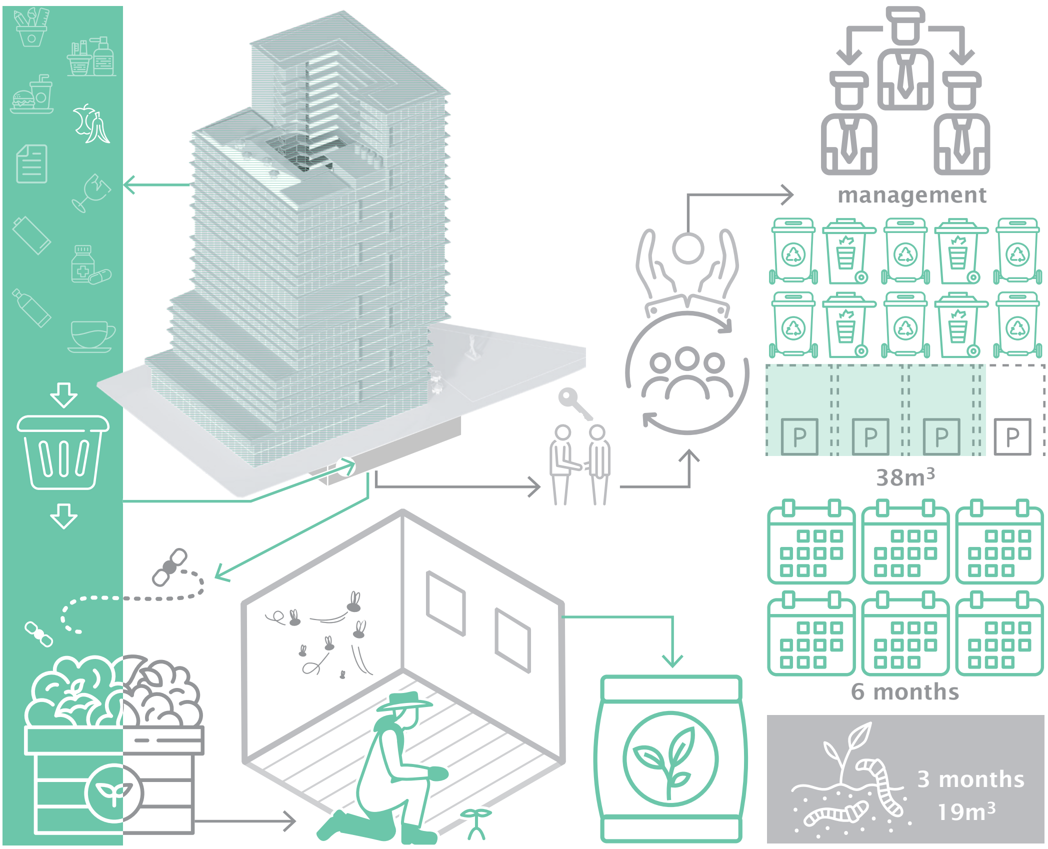
We know from the "All in good time" section of the Soil chapter that a well-managed, possibly vermiculture (worms) compost can reduce organic waste to soil in 3 months. We also know that organic waste has an average density of 750 kg per $m^{3}$.

Every month the Verticapolis produces approximately 4774 kg of organic waste[14], or 6.4 $m^3$. As such, we would need a minimum of

[14] Taking a worst-case scenario of 31 days in the month.

19 m³ for the whole composting process[15] if vermiculture is used, or just over 38 m³ for a full 6-month composting process.

As mentioned previously in the book and later in the Annexes, we also need to remember the management side of things. I'll only be presenting the kg, m³ and m² here. But it is important to remember that composting is an art, a process that needs great care. Without having someone, or a team, to manage and be responsible for the process, there is a great risk that it will short circuit, smell, and attract all sorts of insects and rodents. If this happens the design fails, you therefore will also have failed.




[15] Or set up an agreement between the building administration and a local waste management provider. The example that was given previously was of a pig farm, which can make good use of organic waste to feed pigs.

# Design in the Anthropocene and bringing everything together

There is no one-size-fits-all answer to any Design in the Anthropocene, and the case study drives this point home. If you don't have enough space in your project, then you must at least recognise its limitations. Or better still, get creative and move beyond the project boundaries. Far from being a hindrance, the limitations can be transformed into unexpected opportunities. Your project could have a beneficial impact on Mother Nature, instead of demanding ever more resources from her.

There is no option that is immediately obvious. You need to weigh up all the different possibilities and choose the one that speaks to you most. In the case study, we decided to bring solar photovoltaics into public space. Our water management systems led to the creation of green roofs, vertical gardens, and a park. The in–house waste management enabled kitchen leftovers to become compost. Verticapolis might seem like a utopia, but it is more tangible than you think.

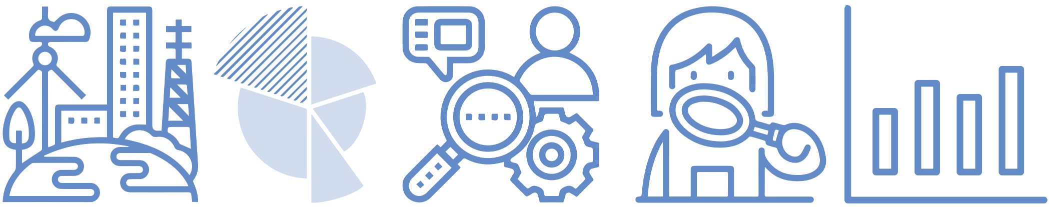
Maybe you disagree and argue that the future lies in having urban suburbs with communities that produce their own energy, process their own water, grow their own food, and produce soil. You could be right, in fact, anything is possible.

You now have the ability to use a few very simple rules of thumb to change the world. Beyond talking about some random ideas, you can quantify your thoughts and bring them into action.

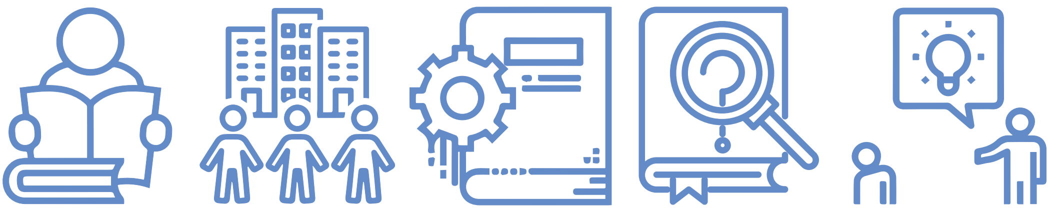
The nuts and bolts behind the rules of thumb were developed through experience and many lessons learnt from mistakes. If you're curious about these seemingly black boxes, you will no doubt enjoy exploring some of the Annexes.

I wish you the best of luck in your next steps, because it is an exciting journey!

# The Annexes



*For those who would like to explore some of the points raised in the chapters of the book in further detail, with some of the nuts and bolts behind the rules of thumb that were given.*



# Research Techniques

There are two broad fields of research techniques: qualitative and quantitative. Quantitative are often the most widely known, such as surveys or questionnaires. These are the ones typically used before democratic votes, or for market research, or health studies. They usually give answers along the lines of '48% of people prefer red tomatoes, 26% would like it if they were blue, 16% would rather pink and 10% were not sure'. The output is usually percentages, trends and numbers.

However, whilst quantitative research is incredibly useful in telling us 'what' the results are, it doesn't usually go very deep into 'why' the results are so (for example, why do 16% of people think pink is a good colour for a tomato?). This is where qualitative research comes into play. It explores people's opinions, beliefs, and views. It gives people time to develop and express their own opinions, and not be restricted to the more binary yes/no/maybe answer found in surveys and questionnaires.

I've covered a few different techniques below. The qualitative ones are observation, semi-structured interviews and focus groups. The quantitative one is questionnaires. This is by no means an exhaustive list, but it does cover the methodologies I've found to work well in practice for Anthropocene Design. I thoroughly recommend using a mix. Kicking off with observation can give you an idea of the context you are working in. You can then get a feel of what to include or not in the quantitative stage (questionnaires), then finally deepen your understanding through semi-structured interviews or focus groups.

# Observation

The art of looking, seeing, listening, noting down, understanding. Observation is a powerful tool that is especially useful in order to get an idea of what is going on, where, and even to an extent why. It's often a useful point of departure for research. There are two techniques for observation: participant and non-participant. For participant observation you become a member of the study group, where you gain a first-hand experience of the activity you are trying to comprehend, whilst at the same time keeping an objective mind to observe how the group lives and experiences the activity. This might seem a bit bipolar at first, but is easy enough once you get the hang of it. The non-participant observation sets out to avoid becoming part of the activity, in part because you might influence the carrying out of the very activity you are trying to observe. This means you take on the role of the onlooker, blending into the background and keeping your eyes, ears and senses open to soak in what is going on around you.

Everyone's memory has a limit, and so you will need tools to log and record things that might be useful. Photographs, videos, recordings and notes jotted down, they can all come in handy. You need to have something you can later refer back to and locate in a spatial, geographical, and emotional time frame. So for example, it is no good taking a photo that you later look at again to think 'Oh yes, now….where did I take that?'. You need to have the photo backed up by a written note, to keep its geo-spatial, sensorial context.

# Semi-structured interviews

Usually taking between 25 minutes and an hour, you can think of a semi-structured interview as a conversation that touches on the issues that you would like to explore in further detail. It's a manner by which you can invite the interviewee to express their opinions, thoughts and views. In order to do this, it is useful to keep a few things in mind. First and foremost, it is hugely important that the interviewee feels comfortable, relaxed and therefore able to freely express what s/he thinks. You therefore need to prepare the space where the interview will take place. Is the temperature too hot or too cold? Is the lighting comfortable? Is the room stuffy? Do you have something to offer, such as water, coffee, tea, biscuits etc.? All of these little details will make a real difference to the spread and depth of results you might achieve. Second, you need to have an interview schedule (framework with a list of items to cover). This should include some of the more obvious basics of inviting someone to converse. For example, it is easy to forget to welcome someone to the interview, explain why s/he has been invited, briefly describe the objectives of the study and above all, to thank them for taking time from what is usually a busy day to be there. You then have questions you would like to discuss and it is handy to have them noted down. Make sure that these are not simple yes/no/don't know type of questions, but that you have framed them in such a manner that they invite the interviewee to explore her/his views. For instance, asking the interviewee if s/he thinks energy efficiency is/is not important leads to a short answer. But if you ask her/him what s/he thinks the most important aspects might be for a family seeking to lower their energy bill, then there is more space to explore the interviewee's opinions and views. Finally, don't forget to bring the interview to a nice, rounded off end. Once again, it is important to thank the person for the time s/he spent with you, let her/him know that you have very much appreciated the conversation, and answer any final doubts s/he might have. Make sure the interviewee walks out feeling that it was a nice experience, which s/he might be open to repeating in the future.

Additionally, an advantage of this type of methodology is that it allows for some flexibility. For example, imagine you wish to discuss preferences and opinions regarding greywater recycling. The interviewee might not be interested or comfortable to discuss this and go off on a tangent onto another subject, say, such as driving that morning in a torrential downpour. In this case you, will need to gently guide the conversation back to the issue at hand, perhaps to another item on your interview schedule. However, if you find that the interviewee begins to go on a tangent that you feel is useful for your work, then you are free to encourage them to explore it further. For instance, you might have asked the interviewee what s/he thinks of recycling water from the shower to wash clothes and in their answer s/he recalls being at an Ecolodge where a rainwater collection system was used for the showers. This wouldn't strictly speaking be an answer to the topic you put on the table, but it is nevertheless a hint of the direction that your Anthropocene Design might take.

Finally, you will need to process your results. It is handy to have recorded the interview, but this will depend on whether the interviewee is happy or not with doing so.

Notes can also be jotted down, but where you need to make sure the interviewee feels s/he is being listened to (difficult to do when you constantly look at your notebook instead of her/him). In short, you will need to find what works for you, but need to be able to have something that you can come back to. In processing the results, you are looking for views, opinions and elements of interest that come from the interviews. Finally, I have found the sooner you process the results the better. It is easier to remember points of interest and nuances of what was discussed immediately after the interview if it is fresh in your mind. You will probably find that days later the interview will have started to retreat into the dark mists of memory.

## Focus groups

Being a group discussion, focus groups usually need more time than a semi-structured interview (45 minutes to 1.5 hours). However, the points that were made above for semi-structured interviews about having a comfortable setting, preparing a schedule (framework, list of items and/or questions) for the session, welcoming and thanking the participants, conducting a conversation, bringing things to a close and finally processing the results are all equally as important for focus groups. Whereas a semi-structured interview allows the interviewee to talk about and explore her/his personal views surrounding a subject, a focus group creates a conversation between the people through which points of interest can be explored. For example, common lines of thought might emerge, or new ideas arise. Focus groups are often used in marketing, where a company wishes to discover how potential consumers might respond to the release of a new product. For instance, they might be invited to a round table discussion to explore a new phone, food or drink.

You will usually need to work in a team for focus groups. First, it will often take more logistics to have more than one participant free on the same day and at the same time. The running of the session will also require a number of different roles. One person needs to lead and facilitate the conversation. This is a role that requires skill and concentration. For example, it needs to be ensured that every member of the group gets the opportunity to express her/his opinion. So, if one loud voice begins to dominate the discussion, the facilitator needs to be able to encourage other participants to enter the conversation. Then there needs to be at least one observer, who acts as a non-participant (see the previous section on ''Observation''). This is an important role to ensure that all of the key points and items of interest are noted down. Also, these might not be verbally expressed, where for example the enthusiasm of a participant might be expressed in a smile and body language.

## Questionnaires

Finally, we come to questionnaires. This is an example of quantitative research, which can give us an idea of numbers, percentages and tendencies. Questionnaires can be carried out in person, or by using one of the many online tools available nowadays. You'll need to consider what type of people you are looking for, and what the best manner will be to reach them. For instance, if you wish to find the tendencies in collar colour preferences for dog owners, there is little use in sending out questionnaires to people who specifically have cats.

Then there is the question of having a reliable representative. In statistical lingo, it is common to have a 95% confidence interval or 5% error margin. This would mean that you can be at least 95% sure that your answer represents what other people think, but you might still be 5% uncertain if this will always be the case. You might also hear of a representative group, where a small number of people are assumed to represent a larger swath of the population.

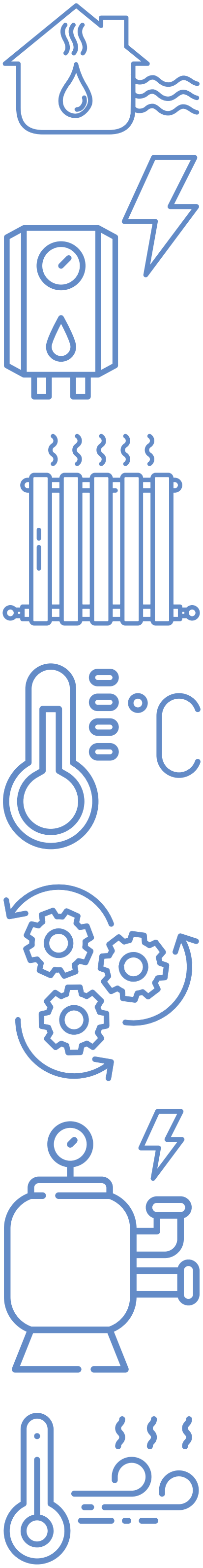
If you are involved in an urban planning project at a large scale, these issues are important enough that the research will need to be carried out by professional specialists in the field. If you are at a building level, then be sensible. It is unfeasible to insist on having questionnaire results from every single person who will need to have signed the contract to purchase her/his department in the building, plus everyone who is to work in the offices, as well as the owners of the yet-to-be constructed commercial areas. Likewise, you cannot expect one, sole questionnaire to have results that are representative of all the end users of your building design. You will need to have a number that you can justify is sufficient for your design inputs, whilst also being achievable by your team within the time and budget available.

In a similar manner to all the qualitative research techniques described above, the questionnaire will need to be prepared, carried out and then the results processed. As mentioned previously, observation is always a good starting point before determining exactly which questions would be good to ask, but this order is not set in stone and you should follow the route you think best for the project at hand.

After you get the results of the questionnaires, they can be processed to find out *what* things you need to know, producing nice tables and charts. This won't be of much use however, if you are not aware of *why* this is the case. For instance, the survey results might show that the potential end users of your building are not prepared to compost their own organic kitchen waste in their homes. And yet, a focus group brings to light that this is because compost is associated with plagues of fruit flies. The problem therefore isn't so much the compost but the fruit flies, and having a management system set up could mitigate this[1].

In short, mixing the quantitative nature of questionnaires with a complementary qualitative study stands the most chance of success when you seek to bring in the most important considerations for Design in the Anthropocene, which, whilst innovative, could bear a heavy risk of being a failure through rejection from the end users of your project.

[1] Fruit flies also occur if the organic waste is stored for a day until an outsourced pick up service takes it away!



# Sun Annex

## Water and space heating: having the capacity and not losing it

We need energy to heat water to shower, wash dishes and suchlike, or warm up a room so that we don't feel uncomfortably cold. There are two manners that we can go about calculating this.

The first is similar to the methodology that was used for the other items in the ''How much are we actually talking about (in kWh)?'' section. You simply take the potential of your (electric) water and space heaters, you determine how long they are switched on for (through research) and, hey presto! You have the result.

You can also estimate the result from first principles, which is quite an interesting exercise, and we can have a look at it here.

### Let's start with water

Water has a *specific heat capacity*, which means the amount of energy that needs to be somehow injected to heat 1 litre of water by 1 degree Celsius, which in this case is 0.00116 kWh/ltr/°C.

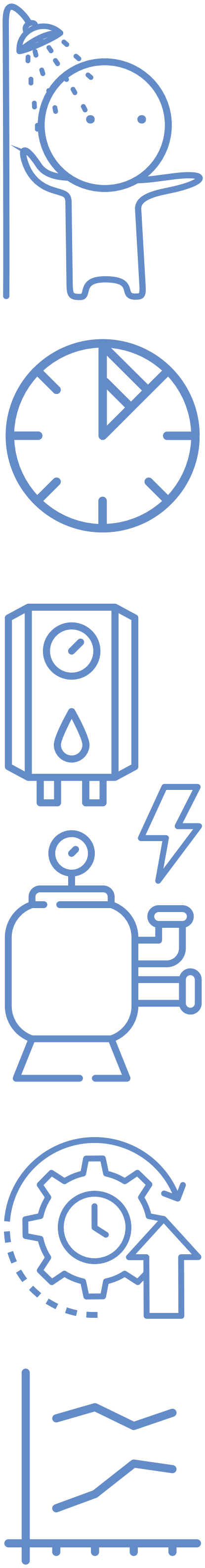
We also know the boiler that heats the water has a certain degree of efficiency. This means that for every litre of water passing through the boiler some of the energy will be lost due to energy transitioning from electric currents, metal resistors etc. to the body of water. Boilers can be incredibly efficient nowadays, just shy of 100%. Even better, for any high-rise building I have worked on over the last 10 years the water is heated through heat pumps. These use electricity to run, but where the (large amounts) of energy needed to heat water is taken from the air. The air can be hot or cold, it matters not.

Finally, we will have heat losses. The hot water will flow a distance through water pipes, which for your Design in the Anthropocene should be separated into hot and cold water (different pipes) and very well insulated indeed. The aim is to avoid losing all the energy put into heating the water at all costs.

So, we just need to know how many litres of water we need to heat, how many degrees we need to heat the water, the efficiency of the boiler or heat pump and the potential loss as it flows through the pipes. The litres are notoriously difficult to determine, and this is discussed in the ''How much are we actually talking about (in litres)?'' section of the book. It requires fieldwork research and interaction with the sample of what would be the end-users or residents of your project.

The number of degrees you need to heat the water can be assumed to be the difference between the temperature of the water coming out of the water network and the heated water used in the shower or tap[2]. The efficiency of the boiler or heat pump can be

[2] A bold assumption is made here. Boilers and heat pumps will have to heat water to well over 60 degrees Celsius in order to kill off any bacteria or nasties that might otherwise build up in warm water tanks. But this is far too hot for us to use. In reality therefore we mix scalding hot water with cold to get the correct temperature. In this Annex I am assuming that in the mix no energy is lost. Building systems engineers are free to give me a righteous slap on the wrists.



gained from the technical specs of the product that will be installed. And the losses have to be minimised as far as possible.

This can be illustrated with a nice, warm shower. We'll assume the person has a shower that uses 100 litres. Don't quote me on this! For your design you need to determine the length of time showered and the water usage through your fieldwork research[3]. Let's assume that the water flows through the ground into the project at around 10 degrees Celsius. We then heat it up the warmest temperature a person can comfortably bear, some 37 degrees Celsius. This gives a change in temperature of 27 degrees. The boiler efficiency is near to 100%, where we'll assume 98% for this exercise. For a heat pump we'll need the Coefficient of Performance: for every kWh of electricity to run the heat pump, it takes a corresponding number of kWh of thermal energy out of the air to heat water. This equates to over 100% efficiency, as for every kWh of electrical energy there is more bang for your buck in terms of the thermal energy. For example, a pretty good heat pump has a COP of 4.5[4], meaning for every kWh of electrical energy the heat pump draws 4.5 kWh of thermal energy out of the air. This might seem counterintuitive, as if the heat pump were somehow 'creating' energy. But it is simply that of the total energy used, most of it is thermal and comes from the air. Finally, we take into account the risk of losing some of that hard gained heat as the hot water gets transported through the pipes to the end point of use.

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[3] The time, length and frequency of washing being an exceptionally sensitive subject.

[4] Used in most of the buildings I have consulted on over the past few years.

For now we will simplify this and assume that you have your plumbing shipshape and that your Anthropocene Design includes the budget needed to insulate the hell around your piping, which would minimise the heat loss.

So, for this particular, theoretical exercise we have: 100 litres of water, heated a total of 27 degrees Celsius, which equates to:

> *100 ltr X 27˚C X* 0.00116 kWh/ltr/˚C = *3.13 kWh for the shower.*

Now, let's take into account the 98% efficiency for the boiler (divide by 0.98): 3.2 kWh for the shower.

Or, let's use the heat pump with a COP of 4.5 (divide by 4.5):

> 0.7 kWh for the shower.

You can see why heat pumps have become popular in high-rise buildings (also see the next section on ''Solar thermal: we have a long wait''). Needless to say, heat pumps are expensive. In terms of a high-rise building they make sense, as the costs become more competitive when a large heat pump is divided between many apartments etc. However, for a single apartment or house, this is not the case, as the heat pump will be many times more expensive than a condensing boiler or electric water heater. It then becomes part of a cost benefit analysis: how many years payback time for the upfront cost of the heat pump against the higher monthly gas or electricity bills.

# Heating and cooling empty space

Similar principles are true for space heating and cooling. In essence, we use energy to heat or cool space. People in this empty space then experience a heat exchange, where they feel comfortable or uncomfortable due to feeling too hot or cold. Povl Ole Fanger led groundbreaking research in the late 60s and early 70s to define at what temperature people feel comfortable, taking into account their clothing and metabolic rate, as well as the temperature and humidity characteristics of the surrounding environment, combined with the average air velocity. He came to the conclusion that a temperature of around 24.5 degrees Celsius, not too dry, not too humid was the sweet point regarding comfort. Decades later, much progress has been made in adaptive comfort models, as can be currently found in the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) guidelines. These argue that the temperature and humidity levels can be adjusted in accordance with the outdoor temperature[5]. Nevertheless, the basic characteristics of Fanger remain pretty much the same.

Things quickly get much more complicated, and thus provide work for building service engineers, programmers (and now AI) for building modelling programs and PhD doctorate studies for fine-tuning these. For example, the ability to take off a suit jacket,

[5] For example, if you are in a hot, humid environment of 32 °C and 70% relative humidity, and then go inside a building with a temperature of 26 °C and 40% relative humidity, you will feel comfortable. In contrast, if the building interior is 23 °C, you might feel cold. The opposite is also true. If the temperature is 5 °C outdoors and the building interior is 20 °C, you will feel warm and toasty even though it is below the 24.5 degrees Celsius of Fanger.

wear no tie or put on a jumper has a significant effect on subsequent building energy demand. There is also the heat loss coefficient of the building, which David MacKay describes as a building's 'leakiness' [6]. Finally, we need fresh air to come in and out of an enclosed space; otherwise, we would expire from a lack of oxygen (or at least start to feel so cumbersome and drowsy that we would have to leave the building).

Let's consider a standard room with dimensions of 3m by 5m in width and breadth, which is 3m high. This gives 45 $m^3$ of air. For now, we will assume that no space is lost due to inconvenient furniture and suchlike. We'll also assume some sort of space age insulation, where there is no heat loss through the walls, floor or ceiling (MacKay's 'leakiness'). ASHRAE recommends a minimum of 0.35 air exchanges per hour for residential buildings; I'll increase this here to 0.5 (one air exchange completed every 2 hours).

For this exercise the outdoor temperature can be a chilly, 5.5 degrees Celsius (the average for a winter's day in Cambridge, UK), and indoors we'll set 24.5 degrees (Fanger's ideal). We will therefore need to heat the air 19 degrees, every time there is an air exchange. Then let's say that the heating kicks in for 6 hours. In total we will need an air exchange every 2 hours over a 6-hour period[7], giving 3 in total. Lastly, air has the specific heat capacity of 0.00033 kWh/$m^3$/degree Celsius, which multiplied by the 45 $m^3$, the 19 degrees Celsius and the 3 air exchanges yield a result of:

[6] Sustainable Energy Without the Hot Air, pg. 291

[7] A few hours in the morning, then a few hours in the evening.

$45m^3$ x 19 C x 3 air exchanges x 0.00033 kWh/ $m^3$/ ˚C = 0.85 kWh

This is very much an estimate. In reality, we do have all sorts of furniture in the room, we also have people and ‘stuff’ that give off heat. Additionally, no matter how good the insulation is, heat will always get lost. We could add a heat exchanger in the ventilation units, which would warm the incoming fresh air with the outgoing indoor stale air. MacKay tells us that an energy efficient 3-bedroom house built in the last century (1980s) in the temperate climate of Cambridge, UK, used 22 kWh per day for heating on average[8]. MacKay’s retrofitted house only needed 13 kWh per day (mainly due to deciding to heat his home to a mere 17 degrees Celsius). Finally, in the section titled ‘‘Bringing the house down’’ using a heat pump brought the heating demand right down to a mere 6.5 kWh a day.

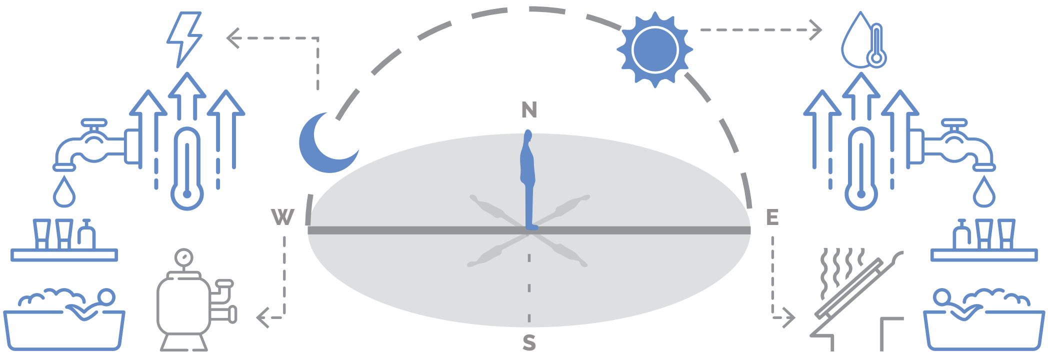
## Solar thermal: we have a long wait

As you will have already noticed, the Sun rises in the morning, arcs through the sky during the day and sets in the evening. Solar radiation and subsequent thermal gain through solar panels follow this pattern. The solar thermal panel starts to gain energy to heat water as the Sun rises; this peaks at some point in the day (depending on the season), and then drops off.

[8] Sustainable Energy Without the Hot Air, pg. 297.

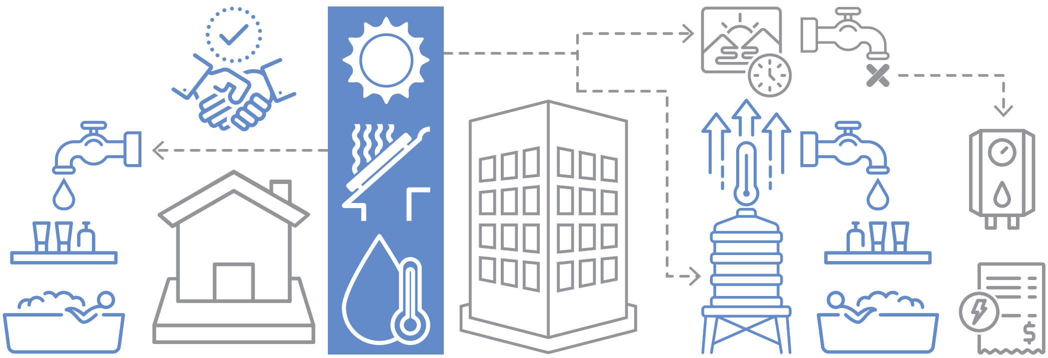
This wouldn't be a problem if we only used hot water once per day after the solar thermal panels had used solar energy to heat all the water in their tank, and then be prepared to wait until the solar panels had heated the water again. In fact, one could argue that in the Anthropocene it would make sense to do so, and 'follow the Sun', so to speak. Unfortunately, we tend not to do that. Some of us wake up in the morning and have a steaming hot shower as part of our morning routine. Others end the day with that hot shower, or sinking into a hot bath. We might even mix and match, depending on the day.

Seldom is it, however, come sometime between midday and 2pm, that most of us will sit up and say: 'Good time to have a wash, and I don't need any more hot water until tomorrow midday'. This has a technical impact. In our consumer age it is unthinkable to not have hot water, even for a minute, let alone a number of hours. To meet this expectation solar thermal systems will have a tank that relies on the Sun as the primary heating source, but have a backup system just-in-case. This backup will usually either run on gas or electricity.



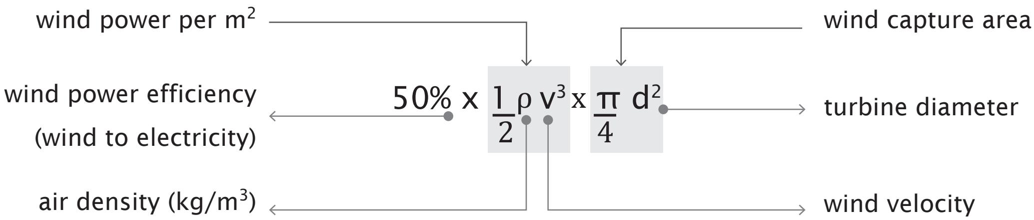

What we have found in practice when using solar thermal for large-scale buildings is that the hot water tank will be emptied early in the morning or late in the evening when there is very little solar gain. As such, the backup system kicks in every day, and the building administration raises a stink about high gas or electricity bills, due to the backup system rushing to fill the hot water tank in the absence of the Sun. This does not have to be the case in semi-detached houses where the client is aware of the Sun, and prepared to wait until the water is heated again[9]. But again, this is not the majority of cases.

In light of this, Design for the Anthropocene recommends (if somewhat controversially) using alternatives for large-scale projects. We have found heat pumps to work very well indeed in practice, which is why we have used one for the case study.



## Wind power: how did we get to 0.00471?

The full equation to get the potential wind power generated would be:




$$50\% \times \frac{1}{2} \rho v^3 \times \frac{\pi}{4} d^2$$

Collecting the numbers together, we get $0.196\ \rho\ v^3\ d^2$ Watts potential, or $0.000192\ \rho\ v^3\ d^2$ kW potential.

Now, have our turbine working 24 hours per day: $0.00471\ \rho\ v^3\ d^2$ kWh production.

---

[9] Although, on wet, cloudy, rainy cold days in the Northern/Southern hemispheres they might have to be prepared to wait quite a while.

And finally, add the Capacity Factor: $0.00471\ \rho\ v^3\ d^2\ CF$ kWh actual production.

*And in case you forgot... Wind power is BIG. This is an actual example from the Central Eólica Villonaco, located in Loja, Ecuador. Photograph by Jaire Cagigal (2024).*

# Biogas: how did we get to 225 kWh per tonne?

In 2016 I had the honour of working with a group of colleagues on a conference paper where we tried to quantify electricity production through biogas derived from organic household waste[10]. I'll present the relevant section of the article here, with a bow to Mathieu Lamour, who was the researcher who cleverly fleshed out this part.

Electricity production from biogas can be estimated as:

$$E_{elec}=Q_{biogas} x F_{CH4} x Cp_{CH4} x \eta_{elec}$$

***Where:***

$E_{elec}$ = the electrical energy produced per tonne of organic residues ($t_{res}$), in kWh/$t_{res}$

$Q_{biogas}$ = the amount of biogas obtained from the organic residues via a biodigester, in $m^3/t_{res}$

$F_{CH4}$ = the quantity of methane (CH4) contained in the biogas, in %

$Cp_{CH4}$ = the specific heat of methane (kWh/$m^3$)

$\eta_{elec}$ = the electrical efficiency, in %

$Q_{biogas}$ and $F_{CH4}$ can vary, where they depend on the exact chemical composition of the organic waste.

The exact ratio of $CH_4$ to $CO_2$ in biogas is related to the type and concentration of organic input, the feedstock of the micro-organisms at work during the anaerobic process, and the process of fermentation. $F_{CH4}$ usually ranges between 55% and 70%, and averages out at approximately 60% of $Q_{biogas}$. Additionally, the following sources can be drawn on for biogas production from organic solid municipal waste:

[10] This section is effectively an extract from Davis, M. J. M., Polit, D. J., & Lamour, M. (2016). Social Urban Metabolism Strategies (SUMS) for Cities. Procedia Environmental Sciences, *34*, 309–327.

- The Institute for Global Environmental Strategies (IGES) GHG Calculator for Solid Waste (Japan): 118 $m^3/t_{res}$, with 60% $CH_4$.

- The Regional Information Service Centre for South East Asia on Appropriate Technology (RISE-AT): 100 to 200 $m^3/t_{res}$, with 55-70% $CH_4$.

- The California Integrated Waste Management Board: 100 to 150 $m^3/t_{res}$, with 50-70% $CH_4$.

For the purposes of the article (and therefore this book) the value adopted was:

$$Q_{biogas} = 125\ m^3/t_{res},\ \text{with}\ F_{CH4} = 60\%.$$

Additionally, the specific heat of methane (also known as net heating value or lower heating value), $Cp_{(CH4)}$ is around 10 $kWh/m^3$.

Finally, in terms of $\eta_{elec}$, this depends on the technology used, as efficiency varies between 25 and 31% (but where certain technologies are capable of up to 43%). The majority of technologies presented have minimum efficiencies of 30%, and this is the percentage we are adopting here.

Overall, the values give:

$$E_{elec} = Q_{biogas} x F_{CH4} x Cp_{CH4} x \eta_{elec} = 125x0.6x10x0.3 = 225\ kWh/t_{res}$$

This means that the expected electricity production from a decentralized biogas plant can be estimated to be approximately 225 kWh per tonne (1000 kg) of organic household waste.

# $H_2O$ Annex

## It's raining, it's pouring

Remember page 31 footnote number 3? 2.5 m by 9.2 m and 7 mm of rainfall equates to 161 litres.

In the section titled ''It's raining it's pouring'' it was mentioned that the annexes would have a runoff coefficient table, and so here it is:

| Surface type | Runoff coefficient |
|---|---|
| Hard surface | 0.9 |
| Extensive greenspace (with a substrate of between approximately 10 and 20 cm deep). | 0.6 |
| Intensive greenspace (with a substrate of around 20 cm to 40 cm deep) | 0.4 |

*Table 3: a reference table example for surface runoff coefficients that were used for the Verticapolis case study.*[11]

Remember, when we say a hard surface has a runoff coefficient of 0.9, this means that 90% of the water that falls upon the surface flows away, and 10% is absorbed by the surface. The same applies to the rest.

There will be slight differences between one table and another. For example, some sources say that a hard surface quickly becomes saturated and that *all* the water flows away. This is true in heavy rainfall, but not so much in lighter showers after a couple of hot, dry days.

In the end, you will have to choose what you think is best for the

[11] Recovered from: Apéndice C3_3.1_02 Regla Técnica de Aplicación del Estándar de Edificabilidad del Plan de Uso y Gestión de Suelo (PUGS) de la Secretaría de Territorio, Hábitat y Vivienda del Municipio del Distrito Metropolitano de Quito (DMQ) (2021).

project you are working on and the environmental conditions of the area.

## Incorporating green infrastructure

Incorporating green infrastructure into your project will have multiple benefits, ranging from mitigating unnecessary thermal gains on the building, to the sustainable management of rainwater runoff, biophilia for the end-users of your project and having a positive impact on local biodiversity.

This then begs the question: what design strategies can be used to maximise green infrastructure in our design projects?

The answer lies in harnessing the power of Mother Nature to incorporate green space into your project design, in a manner that is beneficial for the environment, mitigates the detrimental effects of climate change and is valued by the end-users.

In this annex, we'll consider three types of green surface: extensive or intensive horizontal green roofs, and vertical gardens[12]. Also, we'll give a brief consideration to urban agriculture. Then, we'll talk a bit about bioclimatic design and finish off with biophilia.

If you look at the ''It's raining it's pouring: let's go green'' section of the Verticapolis case study, you will see how this is done in practice: a game of playoffs between water absorbed and water harnessed in the

[12] Although green infrastructure can take many forms, including rainwater gardens, ponds, lakes, reedbeds, biofilters and water treatment areas, to name but a few.

design of the green infrastructure of the building.

Let's talk here in more detail about what we mean by the three types of green surfaces.

## Green roofs

To begin with, extensive green roofs refer to thin layers of substrate that are populated by local plant species. They are generally characterised by having lower rates of rainwater absorption than their intensive garden counterparts, needing little irrigation outside of natural rain cycles, being of very little maintenance and generally are not accessible to the public. The substrate will usually be between 10 and 20 cm deep, which means that the green space will usually be less heavy than an intensive green roof. The term 'green' is used here, but in a dry season an extensive roof might seem quite dry and brown[13]. To this extent, it's important to choose the vegetation for the roof carefully. You will need to consult local experts who are familiar with the plants that will survive over periods of peak solar gain and can highlight any possible maintenance issues[14].

Otherwise, leaving the work to Mother Nature can also be an option. Given the right conditions, she will populate the roof with local plant species who make it their home.

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[13] Hence, they are generally used in roofs that are not accessible to the public: they play an important role in rainwater management and have a positive ecological impact, but might be less attractive for residents to have a 'stroll around the garden' in.

[14] Especially in the tropics, rainforests and similar! For example, the cloud and rainforests can populate any substrate with surprisingly large plants.

Moving on to intensive green roofs, these are basically a garden. They are more suited to areas where residents can walk around, and interact with, the green space. They generally have a greater rainfall retention capacity, but this will come hand-in-hand with higher maintenance needs and irrigation demands[15]. In this case, the substrates will need to be deeper, usually from 40 cm and above, depending on the plant types used. You should have a landscape or garden designer in your team. The structural engineering team will also need to be brought on board, as these kinds of green roofs are heavy!

Finally, be it an extensive or intensive green roof, the devil will be in the detail of the drainage system. Water will always choose the easiest route to follow, and if the drainage system has not been properly installed you will no doubt have water infiltration issues. Nowadays, green roofs are often supplied with a drainage layer as standard. Otherwise, you will need to incorporate this into the detailed design.

*An intensive green roof in Sense, a project in Quito, Ecuador, by Álvarez Bravo Constructores S.A. with sustainability consulting from Evolution Engineering, Design and Energy Systems Ltd. Photograph by Michael Maks Davis (2025).*

[15] Which might also be useful if you need an area to re-use greywater produced by the project.

# Vertical gardens

Vertical gardens can be beautiful and tend to be expensive. There is no better way to make a building shout a sustainable statement than having greenery spread over its facades to show to the world, where they have gained traction worldwide over the decades.

*Vertical gardens by the Green Star Landscaping Group for Essence, a project in Quito, Ecuador, by Rosero Constructores S.A. with sustainability consulting from Evolution Engineering, Design and Energy Systems Ltd. Photographs recovered from the Green Star Landscaping Group archive, 2022.*

In general, you will find the majority of vertical gardens to be of a hydroponic type, where the plants sit in an artificial substrate and are fed by a nutrient-laden irrigation system. However, this can also make them sensitive to change. If the irrigation system fails, the plants will dry up and die. Maintenance should therefore always be incorporated into the project design. The garden is open for everyone who passes by to see and enjoy, where a garden replete with abundant plants and flowers will draw an appreciative eye, but a dry wall with drooping brown vegetation will do the opposite. This can be ameliorated to some extent by using a soil-based substrate instead of an artificial one, but these are heavier, need a stronger supporting structure and can be more expensive to install.

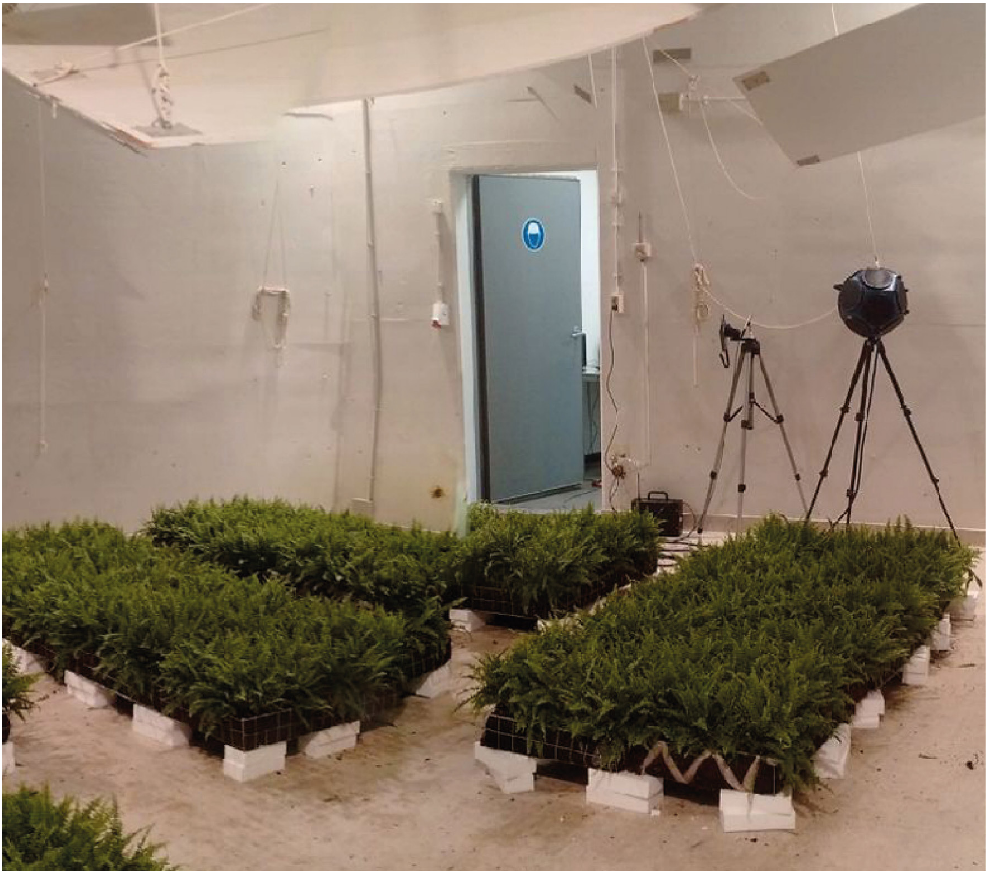
Vertical gardens can also act as an ecological haven, where the right choice of plants can attract birds, bees and butterflies[16].

*Two vertical gardens in Quito, Ecuador. At the Faculty of Arquitecture of the Pontificia Universidad Católica de Ecuador (Left). In the Mediagua showcase sustainable house of the Yaku water museum (Right). Consultancy services from Evolution Engineering, Design and Energy Systems Ltd. and photographs by Michael Maks Davis (2015, 2025).*

Given the cost of a vertical garden, you probably will need to convince your client that it is worth the investment. This might be through the fact that they look amazing on a building and are essential for the image that wants to be shown. Otherwise, the Verticapolis case study shows how they can be useful when you need green space for greywater recycling, but are short of horizontal surfaces.

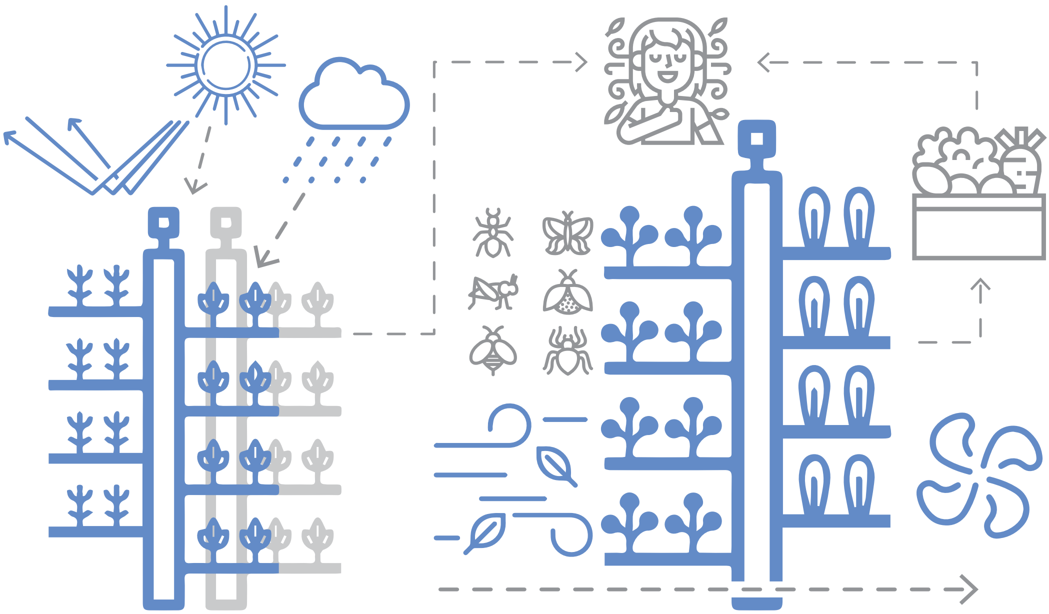
[16] We once found a happy looking frog halfway up a soil substrate vertical garden used for research.

Vertical gardens are also effective for the absorption of noise, depending on the substrate used. Think of it like this, waves of sound can interact with a surface in a different number of manners. A reflective surface will 'bounce' the wave back and echo. An absorptive surface will do the opposite, where the sound disappears. A vertical garden is planted in a substrate that acts as the latter. A thin substrate will absorb some of the sound waves that fall on it. A thick substrate will absorb most of them. A soil substrate will most likely absorb them all. Note: this effect becomes negligible if next to your garden is a massive wall that reflects the sound.



*An image of the research behind the academic article: Davis, M. J. M., Tenpierik, M. J., Ramírez, F. R., & Perez, M. E. (2017). More than just a Green Facade: The sound absorption properties of a vertical garden with and without plants. Building and Environment, 116, 64-72. Photograph by Michael Maks Davis (2016).*

Additionally, vertical gardens can help clean air. They act in many ways like trees, where the leaves capture and retain particle pollutants from the air. The extent to which this is effective will depend on many factors, such as the plants used and the concentration of surrounding pollutants. For example, a conglomeration of vertical gardens surrounding a small public square might have many air-cleansing benefits. But, for a small garden with a few plants next to a heavily used bus stop, the effect will be negligible.



In this sense, vertical gardens can transform buildings from having hard, dead facades into air-filtering, sound absorbing, water-recycling and beautiful ecological powerhouses.

Once again, the devil is in the construction detail. A structural support will be needed, which might be independent from the building wall and creates a handy air buffer. Additionally, an irrigation system will need to be installed, including a pump that can push water to the very top of the garden. Water drips down the garden and will need to be collected at the base to reuse in the following round of irrigation. This will entail a water filter, to stop sediment, leaves and suchlike bunging up the water irrigation points. Nowadays, there are many experts in vertical garden design. Get them on board for your project.

# Urban agriculture

Urban agriculture is another kind of green space: one that produces food. Instead of having a green roof or vertical garden for purely ecological and aesthetic purposes, you can incorporate green infrastructure in the form of tomatoes, broccoli, kale, onions, etc. A whole book could be written on urban agriculture alone, it encompasses the skills of farming interwoven into the city-scape. We are only going to touch on some basic concepts here.

*An example of urban agriculture in action: AMIRA project by Álvarez Bravo Constructores S.A. with sustainability consulting from Evolution Engineering, Design and Energy Systems Ltd. Photograph by Josué Serrano (2025).*

In theory we could go through the whole cycle, and take the compost produced to feed into your urban agriculture and green space. However, in practice you will generally produce more than is most likely needed. Additionally, foodstuffs like tomatoes and suchlike will need feeding every few weeks when they are in their main growth stage. But mature plants, lawns and similar vegetation might only need composting once or twice a year. So, you will need to get expert advice on board.

Also, it is not enough to simply 'install' a vegetable plot in your project. You will need to define who is in charge of the urban agriculture in your design. Does everyone have their own vegetable plot? Does the building administration take on the responsibility?

*Some examples of urban agriculture in Quito, Ecuador. Top: the Yaku Water Museum. Photograph by Michael Maks Davis (2025). Bottom: the HUMA project by Álvarez Bravo Constructores S.A. with sustainability consulting from Evolution Engineering, Design and Energy Systems Ltd. Photograph by Adriana Mejía (2022).*

One of the most enthralling case studies I have come across was a high-rise building that installed recycled PVC tubes to create an interior vertical farm. The security guard had green fingers, growing lettuce and other produce. The crops were then distributed in vegetable boxes sold at each apartment. It was probably one of the most successful initiatives in compact urban agriculture I've ever seen. The lettuce was even served as a salad to the Vice-minister of the

Environment at a reception for an environmental recognition award ceremony that was held on the building terrace[17]. Unfortunately, the vertical farm setup did not live happily ever after. After a time, the building administration decided to save costs by changing to another security company: the guard was taken away and the vertical farm was laid empty. This further proves my point on the need to have people involved in, and responsible for, the urban agriculture that you might design into your project.

## Green infrastructure and bioclimatic design

*An example of green infrastructure for bioclimatic design: the Olivos House by Gonzalo Bardach (Argentina, 2023). Photograph by César Béjar. Recovered from: Arch Daily, 2024.*

Finally, green infrastructure can be incredibly useful for bioclimatic design, acting as a solar protection for your project. Think of it like this. Normally, the Sun will shine onto your project, and in doing so will bombard it with irradiation. Most of this energy will be in the form of heat, which warms up the building surfaces, the surroundings and the building interior. The effects of this are felt in the Urban Heat

[17] My most sincere thanks to Francisco Soria, founding member and CEO of the Corprancagua construction company, who kindly opened his doors and hospitality to us, plus allowed me to describe the story of the vertical farm here.

Island[18] phenomenon, and in a hot building interior. This in turn leads to greater energy demands for the project as the interior spaces will need cooling with air conditioning systems that pump heat out to the exterior[19], installed in sealed, airtight buildings might lead to a Sick Building Syndrome[20]. In contrast, plants and vegetation absorb solar irradiation as part of their photosynthesis process. The energy from the Sun is harnessed by the leaves of the greenery, which is converted into transpiration: the vegetation draws up water laden with nutrients from the substrate, through the plant and emits water vapour. In this sense, the irradiation never makes it to the building surfaces and is not transformed into heat.

*Another green infrastructure example: bioretention or rain gardens. Recovered from: the Department of Energy and Environment, Government of the District of Columbia, 2024.*

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[18] Buildings get hot, and the conglomerated effect leads to urban areas becoming significantly warmer than their rural counterparts.

[19] An air conditioning system works via a heat exchange, which pumps cool, dry air into the building interior at the expense of emitting hot air outside.

[20] The syndrome of feeling uncomfortable (and ultimately unwell) inside a building that is sealed off from the external environment, whereby you feel an ever-increasing need to get out and have 'a breath of fresh air'.

## Biophilia: we feel good

Finally, wherever the green space might be, if we can see it, feel it or somehow interact with it, we will most likely feel all the better for it. 'Biophilia' is understood as humans feeling better through contact with nature, or as Edward O. Wilson stated in his book with the same name: that humans have an innate 'urge' to affiliate with other forms of life[21].

Consider this, for most of our existence humans lived a nomadic life, within the provenance of Mother Nature and in accordance with what she provided as we migrated from one location to another. This was a status quo until a domestication process occurred, where certain, staple crops started to be cultivated in abundance and corresponding communities, villages and urban agglomerations of people began to arise. Nature however, still played a central role. The rise of great civilisations in the Americas, China, Asia and Europe was accompanied by advances in science, health and knowledge that was unprecedented. Then following the industrial revolution, we begin to see the rise of city life, culminating in more people officially living in urban than in rural areas since 2007[22]. It has therefore only been since a very short time ago that the majority of humans as we know them began to live their daily lives mainly in isolation from Mother Nature and her associated plants, trees and vegetation.

In all, given our evolutionary process over the millennia, one might say it is not surprising that we generally feel better when we have daily contact with

[21] Wilson, E.O. (1986). Biophilia. Harvard University Press.

[22] According to data from the United Nations.

nature than when we are continually isolated from it. This is known as biophilia and having green infrastructure incorporated into our project will bring about this feeling with the residents and end users: the project will make them feel good.

*Humans feeling better through contact with nature. Photographs by Michael Davis and Jaire Cagigal (2025).*

# Soil Annex

## Ceci n’est pas une pipe


*René Magritte’s famous painting.*
*(Wikipedia Creative Commons License)*

‘The famous pipe. How people reproached me for it! And yet, could you stuff my pipe? No, it’s just a representation, is it not? So if I had written on my picture ‘This is a pipe’, I’d have been lying!’

— *René Magritte*[23]

Magritte was making a famous point with his painting, which we can bring into the realm of the Circular Economy and the tyres that were mentioned in the ‘‘Let’s get loopy’’ section. The only way to smoke the painting of the pipe would be to roll up the canvas, place an end in one’s mouth, light the other and try to inhale the smoke.

[23] Torczyner, H. (1977). Magritte: Ideas and images. Ann Arbor: HN Abrams.

Additionally, imagine it was the first time you had seen the painting, having never seen nor heard of a pipe before...

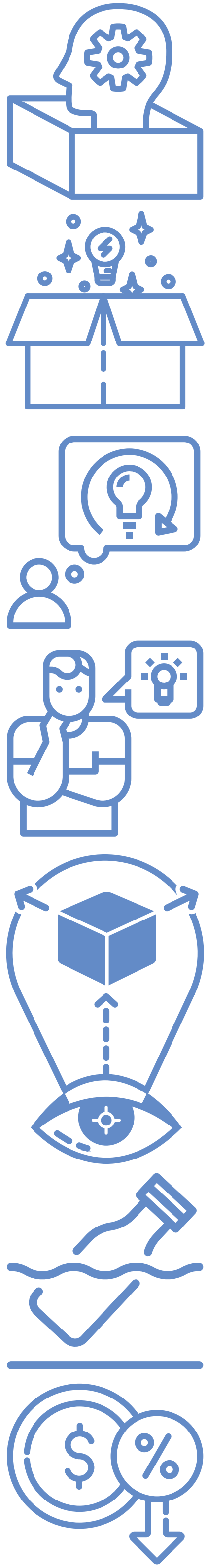
In that case, you would have quite a different interpretation of the strange thing on the canvas, coming up with all sorts of wild theories about what the ‘pipe’ could be (‘a funny plant pot?’, ‘a sort of musical instrument?’, ‘maybe a hammer-like tool?’).

Let’s turn this on its head and put forward that to be truly creative, we need to first completely free our mind from its predetermined conceptions, in order to then be able to see the unbounded, limitless number of possibilities for the application of the object and product in front of us (why not a funny plant pot, musical instrument or tool?). This thinking out-of-the-box methodology is necessary if we are seeking to re-use products in the circular economy context, where we negate the need for them to go through expensive, energy-hungry processes. This was the case for using tyres as a raw construction material that is especially apt for earthquake resistant housing foundations and slope-stabilising walls.

For example, let’s take the humble plastic bottle.

Usually this is bought, used in a single drink and then thrown away. Nowadays, there are more and more initiatives to a) massively reduce the consumption of drinks in plastic bottles, and b) for them to enter a circular economy whereby the base material used is harvested to make clothes, new bottles, and other things.

But!



If you were asked to come up with the best design possible to separate one medium (such as liquid, air, or otherwise) from its surroundings, in something that stands the test of time, is extremely resilient against the surrounding environmental elements … all whilst being cheap to produce … you would find it hard to beat a plastic bottle.

*Plastic bottles as a partition wall in the Mediagua showcase sustainable house of the Yaku water museum, Quito, Ecuador. Design by Veronica Reed with consultancy services for the water management systems from Evolution Engineering, Design and Energy Systems Ltd. Photographs by Michael Maks Davis (2025).*

In fact, very little needs to be done to plastic bottle(s) to change it (them) into:

- Carriers for the next drink (re-use them).
- Partition walls (when strung together).
- Light bulbs (add water with a little chlorine and expose to a light source).
- Plant pots (painted to avoid excessive UV exposure for the roots).
- Percussion instruments (add a handful of rice, close and shake).

- Toys (kids love simply pouring water, or great buoyancy properties for boats and rafts, or add wheels for cars).

*A vertical garden made with plastic bottles at the Mediagua showcase sustainable house of the Yaku water museum, Quito, Ecuador. Design by Veronica Reed with consultancy services for the water management systems from Evolution Engineering, Design and Energy Systems Ltd. Photographs by Michael Maks Davis (2025).*

And the list goes on ...

The same thinking can be used for any 'waste' product really: we don't need to put it through an energy-intensive procedure to mine its raw materials. We just need to rethink the potential uses (of which there are no doubt many!) by looking at the product from a new point of view and through the lens of the inherent qualities it has. I've seen waterproof and resilient crisp packets woven into colourful wallets, bags and purses. Piles of broken plates have been transformed into many a beautiful mosaic. Used cardboard egg boxes are particularly apt at nurturing new plant saplings before composting back into the soil.

Hopefully, we will eventually take the suggestions of circular economy proponents fully on board, where products are designed from the start with the intention of them never turning to waste. For instance, way back in 2007 one of the founding members of Cradle to Cradle,

Michael Braungart, argued that a bottle could be pre-designed to biodegrade when exposed to UV rays from the Sun. It could then have a seed inserted, be used once to drink from and when disposed of become a tree sapling.

## Composting: it's an art

The essence of a good compost is that you take organic waste (leftovers such as vegetable peelings and banana skins, but not meat leftovers!) and break it down to a humus that is rich in nutrients to be used as a fertiliser for plants or food crops. There are some basic rules for a decent compost. First, compost relies on having the right mixture of oxygen, carbon, nitrogen and moisture. Oxygen keeps the process aerobic (for oxygen-dependent bugs and bacteria), carbon is the energy source for the process (generally comes from brown, dry material), nitrogen is harnessed by the composting organisms (think green, moist material) and the correct moisture level ensures an optimum composting environment (not too wet, not too dry).

Also, compost relies on our animal and bacteria friends. Bugs and insects such as ants, beetles, millipedes and earthworms help break down the chunks of organic material into smaller sizes. This then makes it ready for the bacteria to come in, breaking the material down to its core components that make a rich, nutrient-laden humus. First, we have mesophilic bacteria, which set things up before the compost starts to get hot and make it ready for the thermophilic bacteria to take the stage. When they do, the temperatures can rise up to 60 degrees Celsius, which is a way to ensure that any nasty pathogens are killed off. This having been done, the compost pile cools down and the mesophilic bacteria return to the field, further breaking down the final product so that it is easier to be absorbed by plants and vegetation. The whole process can take as little as a few weeks up to a year, depending on the initial mixture, process and maintenance. For example, a pre-designed compost with ground organic waste having an optimal oxygen, carbon, nitrogen and moisture mixture, which is constantly monitored and maintained (turned and mixed) can reach a humus stage in under a month. In contrast, random organic material that is simply piled up and left to its own devices might need some 12 months until it has matured (or more!).

*An example of composting for a household vegetable plot, as seen in the Yaku water museum, Quito, Ecuador. Photograph by Michael Davis (2025).*

After this time, the volume taken up by the broken-down humus will only be around 30% of the initial organic kitchen waste.

Finally, composting can be a hot or cold process, depending on how much organic material we need to process. In large, farm- or industrial- scale composts, thermophilic processes will produce great steaming thermophilic mountains of organic waste-munching machines. In contrast, a simple household composting drum (as mentioned in the section titled ''All in good time'') does not have enough 'oomph' (bacterial charge) to take it to a thermophilic stage. This means it will need more time (months) and turning to ensure the humus stage is reached.

*An example of industrial composting shared in WIkifarmer[24].*

So, what does this all mean for Designers in the Anthropocene. If we are talking about a single-family household around three, kitchen dustbin-sized composting drums will successfully process all of the organic food waste (excluding meat leftovers). However, if we are dealing with a multi-storey, high-rise building then we will need: a) a lot of space, and b) someone responsible for the management of the

[24] From the article: La guía definitiva del compostaje industrial (2024): https://wikifarmer.com/library/es/article/la-guia-definitiva-del-compostaje-industrial

waste flow and compost maintenance. Warning: as I've mentioned various times throughout the book, these two factors are the difference between having a wonderful in-house composting project happening, or piles of rotting waste in bin bags piling up around a fly and rat-infested heap of sludge.

An alternative option is to find and subcontract a professional organisation that collects the organic waste and then processes it. One of the best examples I have seen is a pig farmer, who was paid by the building administration to collect the waste that had previously been separated by each resident, and then used it as pig feed on his farm. As such, not only did he not have to buy pig food, but he was paid to take it, and then earned money from the fed pigs[25].

*A household compost bin by the Planet Natural Research Centre[26].*

[25] From bin to bacon, you could say.

[26] From the article: The Best Compost Tumblers (Plus How + Why to Use Them) by Planet Natural Research Center in 2024: https://www.planetnatural.com/tumbling-composter/

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garantiza la confidencialidad de autores y árbitros.

It's an inspiring time to work in urban and building design, driven by a growing focus on people and sustainability. But the process can often be messy and complex. Michael Maks Davis and his team embrace this complexity, distilling decades of sustainable design consulting, research and university teaching into a handy book that covers renewable energies, water systems, and waste management. Design in the Anthropocene puts people first, transforming the different factors and terminologies involved into one, common parameter: space. The result is an easy-to-use tool designed for readers with varying levels of expertise, from urban designers and architects, to engineers, activists, and anyone interested in sustainable design. This treasure-trove gives young graduates and early-career professionals introductions to each field, offers experienced specialists practical insights from case studies, and opens the black boxes behind the rules of thumb. In short, whether you're new to the field or a professional looking to explore different aspects of sustainable design, you'll find this book a pleasure to read and a valuable tool to have at hand.

*'Enjoyable, informative and both easy to use and understand - highly recommended!'*

Sebastian Kaminski, Associate, Arup

*'Design in the Anthropocene' blends technical expertise with an informal, accessible tone to explore energy, water, and waste management in building projects. Bringing sustainable practices into the design process, it creates the physical spaces needed to meet associated demand.'*

Francesco Alberti, Associate professor, DIDA - Dipartimento di Architettura, Università degli studi di Firenze

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