When the pool is emptied a waterfall appears highly visible from the urban side of the harbar, which creates a stunning backdrop for the harbors activities.

A walkway provides a unobstructed around the intervention. The waterfall can be observed wintin a 2 meter distance.

Wind power is the preferred renewable energy source in Denmark and with good reason -there are few windless days. But the intensity varies and it rarely matches the actual energy needs (see chart at panel 3). Regardless of the amount of wind turbines it will always be necessary to step in with a controllable energy source, when the wind is not sufficient –in most cases with the use of fossil fuel.

As the newest planned wind farms are located far from the cities that actually use the power, the problem is rarely visible for the dwellers. The Copenhagen Tub is staging this issue and partly brings the renewable energy production back to the city. The wind turbines of the Copenhagen Tub do not convert the wind power to electricity. Instead the turbines are connected with a gear box and water pump that converts the wind power to potential energy by pumping sea water from the harbor up to a row of serially connected pools. Eventually the water will be collected in a large pool 25 meters above sea level.

When the conventional wind power can't cover the consumption, an opening in the top pool can be activated which creates a massive waterfall. The effect of the waterfall is captured by turbines placed below the waterfall just above the sea level. The potential energy of the water is converted to kinetic energy and finally electricity at the time it's needed.

Public appearance and social relevance
The water in the harbor is through a focused effort from the city of Copenhagen so clean that it's safe to swim in it. Several small harbor baths has been constructed throughout the latest 10 years, which marks a new sustainable and authentic bathing culture. They are however all placed in the southern end of the harbor in already densely populated areas limiting the scale and extend of the interventions.

The Copenhagen Tub is placed at the Refshaleø which within a near future is likely to be developed. The intervention on the site celebrates the cleanliness of the water and an extensive public approach for the future development. The pools have different depths and edges that invites to a variety of planned and spontaneous activities in and around the pools: Individual training, social activities, kids playing, winter swimming, ice skating e.g. All social classes, ages and cultures can be accommodated in this spectacular harbor park, that provides a green free space above Copenhagen's roofscape.

However, the most important issue is that the intervention strengthens the visibility of renewable energy in the cities that consumes it. A greater awareness of the opportunities and challenges and the link between consumption and production becomes a visible part of the everyday life and the public debate.

Integration into surrounding environment and landscape
The industrial history of Refshaleø is still very evident despite the wharf closed many years ago. The absence of human activity made space for a diversity of plants, insects and animals. This is also the case for the site, which contains a variety of self-sown plants in a post-industrial brownfield, supplemented by a narrow concrete path parallel to the dock. The simple materiality of the site is evident in the Copenhagen Tub, where nine concrete pools are arranged staggered along the length of the pier allowing the brownfield to merge with the new construction.

The level difference between each pool is 2-3 meters, which provides a gentle integration with the surrounding landscape. The lowest pool is placed by the southern dock and the rest are arranged stepwise inclining towards north, which allows the sun to heat the pools and the people using them. The highest pool is placed with a cantilever over the harbor. When the pool is emptied a waterfall appears highly visible from the urban side of the harbor, which creates a stunning backdrop for the harbors activities.

Applied technologies
Copenhagen Tub consist of simple and well-known technologies that are combined in an unconventional way. The kinetic wind energy is captured by vertical axis wind turbines, which has a lower cut in speeds, works on a lower altitude and can capture the turbulence of adjacent turbines if they are placed densely.

Instead of transforming the kinetic energy into electricity, the vertical axis drives a mechanical pump with a gearbox as the only converter minimizing the power loss. The technology is well known from drainage in agriculture in e.g. the south east of the USA: Wind powered water pumps ensure that the fields stay drained without the expense and impact from fossile fuels.

The water is pumped from pool to pool, whereby the kinetic energy is transformed into potential energy. When the need for additional electric energy occurs, an opening in the cantilevering top pool can be activated, which starts the 26 m waterfall. The potential energy is converted into kinetic energy and eventually electricity, when the water meets a number of water turbines placed right above sealevel

Estimated amount of captured energy
The calculation is based on the American manufacturer of wind powered water pumps for agriculture: Ironman windmill co.™ The pumps can transport 118 m3 water/hour to a height of 2 meters. As more pumps perform the same operation simultaneously, the top pool can be filled in 72 hours. By strong wind the time span is reduced to 36 hours and 18 hours if the amount of wind turbines are doubled.

The top pool contains up to 9.000.000 L of water. The water pressure raises 100.000 Pa by 10 meters, resulting in a waterfall pressure of 260.000 Pa. The flow of the waterfall is 2500 L/sec which lead to the emptying of the pool in 1 hour.

Effect [W] = Pressure [Pa] x volume [L] / time [s]
650.000 W = 260.000 Pa x (9.000.000 L / 3600 s)

With an estimated efficiency of 80 % the resulting captured energy per waterfall is 520 kWh. By doubling the amount of wind turbines 245 waterfalls are created per year by medium wind speed. That results in apx 1 MWh a year which is about the half of the average Danish windmills currently operation. However this intervention has the advantage that it can be turned on when needed, can be placed in urban surroundings and provides a variety of recreational opportunities.

List of materials and dimensions
27.000m3 pools of reinforced concrete, partly recycled concrete and reinforcement
300.000m3 of surplus soil
18 vertical axis wind turbines, made of light renewable and non-corrosive fiber reinforced plastic.
Height: 12m. Diameter: 1m
18 water pumps - renewable and non-corrosive fiber reinforced plastic. Each 1m3
5 water turbines - renewable and non-corrosive fiber reinforced plastic. Each 2m3

Return of capital investment
Wind turbines + waterpumps: 40.000 USD x 18 = 720.000 USD
Water turbines: 34.000 USD x 5= 170.000 USD
Construction costs: Concrete, landscape, walkways etc.: 4.000.000 USD
Overall costs: 4.890.000 USD

Average price per kWh in Denmark (2014): 0,35 USD
Expected increase of price per kWh is 160 % within the next year
Return on capital investment: 8 years (see chart at panel 3)

Environmental impact assessment
The intervention of the Copenhagen Tub does have an impact on the local and regional environment, although the damage is limited compared to conventional constructions.

Water: The water pumped from the harbor is strictly separated from the surrounding landscape, so the saltwater doesn't harm the plants. The water from the harbor is oxygenated by the pumping process and the release of waterfalls, which improves the living conditions for the marine culture.

Biodiversity: The brownfield is harmed during the construction, but the reestablishment of the wild landscape on a slope eventually provides an even larger variety of plants, insects and animals.

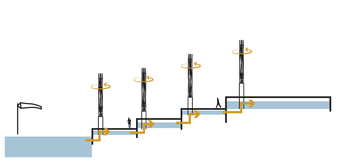
Air: The vertical wind turbines emit a high frequency noise that keeps the birdlife out of distance, while it's not audible for humans. Besides from that noise generated from the vertical axis wind turbines are limited compared to conventional horizontal axis wind turbines.

Soil: Surplus soil from other construction sites nearby is used to build up the landscape. By using soil from local construction sites the amount of energy used on transportation is limited.

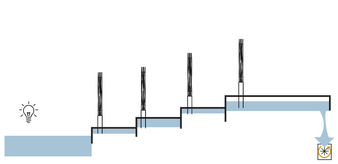
Construction: The pools are prefabricated in a safe environment nearby. The prefabrication process enables the use of renewable energy and reduces the use of fossil powered tools on-site. The amount of failures is statistically lower for off-site castings than in-situ casting.

Materials: Part of the concrete and reinforcement is recycled. The wooden is constructed with Nordic thermo treated wood instead of tropical hardwoods. The reinforced plastic used for turbines and pumps are separable in order to enable recycling if the construction needs to upgrade with more efficient newer wind turbines.

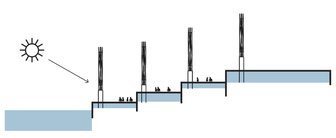
Safety: Filters by the water intake prevent marina culture to get harmed. A safety grid at the lower part of the wind turbines prevents the users from getting injured.



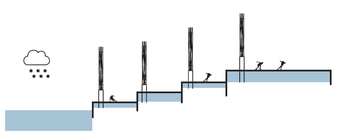
Wind power is converted to potential energy



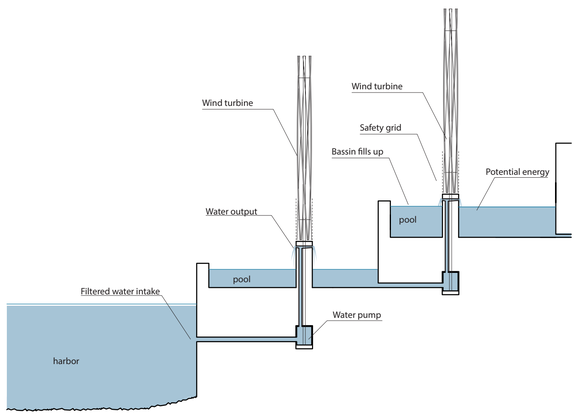
Electricity is captured by emptying the top pool



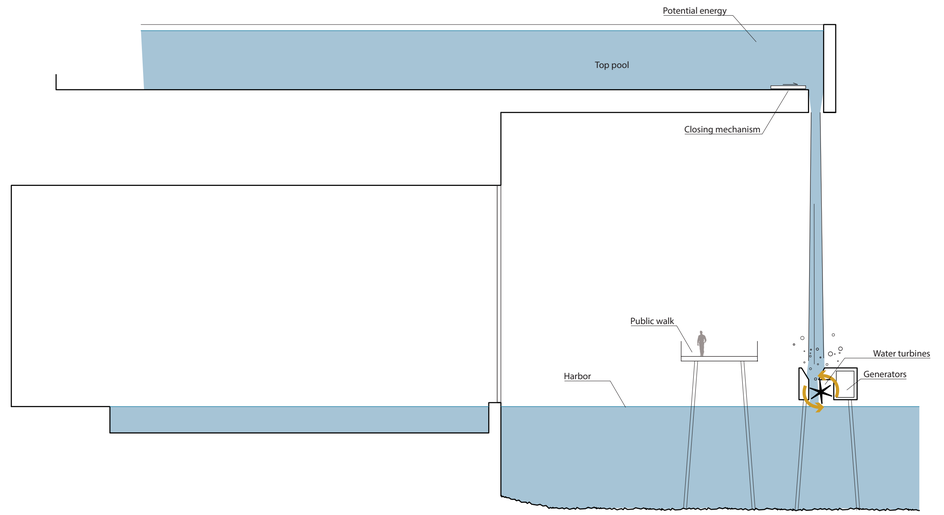
Pools are passively heated by the sun



The pools can be used as ice rink if the pools are frozen



Section through connected pools



Section through top pool, 1:200

CPHTUB14